Environmental Impact Assessment Review 71 (2018) 110–119

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

Power lines and impacts on biodiversity: A systematic review

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ARTICLE INFO

Keywords:
High-voltage lines
Environmental impact assessment
Scoping
Energy infrastructures

ABSTRACT

The growth of energy consumption demands a large expansion of transmission line (TL) networks worldwide. The reduction of the environmental impacts of these infrastructures will depend on the effectiveness of environmental impact assessments, that ultimately depend on the quality of the screening phase, the scoping phase, and the prioritization of potential environmental consequences. We conducted the first systematic review that encompasses all known potential impacts on biodiversity of the installation and operation of energy TLs, documented in the scientific literature and in a sample of Environmental Impact Studies (EIS). We examined 206 articles and 19 EIS and identified 28 impacts that correspond to biotic outcomes at the individual, population and community levels. Although scientific interest on TL impact evaluation is increasing, most studies have been focused on vertebrate taxa, especially birds. There are few published studies concerning habitat loss and the responses of functional groups with lower mobility or sensitive to physical alterations, such as amphibians. Most impacts appear in early stages of a project, during TL construction, but persist during operation. We summarized the biotic impacts in a framework that may guide the screening of relevant impacts to be included in the EIS and consequently improve the outcomes of the environmental licensing process of transmission line projects.

1. Introduction

The increasing need for access to energy demands the installation of new transmission lines (TLs). According to the International Energy Outlook 2016 (IEO, 2016), there is a predicted growth of approximately 48% on energy consumption over the next 26 years worldwide, with a consequent large expansion of the transmission system.

Due to the long distances between power plants and main consumption regions, electricity reaches consumers by an extensive network of transmission (high-voltage) and distribution (low-voltage) lines. Transmission lines differ from distribution lines by supporting higher voltages (from 69 kV to 800 kV), and usually extending for longer distances.

Transmission lines might cause significant impacts on the environment both during the construction and operation phases (Bagli et al., 2011). The most obvious impacts of power lines on the environment are associated with the right of way (RoW), the zone below the cables where vegetation is cleared and managed to avoid interference and risk to line structures and/or to energy transmission. The RoW width varies according to many factors (Weedy, 1989), being wider for lines with higher voltages. Although the disturbed area is limited in width, the linear disturbance may extend for hundreds of kilometers (e.g. Cardoso Junior et al., 2014).

The need to consider the impacts on biodiversity during infrastructure planning and decision-making has been emphasized in some multination agreements such as the Convention on Biological Diversity (CBD, 2005, p. 720–737) and is part of the legal framework of nearly every country (Morgan, 2012). As for numerous other infrastructures, this creates the need for a reasoned evaluation of the environmental viability of the transmission lines during the environmental licensing process.

The Environmental Impact Assessment (EIA) is seen as a rational and systematic process and, in general, has some mandatory stages that have influence on decision-making (Weston, 2000). The earlier stages of the EIA process are the screening phase, where the projects that should be subject to EIA are defined and the scoping phase, that determines which environmental impacts should be subject to assessment (Weston, 2000). The scoping phase results in the Terms of Reference (ToR), the document that guides the preparation of the environmental impact studies (EIS) defining its objectives, content, structure and methods.

Despite its relevance to environmental protection, a number of deficiencies related to the treatment of biodiversity in the EIA process of transmission lines have been identified. Environmental assessments have been superficial, generally focusing only on the direct impacts and on the presence of some species (Thompson et al., 1997; Söderman, 2006). According to Khera and Kumar (2010), the main limitations of these assessments are the lack of representation of different biological

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https://doi.org/10.1016/j.eiar.2018.04.010
Received 17 November 2017; Received in revised form 27 April 2018; Accepted 27 April 2018

levels (habitat, species, and genes) and of different biodiversity measures (composition, structure, and function) on impact prediction, as well as their consideration on mitigation proposals and monitoring plans.

The main opportunity to counteract the limitations of the environmental licensing process is centered on the scoping phase of EIAs (Barnes et al., 2010; Borioni et al., 2017) which could result in the improvement of ToR. The flaws in impact prediction and in proposing mitigation and monitoring plans may be overcome by a good previous understanding of the possible environmental consequences of a project (Mandelik et al., 2005), which would be improved by a comprehensive compilation of accumulated knowledge. Framing key questions to be investigated by studies is the backbone of the scoping phase, which must consider "why sample?", "what to sample?", and "how to sample?" (Ferraz, 2012). In a review of the scoping process in Brazil, that included the analysis of two power line projects, Borioni et al. (2017) demonstrated the complete absence of a previous broad identification of impacts to inform the ToR preparation.

Even with scientific evidence of environmental disturbance caused by transmission lines, reviews of the potential impacts that could inform decision-making are rare. Apart from Richardson et al. (2017), existing references are usually restricted to a single kind of impact and/or taxonomic group, such as bird mortality caused by power lines (e.g. Bevanger, 1998; Erickson et al., 2005; Rubolini et al., 2005; Jenkins et al., 2010; Walters et al., 2014).

Our aim in this study is to review the known impacts of power lines to promote and support the improvement of the impact assessments of those infrastructures. Based on a systematic review of published articles and complemented by a set of environmental impact studies, we identified key impacts of transmission lines on biodiversity. The section dedicated to describing each abiotic impact gives examples about their nature (positive or negative) and the biotic components affected by them. We summarize our findings in a framework based on the sequence "Action – Abiotic impact – Biotic impact". We believe this visual presentation will facilitate communication and discussion during the scoping and other decision-making phases of environmental impact assessments.

To create the framework, we adopted a similar sequence proposed by Karlson et al. (2014) with a modification of some definitions. We defined "Action" as the activity or trait of the project that induces changes on the environment and "abiotic impact" as the alteration of the physical or chemical environment. "Biotic impact" describes the biotic consequences resulting from these alterations, and we distinguished responses at the individual, population, and community levels.

2. Methods

2.1. Systematic review – general approach

We conducted a systematic review following the guidelines proposed by the protocol of the *Collaboration for Environmental Evidence* (CEE, 2013), that recommends a series of steps to identify the study goals, define the research strategy and study inclusion criteria, synthesis and analysis according to the type of demanded information. We restricted our search to a period of 20 years, between January 1996 and February 2016. We first focused the review on peer-reviewed papers published on scientific journals and, later, we complemented the review with grey literature, specifically with environmental impact studies (EIS). The review was performed by two researchers, which reduced biases in article selection and data extraction (Doerr et al., 2015).

At the beginning of our review we perceived a concentration of scientific studies on aboveground impacts on terrestrial habitats observed during the power line operation phase. Thus, to complement the list of potential impacts, we searched for EIS since these studies usually focus mainly on the impacts of the installation phase.

2.2. Strategy for literature search

We used two electronic databases for the scientific literature search: Scopus© and ISI Web of Science©. The search terms were inserted in the categories "Title, abstract, and keywords", and "Topic" (TS). The search was based on combinations of one main group of keywords with five other complementary groups, applied to both databases. The main group was related to the studied structure and included "power line*" OR "power-line*" OR "powerline*" OR "transmission line*" OR "high voltage line*" OR "transmission system*". The other five groups were combined with the main group by the Boolean operator "AND", and were related to the environment: ("habitat*" OR "environment*"); ("landscape*" OR "terrestrial*" OR "soil*" OR "water bod*"); ("bio*-diversity" OR "population*" OR "communit*" OR "specie"); ("*vertebrate*" OR "avian" OR "bird*" OR "mammal*" OR "amphibian*" OR "reptile*" OR "wild*life" OR "human*"); ("vegetation*" OR "plant*" OR "grassland*" OR "forest*" OR "wetland*" OR "artificial*land*" OR "agricultur*"). We restricted the search to studies published in English and to the research areas related to this review (environmental sciences; science; technology and environment). We included literature published until February 17th, 2016.

The EIS review initially included only Brazilian studies due to ease of access through the national environmental agency website (Supplementary Table S1). Then, to increase worldwide representativeness, we searched for a similar number of studies from countries in other continents. We used the general Google search engine by combining "Environmental Impact Assessment Study" AND "power lines" terms. We restricted the search to studies of high voltage lines, in English or Portuguese, published until February 17th, 2016. Each institutional or project website page returned was checked to look for full access to impact evaluation documents. This search resulted in additional studies from United States, Portugal, and South Africa (Supplementary Table S1).

2.3. Screening and analysis of literature

We compiled a list of 5546 unique titles of scientific publications combining results from Scopus© and ISI Web of Science© databases. From this list, we screened papers based on titles and abstracts and excluded studies that were not related to interactions between TLs and biodiversity, obtaining a list with 596 studies. In that step we excluded, for example, all studies that evaluated impacts on humans (e.g. influence of electromagnetic field on human health). Remaining criteria for study exclusion at this phase are specified in the review flowchart (Supplementary material 1).

The second screening phase started after attempting to obtain the full text version of each paper, which resulted in 563 articles. We only selected papers that assessed the impacts caused by transmission lines, and we ended up with 202 studies. We excluded experiments in controlled environments that tested for the magnetic field, studies that looked at damages to line structures (even if caused by the biota, since we were interested in impacts caused to the biota), and studies that focused on methods for RoW maintenance. We assessed reviewer bias on exclusion criteria using the Kappa analysis (0–1 variation, Cohen, 1960) at the end of the first and second screening stages with a random subsample of 20% of the articles in each step. Application of criteria was discussed, and articles reassigned until a minimum index of 0.8 of the agreement was obtained and thereafter adopting the first author's classification. After the second trial, we applied the snowballing method (as in Kabisch et al., 2015), and verified citations and references of the 100 most recent studies selected, adding four studies to our review.

For each of the 206 selected scientific papers (see Supplementary Table S1) we looked for the study year, the targeted taxa, if the studied species was endangered according to study authors, the biotic response studied, and the nature of the biotic impact (negative, positive, neutral