Annex document I

Avian-Power Line Collision

Relevant German studies and guidelines on wire marker effectiveness and evaluation of bird susceptibility to power line collision

Renewables Grid Initiative

Relevant German studies and guidelines on wire marker effectiveness and evaluation of bird susceptibility to power line collision

In recent years, significant contributions to research on the interaction between wild birds and overhead powerlines have emerged from Germany. For example, from the German Federal Agency for Nature Conservation (BfN) and further working groups at national level have drafted reports and released guidelines to scrutinise the available mitigation technologies, summarise international research on effectiveness and developed methodologies which allow for the existing research to be extrapolated to cases where research is lacking. Crucially, much of this work has been done with a view to make the findings accessible to practitioners from the realms of grid operation and thus enable a more informed approach to implementing bird protection measures to infrastructure.

Such work is well known within Germany, however language barriers have sometimes hindered their wealth of information contained within their diverse studies from being accessible to the international community. In this context, we have decided to summarise some key documents from recent years in order to make their rich content–and the implications they carry – available to an international audience.

In this Annex Document, we summarise six pieces of work which we consider to be particularly relevant for an international audience. They are:

1) **Marking of high-voltage and extra-high-voltage power lines - Vote of the State Working Group of the State Bird Protection Authorities (LAG VSW) in favour of the nationwide application of the state of the art (LAG VSW, 2012)**
    a. This is a recommendation for the marking of high- and extra-high-voltage power lines in Germany by a national working group of specialist authorities and bird protection agencies responsible for ornithological oversight of species protection

2) **Bird flight under high voltage – Safer overhead power lines for birds (NABU, 2013)**
    a. This document by Germany's oldest and largest environmental association, NABU (The Nature and Biodiversity Conservation Union), summarises the issue of bird mortality through collision and electrocution and gives recommendations on mitigation measures regarding favourable wire markers and application methods. It highlights the vital importance of power lines for the energy transition and discusses the state of planning in Germany – with reflections of what this could mean for birds, and what must be done to ensure a harmonious co-existence of grids and bird life.

3) **FNN Technical Note: Bird protection markings on high-voltage and extra-high-voltage overhead lines (FNN/VDE, 2014)**
    a. This is a document describing the technical requirements of wire markers and the legal framework for nature conservation and species protection in Germany. It was drafted by a project group consisting of representatives of grid operators, nature conservation organisations, ministries, authorities, environmental planning offices and manufacturer, set up by the Grid Technology and Grid Operation Forum (FNN), which is a committee overseen by the German Association for Electrical, Electronic & Information Technologies (VDE). The VDE is a large technology organisation, specialising in science, standardisation, testing, certification, and application consulting which acts as the technical regulator for the electricity grids in Germany.

4) **Overarching for the Assessment of Mortality in Wild Animals Connected with Human Projects and Impacts ([Bernotat & Dierschke, 2016 & 2021])**
    a. This is a key document written by the BfN which establishes key methodological approaches to assessing impacts of human activities on wild animals, which are used throughout subsequent studies and practical guidelines.

5) **Working aid for species and area conservation assessment for overhead power line projects (Bernotat et al., 2018)**
    a. This document by the BfN created guidelines to establish a uniform evaluation methodology for determining the effects of electricity grid projects on wildlife and their habitats.

6) **Species-specific effectiveness of wire markers on overhead powerlines - A technical convention (Liesenjohann et al., 2019)**
    a. This document by the BfN assesses the species-specific effectiveness of wire markers at power lines in reducing the constellation-specific risk (CSR) of a given powerline project. Furthermore, this research proposed an unprecedented method for evaluating the effectiveness of wire markers for species which had not yet been subject to study, namely through a similarity-index (**provided in Annex II)**

It is important to mention at this point, that we do not necessarily consider that the German model should absolutely be followed – indeed there has been a degree of critique of the matrix-based approach used in some of the above studies[1]. However, the German context provides a good example of where officially mandated bodies and cross-sectoral initiatives provide technical advice and guidelines for practitioners. In this respect, we find it important to transmit these findings to a broader audience, in the hope that they can be useful as they are, but – more importantly – that they can inspire similar initiatives in other national contexts, or indeed overarching, European level guidelines on best practice use of mitigation measures to reduce avian collision with powerlines.

[1] See for example, Jödicke et al., 2021 'Artenschutzprüfung mit dem Rechenschieber?' / , Species conservation assessment with the slide rule?'

1) Marking of high-voltage and extra-high-voltage power lines - Vote of the State Working Group of the State Bird Protection Authorities (LAG VSW) in favour of the nationwide application of the state of the art (2012).

Markierung von Hoch- und Höchstspannungsleitungen - Votum der Länderarbeitsgemeinschaft der Staatlichen Vogelschutzwarten (LAG VSW) für die bundesweite Anwendung des Stands der Technik

The LAG VSW is a German cross federal-state working group of specialist authorities and bird protection agencies responsible for ornithological oversight of species protection. Their tasks include the development of technical principles for species conservation and the coordination of avifaunistic surveys. In 2012, the group released a recommendation for the marking of high- and extra-high-voltage power lines in Germany. Its content is summarised below.

The LAG recommends black-and-white line markers which omit a "blink effect". The LAG considers such markers to have proven effectiveness when taking into account natural signal colours and patterns due to maximal contrast, even in unfavourable or changing light condition. They are to be applied to the earth wire.

In terms of spacing, a general recommendation of 5 -25m intervals is given. Distances between markers can be greater in the vicinity of a tower and, conversely, be shorter further away from a tower. Smaller distances are required in cases of high or very high collision risk, for example in valley crossings, waterbody crossings, flight corridors between roost and foraging area. Furthermore, larger distances between markers can still provide high effectiveness when markers are offset across multiple wire level.

However, the LAG underlines the necessity of suitable route selection as a primary way of reducing collision risk.

2) Bird flight under high voltage: Safe power lines for birds (NABU, 2013)

Vogelflug unter Höchstpannung: Sichere Stromleitungen für Vögel (2013)

The Nature and Biodiversity Conservation Union (NABU) is Germany's oldest and largest environmental association. This document summarises the issue of bird mortality through collision and electrocution and gives recommendations on mitigation measures regarding favourable wire markers and application methods. Its conclusions recommend "high-contrast, movable, as large as possible wire markers, placed at intervals of maximum intervals of 15 metres".

The document beings by stating that collision risk is not universally equal along the grid or for all species. First, it discusses priority areas for retrofitting by drawing on studies throughout the 1980s and 90s, namely river estuaries and coastlines, large water bodies including inland reservoirs, wetlands and lowlands, forests and uplands. Second, the document explains that role of size and vision in influencing risk factors, with ducks, divers, rails, waders, swans, geese, storks and cranes listed as most at risk. Finally, the document explains that birds' familiarity and knowledge of an area also plays a role. For example, breeding birds generally 'get used' to power lines in their proximity, but can be more at risk during display or hunting flights. After the breeding period, inexperienced young birds are most at risk. Migratory birds which are unfamiliar with the area are at a higher risk, especially in strong wings or inclement weather and in the darkness. Resting birds which are disturbed during feeding periods may fly up and into power lines.

Next, the document discusses what must be done:

Protecting bird habitats in grid planning

First, NABU explains the importance of protecting bird habitats in grid planning. They underline the importance of the process of testing for alternative grid corridors in ensuring that planned power lines avoid areas which must be protected according to the Federal Nature Protection Law (BNatSchG), due to presence of protected species, or in Important Bird Areas and wetlands of international importance under the Ramsar Convention. Given the density of Germany's infrastructure network, there are many options to bundle new infrastructure alongside existing streets, railway lines, or power lines. In sensitive areas, they recommend the investigation of burying power lines underground.

Designing bird-friendly power lines

Second, NABU explains how power lines can be created in a bird-friendly way. For example, grid operators can prioritise a horizontal wire configuration and explore thick steel intermediate suspension for conductors to increase visibility, and reduce wire height and corridor width. While more efficient high-temperature wires are welcomed, NABU states that it must be ensured that birds cannot bird their feet upon resting. On page 5 NABU presents each of the different type of power lines and pylons along with their voltage level, share of the grid which is above ground, and the main dangers for birds.

Installing wire markers

Finally, NABU underlines the importance of using wire markers in areas of high risk, especially on the thinner ground wire. The report introduces three models, namely the small spirals, the hanging black-and-white strips and the hanging reflective plastic plate.

Conclusions

The document concludes with a set of science-based recommendations. Several of these refer to wire marking. These are:

- For a needs-based grid expansion, the decisive factor is: which transmission lines are indispensable and considered priority. The most environmentally friendly alternatives must always be must always be found. The identification of a bird-friendly route should be prioritised over the use of bird protection markings.

- EU bird sanctuaries and areas of the Habitats Directives, nature conservation areas, national parks and biosphere reserves, as well as known breeding areas for endangered large bird species and bird resting areas must be avoided as far as possible when planning the network.

- Underground cables as a technical alternative for avoiding bird collisions should be examined at all planning levels, including in ongoing regional planning procedures. If overhead power lines are built, wire markers should be considered as a mitigation option.

- Horizontal conductor arrangements increase the visibility of the conductor cables for birds, so in sensitive areas single-level mast systems should be preferred in sensitive areas.

- **Conductor sections with particularly high risk must be marked with wire markers**.

- The wire markers used should be **high-contrast, movable and as large as possible and placed at intervals of maximum intervals of 15 metres**.

- Together with the bird protection organisations and NABU recommendations on standardised marking types, **spatial criteria and meaningful monitoring should be developed.**

- Investigations into hazard risks for birds when using use of high-temperature ropes and conductor monitoring are necessary.

3) FNN Technical Note: Bird protection markings on high-voltage and extra-high-voltage overhead lines (2014)

FNN-Hinweis. Vogelschutzmarkierung an Hoch- und Höchstspannungsfreileitungen. (2014)

The VDE – the German Association for Electrical, Electronic & Information Technologies (*Verband der Elektrotechnik, Elektronik und Informationstechnik)* - is a large technology organisation, specialising in science, standardisation, testing, certification, and application consulting. As such, they act as the technical regulator for the electricity grids in Germany. The VDE also convenes the FNN – the Grid Technology and Grid Operation Forum *(Forum Netztechnik and Netzbetrieb)* – a project group made up of grid operators, nature conservation organisations, ministries and authorities, planning offices and manufacturers.

Recognisant of the importance of collision risk assessment and mitigation in grid planning, in December 2014, the group published a 'Technical Note' describing the legal framework for nature conservation and species protection related to the technical requirements of bird protection markings – a.k.a. wire markers or bird flight diverters. Therein, a set of recommendations aims to speed up the grid planning procedures while at the same time complying with the legal requirements of animal ecology, in particular the requirements of European site and species protection. The recommendation covers all procedures for planning of new overhead lines from 110 kV ; route sections that are to be marked, but also areas to be avoided.

Key points identified in this document:

- Bird markers are generally an effective tool to reduce collision risk, but their visibility – and thus effectiveness – changes under different conditions.
- Black and white markers give the greatest contrast against various backgrounds and weather conditions and are therefore to be prioritised.
- The 'Blink effect' of rhythmically mobile markers is underlined as desirable.

I – Area of application

Anwendungsbereich

This note is intended for operators of high (110 kV) and very high (220 – 380 kV) voltage grids, planning offices, authorities and nature conservation organizations. They give guidance on which grid sections should be prioritised for the installation of wire markers to reduce collision risk, and also on areas which present too great a risk to birds and thus should not be considered for the construction of new overhead powerlines (OHL). Importantly, however, the Technical Note is more general in its scope and does not replace the need to carry out surveys on a case-by-case basis.

III – Legal framework

Rechtsrahmen

This chapter gives a summary of the relevant legal framework in Germany and Europe, referring to:

- Impact regulation *(Eingriffsregelung)* based on the German Federal Nature Conservation Act (*Bundesnaturschutzgesetzt – BNatSchG)*, which prevents avoidable damage to nature and landscape.
- Natura2000: A European framework which stipulates priority species and habitats (Birds Directive and Habitats Directive) for protection within Europe.

- Provisions for specially protected species according to German law: A summary of the main species protection considerations according to German national regulation which specifies risk to species and their habitat. Mainly relevant for the planning of overhead lines are the regulations against killing and injuring birds. This must be determined on an individual basis and not on a population level. Whether there is a significantly increased risk to the species present must be clarified in each individual case with regard to the location of the power line, the species present, the biology of the species and their use of space at the location.

IV - Avifauna and overhead lines
Avifauna und Freileitungen

This chapter provides a comprehensive summary of the risk posed by OHL to birds, including loss of habitat, disturbance effect of towers, increase in predation, and – primarily – collision risk. One – particularly high - example from systematic surveys in coastal lowlands and inland wetlands quantified the collision risk in particularly conflictual areas to stand at 200-400 individuals per year per km of OHL (Grosse et al. 1980, Richarz & Hormann, 1997). The Note reminds that the main conflict zone occurs on the ground wires, as they are seen too late, with the problem intensifying for migratory birds that are unfamiliar with the area they cross and in in unfavorable weather. Furthermore, breeding birds are less affected. It specifies the factors that influence collision as:

- Morphology of bird: such as weight in relation to length of wings;
- Physiology: poor, straight-ahead vision;
- Behaviour: such as migration, swarming, courtship, night flight and flight of young birds;
- Natural factors: weather, (such as fog, rain, headwinds), vegetation along the overhead line;
- Events such as sudden disturbances;
- Planning and technical factors: line configuration, routing, maintenance of route.

A summary of areas of special ornithological conflict is also provided, drawing on a document from the European Commission (2014) 'EU Guidance on Electricity, Gas and Oil Transmission Infrastructures and Natura 2000' namely:

- Internationally relevant 'high priority areas';
- Conflict hotspots, including:
    - main breeding area for source populations,
    - areas where large gatherings occur,
    - stopover areas,
    - resting areas,
    - wintering areas,
    - main migration routes,
    - bottlenecks,
    - migration between roosting and feeding areas,
- Medium priority areas (nationally); including:
    - important areas for one or a few priority species,
    - core breeding areas of several priority species,
    - significant areas with aggregations,
- Lower priority (regional, or local):

- Locally important areas for priority and non-priority species.

Based on the summaries provided in the BfN study by Dierschke & Bernotat (2014) and the aforementioned EU document, a list of priority bird groups are provided, including: Bustard, Storks, Cranes, Herons, Wading birds, Swans, Geese, Ducks, Divers,
The document reaffirms that various steps can be taken to reduce collision risk, including a reduction in the number of wire levels, bundling of infrastructure and – the focus of the document moving forward – the installation of visible wire markers on earth wires.

V - Requirements for bird protection markers
Anforderungen an Vogelschutzmarkierungen

The chapter provides a comprehensive and science-based summary of the effectiveness of wire markers in reducing collision risk for birds. It lists important considerations the markers must fulfil from a species conservation perspective:

- Wire markers need to be effective for all species, for breeding, resting and migratory birds;
- They need to be visible (and thus effective)
  - under changing light conditions
  - blue, grey sky, clouds, twilight, at night, etc.
  - under different wind conditions and speeds
- The target of wire markers is to attract birds' attention as early as possible to the ground wire

Research has shown that black-and-white markers give a greater contrast against various backgrounds and also at dawn and dusk, compared to coloured markers and are therefore to be prioritised (Haack, 1997). The study draws upon studies from Germany where black-and-white markers in use since 2004 have shown a risk reduction factor of 60-90% (Bernshausen et al., 2007; Bernshausen & Kreuziger, 2009; Bernshausen et al., 2014; Brauneis et al., 2003; Prinsen et al. 2011; Sudmann, 2000). The 'Blink effect' of rhythmically mobile markers is underlined (Haack, 1997). Furthermore, the Nature and Biodiversity Conservation Union (NABU – BirdLife Germany) confirms that from an ornithological point of view, black-and-white markers are to be preferred (NABU, 2013). In terms of distance between wire markers, the Note states that a distance of 20-25 m sufficiently minimises the risk of collision, however in exceptional circumstances, it can be necessary to install them at narrower distances (NABU, 2013).

An overview of the technical requirements of wire markers is also provided, including factors requirements such as:

- Damage to conductor must be prevented;
- Wire markers must be able to operate in short-circuit conditions, operating temperatures and other ambient influences;
- Wire markers and their constituent parts must be protected against loosening and slipping;
- There should be no impermissible emissions (noise, radio interference);
- Materials must be suitable for the purpose (in Germany, according to DIN EN 61284[2]) and pass weather resistance tests;
- Atmospheric corrosion protection must be guaranteed (DIN EN61284);
- The BFD must not suffer damage at temperatures between -20°C to 80°C;

[2] DIN refers to the "German Institute for Standardisation" *(Deutsche Institut für Normung)* and refers to a series of technical standards originating in Germany and used internationally. https://www.din.de/en/about-standards/din-standards

- The BFD must function well throughout its given use period without damage or lessening of effectiveness;
- Marking of the BFD must ensure traceability (type manufacturer's mark, date of manufacture).

Next, an overview of mechanical requirements which must be fulfilled by wire markers is provided, namely that wire markers:

- Must be able to resist a certain amount of wind and ice load (DIN EN 50341-3-4);
- Must not influence the oscillating behaviour of the conductor through swinging behaviour;
- Should be designed to be placed on the earth wire – where no electrical considerations are relevant;
- If wire markers are designed for conductor wires, proof of suitability must be guaranteed through tsting on partial discharge and radio interference. There must be no negative influence on service life;

Certain testing considerations are described:

- Hot-dip galvanization (DIN EN 61284);
- Wind load (45 m/s during 15 minutes, perpendicular and at 45) angle);
- UV resistance (DIN EN ISO 4892-1/2/3);
- 1.000 h salt fog (DIN EN ISO 9227);
- Fatigue strength;
- Slip test (depending on diameter, see table 1 in document).

Furthermore, guidance on mounting wire markers is included with respective considerations for personnel safety, environmental impact, technical feasibility, safety rules, time and cost. The different mounting methods discussed are:

- Elevator working platform: where consideration must consider impact of vehicle accessibility;
- Line trolly or bicycle: most used for the retrofitting of existing OHLs and inspection of earth wire. Not preferred for black-and-white movable markers due to torsion of conductor changing hanging position;
- Helicopter: the fastest option for earth wire mounting. Can be done when lines are in operation.

Next, a summary evaluation of areas for which require and exclude the need for the use of Wire markers (and indeed where line marking using wire markers is not sufficient) is provided. This is done according to categories:

- Category A: high-conflict areas. Line marking is not sufficient, necessary to look for spatial variants.
    - E.g. Bustard area (including 5 km buffer), Southern Golden Plover (including 1 km buffer), breeding area of Bittern (> 5 individuals, including 1 km buffer), Crane resting area (1.000 – 10.000 individuals, including 5 km buffer).
- Category B: conflict exists, but line marking with wire markers reduces mortality risk to an acceptable level.
    - E.g. Breeding areas of some meadow-breeding wader, regionally significant breeding areas of relevant species.
- Category C: low-conflict, marking can be dispensed with (eg. landscape impact).

VII. Further steps to operationalise findings

Weitere Schritte zur Operationalisierung der Erkenntnisse

The final chapter of the Technical Note links its own recommendations to the findings of the Dierschke & Bernotat (2016) which ranks species (or groups) according to the level of collision risk and the effect on population.

4) Overarching criteria for the Assessment of Mortality in Wild Animals Connected with Projects and Impacts

Übergeordnete Kriterien zur Bewertung der Mortalität wildlebender Tiere im Rahmen von Projekten und Eingriffen (Bernotat & Dierschke, 2016 & 2021)

This pivotal study introduces for the first time a standardised, scientific classification system designed to assess species' mortality risk related to different types of human infrastructure (e.g., overhead powerlines, roads, railways, wind turbines). While the system was initially designed only for birds, the method of scaling was adjusted to include other groups including all species of bats, amphibians and reptiles. Crucially, it also makes this knowledge available for the planning and impact assessment of infrastructure projects. Such a species- and project-specific approach enables clear justification for strict protection where necessary, but also prevents infrastructure planning from being restricted where this is not necessary for nature conservation. These guidelines have been widely applied in the German context and carry important lessons for the international community.

The document was originally published in 2016. In December 2021, a fourth revision of this document was published alongside a press release on the website of the BfN which describes the nature of the updates and the structure of the updated document. The documents summarised below refer mainly to three individual parts of a now 10-piece initiative – namely, those which address the topic of avian collision with power lines. These are:

- **Part I: Overarching criteria for the assessment of wildlife mortality in the context of projects and interventions. Part I: Legal and methodological principles.**

  BERNOTAT, D. & DIERSCHKE, V. (2021a): Übergeordnete Kriterien zur Bewertung der Mortalität wildlebender Tiere im Rahmen von Projekten und Eingriffen. Teil I: Rechtliche und methodische Grundlagen. 4 Fassung, Stand 31.08.2021, 193 S.

- **Part II.1: Working aid for assessing the risk of collision of birds with overhead power lines**

  BERNOTAT, D. & DIERSCHKE, V. (2021b): Übergeordnete Kriterien zur Bewertung der Mortalität wildlebender Tiere im Rahmen von Projekten und Eingriffen. Teil II.1: Arbeitshilfe zur Bewertung der Kollisionsgefährdung von Vögeln an Freileitungen. 4. Fassung, Stand 31.08.2021, 94 S.

- **Part III: Appendices to the basic section**

  BERNOTAT, D. & DIERSCHKE, V. (2021c): Übergeordnete Kriterien zur Bewertung der Mortalität wildlebender Tiere im Rahmen von Projekten und Eingriffen. Teil III: Anhänge zum Grundlagenteil. 4 Fassung, Stand 31.08.2021, 196 S.

In the coming pages we will present the methodology behind the classification. As this aggregates a host of concepts and matrixes, which are themselves complex, the next few paragraphs will summarise the main primary steps taken.

A first major achievement of the study was the creation of a **Mortality Sensitivity Index (MSI)** ***(Mortalitäts-Gefährungs-Index)*** which enables an overall assessment of the species-specific significance of anthropogenic causes of mortality. This index is the result of the aggregation of two lower indices, namely the **Population Biology Sensitivity Index (PSI)**

(Populationsbiologischer Sensitivitäts-Index), which includes population trends and (natural) mortality rate, and **Conservation Value Index (CVI)** ***(Naturschutzfachlicher Wert-Index)***, which includes conservation-related parameters. The MSI amounts to a standardised assessment system which enables for the first time to derive the significance of the loss of an individual from a population with respect to conservational issues and decisions in environmental planning and assessments. In other words, the MSI allows one to detect for which species (being rare, threatened and sensitive) the loss of a few individuals is critical – or indeed less relevant (being abundant, non-threatened and generally 'robust').

Having established an index of **species' overall sensitivity to mortality**, the researchers applied knowledge on species-specific factors and mortality data around different infrastructure types in order to determine **project-type-specific mortality risk** ***(vorhabentypspezifisches Tötungsrisiko der Arten)***. This included an extensive literature review on the numbers of animals killed for each project type in German and Europe based on biological and behavioural factors (e.g., home range size, flight altitude, flight behaviour, manoeuvrability, speed, body size, wing span, and vision), on an expert assessment of scaling of numbers (incl. national and international guidelines), and on the authors' professional estimates.

In a final step, the project-type-specific mortality sensitivity (pMS) was aggregated with species' overall sensitivity to mortality (MSI) to produce an **project-type-specific Mortality Sensitivity Index (pMSI)** ***(vorhabentypsezifischen Mortalitätsgefährung).*** The difference here is that the latter accounts for the necessity (or not) of grid operators to act upon a risk from a legal point of view. For example, according to the pMS alone, species such as the Common starling *(Sturnus vulgaris)*, Song thrush (*Turdus philomelos)*, and Fieldfare (*Turdus pilaris*) are classified as being at intermediate to high risk of collision with powerlines. However, according to the pMSI (which includes population biology and conservation status-related parameters), these species have a low project-type-specific sensitivity to mortality rating – meaning that they can usually be neglected from planning considerations.

Importantly, the introduction of the Mortality Sensitivity Index (MSI) does not remove the need to assessment mortality on a case-by-case basis. However, it does bring a differentiated classification to assist in the objective assessment of mortality risks at the project level and thus bring more clarity and uniformity to practice which had previously been rather heterogeneous. In this way, a species-specific approach helps ensure that strict measures taken in the name of nature conservation are justified, while removing unnecessary restrictions. The overall aim of this initiative was to "contribute to the objectification of the debate about impacts and nature conservation, and to increase the objectivity and transparency of impact assessments in this admittedly difficult subject." (Bernotat & Dierschke, 2016:13).

In 2021, the study was published in a new updated and expanded 4th version which includes revision of the MSI methodology. In the new version, the contents have also been prepared in a more user-friendly manner for practical use. The complete publication comprises Part I with legal, technical and planning methodological principles, Part II with several guidelines for specific project types and species groups as for the collision of birds at power lines and Part III with scientific data in appendices.

The Mortality Sensitivity Index related to anthropogenic mortality (MSI)
Mortalitäts-Gefährdungs-Index für die Relevanz anthropogener Mortalität

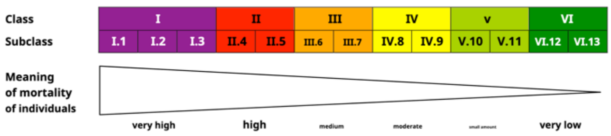
Firstly, by way of a framework for determining species-specific mortality risk, the study proposes a Mortality Sensitivity Index – MSI (*Mortalitäts Gefährdungs Index*). This framework encompasses parameters related to:

1. **Population Biology Sensitivity Index – PSI** *(Populationbiologischer Sensitivitäts-Index)*: This considers factors like the natural mortality rate, how long a bird lives, when it starts reproducing, its potential and actual reproductive rates, the national population size and trend.
2. **Conservation Value Index – CVI** *(Naturschutzfachlicher Wert-Index)*: This is derived from factors like the bird's status on the German National Red List, its abundance in Germany, the overall health of bird species population, and Germany's legal responsibility for a species' conservation in its territory. Furthermore, the conservation status of bird species at the federal state level (regional Red Lists), Red List for Europe (acc. BirdLife International, 2015) and the global context of conservation status for bird species group (Species of European Conservation Concern - SPEC) were used (acc BirdLife International 2004, Südbeck et al. 2007).

Both sub-indices (PSI and CVI) are considered to be of equal importance in conservation terms. Therefore, a 9-level scale for the PSI and a 5-level scale for the CVI was used. When combined using a matrix, this resulted in a 13-level scaling system as presented in Figure 1A. This detailed scaling system can be generalised, resulting in six classes/categories, labelled I to VI as shown in Figure 1B.

Figure 1. Aggregation of PSI and CVI (A) and classes of MSI (B). Bernotat & Dierschke 2016

	Nature conservation value index (5 levels)				
Population biological sensitivity index (9 levels)	1 very high	2 high	3 medium	4 small amount	5 very low
1 (extremely high)	I.1	I.2	I.3	II.4	II.5
2 (very high)	I.2	I.3	II.4	II.5	III.6
3 (high)	I.3	II.4	II.5	III.6	III.7
4 (relatively high)	II.4	II.5	III.6	III.7	IV.8
5 (medium)	II.5	III.6	III.7	IV.8	IV.9
6 (relatively low)	III.6	III.7	IV.8	IV.9	V.10
7 (low)	III.7	IV.8	IV.9	V.10	V.11
8 (very low)	IV.8	IV.9	V.10	V.11	VI.12
9 (extremely low)	IV.9	V.10	V.11	VI.12	VI.13



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1 (extremely high)	I.1	I.2	I.3	II.4	II.5
2 (very high)	I.2	I.3	II.4	II.5	III.6
3 (high)	I.3	II.4	II.5	III.6	III.7
4 (relatively high)	II.4	II.5	III.6	III.7	IV.8
5 (medium)	II.5	III.6	III.7	IV.8	IV.9
6 (relatively low)	III.6	III.7	IV.8	IV.9	V.10
7 (low)	III.7	IV.8	IV.9	V.10	V.11
8 (very low)	IV.8	IV.9	V.10	V.11	VI.12
9 (extremely low)	IV.9	V.10	V.11	VI.12	VI.13

The MSI framework serves as a tool to evaluate the significance of individual losses within species populations, and can thus inform conservation, environmental planning and mitigation measures for appropriate risk-reduction strategies, for different human infrastructure types. This framework therefore underpins the evaluation of bird species' collision mortality risk with overhead powerlines (which is further elaborated in the 2018 and 2019 studies) and thus the necessity to implement mitigation measures. This framework helps in identifying species, especially those that are rare, at risk, or easily affected, where losing even a few individuals is of great concern for conservation and planning. At the same time, it distinguishes robust species that do not necessitate in-depth examination. Species with a low MSI imply a critical significant risk to mortality, thus necessitating rigorous evaluation and strict mitigation measures. Conversely, for species with a high MSI, individual losses are generally less impactful, and extensive mitigation may not be as crucial. MSI should support but not replace specific case assessments.

Project-type-specific Mortality Sensitivity Index for species (pMSI)
Vorhabentypspezifische Mortalitätsgefährdung von Arten

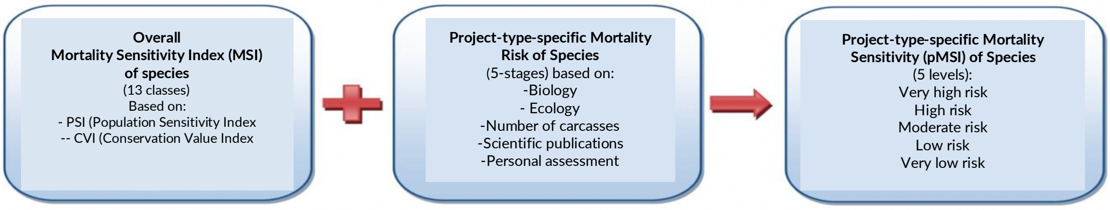
For planning different types of infrastructure (e.g., overhead powerline or wind turbines), it is not enough to just know if a species (and by extrapolation, its population) is particularly sensitive or not. The risk of fatality varies greatly depending on the type of infrastructure in question. Clearly, different infrastructure types pose varying risks for birds. For example, the Red kite *(Milvus milvus)* has a "very high" risk of fatality from collisions with wind energy turbines and electrocution from medium-voltage lines, however a “very low” risk of mortality from collision with powerlines.

The study thus sought to develop a framework for classifying risk levels for certain species relative to different infrastructure types. This was done by combining species’ overall mortality sensitivity (MSI, as described in above), with understandings of their risk related to specific infrastructure types. The result, as described below, is quantified in terms of project-specific Mortality Sensitivity– pMS.

In an initial phase, species’ mortality risk per type of infrastructure (project-type-specific Mortality Risk – pMR) was determined into a 5-level categorisation. This considered understanding of the species' biology and habits, data on the number of deceased animals associated with particular project types, expert assessments of factors of scale, and the authors’ professional evaluations. This was based on an extensive research and analyses of German and European sources. In assessing potential risks to various species, parameters such as mobility, activity, flight behaviour, and visual capabilities play significant roles. Notably, factors like flight altitude, specialised behaviours during mating or hunting, and specific visual capabilities, especially frontal sight, are crucial. Mortality statistics were interpreted in the context of the species' frequency, the likelihood of carcass discovery (e.g., in forest or near water bodies) and reporting. All species for which carcass findings had been documented or species-specific assessments made or assumed to have at least a 'low' collision risk based on their group vulnerability (e.g., birds of prey), were considered based on their German Red List status. The potential discrepancy between found carcasses and actual fatality level – which is influenced by factors like bird size and habitat - is acknowledged, though correction factors for all species and project types was deemed not feasible. For very rare species, an absence of recorded carcass findings might necessitate the assessment of collision risk based on an extrapolation from birds with similar ecology and morphology. For common species, a lack of findings typically indicates a low project-type-specific risk. The focus was on regular breeding and guest bird species in Germany and bat species listed in the German Red List.

In a second phase, the pMR was combined with the overall species’ Mortality Sensitivity Index (MSI) to results in a project-type-specific Mortality Sensitivity Index (pMSI) (*vorhabentypspezifische Mortalitäts Gefährdung Index*) - see Figure 2. This aggregated index combines understandings of project-type-specific mortality risk with biological and conservation-related factors, interpretation of carcases statistics and thus establishes the significance of a project’s risk factor for environmental planning. For example, it is known that birds such as the Mallard (*Anas platyrhynchos*), Wood pigeon *(Columba palumbus*), and Common starling (*Sturnis vulgaris)* frequently face casualties due to collisions with powerlines. Yet, when this pMR factor is taken into account alongside the MSI, the derived project-type-specific Mortality Sensitivity Index (pMSI) results in minor planning relevance for those species. The pMSI has been classified into five distinct levels: **very high risk**; **high risk**; **moderate risk**; **low risk;** and **very low risk**.

Figure 2. Schematic presentation of the project-specific Mortality Sensitivity Index (pMSI) Acc Bernotat & Dierschke 2016

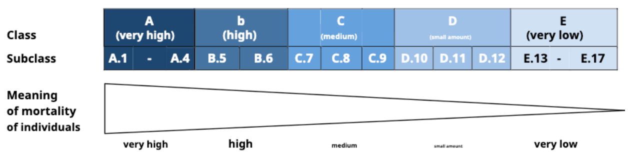


The pMSI primarily measures species-specific sensitivity, but other biological and spatial factors must be considered. For instance, given considerable differences in reproductive and life strategies between small passerines and rare eagles, there is a corresponding distinction on the additional risk posed by infrastructure projects. Many small passerines naturally face high mortality rates: it is normal for a high rate of fledgling passerines not to reach adulthood due to various natural threats such as predators or environmental factors, and they generally exhibit a greater resilience to additional risks. Consequently, additional risks posed by human projects might not necessarily result in a significant increase in their overall mortality risk. Thus, while on the one hand, for species which are critically endangered and in a deteriorating state of conservation, minor threats can drastically amplify these risks overall, on the other hand, species like thrushes, and finches, which are widespread and not at risk, ought not be given the same attention.

Furthermore, in terms of statistical relevance, the importance of considering a species' overall frequency in evaluations is crucial. If we were to focus only on the absolute, mathematical probability of collision death, the risk for a common species would always be significantly higher than for rare ones. Interpreting the legal norm in this way would mean that almost all infrastructure planning would fail due to species protection laws. Thus, when addressing planning concerns about the relevance of mortality threats, just to understand a species' general vulnerability isn't adequate. The pMSI allows for this more detailed analysis of their sensitivity or endangerment level - see Figure 3 A and B.

Figure 3. Matrix for deriving pMSI for species (A)and classes of pMSI (B). Acc Bernotat & Dierschke 2016/2021

Mortality Threat Index (MGI) of the species	Classification of the project type-specific killing risk of the species				
	1 very high	2 high	3 medium	4 low	5 very low
I.1	A.1	A.2	A.3	A.4	B.5
I.2	A.2	A.3	A.4	B.5	B.6
I.3	A.3	A.4	B.5	B.6	C.7
II.4	A.4	B.5	B.6	C.7	C.8
II.5	B.5	B.6	C.7	C.8	C.9
III.6	B.6	C.7	C.8	C.9	D.10
III.7	C.7	C.8	C.9	D.10	D.11
IV.8	C.8	C.9	D.10	D.11	D.12
IV.9	C.9	D.10	D.11	D.12	E.13
V.10	D.10	D.11	D.12	E.13	E.14
V.11	D.11	D.12	E.13	E.14	E.15
VI.12	D.12	E.13	E.14	E.15	E.16
VI.13	E.13	E.14	E.15	E.16	E.17



It is from this study guidelines that the by data in the righthand column of the table on page 3 of the RGI Brochure was sourced. By including these figures, we sought to highlight a list of representative species for which collision risk with overhead powerlines is particularly high (considering both population biology, conservation factors, and reported cases of mortality), and thus where particular attention should be paid. Due to the size-limitations of the brochure format, we were able to include only representative species from the three uppermost levels of collision risk in the brochure table. However, in Chapter 3.3 of the Methodology Report, readers can find a full list of breeding, resident & migratory species with their corresponding collision risk factor levels as presented in this study.

Methodological assessment of mortality risk of species in planning – criteria, thresholds and parameters

The indices discussed in the previous sections make a considerable step towards understanding species' risk from different types of infrastructure projects, and the relevance of this for population viability and in terms of legal and conservation implications. Still, a further step is required in order to make them useful to specific infrastructure development projects, namely the consideration of each infrastructure project in the context in which it exists, including technical, spatial and geographical factors, as well as mitigation measures which may decrease risk. These factors come together to create what Bernotat & Dierschke (2016) describe as the **Constellation-specific Risk (CSR)** of a project – meaning the conflict level in each specific case. When determining the CSR, various spatial and project-related parameters must be taken into account. Chapter 9 offers a methodological approach to do so. In a next step, the CSR is presented in terms of actual legal provisions.

Spatial parameters

Relevant spatial parameters mainly address factors influencing the presence of animals and the importance of the habitats present. For example, zones with a high concentration of nesting birds or frequent presence of visiting or migrating birds are to be seen as more susceptible to project-related deaths compared to areas of lower avian significance. Key points to focus on during individual evaluations include: the observed presence of a species in the affected zone, including distribution, count, density, and regularity; the frequency of animals present in the project's high-risk zone; the quality and role of the habitat for breeding, resting, feeding, etc.; the conservation value of the region for breeding, resting, and wintering; and specific environmental factors that heighten risks, such as regular foggy or windy weather conditions affecting birds' visibility or flight. Moreover, Natura 2000 sites hold a distinct conservation and legal value for species and their communities, and this may correlate with a high CSR.

Furthermore, a project's conflict intensity relates to its proximity to impacted species and habitats. Key *factors* include: distance to endangered species' habitats (both within and outside protected zones); position relative to primary activity zones (like breeding areas); alignment with main flight or migration paths (either crosswise, parallel, or side-by-side).

Project-related technical parameters

The given project should be assessed based on its potential conflict arising from its structure and location. Key parameters for power lines to consider include: number, distance, orientation, arrangement, material, thickness, visibility, and insulation.

Risk mitigation measures

Project level risk evaluation should also consider any measures to mitigate risk. Depending on the project-type and the species affected, various spatial and technical solutions can minimise risk. Examples include: marking powerlines with wire markers, relocating project routes to less sensitive areas, reducing the number of installations (e.g. powerlines), leaving sufficient and clear migration pathways for species, optimising project design for conservation, using underground cables to prevent bird collisions, marking high-voltage powerlines for better bird visibility, and following specific construction timing to minimise habitat disruption. The effectiveness of these measures varies and should be evaluated on a case-by-case basis.

With the above in mind, Chapter 9 discusses the methodological approaches to evaluating mortality risks of species with a focus on the planning process for specific projects. It considers species' Mortality Sensitivity Index (MSI) in order set thresholds for the gravity of species losses. Importantly, rather than seeking to set clear accepted standards for these thresholds, the proposal defines broad classes of significance, thus allowing room for expert determination on a case-by-case basis. The higher the general MSI of a species, the lower the respective threshold should be in terms of tolerable risks or losses. For the assessment of the legal permits of a project associated with species mortality, the following basic criteria are always relevant:

1. General Mortality Sensitivity Index (MSI) of species taking into account:
    - Population Biology Sensitivity Index (PSI) and
    - Conservation Value Index (CVI) of species (see section I above)
2. Project-type-specific Mortality Sensitivity Index (pMSI) of species taking into account:
    - Species-specific parameters and proven mortality rates (see section II above)
3. Constellation-specific Risk (CSR) of the project considering, e.g.,
    - The specific potential for conflict of the respective project and
    - The number of individuals endangered (detailed below)

As explained in section II above, the general MSI is aggregated with the project-specific mortality risk to provide the pMSI of a species. The tresholds are assigned to the pMSI for determining the CSR of a project are presented in table 5 below. A nature conservation-based rule-of-thumb served as the evaluation framework.

Table 1. pMSI threshold/levels and CSR – risk assessment. Acc Bernotat & Dierschke 2016/2021

Project-type-specific Mortality Sensitivity Index (pMSI)				
Very high **=>**	High =>	Moderate =>	Low =>	Very low =>
Usually relevant for planning in the case of a low CSR	Usually/ relevant for planning in the case of a medium CSR	Relevant for planning in individual cases/at at least high CSR	Usually not/only relevant for planning in case of very high CSR	Usually not/only relevant for planning in case of extremely high CSR.

This study establishes a methodological framework for quantifying risk level at species- and project-specific level and makes this information available to project developers of several types of infrastructure. The upcoming study by Bernotat et al. (2018) builds on this foundation, focussing specifically on the impact of overhead powerlines on bird species. This next study applies the criteria and methodologies established in 2016 to deepen our understanding of how infrastructure affects avian species and their habitats.

5) Working aid for species and area conservation assessment for overhead power line projects

Arbeitshilfe Arten-und gebietsschutzrechtliche Prüfung bei Freileitungsvorhaben (Bernotat et al., 2018)

Based on the method developed by Bernotat & Dierschke (2016/2021) and making use of more updated bird population and trend data, this 2018 paper establishes a uniform evaluation methodology for determining the effects of electricity grid projects on wildlife and their habitats, and proposes practical guidelines for its use. The study underscores the ubiquitous threat of mortality faced by all bird species, especially regarding collisions with (mainly) ground wires of overhead power lines and affirms varying risk levels according to species-specific biology and behaviour. The 2021 versions of Bernotat & Dierschke (2021 a; b; c) updated this approach, but certain chapters are more detailed in the 2018 version, and so still relevant. These include, for example, chapters on mapping and existing data of sensitive birds (ch. 7), the collision risk of projects (ch. 9) and the assessment of derogations (chs. 13-16).

The study presents a detailed 'Avian mortality sensitivity index with high voltage power lines', according to the project-specific Mortality Sensitivity Index (pMSI) discussed in the 2016/2021 paper and arranges these species into tables according to level of sensitivity in Germany (first breeding & resident birds, then migrant/visiting birds). Specifically, the list presents species for which collision risk with overhead powerlines is particularly high (considering both population biology, conservation factors, and reported cases of mortality), and thus where particular attention should be paid. Whilst these lists uses some factors specific to the German context to calculate risk, we still consider this approach to be useful, informative and – to a certain degree – transferable. Thus, we used this format (updated according to the data from the 2021 edition of the Bernotat & Dierschke study - Tabs 10-5 & 10-6, p14) to inform the righthand column of the table on page 3 of the RGI Brochure 'Which birds are most susceptible to collision?'. Due to the size-limitations of the brochure format, we were able to include only representative species from the three uppermost levels of collision risk in the brochure table.

I. Assessment methodological framework of the MGI methodology & project type-specific mortality sensitivity of birds on overhead lines due to collision
Bewertungsmethodischer Rahmen der MGI-Methodik & Vorhabentypspezifische Mortalitätsgefährdung von Vögeln an Freileitungen durch Leitungskollision (Chapters 4 and 5, Bernotat et al. 2018)

In Section 3.3 of the Methodology Report, we detailed the extensive project-type-specific Mortality Sensitivity Index (pMSI) framework presented by Bernotat and Dierschke (2021b). Bernotat et al. (2018) further developed this methodology with reference only to overhead powerlines and include updated scientific information on bird species.

A key departure point for the Working Aid is the understanding that avian collision risks with overhead power lines are indeed a major environmental concern, with all bird species potentially susceptible, especially under poor visibility conditions. However, this risk clearly varies greatly depending on species biology, behaviour, and a range of other factors (i.e. constellation-specific factors, such as technical specification of the powerlines, geographical and spatial factors). Comprehensive studies, notably from Germany and across Europe provide a wealth of documentation on collision incidents.

Find the translated table and an explanation of the methodology in Section 3.3 of the Methdology Report.

6) Species-specific effectiveness of wire markers on overhead powerlines - A technical convention

Artspezifische Wirksamkeiten von Vogelschutzmarkern an Freileitungen – ein Fachkonventionsvorschlag (Liesenjohann et al., 2019)

In 2019, the German Federal Agency for Nature Conservation (BfN) released a document which specifically examined the effectiveness of the available wire markers (s). As a base for its estimations of bird mortality risk with power lines, it used the methodology from their previous guidelines (Bernotat & Dierschke, 2016; Bernotat et al., 2018). The 'Technical convention' assesses the species-specific effectiveness of wire markers at power lines in reducing the constellation-specific risk (CSR) of a given powerline project. Furthermore, this research proposed an unprecedented method for evaluating the effectiveness of wire markers for species which had not yet been subject to study, namely through a similarity-index.

The drafting of this Convention was subject to multiple rounds of review and involved international experts. First, an extensive meta-study compiled and evaluated international literature and knowledge regarding the effectiveness of different types of wire markers. This was supplemented by targeted outreach to 29 international scientists, authorities, consultancies, nature conservation authorities and energy companies, who provided access to unpublished data and more knowledge on factors influencing collision risk, line marking design and the need for further research. Findings were discussed in an expert workshop, before being compiled in a first draft and subject to two rounds of feedback by national experts.

Although the summary present in RGI's brochure does not seek to refine its summary of research into BFD effectiveness to the species-specific level, we consider the findings of the study and its comprehensive approach to be useful and relevant for the international audience and have thus have decided to summarise its approach and findings in the following pages. Moreover, the extensive bibliography included in this meta-study provided many sources for our brochure, which are in turn reflected in the bibliography at the end of this document.

Importantly, the executive summary of the document (which is available in English), clearly makes the statement that the empirical basis for evaluating the effectiveness of wire markers is comparably small in terms of number of studies, respective sample size and the methodological and statistical reliability and homogeneity. Thus, while estimations can be made, it is "generally impossible" to accurately determine the effectiveness of wire markers by means of empirical studies. Furthermore, as discussed on page 4 of our brochure, a complex matrix of environmental, climatic, and other factors convalesce to influence levels of risk in a certain context. Thus, while the findings of this study provide important indications and useful guidelines, practitioners are reminded of the need to consider the many other factors at play when selecting mitigation measures.

The following section offers a concise overview of the document structure and methodology employed in the technical convention. It culminates with Table 22, which presents species-specific collision reduction values associated with the use of different wire markers on powerlines, encompassing both species which have been previously assessed and those which had previously remained unexamined. The document summary follows the same chapter structure as the original Technical Convention, namely:

II: Initial steps *(Ausgangssituation)*

III: Research *(Recherche)*

IV: Types of wire markers *(Markertypen)*

V: Design of wire markers *(Markierungsdesign)*

VI: Effectiveness of wire markers (*Wirksamkeit von Vogelschutzmarkern)*

VII: Rule-based reduction of constellation-specific risk (CSR) through wire markers *(Regelbasierte Reduzierung des konstellationsspezifischen Risikos (KSR) durch Vogelschutzmarker*

VIII: Similarity-based CSR-reduction *(Ähnlichkeitsbegründete KSR-Reduktion)*

Chapter II: Initial steps

Below we provide an in-depth insight into a specific aspect of the research related to the effectiveness values of wire markers in mitigating bird species collisions with powerlines. It will show how these findings can be transferred and contribute to assessing the effectiveness of methods for other bird species where direct field investigation research is currently lacking.

As mentioned, this Technical convention relies on the evaluation of the risk of mortality from overhead powerline collisions, following the BfN methodology from Bernotat and Dierschke (2016). The methodology consists of multiple modules, namely:

- Mortality Sensitivity Index (MSI)
- Project-type-specific Mortality Sensitivity Index (pMSI)
- Constellation-specific Risk (CSR) of a project

According to the German legislation there are high legal requirements for proving the effectiveness of risk mitigation measures in order for their installation to be considered sufficient in reducing risk. The need for a granular approach here was underlined by a 2016 case in which the Federal Administrative Court *(Bundesverwaltungsgericht)* nullified the previously granted planning approval of the Uckermark transmission line within a Natura 2000 area in the federal state of Brandenburg on the grounds that the predicted risk to protected bird species was not calculated at the species-specific level and thus may have been set too low for particularly endangered species. This case recalls a wider truth in the research, namely that the effectiveness of wire markers has for many bird species (especially rare and endangered species) not yet been subject to scientific study. The Technical convention is thus an attempt to remedy this gap in the research and make is to methodology applicable so that an estimated potential of a BFD to reduce a powerline project's CSR for all relevant species might, with reasonable accuracy, be quantified.

Chapter III: Research

This chapter provides in-depth insights into the scientific evaluations and analogical inferences concerning wire markers and their efficacy, shedding light on their impact within different bird communities and offering valuable information for the assessment of their effectiveness.

This section concerns two critical aspects:

1) Study-based effectiveness assessments of wire markers for various bird species and groups and
2) Similarity-based theoretical classification of wire marker effectiveness for the bird species used as references for comparison.

The literature review at the base of the BfN study included 188 studies into into bird collisions and wire markers from a wide range of data sources, including international scientific studies (e.g. experimental field studies), meta-studies, expert recommendations, and grey literature. The main focus was on field studies which directly evaluated the effectiveness of wire markers on high and extra-high voltage powerlines, however high-quality studies on the medium voltage were included. For each source included, a fact sheet was produced (chapter 11).

In order to take account of differing levels of scientific rigour of field investigation studies considered, they were were subject to an evidence grading process. This methodology was adapted from SIGN (Scottish Intercollegiate Guidelines Network) and employed four categories of publications:

- Experimental studies assessing the effectiveness of specific bird protection markers for species-specific collision reduction;
- Studies with cross-species effectiveness;
- Meta-studies and reviews on marker effectiveness; and
- Expert recommendations, standards, or guidelines with relevant thematic content.

Research robustness and scientific validity was based on four key evidence criteria, which considered whether a study:

1) Recorded flight frequencies and behaviour;
2) Conducted standardised and systematic collision victim searches (carcass searches);
3) Accounted for correction factors such as carcass persistence, detection rate, and search efficiency; and
4) Employed statistically sound data analysis techniques.

Studies that fulfilled 3 or 4 of the above evidence criteria were grouped into the ++ or + evidence class, while those meeting only 1 or 2 of these criteria were categorised in the - evidence class. If none of these criteria were met, the document was designated as F - non-analytical studies. Additional data from the studies, like sample size, powerline length, or weather conditions, provide further context and demonstrate the qualitative diversity within the evidence classes. In this way, the study gave more or less weighting to a document according to its level of scientific rigour.

Table 2. Evidence evaluation/rating of the relevant literature sources. According to Liesenjohann et al. 2019.

Study type	Level	Description
Meta-analysis	M++	High-quality meta-analyses, systematic reviews of studies with randomised controlled trials (RCTs) based on statistically validated random sample distributions, with very low risk of systematic errors.
	M+	Well-conducted meta-analyses, systematic reviews of RCTs with low risk of systematic errors.
	M-	Meta-analyses, systematic reviews of RCTs with a high risk of systematic errors.
Study	S++	High-quality systematic reviews of case-control studies with very low risk of systematic biases and a high probability that the "measure-effect" relationship is causal.
	S+	Well-conducted case-control studies with a low risk of systematic biases and a moderate probability that the "measure-effect" relationship is causal.
	S-	Case-control studies with a high risk of systematic biases and a significant risk that the "measure-effect" relationship is not causal; sometimes contradictory study results.

Non-analytical study	F+	Non-analytical studies, e.g., case reports, case series with predominantly consistent trends toward a positive correlation between measure and effect.
	F-	Non-analytical studies, e.g., case reports, case series with sometimes contradictory statements regarding the "measure-effect" relationship.
Expert recommendation	E++	Consistent expert recommendations in multiple guidelines and practical guides, e.g., from regional or federal authorities, mentioned in research reports, working papers, or publications with accompanying expert groups, workshops.
	E+	Expert recommendations in individual practical guides, guidelines, or publications with an accompanying expert group or quality assurance through an expert committee (peer-review), with no well-founded objections by other experts known.
	E-	Individual expert opinions, sometimes conflicting with other expert opinions.

It is important to mention that there were only a few species for which research provided scientifically valid results. Instead, numerous studies offered cross-species reduction estimates due to limited sample sizes for individual species. Cross-species estimates are not directly transferable to cases requiring species-specific assessments.

Afterwards, the results from a literature review were evaluated and supplemented through written consultations with international ornithological experts and public representatives. A detailed questionnaire was sent to 29 national and international experts, including authors of the studies from the literature review. Out of these, 18 were returned (62% response rate). The expert survey aimed to reveal hidden data and consider the possibility of conducting more specific species-focused assessments through unpublished materials and expert opinions on the effectiveness of specific markers.

In a next step, an expert workshop was organised, where findings from the literature review and surveys were discussed by 20 national and international scientists and experts. The workshop covered four main topics related to wire marker types and design, documented effectiveness of markers, creation of a basis for similarity-based transfer of knowledge on marker effectiveness, and similarity-based classification of marker effectiveness. Each topic was followed by in-depth discussions to achieve a comprehensive understanding and consensus among the experts. For example, in the discussions, 'reference species' were determined for which results from studies on BFD effectiveness could be extrapolated to species for which no specific data was available. All experts agreed that wire markers were a useful tool in reducing collision risk, however their expert estimates ranged from 9-100%.

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The subsequent chapters detail the methodology for deriving species-specific collision-risk reduction, considering various criteria and evidence from the studies.

Chapter IV: Types of wire markers

This chapter of the Convention gives an overview of the state of scientific understanding of the factors influencing a BFD's effectiveness. Furthermore, it summarises the different wire markers available on the market and their use across the globe.

It begins by stressing the significance of the earth wire for causing most casulaties by collision, due to it being thinner and less visible to approaching birds. Hence, most of the developments on wire markers in recent years have focussed on this wire. It underlines that markers are designed to enhance the visibility of power lines for birds while adhering to both technical and mechanical standards needed for a safe electricity grid. They aim to be universally effective, serving to every bird species in a particular region. Factors like the wire marker's design, lightness or darkness of the colour, and adaptability play crucial roles in ensuring visibility during varying observational and atmospheric conditions. Modern wire markers fall into two main groups: passive and active. While passive wire markers remain stationary, active ones are typically fixed to the ground wire using a clamp and possess components that have the ability to turn or swing. Reference is also made to the 2012 APLIC study as a further source of information on other types of wire markers.

In terms of its practical and theoretical understanding of how to use markers, the Convention roots its itself within the guidelines provided by the VDE/FNN Technical Note from 2014. It recalls that the preference from the VDE document is for black and white active markers, due to the produced 'Blink-effect'. The preference for black and white markers is also affirmed by Haack (1997). More specifically, studies in Germany have indicated positive results from using a combination of black tapes and white spiral bands. Further innovations have introduced rods with contrasting colours mounted on metal structures, which ensure movement and create a noticeable blinking effect for birds.

The report recalls that markers should be designed to be visible in a variety of environmental conditions, including low light and adverse weather. One of the most effective designs uses a strong black and white contrast, which performs consistently across different light spectrums (Martin, 2017). Furthermore, markers with colours or UV coatings might have varying visibility due to the surrounding light's spectral characteristics. Factors like the size of the marker and its movement can also play a role in its detectability from birds.

The importance of wire markers' longevity and failure rate is also highlighted. In this regard, a study in the Gobi desert (Batsuri et al., 2016) into two types of wire markers – one active 'flapper' and one passive spiral - was referenced. It demonstrated a higher loss rate for the active wire marker. Furthermore, it indicated that the marker's position relative to the mast and its height could influence its durability.

Next, the Convention gives an overview of the different wire markers, splitting these into passive and active markers.

Passive wire markers used include balls, spheres, spirals, and bands. Some manufacturers add black lines or dots to coloured balls (orange, red, white, yellow) to enhance visibility. In the USA, brightly coloured PVC spirals are popular. There are two spiral types: the smaller 'Bird Flight Diverter' (BFD) and the larger 'Swan Flight Diverter' (SFD) available in colours like yellow, red, white, and gray. A BFD spiral has one end attached to the earth wire with increasing loop radius, ranging from 18-60 cm in size and 4-12 cm in loop diameter. The SFD spiral, also called a double-loop BFD, has two fixed ends and a larger loop in the middle, ranging from 50-115 m in length with a loop diameter of about 20 cm. interesting, studies on spiral sizes showed contrasting results. Researchers have observed varying results regarding the efficacy of spiral sizes: for example, Barrientos et al. (2012) found larger spirals to be more effective, whereas Crowder (2000) concluded the opposite. Additionally, the effectiveness of colour has been found to be size-dependent. For instance, in the smaller spiral wire markers, yellow spirals outperformed gray ones, but for the larger SFDs, grey has found to be superior.

Active markers are a variety of movable, flexible wire markers attached to (usually) ground wires. Unlike passive markers, they aim to grab birds' attention through their movement in the wind. The marker's movement, along with its shape, colour, and size, enhances visibility for birds. Some markers are equipped with reflective or fluorescent parts to boost visibility during dusk or nighttime. Various active marker types have been studied. Movable boards and discs, such as FireFly and Bird flapper (BirdMark), have been primarily used and researched in the USA, South Africa, and Hungary to reduce bird collision risks (see Anderson 2002; Brown & Drewien 1995; Murphy et al. 2009; Murphy et al. 2016; Shaw 2013; Raab et al. 2012).

The Convention then provides a 5 page overview (pg 32-37) of studies into wire marker effectiveness.

The following key takeaways were drawn from the expert questionnaires and workshop:

1. Experts unanimously agreed on a preference for contrasting or two-coloured (preferably black-white) and active **wire markers**.
2. There is a need for future research on **luminescent marker types** to enhance visibility under diffuse lighting conditions, such as during twilight, night, or heavy rain.
3. **Passive wire markers:** Fixed 'passive' markers make thin earth wire more visible but lack the attention-boosting effect of active markers. Hence, they are considered less effective than active markers. An alternating black-white pattern is recommended, with emphasis on the importance of the colouring's UV resistance. Yellow is seen as a highly effective colour for markers due to its light reflection capability and contrast against the background.
4. **Active wire markers:** Experts unanimously agree that active markers are more effective because they are perceived earlier and better from a distance. For the marker design, the same recommendations as for passive markers apply here.
5. There is a need for more research and input from technicians regarding potential technical issues to earth wire arising due to increased loads from active markers.
6. In the expert workshop, the potential to increase the effectiveness of individual marker types, such as using luminescent or fluorescent elements, was discussed. However, there is a significant need for research as there's a lack of evidence of their effectiveness. Large, contrasting markers are recommended for better perception under poor visibility.
7. In discussions, active Zebra markers (e.g., RIBE®) were debated for their resistance/durability to strong wind loads. FireFly markers were deemed unsuitable for strong wind conditions, while Zebra markers were found to be stable.
8. **Conclusion on wire marker types:** Literature research indicates the effectiveness of two marker types in reducing bird collision risks with power lines: the mobile, contrasting Zebra marker and black-white spirals. However, experts agreed that the Zebra marker is the current "state of the art". This aligns with the guidelines of VDE/FNN (2014).

Chapter V: Design of wire markers

This chapter discusses the wire markers design, but also how they are applied along the powerline. Key parameters include the number of markers per unit length, spacing between markers, optical densities, and alternative marking of conductor wires or/and earth wires, or of both earth wires (when two are present).

Regarding marking distance, studies analysed showed a broad range in spacing, between 3.3 - 61m for passive markers and 1.2m - 32m for active markers. Out of 26 analysed studies, nine did not specify marker distances.

The Convention recalls that the VDE/FNN (2014) recommends a spacing of 20-25m as the absolute minimum for both active and passive markers to have an effect in reducing collision risk. In high-risk areas, Albrecht et al. (2013) recommends closer intervals, such as 10m. Germany's foremost nature conservation NGO, NABU (BirdLife Germany) suggests 15m to be the maximum distance, especially for smaller markers, and recommends staggered installations across multiple conductor levels (NABU, 2013)

Furthermore, a preference is described for wire markers to be applied to the central part of a span of powerline. This was backed up by research by Anderson (2002), wherein 84-91% of Blue crane (Grus paradisea) collision victims collided with the central 2/3 of the span. Increasing marker density in the middle section (60%) of the span field is not standard but has been explored by Kalz & Knerr (2017). Furthermore, alternating markings of ground and conductor cables offer a way to visually increase marker density. When multiple ground wires are present, overlapping or alternating marker placement is unanimously recommended.

The following statements were concluded from exchanges with experts:

- Small distances between markers and alternation are preferable for effectiveness, especially where different wires are present.
- Different marker types can be beneficial when this is of importance for the different species.
- Distances between markers of 10m are recommended for new or renewed lines. For existing lines, stability aspects should be considered (additional weight should not oblige avoiding to have to rebuild larger towers). A maximum distance of 25 m should be kept.[3]
- One should also consider weight, size, material and durability (impacting stability by wind and ice, and impact on the landscape)
- It is recommendable to regularly control wire markers once placed in the field, and if necessary, to replace them.
- Closer distances in the middle of a span are controversial. The conclusion was rather that the distance should be regular over the whole distance.
- Marking of conductors can impact stability. Corona-effects must be avoided, however in areas with many birds or when the line passes over feeding and roosting areas, it can be important to mark conductor wires.
- It is not necessary to mark all levels of overhead lines due to the potential visual impact. Rather,; one should more concentrate on identification of conflict areas, and then decide whether avoiding should prevail, or marking is enough.
- It is not so that reducing the distance between markers enables a risk reduction to a lower level.

Chapter VI: Effectiveness of wire markers

This chapter summarises contemporary understanding on the effectiveness of wire markers based on research and expert opinion. In general, the results of field studies regarding the effectiveness of passive and active markers vary, with reductions in bird collisions ranging from

[3] NB: This spacing reference likely refers to the RIBE flapper device and should not be taken as a recommendation for all markers. Other recommendations cite 5-10m as optimal interval placement. Grid operators are advised to consult the advice given by manufacturers.

9% to 100% for passive markers and 29% to 95% for active markers. As aforementioned, only a few published field studies provided specific reduction values for individual species and instead, most took a cross-species approach. Experts agreed that findings on the effectiveness of wire markers for certain species could be extrapolated to similar, unstudied species using analogy conclusions.

The Convention recalls that active markers are generally considered more effective than passive ones, even though various field studies have achieved good reduction rates with both. The expected reduction in collisions requires an assessment of potential influencing factors, such as behaviour, perception physiology, and flight characteristics. Knowledge of flight activities of relevant species/groups in an area is still helpful in choosing the right type of marker. The visual perception ability of birds is highly significant regarding the effectiveness of bird protection markers (see Martin & Shaw, 2010).

The authors underline that future research on the effectiveness of bird markers should focus more on specific species' effectiveness and the interaction between biological and marker-specific properties. There are still knowledge gaps concerning the effectiveness for nocturnal species and in adverse weather conditions. Experts also highlighted the technical feasibility of powerline systems and the cost-benefit analysis of markers. Wear and tear can lead to reduced effectiveness of the markers, and technical issues arise, especially in high wind and ice loads.

Experts agreed that wire markers do in general reduce the Constellation-Specific Risk (CSR) for a broad range of species. It was established that the reduction in CSR due to the use of bird protection markers can be up to three levels. This is aligned with Bernotat & Dierschke (2016) and provides a consistent framework and better comparison possibilities between different causes of mortality. The group categorised specific reductions in CSR based on the percentage effectiveness of the markers as follows:

- 20%-40% effectiveness results in a one-level CSR reduction,
- 40%-80% results in a two-level CSR reduction, and
- >80% results in a three-level CSR reduction.

The authors recall that the empirical foundation for species-specific evaluation of marker effectiveness is limited. This relates to the number of available studies, their sample sizes, and their methodological and statistical robustness. A statistically significant quantification of marker effectiveness is methodically challenging and is only achievable for species with high individual numbers. For example, even in the study by Jödicke et al. (2018) which met all methodological requirements, a statistically significant reduction effect of the wire markers was proven for only five species. Thus, it is clear that determining marker effectiveness for rare species through empirical studies is generally not feasible.

Therefore, recognisant of the need to determine species-specific marker effectiveness, a two-step approach was developed:

1. Identification of species for which empirically determined results on the effectiveness of bird protection markers are available.
2. Detailed transfer of the determined marker effectiveness to species for which no empirically determined results are available, based on a comprehensive set of similarity criteria.

VII: ***Rule-based reduction of Constellation-specific Risk (CSR) through wire markers***

The main goal of this chapter is to identify species for which empirical results on the effectiveness of wire markers have indeed been demonstrated in scientific studies. These species are categorised into primary and secondary species.
Primary species are those species for which a species-specific value for the reduction collision effectiveness has been determined by a scientifically valid number of studies. Secondary species are species which were grouped with other species in a study (frequently belonging to different genus) wherein the value was pooled across species.

Below are the names of the 17 primary and 15 secondary species for which a reduction value could be calculated. Note that if a species had at least a 10% share of the overall flight frequency or total number of casualties before BFD installation, it is considered a secondary species. Species with no casualties after BFD installation are not included, as it is unclear whether this is due to BFD effectiveness or species absence. Also, studies which only provide data post-installation or do not distinguish between study periods are excluded.

The primary and secondary species are presented by A) species name, B) results in terms of BFD effectiveness in reducing collision risk and C) the study reference:
Primary species –

- Great bustard *(Otis tarda)*- (41%, Raab et al. 2016)
- Ludwig's bustard *(Neotidae ludwigii)* - (61.5%, Anderson 2002)
- Sandhill crane *(Grus canadensis)* - (42%, Murphy et al. 2009; 54%, Morkill & Anderson 1991)
- Blue crane *(Anthroporides paradiseus)* - (76.7% / 86%, Anderson 2002; 31%, Shaw 2013)
- Red-crowned crane - *(Grus japonensis)*(43%, Brown et al. 1987)
- White stork *(Ciconia ciconia)* - (not quantified, Fangrath 2008)
- Grey heron *(Ardea cinerea)* - (100%, Frost 2008)
- Mute swan *(Cygnus olor)* - (95%, Frost 2008)
- Barnacle goose *(Branta leucopsis)* - (82%, Jödicke et al. 2018)
- Greylag goose *(Anser* anser) - (89%, Jödicke et al. 2018)
- Mallard *(Anas platyrhintyrhynco)* - (79%, Jödicke et al. 2018)
- Eurasian wigeon *(Mareca Penelope)* - (77-84%, Hartman et al. 2010)
- Gadwall *(Mareca strepera)* - (100%, Frost 2008)
- Great cormorant *(Phalacrocorax carbo)* - (100%, Frost 2008)
- Northern lapwing *(Vanellus vanellus)* - (48%, Hartman et al. 2010)
- Wood pigeon *(Columba columba)* - (88%, Jödicke et al. 2018)
- Carrion crow *(Corvus corone)* - (91%, Jödicke et al. 2018)
    - *NB: Datasheets are available in chapter 11.1.*

Secondary species –

- White-fronted goose from geese *(Anser albifrons)* - (93 %, Lower Rhine study in Bernshausen et al. 2014)
- Ludwig's bustard *(Neotidae ludwigii)*, White-winged bustard *(Afrotis afraoides*), and White stork *(Ciconia ciconia)* from large birds (60%, Shaw 2013)
- Sandhill crane *(Grus canadensis*, Canada goose (Branta canadensis), and Mallard (Anas platyrhynchos) from ducks spec. (61%, Brown & Drewien 1995)
- Song thrush *(Turdus philomelos)* from thrushes (72%, Kalz & Knerr 2017)
- Black-crowned night heron *(Nycticorax nycticorax)* from herons, Blue-winged teal *(Spatula discors)* from ducks, and American purple gallinule *(Porphyrio martinica*) from rails (60%, De La Zerda & Roselli 2002)
- Black-headed gull *(Chroicocephalus ridibundus)* from gulls, Mallard *(Anas platyrhintyrhynco)* from ducks, Common starling (*Sturnus vulgaris)* and Great cormorant (*(Phalacrocorax carbo)* - (90%, Alfsee study in Bernshausen et al. 2014)

- Woodpigeon *(Columba columba)*, Eurasian Crane *(Grus grus)*, Black-headed gull *(Chroicocephalus ridibundus)* from total pool - (60%, Alonso et al. 1994)
- Woodpigeon *(Columba columba)* from total pool - (73 %, Brauneis et al. 2003)
- Woodpigeon *(Columba columba)* from pigeons - (37 %, Lippeaue study in Bernshausen et al. 2014)
- Mallard *(Anas platyrhintyrhynco)* from total pool - (70%, Crowder 2000)
- Eurasian crane *(Grus grus)*, Little bustard *(Tetrax tertrax)* (81%, 76%, Janss & Ferrer 1998)
- Rock dove *(Columba livia)*, Little bustard *(Tetrax tetrax)*, Great bustard *(Otis tarda)* from species pool - (9.6 %, Barrientos et al. 2012)
  - *NB: Datasheets are available in chapter 11.2*

When the data baseline for the effectiveness of wire markers on a species was deemed sufficient, they were chosen as the **reference species** to estimate BFD effectiveness for those species for which no efficacy evidence exists. To reach provide a comprehensive picture, an average of the mortality reduction value was calculated from the results from all available studies for these species. This derived value represents the effectiveness reduction value of rule-based CSR of wire markers from studies. A reduction effect documented in studies under 20% is seen as very low and considered insufficient for European species and habitat protection to recognise its rule-based CSR. The categorisation rule-based CSR are provided here:

- **> 20% to 40% (low to moderate) - 1 Level**
- **> 40% to 80% (medium to high) - 2 Level**
- **> 80% (very high) - 3 Level**

Following the above logic, a species becomes a reference species when:

- at least 1 species-specific study with a reduction value is present or
- at least 2 pooled studies consider that species with reduction values or
- the reduction value at least reaches level 1.

It is here, the weighting of the individual studies (as discussed in chapter II) according to their quality and risk of systematic errors comes into play, according to the logic presented in Table 3 below:

Table 3. Weighting of the evidence rating of a study according to Liesenjohann et al. 2019

Level	Weighting
M++	High-quality studies with very low risk are given triple weight
M+	Well-conducted studies with low risk are given double weight
M-	Studies with a high risk aren't specially weighted
S++	High-quality studies with very low risk are given triple weight
S+	Well-conducted studies with low risk are given double weight
S-	Studies with a high risk aren't specially weighted
F+	No percentage figures for marker reduction are provided; however, the study is considered for decision-making
F-	Data from non-analytical studies with conflicting tendencies aren't used for CSR reduction assessment. Study is not considered
E++	No percentage figures for marker reduction are provided; however, the study is considered for decision-making
E+	No percentage figures for marker reduction are provided; however, the study is considered for decision-making

Chapter 7.4. gives further detail explaining the different criteria for species-specific studies, pooled studies (including several species), and the combination of both.

For primary species whose rule-based CSR reduction is based on results from only one study (e.g., Grey heron and Carrion crow), the evidence evaluation of the study is considered. It must either be a meta-analysis (studies with evidence M++, M+, M) or a case-control study (studies with evidence S++, S+, S-). However, none of the currently available and evaluated studies was a meta-analysis, so no meta-analyses appear in the evaluation framework. Furthermoere, studies with evidence ratings of F or E are not considered as individual studies. For primary species with results from multiple studies, the determination of species-specific CSR reduction involves weighting all involved studies based on the classification of their respective scientific evidence.

For secondary species, where only studies with pooled reduction values are available, the evaluation of rule-based CSR is conducted in the same way as for primary species with species-specific reduction value. For clarity, the example of Eurasian crane is provided here:

For the Eurasian crane *(Grus grus)*, there are two studies with pooled effectiveness reduction values. These studies differ in their scientific quality:

1. Alonso (1994) was rated as S+ (double weighting of the marker reduction effect). The study found an effectiveness collision reduction of 60% for bird markers, corresponding to a 2-level CSR reduction.
2. Jannss & Ferrer (1998) was rated as S- (single weighting of the marker reduction effect). They reported an effectiveness collision reduction of 81%, equating to a 3-level CSR reduction.

Considering the evidence ratings, the average bird marker effectiveness reduction value is calculated as: ((2 x 60%) + (1 x 81%)) / 3 = 67%, resulting in a rule-based CSR reduction of 2 levels.

When both species-specific data (primary species) and pooled data (secondary species) data are available for a species or group of species, the rule is to use only the results of the study with species-specific reduction values for evaluating the rule-based CSR reduction. An example is for the Ludwig's bustard *(Neotis ludwigii)* with one study with a species-specific reduction value (Anderson, 2002 - 62%) and another with a pooled reduction value (Shaw 201360%). The rule-based CSR is based only on the former study, where a species-specific reduction value was given.

The reference species and their rule-based CSR reduction values are these 14 species that were used for similarity comparisons (extrapolation of data) with species for which there was no evidence of the effectiveness of wire markers:

- Great bustard *(Otis tarda)* - (CSR two-level, 41%)
- Eurasian crane *(Grus grus)* - (CSR two-level, 67%)
- Grey heron (*Ardea cinera)* - (CSR three-level, 100%)
- Mute swan *(Cygnus olor)* - (CSR three-level, 95%)
- Great cormorant (*Phalacrocorax carbo)* - (CSR three-level, 100%)
- Northern lapwing *(Vanellus vanellus)* - (CSR two-level, 48%)
- Gadwall *(Mareca strepera)* - (CSR three-level, 100%)
- Eurasian wigeon *(Mareca penelope)* - (CSR three-level, 84%)
- Mallard *(Anas platyrhintyrhynco)* - (CSR three-level, 79%)
- Wood pigeon *(Columba columba)* - (CSR three-level, 88%)
- Barnacle goose *(Branta leucopsis)* - (CSR three-level, 82%)

- Greylag goose *(Anser anser)* - (CSR three-level, 89%)
- Carrion crow *(Corvus corone)* - (CSR three-level, 91%)
- Black-headed gull *(Chroicocephalus ridibundus)* - (CSR three-level, 75%).

I. *Similarity-based CSR reduction*
ähnlichkeitsbegründete KSR-reduktion (chapter 8 from Liesenjohann et al. 2019)

As aforementioned, there are many species for which study sizes have historically been too low in order to empirically calculate the CSR reduction values of wire markers. Hence, there is a need for a method by which to draw upon the research basis for bird species where BFD effectiveness has been proven at the species-level – 'reference species' – can be transferred to other species lacking such proof – 'comparison species' on the basis of acceptable similarity comparison. This is called 'Similarity-based CSR reduction'.

The logic of CSR reduction and similarity comparison can be explained according to the following analogy.

Think of CSR reductions as levels of safety measures. The use of a BFD can confer to a reference species can have up to 3 levels of these safety measures depending on its effectiveness (with 3 being the highest). Now, when we want to apply these measures to another species, we first check how similar the species are. If they score less than 10 on the similarity scale, it's a no-go; they're just too different – meaning we can't reasonably expect the BFD to confer the same amount of safety. But if the two species are very similar, scoring 24 or more, they get the same safety measures as our reference species. For instance, imagine a Great bustard *(Otis tarda)*, a reference species, with two safety measures (a 2-level CSR reduction). The Hazel grouse *(Tetrastes bonasia)*, a similar bird but not identical, scores 13 on the similarity scale. This means we subtract two levels from the Great bustard's score, leaving the Hazel grouse with none. So, while some birds benefit from this knowledge transfer and get additional safety measures, others, like our Hazel grouse, only get the basics. This system ensures that bird protection efforts are tailored based on the best available knowledge.

Importantly, the Convention notes that relying only on taxonomic relationships can be misleading, as species within the same group can be very different. Thus, a detailed ecological similarity assessment was developed to determine how closely a comparison species matches a reference species. The similarity assessment is done with the closest reference species, prioritising European species. To determine the most similar species, preliminary choices are made based on relationships, size, or habitat. The entire decision process is detailed in the annex of the original document. The following paragraphs present the criteria for similarity-based analogies and the considered species pairings.

A comprehensive set of 10 criteria was identified to determine species similarity: taxonomy, manoeuvrability, body size, flight speed, vision in flight, habitat usage, foraging behaviour, activity patterns, migratory behaviour, and flocking formation. These criteria were subject to thorough scrutiny during expert consultations. Feedback from experts led to adjustments in the weighting of certain criteria, especially taxonomy, to ensure a fair assessment across diverse species groups.

Based on the 10 criteria below, a maximum of 30 similarity points can be allocated to a species in relation to the reference species.

The degree of similarity is categorised into four levels, and the mechanism for this categorisation is further detailed here.

1) **Taxonomy**:

Table 4. Taxonomy categorisation

Similarity	Taxonomic relation
3 (Very High)	Species of the same genus
2 (High)	Species of the same family
(Moderate)	Species of the same order
0 (None)	No established relationship

2) **Manoeuvrability** - determined based on the wing loading (weight in g/wingspan in cm:

Table 5. Manoeuvrability categorisation

Similarity	Manoeuvrability
3 (Very High)	Deviation ≤10%.
2 (High)	Deviation between >10% and ≤20%
(Moderate)	Deviation between >20% and ≤30%
0 (None)	Deviation >30%

3) **Body size** - refers to the length from the tip of the tail to the beak (in cm):

Table 6. Body size categorisation

Similarity	Size
3 (Very High)	Deviation ≤10%.
2 (High)	Deviation between >10% and ≤20%
(Moderate)	Deviation between >20% and ≤30%
0 (None)	Deviation >30%

4) **Flight speed** - Flight speed was introduced as a new criterion based on expert workshops. The purpose is to understand how flight speed can influence the visibility of markings. The data for flight speeds was primarily sourced from Alerstam et al. (2007) and supplemented by other references. Since exact flight speed values are not available for all species, relative speed estimations from Alerstam et al. (2007) were applied:

Table 7. Flight speed categorisation

<table>
<tr><th>Flight speed</th><th>Bird species/groups</th></tr>
<tr><td>Slow Flight Speed (< 40 km/h)</td><td>Raptors, songbirds, swifts, gulls, terns, and herons.</td></tr>
<tr><td rowspan="4">Intermediate Flight Speed (40-60 km/h)
• Slow Intermediate (40/ 40-45 km/h)
• Intermediate (50/ 46-55 km/h)
• Fast Intermediate (60/ 56-60 km/h)</td><td></td></tr>
<tr><td>Great skua (Stercorarius skua)</td></tr>
<tr><td>Eurasian crane (Grus grus)</td></tr>
<tr><td>Cormorant (Phalacrocorax carbo)</td></tr>
<tr><td>Fast Flight Speed (> 60 km/h)</td><td>Pigeons, certain waders, divers, swans, geese, and ducks</td></tr>
</table>

For species not categorised in the table, verbal descriptions were added. In the case of snipes and rails, categorisation based on the above criteria was not possible. For snipes, the value is inferred from a related species, while for rails, an intermediate flight speed (40-60 km/h) was assumed based on available data and descriptions.

More detail on this similarity comparison is presented below.

Table 8. Assigned degree of flight speed similarity between reference and comparison species

Pair constellations flight speed (reference & comparison)		Similarity points
Fast	Fast	3
Fast	Intermediately fast	2
Fast	Intermediate/intermediately slow	1
Fast	Slow	0
Slow	Slow	3
Slow	Intermediately slow	2
Slow	Intermediate/intermediately fast	1
Slow	Intermediate (either fast or slow)	3

5) **Visual Physiology and Perception in Flight Direction -** The primary factor determining birds' perception in the flight direction is the presence and extent of the blind area within their field of vision and its position when the head is tilted (according to Martin 2017).

Categories of birds based on blind area:

- **Extended blind area** when looking downward: e.g., vultures, eagles, bustards, cranes.
- **Some blind area**, but limited in flight direction: e.g., ducks.
- **No significant blind area** in flight direction: e.g., herons.

Not all bird species have documented data about their blind areas in literature. Grouping similar species is done by assuming a plausible similarity in the extent of the blind area to that of a reference species.

Table 9. Similarity Grades Based on Visual Physiology and Perception in Flight Direction

Similarity	Perception in flight direction
3 (Very High)	Species have the same perception in flight direction
2 (High)	Species mostly have similar perceptions. Differences might include having an extended blind area vs. some blind area or having no blind area vs. some blind area.
(Moderate)	Species have moderately similar perceptions only in certain situations, e.g., blind when looking downward, otherwise no or some blind area.
0 (None)	Species have completely different perceptions in flight direction.

a) **Habitat usage** – Habitat usage this is a complex indicator for various ecological aspects. Species in the same type of habitat (e.g., forest species) often share similarities, as do open land and water species.

Species that predominantly inhabit the same habitat are assigned similarity grades based on their alignment. For species primarily found in Germany as migratory birds, both breeding and resting habitats are considered. In the table below we explain the justification for habitat usage categorisation according to the example of forest-dwelling species.

Table 10. Habitat usage categorisation

Similarity	Habitat usage
3 (Very High)	Both species are typical of the same habitat, e.g. forests, waters, or grasslands
2 (High)	For a forest reference species, primary use of forest but also shrubs, or semi-open land. For a grassland reference, primary use of grassland but also fields or semi-open land. For a still water reference, primary use still water but sometimes other partial habitats or flowing waters or coasts.
(Moderate)	For a forest reference species, occasional use of forest but also shrubs, copses, or semi-open land. For a grassland reference, occasional use of grasslands but also fields or semi-open land. For a still water reference, occasional use of still water but sometimes other partial habitats or flowing waters or coasts.
0 (None)	The species has a predominantly different habitat usage, like a typical forest species compared to a typical open land species.

b) **Foraging** – Foraging is the primary activity on which a species' perception or physiology depends, especially in terms of eye orientation. Similar foraging behaviour results in similar perceptual abilities. Thus, this criterion is given significant importance in the assessment. Basic types of foraging are first distinguished, and then differentiated behaviours within these basic types are analysed.

The criterion "Foraging" is differentiated based on the following basic types related to the foraging area. The example presented below is for birds which forage in or from the air:

Table 11. Birds foraging in or from the air

Reference Type	**Comparison Type**	**Similarity Points**
Picking up from the ground and water surface (Black-headed Gull)	Picking up from the ground and/or water surface, e.g. Great black-backed gull *(Larus marinus)*, Common Gull *(Larus canus)*, Lesser black-backed gull *(Larus fuscus)*, Mediterranean gull *(Ichthyaetus melanocephalus)* etc.	3
Picking up from the ground and water surface (Black-headed Gull)	Aerial hunting over land and water, picking up from the water surface, e.g. Little gull *(Hydrocoloeus minutus)*.	3
Picking up from the ground and water surface (Black-headed Gull)	Picking up from the water surface, partly plunge diving, partly hunting, e.g. Great skua *(Stercorarius skua)*, Pomarine jaeger (*Stercorarius pomarinus*), Parasitic jaeger *(Stercorarius parasiticus)*, Long-tailed jaeger *(Stercorarius longicaudus)*	2
Picking up from the ground and water surface (Black-headed Gull)	Plunge diving, picking up from the water surface, partly aerial hunting, e.g. Common tern *(Sterna hirundo)*, Arctic tern *(Sterna paradisaea)*, Black tern *(Childonia niger)* etc.	2

Picking up from the ground and water surface (Black-headed Gull)	Picking up from the water surface, partly plunge diving, e.g. Northern fulmar *(Fulmarus glacialis)*.	2
Picking up from the ground and water surface (Black-headed Gull)	Plunge diving e.g. Northern gannet *(Morus bassanus)*.	1
Picking up from the ground and water surface (Black-headed Gull)	Diving, swimming, e.g. Common guillemot *(Uria aalge)*.	1

If both species belong to the same basic type, similarity points are assigned based on the alignment of specifics, ranging from 1 to 3 points. If the species belong to different basic types, there is no similarity (0 points).

c) **Active time -** The criterion was deemed relevant in terms of the visibility of wire markers and the similarity of species. The "Activity time" criterion was differentiated based on the following basic types:

- Diurnal (active during the day)
- Nocturnal (active at night)
- Crepuscular (active during twilight)
- Combinations of the above three basic types

If species clearly belong to different basic types, then there is no similarity (0 similarity points). If both species belong at least partly to a basic type, similarity points between 1, 2, and 3 are assigned depending on the match.

Table 12. Active time category

Reference Species	**Comparison Species**	**Similarity Points**
Predominantly diurnal (Barnacle Goose, Cormorant, Wood Pigeon)	Predominantly diurnal (Lesser White-fronted Goose, Brent Goose, Common Merganser)	3
Predominantly diurnal (Barnacle Goose, Cormorant, Wood Pigeon)	Diurnal and nocturnal (Pink-footed Goose, Greylag Goose, Great Crested Grebe)	2
Predominantly diurnal (Barnacle Goose, Cormorant, Wood Pigeon)	Diurnal and crepuscular (Common Guillemot)	2
Predominantly diurnal (Barnacle Goose, Cormorant, Wood Pigeon)	Predominantly diurnal; Migration mainly at night (Brent Goose, Goosander, Smew)	2
Diurnal and nocturnal (Mute Swan, Lapwing, Greylag Goose)	Predominantly diurnal (Common Sandpiper, Little Crake, Goldeneye)	2
Diurnal and nocturnal (Mute Swan, Lapwing, Greylag Goose)	Diurnal and nocturnal (Whooper Swan, Bewick's Swan, Eurasian Curlew)	3
Diurnal and nocturnal (Mute Swan, Lapwing, Greylag Goose)	Diurnal and crepuscular (Common Guillemot, Little Crake, Capercaillie)	2
Diurnal and crepuscular (Great Bustard)	Predominantly diurnal (Hazel Grouse)	2

Diurnal and crepuscular (Great Bustard)	Nocturnal (Quail)	2
Diurnal and crepuscular (Great Bustard)	Diurnal and crepuscular (Capercaillie, Black Grouse, Rock Ptarmigan)	3
Diurnal, crepuscular, and nocturnal (Black-headed Gull)	Predominantly diurnal (Pomarine Skua, Arctic Skua, Common Tern)	2
Diurnal, crepuscular, and nocturnal (Black-headed Gull)	Diurnal and nocturnal (Northern Fulmar, Herring Gull)	2
Diurnal, crepuscular, and nocturnal (Black-headed Gull)	Diurnal and crepuscular (Common Gull, Common Guillemot)	2
Diurnal and crepuscular (Great Bustard)	Crepuscular (Ptarmigan or Rock Ptarmigan)	2
Diurnal and crepuscular (Great Bustard)	Diurnal and nocturnal (Quail)	2
Diurnal and crepuscular (Great Bustard)	Diurnal and crepuscular (Capercaillie, Black Grouse, Rock Partridge, Grey Partridge)	3
Diurnal, crepuscular, and nocturnal (Black-headed Gull)	(Predominantly) diurnal (Pomarine Jaeger, Skua, Tern species, Little Tern, Common Tern, Northern Gannet)	2
Diurnal, crepuscular, and nocturnal (Black-headed Gull)	Diurnal and nocturnal (Fulmar, Herring Gull)	2
Diurnal, crepuscular, and nocturnal (Black-headed Gull)	Diurnal and crepuscular (Common Gull, Common Murre)	2
Diurnal, crepuscular, and nocturnal (Black-headed Gull)	Diurnal, crepuscular, and nocturnal (Great Black-backed Gull, Mediterranean Gull etc)	3
Diurnal, crepuscular, and nocturnal (Black-headed Gull)	(Predominantly) diurnal; migratory (also/mainly at night) (Little Gull, Pomarine Skua, Arctic Skua, Arctic Tern, Common Tern etc)	2
Diurnal, crepuscular, and nocturnal (Black-headed Gull)	Diurnal and crepuscular; migratory also at night (Black Tern)	3
Diurnal and crepuscular; migratory also at night (Eurasian Crane, Grey Heron)	Mainly diurnal (Black Stork, Great White Egret, Little Egret)	2
Diurnal and crepuscular; migratory also at night (Eurasian Crane, Grey Heron)	Diurnal and nocturnal (Purple Heron)	2
Diurnal and crepuscular; migratory also at night (Eurasian Crane, Grey Heron)	Diurnal and crepuscular (Spoonbill)	2
Diurnal and crepuscular; migratory also at night (Eurasian Crane, Grey Heron)	Crepuscular and nocturnal (Eurasian Bittern)	1
Diurnal and crepuscular; migratory also at night (Eurasian Crane, Grey Heron)	Diurnal and nocturnal; especially crepuscular; migratory mainly at night (Little Bittern)	2

d) **Migration behaviour -** This criterion, as an expression of an ecological basic type and in relation to bird migration and mobility of species, is significant for similarity considerations. The basic types for the "Status and Migratory Behaviour" criterion are:

- Resident/Year-round bird (J)
- Migratory bird (Z)
- Winter visitor (W)
- And all pair combinations of the above three types.

Table 13. Similarity evaluation of the criterion migration behaviour

Degree of Similarity	**Status or Migratory Behaviour**	
	Reference species	**Comparison species**
3 (very high)	Three Basic Types (JZW)	All three basic types match (JZW)
2 (high)	Three Basic Types (JZW)	Two out of three basic types match (JZ, JW, WZ)
1 (moderate)	Three Basic Types (JZW)	One of the three basic types matches (J or Z or W)
3 (very high)	Two Basic Types (JW or JZ or WZ)	Both basic types match (JW - JW, JZ - JZ, WZ - WZ)
2 (high)	Two Basic Types (JW or JZ or WZ)	One of the two basic types matches (JW – J/W, JZ - J/Z, WZ - W/Z)
0 (none)	Two Basic Types (JW or JZ or WZ)	No basic type matches (JW - Z, JZ - W, WZ - J)
3 (very high)	One Basic Type (J or Z or W)	Basic type matches (J - J, Z - Z, W - W)
0 (none)	One Basic Type (J, Z, W)	Basic type does not match (J - W/Z, Z - J/W, W - J/Z)

e) **Congregation/flocking** - The behavioural-ecological criterion of congregation is relevant in terms of reaction capability and risks during flight activities and in the perception of markers.

Two basic types are distinguished:

- Flock formation - including formulations such as in larger swarms, outside of breeding season or as a winter visitor in (larger) flocks/groups, often in smaller flocks, outside breeding season or during migration season sociable, tendency for flock formation, roosting communities.
- Colony breeder – including formulations like preferably colony breeder, partly colony breeder, breeding in loose colonies.

Table 14. Similarity rating of the criterion formation of flocks / aggregations.

Degree of Similarity	**Aggregations**	
	Reference species	**Comparison species**
3 (very high)	Flock formation	Flock formation
2 (high)	Flock formation	Colony breeder
2 (high)	Flock formation	Colony breeder and flock formation
0 (none)	Flock formation	Neither flock formation nor colony breeder
3 (very high)	Colony breeder	Colony breeder

2 (high)	Colony breeder	Colony breeder and flock formation
0 (none)	Colony breeder	Neither flock formation nor colony breeder
3 (very high)	Colony breeder and flock formation	Neither flock formation nor colony breeder
2 (high)	Colony breeder and flock formation	Colony breeder and flock formation
2 (high)	Colony breeder and flock formation	Flock formation
0 (none)	Colony breeder and flock formation	Neither flock formation nor colony breeder
3 (very high)	Neither flock formation nor colony breeder	Neither flock formation nor colony breeder

The research was unable to identify similar reference species with reliable data on the effectiveness of wire markers for songbirds, birds of prey, and owls. Assigning them to the reference species would likely yield low similarity scores, making assumptions on similarity-based CSR reductions unfeasible. While there are limited studies on songbirds, research by Kalz et al. (2017) on thrushes, Bernshausen et al. (2014) on starlings, and Jödicke et al. (2018) on corvids suggest that wire markers are highly effective for these birds. Generally, for songbirds, it is assumed that the collision risk is very low and due to the vast variety within this group and the few studies showing marker effectiveness, it is assumed that line marking will yield a minimum CSR reduction of one level.

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Once the similarity points (out of 30) have been calculated, it then becomes possible to transfer the CSR reduction level of the BFD in question from a reference species to a comparison species, according to the strength of this similarity. Before we explain the calculation in place here, it is worth mentioning that the Convention considers that all wire markers which conform with the standards of the VDE/FNN (2014) enable a CSR reduction level of at leastone level for all species: the so-called '**Basic effectiveness'** *(Grundwirksamkeit)*. Even for relatively similar species, CSR reduction for the comparison species does not occur in all cases. This happens when the difference between the CSR reduction of the reference species and the deduction based on the similarity rating results in values of ≤1. In such cases, it is assumed that only the basic effectiveness of one level remains.

To transfer the **reduction value of the CSR** of a reference species to a comparison species, the following approach is used.

The similarity-based CSR reduction with respect to respective reference species is divided by **up to three levels**.

1. **Very High Similarity (30-24 points)**: The comparison species receives the same CSR reduction as the reference species.
2. **High Similarity (23-17 points)**: The comparison species gets one level less CSR reduction than the reference species, but at least the basic level of effectiveness.
3. **Moderate Similarity (16-10 points)**: The comparison species gets two levels less CSR reduction than the reference species, but still maintains a baseline effectiveness.
4. **Low to Very Low Similarity (<10 points)**: It is not possible to determine the CSR reduction based on similarity for these species, but they still get the basic level of protection.

Two illustrative examples here are:

- Reference species - Grey heron *(Ardea cinerea)* - receives 3-level CSR reduction. Comparison species - Great egret *(Ardea alba)* has 27 similarity points, and therefore receives the same 3 levels CSR reduction;
- Reference species - Great bustard *(Otis tarda)* - receives 2-levels CSR reduction Comparison species - Common quail *(Coturnix coturnix)* has 14 similarity points, and therefore receives 2-2 = 0 level CSR reduction. Thus, the basic effectiveness of wire markers is 1 level CSR reduction.

As a final result, the similarity-based CSR reduction method extended the 14 initial references species to:

- 25 comparison species with very high similarity. These receive the same CSR reduction level.
- 69 comparison species with high similarity. These receive one less CSR reduction level.
- 23 species with moderate similarity. These receive two less CSR reduction levels.

This tables presented in Annex II present the comprehensive list of the species evaluated by the Convention. The reference species are in dark grey and followed by the comparison species. The table consolidates the findings from both Table 20 and Table 22 as presented in Liesenjohann et al. (2019).