Bundling of transport infrastructure (TI) with photovoltaic facilities and bundling of TI with one another: Standards for safeguarding biological diversity and for accelerating pla...

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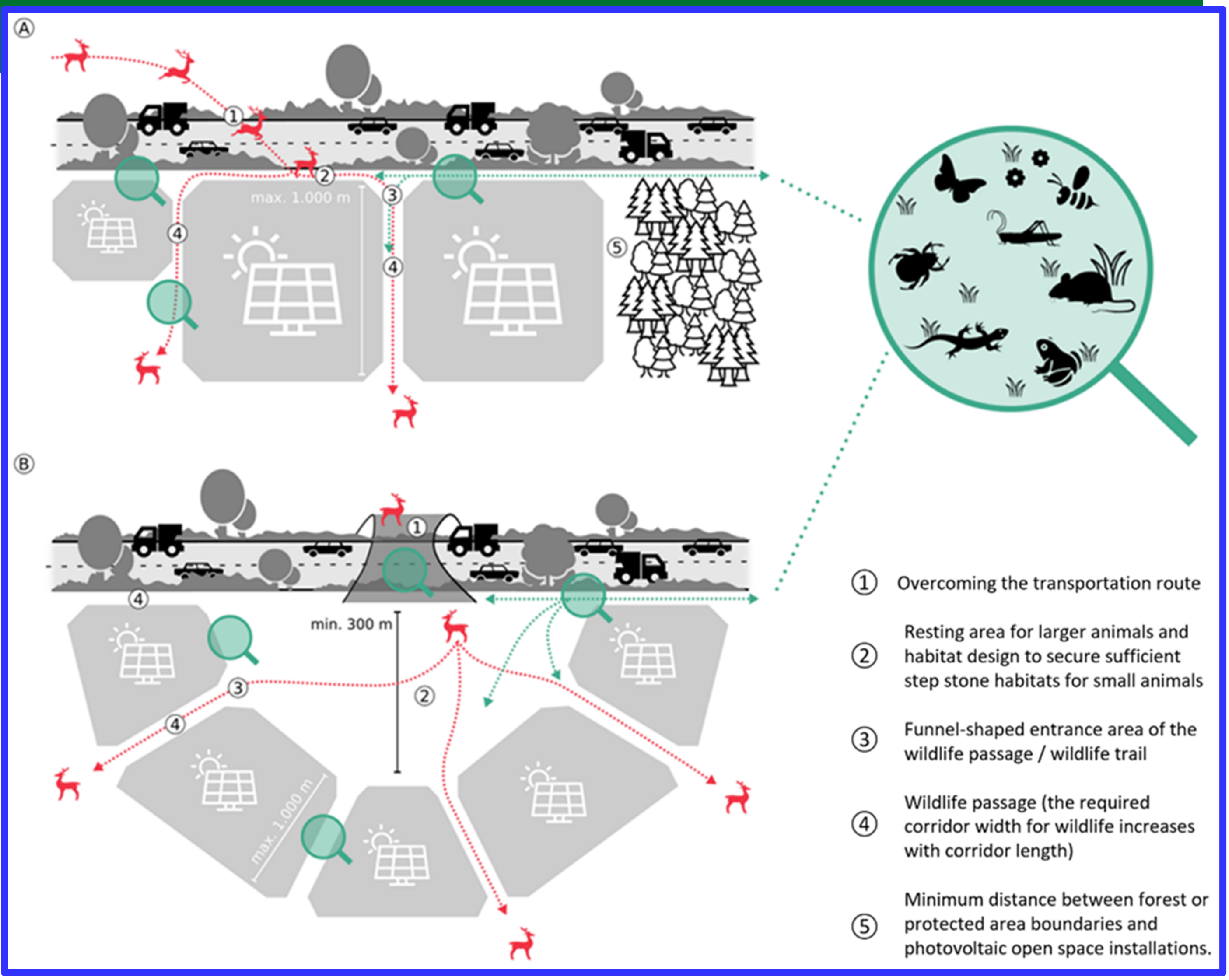
Bundling of transport infrastructure (TI) with photovoltaic facilities and bundling of TI with one another: Standards for safeguarding biological diversity and for accelerating planning procedures

A contribution to Deliverable 5.3 of the Horizon 2020 BISON project

by H. Reck, F. Peter, J. Trautner, M. Böttcher, M. Strein, M. Herrmann, H. Meinig, H. Nissen & M. Weidler



Imprint

Cover: Standards for the positioning of photovoltaic ground mounted systems (PV-GMS), from Peter et al. 2023, submitted.

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The BISON project objectives are: (1) Detecting the methods and materials that can be used by different transport modes to mitigate negative impacts on biodiversity while making infrastructure more performant and reliable, (2) Identifying research and innovation needs for biodiversity mainstreaming in transport infrastructure, (3) Supporting European member states to fulfil their regional and international commitments for sustainable development and (4) Developing collaboration among European States to become political leaders on jointly addressing biodiversity and infrastructure challenges (https://bison-transport.eu/).

Subject 1 of D5.3 (by C. Baierl, M. Böttcher & H. Reck) is the development of a European Defragmentation Map (EDM), which indicates priority sections to reduce barrier effects from the TEN-T and European eco-corridors that need to be protected from negative impacts on their functions or even improved as transport infrastructure is developed. Subject 2 (by H. Reck, M. Böttcher & C. Baierl) is detailed minimum standards for TI planning and for defragmentation planning, including guidelines for the use of the EDM. Related research and development needs are thereby identified.

The standards for bundling of transport infrastructure with photovoltaic facilities was adapted for BISON from selected chapters of a manuscript by F. Peter, H. Reck, J. Trautner, M. Böttcher, M. Strein, M. Herrmann, H. Meinig, H. Nissen & M. Weidler (Peter et al. 2023, submitted to Natur und Landschaft) the **standards for bundling of TI with one another** were authored by H. Reck & M. Böttcher, based on discussions with the colleagues.

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BIODIVERSITY AND INFRASTRUCTURE SYNERGIES AND OPPORTUNITIES FOR EUROPEAN TRANSPORT NETWORKS.

Abstract and policy implications

Bundling is not automatically a mitigating precaution against increasing fragmentation, although if the interspaces or facilities are suitably designed, there may even be advantages in terms of safeguarding habitat networks. At first glance, bundling projects reduce landscape fragmentation, but when looking at a larger scale, it often becomes apparent that fragmentation effects are intensified by bundling and that reconnection measures can become impossible or very costly due to bundling.

Instead of minimising negative effects on nature, bundling can lead to excessively increased land and material consumption, higher emissions, enormous barrier effects and excessive costs. Therefore, a comprehensive ecological and economic balance of bundling options and alternatives is always required.

In any bundling, it must be ensured that ecological networks (biotope network / biotope connectivity / migration corridors) or their restorability are sufficiently safeguarded. For this purpose, preliminary standard requirements and proposed solutions are formulated and the corresponding need for research is outlined.

Key words:

Bundling - Roads - Railways - Canals - Photovoltaics - Biodiversity - Habitat networks - Habitat protection - Wildlife - Barrier effects – Habitat fragmentation – Ecological permeability

Key hypothesis

“Not all bundling routes and not every bundling of TI with other infrastructure are ecological errors but many (at least in densely populated cultural hilly landscapes)”

1 What is bundling

In this paper, we do not consider 'bundling' as a procedural term, but rather as a spatial-functional concept. The limits of advantageous bundling are reached when non-bundled projects "prove to be more spatially and environmentally compatible in individual cases," or when "an unreasonable or unlawful additional burden arises from the bundling of existing and new effects" (BNetzA 2019)."

Bundling and respective standards as part of accelerated planning

Spatial-functional bundling, understood as aiming for solutions with minimal conflicts, can not only contribute to conflict avoidance and mitigation as a planning approach, but also to accelerated planning when consistently applied. The same applies to the use of sound and task-appropriate standards. Compliance with such standards (see following texts) shortens planning and decision-making processes and often reduces the need for specialized analyses in individual cases.

Part A:
Bundling of transport infrastructure (TI) with photovoltaic facilities (PV-GMS)

2 Part A (TI/PV-GMS) Introduction

Solar power plants can be significant barriers to habitat connectivity. Especially critical is their installation over long distances parallel to transport infrastructure.

Although the roof and building potential for solar energy is high, photovoltaic ground-mounted systems (PV-GMS) are increasingly being installed, mainly along transport routes, partly for cost reasons partly because the areas adjacent to traffic routes are considered to have above-average pollution levels and are therefore of inferior habitat quality. This assessment is based on experiences from the last century when the pollution along transport routes was very high and the habitat potential in the hinterland of transport routes was still large. However, this is outdated (Reck 2022). It is not clear how today's political statements on existing pollution are justified. Pollution of areas far from traffic routes e.g. by agricultural inputs (fertilizers, pesticides) or by soil tillage may be weighted less heavily than pollution by noise or tyre wear, for example.

The spatial bundling of transport routes and freestanding photovoltaic systems has enormous potential to disproportionately increase the barrier effect of linear infrastructure and to intensify functional fragmentation effects, so that habitat connectivity and wildlife routes in particular can be impaired. In addition, high-quality habitats and refuges for species worthy of protection may be located on both sides of the transport routes (e.g. Verstrael et al. 2000). The occupation of which may result in the loss of habitats and populations and thus jeopardize the habitat network. For animals crossing roads in bundled areas, for example, the stress situation can become critical if possible resting areas or areas for reorientation on the opposite side of the road are missing and the risk increases that animals turn back into the traffic (Xu et al. 2020), thus increasing traffic mortality.

It is particularly important in this respect to note that both on national levels and at the European level, e. g. through the Biodiversity Strategy of the European Union, all countries and Member States are called upon to create ecological corridors and to ensure the connectivity of the various habitats (EU Commission, Proposal for a Directive COM (2020), 0380, p. 6).

In the following, this paper only refers to the planning and design of PV-GMS, in the context of linear transport infrastructure (roads, railways and waterways). Transportation infrastructure (TI) associated with pipelines and other photovoltaic facilities (PVF), as well as floating PVF, are not addressed.

Fig. 1: Examples of, until now, still initial bundling of PV-GMS and transport routes

Improper bundling of PV-GMS and transport routes can prevent biotope and population connectivity on a large scale and thus excessively impair the mobility of species, which is essential for safeguarding biodiversity. Sources: Aerial photograph Mecklenburg-Western Pomerania (No. 1): Map data © 2015 Google; Orthofotos Brandenburg (No. 2 – 6): GeoBasis-DE/LGB, dl-de/by-2-0

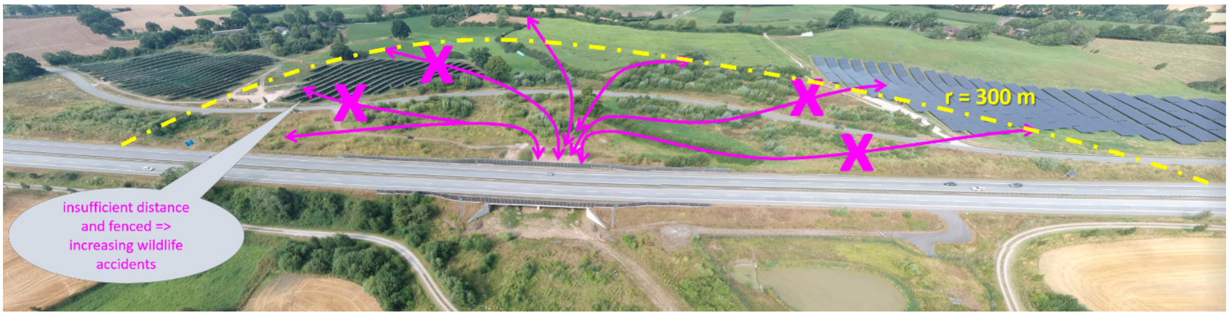

Fig. 2: PV-GMS at a fauna underpass

If PV-GMS are fenced and built too close to wildlife crossings or unfenced roads, the functionality of the wildlife crossings can be significantly impaired or completely prevented and/or the risk of accidents can increase. Aerial photo "Stolpe wildlife underpass" by B. Schulz; for orientation purposes regarding fig. 3, a radius of approx. 300 m west of the underpass is drawn in.

3 The spatial reference of the proposed standards for bundling PV-GMS and TI

Although bundling cannot be expressed uniformly with a single distance value for every case, it is necessary (for practical reasons) to establish a magnitude for the following recommendations. In this context, we consider:

- In general, PV-GMS that are less than 100 to 110 meters away from TI. If the distance is more than 110 meters, there may be sufficiently large areas with independent habitat functions between TI and PV-GMS.
- As a special case the surroundings of specific, integrative wildlife crossings; in this case, a radius of 300 meters must remain barrier-free (see figure in the following text).

4 Goals, benefits, and limitations of bundling PV-GMS and transportation routes

In contrast to spatially separate facilities, the bundling of PV-GMS and transportation routes (but also TI with TI) is expected to result in obvious benefits for the natural environment, particularly in terms of reducing functional fragmentation and improving functional habitat connectivity in landscapes. However, bundling must never lead to a significant ecological barrier effect that cannot be sufficiently avoided or functionally compensated, especially due to the close proximity. Accordingly, suitable spaces or corridors for habitat connectivity and animal movements, as well as special development potentials for eco-corridors, must be secured. Such include international/European and national habitat networks, state-wide and regional habitat connectivity systems or wildlife corridors, and other ecological corridors (that means particularly suitable areas, as well as linear elements in the landscape that enable the movement of individuals, genes, and ecological processes; see Drobnik et al. 2013, Chetkiewicz et al. 2006).

Under no circumstances should the bundling of PV-GMS and transportation routes impair the (future) implementation and/or effectiveness of habitat connectivity measures across existing transportation routes. In particular, the functionality of animal crossing aids and underpasses for water bodies, as well as their access areas (or corridors for large animals), must be ensured. This also applies to particularly suitable areas for the development of green infrastructure (e.g. critical sections in the European defragmentation map (BISON D3.5/1) or in national or regional defragmentation concepts or suitable areas for implementing the needed minimum density of fauna passages (Hlavac et al. 2019, Reck et al. 2023).

The preservation of habitat connectivity axes / habitat networks is particularly important and is required, for example, by the Schleswig-Holstein PV-GMS decree (MI/MELUND 2021). However, migration routes of, for example red deer and other large mammals are often not adequately represented by these axes. Therefore, important migration corridors must be identified and preserved on a project-specific basis in addition to the habitat connectivity corridors. In accordance with the EU Biodiversity Strategy (EU Commission, Proposal for a Directive COM (2020), 0380, p. 4 ff), all supra-local connectivity axes as depicted or planned on European or statewide or regional levels must be kept free.

In any case bundling should never be achieved through a one-sided consideration of potentially less important nature conservation benefits, such as less general landscape fragmentation. A usually undifferentiated perspective only with regard to undissected areas despite their quality, or only with regard to the landscape scenery. Such can lead to habitat fragmentation, i.e., the consumption of ecologically important habitats or corridors or recreational areas. **If less conflicting alternatives are available through spatial distancing of PV and TI (or TI and TI), it is no longer ecologically sensible bundling, regardless of the spatial proximity.**

The corridor function of roadside green infrastructure, for example, for hazel dormice (Friebe et al. 2018), sand lizards (Zimmer et al. in print), and many species of invertebrates (e.g., Vermeulen 1994), must also be taken into consideration. Verge areas (accompanying greenery) can be ecologically significant habitats or have high potential as habitats and ecological corridors. So far, verge areas have mostly not been commercially exploited, allowing for ample opportunities for conservation-oriented enhancements to secure biodiversity. Accordingly, the ecological potential of verge areas must be considered in decision-making processes for bundling.

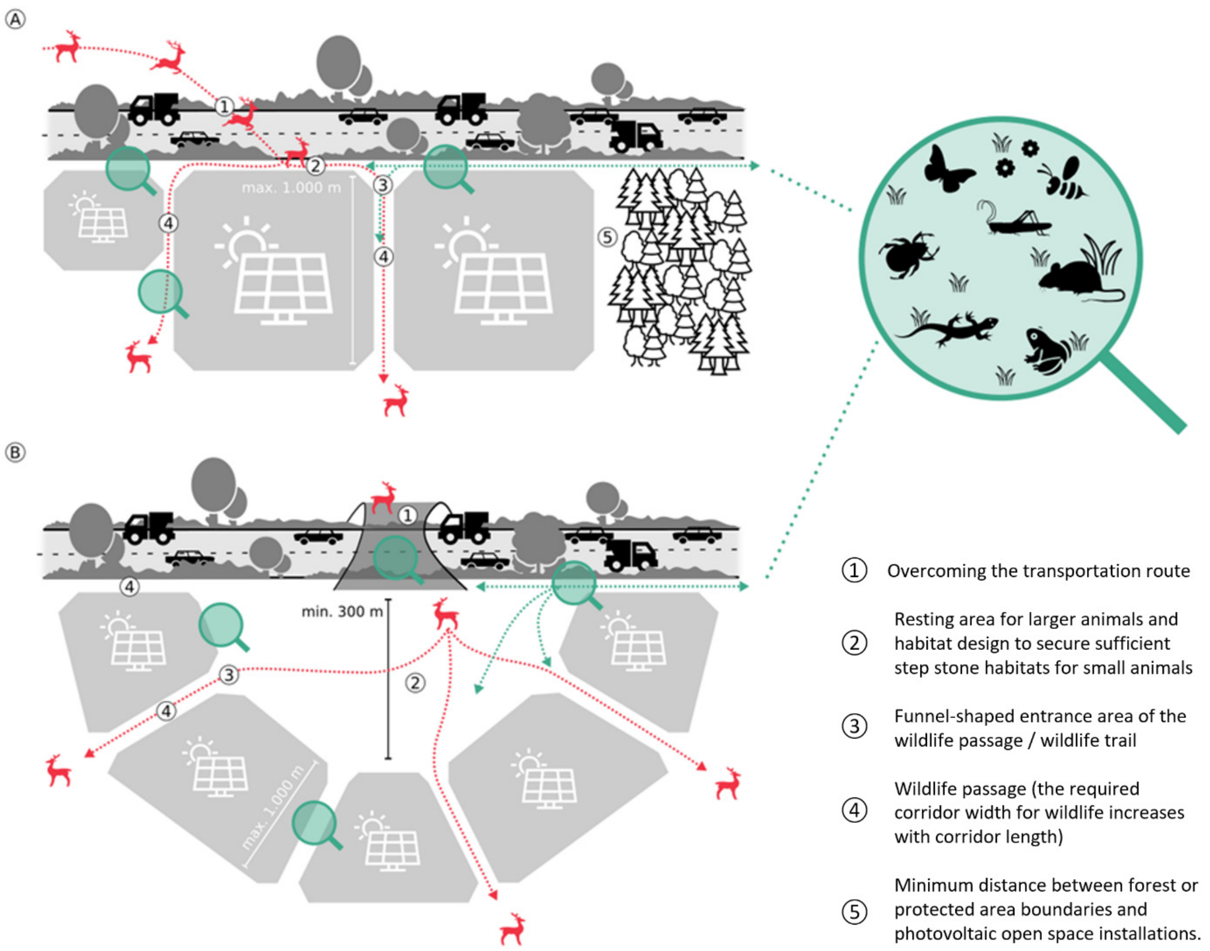

Fig. 3: Standards for the positioning of PV-GMS

(A) along transportation routes and (B) along transportation routes with special integrative crossing aids as *green bridges/underpasses, fauna overpasses/underpasses, water underpasses

The illustrated principle also applies to the construction of parking or resting areas and other infrastructure along transportation routes in the open countryside.

Expansion projects (upgrading), i.e. widening of traffic routes, must not be carried out at the expense of parallel green corridors (species-rich verges); in case of conflict, these must be relocated to the outside.

In the special case of long-term fenced traffic routes, corridors parallel to roads and intersecting PVF can become non-functional. If necessary, animal crossing aids must then be built at suitable locations, at least at intervals of around 2.5 km (cf. Hlavac et al. 2019, Reck et al. 2019). Feeding corridors to existing or future animal crossing aids / animal crossing points must be secured or kept free for this purpose.

5 Standards for bundling PV-GMS and transportation routes

Standards
for fencing and sizing of PV open space installations,
for keeping areas free of PV-GMS and
for the design of wildlife passages between PV-GMS and between PV-GMS and TI

1. **No wildlife fences around PV-GMS**

   Wildlife-proof fencing is generally not considered necessary for the operation of PV open space installations and constitutes an intervention in nature and landscape that affects the mobility of keystone species (vector and habitat formation function of large mammals), among other things. Wildlife-proof fencing (without reasonable cause) represents avoidable impacts that should be avoided using proportionate means.

2. **No eutrophic and/or dense and tall border vegetation**

   Bordering grass and herbaceous verges should not be too dense and thereby hinder or restrict the mobility of smaller ground-dwelling animals. Very dense vegetation bands can arise from improper substrate selection or soil-bound wire mesh. They can prevent the spread of flightless small animals to a similar extent as heavily trafficked roads. In combinations with other barriers, they can hinder the necessary supra-local exchange of individuals between different habitats.

   By choosing nutrient-poor substrates and suitable seed mixtures, barrier effects can be prevented and maintenance efforts reduced. Therefore, intentional or accepted development of dense border structures without reasonable cause generally contradicts the objectives of nature protection.

3. **Mandatory taboo areas for PV-GMS installation**

   Designated areas of the ecological network, such as regionally important habitat corridors and wildlife corridors, must be kept free from PV-GMS installations. In addition, planned reconnection measures as part of reconnection programs should be taken into account, and priority areas for reconnection should be excluded from PV-GMS development. Consideration should be given to European concepts or plans, as well as such on national, regional and even local levels, including special areas with a high suitability for creating eco-corridors in already highly fragmented landscapes. The latter, especially migration corridors for large mammals, must be identified on a project-specific basis, for example based on habitat network analyses (analysis of habitat topology), based on wildlife accident hotspots on roads, or through consultation with hunting rights holders.

4. **Mandatory establishment of wildlife passages through PV-GMS**

   PV-GMS installations, especially in situations where they are concentrated, can disrupt or hinder individual movement between populations, wildlife migration, or colonization and recolonization processes, which may occur independently of specific ecological network axes, on a large scale. Therefore, a minimum level of permeability must be maintained, which also defines the size of spatially contiguous units of PV-GMS.

To ensure sufficient wildlife mobility, a passage corridor with a minimum width of 100 m must be kept free at least every 1,000 m (Fig. 3). The exact location should be derived based on the ecological conditions on site. Obligatory network corridors along water bodies, etc., can support habitat connectivity and serve as wildlife corridors. All main and secondary corridors of connectivity systems (habitat networks), etc., must be fully secured even if they are realized with narrower spatial distances than the 1,000 m spacing, for example.

The minimum width of 100 m for passage corridors is necessary to allow large animals to use these corridors between PV-GMS without significant restrictions and at the same time allow for the design of sufficient stepping-stone habitats for small animals. The otherwise stochastic and extensive dispersal of small animals and the connectivity of their habitats are narrowed by PV-GMS to the passage corridors, which requires an increase in habitat suitability for such species in the corridor. Therefore, 10% of the area of any PV-GMS is required for connectivity functions, either in the form of passage corridors between otherwise closed blocks of PV-GMS and/or, in the case of PV-GMS outer edges < 1 km, for the edge design of PV-GMS as habitat bands. It is a prerequisite that no road use takes place in the passage corridor (short crossings are possible) and that the passage corridor remains free from sealing and technical infrastructure. This, along with ecologically sound area design, is at the same time sufficient for compensating habitat loss on formerly intensively used and ecologically low-value areas.

Furthermore, in order to maintain habitat connectivity parallel to traffic routes, a minimum distance of 30 m must be kept between traffic routes and PV-GMS. This minimum distance, when appropriately designed, provides a resting area between traffic routes and PV-GMS and reduces the risk of wildlife accidents after crossing a road (rebound effect), and it also serves as a connecting corridor between passage corridors through PV-GMS. For fenced traffic routes, this distance is not required if there are no worthy-of-protection stepping-stone biotopes present, and if the wildlife fence in question is likely to remain permanently installed. However, wildlife or traffic protection fences should always be removed when, for example, no significant wildlife accidents are expected due to a reduction in maximum speed, or when they constitute disproportionate barriers in the biotope network.

5. Taboo areas for PV-GMS installation around integrative crossing aids like ecoducts, multi-species fauna overpasses/underpasses or water course underpasses

Crossing aids are intended to maintain or restore ecosystem connectivity along traffic routes, but they can only function effectively if their access area and at least the immediate surroundings are obstacle-free, and stepping-stone biotopes in this area are not compromised in their function. Accordingly, no PV-GMS should be established within a radius of 300 m around existing green bridges, green underpasses, fauna bridges, fauna underpasses, as well as viaducts, water underpasses, and access corridors to crossing aids (Fig. 3). Outside the 300 m radius, or into the taboo zone, 30 m wide connection corridors must be kept parallel to the traffic route (as mentioned above and shown in Fig. 3). In addition, within a wider radius of 900 m, at least three continuous wildlife corridors, each 100 m wide, must be kept clear on each side of the road, to ensure access to the crossing aids from different directions and minimize disturbance. Deviations may occur depending on specific circumstances such as the location of settlements, special land use, local or regional important deer paths or special habitat topology (location of particularly worthy-of-protection habitats / stepping-stone biotopes) (cf. Reck et al. 2019).

6. **Minimum distance of PV-GMS from water bodies, forest edges, and small or minor crossing aids**

   Due to the high importance of watercourses (natural or formerly natural, including straightened water bodies, as well as main ditches with a minimum width of 1.5 m) and standing water bodies for habitat connectivity and as wildlife habitats, PV-GMS must maintain a distance or buffer zone of 50 m from these water bodies. The same applies to a buffer zone of 50 m around minor crossing aids (e. g. small animal passages, green strip bridges, etc.) and bridges or underpasses for e.g. agricultural and forestry traffic cyclists or pedestrians, if they are unsealed or known to be used as crossing points by wildlife.

   Forest edges, like water bodies and their surroundings, are particularly important habitats and migration corridors for various species in the habitat connectivity network. Because they can be utilized by animals both, in the open land area and within the forest stand, a distance of 30 m from PV-GMS is sufficient.

7. **Quality of the wildlife passages or the habitat linkage corridors through solar power plants (and similar facilities) // connectivity corridor**

   The quality of the passage corridors should, according to recommendations for the design of crossing aids (Iuell et al. 2003, Kruidering et al. 2005, Reck et al. 2019), primarily consist of open land with occasional individual bushes and groups of shrubs, which together do not exceed 10 % - 20 % of the area. Only in cases where roadside areas are designed in a gallery forest-like manner and the passage corridor is oriented towards a woody stand, the woody cover in the corridor (patchy or strip-like) should be 50 to 70 %. The vegetation development in the passage corridors should primarily take place on poor soils preserving, if species-rich or natural, existing vegetation or based on adapted seeding and appropriate maintenance. The aim is to develop mainly insect-pollinated, sparse herb and grass layers with usually significant proportions of bare ground structures on one hand, and perennial plant structures on the other hand. The species composition and design of the passage corridors should be oriented towards the primary nature conservation goals and site potentials in the respective natural region (see, at least for Central Europe, Finke & Werner 2020, Reck 2022, Rosell et al. 2020, Unterseher 2015, Werner 2014).

8. **Avoidance of lighting**

   Special requirements exist for avoiding lighting that may deter, disturb, or attract wildlife. Lighting can impede or disrupt the use of the elements of the ecological network, in addition to causing individual losses. Negative effects of lighting can be minimized (Schroer et al. 2019) and therefore should be actively avoided.

Part B: Bundling of transportation routes

6 Part B (TI/TI) Introduction

The same principles as those described for the bundling of transportation routes with large-scale (or long) parallel other technical infrastructures that affect the shape or use of areas as PV-GMS apply to the bundling of transportation routes with one another. Only additional specific features will be described below.

7 Effects of close bundling of transportation routes (impact factors and impacts)

As already mentioned in Part A, unlike spatially independent TIH, the bundling of transportation routes is expected to result in apparent benefits for the natural environment, particularly in terms of reducing functional fragmentation and improving functional connectivity of habitats in landscapes and at a scale of < 1: 50,000, this appears to be the case. However, in reality, this impression is often not true, except in large natural and underutilized areas where bundling can regularly reduce additional burdens. Otherwise, in most European areas, it should be considered that there could be disproportionate additional burdens by TI bundling.

Critical factors of bundling

- Disproportionate effort for maintenance roads, emergency roads, forestry roads or agricultural roads, crossing structures, drainage and rainwater retention basins, as well as for the development of stops or stations, rest areas, and agricultural areas.
- Disproportionate (area) requirements for the dimensions of crossing structures for traffic and even more so for necessary fauna passages (see below), with disproportionate material consumption and therefore disproportionately high emissions, including CO_2.
- Significant intensification of barrier effects, as bundling roads can be absolute barriers for many species. This is due to the frequent use of protective walls (or concrete guards respectively) in close bundling, as well as the cumulative and potentially multiplicative effects on fragmentation and mortality (resulting high distance of stepping-stone habitats, psychological barrier, cumulative filtering effect due to higher risk of collisions and the possibly enhanced need for construction of wildlife fences).
- The effort for ecological crossing aids increases, as longer crossing aids may need to be disproportionately wider in close bundling, and some solutions may become impossible (long underpasses may no longer be usable by many species or wildlife warning systems at crossing points may be ineffective due to the higher collision risk by rebound effects).
- Implementation of measures for reconnection of habitats can be significantly hindered by conflicts of jurisdiction due to different administrations or responsibilities for different transportation modes, and higher planning and construction costs arise due to the high need for coordination and necessary separation devices as protection walls or concrete guards etc.
- Overall, the land consumption can be considerably higher (see points above - but also,

due to the different possibilities of different transports to overcome gradients, large intersecting areas may arise) and thus the competition for land between nature conservation and commercial land use is increased. In addition, bundled TI are less able to avoid biotope losses due to fewer possibilities for swiveling the respective routes.

Fig. 4: Bundling of a motorway with a high-speed railway

Highlighting disproportionately high expenditure for bridges, maintenance and rescue routes, protective walls/concrete guards, separating strips, etc.

Potentially positive factors of bundling

- Disproportionate effort for maintenance roads, emergency roads, forestry roads or agricultural roads, crossing structures, drainage and rainwater retention basins, as well as for the development of stops or stations, rest areas, and agricultural areas.
- Potentially lower landscape fragmentation e.g. affecting the effective mesh size indicator, M_{eff} after Jäger 2002 if applied to areas without differentiation of habitat qualities or land use (regarding only pure area fragmentation). A different effect occurs when the fragmentation effects or the M_{eff} are related to recreational areas or valuable habitats, or ecological networks and when different barrier strengths are considered. Nota bene: Habitat fragmentation and landscape or area fragmentation are ecologically different phenomena.
- Reduced need for the number of crossing aids for vehicles, people, or animals (if very close bundling is executed) but with disproportionately higher requirements for their size and construction effort.
- Overlapping and therefore overall smaller impact bands (when only operational emissions are considered, while construction emissions and construction site areas or impact bands of barrier effects are ignored).

- The creation of large intermediate spaces (technical offset areas) that could be used as habitats and parallel ecological corridors (if there is no competition with solar plants or other land uses privileged in the traffic area).

The basic assumption
and often pursued planning premise
that bundling is the most environmentally friendly solution
is incorrect.

Both scenarios are possible, i.e., mutual reinforcement of the impact intensity (presumably in many cases), but also a reduction of the overall burden (presumably in more exceptional cases). Therefore, an individual case examination of the advantages and disadvantages is always required. Any pre-determination of bundling options as "more environmentally friendly alternatives" leads to planning errors.

The crucial factor here is the "tightness" of the bundling and the utilization of the intermediate space e.g. as stepping-stone biotopes.

Any new construction or expansion of two different modes of transport in close proximity must be evaluated in a cross-modal manner with regard to fragmentation effects and approved with reference to each other.

Pre-existing impacts from one mode of transport cannot lead to the subsequent mode having no obligation to mitigate.

Otherwise, necessary reconnection efforts are hindered and the intention of the EIA directive to consider cumulatively or synergistically acting impairments is disregarded.

The consequences of bundling can only be evaluated and addressed in a cross-modal manner.

8 Standard requirements for the bundling of transport infrastructure

Standard requirements for bundling of TI are:

- A comprehensive and careful life cycle assessment (ecological and economic balance) must be conducted, weighing all the advantages and disadvantages of bundling.
- The needs for safeguarding eco-networks and ecological reconnection must not be considered individually for each mode of transport but must always be assessed and addressed in a cross-modal manner for the entire bundling sections.
- In accordance with the minimum requirements for the density of fauna passages and regarding habitat-networks and migration corridors, fully functional crossing aids or combinations of crossing aids must be installed across all bundled transportation modes. Due to the restricted access areas caused by bundling and the potentially limited func-

tionality of fauna passages due to their length, their hinterland connection must be carefully designed and secured.

> With regard to landscape fragmentation, it must be emphasized that there is a significant difference between landscape fragmentation and habitat fragmentation. Natural or species-rich habitats are limited to small proportions of most European landscapes, and functional habitat corridors are only preserved or restorable on a few axes. These must be prioritized for functional connectivity. Therefore, it must be ensured that transport infrastructures can be safely crossed at a sufficient density (Hlavac et al. 2019, Reck et al. 2023) in any bundling scenario, even if this leads to significantly higher requirements for structures as overpasses or underpasses or for land provision for wildlife corridors or stepping-stone biotopes.

Part C: Research and development

9 Research and development needs (r+d) related to bundling

Regarding the poor knowledge about bundling effects and the contradicting hypotheses about positive and negative impacts of bundling the following r+d needs should be answered:

- Initiating representative case studies to get comprehensive ecological and economic assessments for typical bundling projects in comparison to typical alternatives as an orientation for strategic environmental assessment (and/or creating guidelines for conducting individual life cycle assessments regarding land use, energy and material demands, total costs including planning and administrative efforts, barrier effects and possibilities for ensuring sufficient ecological connectivity).
- Conducting research on ecological function of buffer areas or the minimum required distance between bundled transport infrastructure and/or technical facilities accompanying transport infrastructure.

  The distance between traffic areas and parallel intensive land use, and especially parallel bundled transport routes, has a decisive influence on the behavior of animals in terms of rebound effects, and thus on the risk of accidents or the barrier effect. Necessary stepping-stone biotopes must be designed in the intermediate spaces for small animals. Therefore, it is necessary to determine the dependency of the barrier or connectivity function on the width (and design) of resting or intermediate spaces for different indicator species (e.g., lynx, red deer). For small animals, the minimum width is determined by the required size and density of stepping-stone biotopes. Better data on the surmountable distances between stepping-stone biotopes depending on the sizes and frontages (mirrored fronts) of habitats, as well as the resistance to movement of interstitial land uses, would be desirable.
- Conducting research on the ecological function of wildlife passages through technical areas as PV-GMS related to TI. What is the optimal or most efficient length and width ratio of such passage corridors?

  When large marshalling yards, resting and parking areas, ports, or industrial facilities, such as photovoltaic systems, are designed to be traversable for animals the question arises as to the necessary minimum width depending on the length.

- Conducting research on the resistance of dense herb and grass strips on small animal movement and thresholds for verge vegetation or green strip vegetation densities. Because overly dense strips can significantly hinder the dispersal of epigeic small animal species and thereby impair the connectivity function of passage corridors or green infrastructure alongside transportation routes, the difference between species-rich, sparsely growing strips versus dense overgrowth should be investigated in terms of animal mobility. This will also allow an estimation of how far small animals can be steered towards green bridges or stepping-stone biotopes.

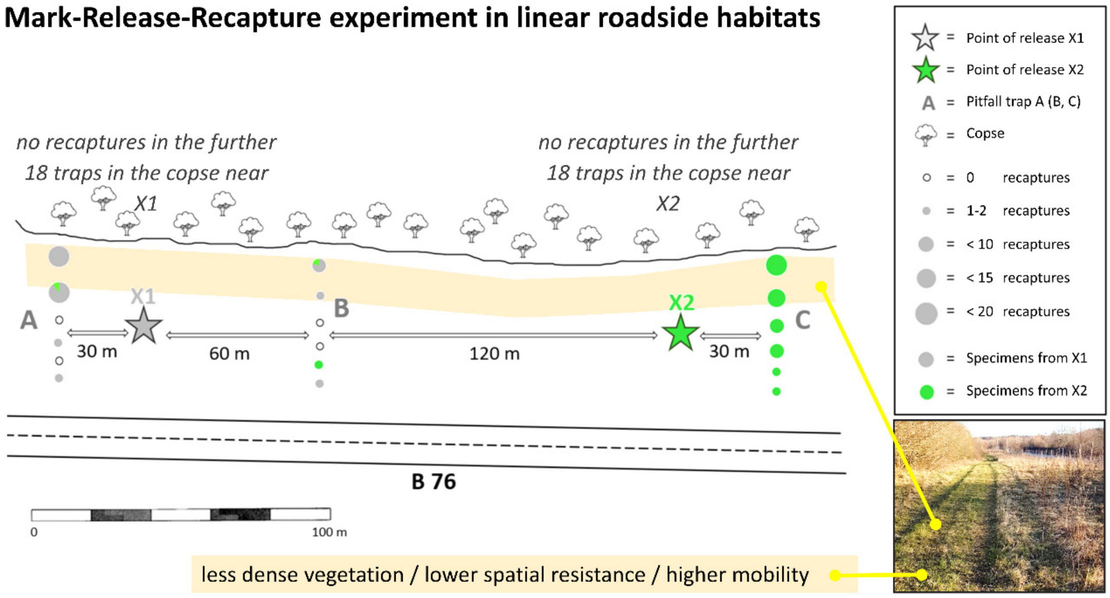

Fig. 5: Ground beetle mobility along the highway B76

(mark-recapture experiment 2022 from D. Bockwoldt) The topology of the verge habitats leads to a clear corridor effect for species of open habitats (as described by Vermeulen 1994, Rietze & Reck 1998 or Noordijk et al. 2011). In less dense vegetation, mobility (and dispersal) seems to be decisively higher.

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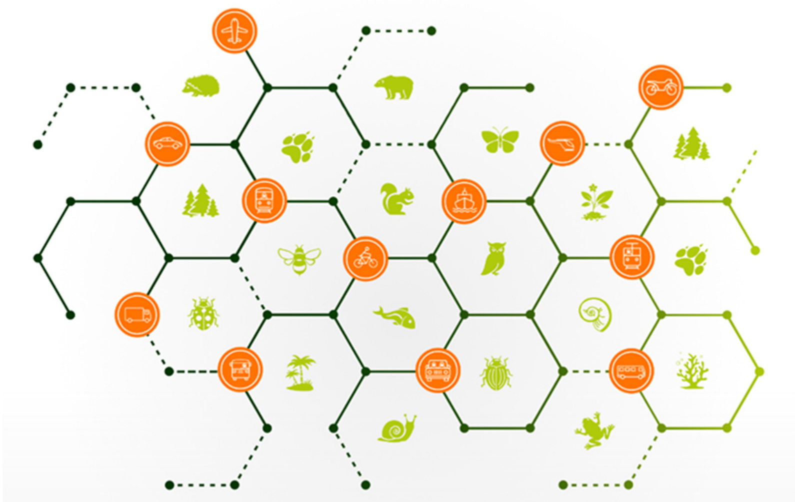

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