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Rapid Review

Title
How effective are existing solutions to mitigate impacts of onshore wind farms on flying vertebrates and invertebrates? A Rapid Review

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Keywords
Renewable energy; flying vertebrates; flying invertebrates; mitigating measures; efficacy

Background
The negative impacts of anthropogenic climate change (e.g., global warming, extreme weather events, food insecurity, etc.), are among the driving factors behind the phase-out of fossil fuels and shift to renewable energies that do not emit greenhouse gases, such as wind (Msigwa et al., 2022). Consequently, wind energy is becoming a major component in national (and global) strategies to reduce carbon emissions. Indeed, it is a fast-growing industry as markets for renewable energy production have continued to increase over the past decade. For instance, total global wind power capacity measured 743 Gigawatts in 2020, having doubled since 2014 (REN21). However, wind energy is not free of impact on biodiversity: turbines can have substantial effects on both populations (e.g., displacement of individuals, increased mortality by collision) and on ecosystems (e.g., fragmentation/loss of habitats). In particular their impact on flying vertebrates, such as birds and bats, has been widely documented (Thaxter et al., 2017), but information on insects is also emerging (Voigt, 2021). Indeed, fatalities induced by collisions pose major conservation concern, adding to the existing pressures from other anthropogenic sources. Although mitigating solutions have been proposed across the literature, we lack systematic reviews cataloguing mitigating strategies in a standardised and comprehensive way while also assessing their effectiveness. We will undertake a Rapid Review to provide a set of existing solutions to various impacts of wind technology installations, across scales (i.e., from single turbines to large multi-turbine facilities) on flying vertebrates and invertebrates. Focusing on impacts on species' populations, this review will summarise and transfer reliable and consolidated information to practitioners, decision-makers, and investment companies alike in terms of what effective solutions exist. In the context of the current green–green dilemma, this should aid in realigning the development of onshore wind farms with current biodiversity issues (Straka et al., 2020)

Theory of change or causal model
Implemented mitigating strategies should offset the negative impacts of wind turbines/farms on terrestrial flying fauna, without drastically reducing productivity and economic returns. While wind technology remains an efficient response to reducing greenhouse gas emissions, the interference with biodiversity is a major concern as it may affect the long-term conservation of species and the functioning of ecosystems. Both climate change and biodiversity must be faced together as one

undistinguished societal challenge. To this end, there is growing recognition that solutions are necessary to resolve this green-green dilemma by better aligning these technological developments with biodiversity conservation policies (Figure 1).

Stakeholder engagement

This review will be conducted with the engagement of MIROVA, an investment company that develops innovative investment solutions for their clients, individual and institutional investors, aimed at increasing positive impact on environmental issues. Indeed, this project was born out of a request from this stakeholder partner of the French Foundation for Biodiversity Research. They will also provide input in terms of scope, and question formulation, and are free to raise comments on various parts of the review as it progresses.

Objectives and review question

This Rapid Review's main objective is to highlight existing solutions available to mitigate the impacts of wind technology on flying vertebrates and flying invertebrates, and secondly underline the efficacy of such mitigation strategies. The principal review question is thus as follows: "How effective are existing solutions to mitigate impacts of onshore wind farms on flying vertebrates and invertebrates?".

Definitions of the question components

The components of the question according to a "PICO" structure are as follows: Population: Flying vertebrates i.e., birds and bats, and flying invertebrates i.e., insects Intervention: Mitigating solutions implemented at single, multiple turbines, and/or wind farm facilities. Comparator: Spatial or temporal comparisons e.g., solutions implemented to mitigate vs. no implemented solution. This may translate as Before-After, Control-intervention, Before-After-Control-Intervention studies. Outcomes: All impacts on species' population size and density e.g., collisions/mortality, avoidance behaviour, displacement etc.

Search strategy

We will search for peer-reviewed and grey literature (e.g., journal articles, books, theses, non-commercial technical reports) through database searches, search-engines, and specialist websites. To control the volume of literature and achieve review objectives within a timeframe of approximately 6 months we will search one database: Web of science core collection (WOSCC), two web-based search engines: Google Scholar, and Bielefeld academic search engine (BASE) using a search string of English terms only. We will also search appropriate organisational websites for grey literature. Based on the question elements, we have identified key terms referring to the population, intervention, and outcome. These will be combined using 'OR' within each block and with 'AND' between blocks (cf. see 8.1), such that a publication will be retrieved if it studies a mitigating strategy for offsetting impacts of wind technology on flying fauna. Review articles will not be included because the request is to focus primarily on empirical evidence. No context limitation will be applied. Thus, worldwide studies will be eligible. Likewise, no date range limitation will be applied.

Bibliographic databases

Firstly, a scoping exercise was conducted in the Web of Science Core Collection database to explore the sensitivity and specificity of chosen keywords. In accordance with our objectives, we combined all search terms relating to flying fauna, mitigation solutions, outcomes, and their efficacy. The final search string is as follows: TS = ((insect$ OR invertebrate$ OR butterfly OR lepidoptera OR dragonfly OR odonata OR vertebrate$ OR avifauna OR aves OR avian OR bird$ OR bat$ OR chiroptera OR passerine$ OR raptor$ OR vulture$ OR owl$ OR piciforme$ OR columbiforme$ OR passeriforme$ OR falconiforme$) AND (("wind energ*" OR "wind farm$" OR "wind power" OR "wind turbine$" OR "wind technolog*" OR " wind park$" OR "wind power station$" OR "wind power plant$") AND (evaluat* OR solution$ OR mitigatg* OR "risk assessment" OR option$ OR measur* OR priorit* OR reduc* OR avoid* OR compensat* OR minimize OR adapt* OR interven* OR action$ OR manag* OR protect* OR manipulat* OR counteract* OR removal OR engineer* OR plan* OR strateg* OR offset* OR deterren* OR curtail* OR "flight divert*" OR "attract* remov*" OR "nest* management" OR "m?cro-siting" OR deterr*)) AND (impact* OR effect* OR collision$ OR behaviour OR aversion OR repulsion OR disturb* OR mortalit* OR fatalit* OR carcass* OR "population size" OR "population density" OR abundance OR occurrence)) The entire WOSCC database i.e., all citation indexes were searched by Topic i.e., using the “TS” field tag, which searches for key words in the title, abstract, and keywords of the indexed documentation

Web-based search engines

A supplementary retrieval of publications will be undertaken using web-based search engines. Firstly, BASE, then Google Scholar. Concerning Google scholar, we will use the software program ‘Publish or perish’ (version 6) to retrieve all academic citations. The use of boolean operators and the number of permitted keywords in Google Scholar differs from WOSCC. As a result, the search string will be broken down into separate searches to achieve a similar sensitivity, as only a maximum of 256 characters can be used per search string. Additionally, Google Scholar is less effective compared to other sources, thus we will limit each sub-search to the first 100 hits, in line with recommendations (Haddaway et al., 2015)

Organisational websites

The following specialist organisations will be searched for relevant technical reports containing primary data on mitigation strategy effectiveness for flying fauna: The International Renewable Energy Agency (IRENA): https://www.irena.org/ The Wind Technology Office: https://www.energy.gov/eere/wind/wind-energy-technologies-office The U.S. Wind Turbine Database: https://eerscmap.usgs.gov/uswtdb/ The Bats and Wind Energy Cooperative (BWEC): https://www.batsandwind.org The ‘Publication Library’ of The Scotland Centre of Expertise Connecting Climate Change Research and Policy: https://www.climatexchange.org.uk/research/publications-library/ La Libraire “Energies renouvelables, réseaux et stockage”, Agence de la Transition Ecologique (ADEME) https://librairie.ademe.fr/2889-energies-renouvelables-reseaux-et-stockage

Comprehensiveness of the search

To ensure comprehensiveness of the search, an iterative process was carried out to test the preliminary strings against a pre-determined list of 16 benchmark articles (i.e., Test List). The Test List was composed of relevant scientific journal articles pre-identified by the review team. The strings’ sensitivity and specificity were tested in Web of science Core Collection. We tested different keyword combinations and checked whether the benchmark articles were retrieved. The process is outlined in the Additional File 2. If missing articles from our benchmark list prevailed, the search string was improved by adding words to increase sensitivity - without jeopardising specificity - until all articles were retrieved.

Search update

No update of the literature search is planned as the initial timeline must be respected for the stakeholder’s use of results.

Screening strategy

In accordance with the pre-defined screening and study eligibility criteria (cf. Additional File 3), study selection will follow a three-step filtering process carried out by the review team. Firstly, all titles will be screened, then all retained abstracts, followed by a full-text screening stage. During screening, we will apply a conservative approach. Hence, if the qualifying information is not detailed sufficiently to reject or to retain with certainty, then the publication (i.e., title or abstract) in question will be retained for assessment at the next eligibility step (i.e., abstract or full text). In addition, publications that do not contain an abstract will pass, by default, to the full-text screening stage. Lastly, should our search string retrieve any relevant published material in French it will also be incorporated into the review process because these are the two languages spoken and understood by all members of the review team.

Eligibility criteria

We will review the collated studies obtained from the searches using the flowing set of criteria: Title and abstract inclusion criteria: regarding Population components, firstly, all titles and abstracts will be retained if presence of terms matching the targeted species groups i.e., flying vertebrates and flying invertebrates. All possible synonyms referring to appropriate ecological groups, guilds etc. (e.g., passerines, hawking bats, raptors, vultures, Lepidoptera, Odonata) will also qualify. Regarding Intervention components: equally, any title and abstract containing compatible terms relating to wind energy technology will be retained. Title and abstract exclusion criteria: all biodiversity groups other than terrestrial flying fauna and any renewable energy technology other than onshore wind power will be excluded. Full-text inclusion criteria: regarding comparator components: all studies analysing the efficacy of mitigating solutions, using temporal or spatial comparisons. If compared, we will retain study designs such as "Before-After" (B-A) studies, "Control-Impact" (C-I) studies, and "B-A-C-I". For outcome components only results which have been obtained from field studies will be retained. All publications that clearly study the impact of wind technology on the above species' populations will be retained (e.g., mortality, flight behaviour, etc.). Full-text exclusion criteria: similar to those applied at title and abstract screening. But in addition, type of publication other than field studies will be excluded (e.g. reviews, discussion papers, conference objects, etc.).

Consistency checking

To fully assess whether reviewers adhere to the eligibility criteria, a Kappa Cohen test will be performed at the start of each filtering stage. Accordingly, 10% of titles, 10% abstracts and 10% of retained full texts will be pre-screened to check for agreement. Kappa scores should be equal to or greater than 0.6 (Frampton et al., 2017; Livoreil et al., 2017). If differences of opinion arise, discussions will be held to refine the criteria; the process will be repeated with new samples until a score of 0.6 or greater is reached. Once statistical agreement is reached, all (if any) remaining disagreements will be discussed before beginning the screening process. A consistency check for meta-data extraction will also be undertaken based on a sample of 'training articles' representing 5% of the retained corpus. All eventual disagreements will be discussed between the review team.

Reporting screening outcomes

We will provide a list of articles excluded at full text with reasons for exclusion. An additional file will also be provided in the Review. In addition, we will follow the Environmental Evidence Guidelines and will conform to the ROSES standards. Equally, an additional file for our declaration and checklist of adherence to the ROSES guidelines will be included in the Review. The standardised ROSES flowchart template will also be used to illustrate the number of publications/studies that pass - or are eliminated at - each step. This flowchart will also be provided in the Review report.

Study validity assessment

A critical appraisal phase is central to the procedure of systematic reviews and will be carried out to assess both internal validity (e.g., risk of bias due to confounding ecological factors) and external validity (e.g., relevance and generalisability of study) of all articles/studies retained after the full-text screening stage (Haddaway et al., 2020). The study validity assessment will categorise the retained studies into "Low", "Medium", or "High" risk of bias based on pre-defined criteria. A series of questions will be chosen based on previous review protocols, and on the CEE Critical Appraisal Tool. In each research article, these questions will ensure robustness, in terms of the method of site selection, the quantification and reporting of variables, the number of replicates in relation to the variance; the accounting for pseudo-replication, suitability of outcome parameters, sampling method and analyses, and lastly the detail in methods and reporting of the outcomes. Additional criteria and further specification may be developed in an iterative way as the review process progresses. If a severe lack of information prevails hindering the ability to make an objective judgement, this will automatically qualify as 'High' risk of bias. The outcomes of the study validity assessment will be provided as an additional file to the Review. This file will include the categorization for each study as well as the reasons for all studies deemed as being of "High" or "Medium", or "Low" risk of bias. A high risk of bias will lead to exclusion from the narrative synthesis and meta-analysis.

Consistency checking

The critical appraisal tool will be pilot-tested on a sample of 5 articles retained after full-text screening. This will be a preliminary step to allow reviewers a 'training phase'; a chance to discuss and refine criteria if interpretation differs (Frampton et al., 2017). Then, before beginning the critical appraisal, a formal pilot-test will be undertaken by two reviewers on a random subset of 5% of the retained articles from the full-text screening stage. This will allow for further refinement of criteria if disagreements persist. Once reviewers are satisfied that agreement has been reached, all studies will be critically appraised by one or two reviewers. However, at the end of the validity assessment stage, a 2nd reviewer will cross-check 5% of articles critically appraised by the 1st reviewer. This will result in 10% of the final corpus being critically appraised by two reviewers (e.g., Lafitte et al., 2022). Concerning disagreements across the 10 % of double-appraised articles, if classification differs between the reviewers, these studies will be discussed by the review team, and if agreement still cannot be reached, the most cautious (i.e., highest risk) evaluation will stand.

Data extraction strategy

All studies having been classed as "Low" and "Medium" risk of bias from the critical appraisal will go through to data extraction. All summary data and meta-data will be extracted in two steps. In step one, all publications will be subject to meta-data extraction for narrative review. During this step, studies from which sufficient summary data (i.e., mean, standard deviation, and sample size) can be extracted, will be labelled "suitable for meta-analyses". If enough studies are found suitable for meta-analyses and comparable to each other to undertake a biologically meaningful analysis, these will proceed to step two in which effect sizes will be calculated from extracted mean, standard deviation/standard error, and sample size. In some instances, if relevant data is missing, study authors will be contacted to request data. However, due to our Rapid Review timescale if the review team does not receive responses from authors quickly, these comparisons will be subsequently excluded. Concerning summary data, these will be extracted from i) text, ii) figures, iii) tables, and supplementary materials if information from i, ii, and iii are not available in the article. We will use the R package metaDigitise (Pick et al., 2018) for summary data extraction from figures.

Meta-data extraction and coding strategy

The parameters for meta-data extraction will address the primary question, as well as effect modifiers. Information will include bibliographic details (title, authors, year, journal); study context and other effect modifiers (country, location, altitude, topography), study design details such as study type (BA, CI, BACI), methodology details (time span of study); and landscape details (matrix e.g., woodland, farmland without hedgerows, bocage landscape etc.). The different types of solutions (curtailment, deterrence, ultrasounds, audible sounds etc.). Information on population, i.e., the study subjects, will be extracted (species name, species group) and the outcome type such as (mortality rate, number of carcasses, abundance...). In addition, the direction of the outcome. Data will be extracted into a bespoke excel spreadsheet. A supplementary file is provided with full details (cf.

Additional file 4).

Consistency checking
A thorough meta-data extraction will be performed by two members of the review team. To ensure consistency in terms of data extraction a Kappa Cohen test will be run on a sample representing 20 retained papers after critical appraisal. This will enable checking and discussion to ensure interpretation of data is homogeneous. In addition, an a posteriori 'cross-check' will be carried out by one of the reviewers once data extraction has ended to check against error, i.e., heterogeneity between coders (see Langridge et al., 2020). Any disagreements will be discussed until a consensus is reached. Concerning missing data, if data is not sufficiently detailed or simply unknown, it will be coded as 'Unknown'.

Potential effect modifiers/reasons for heterogeneity
To understand the variation in outcomes we will identify and list the potential effect modifiers from the studies. There may be several biogeographic and environmental factors that could result in the heterogeneity of impacts across studies. Some of the potential effect modifiers identified through author's experience and previous findings that will be explored are: (i) type of mitigation solution, (ii) type of pressure the implemented solution is attempting to mitigate, (iii) location of wind farm (e.g. region, importance as migratory route, topography, altitude), (iv) size of wind farm (or number of turbines, height of turbines), (v) number of turbines equipped since establishment, (vi), type of matrix in which wind farms are installed. This list is not exhaustive and may be improved. If sufficient data are acquired, sub-group analyses will be conducted in R (R Core Team, 2020) using the package metafor (Viechtbauer, 2010).

Type of synthesis
The type of synthesis planned is narrative and quantitative. However, we underline that quantitative analysis (i.e., meta-analytical approaches) will only be performed if enough studies - and quantitative data - with comparable outcomes are identified.

Narrative synthesis methods
All publications going through data and meta-data extraction will be part of the narrative synthesis. The aim of the narrative review will be to describe the findings and the quality of the studies, including a summary of the critical appraisal. A synthesis database will be provided, detailing all included articles from the full text screening stage and critical appraisal. The database will include all metadata coded for each article. For the cases where more than one study is reported in the same article, each study will be recorded as a unique entry in the excel database with its corresponding meta-data. The narrative database will be described with summary figures and tables of the relevant study characteristics. A geographic map will present the locations of solution interventions. Possible knowledge gaps (under-represented subtopics that warrant further primary research) and knowledge clusters (well-represented subtopics for quantitative synthesis) will be identified by cross-tabulating key meta-data variables (e.g., biological groups x solutions x outcomes).

Quantitative synthesis methods
All summary data will be extracted from the text, tables, and graphs of appropriate publications. We will use the R package metaDigitise (Pick et al., 2018) for the latter. Meta-analyses will be carried out in R 4.0.3 (R Core Team, 2020) using the package metaphor (Viechtbauer, 2010). We will calculate log response ratio effect sizes. This effect size gives an estimate of the logarithm of percentage of variation in the chosen metric between the experimental group (XE) and the « true » control group e.g., « no mitigation measure », or the « before » condition (XC). It has the advantage of being directly interpretable in terms of magnitude (Barbier et al., 2009). Mixed-effects models will be used. Where possible, different outcomes types i.e. mortality rate or collision rate will be

assessed by sub-group analyses or model comparison. Effect modifiers will be included as fixed-effect factors, while "case study" nested within "publication" will be included as random effects to account for correlation among multiple case studies within the same primary study. The multiple use of the same control will be controlled for by using a variance-covariance matrix. Forest plots will be produced to visualise the effect size and confidence intervals for subgroups. Finally, the strength of evidence to answer to the primary question will be discussed according to the significance of statistical tests and magnitude of mean effect sizes.

Qualitative synthesis methods
NA

Other synthesis methods
NA

Assessment of risk of publication bias
In the case where quantitative analyses can be run, we will examine the influence of publication bias on the results of our mixed-effects models by firstly qualitatively diagnosing meta-analytic models with classical funnel plots (Sterne and Egger, 2001), a common diagnostic tool that works well with models fitted in the metafor package. We may also use the Rosenberg's fail-safe numbers, and/or Q-Q plots to identify outliers.

Knowledge gap identification strategy
The research gaps will be identified by analysing the distribution of the meta-data. Firstly, a geographic map may be used to visualise the distribution of studies in terms of country and location. This will show what countries are developing mitigation solutions to address anthropogenic pressures. Possible knowledge gaps (under-represented subtopics that warrant further primary research) and, in parallel, knowledge clusters (well-represented subtopics for full synthesis by a systematic review) will be identified by cross-tabulating key meta-data variables categories.

Demonstrating procedural independence
Authors of research studies included in this review will not be involved in any decisions regarding their own work. Procedural independence will be assured by not allocating articles during critical appraisal for which members of the review team are authors.

Competing interests
The authors declare no financial or non-financial conflict of interest.

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Author's contributions
JL and LD wrote the protocol, which was reviewed and edited by NHT, HJ, and AB. JL and LD defined the search string and screening criteria. All authors read and approved the final manuscript

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