Additional file 1: Geodata used in the analysis and classification of their spatial resistance classes

Ole Badelt[1] (https://orcid.org/0009-0000-9768-2826), Julia Wiehe[2] (https://orcid.org/0000-0002-1224-4825), Christina von Haaren[1] (https://orcid.org/0000-0003-4457-2409)

[1]Leibniz University Hannover, Institute of Environmental Planning, Hannover, Germany

[2]Competence Centre for Nature Conservation and Energy Transition, Berlin, Germany

Correspondence

Ole Badelt, Leibniz University, Hannover, Institute of Environmental Planning, Herrenhäuser Str. 2, 30419 Hannover, Germany. Email: badelt@umwelt.uni-hannover.de

	Very High Spatial Resistance
1	National Parks
2	Nature Conservation Areas
3	Biosphere Reserves
4	Water Protection Areas
5	Riparian Strips
6	Special Areas of Conservation (Habitats Directive)
	High Spatial Resistance
7	Potential breeding habitats of sensitive bird species outside protected areas
8	Resting and feeding areas of wintering northern guest birds
9	Landscapes with a high visual quality rating
10	Areas of importance for the biotope network (except for crop land)
11	Crop land with high soil fertility
12	Flood hazard zones
14	Low input grassland (that is not protected through Habitats Directive)
	Medium Spatial Resistance
14	Landscape protection areas
15	Biosphere reserves (maintenance zones and development zones)
16	Representative cultural-historical landscapes
17	Water protection areas (middle zone)
18	Special Protection Areas (Birds Directive)
19	Landscapes with medium visual quality rating
20	Crop land within biotope network
	Low Spatial Resistance
21	Water protection areas (outer zone)
22	Intensively managed Grassland
23	Crop land with low soil fertility
24	Landscape with a low visual quality rating
	Other land use categories
25	Forest

26	Infrastructure (railways, roads, motorways)
27	Water bodies and North Sea
28	Airports
29	Topography (slope and orientation)
30	Shaded areas around forests and woods
31	Settlement areas

Very High Spatial Resistance

Spatial units which have a very high sensitivity to ground mounted PV and a very high value or on which ground mounted PV is legally strictly excluded (mandatory) a priori.

1. National Parks

National Parks in Germany are protected by national law (§ 24 German Federal Nature Conservation Act, BNatSchG, [1]) with the objective that "natural processes, in their natural dynamics, can take place in the most undisturbed manner possible." Because of their size und largely unfragmented territory, that has not been affected by human intervention, the construction of ground mounted PV would contradict its purpose of protection. Geodata was obtained from the [2].

2. Nature Conservation Areas

Nature conservation areas are characterized by a special protection of nature and landscape because of:

- their relevance for conserving, developing or restoring living sites, biotopes or communities of certain species of wild fauna and flora, or
- their relevance for science, natural history or national heritage, or
- their rarity, special characteristics or outstanding beauty (§ 23 BNatSchG, [1])

Any action that could cause a change in state is prohibited. Geodata was obtained from [2].

3. Biosphere Reserves

Biosphere Reserves represent a typical landscape type where sustainable land use and nature conservation are practiced together (§25 BNatSchG, [1]). They are divided in the core zones, protected

as nature conservation areas with a corresponding protection status and maintenance and development zones protected as landscape protection areas. The construction of ground mounted PV is therefore prohibited within the core zones that have a very high spatial resistance. However, and maintenance development zones are classified as medium spatially resistant. Because one of their objectives is to “illustrate ways of developing and testing forms of economic activity that are especially conserving of natural resources”, testing of low-impact management practices may also include the use of renewable energies [3]. Therefore, the integration of solar energy is a possibility here. Due to their character as sustainable model regions, innovative technical adaptations of ground mounted PV can be implemented here in particular. Geodata was obtained from [2].

4. Water Protection Areas

The core zones of water protection areas serve for obtaining clean drinking water and therefor have a very high sensitivity and value for human well-being. There is strict prohibition of any construction (§§ 50 – 53 WHG, Federal Water Act, [4]). For the middle and outer zone, the sensitivity to ground mounted PV generally declines with distance to the core zone. The combination of drinking water protection and ground mounted PV can sometimes also produce synergies if PV systems, when installed professionally and considering the protection purposes [5], result in an improvement of the water balance. The middle and outer zones of water protection areas are accordingly classified with a medium and low spatial resistance. Geodata was obtained from [6].

5. Riparian Strips

Riparian strips or shoreline zones describe the interface between land and a river or stream. No structures may be constructed here (§ 61 BNatSchG, [1]) except for related water infrastructure and public transport infrastructure, if adverse effects on the natural balance or landscape appearance are minor or if reasons of overriding public interest exist. As riparian strips fulfil various ecological functions, e.g. the protection of waterbodies from immissions, safeguarding water runoff and water storage they have a very high ecological value. They also provide habitats and migration corridors for

many animal and plant species resulting in a very high sensitivity to ground mounted PV. Geodata was obtained from [7].

6. Special Areas of Conservation (Habitats Directive)

As part of the European ecological network "Natura 2000", special areas of conservation (SAC) were established for the protection of habitats and species listed in annex I and II of the European Union's Habitats Directive (92/43/EEC) [8]. Any changes or disturbances leading to significant adverse effects on a Natura 2000 site are prohibited if they affect the conservation objectives or protection purpose. In difference to other protected areas in this class, exceptions to this prohibition are possible e.g. if imperative reasons of overriding public interest outweigh conservation concerns (Art. 6 (4) RL 92/43/EEC). However, because of their very high value for the coherence of a European-wide ecological network they are nevertheless assigned a very high spatial resistance. Geodata was obtained from [2].

High Spatial Resistance

Spatial units with a high to very high probability that the condition of biodiversity and ecosystem services will be impaired by ground mounted PV and because of their very high value, the impairment cannot be compensated. There is no strict, legal protection status although their exclusion from ground mounted PV installation is legitimate (e.g. by expert specification) but not specified sufficiently. Despite high to very high legitimate reasons for exclusion from ground mounted PV installation the legal protection status is not specified sufficiently for categorical exclusion.

7. Potential breeding habitats of sensitive bird species outside protected areas

Although bird protection has a very high legitimacy in Germany and Europe and is covered by various legal bases [9, 8, 10], an impairment of potential breeding habitats of sensitive bird species outside protected areas cannot be ruled out. An extensive literature study in [11] indicates, that for the

Eurasian Curlew (Numenius arquata), Black-tailed Godwit (Limosa limosa), Redshank (Tringa totanus) and Ruff (Philomachus pugnax) losses of breeding and foraging habitats due to ground mounted PV are possible.

Figure 1: Bird species that are sensitive to ground mounted PV: Eurasian Curlew (Numenius arquata), Black-tailed Godwit (Limosa limosa), Redshank (Tringa totanus) and Ruff (Philomachus pugnax). Their breeding habitats should not be used for solar park installation.

The distribution areas of these species are concentrated in northern Lower Saxony [12]. Respective geodata exists in the form of grid areas (approx. 11x11 km) without exact locations of breeding habitats. In order to nevertheless be able to consider the habitats of these species in the analysis, the locations of potential habitats were mapped via a spatial random distribution within the grid areas (see [13]). For this purpose, the potential habitats were selected in the form of land use classes (CORINE Land Cover) and intersected with the grids. These areas represent the potential breeding habitats. Within these, random breeding sites were distributed based on the number of breeding pairs indicated in [12] and a buffer of 100 m was set.

8. Resting and feeding areas of wintering northern guest birds

Northern migratory birds are protected species in Lower Saxony under Annex I and Art. 4 (2) of the Birds Directive (Table 1). The state of Lower Saxony is obliged to permanently conserve the habitats of these protected species. Since the habitats also include agricultural areas outside protected areas, the state of Lower Saxony compensates farmers for potential losses through funding from the European Agricultural Fund for Rural Development (EAFRD). It is assumed that northern geese and swans will avoid ground mounted PV [11] and that these areas will be lost as foraging habitat, causing them to move to adjacent farmland. This could cause considerable damage to agriculture as well as an impairment of said species.

Table 1: Protected northern guest birds in Lower Saxony according to the EU Birds Directive.

Species
Cygnus olor
Cygnus cygnus
Cygnus columbianus
Branta [canadensis] leucopsis *
Anser [f.] fabalis
Anser anser *
Anser albifrons
Anser erythropus
Anser brachyrhynchus
Branta bernicla
Anas [p.] penelope

As the effects of ground mounted PV on these birds have not yet been sufficiently studied, habitat loss cannot be entirely ruled out. Geodata was obtained from [14].

9. Landscapes with a high visual quality rating

The diversity, characteristic features and beauty of nature and landscape, as well as their recreational value belong to the main purposes of nature conservation and landscape management in Germany (§1 (1) BNatSchG, [1]). In order to ensure this, areas of landscape value suitable for recreation must be kept be kept free of objects that are not part of the landscape [15]. In practice, the identification of such areas happens at the county or local level through verbal-argumentative assessment methods. To integrate the visual quality of landscapes as a criterion into our assessment for the whole state, we chose the method of [16] who have assessed the aesthetic quality of landscapes in Germany. Geodata is freely available [17]. It is based on the main evaluation criteria diversity, naturalness and uniqueness using lists of indicators (usually landscape features). Geodata in raster format (100 x 100m) shows the aggregation of these criteria to the landscape aesthetic quality of Lower Saxony on a scale from 0 – 100. The classes were calculated as 33% and 66% quantiles of all grid cell values in Lower Saxony:

Scale	**Visual quality of the landscape**	**Spatial resistance**
n > 59	high	high
49 > n < 59	medium	medium
n < 49	low	low

Although it's very high value for human well-being and its high sensitivity to impacts from changes such as the development of infrastructure, safeguarding aesthetic landscapes is difficult. Specifications in law about high quality landscapes remain vague as general applicable measures for visual quality of landscapes are difficult [18]. With classification of the visual landscape quality from low to high, we proposed that the 33% most beautiful landscapes in Lower Saxony should not be used as areas for ground mounted PV even if they are not protected on from of other protected areas. Areas with a medium landscape quality rating are classified with a medium spatial resistance as sensitivity and value are lower. In the least beautiful areas visual impacts from ground mounted PV are expected to be low.

10. Areas of importance for the biotope network (except for crop land)

The creation of a nationwide network of connected biotopes on 10% of the state's area is laid down as a general principle in the Federal Nature Conservation Act (§20 BNatSchG, [1]). In order to avoid fragmentation of the landscape and to promote biotope connectivity, biotope connection areas are to be kept free of infrastructure measures (§21 BNatSchG, [1]).

The areas of the Lower Saxony biotope network consist of core areas and functional areas [19]. Core areas include biotope areas of open land, forests, watercourses with their floodplains and coastal biotopes and form the nodes of the network. The functional areas represent connecting elements, in which new fragmentation effects are to be avoided and consist of different types of protection areas as well as non-specified areas and landscape elements (§21 (3) BNatSchG, [1]). For the analysis, the functional areas of open land and forests were considered from the Lower Saxony Landscape Program [19].

Although [20] suggest a connecting effect of PV for some species, a fragmenting effect cannot be ruled out. This can lead to the isolation of individual biotopes, which is why the functional areas of the biotope network are of high value for migratory species. Despite a very high degree of specification as to which areas belong to the biotope network, a mandatory exclusion of ground mounted PV for this category is difficult, as it consists of several other protected area types with different legal grounds and implications.

11. Crop land with high soil fertility

The protection and conservation of natural soil functions are established in § 2 of the Federal Soil Protection Act (BBodSchG, [21]). This also includes the potential for agricultural production. Fertile soils should therefore be kept available for agriculture in order to keep the use of inputs (e.g. pesticides, fertilizer) low and to conserve resources. We used geodata on soil fertility from [22] where fertility is classified on a scale from 1 to 7. The two highest soil fertility classes represent areas to be excluded from ground mounted PV.

12. Flood hazard zones

According to EU Directive 2007/60/EC (Flood Directive, [23]), flood hazard zones are areas where floods occur with different probabilities. For areas where floods statistically occur every 100 and every 20-25 years (medium and high probability) the federal state of Lower Saxony has prepared flood hazard maps [24]. Large-scale technical installations such as ground mounted PV can negatively affect the retention capacity and runoff behaviour in flood situations [25] potentially leading to impacts on human well-being and other infrastructure. Measures to avoid all actions leading to potential adverse flood consequences are laid out in flood risk management plans.

13. Low input grassland (that is not protected through Habitats Directive)

Low input grasslands are extensively managed meadows and pastures with a very high conservational value as they are habitat to species-rich plant communities. Due to their often nutrient-poor soils and low economic yield, low input grassland has become rare in today's agricultural landscapes in Germany [26]. When ground mounted PV is installed on grasslands, many influencing factors change, such as solar radiation, water balance and the mowing regime.

There is legitimate cause to protect grassland and efforts to preserve it are implemented in the common agricultural policy of the EU. For the new funding period as of 2023, direct payment for farmers is linked to mandatory practices such as maintaining permanent grassland, called green direct payment or greening (Regulation (EU) 2021/2115, [27]). This also means, that farmers who not claim this funding, are not obliged to follow these practices.

Unfortunately, there is no geodata for low input grassland that covers all of Lower Saxony. Therefore, we used data from a selective biotope mapping of the state that contains valuable biotope types in Lower Saxony [28] where different types of low input grassland were mapped.

Medium Spatial Resistance

14. Landscape protection areas

The purpose of landscape protection areas is the protection of landscapes from a scientific as well as a cultural point of view and to preserve its unique character. Compared to nature conservation areas, they usually cover a larger area and are associated with fewer legal restrictions. Almost a third of Germany is classified as a landscape conservation area [29]. In landscape protection areas, actions that change the character of the area or which are not compatible with the purpose of its protection are prohibited, except for agriculture, forestry and fishery (§26 BNatSchG, [1]). For ground mounted PV this means, that there is no general exclusion in terms of legitimacy, but permission is granted only in compliance with their purpose of protection and if the overall character is not impaired. To which degree this area category is suitable for ground mounted PV therefore depends to a large extent on the individual site characteristics (e.g. location, exposition) of the area and the technical dimensions of the solar park (size, height). For wind energy in landscape protection areas, a study of the German Environment Agency (UBA) assumed, that a maximum of 25% of landscape protection areas can be used for wind energy [30]. Geodata was obtained from the [2].

15. Biosphere reserves (maintenance zones and development zones)

see 3

16. Representative cultural-historical landscapes

Landscapes that have been formed through cultivation that is no longer contemporary offer a glimpse into the past and are irreplaceable testimonies to the development of the landscape. The value of these landscapes derives primarily from their historical significance and their protection is laid down as a nature conservation task in Germany (§1 (4) BNatSchG, [1]). For Lower Saxony there are 71 cultural-historical landscape types, that represent different phases in the state's landscape history and which are still strongly characterized by historical structures [31]. In individual cases, solar parks adapted to the landscape can be implemented, as long as the historic character of the area is not affected. Geodata was obtained from [19].

17. Water protection areas (middle zone)

see 4

18. Special Protection Areas (Birds Directive)

Just like special areas of conservation (SAC), special protection areas (SPA) are part of the European ecological network "Natura 2000" which aims to protect all European wild birds and the habitats of listed species [9]. Any changes or disturbances leading to significant adverse effects on a Natura 2000 site are prohibited if they affect the conservation objectives or protection purpose. Nevertheless, exceptions to this prohibition are possible e.g. if imperative reasons of overriding public interest outweigh conservation concerns (Art. 6 (4) RL 92/43/EEC, [8]). Additionally, and in difference to SAC, a literature review of [11] suggest, that not all bird species protected in Lower Saxony by Directive 79/409/EEC are endangered by ground mounted PV (see 8). At the same time, there is still insufficient knowledge about the long-term effects of an increased expansion of solar energy on avifauna. In Lower Saxony in particular, there are hardly any field studies on existing solar parks to be able to make reliable statements. Geodata was obtained from [2].

19. Landscapes with medium visual quality rating

see 9

20. Crop land within biotope network

Arable land presents a special case within the biotope network. Studies suggest, that solar parks on former intensively managed arable land could have a positive effect on habitat connectivity under certain circumstances [11, 20]. Niemann, Rüter, Bredemeier, Diekmann, Reich, Böttcher [20] indicate, that, although conflicts may arise from barrier effects (fencing) and habitat loss, for butterflies solar parks with extensively maintained grassland may have a positive impact on biodiversity. In a critical assessment of the role of ground mounted PV for the biotope network, Trautner, Attinger, Dörfel [32] come to the conclusion, that ground mounted PV is not a suitable means for biotope connectivity per

se but might be unproblematic on intensively managed grassland or cropland (e.g. maize). In open agricultural landscapes, however, ground mounted PV would cause a loss of habitat for ground-nesting birds (e.g. *Alauda arvensis*). Both studies strongly advise for individual assessments on-site as well as further research in this area. For the assessment in this study, crop land within the biotope network is categorized with a medium spatial resistance as is might be suitable under reserve depending on site-specific conditions. Geodata was obtained from [7] and [19].

Low Spatial Resistance

21. Water protection areas (outer zone)

see 4

22. Intensively managed Grassland

Intensively managed grassland that lies outside protected areas and has a low nature conservation value is suitable for ground mounted PV. The reduction of fertilizers, pesticides and an appropriate mowing regime can lead to an enhancement of nature conservation value. The condition for this is a comparison with landscape planning, which functions the area fulfils on a regional or local level. Geodata was obtained from [7].

23. Crop land with low soil fertility

There are compelling reasons to consider using crop land with low soil fertility for ground mounted PV. First, it's important to recognize that this type of land is often not economically viable for agricultural production due to its low soil fertility. Rather than needing a high resource input for fertilizer or pesticides with comparatively low output, converting it to a solar park can provide an opportunity for economic development and investment in renewable energy infrastructure.

Additionally, objectives of nature conservation should be covered by area categories from higher spatial resistance classes. This is important because crop land with low soil fertility can be a habitat for threatened arable field species that have historically adapted to human agricultural practices [33].

Their occurrence can be attributed to a combination of factors, including reduced competition from other plant species [34], specialized functional traits [35], and management practices that favor their growth [36]. Suitable geodata for arable field species was not found which stresses the importance of on-site-control with local data for this area category. Furthermore, §2 BBodSchG [21] still applies, meaning that soil functions are not to be impaired. Geodata was obtained from [7, 22].

24. Landscape with a low visual quality rating

see 9

Other land use categories

The following land use categories were included in the analysis because they are not suitable for ground mounted PV due to technical or economic reasons. In the GIS model they are assigned to the very high spatial resistance. We used freely available Geodata from [7].

25. Forest

Forests are essential, among other things, for the efficiency of the natural balance, forestry production and the recreation of the population (§ 9 BWaldG, [37]). Clearing and conversion of the area to another land use is only possible in exceptional cases (ibid.). A dual use of forests and photovoltaic plants on the same area is ruled out for technical reasons [25]. Geodata is availabe from [7].

26. Infrastructure (railways, roads, motorways)

The category includes railways, federal, state and district roads as well as federal motorways. Different buffers were assigned to those types according to their nominal widths. The construction of conventional ground mounted PV is not possible on roads and railways. Further development of the technology could make these categories usable in the future. Geodata is availabe from [7].

27. Water bodies and North Sea

Floating PV systems were not considered in the analysis. The construction of conventional ground mounted PV on water surfaces is not possible. Geodata is availabe from [7].

28. Airports

Airports generally require a construction protection area to ensure unhindered flight operations (§ 12 LuftVG, [38]). Therefore, airport runways including their protective strips must be kept free of buildings for safety reasons. A safety distance around the airport site, as is the case with wind turbines [39], which violate obstacle clearance requirements, is not necessary due to the low height [40]. Geodata is availabe from [7].

29. Topography (slope and orientation)

The choice of location plays a fundamental role in the economic viability of ground mounted PV. If the area to be built on is too steep (slope >45°), the financial construction costs of the systems on the slope would be too high. The same applies to the exposure of the area: if the solar radiation during the day is too low, for example on north-facing slopes with an inclination >30°, the system will not work economically. On the other hand, plants on north-facing slopes with an inclination <30° can still expect an annual yield of 60% compared to reference plants [11]. Geodata is availabe from [7].

30. Shaded areas around forests and woods

The shading or partial shading of PV modules can sometimes lead to a drastic reduction in the performance of the system. Depending on their height and extent, different objects can cast shadows of different lengths. The most relevant in terms of area are forests (incl. woodlands) and shrubs. These areas, which are shaded during the course of the day, were simulated in the GIS in the form of buffers around all forest and wooded areas. 50 m and 20 m buffers around forest and wooded areas were assumed. Geodata is availabe from [7].

31. Settlement areas

Settlement areas and buildings whose roof surfaces are also available for the electricity production were not included in the analysis of ground mounted PV. Geodata is availabe from [7].

References

1. German Federal Nature Conservation Act (BNatSchG). BGBI. I 2542, 2009.
2. Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (2022) Naturschutzrechtlich besonders geschützte Teile von Natur und Landschaft. https://www.umwelt.niedersachsen.de/service/umweltkarten/natur_landschaft/besonders_geschuetzte_teile_von_natur_und_landschaft/naturschutzrechtlich-besonders-geschuetzte-teile-von-natur-und-landschaft-9065.html. Accessed 18 Jul 2023
3. Gehrlein U, Mengel A, Milz E (2017) Nationale Naturlandschaften (NNL) und erneuerbare Energie. Ein Handlungsleitfaden. BfN-Skripten, Bonn-Bad Godesberg
4. German Federal Water Act (WHG). BGBI. I 2585, 2009.
5. Bayerisches Landesamt für Umwelt (2013) Planung und Errichtung von Freiflächen-Photovoltaikanlagen in Trinkwasserschutzgebieten. Merkblatt, Augsburg
6. Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (2019) Wasserschutzgebiete. https://www.umwelt.niedersachsen.de/startseite/themen/wasser/trinkwasserschutz/wasserschutzgebiete-9086.html. Accessed 19 Jul 2023
7. Landesamt für Geoinformation und Landesvermessung Niedersachsen (2019) Basis Landscape Model (BasisDLM): Auszug aus den Geodaten des Landesamtes für Geoinformation und Landesvermessung, Niedersachsen ©2019. https://opengeodata.lgln.niedersachsen.de/#bdlm. Accessed 19 Jul 2023
8. Council Directive on the conservation of natural habitats and of wild fauna and flora. 92/43/EEC, 1992; Official Journal of the European Union, L 206/7, 1992.
9. Council Directive on the conservation of wild birds. 79/409/EEC, 1979; Official Journal of the European Communities, L 103/1, 1979.
10. Council Regulation on the protection of species of wild fauna and flora by regulating trade therein. 338/97/EC, 1996; Official Journal of the European Union, L 061/3, 1997.
11. Badelt O, Niepelt R, Wiehe J et al. (2020) Integration von Solarenergie in die niedersächsische Energielandschaft (INSIDE), Hannover
12. Krüger T, Ludwig J, Pfützke S et al. (2014) Atlas der Brutvögel in Niedersachsen und Bremen 2005-2008. Naturschutz und Landschaftspflege in Niedersachsen, Hannover
13. Busch M, Trautmann S, Gerlach B (2017) Overlap between breeding season distribution and wind farm risks: a spatial approach. Vogelwelt:169–180
14. Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (2019) NG 1 - Nordische Gastvögel auf Ackerland. https://www.ml.niedersachsen.de/startseite/themen/landwirtschaft/agrarforderung/agrarumweltmassnahmen_aum/aum_details_zu_den_massnahmen/ng1_nordische_gastvogel_auf_ackerland/ng-1-nordische-gastvoegel-auf-ackerland-122559.html. Accessed 19 Jul 2023

15. Herden C, Gharadjedaghi B, Rassmus J (2009) Naturschutzfachliche Bewertungsmethoden von Freilandphotovoltaikanlagen. Endbericht. BfN-Skripten, Bonn
16. Hermes J, Albert C, Haaren C von (2018) Assessing the aesthetic quality of landscapes in Germany. Ecosystem Services 31:296–307. https://doi.org/10.1016/j.ecoser.2018.02.015
17. Hermes J (2020) KOeSL-Ergebnisse-Geodaten_V1. https://doi.org/10.25835/0006102
18. Albert C, Boll T, Haus P et al. (2019) Measures for Landscape Aesthetics and Recreational Quality. In: Haaren C von, Lovett AA, Albert C (eds) Landscape Planning with Ecosystem Services. Springer Netherlands, Dordrecht
19. NLWKN (2018) Niedersächsisches Landschaftsprogramm: Kapitel 4.3 Landesweiter Biotopverbund. unveröffentlicht
20. Niemann K, Rüter S, Bredemeier B et al. Photovoltaik-Freiflächenanlagen an Verkehrswegen in Deutschland: Ausbauzustand und mögliche Folgen für den Biotopverbund, vol 92
21. German Federal Soil Protection Act (BBodSchG). BGBI. I 502, 1998.
22. Landesamt für Bergbau, Energie, und Geologie (2019) NIBIS-Daten: BK50-Auswertungskarte zur Bodenfruchtbarkeit (Ertragsfähigkeit), Hannover
23. Directive on the assessment and management of flood risks (Flood Directive). 2007/60/EC, 2007; Official Journal of the European Union, L 288/27, 2007.
24. Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (2013) Grenzen der Hochwasser-Gefahrengebiete HQ häufig, HQ 100 und HQ/HW extrem. https://numis.niedersachsen.de/trefferanzeige?docuuid=4A68E6A2-2E4E-416F-AF31-57AE08AA6ABF&plugid=/ingrid-group:iplug-csw-dsc-nokis&docid=GK5fDXoBWJMhXtJrNpLM. Accessed 19 Jul 2023
25. Bundesministerium für Verkehr und digitale Infrastruktur (2015) Räumlich differenzierte Flächenpotentiale für erneuerbare Energien in Deutschland. BMVI-Online-Publikation
26. Umweltbundesamt (2022) Indicator: Grasslands. https://www.umweltbundesamt.de/en/data/environmental-indicators/indicator-grasslands#at-a-glance. Accessed 08 Mar 2023
27. Regulation (EU) 2021/2115, 2021; Official Journal of the European Union, L435/1, 2021. Establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013.
28. Niedersächsischer Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (2019) Landesweite Biotopkartierung 1984 - 2004. https://www.nlwkn.niedersachsen.de/naturschutz/biotopschutz/biotopkartierung/erfassung_der_fur_den_naturschutz_wertvollen_bereiche_1984_2004/erfassung-der-fuer-den-naturschutz-wertvollen-bereich-in-niedersachsen-1984-2004-45108.html. Accessed 19 Jul 2023
29. Bundesamt für Naturschutz (2016) Daten zur Natur 2016, Bonn
30. Umweltbundesamt (2013) Potenzial der Windenergie an Land – Studie zur Ermittlung des bundesweiten Flächen- und Leistungspotenzials der Windenergienutzung an Land, Dessau-Roßlau
31. Wiegand C, Platte H, Rohr A et al. (2017) Landesweite Erfassung, Darstellung und Bewertung der niedersächsischen Kulturlandschaften sowie historischer Kulturlandschaften landesweiter Bedeutung im Rahmen der Neuaufstellung des Niedersächsischen Landschaftsprogramms, Hannover
32. Trautner J, Attinger A, Dörfel T (2022) Umgang mit Naturschutzkonflikten bei Freiflächensolaranlagen in der Regionalplanung - Orientierungshilfe zum Arten- und Biotopschutz für die Region Bodensee-Oberschwaben., Filderstadt

33. Twerski A, Fischer C, Albrecht H (2021) Effects of rare arable plants on plant diversity, productivity and soil fertility in agricultural fields. Agriculture, Ecosystems & Environment 307:107237. https://doi.org/10.1016/j.agee.2020.107237
34. Rydberg NT, Milberg P (2000) A Survey of Weeds in Organic Farming in Sweden. Biological Agriculture & Horticulture 18:175–185. https://doi.org/10.1080/01448765.2000.9754878
35. Lososová Z, Chytrý M, Kühn I et al. (2006) Patterns of plant traits in annual vegetation of man-made habitats in central Europe. Perspectives in Plant Ecology, Evolution and Systematics 8:69–81. https://doi.org/10.1016/j.ppees.2006.07.001
36. Richner N, Holderegger R, Linder HP et al. (2015) Reviewing change in the arable flora of Europe: a meta-analysis. Weed Res 55:1–13. https://doi.org/10.1111/wre.12123
37. German Federal Forest Act (BWaldG). BGBI. I 1037, 1975.
38. German Federal Aviation Act (LuftVG). BGBI. I 698, 2007.
39. Walter A, Wiehe J, Schlömer G et al. (2018) Naturverträgliche Energieversorgung aus 100 % erneuerbaren Energien 2050. BfN-Skripten, Bonn-Bad Godesberg
40. Bundesministerium für Verkehr, Bau- und Stadtentwicklung (2012) Gemeinsame Grundsätze des Bundes und der Länder für die Anlage und den Betrieb von Flugplätzen für Flugzeuge im Sichtflugbetrieb: BAnz AT 24.08.2012 B3