Estimation of the potential for expanding use of wind energy along infrastructure corridors, and development of pertinent reliability criteria

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1 Tasks and aim

The applicable procedures for planning and licensing of outdoor wind energy plants are precisely specified by existing laws and jurisdiction. Partly as a result of conflicts with immission-protection and nature-conservation / landscape-protection frameworks, wind energy plants are concentrated in the priority or suitability areas defined by regional plans (Raumordnungspläne) and tend not to be found outside of such areas. For control of wind energy plants, the German Länder have special provisions and minimum-distance directives in place that permit virtually no exceptions, even under special circumstances. Under the established system, which is restrictively structured, and under the applicable jurisdiction, it can seem that virtually no additional areas could be developed for further expansion of wind energy use.

On the other hand, if the ambitious climate protection aims of the Federal Government and of the European Union are to be fulfilled, the role of wind in electricity generation from renewable energy sources will have to be increased. Consequently, additional locations for wind energy plants will have to be found that entail minimal additional burdens for local residents and for the natural environment. This also applies to repowering with more powerful new-generation systems, which tend to be taller and have larger rotors and thus require installation sites to be reassessed in terms of potential conflicts. To these ends, defined procedures for identifying suitable sites need to be reviewed and supplemented.

This is the context for the present research project. In its findings, it shows how, in the search for suitable sites for wind energy plants, the environmental burdens connected with existing highways, railways and power-transmission lines, such as noise and impairments of of natural beauty, can be harnessed for "bundled" construction of new wind energy plants, in order to keep the additional burdens resulting from new wind energy plants to a minimum. To date, such existing environmental burdens have not yet been taken into account in designation of priority or suitable sites for wind energy plants. With this approach, significant additional potential for energy generation could be developed, without a departure from the existing regional planning system.

The method as developed works from the assumptions that infrastructure corridors and wind energy plants, under certain circumstances, have comparable or similar environmental impacts, and that the two categories of impacts can overlap in such a manner that new wind energy plants do not, or do not significantly, add to infrastructure corridors' existing impacts. On the basis of these assumptions, environmental studies can show and justify, with respect to existing practice in designation of priority or suitability areas, that the value of area categories with exclusion designations may be reduced and that the applicable distance regulations in such areas with strong existing impacts may be modified. The various existing impacts of infrastructure corridors – especially noise and reductions of natural beauty – may be seen as justification for concentrating additional impacts of wind energy plants in such areas and, as a result, sparing undisturbed landscape areas with no impacts to date.

By way of example, the additional areas that could be made available for wind energy use, in impacts swaths of major transport pathways and high-voltage power lines, are determined in three model regions. In a subsequent step, the total available area is extrapolated to the national level, taking account of relevant alternative scenarios.

2. Regional planning as the most important factor in selecting areas for wind energy use

In Germany, regional planning is the key level for decision-making within regard to wind energy use. Any development of new sites or areas for wind energy use must begin on that level.

Currently, on the medium-scale level of regional planning, conflicts between wind-energy use and other types of land uses are being minimised via rather general prohibition of wind-energy use in areas given over to certain sensitive uses and in protected areas, along with the relevant assigned separating areas. At the same time, the existing environmental burdens from such sensitive uses are not taken into account in this context – at least not systematically.

In the interest of yielding additional suitable potential sites for wind-energy use, on the regional-planning level, we propose, from a specialised environmental perspective, that

excluded areas reduced in value via existing burdens be considered in a more differentiated manner that takes account of specific local circumstances and that reduces the degree of restriction found in the more general determinations of regional planning.

3 Approach and methods

The approach applied by the research project is based on the following assumptions:

1. Infrastructure corridors have associated areas that are more suited for wind-energy systems than are "open" landscape areas. The reason for this is that such associated areas have environmental impacts (existing impacts) that are comparable to those of wind-energy systems.
2. The areas of the zones with existing impacts that would be of relevance for installation of wind-energy systems can be estimated and substantiated from an informed environmental perspective.
3. In such corridors with existing impacts, the environmental and regional-planning criteria that would hinder designation of area categories for wind energy use can be weakened or modified in terms of their degrees of restriction. Such modification can include changes in any minimum separations that must be maintained to defined categories or objects worthy of protection.
4. Use of sites near infrastructure corridors can be intensified even in conjunction with conformance with required minimum distances – which usually result from technical criteria.
5. The additional potential sites available for wind energy use along infrastructure corridors, as a result, can be quantitatively estimated. At the same time, ultimately, the suitability of any specific site must be verified via individual-case review.
6. The total potential site areas determined for sample regions, via a model procedure, can be extrapolated – subject to reservations with regard to specificity – to obtain an estimate of the total available site area for all of Germany.

On the basis of these assumptions, a method was developed, and applied in the sample regions, for identifying those areas within infrastructure impacts corridors that, in light of their specific existing impacts, should no longer be off limits to wind energy use and that, instead, should be studied, in the framework of individual-case review, for suitability as sites for wind energy plants (cf. Fig. 1).

Figure 1: Method for determination of sites for wind energy plants in the impacts zones of infrastructure corridors

<table>
<tr><td>Definition of existing impacts corridors along infrastructure corridors, with regard to potential for wind energy plants => Result: infrastructure corridors with corridor-specific impacts-strip widths</td><td>Analysis of value reduction, of off-limits areas as defined under regional planning, via impacts from infrastructure corridors => Provisions for overlapping of existing impacts and of areas that are off limits for wind energy use under regional planning</td></tr>
<tr><td>⇩</td><td>⇩</td></tr>
<tr><td colspan="2">Overlapping of existing-impacts corridors with regional off-limits areas for wind energy => Additional areas on which wind energy plants should not be completely ruled out and that should be seen as regions for searching in individual-case review</td></tr>
</table>

3.1 Derivation of existing-impacts zones along infrastructure corridors

The method concept is based on the assumption that, in assessment for new wind energy plants, and with regard to an overall landscape situation, use of sites already subject to comparable impacts must be assessed more favourably than use of open landscape areas that thus far are considered to have no relevant impacts. At the same time, the method focuses especially on linear infrastructure corridors that, via their visual impacts and other emissions, form ribbon-like impacts zones.

In a regionally independent approach, the procedure began by systematically analysing and compiling the environmental impacts – along with their relevance and ranges – of heavily trafficked highways and autobahns, main railway lines and high-voltage power lines. In addition, the environmental impacts of wind energy systems were studied, with a view to determining the extent to which their specific impacts spectrums are similar in sum or are comparable with respect to specific impacts. Where comparable impacts exist – i.e. especially noise emissions and impairments of landscape beauty – they may be taken into account as existing impacts.

Where new wind energy plants are erected in the impacts zones of infrastructure corridors, the resulting environmental impacts, via interaction between the existing and new impacts, can take three basic forms:

1. Similar impacts reinforce each other, adding to the burdens on certain protected natural features or resources (summation impact, additive impact).
2. Differences between the impacts factors involved lead to additional burdens that formerly were not present (indirect interaction; synergistic impact).
3. The added, but similar, impacts are considerably weaker than the existing impacts. They present only a minor added burden for certain relevant protected natural features or resources (modified impact). In the most favourable scenario, the added impacts completely disappear within the existing impacts.

With respect to existing impacts, the following impacts of infrastructure corridors / routes are considered to be generally comparable to those of wind energy plants:

- Impairments of natural beauty (landscape scenery)
- Noise disturbances for people (does not apply to power lines)
- Noise and scare impacts on birds (does not apply to power lines)
- Collision risks for animals, especially birds and bats
- Barriers for animals, especially birds

Detailed study reveals differences in the nature and scale of the relevant impacts and in the standards for legal assessment that must be applied.

Wind energy plants and power lines **impair natural scenery** in comparable ways, since both have tall, mast-like structural elements. The impairments on natural landscape scenery resulting from power lines increase with the height of the line masts involved and with the numbers of lines that are combined. The greater the impairments resulting from such lines, the smaller the additional impairments resulting from new wind energy plants. In particular, 220 kV and 380 kV lines, with masts up to 60 m tall, and in configurations as combined lines, are relevant existing impairments.

By comparison, the structural features of electrical railway lines jut up much less conspiciously in landscapes. On the other hand, in rolling terrain, rapid-transit railways, like highways and autobahns, are often visible from a considerable distance as pronounced cuts through the landscape. The scenic impairments resulting from such features must be assessed in individual cases; in the present context, such impairments cannot simply be defined, methodically, as general corridors of existing impacts.

Noise impacts are caused especially by heavily trafficked roads and railways; high-voltage power lines are of no relevance in this regard. The noise emanating from roads with traffic volumes of more than 10,000 vehicles per day tends to be a continuous accompanying phenomenon, while railways emit noise in intensive, short phases (while trains are passing) that are followed by lengthy (more or less) phases of quiet. This difference is taken into account in noise-calculation procedures, as a "railway bonus" for railway noise. In addition, it is assumed that railway noise has a less pronounced effect on animal communication than does continuous road noise. In general, the noise from a wind energy system is comparable to such infrastructure noise. Its energy levels are lower than those of traffic noise, however, and in its structure, as a continuous background sound, it is more similar to road noise than to railway noise. Depending on the distances and intensities involved, noise immissions from roads can physically drown out – either partly or completely – those from wind energy plants. Another factor that must be considered in any assessment is that traffic noise tends to decrease at night, while the noise from wind energy plants tends to remain constant.

With regard to licensing issues, comparative consideration is hampered by certain factors – for example, with regard to **residential developments**, the maximum permitted levels of traffic noise resulting from new projects are higher than the standards set by the Technical Instructions on Noise Control (TA Lärm) for industry / commercial noise. These differences are not founded on stringent scientific criteria; they result in that the standards are political definitions issued by the organs responsible for relevant regulations. In addition to considering disturbances as such, one must also consider relevant aspects such as public acceptance, economic acceptability and the possibility of financing protective measures. For example, new wind energy plants must conform to night noise standards of 40 dB(A) in neighbouring residential areas. Existing, additional noise loads on such a neighbouring residential area, resulting from an existing federal highway, are not considered significant. New through roads (Bundesstraße), on the other hand, have to comply with a standard of "only" 49 dB(A) at night. If a wind energy system's noise emissions into a residential area are over 40 dB (A), the facility is impermissible even if its noise emissions are swallowed completely by the noise of a neighbouring road. In light of this complicated legal situation, the present project uses highly general assumptions regarding the range and combined effects of noise impacts, assumptions that cannot take the place of individual-case assessments with regard to immissions issues.

Noise and scare impacts on animals, especially avifauna, have been intensively studied for both traffic routes and wind energy plants. Both breeding and resting birds maintain relatively large "effect distances" to roads, ranging from 150 to 500 m, depending on the bird species in question. Consequently, the existing noise-related impacts must be considered high in this area. At the same time, different bird species react in different ways, and thus any specific assessment must be based on a survey of the species occurring in the area in question. Only a few of the bird species that have been intensively studied to date are especially noise-sensitive per se. Relevant structures prompt all other species to maintain an "effect distance" and to reduce breeding and resting within that distance.

The situation for railways differs from that for roads in that noise along railways, which is only intermittant, does not significantly reduce birds' breeding success if certain

maximum durations of disturbance are not exceeded and if the quiet periods between train passages are long enough for birds to provide necessary acoustic signals (song, warning calls). As a result, existing noise-related impacts along railways may be considered a relatively minor factor for breeding birds. On the other hand, since there is solid evidence that resting birds tend to avoid railways, and that certain bird species maintain distances of over 500 m to railways, heavily trafficked traffic routes are considered, in general, to have significant existing impacts.

For all types of projects, including wind energy plants, **collision and barrier impacts of relevance for animals** are described. Since different relevant impacts have highly different focal points, such impacts, which ultimately have additive effects, are not considered to be relevant existing impacts within the meaning of a preference for wind energy plants.

From an analysis of the manner in which impacts overlap, general existing-impacts corridors were derived for each pertinent type of route or line. These corridors were then used as a basis for further studies on the potential for modifying areas "off-limits" to wind energy use (cf. Tab. 1).

Tab. 1: Widths of corridors, along infrastructure corridors, of relevance with regard to existing impacts

Project type	Range of assessment-relevant impacts	Affected protection category	Generalised width of corridor relevant to existing impacts (methodical definition)
Long-distance road (> 10,000 – 20,000 DTV)	About 500 m (49 dB(A) at night) About 200 - 500 m (Effect distance for avifauna)	People Animals	700 m (2 x 350 m)
Long-distance road (> 20,000 DTV)	About 900 m (49 dB(A) at night) Ca. 200 – 500 m (Effect distance for avifauna)	People Animals	1,000 m (2 x 500 m)

Main railway line (> 40 trains / day)	About 620 m (49 dB(A) at night) Ca. 150 – 350 m (Effect distance for avifauna)	People Animals	1,000 m (2 x 500 m)
High-voltage power line (Mast height > 40 m)	Scenery impairment, individual-case assessment	Landscape	1,000 m (2 x 500 m)
For comparison:			
Single wind energy system	About 450 m (40 dB(A) at night)	People	
Wind farm	About 750 m (40 dB(A) at night) Ca. 100 – > 300 (Effect distance for avifauna)	People Animals	

3.2 Evaluation and analysis of guidelines for minimum distances

In identification of potential sites for wind energy plants, specifications regarding minimum distances to infrastructure corridors must also be taken into account, along with the range and overlapping of impacts. A nation-wide evaluation of the pertinent administrative provisions has revealed major differences between the Länder. Guidelines regarding minimum distances between infrastructure corridors/lines (roads, railway lines, power lines) and wind energy plants are oriented largely to the distances required from a substantiated safety perspective. They give no indication of efforts to apply exaggerated restrictions. At the same time, it emerged that existing-impacts zones tend to extend beyond the required minimum distances, and thus use of sites with existing impacts would not violate minimum-distance requirements.

3.3 Modification of regional-planning restriction categories and minimum distances in existing-impacts corridors

In regional planning, the established procedure for identifying priority or suitability areas for wind energy use normally applies an exclusion principle: certain categories of areas, such as protected areas or defined minimum buffer areas around settlements, are excluded from the outset and thus are not available for any interest-balancing in individual cases.

By contrast, the method concept developed in the project is based on the following assumption with regard to areas excluded from the outset for wind energy use, as a result of their specific importance in regional planning: where such areas fall within impacts corridors of infrastructure corridors, existing infrastructure-related impacts may reduce the quality of such areas to such an extent that, subject to detailed individual-case review, such exclusion is no longer justified, meaning that construction of wind energy plants may be possible after all (such areas then become "search areas").

In infrastructure corridors with existing impacts, a more flexible approach, oriented to individual cases, should thus be used in considering such exclusion criteria. Decisions on the actual suitability of possible sites within so-defined "search areas" would then have to be taken at the regional or local levels of development planning. The aim of such efforts should be to provide new latitude for decision-making in regional planning, via an approach whereby sites that are potentially suited, as a result of their existing impacts, would no longer be excluded from the outset via overly general procedures. The method, which is easy to apply locally, can be of value in efforts to find additional sites for erection of new wind energy plants and for repowering, and it can also help minimize usage conflicts.

On the basis of the average ranges of key infrastructure-specific impacts (cf. Tab. 1), a general existing-impacts corridor is defined for each type of infrastructure corridor / axis.

A specific intersection rule is defined for each type of infrastructure corridor / axis, as well as for each type of excluded area that would be degraded by impacts (areas of specific importance for landscape beauty, bird-protection areas, buffer zones around settlement areas, recreational areas, etc.). With the help of a Geographic Information System (GIS), intersection operations are carried out on the existing impacts zones with the restriction categories, in keeping with these rules. As a result, this procedure

identifies "search areas" and "search sections", along infrastructure corridors, that, on the subsequent planning level, and within the context of individual-case review, should be studied more closely for suitability as sites for wind energy plants.

Since areas off limits to wind energy use are specifically defined in every German Land (state) and in every planning region, the intersection rules have to be individually adapted for every planning region. In the process, the following must be determined, for each type of infrastructure corridor, and for each relevant area type that occurs within the relevant existing impacts corridor: whether the area should remain off limits to wind energy use nonetheless or whether the "off-limits" categorization should be abandoned and the area should be approved for individual-case review of its suitability for wind energy use.

Tab. 2: Selection of intersection rules for existing impacts corridors along roads and railway lines, illustrated with the example of the greater Brunswick (Braunschweig) region

Existing exclusion criteria	Intersection rule	Remarks
Immission protection (minimum distances to residential uses)		
Existing settlement area or area reserved in the context of land-use planning	Remains excluded	
500 m buffer for existing settlement area or area reserved in the context of land-use planning	Remains excluded	
500 m to 1,000 m buffer for existing settlement area or area reserved in the context of land-use planning	Individual-case review	Existing noise impacts; if buffer distance suffices with regard to protection of landscape beauty, approval of wind energy plants could be possible
Nature conservation and species protection		
Priority area for nature and landscapes	Individual-case review	Collective category that includes the data described below; must be assessed in keeping with the relevant basic data

200 m buffer for priority area for nature and landscapes	Individual-case review	
Priority area, Natura 2000	Individual-case review	Preliminary review: if conservation aims would be considerably countered, exclusion
200 m buffer, priority area, Natura 2000	Individual-case review	Preliminary review: if conservation aims would be considerably countered, exclusion
Nature conservation area, set aside under Art. 24 Lower Saxony Nature Conservation Act (NnatG)	Remains excluded	
200 m buffer for nature conservation area set aside under Art. 24 Lower Saxony Nature Conservation Act (NnatG)	Individual-case review	Suitability depends on the sensitivity of the objects to be protected
National park, Art. 25 Lower Saxony Nature Conservation Act (NnatG)	Remains excluded	
200 m buffer for national park set aside under Art. 25 Lower Saxony Nature Conservation Act (NnatG)	Individual-case review	If there are neighbouring sensitive objects, exclusion
Landscape protection area	Individual-case review	Suitability depends on the applicable protected-area ordinance
Protected landscape element	Remains excluded	
Landscape beauty		
Priority area for recreation	Individual-case review	
Area subject to reservation for recreation	Individual-case review	
Priority area for open-area functions	Individual-case review	
Landscape beauty: off-limits areas, not including the Harz and Elm areas	Individual-case review	
Landscape beauty: off-limits areas around the Harz and Elm areas (10 km and 5 km, respectively)	Remains excluded	
Areas of importance for animal protection		
Avifaunistically important area for breeding birds / visiting birds	Remains excluded	
500 m buffer for avifaunistically important area for breeding birds / visiting birds	Individual-case review	If sensitive bird species occur, exclusion; otherwise, review, with regard to species-protection laws, in connection with approval

So-identified additional areas are likely to contain additional sites for wind energy plants, since detailed individual-case review will probably show that, at least in parts of such areas, installation of wind energy plants would not create any relevant additional disadvantages or impairments. Where that is the case, the areas can then be included within the relevant regional wind energy concept.

The existing impacts zones have been defined as no wider than 500 m. As a result, it is assumed, in calculations, that rows of wind energy plants could be installed along infrastructure corridors. In each case, the systems would be sited as closely as possible – taking applicable required safety margins into account – to the infrastructure corridors. The total length of suitability areas identified via use of intersection rules (search sections) serves as a sufficient measure for determining the number of additional wind energy plants that could be installed in a given existing impacts zone.

4 Application in sample regions

By way of example, the method was applied to three sample regions of the administration union comprising the greater Brunswick area (Großraum Braunschweig), the regional administrative authority for central Hesse (Regierungspräsidium Mittelhessen) and the Uckermark-Barnim planning association (Planungsverband). These areas range in size from 4,000 to about 7,000 km^2. In addition, the City of Bremen was studied as a model case for identification and development of wind energy sites at the local level.

In planning processes carried out in the sample regions for identification of areas for possible wind energy use, certain area categories are ruled out from the outset, because of their special requirements for protection, at the regional-planning level (cf. the general discussion above of such an approach). As a rule, for example, Natura 2000 areas, landscape-protection areas and nature conservation areas, along with attached 200 m buffer zones, are defined as off limits to wind energy use. Settlement areas, along with buffer zones from 500 to 1000 m wide, are also not considered for wind energy use. To date, as a rule, forest areas, open water areas and special topographical features (such as "landscape-shaping ridges") are also considered off limits. Furthermore, potential

sites are reduced via the minimum margins that must be observed to other uses; the buffer areas within such minimum margins are also considered to be off-limits areas.

In the sample regions considered, a further restriction with regard to possible sites results from an applicable "concentration requirement" for wind farms that involves a defined minimum size for wind farms. Where the regional-planning category "suitability area" – which, in the greater Brunswick area, for example, is 50 hectares in size – is applied, regional planning may not provide for installation of additional wind energy plants outside of such areas.

In sum, these requirements have the result that, at the regional planning level, a large portion of the total planning area is already defined from the outset as off-limits for wind energy use. In all of the sample regions considered, this effect results even for areas that lie within existing impacts corridors of infrastructure corridors. As a result, therefore, such planning does not take into account that certain areas classified as off limits within existing impacts corridors, due to their value, are actually so reduced in value that wind energy use should not be ruled out in principle.

Pursuant to the designation procedure used by authorities in the sample regions, in regional planning, only about 1-10 % of the existing impacts corridors studied in the sample regions would be suitable as sites for wind energy plants (the spread in the figure results from differences between regions and infrastructure-corridor types). By contrast, the method applied in the research project, for modification of restriction categories in areas with existing impacts, shows that 15 to 40% of the areas would no longer have to be categorically ruled off limits to wind energy use. Significantly, the model regions differ considerably with regard to applicable definitions of existing restrictions (excluded areas) and, consequently, in their additional areas that could be made available by taking account of existing impacts from infrastructure corridors (cf. Tab. 3).

The assessments found that "settlement areas and their buffer margins" is the use category with the largest amount of excluded areas. At present, an average of 77 % of the areas lying in existing-impacts corridors are not available for wind energy use because they fall into that category. Areas falling into the nature conservation category

of "landscape beauty" rank a distant second, accounting for only 37 % of areas in existing-impacts corridors that are not available for wind energy use. Areas set aside for avifaunal protection or noted for avifaunal significance account for about 30 % of excluded areas within corridor areas.

The various regions involved differ considerably in terms of percentage sizes of restriction areas with regard to relevant total corridor areas. While in the Brunswick region the criterion of landscape beauty applies to some 60 % of infrastructure corridors, the corresponding percentages are only 39 % for Uckermark-Barnim and 13 % for central Hesse (Mittelhessen).

5 Extrapolation to obtain total potential additional areas for wind energy use along infrastructure corridors in Germany

5.1 Available area for wind energy use

The results obtained in the model regions were used to prepare a nation-wide estimate of the total area potentially available for wind energy use. The results obtained for the model regions studied were applied to Germany's main natural-area units and extrapolated to the level of the entire country. At the same time, differences in prevailing wind conditions were taken into account; for example, specific deductions were applied for the Länder Bavaria and Baden-Württemberg.

Significantly, the various relevant areas differ considerably with regard to the manner in which regional-planning area categories are specified in the planning regions, as well as to the manner in which excluded areas can be modified via existing impacts. These differences lead to considerable uncertainties with regard to transfer of the model assumptions to the national territory as a whole. Consequently, the results of the extrapolations, which are based on the model assumptions, are subject to similar uncertainties; in fact, they should be considered solely as indications of the general total area of additional available areas.

Along with the method-based uncertainties in extrapolation to the nation-wide level, an additional difficulty presented itself: at the regional-planning level, for the sample regions, it was not possible to reliably determine the likelihood that potential sites found

within the infrastructure-corridor sections identified as "search areas" could actually serve as sites for wind energy use. For this reason, three different relevant scenarios were developed in which different assumed degrees of relevant probability (i.e. probability of actually being able to serve as a site for wind energy use) were assigned to different relative percentages of the search areas involved. In addition, the percentages were applied to search areas with restrictions and search areas without restrictions. This produced, as a final result, a potential range for the category "usable additional sites".

Tab. 3: Areas along infrastructure corridors in which sites for wind farms can be sought (search sections)

Infrastructure corridor types in the sample regions	**Total length of existing-impacts corridors**	**Search sections with no excluded areas** (already suited for wind energy plants)		**Search sections with modified excluded areas** (additional search areas for individual-case assessment)		**Total length of search area**		**Percentage of search route with no exclusion criteria that is already designated for wind energy use**		**Remaining length of search route that could have additional potential sites** (=> individual-case assessment)	
Greater Brunswick											
Roads	420 km	6.9 km	1.6%	66.6 km	15.9%	**73.5 km**	**17.5%**	3.4 km	50%	**70.1 km**	**16.7%**
Railway	149 km	0.6 km	0.4%	29.1 km	19.5%	**29.7 km**	**19.9%**	0 km	-	**29.7 km**	**19.9%**
Power lines	125 km	2.5 km	2.0%	55.5 km	44.4%	**58.0 km**	**46.4**%	1.7 km	2.9%	**56.3 km**	**45.0%**
Uckermark-Barnim											
Roads	164 km	18.4 km	11.2%	59.4 km	36.2%	**77.8 km**	47.4%	11.7 km	63%	**66.1 km**	**40.3%**
Power lines	169 km	18.2 km	10.8%	24.7 km	14.6%	**42.9 km**	**25.4**%	12.0 km*	66%	**30.9 km**	**17.2%**
Central Hesse											
Roads	441km	111.0 km	25.2%	61.9 km	14.0%	**172.9 km**	**39.2***%	4.1 km	3.7%	**168.8 km**	**38.3%**

*estimated value

Potentially available areas along roads

Taking account of regional wind conditions, and of the manner in which the relevant values determined for the sample regions are distributed over the route sections in the various pertinent landscape areas, about 1,900 km (or 12 %) of the some 16,000 km of heavily trafficked national long-distance roads with existing impacts (federal autobahns and federal highways > 10,000 daily traffic volume (DTV)) can be classified as usable search sections, in principle, with no regional-planning restrictions. Applying the three different feasibility scenarios following individual-case assessment (60 %, 40 %, 20 % feasibility), one obtains a result of 380 to 1,150 km of route sections that, without any modification of existing restriction areas, would be available for installation of wind energy plants.

Furthermore, taking account of the relevant distribution with regard to landscape areas, an additional some 2,500 km (or 15.5 %) of routes can be derived as search areas, with reducible restrictions, for potential wind energy use. Pursuant to the optimistic scenario, Scenario 3, some 30%, or about 750 km, of these areas would become available for use following individual-case assessment. The other two scenarios, a less-optimistic scenario and a cautious one (with 20% and 10% degrees of feasibility), show that 3% and 1.5% of the total length of pertinent federal highways, or 480 and 240 km sections, could serve as areas for installation of wind energy plants.

Summing of the relevant values in the two aforementioned availability scenarios produces total values ranging from nearly 2,000 km (12.5%) as a maximum to nearly 650 km (4%) as a minimum. Tab. 4 summarises the results for the different scenarios.

Tab. 4: Scenarios for nation-wide extrapolation of total search area (all search sections) and total available potential sites for wind energy plants along roads

Search sections with no restrictions (km)	Search sections with modified restrictions (km)
Total length: 1,973	Total length: 2,537

Percentage of area that could be available for wind energy plants		Percentage of area that could be available for wind energy plants	
Low implementation level (20%)	395	Low implementation level (10%)	254
Medium implementation level (40%)	790	Medium implementation level (20%)	508
High implementation level (60%)	1,185	High implementation level (30%)	762

Scenarios for potentially available route sections (km)	
Total search area (all search sections): 4,510	
Percentage of area that could be available for wind energy plants	
Pessimistic scenario (low implementation level)	649
Optimistic scenario (high implementation level)	1,947

Available sites along railways

Germany has some 18,300 km of multi-track railway lines that are so heavily used that they may be considered to have existing impacts with regard to installation of wind energy plants. Certain railway-line sections in Bavaria and Baden-Württemberg have to be deducted from that figure because the prevailing wind conditions along those sections basically rule out wind energy use. Such deduction yields a total of some 15,900 km of railway lines that must be taken into account in extrapolation to obtain total potential areas. In the procedure used, the Brunswick model region's share of the search sections, i.e. of the areas that should not be considered off limits to wind energy use, in principle, is applied to that total figure. In the case of search sections with no restrictions, a section length of 64 km results; for search sections with modified restrictions, a section length of 3,100 km results. Since data availability required this extrapolation to be based on reference values from only one sample region, this result is relatively poorly founded, however.

For estimation of the actually usable areas along these search sections, the same scenarios are used that were used for the roads sector (i.e. 20 %, 40 % and 60% for search sections with no restrictions, and 10 %, 20 % and 30% for search sections with modified restrictions). The resulting totals range from nearly 1,000 km of railway sections as a maximum and about 320 km as a minimum for areas suitable for installation of additional wind energy plants. Tab. 5 summarizes the results for the different scenarios.

Tab. 5: Scenarios for nation-wide extrapolation of total search area (all search sections) and total available potential sites for wind energy plants along railways

Search sections with no restrictions (km)		**Search sections with modified restrictions (km)**	
Total length: 64		Total length: 3,100	
Percentage of area that could be available for wind energy plants		Percentage of area that could be available for wind energy plants	
Low implementation level (20%)	12	Low implementation level (10%)	310
Medium implementation level (40%)	24	Medium implementation level (20%)	620
High implementation level (60%)	36	High implementation level (30%)	930

Scenarios for potentially available route sections (km)	
Total search section: 3,164	
Total length of sections with available sites for wind energy plants	
Pessimistic scenario (low implementation level)	322
Optimistic scenario (high implementation level)	966

Potentially available additional sites along power lines

In comparison to roads and railways, power lines have low levels of existing impacts with regard to the additional impacts of wind energy plants. In fact, the only possible existing impacts from power lines that can be assumed are impairments of scenic beauty caused by high-voltage lines. As a result, the issue of public acceptance plays a special role with regard to the question of installation of wind energy plants within search areas along power lines.

The values determined in the model regions for the existing search sections were applied to the nation-wide total of 17,500 km of high-voltage power lines. For search sections with no restrictions, the resulting value is 1,120 km (6.4 %); for sections with restrictions, it is 5,705 km (32.6 %).

For estimation of the total area of actually usable areas along these search sections, considerably more modest scenarios are used, in keeping with the special uncertainties applying to installation of wind energy plants within search areas of power line routes (e.g. 4 %, 10 % and 20 % for search sections with no restrictions, and 2 %, 5 % and 10 % for search sections with modified restrictions). The resulting totals range between 794 km of power-line sections as a maximum and 159 km as a minimum for areas with existing impacts that are suitable for installation of additional wind energy plants. Tab. 6 summarizes the results for the different scenarios.

Tab. 6: Nation-wide extrapolation of total search sections along high-voltage power lines

Search sections with no restrictions (km)		**Search sections with modified restrictions (km)**	
Total length: 1,120		Total length: 5,705	
Percentage of area that could be available for wind energy plants		Percentage of area that could be available for wind energy plants	
Low implementation level (4%)	45	Low implementation level (2%)	114
Medium implementation level (10%)	112	Medium implementation level (5%)	285
High implementation level (20%)	224	High implementation level (10%)	570

Scenarios for potentially available route sections (km)	
Total search area (all search sections): 6,825	
Total length of sections with available sites for wind energy plants	
Pessimistic scenario (low implementation level)	159
Optimistic scenario (high implementation level)	794

5.2 Potential for energy generation along infrastructure corridors

The energy-generation potential correlated with the potentially available additional sites is estimated by extrapolation on the basis of the sections assumed to be available for wind energy use. In each case, three different implementation scenarios are used that differ in terms of the sizes of the installations that would be installed.

Here as well, different scenarios with different basic assumptions regarding the implementation level – low, medium or high – are used. The implementation level involves the degree to which potentially available areas, within the search sections, can actually be used for the purpose in question, and it also depends on technical aspects of feasibility.

Tab. 7 summarises the potential generating capacity, as determined in this sense, with regard to the various infrastructure corridors, and broken down in accordance with the possible technical scenarios for installation (addition of 2 MW, 3.5 MW or 5 MW systems).

Tab. 7: Potential nation-wide wind-energy generating capacity along infrastructure corridors

	Installed output (MW)		
Potential nation-wide wind-energy generating capacity along infrastructure	2 MW systems 2.5 systems/km 5 MW/km	3.5 MW systems 2 systems/km 7 MW/km	5 MW systems 1.5 systems/km 7.5 MW/km

corridors						
Implementation level for search sections						
Roads	3245	9735	4543	13629	4868	14604
Railways	1610	4830	2254	6762	2415	7245
Power lines	795	1193	1985	2977	3570	5955
Total	**5650**	**15758**	**8782**	**23368**	**10853**	**27804**

For the first of the technology scenarios – i.e. the potential additional capacity resulting via installation of 2 MW-class systems, and with the possibility of installing 2.5 systems per kilometer of search section – a total potential of 5,650 MW results in the case of a pessimistically assumed level of implementation of search sections (10% with modified restrictions, and 20% with no restrictions). In the second and third technology scenarios, the pessimistically assumed implementation levels, i.e. installation of 3.5 MW and 5 MW systems, yield potential generating capacity of 8,782 and 10,853 MW, respectively. This result shows that – at least with 5 MW-class systems – installed capacity could be increased by nearly 50% (total installed capacity as of the end of 2008 in Germany: 23,900 MW).

With an optimistically assumed implementation rate, in technology scenario 1 total capacity of 15,758 MW could be installed via installation of 2 MW systems. On the other hand, 2 ½ times as many systems would be required to reach that figure as would be required with 5 MW systems, under the same assumptions.

In sum, infrastructure corridors indeed offer opportunities for installing additional wind energy plants. What is more, this can be achieved via use of areas that to date have been off limits to wind energy use. Such areas could be taken into account in updating of regional regional-planning plans.

6 Summary

In general, it makes sense to use areas available along infrastructure corridors for installation of additional wind energy plants. Such areas offer advantages over many areas in open landscapes.

In light of the existing impacts along traffic and power-line routes, the added impacts resulting from installation of wind energy plants tend to be smaller along such routes than on sites in open landscapes that have few or no impacts.

Certain regional-planning area categories that, in light of their special importance and sensitivity have thus far been off limits to wind energy use, in the context of regional planning, tend to have reduced environmental characteristics and value when exposed to existing, strong environmental impacts in the vicinity of infrastructure corridors. As a result, new potentially available areas can gradually be identified at the regional-planning and land-use planning (Bauleitplanung) levels and then subjected to individual-case review with regard to their actual suitability and implementation feasibility.

Using sample studies and calculations in three planning regions, the project was able to show that the total potentially available area would be considerable, even if, at the regional planning level, the amounts of areas produced via such modification of restriction categories within impacts corridors can vary widely in accordance with infrastructure-corridor type and planning region.

Existing procedures could be systematically reviewed in updating of regional plans, and in the framework of a well-planned overall concept for identifying priority areas for wind energy use. In the process, value-reducing existing impacts along infrastructure corridors should be "reassessed" in a manner that will enable additional, suitable potential areas in the vicinity of infrastructure corridors to be made available for wind energy use. Final assessment of suitability and permissibility must then take place at the land-use-planning level (Bauleitplanung) or within the relevant procedures under immissions-control law. Areas in question should not be set aside in advance as regional-planning suitability categories, however, since the necessary decision-making latitude in the present specific case context should not be overly restricted.

Even in a conservative scenario in which modification of restriction categories along infrastructure corridors would be expected to make only 2-10% of the total relevant area additionally available, more than 5,000 MW of additional wind-energy capacity could be installed. And that figure, which is of a significant order, includes consideration of the uncertainties – which from a perspective of methods undoubtedly are present – in transferability of model results to Germany as a whole.

The described method for "reassessment" of areas previously classified as restriction areas is simple to apply at the local level. It can be of use in identifying additional new sites for wind energy plants, sites that would entail only modest additional impacts at most and thus would not be likely to conflict seriously with the aims of nature conservation and immissions protection.