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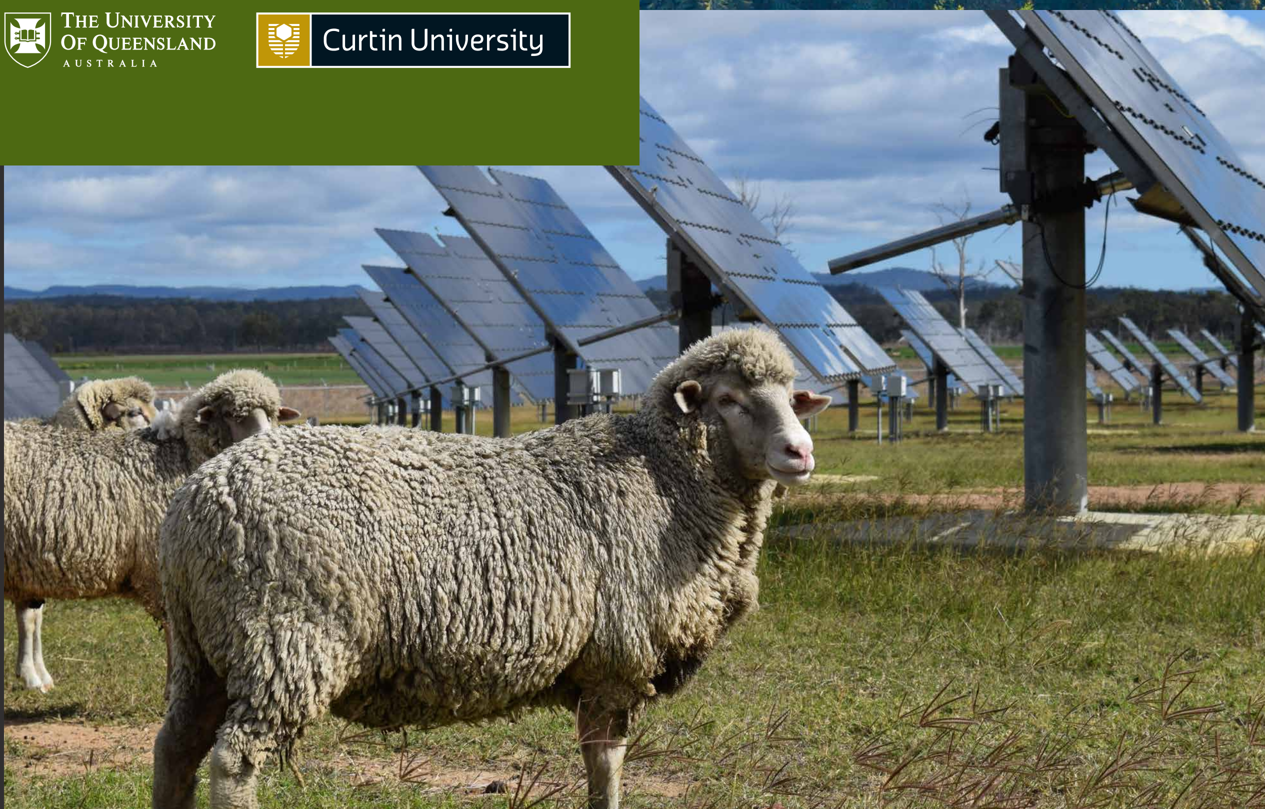
Environmental Aspects

Comparing high voltage overhead and underground transmission infrastructure (up to 500 kV)

Audrey Cetois, Nasrin Aghamohammadi, Gary Madigan, Fran Ackermann and Peta Ashworth

The University of Queensland Australia

Curtin University



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1.

Introduction

This study aims to investigate the benefits and trade-offs between overhead and underground transmission line infrastructure, specifically focusing on issues associated with under-grounding new transmission infrastructure. It seeks to establish a clear and consistent approach to the evaluation of overhead lines and underground cable transmission, including the consideration of community concerns around the need for new transmission infrastructure to connect large renewable energy generation projects. It does this through systematic reviews of the literature as well as incorporating experiences of Transmission Network Service Providers (TNSPs) in Australia and overseas. The study has a particular focus on 500kV transmission infrastructure which are projected to figure in most large projects in Australia going forward.

Historically, transmission networks in Australia developed from the need to transfer large amounts of power from large coal fired power stations, typically co-located near coal reserves, over long distances to major cities and industrial load centres. In contrast, the proposed large scale renewable generation facilities, mainly solar and wind farms, require greater land areas and are largely being located in greenfield areas with little or no existing transmission network infrastructure. These new developments are naturally creating community interest and concerns around a range of potential impacts, including but not limited to: visual amenity; environment; Traditional Owner lands; agricultural land use; and social licence to operate concerns This has led to questions surrounding when it is appropriate to underground transmission infrastructure and the likely implications of doing so.

This chapter focuses on the environmental aspects of overhead and underground transmission lines. A systematic review of papers published between January 1996 and February 2016 on the environmental impacts of power lines on biodiversity was undertaken by Biasotto and Kindel in 2018 [1]. Their review showed that the life cycle of transmission lines lead to impacts which can have multiple effects on the environment and biodiversity This review summarises and updates the Biasotto and Kindel, 2018 study with the published literature up to June 2023.

According to the search strategy, 823 publications about transmission lines were found through the Web of Science and Scopus, after removal of duplicates and papers outside of the inclusion criteria, 427 were determined to be potentially contributing to the scope of this study. The papers were then screened by reading all publications' titles and abstracts and 56 were deemed within scope. These shortlisted publications were read in detail resulting in 35 publications selected. Citation and purposeful (fire, EMF and noise) searches were also used resulting in an additional 14 publications selected. In total, 49 studies were considered for further analysis in this review, none of which focused on Australia.

Biasotto and Kindel (2018)'s review was aimed at all powerlines—distribution and transmission—and did not distinguish between overhead and underground. Where possible, this review focussed on transmission lines and specifically findings relating to underground powerlines. Of the life cycle of transmission lines, impacts during operation tended to be evaluated in the environmental peer-reviewed literature. Construction, decommissioning and removal were rarely addressed. While these potential impacts are described within Environmental Impact Assessments (EIAs) of which the process is detailed in section 3, the mitigation of EIAs through Environmental Management Plans (EMPs) are outside the scope of this review. Only eight publications mentioned underground transmission cables, and none were specifically aimed at the environmental impacts of underground cables.

2.

Results

2.1 Framework

This review used a simplified version of Biasotto and Kindel's (2018) framework to analyse the data in the literature. It includes phases, actions, abiotic (physical) impacts, and their impacts on organisms [1]. Importantly, Biasotto and Kindel's framework was developed for all power lines - both distribution and transmission lines.

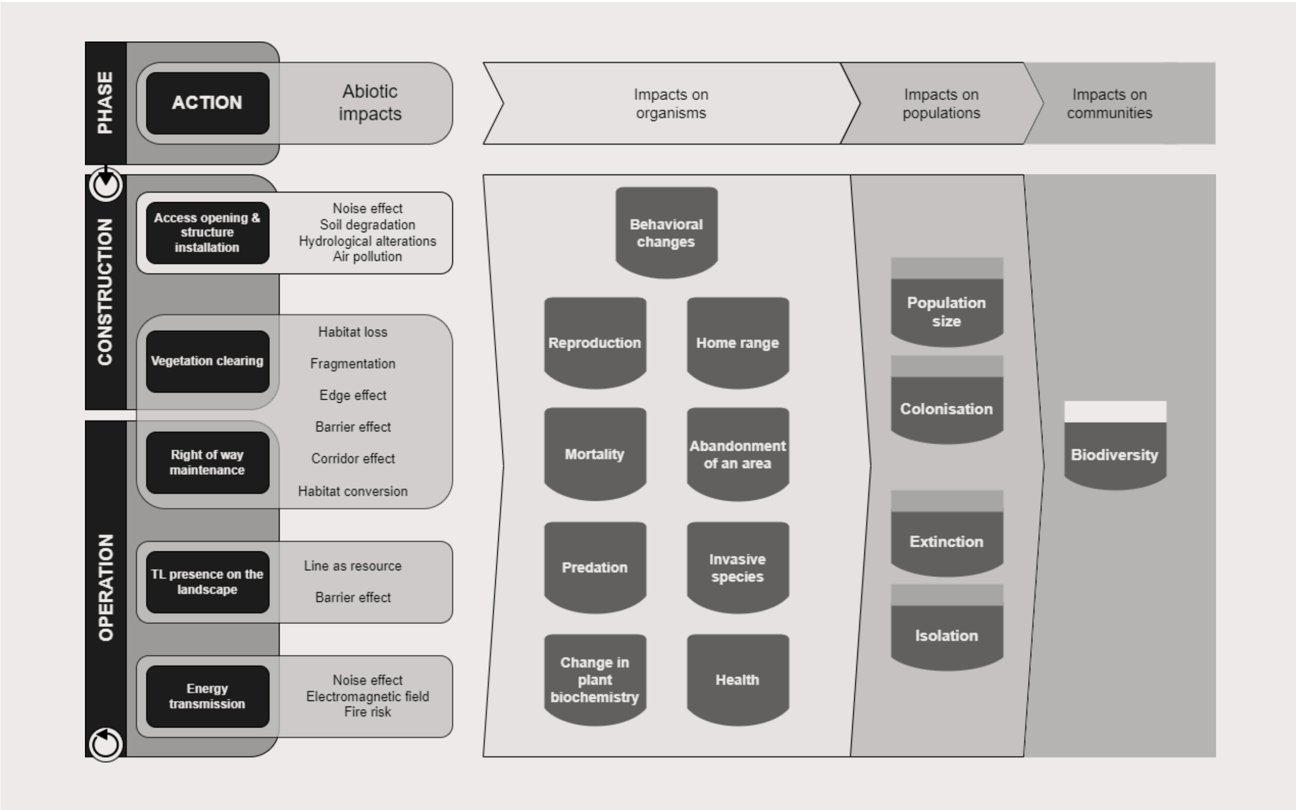

Figure 1. Study Framework Adapted from Biasotto and Kindel (2018)

2.2 Context dependency

Every publication reviewed emphasised the difficulty in applying their findings in different contexts and to different communities or species. While some of the literature findings may be applicable in an Australian context, without any major studies emerging from this review in Australia since 2016, any extrapolation of findings needs to be made with caution. Particularly, given Australia's unique biosphere and its high level of endemism (i.e., species specific to Australia). However, this review does describe the range of potential impacts observed in other regions that provide an indication of potential impacts in Australia.

2.3 Barrier effect

Transmission lines can act as a physical barrier hindering movement across and along them for some fauna. According to Biasotto and Kindel (2018), the barrier effect can occur for a variety of reasons. These include easement vegetation clearance along with the physical presence (size, shape etc.) of transmission lines and towers. This effect can start as early as the construction phase and endure throughout operation and decommissioning activities [1].

In Biasotto and Kindel's (2018) review "*28% of the papers (n = 57) focused on bird collisions*" [1, p. 114] and was featured in 61 % of the papers in this systematic review. Unsurprisingly, the main barrier effect noted in the literature is bird collision and electrocution with overhead lines. It can be a major cause of death and population decline for some species, including some endangered ones. These effects might only be noticed several decades after construction, making restoration difficult. It is also worth noting that it is difficult to generalise and compare such impacts between distribution and transmission lines because of the significant difference in midspan clearance. Similarly, while there is a barrier effect, they are significantly less than many other linear assets such as roads and railway lines.

The factors potentially increasing bird collision, electrocution and mortality are multiple and were found to fall into three categories. These include:

1. **Bird morphology and behaviour** - such as birds having a narrow visual field, a heavy body and either small or wide wingspans; low manoeuvrability; gregariousness; whether they are migratory or nocturnal birds ;and whether they use the line as a resource (section 2.4) [2].
2. **The geography** which includes considerations around the lines' proximity to wetlands, coastline, valleys, hilltops, and forest edges [2]–[5] and weather such as fog, rain and wind [2]. Other issues include if the line is the only tall structure in the area or is higher than the forest canopy surrounding it [6] and whether the lines intersect daily flight paths e.g. between foraging and nesting locations, and migration paths [6], [7].
3. **The transmission line design** including if distance is increased between towers [6]; lines are thinner; the presence and position of insulators [2]; heights of towers [8]; and the use of overhead shield wires [9].

The literature also reported that bird electrocution and collision have flow-on impacts such as abandonment of territories where the risk of collision is high; bird carcasses serving as hosts for botulism can increase affliction and mortality of other birds; scavenger activity [10, p. 1807]; and population decline leading to eventual extinction [12].

Mitigation measures proposed in the literature include the use of line markers, different tower designs, and sounds to scare the birds away[6]. While there has been a limited number of tests of their effectiveness, those that were tested, exhibited a broad range of efficacy between bird species [8], [9], [13], [14]. Line marking, for example using large, coloured balls, specifically in highly frequented areas was often suggested. A systematic review of line marker effectiveness did show that they reduced collision with the overhead line by half. However, multiple limitations and biases were highlighted with no explanatory variables being statistically significant [15]. A systematic review of factors driving bird electrocution revealed that tower design was the least influential factor, and climate was found to be the most influential [16]. Undergrounding was suggested in eight studies as a way to entirely prevent collision.

Some studies suggested that lines should run with, or parallel to, other linear developments to potentially make the lines more visible or create a form of habituation. However, the effect of such a measure on collision and electrocution rates has not been verified [6], nor does it take into account negative outcomes from increased flight path alteration or the cumulative impacts from housing several infrastructures in close proximity to each other.

The barrier effect also includes avoidance behaviour in animals. Biasotto and Kindel (2018) documented such behaviour for birds (grassland, forest and raptors) and smaller arboreal mammals and vertebrates. However, it did not seem to effect reptiles [1]. Avoidance behaviour was noted for several bird species [2], [7], [17], [18], and bats [19] and could lead to habitat loss and fragmentation. Ungulates (reindeers) in Sweden showed no long-term impacts from the barrier effect [20].

2.4 Line as resource

One of the most recognised benefits of transmission lines for biodiversity is the use of the infrastructure itself, as a resource. Transmission towers provide a tall, permanent structure, mostly free of human interaction which makes them suitable for birds perching, resting, hunting and nesting. Biasotto and Kindel (2018) highlighted that while the impacts can be positive (e.g. expanded home range, population size), increased use of lines and towers may lead to increased collision and other negative impacts such as nest overexposure to weather or predation compared to natural nesting settings [1].

The literature since 2016, confirmed and expanded on those findings and highlighted the requirement to balance the positive aspects of line as a resource with the negative impacts on specific species, overall biodiversity and the operation of the powerlines. D'Amico et al. (2018) were critical of the lack of studies that focused on the cost benefit analysis at a population level and "s*uggested establishing a collaborative dialogue among the scientific community, governments, and electricity companies, with the aim to produce a win–win scenario in which both biodiversity conservation and infrastructure development are integrated in a common strategy*" [2, p. 650].

In Spain and Portugal, storks used transmission line towers for nesting, allowing for an increase in their home range and abundance. Their occupation increased near landfills, where the lines are the only tall structures in the landscape, in proximity of water [2], [21]. Whilst stork electrocution remains an issue, Moriera et al. (2017) showed a correlation between increasing stork population and transmission network expansion [22]. This positive impact on population size and range has become problematic for power companies, specifically for large nests as it may compromise the operation (e.g. power outages), maintenance (e.g. removal of nests) and the structural stability (e.g. load distribution and aerodynamics) of transmission line towers [11], [21].

Raptors (birds of prey) use transmission line towers and the area surrounding it extensively [23], [24], because of their proximity to abundant food sources and from roads [24]. This can lead to collisions and electrocutions - the main cause of mortality for some populations predominantly in 132kV transmission lines. In the US, corvid's (ravens and crows) extensive use of transmission lines is associated with an expansion of their home range and population, which leads to increased predation on other species [5], [17], [18], [25].

Because the risk of collision increases with transmission line tower use, locating transmission lines within or near known habitats of endangered bird species needs to be collaboratively assessed to avoid significant impacts [26].

Line as resource is unlikely to occur for underground cables.

2.5 Habitat loss

Habitat loss, destruction or reduction is defined as a loss in capacity to sustain life and/or functions (i.e. foraging or nesting) of an area due to the construction and operation of transmission lines. It can occur through vegetation clearing, particularly in forested areas [27], from the edge effect (section 2.7) and/or the infrastructure itself (section 2.4) [5].

Biasotto and Kindel (2018) highlight that habitat loss was understudied, with all studies focussing on birds and reporting negative impacts on reproduction, and that area abandonment by certain species is inversely proportional to powerline density. In this review, we found only three studies addressing powerlines and habitat loss and they focussed solely on their impacts on the behaviour and population of the grassland species sage grouse in the US. Declines in sage-grouse populations were shown to be affected by the destruction of sagebrush habitat as well as transmission line influence on the distribution and abundance of raptors and corvids and the associated increased predation. The buffer area to mitigate these impacts was reported to extend from 2.5 km to 12.5 km from the transmission lines [17], [18], [25].

Habitat loss will occur for underground cables due to vegetation clearance, however specific findings did not emerge within the peer-reviewed literature. The Renewables Grid Initiative in Europe suggested that ground nesting birds would be particularly affected during underground transmission cable construction, suggesting those effects could be mitigated by avoiding work during the breeding season [28].

2.6 Habitat Fragmentation

Habitat fragmentation has several definitions in the literature. It can lead to a loss of surface area and connectivity in previously connected landscapes and is a consequence of easement vegetation clearance and access openings for construction [1]. The degree of fragmentation can depend upon transmission voltage, the associated easement width, the type of tower (lattice, tubular…), and their location within the landscape [18]. In their review, Richardson et al. (2017) highlight that habitat fragmentation is an understudied area and, as most of the studies in the literature focus on single species population impacts rather than community or ecosystem impacts, they do not evaluate the impact of connectivity loss across areas interrupted by transmission lines [10].

Biasotto and Kindel (2018) reported that fragmentation resulted in negative impacts on mammals, birds, and amphibians from altered movement patterns, isolation and population [1]. Since 2016, only one study directly aimed at evaluating movement across powerlines, based on the Indian Thar Desert, found a decrease in bird crossings with increasing powerline voltage [29]. Hyde et al. (2018) concluded that transmission lines in the Amazon did lead to habitat fragmentation, however its biodiversity impacts required further investigations [27].

Richardson et al.'s (2017) review of powerline impacts on biodiversity highlighted that fragmentation not only arises from powerlines but also from other infrastructure such as pipelines, oil and gas wells, road, forestry and agriculture. When those developments are in proximity their impacts become cumulative. Although, once again this remains an understudied area [10].

Aerial wildlife (e.g. birds, small mammals, insects) can alleviate some negative impacts of fragmentation by maintaining ecological functions between fragmented landscapes. As such, the barrier effect (section 2.3) of transmission lines was considered particularly damaging due to its potential reduction of aerial wildlife mobility, population and diversity across landscapes, and loss of ecological functions across landscapes [30].

Habitat fragmentation will occur for underground cables due to vegetation clearance.

2.7 Edge effect

An edge effect arises at the interface of two or more habitats. When access openings and easements are created with vegetation clearance, habitats within are modified and an edge is created between the access opening or transmission lines easement's new habitat and the original surrounding habitats. Biasotto and Kindel (2018) raised the issue of changes in abiotic conditions at the edge, with distinct microclimates (sun exposure, temperature, humidity etc.) and was seen to be particularly important for forest openings.

The impacts of edge effect reported can be positive, neutral or negative depending on species and their habitat. Froidevaux et al. (2023) showed that edge specialist bats benefitted from increased available habitat, however forest foraging bats suffered [19]. Hrouda and Brl̀ik (2021) posited that the trees at the edge of the easement died because of stress due to direct sun exposure and continuous vegetation clearing. Those dead trees provided a habitat for rich insect communities as well as foraging and nesting for forest bird species which would not normally occupy open habitat [31].

Hyde et al. (2018) highlighted that, in the Amazon tropical forests, transmission line easements' edge had a warmer and drier climate than the surrounding forest. This could result in "*altered vegetation community structure and composition*" [27, p. 347] and the authors expected "*a cascade of edge related changes to most of the forest within the impact areas*" [27, p. 348] as the network expands.

Edge effect will occur for underground cables due to vegetation clearance.

2.8 Habitat conversion

Transmission lines construction and operation result in significant habitat change within easements due to vegetation clearing which can result in positive, neutral or negative impacts on biodiversity. Biasotto and Kindel (2018) reported mostly positive impacts such as new species' (rarer in the area) establishment within the easement such as plants, gastropods, beetles and bees, as well as increased home range from some birds, butterflies and lizards. Because sites under towers are often undisturbed for extended periods of time and are located below perching sites for birds, this facilitates seed dispersal and plant development including native, non-native and invasive species. As such, biodiversity abundance and richness within easements were reported to potentially increase. [1].

The literature confirms potential positive impacts in agricultural and forested areas for some birds, mammals, insects and plants if the easement vegetation is effectively managed. Because powerline easements are typically maintained in an early successional stage permanently, without tall woody species, they can offer significant ecosystems for a variety of species [32, pp. 9–10]. D'Amico et al. (2018) also highlighted that positive impacts occurred in effectively managed easements, specifically for densely forested and intense agricultural land resulting in a shrubland ecosystem being developed that was suitable for bush birds [2].

Easements also have the potential to provide habitat for pollinators if managed effectively. However, it was recognised that they should not be considered as a replacement for natural and semi-natural habitats for the most specialised species [33]–[35]. This effect was also observed on road verges and railways [35]–[37]. Easements tend to have distinct biodiversity from nearby natural or semi-natural (pastoral) lands, for both plants and pollinators such as butterflies and bumblebees. As such, they can be assets for conservation [33]–[35]. Hill and Bartomeus (2016) and Russo et al. (2021) showed that mowing could be beneficial to establish and maintain pollinator habitats [32], [35]. However, mowing frequency and timing combined with other easement management practices (e.g. use of herbicides) can also be detrimental to pollinator community richness and abundance, highlighting the importance of developing targeted management practices [37]. Because of their large spatial and temporal extent, transmission line easements have the potential to provide long-term habitat for wild pollinators [35] if managed adequately. Within agricultural land, the non-farmed sections under pylons have been known to be attractive to some medium-size mammals, particularly if located in landscapes lacking semi-natural habitats [38].

Transmission lines easement have specific impacts on forests and woodland areas, as their regular maintenance leads to changed climatic and ecological conditions compared to the nearby forest interior. Within forested areas, the cleared transmission line easements provide open habitat for insect species e.g. butterflies and beetles and as such increase biodiversity [39]. Hrouda and Brl̀ik (2021) showed transmission lines in woodlands hosted a greater abundance of bird species, particularly open-habitat varieties, than the surrounding woodland habitats [31].

The European Renewables Grid Initiative and Ecofirst are developing a database of practices to enhance the positive effect of habitat conversion in transmission line easements. In the European Renewable Grid Initiative document (2012), practices such as selective tree cutting to create natural progressive forest edges, restoration of natural and semi natural grasslands e.g. sowing of local seed mixes, restoring heathland and peatbogs through soil scraping and intentional waterlogging, digging new ponds and invasive species control were explored with positive effects on environmental quality and biodiversity [40].

Habitat conversion will occur for underground cables due to vegetation clearance.

2.9 Corridor effect

The corridor effect arises from easements providing a connection between areas of habitat. The transmission lines' linear profile can have positive, neutral and negative effects. This is because native, non-native and invasive species can spread using the easement corridor [33]. Biasotto and Kindel (2018) reported that "*large carnivores exhibited a strong preference to move*" through powerline easements [1, p. 115]. The authors also highlighted that corridors may facilitate access for poachers and hunters. The corridor effect arises from the easement providing a connection between areas of habitat.

There appears to be a correlation between powerlines and corvid range expansion [5], which would have consequences for species they compete with for habitat and prey upon. Gibson et al. (2018) reported an annual rate of increase of ravens along the Falcon-Gondor transmission line in Nevada, in the US was about three times greater that the annual rate of increase for North America, leading to a decline in grassland bird (greater sage-grouse) populations due to increased predation [17].

Improved corridor effects can be planned, for example, by planting native shrubs within the easement in already degraded environments such as forestry and farmlands [2] to provide ecological or green corridors. However this positive effect requires further study as one study showed that the transmission lines linear shaped novel grasslands did not provide effective connectivity for pollinators and did not lead to homogenised communities along and around it [34].

Corridor effect will also occur for underground cables due to vegetation clearance.

2.10 Electro Magnetic Field

Biasotto and Kindel (2018) reported that continuous exposure to EMF could lead to behavioural and reproductive effects, potentially leading to survival impacts, as well as "*other "silent" disturbances in biochemical processes*" [1, p. 115]. The authors found studies on cattle, birds and plants showing negative or neutral impacts. The search term of our review only returned one study however, a subsequent purposeful search for "EMF" AND "biodiversity" returned three more studies related to transmission lines and these were included in this review.

Froidevaux et al.'s (2023) study on insectivore bats showed that EMF was the most likely reason for powerline avoidance [19]. Balmori (2021) reported negative impacts on honey bees from exposure to EMF from transmission lines [40]. A lab study on honey bees reproducing transmission lines EMF directly under, or immediately next to conductors, showed the following effects: "*reduced learning, altered flight dynamics, reduced the success of foraging flights towards food sources, and feeding*" [41, p. 1]. Similarly in Italy, Lupi et al. (2021), studied the impacts of pesticide and EMF on honey bees and they found that the combination of stressors induced "biochemical, physiological and behavioural alterations" [42, p. 1]. Those studies concluded that EMF posed a threat to pollination and survival of bee colonies in direct proximity of transmission lines. However, these negative impacts on bee colonies contradict the findings in the Habitat Conversion section.

EMF impacts will also occur for underground cables.

2.11 Fire

According to Biasotto and Kindel (2018), transmission lines presented an increased fire ignition risk due to bird electrocution and allow fires to spread and intensify because of invasive plant species within the easement.

In this review, fire risk was found to be understudied, rarely differentiated between distribution and transmission lines and solely focused on bird electrocution. The rate of fire ignition from bird electrocution from distribution lines versus transmission lines is unknown, (but is unlikely for transmission lines above 100kV, which have larger phase to phase clearances). Barnes et al. (2022) cited a study from Dwyer et al. (2019) calculating that worldwide, 84% of fires induced by bird electrocution occurred in North America, of which 22% were in California with Mediterranean regions being most affected [43]. Guil et al. (2018) showed that in Spain, between 2000 and 2012, 1.22% of fires were powerline induced and that of those 2.4% were due to bird electrocution. Raptors and corvids were the main cause of fire ignition from electrocution [44].

A purposeful search returned studies relating to fire impacting powerlines rather than powerlines igniting fires. Fire is unlikely to occur for underground cables.

In Australia, recent bushfire seasons have resulted in several inquiries. Of the 32 fires listed in the 2019 NSW Inquiry, two were started by powerlines and no distinction was made in the document between distribution or transmission lines [45]. The Royal Commission into National Natural Disaster Arrangements Report 2020 also highlighted the vulnerability of power lines to bushfires and noted that underground power lines were damaged by the fires [46]. Nonetheless both inquiries recommended undergrounding to improve electricity systems and community resilience. They did not mention undergrounding to mitigate power line induced fire risk.

2.12 Noise

Noise around transmission lines is caused by construction and maintenance, corona discharge from the power moving through the line and cable vibration induced by wind. Biasotto and Kindel (2018) highlighted that the area was significantly understudied with only one investigation showing that corona noise could be perceived by reindeers up to 79 metres away. The authors also raised that noise during construction could trigger change in animal behaviours and interfere with animal communication [1].

This review only found one study by Froidevaux et al. (2023), that showed corona noise effects were neutral on insectivore bats in France [19]. A purposeful search did not return further results. No study related to noise induced by wind and construction activities was found. Noise impacts are unlikely to occur for underground cables during operation, however, noise would be an issue during construction activities. It was not the subject of investigation within the reviewed literature.

2.13 Ultra Violet light

Ultra Violet (UV) light was not identified in the Biasotto and Kindel review. The ability of birds to detect UV light from transmission lines is debated and has not been verified through any experiments [6]. Froidevaux et al. (2023) showed that UV light attracted insects which in turn attracted insectivore bats. The effect increased during high humidity nights when corona discharge is more intense [19]. UV light impacts do not occur for underground cables.

2.14 Electric fields

The impact of electric fields (EF) was not identified by Biasotto and Kindel's review which is not surprising since HVDC transmission line use has only begun to increase in the last few years. Petri et al. (2017) conducted a PRISMA systematic review of HVDC transmission lines' static EF effects on humans and vertebrates [47], followed by Schmiedchen et al. (2018)'s review on plants and invertebrates [48]. Both studies drew similar conclusions showing that all groups can perceive DC EF. Whilst EF do not appear to result in adverse effects, in humans and animals, EF superficially stimulates hair and skin and Schmiedchen et al. (2018) suggested that annoyance levels may require further investigation [49].

EF impacts do not occur for underground cables, and thus were not investigated within the reviewed literature.

2.15 Soil degradation and hydrological alterations

As highlighted in Biasotto and Kindel, soil degradation is not addressed in the peer-reviewed literature [1]. Richardson et al.'s 2017 review posited that soil microbes and invertebrates which are responsible for soil functionality could be impacted by transmission lines construction and operation. However, soil degradation and recovery remained understudied in relation to powerlines [10]. Hydrological alterations also appear to remain unstudied, although the investigation of such impacts are important, especially for underground transmission cables.

Soil degradation and hydrological alterations would be markedly different and likely more significant for underground cables for the life cycle of the infrastructure. Horizontal drilling and open trench have different soil and hydrological impacts, each method impact requires careful investigation in local contexts. The European Renewables Grid Initiative highlighted the risk of soil compaction, wetting, erosion, contamination and loss of primary function as well as disruption of hydrological process, drainage and reduced water quality as a result of underground transmission line construction. Their publication recommended to engage with experts in local farming practices, soil and hydrological issues, to design construction and restoration methods allowing for soil and hydrological function to be maintained or restored [28].[28]. The thermal impact from operational heat dissipation on soil and soil biota required further investigation [28].

2.16 Air pollution

Air pollution is associated with the construction phase and was not the subject of any peer-reviewed studies in Biasotto and Kindel review or ours. Air pollution is likely to occur for underground cables during construction and removal, but would not be an issue during operational activities.

3.

Environmental Assessment Processes

3.1 Overview of Regulatory Requirements

Environmental Impact Assessments (EIA) are an essential and critical stakeholder engagement activity forming part of the approval process for a transmission project. The purpose of an EIA is to systematically evaluate and understand the potential environmental, social, cultural and economic impacts associated with the construction and on-going operation of a project. The triggers, requirements and process for EIA's are stipulated in legislation which in principle, is similar around the world. The following discussion focusses on the legislation that applies nationally and in the state of Queensland, for environmental assessments and approval of developments and infrastructure projects.

The Federal **Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)**[1] and regulations are Australia's main environmental law. It provides a regulatory framework to protect and manage matters of national environmental significance including unique plants, animals, habitats and places. These include heritage sites, marine areas and some wetlands. The Act also protects listed threatened and migratory species (Australian Government [49]). It requires detailed assessments and surveys with a typical timeframe to complete the process being approximately two years.

The Queensland **Environmental Protection Act 1994**[2] is the key legislation in Queensland to manage and regulate environmental protection and conservation. Its primary purpose is to safeguard Queensland's natural environment, including land, air, water, and biodiversity. An Environmental Impact Statement (EIS) is a key element of the Environmental Protection Act and is applied to evaluate and assess the potential environmental impacts of proposed activities, developments, or projects.

To streamline the process and avoid duplication between Federal and State regulatory processes, the Australian government and state governments, including Queensland, can enter into **bilateral agreements**. These agreements aim to harmonise and integrate the environmental assessment and approval processes between the Commonwealth (EPBC Act) and the state (Queensland's environmental legislation). In Queensland, the bilateral agreement applies to proposals that are 'controlled actions' requiring assessment under Part 8 of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). Controlled actions are defined in Section 75 of the EPBC Act. They include actions that are likely to have a significant impact on a matter of national environmental significance, or that involve a change in the population, distribution, or migration of a listed migratory species.

There are two broad categories of EIA and approval processes that are applicable to transmission projects in Queensland (Queensland Government [50]):

(1) **'Infrastructure' assessable under the Planning Act 2016**[3] **Infrastructure Designation (ID) process**. ID is a planning process under Chapter 2, Part 5 of the Planning Act 2016 that allows the Minister to designate premises for a type of infrastructure. Most transmission line projects are in this category and will require an Environmental Assessment Report (EAR). Planning Regulation 2017[4], which identifies the types of infrastructure that may be designated. Minister's Guidelines and Rules (MGR)[5], which includes processes for making or amending ministerial designations (Chapter 7 of the MGR).

(2) **'Coordinated projects requiring an environmental impact statement' (EIS), declared by the Coordinator-General under Part 4, section 26(1)(a) of the State Development and Public Works Organisation Act 1971 (SDPWO Act)**[6]**.** This category of projects are typically large infrastructure projects in the mining and resource sector. However larger transmission line projects can be

[1] Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) - DCCEEW
[2] Environmental Protection Act 1994 - Queensland Legislation - Queensland Government
[3] Planning Act 2016 - Queensland Legislation - Queensland Government
[4] Planning Regulation 2017 - Queensland Legislation - Queensland Government
[5] Minister's Guidelines and Rules | Planning (statedevelopment.qld.gov.au)
[6] State Development and Public Works Organisation Act 1971 - Queensland Legislation - Queensland Government

declared a 'coordinated project'. An example is the CopperString project[7] in North Queensland.

Under the Environmental Protection Act 1994, a proponent for a project may also voluntarily prepare an EIS for the project by using the EIS process, if it is appropriate to do so.

3.2 Purpose of Environmental Impact Assessment

The main purpose and objectives of an EIA is to:

(a) **Identify Environmental Impacts:** The EIA process helps identify and assess the potential adverse effects that the construction and operation of the transmission line may have on the natural environment, including ecosystems, wildlife, water bodies, and air quality. This includes considering the potential impacts on endangered species, habitats, and protected areas.

(b) **Evaluate Social and Cultural Impacts:** An EIA also considers the social and cultural aspects of the project. This includes assessing the potential impacts on local communities, such as changes in land use, noise, visual aesthetics, and impacts on cultural heritage sites or Indigenous communities. It may also consider community concerns and gather input from stakeholders.

(c) **Assess Economic Impacts:** EIAs examine the economic implications of the transmission line project, including its potential to create jobs, stimulate economic growth, or affect property values. This assessment can help stakeholders understand the project's economic benefits and challenges.

(d) **Mitigation and Alternatives:** EIAs provide an opportunity to identify measures to mitigate or minimise adverse impacts. Project developers can propose mitigation strategies to lessen environmental and social harm, which may include modifications to the project design, construction techniques, or operational practices. The EIA process also considers alternative project designs or locations that might have fewer negative effects.

(e) **Compliance with Regulations:** In many jurisdictions, regulatory authorities require an EIA as part of the permitting process for certain projects. Conducting an EIA helps ensure compliance with legal requirements and environmental regulations. This also includes any assessment requirements under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act; projects that are a controlled action under the EPBC Act and being assessed by EIS under the bilateral agreement).

(f) **Informed Decision-Making:** The findings of the EIA are used to inform decision-makers, including government agencies, regulatory bodies, and the public, about the potential impacts and benefits of the transmission line project. This information is crucial for making informed decisions regarding project approval, permitting, and conditions.

(g) **Transparency and Public Engagement:** The EIA process often involves public consultation and engagement, allowing affected communities and stakeholders to provide input, express concerns, and offer suggestions. This transparency helps build trust and allows for a more comprehensive assessment of potential impacts.

(h) **Long-Term Sustainability:** By considering the environmental, social, and economic consequences of a transmission line project, an EIA aims to ensure that the project is developed and operated in a way that is environmentally sustainable and contributes positively to the well-being of communities.

In summary, an environmental impact assessment for a transmission line project serves to identify, assess, and address potential adverse effects while promoting sustainable development and informed decision-making. It plays a crucial role in balancing the need for infrastructure development with environmental and social protection.

3.3 Typical Content for a Transmission Line Environmental Impact Statement or Report

An EIS or EAR for a transmission project covers a range of factors and impacts that may arise during the design, construction, operation, or maintenance of the infrastructure including:

- a description of the project
- project need, justification and feasibility, and any alternatives that have been considered
- a review of the planning laws and approvals which are relevant to the proposed infrastructure.
- environmental considerations including the existing environment and any potential impact on factors such as biodiversity, flora, fauna, air quality, noise, waterways, vegetation, and soils
- matters of environmental significance in the area
- transport and traffic

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- bushfire risk
- health and safety
- land use
- social considerations
- economic considerations including benefits such as local jobs
- current and future land use
- visual amenity
- electric and magnetic fields
- cultural heritage – Indigenous and non-Indigenous
- the community and stakeholder engagement and consultation process
- the location of other infrastructure and industry
- the actions the proponent will take to manage and minimise environmental and social impacts that may result from the design, construction, operation, or maintenance of the new infrastructure.

3.4 Environmental Impact Assessment Process

The regulatory requirements for environmental impact assessment process typically include the following formal stages (Queensland Government [50]):

1. Submission of a draft Terms of Reference (ToR)
2. Publication notification of a draft (ToR)
3. Final ToR issues – EIS in preparation
4. Public notification of EIS
5. Proponent responds to submissions
6. EIS Assessment report

For a transmission line project the process however starts with early engagement of key stakeholders to develop alternative solutions including route corridor options to inform the draft Terms of Reference for the environmental impact assessment.

4.

Discussion

As highlighted in the original framework by Biasotto and Kindel (2018), all abiotic factors studied are interlinked. While such categorisation can be helpful for study purposes, it is recognised that it may preclude generating a more holistic view of transmission lines' environmental impacts.

The literature review highlighted several shortcomings in the current body of knowledge which include:

- Studies' methodologies varied greatly rendering meta-analyses difficult.
- There was a lack of studies addressing cumulative impacts from infrastructure developments in regions.
- There was a lack of studies considering impacts on communities (interacting species sharing a location) from all abiotic impacts.
- No studies addressed regional biosphere impacts for the whole length of transmission lines
- There was a lack of studies pre- and post-transmission line installation.
- Construction and removal phase impacts, however remained unstudied in the peer reviewed literature.

Despite these shortcomings the regulatory requirements of EIA's are fundamental to the development of any new transmission project. As such, they are well entrenched in the processes of TNSPs and other providers globally. However, with the growing focus on biodiversity impacts and a call to net-positive biodiversity impacts overall, means that increased scrutiny of EIA's is likely to occur. With the scale of renewable energy projects proposed, we are already seeing some environmental groups and others insist on a much more precautionary approach to project development as they relate to the environment. This again highlights the complexity for decision makers as the longer term impacts of climate change will be far more devastating to the environment and impacted biodiversity than a single project. Again pointing to the need for a nuanced understanding and pragmatic approach when trading off potentially near term negative impacts, often quite locally based, for a longer term environmental gain.

Regardless of the EIA process, while the body of knowledge regarding overhead transmission line impacts on biodiversity has grown over the years and points to an overall negative impact on local biodiversity, quantification of the magnitude, pathways and details of this loss are not well known. Undergrounding has been suggested as a mitigation measure for bird collision and electrocution, specifically in protected areas and in endangered species' habitats. However, the studies also highlight that the biodiversity impacts from habitat loss, conversion and fragmentation, and edge and corridor effects would remain. Additionally, the underground cable impacts on surface and underground soil, water and their associated life over time is less well known and documented.

Beyond the local biosphere impacts, both overhead and underground technology accrue environmental impacts to the global biosphere from material extraction, manufacturing, transport, installation, and operation to removal and recycling impacts such as greenhouse gas emissions, resource depletion, acidification, eutrophication, and toxicity. Those impacts are accounted for in lifecycle assessments (LCAs). A purposeful search of the LCA literature revealed that power losses during the operation of transmission lines is the main contributor to environmental impacts over the lifecycle of the infrastructure. Those environmental impacts are due the extra power required to compensate for the power losses. This extra power results in additional greenhouse gas emissions throughout the operational phase [51], [52]. Considering the current Queensland electricity generation mix that is dominated by coal, the emissions would be significant. However, the new transmission lines are built to connect renewable energy rendering this calculation inadequate. LCAs comparing overhead and underground technologies concluded that underground had the greatest footprint due to cable production, however this equation may be changed by HVDC cable [51]. Finally, all these impacts have to be weighed against the impacts of not building sufficient transmission line capacity in an adequate timeframe to counteract climate change impacts.

The lack of studies considering the environmental impacts through an Indigenous lens and utilising traditional knowledge is a gap in the literature and more work in this area will provide a valuable perspective and understanding of other dimensions of environmental impacts.

5.

Limitations

Overall, there is limited data in the peer reviewed literature regarding the construction and removal phase. Those potential impacts are described within Environmental Impact Assessments (EIAs) the scope of which has been detailed above. However, they are mitigated through Environmental Management Plans (EMP) which are not included as part of this systematic review. It is important to note that EIAs are not subject to long-term monitoring and evaluation. As such, the data within those documents offers a view of the anticipated impacts not the actual impacts, nor the effectiveness of the mitigation measures recommended to be implemented.

6. Conclusions

6.1 Key Findings

1. As with any large infrastructure projects, the environment is generally negatively impacted by transmission line infrastructure projects, whether they are overhead or underground, with regulated EIAs forming a critical part of the process for ensuring such impacts are minimised wherever possible. Such regulations are considered important elements for ensuring a social licence to operate providing comfort that all likely impacts are acknowledged and accordingly accounted for. Regardless, as with communities, each environment is context dependent and needs to be considered independently to ensure all likely impacts are identified.
2. Principally, habitat loss, fragmentation, and the alteration of environmentally sensitive areas are key negative outcomes of the construction of transmission infrastructure on the natural environment. Overhead lines are more likely to create a barrier effect, where biodiversity is negatively impacted through changes in bird migration patterns because of collision and avoidance of the transmission lines but mitigation measures through the use of markers such as bright coloured balls have been successful in reducing such impacts.
3. The clearing of vegetation for easements is also likely to have a significant impact on wildlife habitats as well as cause changes in the microclimate by restricting the growth of plants and trees, with secondary impacts on some species including insects, birds, and other mammals.
4. Avoiding transmission lines being constructed in highly sensitive natural environments including watercourses, wetlands, and national parks is also a high priority, although not always possible given the scale of developments required.
5. Bushfires are raised as an environmental concern and according to Biasotto and Kindel (2018), transmission lines can present an increased fire ignition risk at times due to bird electrocution. They also mention fires spreading and intensifying as a result of invasive plant species in easements. In Australia, the 2019 NSW Inquiry into bushfires suggested two were started by powerlines but no distinction was made between distribution or transmission lines. While undergrounding may help mitigate these risks, reviews have also highlighted they can also be vulnerable to fire impacts.
6. Understanding the interplay between the environment and other cultural heritage considerations is also an important consideration that is starting to gain more attention but requires further research and engagement.
7. There is no one size fits all when deciding between overhead and underground transmission infrastructure based on environmental considerations and as the increasing severe weather impacts occur including floods and fires the ability to maintain and have transmission lines continue to operate will be of utmost importance when considering how and where they should be constructed.
8. Environmental Impact Processes through both the EPBC Act and Queensland's Environmental Protection Act, are critical components of the approval process for all transmission projects with a typical timeframe to complete the process being approximately two years.

6.2 Comparison Table - Environmental Factors of HV Transmission Infrastructure

A summary comparing the environmental factors of HV overhead and underground transmission infrastructure is presented in Table 1.

Table 1. Comparison of HV Overhead and Underground Cable Transmission – Environmental Factors

	Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Under-ground
		Environmental Factors			
1	**Overall environmental impacts**	Overall negative impacts on the local biodiversity. The geographical context as well as the local ecosystem influence overall impacts. Transmission line add to the cumulative impacts from all infrastructures and developments in a region.	Likely overall negative impacts on the local biodiversity.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC under-ground.
2	**Barrier effect**	Barrier effect impacts biodiversity negatively. Bird collision and avoidance are the most cited impacts. Flow-on impacts are multiple, including change in migration path and extinction. Potential mitigation measures are through line routing and line markers.	Undergrounding is an effective mitigation measure for the barrier effect.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC under-ground.
3	**Line as resource**	Line as resource is considered positive though with potential negative impacts, particularly on birds. Positive impacts include increased population size and home range. Negative impacts include increased collision, electrocution, predation and invasive species colonisation.	Underground lines cannot act as a resource.	*Expected to be similar to HVAC overhead.	Expected to be similar to HVAC under-ground.
4	**Habitat loss**	Habitat loss arises mostly from vegetation clearance, particularly in forested area. The most cited impacts are area abandonment and population decline.	Underground line would result in habitat loss from vegetation clearance.	*Expected to be similar to HVAC overhead.	Expected to be similar to HVAC under-ground.
5	**Habitat fragmentation**	Habitat fragmentation arises mostly from vegetation clearance and the barrier effect. Negative impact such as altered movement for mammals and amphibians, and reduced bird crossings with increasing voltage.	Underground line would result in habitat fragmentation from vegetation clearance.	*Expected to be similar to HVAC overhead.	Expected to be similar to HVAC under-ground.
6	**Edge effect**	Edge effect arises from vegetation clearance and can have positive, neutral or negative impacts on biodiversity. Most intense impacts are in forested areas. Impact on vegetation from change in microclimate and associated species in those communities such as insects, birds, bats and mammals.	Underground line would result in edge effect from vegetation clearance.	*Expected to be similar to HVAC overhead.	Expected to be similar to HVAC under-ground.

	Factor	HVAC Overhead	HVAC Underground	HVDC Overhead	HVDC Under-ground
7	Habitat conversion	Habitat conversion arises from vegetation clearance and can overall be positive, particularly in forestry and intense agricultural land. Maintenance in semi-natural grassland can provide significant ecosystems for a variety of species, notably pollinators and open habitat bird species. To be positive, it requires management practices designed for the local context.	Underground line would result in habitat conversion from vegetation clearance.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC under-ground.
8	Corridor effect	Corridor effect arises from the easement providing a connection between areas and can have positive, neutral, and negative impacts. Increased home range for native, non-native, and invasive species. Large carnivores and birds expand their home range, most notably the crow or raven. Limited home range expansion for pollinators. To be positive, it requires management practices designed for the local context.	Underground line would result in corridor effect from vegetation clearance.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC under-ground.
9	EMF	Potential behavioural, reproductive effects. Some bat species powerline avoidance behaviour is attributed to EMF. EMF affects bees and may pose threat to pollination and colonies survival.	EMF impacts are likely to occur for underground.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC under-ground.
10	Fire	Overhead lines can be a source of fire ignition (1.2% of fires in Spain). Bird electrocution can induce fire – mainly distribution lines (2.4% of the 1.2% in Spain).	Undergrounding would mitigate power line induced fires.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC under-ground.
11	Noise	Noise arises from construction and maintenance, corona discharge and cable vibration from wind. Noise may alter animal behaviours and interfere with animal communication.	Undergrounding would mitigate corona discharge and wind induced noise.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC under-ground.
12	Soil degradation, hydrological alterations, air pollution	Those impacts are mostly associated with the construction and removal phase. Limited data on their impacts in the peer-reviewed literature.	Those impacts would be markedly different and likely more significant for underground cables for the life cycle of the infrastructure.	Expected to be similar to HVAC overhead.	Expected to be similar to HVAC under-ground.
13	Environmental Assessment Processes	The Federal Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and the State's Queensland Environmental Protection Act 1994 are the key legislative requirements for all projects. Detailed Environmental Impact Assessments (EIAs) and surveys are required to ensure protection of environmental significance including unique plants, animals, habitats and places.			

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Appendix A:

PRISMA Methodology for Environmental Aspects

1. Eligibility Criteria (Inclusion & Exclusion):

Inclusion criteria

- Studies which cover environmental impact of overhead transmission line and underground cables
- "Transmission line" and "powerlines" rather than voltage levels were used as this is common practice in this type of literature

Exclusion criteria

- Any duplicated studies
- Distribution powerlines
- Studies that are irrelevant to the scope of this review for example, technology other than transmission lines and impact on humans as well as the environment impacting the transmission lines
- Language other than English

2. Information Sources

Both Scopus and Web of Science databases were used to find peer reviewed articles.

3. Search Strategy

An initial search was conducted to refine search terms and through this a systematic literature review by Biasotto and Kindel (2018) on the impact of power lines on biodiversity was found. The Biasotto and Kindel review analysed publications between January 1996 and February 2016. The authors developed a framework to categorise their findings. This review built on their findings, it adapts the framework, used the same search terms and included literature between 2016 and June 2023.

The final search terms were:

To establish the domain of enquiry: ("transmission" OR "High voltage" OR "electric*") AND ("powerline" or "power line") AND (impact* OR effect* OR loss* OR damage*)

To target specific impacts, the following groups were used:

- "habitat*" OR "environment*" OR "landscape*" OR "terrestrial*" OR "soil*" OR "water bod*"
- "biodiversity" OR "population*" OR "communit*" OR "specie*" OR "assemblage*" OR "biota"
- "*vertebrate*" OR "avian" OR "bird*" OR "mammal*" OR "amphibian*" OR "reptile*" OR "wild*life"
- "vegetation*" OR "plant*" OR "grassland*" OR "forest*" OR "wetland*" OR "artificial*land*" OR "land use" OR "agricultur*"

Both databases were searched for Title, Abstract and Keywords.

4. Data Collection Process

Based on the eligibility criteria, information sources and search strategy, publications are identified as per the procedures presented in the flow chart in Figure 2. According to the search strategy, 823 publications about transmission lines were found through the Web of Science and Scopus, after removal of duplicates and papers outside of the inclusion criteria, 427 were determined to be potentially contributing to the scope of this study. The papers were then screened by reading all publications' titles and abstracts and 56 were deemed within scope. These shortlisted publications were read in detail resulting in 35 publications selected, citation and purposeful (fire, EMF and noise) searches were also used resulting in an additional 14 publications selected. In total, 49 studies were considered for further analysis in this review.

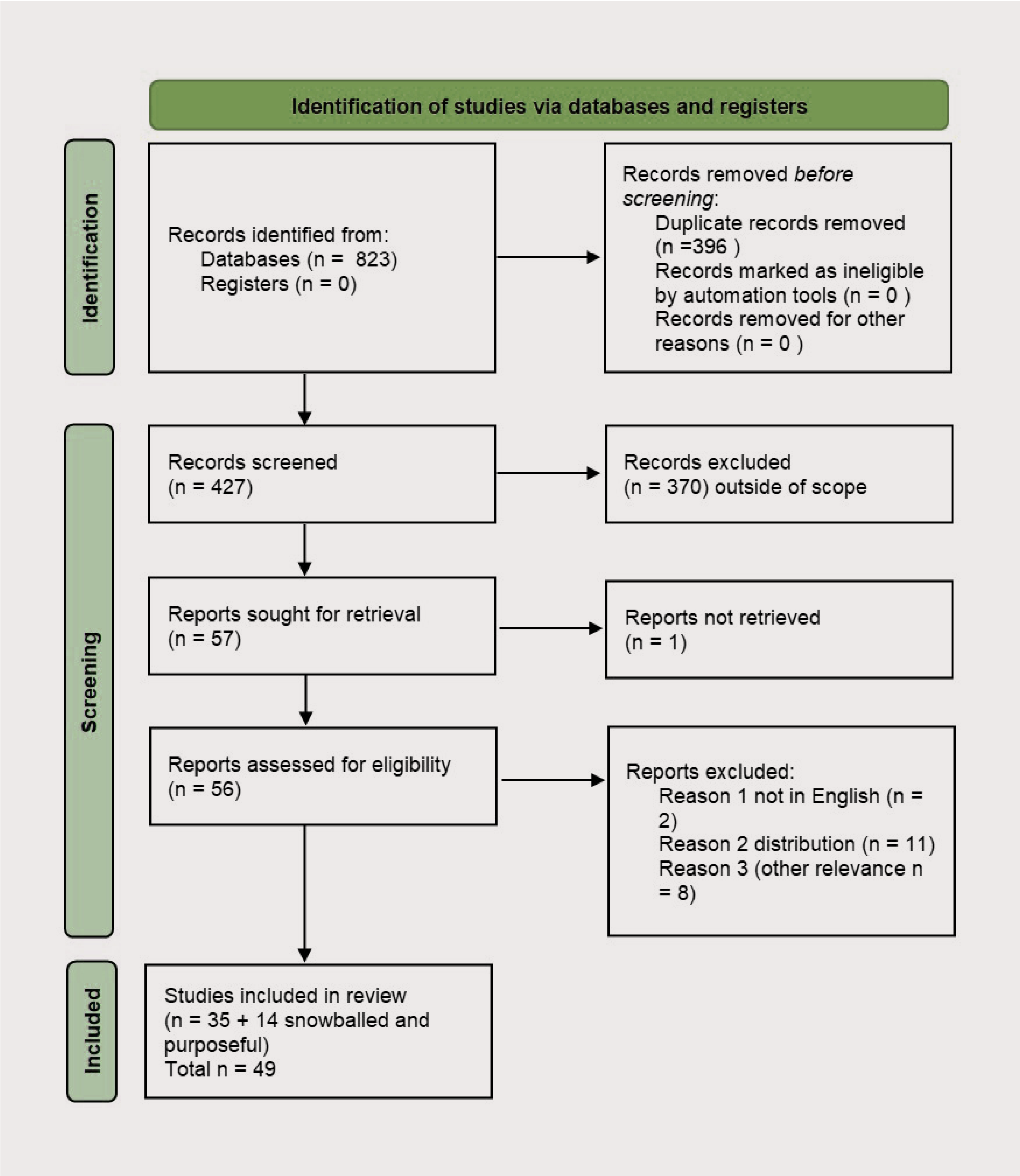

Figure 2 - Prisma flow diagram of studies to be included in the systematic literature review

5. Data Analysis

The 49 articles were analysed. See Table 2 for the further details on the 49 papers analysed for this review. Data analysis was performed using the software NVivo 12, used to organise and help analyse the data through the following methods. This first stage of the analysis consisted of sorting text extracts to the categories within the Biasotto and Kindel framework and identifying any missing categories since 2016. The second stage consisted of categorising extracts further and organising the findings to update and further the Biasotto and Kindel analysis.

Literature characteristics

Biasotto and Kindel (2018)'s review was aimed at all powerlines—distribution and transmission—and did not distinguish between overhead and underground. Where possible, this review focussed on transmission lines and specifically findings relating to underground powerlines. In this review, since 2016, 37% of the studies took place in Europe and 27% in North America (Figure 3) and none were conducted in Australia.

The distribution of abiotic impacts evaluated is similar to Biasotto and Kindel's with a strong prevalence of barrier effect studies (Figure 4). We note that 39 per cent of studies assessed two or more abiotic impacts, which is essential to gauge the overall effect of transmissions lines.

This review revealed a similar distribution of biotic components (fauna and flora) to the Biasotto and Kindel (2018) review (Figure 5). Three studies evaluated a combination of biotic components which are again essential to gauge the overall effects of transmissions lines on the environment.

Of the life cycle of transmission lines, impacts during operation tended to be evaluated in the environmental peer-reviewed literature. Construction, decommissioning and removal were rarely addressed. Only eight publications mentioned underground transmission cables, and none were specifically aimed at the environmental impact of underground cables.

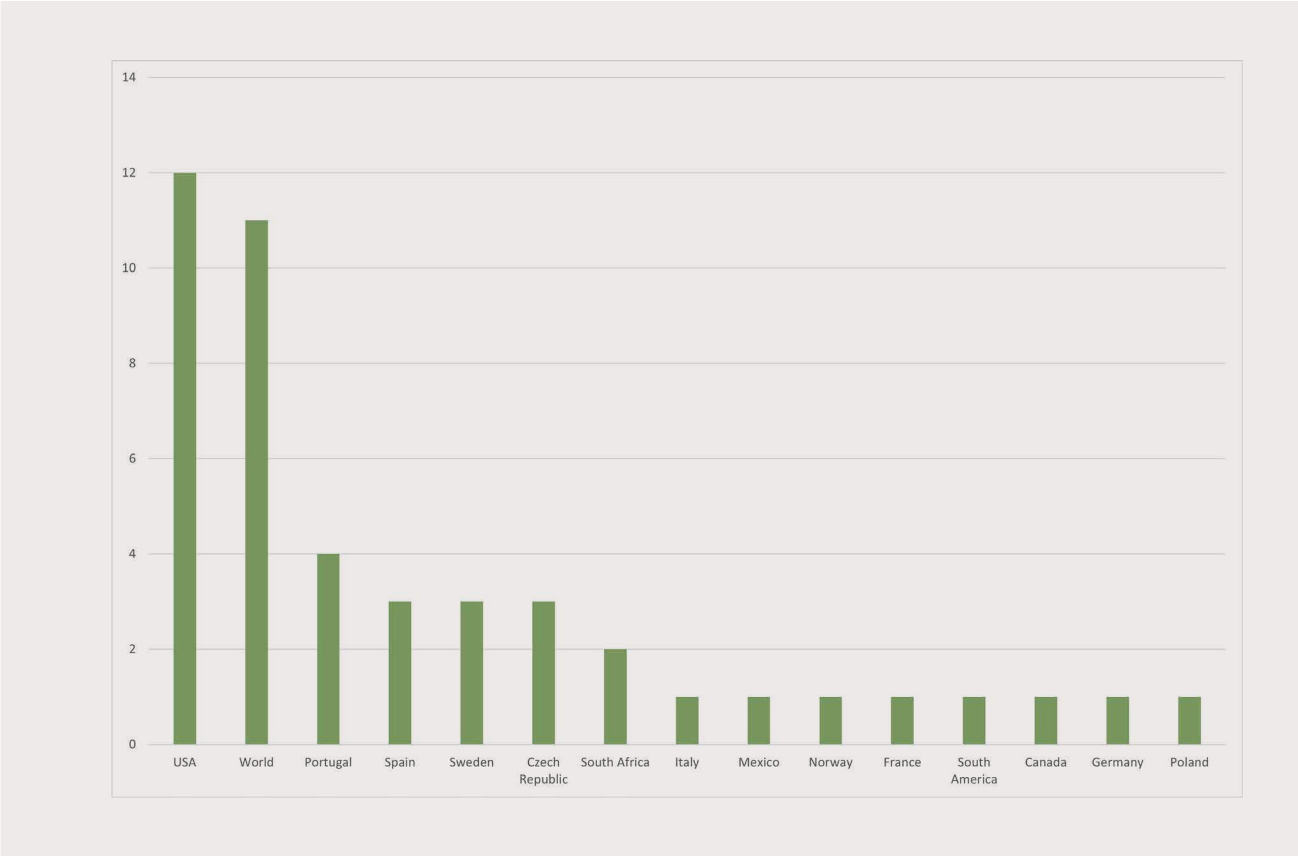

Figure 3. Number of Publications per Country or Region

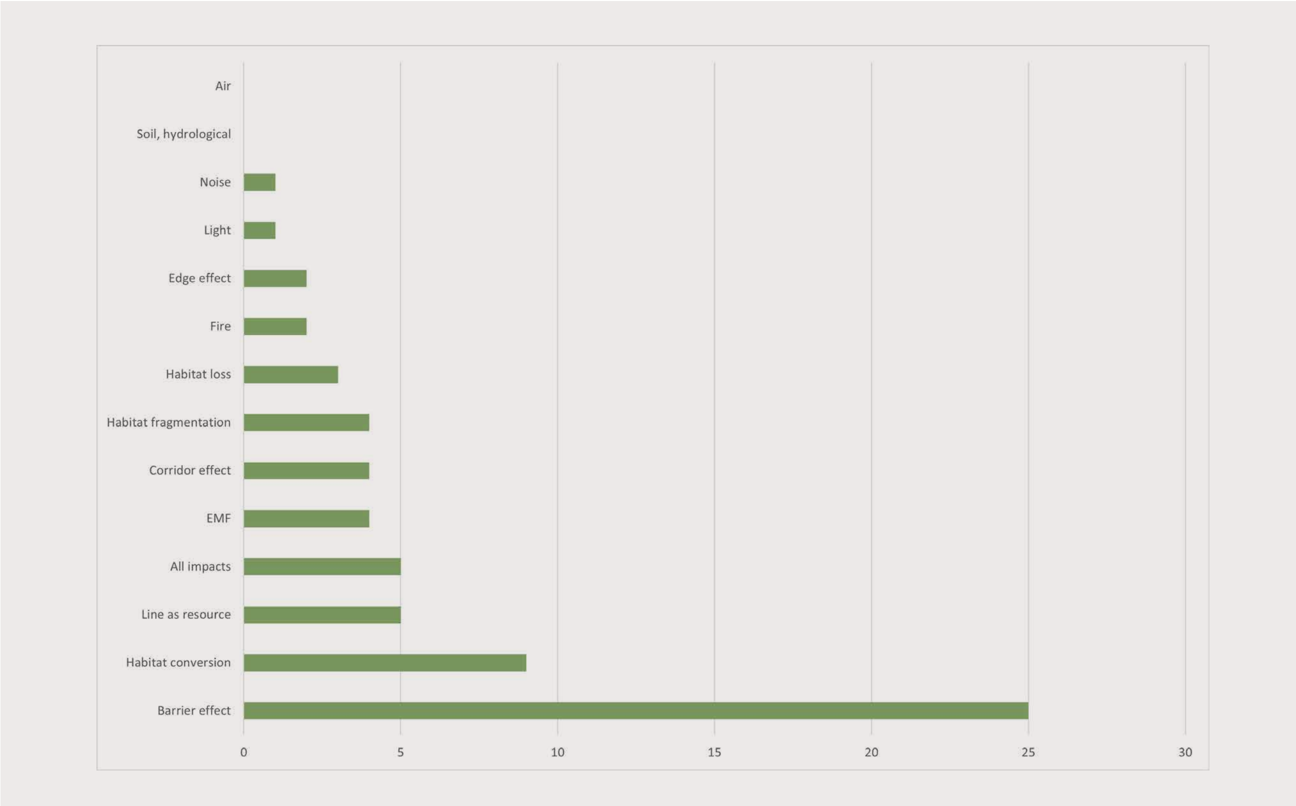

Figure 4. Number of Publications per Abiotic Impacts Assessed

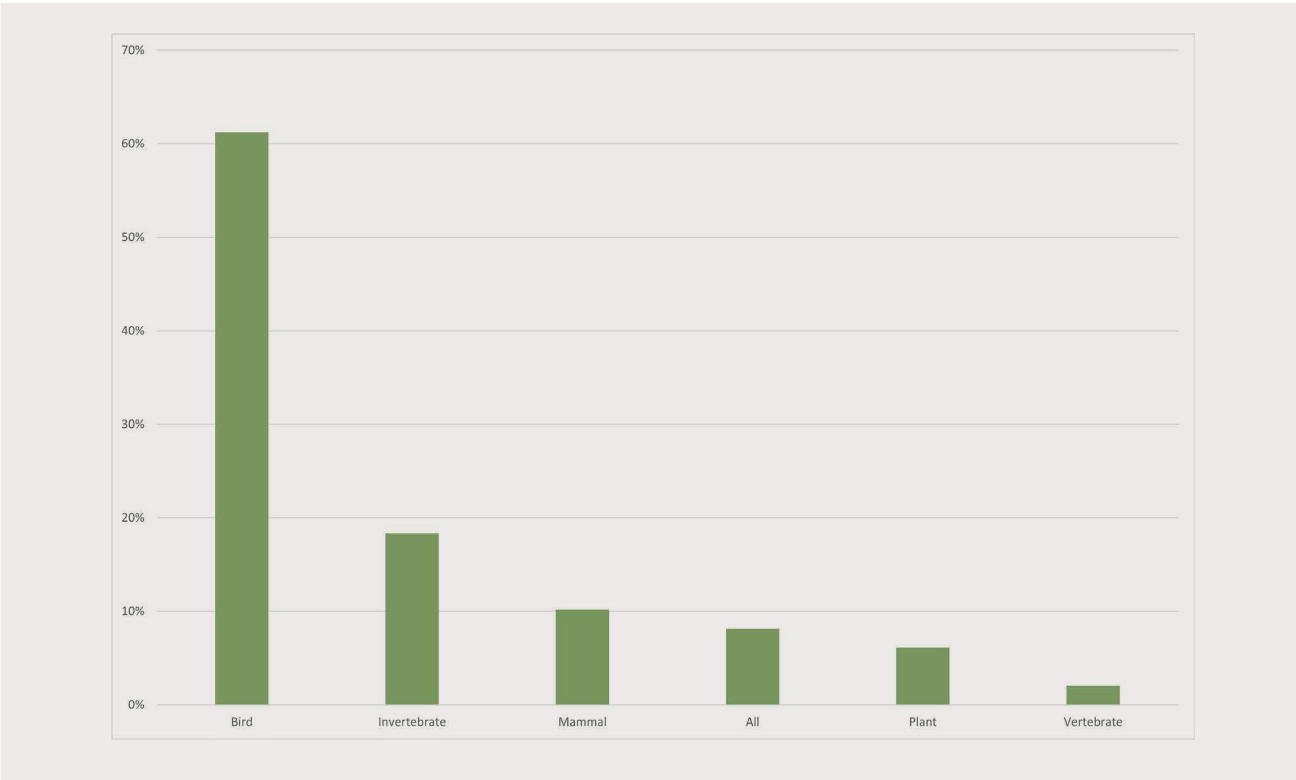

Figure 5. Target of Publications on Biotic Components

Table 2 - Summary of references

Authors	Year	Title	Abiotic factors	Country	Target
Balmori, A	2021	Electromagnetic radiation as an emerging driver factor for the decline of insects	EMF	World	Invertebrate
Barnes, TA; Dwyer, JF; Mojica, EK; Petersen, PA; Harness, RE	2022	Wildland fires ignited by avian electrocutions	Fire, barrier	USA	Bird
Bernardino, J.; Martins, R. C.; Bispo, R.; Moreira, F.	2019	Re-assessing the effectiveness of wire-marking to mitigate bird collisions with power lines: A meta-analysis and guidelines for field studies	Barrier effect	World	Bird
Bernardino, J.; Bevanger, K.; Barrientos, R.; Dwyer, J.F.; Marques, A.T.; Martins, R.C.; Shaw, J.M.; Silva, J.P.; Moreira, F.	2018	Bird collisions with power lines: State of the art and priority areas for research	Barrier effect	World	Bird
Biasotto, L.D.; Kindel, A.	2018	Power lines and impacts on biodiversity: A systematic review	All	World	All
Burdett, E.M.; Muriel, R.; Morandini, V.; Kolnegari, M.; Ferrer, M.	2022	Power Lines and Birds: Drivers of Conflict-Prone Use of Pylons by Nesting White Storks (Ciconia ciconia)	Line as resource	Spain	Bird
D'Amico, M; Catry, I; Martins, RC; Ascensao, F; Barrientos, R; Moreira, F	2018	Bird on the wire: Landscape planning considering costs and benefits for bird populations coexisting with power lines	All	World	Bird
Daniel-Ferreira, J; Bommarco, R; Wissman, J; Ockinger, E	2020	Linear infrastructure habitats increase landscape-scale diversity of plants but not of flower-visiting insects	Habitat conversion	Sweden	Plant
Dániel-Ferreira, J; Fourcade, Y; Bommarco, R; Wissman, J; Öckinger, E	2023	Communities in infrastructure habitats are species rich but only partly support species associated with semi-natural grasslands	Habitat conversion, corridor effect	Sweden	Invertebrate, plant
Day, RH; Cooper, BA	2022	Behavior of Hawaiian Petrels and Newell's Shearwaters (Ayes: Procellariiformes) Around Electrical-Transmission Lines on Kaua'i Island, Hawaiian Islands	Barrier effect	USA	Bird
Dean, W.R.J.; Seymour, C.L.; Joseph, G.S.	2018	Linear structures in the Karoo, South Africa, and their impacts on biota	All	South Africa	All
Eftestol, S; Tsegaye, D; Flydal, K; Colman, JE	2016	From high voltage (300 kV) to higher voltage (420 kV) power lines: reindeer avoid construction activities	Barrier effect	Norway	Mammal
Escobar-Ibáñez, J.F.; Aguilar-López, J.L.; Muñoz-Jiménez, O.; Villegas-Patraca, R.	2022	Power Lines, an Understudied Cause of Avian Mortality in Mexico	Barrier effect	Mexico	Bird
Froidevaux, J.S.P.; Jones, G.; Kerbiriou, C.; Park, K.J.	2023	Acoustic activity of bats at power lines correlates with relative humidity: a potential role for corona discharges	Barrier, edge effect, noise, light, EMF	France	Mammal

Authors	Year	Title	Abiotic factors	Country	Target
García-Alfonso, M; van Overveld, T; Gangoso, L; Serrano, David; D, Donázar, J. A.	2021	Disentangling drivers of power line use by vultures: Potential to reduce electrocutions	Line as resource, Barrier effect	Spain	Bird
Garfinkel, M; Yakandawala, K; Hosler, S; Roberts, M; Whelan, C; Minor, E	2023	Testing the accuracy of a Rights-of-Way pollinator habitat scoring system	Habitat conversion	USA	Invertebrate
Gibson, D; Blomberg, EJ; Atamian, MT; Espinosa, SP; Sedinger, JS	2018	Effects of power lines on habitat use and demography of greater sage-grouse (Centrocercus urophasianus)	Habitat loss, corridor effect	USA	Bird
Guil, F.; Pérez-García, J. M.	2022	Bird electrocution on power lines: Spatial gaps and identification of driving factors at global scales	Barrier effect	World	Bird
Guil, F.; Soria, MA, Margalida, A, Perez-Garcia, J.	2018	Wildfires as collateral effects of wildlife electrocution: An economic approach to the situation in Spain in recent years	Fire, barrier	Spain	Bird
Hays, QR; Tredennick, AT; Carlisle, JD; Collins, DP; Carleton, SA	2021	Spatially Explicit Assessment of Sandhill Crane Exposure to Potential Transmission Line Collision Risk	Barrier effect	USA	Bird
Hill, B; Bartomeus, I	2016	The potential of electricity transmission corridors in forested areas as bumblebee habitat	Habitat conversion, corridor effect	Sweden	Invertebrate
Hrouda, J; Brlik, V	2021	Birds in power-line corridors: effects of vegetation mowing on avian diversity and abundance	Habitat conversion, edge effect	Czech Republic	Bird
Hyde, JL; Bohlman, SA; Valle, D	2018	Transmission lines are an under-acknowledged conservation threat to the Brazilian Amazon	All	Brazil	All
Kohl, MT; Messmer, TA; Crabb, BA; Guttery, MR; Dahlgren, DK; Larsen, RT; Frey, SN; Liguori, S; Baxter, RJ	2019	The effects of electric power lines on the breeding ecology of greater sage-grouse	Habitat loss, fragmentation	USA	Bird
Lebeau, CW; Smith, KT; Holloran, MJ; Beck, JL; Kauffman, ME; Johnson, GD	2019	Greater sage-grouse habitat function relative to 230-kV transmission lines	Habitat loss, fragmentation	USA	Bird
Lupi, D.; Palamara Mesiano, M.; Adani, A.; Benocci, R.; Giacchini, R.; Parenti, P.; Zambon, G.; Lavazza, A.; Boniotti, M. B.; Bassi, S.; Colombo, M.; Tremolada, P.	2021	Combined Effects of Pesticides and Electromagnetic-Fields on Honeybees: Multi-Stress Exposure	EMF	Italy	Invertebrate
Luzenski, Jeff; Rocca, Claudia E; Harness, Richard E; Cummings, John L; Austin, Daryl D; Landon, Melissa A; Dwyer, James F	2016	Collision avoidance by migrating raptors encountering a new electric power transmission line	Barrier effect	USA	Bird
Marques, A.T.; Palma, L.; Lourenço, R.; Cangarato, R.; Leitão, A.; Mascarenhas, M.; Tavares, J.T.; Tomé, R.; Moreira, F.; Beja, P.	2022	Individual variability in space use near power lines by a long-lived territorial raptor	Barrier effect, line as resource	Portugal	Bird

Authors	Year	Title	Abiotic factors	Country	Target
Marques, AT; Martins, RC; Silva, JP; Palmeirim, JM; Moreira, F	2021	Power line routing and configuration as major drivers of collision risk in two bustard species	Barrier effect	Portugal	Bird
Martin, CJ; Bork, EW; Nielsen, SE	2022	Mortality of grassland birds increases with transmission lines	Barrier effect	Canada	Bird
Mercker, M; Jodicke, K	2021	Beyond BACI: Offsetting carcass numbers with flight intensity to improve risk assessments of bird collisions with power lines	Barrier effect	Germany	Bird
Moreira, F; Encarnacao, V; Rosa, G; Gilbert, N; Infante, S; Costa, J; D'Amico, M; Martins, RC; Catry, I	2017	Wired: impacts of increasing power line use by a growing bird population	Barrier effect, line as resource	Portugal	Bird
Moreira, F; Martins, RC; Catry, I; D'Amico, M	2018	Drivers of power line use by white storks: A case study of birds nesting on anthropogenic structures	Line as resource	Portugal	Bird
Murphy, RK; Dwyer, JF; Mojica, EK; McPherron, MM; Harness, RE	2016	Reactions of Sandhill Cranes Approaching a Marked Transmission Power Line	Barrier effect	USA	Bird
Petri, AK; Schmiedchen, K; Stunder, D; Dechent, D; Kraus, T; Bailey, WH; Driessen, S	2017	Biological effects of exposure to static electric fields in humans and vertebrates: a systematic review	Static field	World	Vertebrate
Plewa, R; Jaworski, T; Tarwacki, G; Gil, W; Horak, J	2020	Establishment and Maintenance of Power Lines are Important for Insect Diversity in Central Europe	Habitat conversion	Poland	Invertebrate
Rebolo-Ifran, N; Plaza, P; Perez-Garcia, JM; Gamarra-Toledo, V; Santander, F; Lambertucci, SA	2023	Power lines and birds: An overlooked threat in South America	Barrier effect	South America	Bird
Richardson, M. L.; Wilson, B. A.; Aiuto, D. A. S.; Crosby, J. E.; Alonso, A.; Dallmeier, F.; Golinski, G. K.	2017	A review of the impact of pipelines and power lines on biodiversity and strategies for mitigation	All	World	All
Russo, L; Stout, H; Roberts, D; Ross, BD; Mahan, CG	2021	Powerline right-of-way management and flower-visiting insects: How vegetation management can promote pollinator diversity	Habitat conversion	USA	Invertebrate
Šálek, M; Riegert, J; Krivopalova, A; Cukor, J.	2023	Small islands in the wide open sea: The importance of non-farmed habitats under power pylons for mammals in agricultural landscape	Habitat conversion	Czech Republic	Mammal
Šálek, M; Václav, R; Sedláček, F	2020	Uncropped habitats under power pylons are overlooked refuges for small mammals in agricultural landscapes	Habitat conversion	Czech Republic	Mammal
Schmiedchen, K.; Petri, A.-K.; Driessen, S.; Bailey, W.H.	2018	Systematic review of biological effects of exposure to static electric fields. Part II: Invertebrates and plants	Static field	World	Invertebrate, plant

Authors	Year	Title	Abiotic factors	Country	Target
Shaw, J.; Reid, T.; Gibbons, B.; Pretorius, M.; Jenkins, A.; Visagie, R.; Michael, M.; & Ryan, P.	2021	A large-scale experiment demonstrates that line marking reduces power line collision mortality for large terrestrial birds, but not bustards, in the Karoo, South Africa	Barrier effect	World	Bird
Shaw, J.M.; Reid, T.A.; Schutgens, M.; Jenkins, A.R.; Ryan, P.G.	2018	High power line collision mortality of threatened bustards at a regional scale in the Karoo, South Africa	Barrier effect	South Africa	Bird
Shepherd, S.; Lima, M. A. P.; Oliveira, E. E.; Sharkh, S. M.; Jackson, C. W.; Newland, P. L.	2018	Extremely Low Frequency Electromagnetic Fields impair the Cognitive and Motor Abilities of Honey Bees	EMF	Lab	Invertebrate
Slater, S. J.; Dwyer, J. F.; Murgatroyd, M.	2020	Conservation Letter: Raptors and Overhead Electrical Systems	Barrier effect	USA	Bird
Smith, JA; Dwyer, JF	2016	Avian interactions with renewable energy infrastructure: An update	Barrier, corridor effect	USA	Bird
Uddin, M; Dutta, S; Kolipakam, V; Sharma, H; Usmani, F; Jhala, Y	2021	High bird mortality due to power lines invokes urgent environmental mitigation in a tropical desert	Barrier effect, fragmentation	India	Bird
Zuluaga, S.; Speziale, K. L.; Lambertucci, S. A.	2022	Flying wildlife may mask the loss of ecological functions due to terrestrial habitat fragmentation	Barrier effect, fragmentation	World	Bird, mammal, invertebrate

The University of Queensland
Professor Tapan Saha
saha@eecs.uq.edu.au

Curtin University
Professor Peta Ashworth
peta.ashworth@curtin.edu.au