Wildlife and power lines

Guidelines for preventing and mitigating wildlife mortality associated with electricity distribution networks

Editors: Justo Martín Martín, José Rafael Garrido López, Helena Clavero Sousa and Violeta Barrios

INTERNATIONAL UNION FOR CONSERVATION OF NATURE

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Foreword

Climate change and biodiversity loss have become an existential threat facing our planet, each exacerbating the effects of the other. While there is consensus on the leading causes, mainly human activities including the burning of fossil fuel and deforestation, the solutions are also becoming apparent.

In order to reach the goals of the Paris Climate Agreement and limit global warming to 1.5°C, thereby avoiding the most catastrophic effects of climate change, we humans must attain carbon dioxide emissions of net zero by 2050. Reducing CO_2 emissions from energy generation will be imperative, even as significant numbers of people across the globe do not yet have access to electricity.

Using renewable energy is one of the most effective and readily available ways of reducing CO_2 emissions, while increasing the availability of energy. A combination of renewable energy, mostly from wind and photovoltaic solar with more electrification to substitute fossil fuel use, could deliver three-quarters of the required energy-related emissions reductions. In addition, if we are to include communities that have previously been left behind on this journey to cleaner, greener energy, we will need to construct more transmission and distribution lines.

As we move to embrace renewable energy, it is crucial that mistakes from the fossil fuel era are not repeated and that they are mitigated going forward. We must avoid permitting poorly managed expansion of renewable energy generation to cause additional loss of biodiversity and disruption to ecosystem services on which we all depend.

The much-needed transition to renewable energy can be done in a manner that not only avoids harm to biodiversity but also promotes conservation. To achieve this outcome, however, it will require support from all decision makers at every stage of planning and implementation.

Within this framework, the need for technical guidelines is clear, both in terms of the identification of elements that make infrastructure dangerous for species and the environment, and in regards to the promotion of best practice to avoid and minimise

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impacts. To deal with this from a global and multi-institutional perspective, IUCN works to strengthen cooperation and dialogue between stakeholders and develop new guidance and tools for the industry. With the support of civil society and regulators, IUCN is helping businesses demonstrate the benefits of a biodiversity net gain goal in and around their operations. By applying avoidance and mitigation approaches, businesses can often scale-up their contribution to biodiversity conservation and society. Since 2015, the IUCN Centre for Mediterranean Cooperation (IUCN-Med) has been developing several activities for the conservation of threatened birds of prey in the region, involving actors from all sectors with a particular emphasis on their main threats: collision and electrocution with energy infrastructure. This manual sets the stage for a series of future publications on the solutions to different problems that the development of the energy sector poses to biodiversity conservation.

By providing the best available information on power lines management, this publication is a crucial tool for electricity companies, regulators and other stakeholders in ensuring that power lines are able to supply electricity as we drive towards a low carbon and sustainable future – one that avoids harming and instead embraces biodiversity.

Chris Buss

Director, IUCN Centre for Economy and Finance

Executive summary

The state of well-being and socio-economic progress achieved by modern societies is largely based on electricity. Ensuring that everyone has access to it is a priority in order to achieve a fairer and more egalitarian society. Over the last decade, access to electricity has expanded and energy efficiency has improved, in line with Goal 7 of the United Nations Sustainable Development Goals (Affordable and clean energy), but progress in supplying this basic necessity has not yet reached all regions and millions of people are still without electricity. Globalising electrification for all involves developing the necessary infrastructure to produce this type of energy and transport it from production centres to final consumers. For this, an efficient electricity grid is essential. In fact, a lot more electricity infrastructure will be required and some of the existing infrastructure will need to be modernised if current socio-economic development policies around the world are to be implemented.

Moreover, promoting renewable energies, which are essential to halt climate change and to meet the commitments of the Paris Climate Change Agreement, means new power plants must be constructed and new power lines added to the ones that already exist. However, as with all other infrastructure development, electricity grid expansion is likely to have environmental costs; the scale of the impacts caused will depend on the effort put into avoiding, minimising or remedying them. Even 'clean' energy-related infrastructure is not exempt from generating adverse effects on nature, especially in sensitive or protected areas. Given that the existence and development of power lines is inevitable, it is essential to ensure that they can coexist with biodiversity by doing everything possible to prevent unacceptable costs to the environment. Nevertheless, the reality is that development of the electricity grid often takes place without consideration of many of its potential negative effects on nature.

When poorly planned and managed, electric power lines can have major consequences for the environment, leading to biodiversity loss, habitat modification and degradation and disruption of landscape connectivity. Their best-known impacts are probably those related to their direct interactions with fauna, since it is estimated that every year they cause the deaths of millions of birds and other animals, including mammals, through electrocution and collision with wires. These hazards lead to high fatality rates across a wide range of species. Birds of prey are among the groups most

Figure 1. The promotion of renewable energies, essential to halt climate change, means new power plants must be constructed and new power lines added to those that already exist. Wind farm in Spain and its associated power line. © Justo Martín

seriously affected: electrocutions have been documented in more than 70 raptor species and millions of raptors are estimated to have been killed in collisions with overhead lines around the globe. Of special concern are the impacts on imperilled species that are already considered vulnerable because of their poor conservation status. Studies indicate that electrocution and collision are the main causes of decline for several such species (and sometimes for several populations and subpopulations of these species), whether they are resident in the areas crossed by power lines, overwintering there, or passing through during migration or dispersal. The effects are ubiquitous and may occur wherever electric power lines have been poorly designed or do not have appropriate mitigation measures in place. Far from improving, the situation is getting worse as electricity production and consumption increase worldwide and spread to remote areas, without in many cases taking into account the associated potential risks that power lines pose to many species.

Conversely, wildlife interactions with electric power lines (especially electrocutions, but also nesting) are also an issue for electricity companies and can be costly and disruptive, since they cause power outages, damage to equipment and fires. That is why it is also in the companies' interest to avoid adverse interactions between power lines and biodiversity. Consequently, risk analysis, prevention and minimisation should be important aspects of their operations and should be considered throughout the lifecycle of all infrastructure projects.

Figure 2. Power lines have become a common element in ecosystems, and wildlife interactions with them are often harmful. Power lines in Spain. © Justo Martín

The transition towards a clean, fair, efficient, safe and sustainable energy system will only be possible if all the relevant actors collaborate and take steps to avoid any potential damage to nature. The challenge of balancing the development and provision of electricity supply with species protection must be taken up by all parties: the electricity companies as well as project financial institutions, governments, relevant authorities and all the decision makers involved at every stage of planning and implementation. The conservation community and civil society in general can and should play a very important role in safeguarding biodiversity too, by demanding that electricity infrastructure and supply systems are safe for wildlife and respectful of the environment. Likewise, further scientific research, both privately and publicly funded, is needed to produce the information on which decisions should be based – on the species and habitats potentially affected, on the impacts that are already occurring and on new technologies and products to better prevent electrocutions and collisions. Major efforts should be directed towards data-poor regions where the extent of the impacts and the conservation status of habitats and species are not adequately known.

Given the vital role of power lines for social development, the rapid spread of such infrastructure worldwide and the fact that power lines can be one of the main causes of direct mortality for several species of birds and other wildlife, including mammals, it is essential to have suitable tools to ensure that these lines are built and maintained in accordance with environmentally friendly principles, and that priority is given to avoiding and reducing negative impacts.

This manual is intended to be a technical guide for use by all stakeholders, from companies and businesses in the energy sector – including project developers, distribution and transmission system operators and their technicians – to authorities and government planners, investors and civil society. It contains recommendations and standard good practices for avoiding the adverse effects of new power lines and managing risks early in the process, so as to ensure that infrastructure expansion takes account of biodiversity in the spatial planning and early project implementation phases, when they will be most effective. In the case of existing dangerous and poorly designed power lines, the negative impacts that they may be generating must be analysed and addressed promptly; these guidelines also provide information on the best technical solutions available. The manual also includes a round-up of the current state of affairs and practical solutions that have been shown to significantly reduce wildlife fatalities, all contributed by experts from around the world. The construction of electric power lines using safe design principles for wildlife and the fitting of anti-electrocution insulating materials and marking devices that increase cable visibility are measures that, if implemented correctly, drastically reduce the risks both for fauna and for the line operators.

We are firmly convinced that, with the commitment and collaboration of the electricity companies and all the other actors involved, power lines can fulfil their function of supplying electricity throughout the world as part of a system of clean, renewable energy, and at the same time it is possible to ensure that they can coexist with the wildlife of the areas where they are located, helping to generate positive results for both people and nature.

Figure 3. This document provides information on the most effective preventative and mitigating measures for cutting negative interactions between wildlife and power lines to a minimum. Power lines and white storks (*Ciconia ciconia*). © Justo Martín

About these guidelines

Scope and objectives

These guidelines aim to provide the best available information on effective power line management from around the globe to appropriately inform decision making and to reduce negative impacts on land use, landscapes, ecosystems and species. The main objective is to disseminate information on the most effective measures to reverse the current situation, notably preventative and mitigating measures, which should be implemented as part of conservation strategies and planning processes at all levels, from international to local. This manual offers an overview of the issue, its causes and its consequences, and discusses the various approaches for dealing with the problem with the aim of promoting awareness and prevention and seeking solutions wherever possible. It is intended for all stakeholders involved in electricity production and distribution and in biodiversity conservation – developers, funders, planning authorities, electricity companies and civil society. The text includes guidelines for identifying and monitoring dangerous power lines and suggests how they should be modified to be safe for wildlife. It also provides information on creating safe electricity infrastructure, avoiding damage and loss of biodiversity through the early planning of energy infrastructure deployment, and locating problematic areas by means of sensitivity mapping tools.

How to use these guidelines

The first part of the manual deals with the following topics:

- Basic concepts and terminology regarding electric power lines; essential technical information for understanding the causes of the problem and its possible solutions;

- The impacts of electric power lines on wildlife and ecosystems, the causes of electrocutions and collisions, constraints, and the identification of risks, including the most effective preventative and corrective measures;

Figure 4. We need to improve our knowledge of the impacts of power lines on wildlife. In the case of new lines, the planning phase is critical to minimise impacts on biodiversity and to ensure their sustainability. Power line in Canada. © Íñigo Fajardo

- Characterisation of the groups of species that are most vulnerable to the impacts of power lines, identifying the features that make them susceptible, and which species are a priori most likely to be affected;

- Diagnosis and assessment of wildlife mortality caused by electric power lines, identifying the signs that allow for proper diagnosis of the cause of death to provide an accurate assessment of current mortality;

- The most appropriate protocols and procedures for collecting and analysing information on dangerous power lines, including database creation, preparation of sensitivity and risk maps and identification of priority areas for prevention and action;

- The bases for drawing up an action plan to tackle the problem from an effective overall perspective, with a view to national and regional solutions.

After this first part, the manual continues with a compilation of case studies written by international experts, providing the first systematic assessment of the current situation on the ground across five continents. Sharing positive and negative experiences from around the world in this way is intended to initiate a forum in which stakeholders can continuously evaluate the situation and exchange knowledge and experience.

Appendices to the manual contain a guide to the identification of dangerous power lines that kill wildlife. The guide contains data sheets for each known type of dangerous support and line, including a description, an explanation of the dangers and recommended corrective measures, as well as examples where measures have been implemented and images of each type of tower or pole. The appendices also include an explanation of how new power lines should be designed in order to avoid any danger to wildlife, together with structural and procedural recommendations.

This survey of the diversity of power lines takes a broad approach, including as many different line and support designs as possible from around the world. However, information on existing types is fragmentary and some designs may have been missed, despite the authors' best efforts. The wide variety of types and options presented will make it relatively straightforward to characterise other types not listed here, together with the dangers they pose and the most appropriate corrective measures. The guide may therefore be used to assess how dangerous each type is and to support stakeholders in deciding which to choose or reject. The guide also provides the first global assessment of the risks of power lines to other fauna besides birds (especially primates and other mammals) and how to eliminate or at least mitigate them.

Key messages

➔ We need to improve our knowledge of the impacts of electric power lines on wildlife and devote substantial efforts to identifying existing high-mortality hotspots and making them safe.

➔ In the case of new power lines, the planning phase is critical to minimise impacts on biodiversity and to ensure their sustainability. Installation should be avoided in sensitive areas such as migration routes or areas where threatened species occur; if this is not possible, the paths and designs of new lines must be carefully assessed to ensure minimum impact.

➔ The selection and implementation of actions to avoid or minimise impacts must involve scientific experts and conservationists who know the groups of wildlife potentially affected. To guarantee success, it is essential to have the support and collaboration of all stakeholders (energy companies, governments, civil society), so that appropriate work can be carried out to solve problems in the field.

➔ The problem and its solutions obey the same principles everywhere, but mitigation measures need to be targeted specifically at the species that are most sensitive and suffer the greatest impacts at local level; a measure may be necessary in one place but completely useless in another. Additionally, the technical and economic possibilities of each location must be taken into account to make the best possible use of the available resources and efforts.

Figure 5. Mitigation measures need to be targeted specifically at the species that are most sensitive and suffer the greatest impacts at local level. Wedge-tailed eagle (*Aquila audax*) and power pole in Tasmania. © Peter Thorpe

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Glossary of key terms used in this publication

adult a bird that has acquired its final plumage.

air gap the empty space or ‘window’ around conductors on a steel transmission structure. This empty space provides insulation for the conductors. A fault can occur when something bridges all or a sufficient portion of the air gap between the steel tower and an energised conductor.

AMPACT metal wedge clamps used to connect the conductors on a jumper.

ampere unit measure of current.

anchor clamp clamp attaching a jumper wire to a conductor.

anti-perching devices elements that stop birds perching or make it harder for birds to perch on dangerous parts of a crossarm on an electric pole.

arm one of the elements or crosspieces that make up the crossarm.

avian-safe a power pole configuration designed to minimise avian electrocution risk by providing a separation between energised conductors or phases and grounded hardware that is larger than the wrist-to-wrist or head to-foot dimension of a bird. If such separation cannot be provided, exposed bare parts are covered to reduce electrocution risk, or anti-perching devices are installed’.

bushing (transformer) insulator inserted in the top of a transformer to isolate the electrical leads of the transformer.

catenary curve created by the cable between two poles.

circuit (single) a conductor or system of conductors through which an electric current is intended to flow. The circuit is energised at a specified voltage.

circuit (multiple) a configuration that supports more than one circuit.

conductivity the capacity to transmit electrical energy.

conductor wire or cable that carries an electric current, usually made of copper or aluminium.

configuration the arrangement of parts or equipment. A distribution configuration would include the necessary arrangement of crossarms, braces, insulators, etc. to support one or more electric circuits.

crossarm upper part of a pole or pylon used to support electrical conductors and equipment for distributing electrical energy. It is made of wood, fibreglass, concrete or steel and can have different configurations and lengths.

current a movement or flow of electricity passing through a conductor. Current is measured in amperes.

de-energised the state of any electrical conducting device disconnected from all sources of electricity.

disconnector the most commonly used switching device. In single-phase circuits, single-pole disconnectors are used (see Figure 36) and three-pole disconnectors are used in three-phase circuits. They include a variable number (two or three per phase) of polymer or glass insulators, and can be mounted in a vertical position on the crossarm or suspended from it.

distribution line circuit of low, medium or high-voltage wires, usually energised at voltages below 66 kV (although sometimes higher), used to distribute electricity from distribution substations to end consumers.

cable earthing see ground wire.

ecotone areas transitional areas between two ecosystems with a mix of environmental characteristics from each one.

electric arc electric current passing between two conductors through a non-conducting medium like air when the difference in electrical potential between the conductors exceeds a certain value.

electroporation generalised cell disorganisation with a loss of consistency and muscular structure caused by the sudden high temperature due to electricity passing through the tissues when a bird is electrocuted. In these cases, there are white spots with a viscous appearance on the skin of the legs.

EMF electromagnetic field created by power lines.

energised the state of any electrical conducting device connected to any source of electricity.

fault a power disturbance that interrupts the quality of electrical supply, for example caused by fires, storms, lightning, animal electrocutions, etc.

fledgling a bird that has recently left the nest and may still be dependent on its parents for food.

fuse-switch-disconnector (cut-out fuse) device that allows for switching while at the same time protecting against power surges and short circuits (see Figure 31). It often replaces a disconnector.

fused cutouts electrical switches fitted with a fuse, so that the switch will open when the current rating of the fuse is exceeded. Fused cutouts are used to protect electrical equipment and circuits from lightning and short-circuit caused by wires, wind, animals or conductive equipment of all kinds.

generation plant a facility that generates electricity.

ground an object that makes an electrical connection with the earth.

ground wire wire that makes an electrical connection with the earth and therefore is at ground potential.

high voltage voltage from 36 to 132 kV (according to the International Standard of the International Electrotechnical Commission (IEC 60038), although these values may vary depending on the country).

insulator nonconductive material in a form designed to support a conductor physically and to separate it electrically from another conductor or object. Insulators are normally made of porcelain, glass or polymer. They are deployed singly (**single insulator**) or, more frequently, in several units making up an **insulator string**.

jumper wire, jumper cable or jumper a conductive wire used to connect types of electrical equipment and to ensure the continuity of electrical conductors where the line changes direction (e.g. at angle poles, dead-end poles).

junction box connection structure in which a bare overhead cable goes into the insulated ground, which takes place in transformers.

juvenile young bird in its first year of life.

kilovolt 1,000 volts, abbreviated kV.

lightning arrester an electrical protection device used to divert the energy of lightning strikes to earth.

line markers types of marking device used to reduce collisions between birds and power lines.

low voltage voltage ≤ 1 kV (according to IEC 60038, although this value may vary depending on the country).

mast see support.

medium voltage voltage from 1 to 35 kV (according to IEC 60038, although these values may vary depending on the country).

metacarpal bones a bird's 'wrist'.

metapopulation a regional group of connected populations of a species.

nest substrate the base upon which a nest is built, e.g. cliffs, trees, ground, power poles, boxes, platforms, etc.

neutral conductor a conductor or wire that is at ground potential, i.e., ground wire.

outage event that occurs when the energy source is cut off from the load.

perimortem injuries injuries produced immediately after death when the blood is still circulating.

phase an energised electrical conductor.

phase to ground (**or phase to earth**) contact from an energised phase conductor to ground potential. A bird can cause a phase-to-ground fault when fleshy parts of its body (or its bill or wet wing or tail feathers) touch or are connected by an electric arc to an energised phase and ground simultaneously.

phase to phase contact between two energised phase conductors. A bird can cause a phase-to-phase fault when the fleshy parts of its wings or other body parts (including bill or wet feathers) touch or are connected by an electric arc to two energised phase conductors at the same time.

pin insulator insulator installed on top of the crossarm (see Figure 34).

pole a support comprising a single member. It can be made of wood, fibreglass, concrete or steel.

polymer insulators insulators made of polymer material that prevent electricity from passing to a metal crossarm on a pole. These insulators have a specially designed shape to prevent birds landing on them or they are accompanied by structures that stop them landing.

population a subset of individuals of one species that occupies a particular geographic area and, in sexually reproducing species, interbreeds.

power line a combination of conductors used to transmit or distribute electrical energy, normally supported by poles or towers.

primary feathers also called primaries. The 10 outermost flight feathers of the wing that meet at the wrist to form the 'hand' of the wing.

problem pole a pole used by birds (usually for perching, nesting or roosting) that has electrocuted birds or poses a high electrocution risk.

pylon a lattice steel tower. See support.

raptor-safe see avian-safe.

retrofitting the modification of an existing electric power line structure to make it avian-safe.

sag distance between the point where a straight line passes through the fixation points of a conductor on two successive pylons and the lowest point of the same conductor.

sensitivity mapping tools geographical tools for regional planning to guide decision making on the siting of energy developments; they are the first step in helping identify sensitive areas in which to avoid building infrastructure that is dangerous for affected species or to prioritise areas where impact mitigation work can be carried out.

separation or **spacing** the physical distance between conductors and/or ground wires.

span distance between successive pylons.

strain insulator insulator attached to the crossarm in a horizontal direction, carrying the conductor and supporting the line under tension (see Figure 34).

streamer a jet of excrement produced when large birds defecate.

structure a pole or lattice assembly that supports electrical equipment for the transmission or distribution of electricity.

subadult a bird aged between juvenile and adult.

subpopulation a subset of a larger population.

substation a transitional point (where voltage is increased or decreased) in the transmission and distribution system.

support a vertical structure that keeps the electrical conductors and equipment sufficiently high above the ground for the purpose of transmitting or distributing electrical energy. It can be made of wood, fibreglass, concrete or steel.

surge arrester synonymous with lightning arrester.

suspension insulator insulator suspended beneath the crossarm (see Figure 34).

switch or switching device an electrical device used to sectionalise electrical energy sources.

tension member the member in steel lattice towers that supports the crossarm from above.

terminal end point of a power line.

tower a support, often of steel lattice construction.

transformer a device used to increase or decrease voltage.

transmission line a circuit of high-voltage wires, usually energised at voltages above 60 kV, used to carry electricity from power plants to distribution substations.

very high voltage voltage > 132 kV (according to IEC 60038, although this value may vary depending on the country).

volt the measure of electrical potential.

voltage electromotive force expressed in volts.

wrist joint in the middle of the leading edge of a bird's wing. The skin covering the wrist is the outermost fleshy part of a wing.

Acronyms

AEWA	Agreement on the Conservation of African–Eurasian Migratory Waterbirds
AMPOVIS	Association Marocaine de Protection des Oiseaux et de la Vie Sauvage (*Moroccan Association for the Protection of Birds and Wildlife*)
AMPR	Association Marocaine pour la Protection des Rapaces (*Moroccan Association for Raptor Protection*)
ANEF	Agence nationale des eaux et forêts (*National Water and Forests Agency*)
APLIC	Avian Power Line Interaction Committee
ASARA	Association des Amis des Rapaces (*Association of Friends of Raptors*)
BSI	bird strike indicator
CAD	Centro de Análisis y Diagnóstico de la Fauna Silvestre (*Wildlife Analysis and Diagnosis Centre*)
CAGPDS	Consejería de Agricultura, Ganadería, Pesca y Desarrollo Sostenible (*Regional Ministry of Agriculture, Livestock Production, Fisheries and Sustainable Development*)
CBD	Convention on Biological Diversity
CECARA	Centro para el Estudio y Conservación de las Aves Rapaces en Argentina (*Centre for Raptor Research and Conservation in Argentina*)
CEMAVE	Centro Nacional de Pesquisa e Conservação de Aves Silvestres (*National Center for Bird Conservation and Research*)
CIBIO	Centro de Investigação em Biodiversidade e Recursos Genéticos (*Research Center on Biodiversity and Genetic Resources*)
CMS	Convention on Migratory Species
CNFL	Compañía Nacional de Fuerza y Luz (*National Power and Light Company*)

CONAGEBIO	Comisión Nacional para la Gestión de la Biodiversidad (*National Biodiversity Management Commission)*
CONICET	Consejo Nacional de Investigaciones Científicas y Técnicas (*National Science and Technology Research Council*)
CSIC	Consejo Superior de Investigaciones Científicas (*Spanish National Research Council*)
DEF	Département des Eaux et Forêts (*Department of Water and Forests*)
EIA	environmental impact assessment
EPRI	Electric Power Research Institute
ESPH	Empresa de Servicios Públicos de Heredia (*Heredia Public Services Company*)
ETF	Energy Task Force
EU	European Union
EWT	Endangered Wildlife Trust
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic Information System
GOMAC	Groupe d'ornithologie du Maroc (*Moroccan Ornithology Group*)
GPS	Global Positioning System
GREFA	Grupo de Rehabilitación de la Fauna Autóctona y su Hábitat (*Group for the Rehabilitation of Indigenous Fauna and its Habitat)*
GREPOM	Groupe de Recherche Pour la Protection des Oiseaux du Maroc (*Research Group for the Protection of Birds in Morocco*)
GSM	Global System for Mobile Communications
HCEFLCD	Haut Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification (*High Commission for Water, Forest and Fight against Desertification*)
IBA	Important Bird Area
IBAT	Integrated Biodiversity Assessment Tool
IBPLC	Iran's Birds and Power Lines Committee
ICBP	International Council for Bird Protection
ICMBio	Instituto Chico Mendes de Conservação da Biodiversidade (*Chico Mendes Institute for Biodiversity Conservation*)

IEA	International Energy Agency
IEC	International Electrotechnical Commission
INCITAP	Instituto de Ciencias de la Tierra y Ambientales de La Pampa (*La Pampa Institute of Earth and Environmental Science*)
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
IUCN-Med	IUCN Centre for Mediterranean Cooperation
MBZRCF	Mohamed bin Zayed Raptor Conservation Fund
MINAE	Ministerio de Ambiente y Energía (*Ministry of Environment and Energy*)
MME	Magyar Madártani *és* Természetvédelmi Egyesület (*Hungarian Ornithological and Nature Conservation Society*)
NGO	non-governmental organisation
NRECA	National Rural Electric Cooperative Association
NSW	New South Wales
ONEE	Office National de l'Électricité et de l'Eau Potable (*National Office for Electricity and Drinking Water*)
OPGW	optical ground wire
PVC	Polyvinylchloride
RRRCN	Russian Raptor Research and Conservation Network
SEA	strategic environmental assessment
TSO	transmission system operators
UAS	unmanned aircraft systems
UNEP–GEF	United Nations Environment Programme–Global Environment Facility
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USFWS	United States Fish and Wildlife Service
USSR	Union of Soviet Socialist Republics
UTM	Universal Transverse Mercator
VCF	Vulture Conservation Foundation
WWF	World Wide Fund for Nature

1 Introduction

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1.1. CONTEXT

Figure 6. Enabling the entire population to have access to electricity is key to achieving high levels of well-being and equal opportunities in our societies. Power lines in Ethiopia. © Helena Clavero

The production of energy and its consumption for various purposes is one of the foundations of modern societies. As human populations and development expand, energy demand is increasing globally.

Electricity is one of the main types of energy we consume and there is no doubt that enabling the entire population to have access to it is key to achieving high levels of well-being and equal opportunities in our societies (Figure 6).

Energy consumption by human beings has numerous impacts on ecosystems and is detrimental to many species. These impacts can be more or less local, such as those caused by the direct extraction of fuel and raw materials (coal, oil, natural gas, etc.) or the use of land for energy infrastructure (dams for hydroelectric production), or global in the case of increased emissions of gases into the atmosphere and climate change.

These impacts include those associated with electric power lines, since the use of electric energy requires an effective distribution system between production sites and consumers consisting of a dense network of power lines.

Figure 7. Linear infrastructure has fragmented and degraded at least 75% of the terrestrial environment. Power line crossing and fragmenting a riparian forest in Spain. © Justo Martín

Linear infrastructure (roads, railways, navigable channels, waterways, canals, power lines and pipelines) is currently one of the main areas of conflict between socio-economic development and nature conservation, with more than 100 million kilometres around the planet (Figure 7). Linear infrastructure of all kinds has fragmented and degraded at least 75% of the terrestrial environment, so it is urgent to ensure that infrastructure development is sustainable and safe for both humans and biodiversity (Georgiadis, 2020).

Figure 8. Electric power lines form part of current landscapes. It is estimated that there are over 65 million km of power lines in use around the world. Landscape in Mongolia. © Mongolian Bird Conservation Center

Power lines are widespread in our landscapes and in many places it is almost impossible to see an open horizon without pylons or cables, even in uninhabited areas (Figure 8). **It has been estimated that in the first decade of the 20th century there were over 65 million kilometres of medium- and high-voltage power lines in use around the world**, rising at a rate of 5% each year (Jenkins et al., 2010) especially in growing world economies. This figure is even higher today, given the increased electricity generation associated with new wind and photovoltaic power farms and other renewable sources. These are made inevitable by the change in energy model that is underway, conditioned to a large extent by the necessary fight against climate change. According to forecasts by the International Energy Agency (IEA), 2 million km of transmission and 14 million km of distribution lines will be added over the next 10 years, 80% more than the network expanded over the past decade (IEA, 2020).

Climate change and biodiversity loss are the biggest challenges facing humanity since they are destabilising the whole planet. Climate change itself is a great threat to biodiversity through species extinction and is among the five most significant drivers of nature destruction (UNFCCC & IPBES, 2019). Without immediate action to reduce greenhouse gas emissions there will be devastating consequences for humans, in addition to risking the extinction of thousands of species (Thomas et al., 2004). The deployment of more renewable energy (replacing high-emission technologies) and its infrastructure will help decrease the overall threat to biodiversity if correctly planned. Consequently, electricity infrastructure must be part of the solution to fight climate change, although it also has an impact that needs to be appropriately addressed (Figure 9).

Figure 9. The development of renewable energies as a means to combat climate change leads to an increase in electricity infrastructure. Photovoltaic solar plant and associated power lines. © Justo Martín

Electric power lines can lead to biodiversity loss, pollution and degradation of the environment through their various impacts on the ecosystems they cross, resulting in high economic costs (Biasotto & Kindel, 2018; see Chapter 3). They have a significant visual impact on landscapes and transform natural habitats, creating a barrier effect for some animal species. They also create an electromagnetic field and noise pollution around them and contribute to air pollution, because there is a higher risk of forest fires nearby because of short circuits (FAO, 2001; Keeley et al., 2011; Cruz et al., 2012; Mitchell, 2013; Syphard & Keeley, 2015; Guil et al., 2018). But the best-known impacts are probably those involving interactions with fauna. These may be beneficial, favouring certain species such as by allowing birds to nest, perch and roost on pylons (Figure 10), or harmful, resulting in the death of individuals, mainly through electrocution and collision (see Chapters 3, 4 and 5).

Figure 10. Power lines may be beneficial to certain wildlife species by allowing birds to nest, perch and roost on pylons. Red-necked falcons (*Falco chicquera*) on a 220 kV tower in India. © Pranay Juvvadi

Although data shows that large bird species are most impacted by electrical infrastructure, there are hundreds of records of other groups, such as mammals (mainly primates) and even reptiles, amphibians and invertebrates (see Chapters 3 and 5 and Case studies 2, 4 and 16).

The intensity of this impact is not uniform and varies enormously depending on the different environments and species present. **Birds of prey are among the groups most seriously affected; electrocutions have been documented in more than 70 raptor species worldwide** (Hunting, 2002; Lehman et al., 2007). Similarly, avian collisions with overhead lines are a global phenomenon killing millions of raptors around the globe. Such incidents contribute to the decline in populations and subpopulations of some species with poor conservation status, whether they are resident in areas crossed by power lines, overwintering there or passing through during migration or dispersal, and they affect both juveniles and adults (Ferrer, 2012; Bernardino et al., 2018; Eccleston & Harness, 2018; Uddin et al., 2021; see also Chapters 3 and 4 and the Case studies in Chapter 9).

This impact is ubiquitous and may occur wherever in the world there are electric power lines. It has been documented, for example, in threatened European raptors wintering in North Africa (see Case study 1) and in migratory birds from other countries that were electrocuted in China (see Case study 6). Some estimates based on observed data indicate that more than 100 million birds die every year in North America (Loss et al., 2014), with several million more in Europe (Prinsen et al., 2011a) and around 10 million per year in Russia (Matsyna & Matsyna, 2011), to give just a few examples. Considering that avian electrocution has undoubtedly been underestimated in other parts of the world (see several of the Case studies), the numerical magnitude of the conservation problem is evident.

While interactions with electric power lines are one of the main threats to certain species, these interactions (especially electrocutions, but also nesting) are also an issue for electricity companies and can be costly and disruptive, causing supply faults and damage to equipment (NRECA, 1996; EPRI, 2001; Barret, 2002). However, despite the large amount of information about bird electrocutions and collisions on power lines, and the many positive steps taken by power companies, bird electrocutions and collisions are still abundant (Figure 11).

Figure 11. Despite the positive steps taken by power companies, bird electrocutions and collisions are still abundant. White stork (*Ciconia ciconia*) after collision. © Justo Martín

Although the environmental damage that power lines cause poses an evident threat and measures to minimise their impact on affected species should be applied without exception, there are still many areas where adequate measures are not taken to prevent these impacts. Today, there is the scientific, engineering and industrial capacity to implement prevention and mitigation measures, which would help conserve animal populations and halt the loss of biodiversity (Figure 12). All actions to protect animals against electrocution must be accompanied by preventative, mitigating and corrective measures, which can only be carried out by electricity companies. Thus, it is essential to secure the involvement of this industrial sector in the programmes to conserve and protect affected species, especially threatened species.

Figure 12. There is the scientific, engineering and industrial capacity to implement effective prevention and mitigation measures. Pylon retroffited with different types of insulation devices. © Justo Martín

Figure 13. Bonelli's eagle (*Aquila fasciata*) occurs on both shores of the Mediterranean. © Íñigo Fajardo

To address this problem and the need for solutions, several international treaties target the protection of birds and other affected species on power lines and many countries around the world have been implementing corrective measures on dangerous power structures for several decades (see Case studies). There are two main models for reconciling the increase in the electricity network and its impact on wildlife with biodiversity conservation issues. On the one hand, several countries have protected species through laws regulating the construction of power lines to make them safer for most affected species, invoking the polluter-pays principle if electrocutions and collisions are not avoided, including penalties for violating these laws. On the other hand, some governments and NGOs have been working collaboratively with electricity companies to identify dangerous power lines, modify them and install new wildlife-friendly power lines. Both models have proved useful in some areas, helping threatened populations to recover, but millions of dangerous pylons where wildlife can be electrocuted and millions of kilometres of lines with which birds collide still claim untold numbers of victims.

In this context, over the last few years IUCN-Med has worked on a series of activities aimed at promoting cooperation between the various stakeholders involved in the conservation of raptors in the Mediterranean, focusing in particular on the effects of electric power lines on these birds (see for example Case studies 1 and 17). The Mediterranean Basin contains a rich community of raptors. Numerous species occur on both shores and are thus spread out in metapopulations between southern Europe and North Africa. The connection between the different subpopulations is without doubt a great advantage for their conservation (Figure 13).

Figure 14. The Guelmim–Oued Noun region in south-western Morocco, where specialists from IUCN-Med, the Autonomous Government of Andalusia and Morocco discovered a major electrocution black spot in 2016. © Daniel Burón

Electricity infrastructure must be part of the solution to fight climate change, although it also has a variety of impacts that needs to be appropriately addressed; the best-known are probably those involving interactions with fauna through electrocution and collision.

Figure 15. In Guelmim, 70 electrocuted birds belonging to seven different species were found during an inspection of just over 400 pylons. Electrocuted white stork (*Ciconia ciconia*). © Daniel Burón

Figure 16. Participants in the workshop on electricity infrastructure and birds held in Tunisia in 2022. © Hichem Azafzaf

In 2016 a major electrocution mortality black spot was found in south-western Morocco, thanks to collaboration between the Action Plan for the Spanish Imperial Eagle in Andalusia, IUCN-Med and the Kingdom of Morocco (Figures 14 and 15; Godino et al., 2016). This discovery led to the organisation in 2016, 2017 and 2018 of specific training courses for stakeholders (government authorities, electricity companies and NGOs) in North Africa on identifying and mitigating the impact of electricity infrastructure on the avifauna (Figure 16). In 2019, to provide a tool to address this conservation problem, IUCN-Med published a practical guide to the identification and prevention of dangerous power lines to birds (Martín Martín et al., 2019), which provided the basis for this manual.

At the same time, to determine the real extent of this threat to raptor populations in North Africa, IUCN-Med has developed several initiatives to locate dangerous power lines and to inventory and monitor breeding raptor populations (UICN & DEF, 2020) and to draw up the North African Red List of breeding raptors (Garrido et al., 2021).

1.2. TARGET AUDIENCE AND OBJECTIVES

In view of the worldwide effect of power lines as a major cause of non-natural mortality for various species of birds (Lehman et al., 2007; Jenkins et al., 2010) and other groups such as mammals, **this guide is intended for all stakeholders involved in electricity production, transmission and distribution, and in biodiversity conservation: project developers, funders, planning authorities, electricity companies and civil society**. It aims to provide the best available information from around the globe on effective power line management so as to avoid negative impacts on ecosystems, species, land use and landscapes.

The objective is not simply to raise awareness of the potential interactions between wildlife and power lines, but also to disseminate information on the most effective measures to reverse the current situation, notably preventative measures, which should be implemented as part of conservation strategies at international, cross-border and national levels. In other words, we hope to show how to design power lines that coexist in harmony with the animal species that occur on and above the land they cross, and to ensure that the lines have minimal impact on these species (Figure 17).

> *All the examples gathered here show that all over the world – from South Africa to Iran, Argentina to the United States, Australia to China or Spain to Russia – power lines cause a huge number of casualties among birds and some mammals, and adapting them to render them harmless will mark a turning point in the recovery of the populations affected.*

The chapters below include descriptions of dangerous power lines and recommendations for avoiding or mitigating their impacts contributed by prominent international experts. For the first time, this information is combined with a systematic assessment by local experts of the current situation on the ground across five continents, through case studies (Chapter 9). Sharing positive and negative experiences from around the world in this way is intended to initiate a forum in which stakeholders can continuously evaluate the situation and exchange knowledge and experience.

Another objective is to provide guidelines for identifying and monitoring dangerous power lines and to suggest how to modify them to make them safe for wildlife. **This survey of the diversity of power lines takes a broad approach, including as many different line and support designs as possible from around the world**. However, information on existing types is fragmentary and some types may have been missed, despite the authors' best efforts. The wide variety of types and options presented will make it relatively straightforward to characterise other types not listed here, together with the dangers they pose and the most appropriate corrective measures (Figure 18). The guide may therefore be used to assess how dangerous each type is and to support stakeholders in deciding which to choose or reject. **The guide also includes the first global assessment of the risks of power lines to other fauna besides birds (especially primates and other mammals) and how to eliminate or at least mitigate them**.

Finally, **the guide provides information on producing safe electricity infrastructure, avoiding damage and loss of biodiversity through the early planning of electrical infrastructure deployment, and locating problematic areas** by means of sensitivity mapping tools. These tools make it possible to develop regionally cohesive mitigation strategies to increase the effectiveness of mitigation measures, because they can be used to identify the most sensitive areas where infrastructure that is dangerous for affected species should not be built or to prioritise areas where impact mitigation work can be carried out. Accordingly, governments and electricity companies can use this guide when producing environmental impact assessments (EIAs) of power lines to determine areas where potential collisions and electrocutions might be expected and mitigation works should be implemented.

In summary, the guide has sought to collect existing information fom around the world on the impact of power lines on wildlife so that stakeholders can use the best remedial and proactive measures to minimise their impact on biodiversity and prevent animal mortality.

Figure 17. We must ensure that electric power lines coexist in harmony with the birds that fly over the land that they cross. Landscape with power lines in Algeria. © Lahouari Djardini and Amina Fellous-Djardini

Figure 18. This manual aims to characterise all the different types of electric power line. Power lines in India.
© Juan José Iglesias Lebrija

2

Energy and power lines

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2.1. ENERGY PRODUCTION AND TRANSMISSION

Electricity cannot be stored unless it is transformed. Small-scale generated electricity cannot be stored either, unless it is put in a battery, in the grid or transformed into something else. Therefore, consumption needs are covered by maintaining a constant balance with production. This balance is achieved through electricity grids, which link power generation plants to consumption points, often located hundreds of kilometres apart (Figure 19).

Figure 19. The high demand for electricity in modern society requires large generation plants. Coal power plant in Spain. © Justo Martín

The electricity supply system involves three separate activities:

- **Generation**, which transforms one form of energy – chemical, mechanical, thermal, light, etc. – into electricity.
- **Transmission**, which transmits the electricity from the point of production to the vicinity of the points of consumption.
- **Distribution**, which carries the electricity to the end consumers.

Most **generation** takes place in **power plants**, where electricity is produced through mechanical energy, which in turn is derived from other primary energy sources.

This mechanical energy normally comes from thermal energy that is used to heat water in order to produce high-pressure steam, which drives turbines where this mechanical energy is transformed into electrical energy. There are various types of power plant, which can be differentiated by the source of the heat used to turn the water into steam.

Figure 20. The generation of high-pressure steam to drive turbines is the most common means of producing electricity on a large scale. Solar thermal power plant in Morocco. © ONEE

In **thermal** power stations, the source of heat is coal, fuel oil, gas or even biodiesel. **Nuclear** power plants use the heat generated by the fission of uranium nuclei. In **solar thermal** power plants, the source of heat is solar energy, concentrated through a system of reflectors (mirrors) (Figure 20). Finally, **biomass** power plants use agricultural, forest and wood residues, while **waste-to-energy** plants operate using materials that are neither recycled nor reused.

In **hydroelectric** power stations, the potential energy of water is used. The height difference ('head of water') between the inflow and the outflow drives the turbines. In **wind farms,** wind energy is turned directly into electricity by a wind turbine connected to rotor blades.

A different case is that of **photovoltaic** power stations, which produce electricity through special structures, photovoltaic cells, capable of capturing sunlight and converting it into electricity by harnessing the photoelectric effect.

Today most of the world's electricity generation comes from burning oil or coal, despite the recent sharp increase in production from renewable sources all over the world.

In power stations, the electricity is generated with a voltage of 10 to 22 kilovolts (kV). The electricity produced is transmitted directly to a step-up transmission substation in order to achieve a voltage of between 66 and 400 kV or more, so as to optimise the transmission of electricity in the grid and minimise any losses that may occur as it moves through the power lines.

Electricity then passes through **transmission** lines until it reaches an area close to the points of consumption where step-down transmission substations are located. There, the voltage is stepped down to values of between 25 and 132 kV and the electricity is then transferred to **distribution** lines. The latter carry the electricity to **distribution substations** where the voltage is once again stepped down, this time to 3-30 kV (Figure 21).

The electricity is then sent to **transformers**, where the voltage is stepped down further to levels suitable for the end-users (100/240 V for domestic usage or 220/400 V for industrial usage) and the electricity is then distributed directly to the consumers. These transformers can be situated inside a building or construction, or outdoors on a power line. In the latter case they are known as power line transformers or overhead transformers.

Figure 21. In substations, the electricity from transmission lines is stepped down in voltage and then transferred to distribution lines. Substation in Morocco. ©ONEE

Within the system that transmits electricity from power stations to the final points of consumption, various **types of electric power line** can be distinguished according to their function and their voltage (Figure 22):

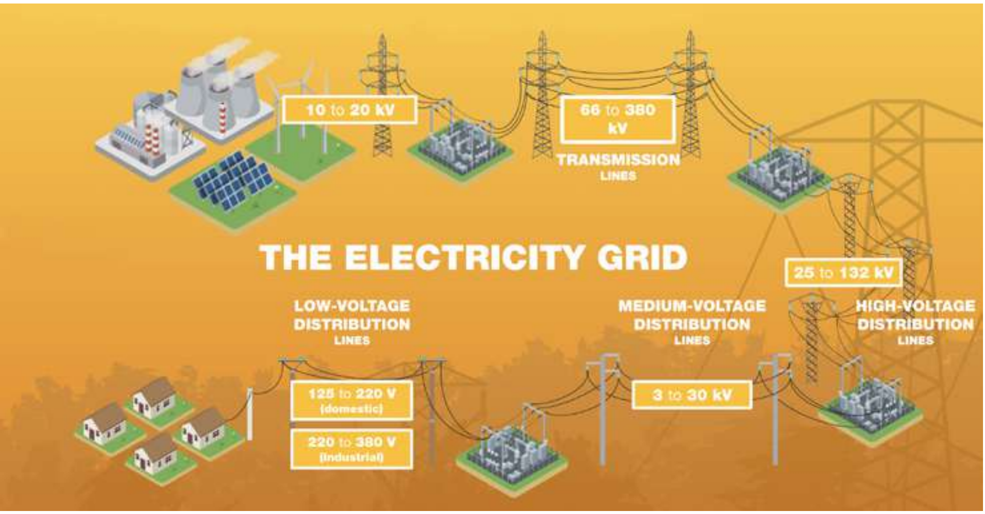

Figure 22. Electric power lines carry electricity from power stations to the points of consumption. Diagram of an electricity grid. ©IUCN

➔ **Transmission lines**, often called **high-voltage power lines**, carry electricity from power stations to transmission substations at voltages above 60 kV (up to 700 kV or even more, depending on the country).

➔ **Distribution lines** carry electricity from transformation substations to points of consumption. There are three types of distribution line:

a) **High-voltage distribution lines** carry the electricity from the transmission substations to the distribution transformation stations (36 to 132 kV).

b) **Medium-voltage distribution lines** link distribution transformation substations to transformers (3 to 35 kV).

c) **Low-voltage distribution lines** carry electricity from transformers to end consumers (120 V, 230 V, 400 V, 600 V, etc.).

The terminology of high-, medium- and low-voltage lines is very commonly used. IEC 60038, the International Standard of the International Electrotechnical Commission, defines the following set of nominal voltages for use in alternating-current electricity supply systems:

- **very high voltage** > 132 kV;
- **high voltage** 36–132 kV;
- **medium voltage** 1–35 kV;
- **low voltage** ≤ 1 kV.

However, other definitions can also be found and can cause confusion. Sometimes lines carrying more than 1 kV are called ‘high-voltage’ lines; whereas in other cases transmission lines alone are considered to be ‘very high voltage’, and the term ‘high voltage’ is used for distribution lines carrying voltages higher than 132 kV. Likewise, other names overlapping the standard names may form categories based on different voltage ranges.

2.2. COMPONENTS OF AN ELECTRIC POWER LINE

An overhead power line consists of two basic elements (Figure 23):

- **Phases** or **conductors:** the cables through which the electrical current flows.
- **Pylons, supports, poles, towers** or **masts:** the structures that keep the conductors sufficiently high above the ground and far enough apart from one another.

The conductors can be made of copper, aluminium or an aluminium-steel alloy; they are generally bare, not covered, although in medium- and low-voltage lines covered cables can be used. In low-voltage distribution lines braided or twisted cables are more common, consisting of three individual phases each covered in insulating material, stranded around a central core. The use of covered conductors in medium-voltage distribution lines is limited due to their higher cost: cables of this type are more expensive and, since they weigh more, they need a larger number of supports. Thus, its use is restricted to very specific situations, for example to prevent forest fires in areas with dense vegetation.

For various reasons of efficiency, to facilitate usage and transport, electricity is produced and transmitted as three-phase alternating current. A **three-phase system** is made up of three alternating single-phase currents with the same frequency and voltage amplitude, which have an electrical phase angle difference of 120° between them. Each of the single-phase currents that make up the system is called a **phase**. That is why conductors are seen in threes or groups of three on electric power lines, with each group constituting a different circuit. Homes normally have a single-phase power supply in which the electricity arrives via two wires, one live and one neutral, from a three-phase circuit, while shops and industries consume three-phase electricity (Figure 24).

For low-voltage lines, the cables are sheathed and twisted, although they can also be bare and separated, mounted on supports similar to those used for medium-voltage lines. However, in this case, in addition to the three conductors, there is a neutral conductor (typical of low voltage), with the fourth cable running along at a lower level (Figure 25).

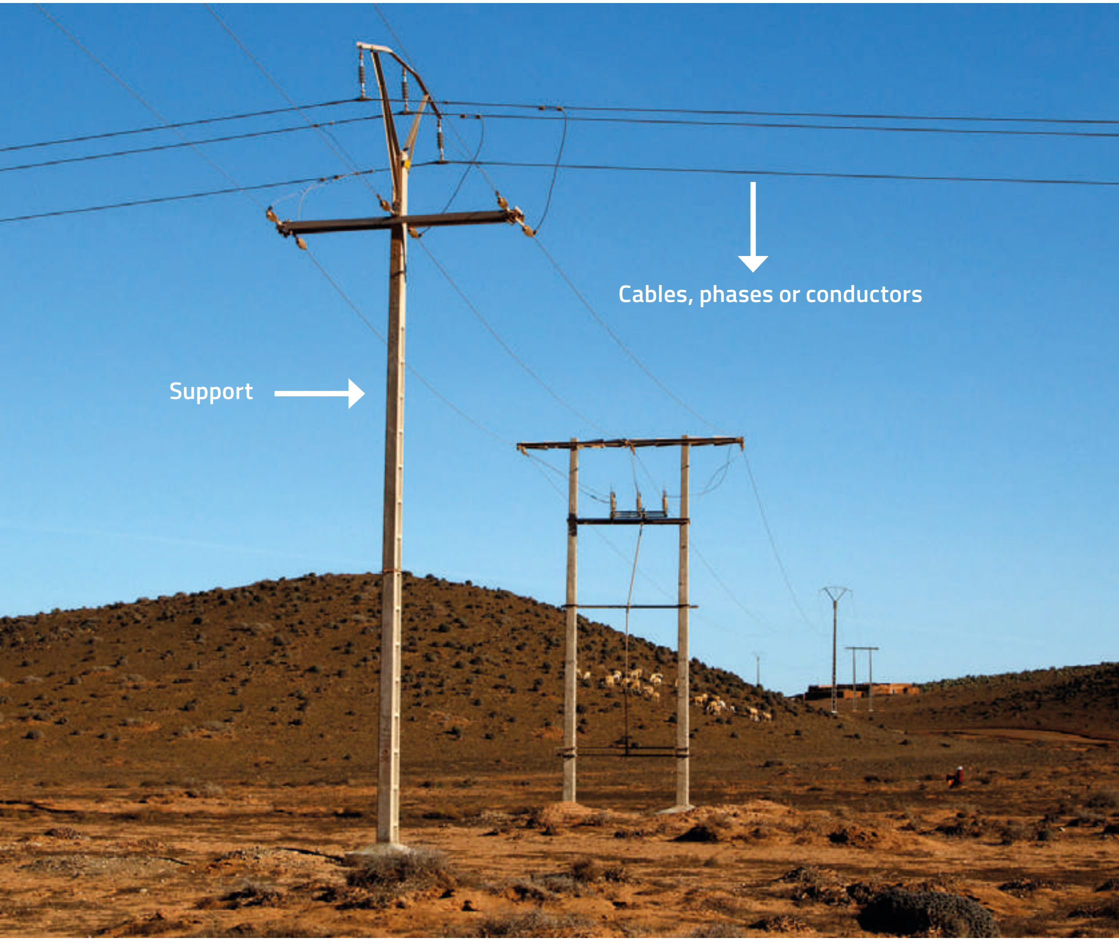

Figure 23. The two basic elements of an overhead power line are the cables (phases or conductors) that the electricity passes through and the structures that support them (supports, towers or pylons, masts and poles). The photo shows a single concrete pole (monopole) and an H-frame. © Daniel Burón

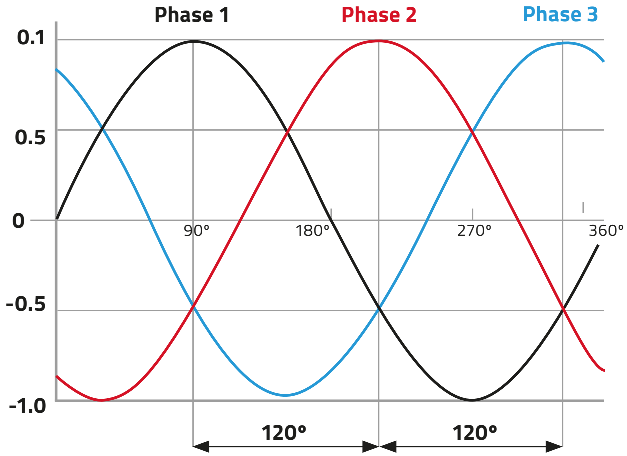

Figure 24. Electricity is transported in the form of three alternating currents with the same frequency and voltage amplitude, which have an electrical phase angle difference of 120° between them. Voltage of electrical phases in a balanced three-phase system. Source: Wikipedia CC BY 3. 0 J JMesserly

Figure 25. On the left, low-voltage line, with sheathed, twisted conductors; on the right, medium-voltage line with three bare phase conductors. © Justo Martín

High- and very high-voltage lines have one or two wires in addition to the conductors, called **earthing cables or ground wires (also shield wires or guard wires)**; these cables, generally made of aluminium-clad steel, do not carry current and are connected to earth on each of the pylons supports. Their function is to protect the line against direct electrical discharges (lightning). They are usually, but not always, installed above the conductors (Figure 26).

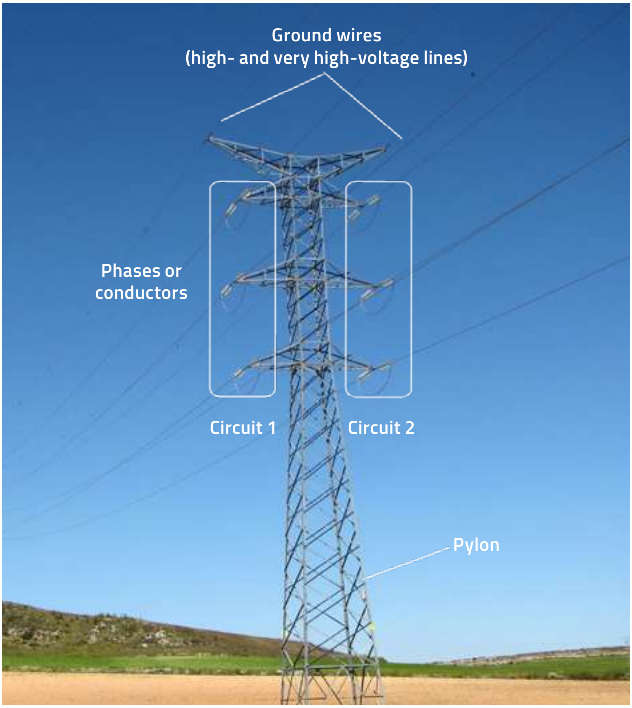

Figure 26. Basic elements of an overhead power line.
© Justo Martín

This protection system is completed with the earth (or ground) wire found on all types of line, linking the pylon to the ground through a cable attached to one or several posts or metal pins driven into the ground.

Recently, another function was added to the ground wire with the installation of Optical Ground Wire (OPGW) cables, whose external function is similar, but inside they have a fibre optic core, constituting an efficient system for deploying this type of telecommunication line throughout the country.

Medium-voltage lines also have the earthing system (ground wire) to prevent overvoltages when pylons are made of conductive material (metal or reinforced concrete). If pylons are made of non-conductive material (wood, unreinforced concrete, fibreglass), it is not necessary, although it may be present if the crossarm is metallic.

In some countries such as the USA, medium-voltage distribution lines may have four wires, the three phase conductors and a neutral (grounded) conductor. The neutral conductor could be placed on the top of the support, below or even with the phase conductors. This neutral wire serves to return the current back to the substation and is linked to the ground, balancing the electricity in the system.

As explained in Appendix A, the presence and position of ground or neutral wires are very important in assessing the risk of electrocution.

The supports may be steel lattice **towers** (often known as **pylons**) or metal, concrete, fibreglass or wooden **poles** and are anchored to the ground with concrete, reinforced concrete or steel foundations. Their height and configuration are very variable and mainly depend on the voltage of the current that passes through the conductors (Figures 27, 28 and 29). Steel lattice towers are generally used on transmission lines. Supports are usually earthed (grounded), either through a wire or through the structure itself in the case of steel supports. Supports can be self-supporting or, on lower-voltage lines, they may be guyed, i.e. fastened to the ground by cables.

Figures 27, 28 and 29. Supports are built of metal (left), concrete (centre) or wood (right). © Daniel Burón

The space between two consecutive supports is called the **span**; its length depends on the type of line and the size of the supports; it can be over 500 m on large transmission lines and under 50 m on smaller distribution lines. The **sag** is the vertical distance between a straight line passing through the fixation points of a conductor on two successive supports and the lowest point of the same conductor. The curve created by the cable is known as a **catenary** (Figure 30).

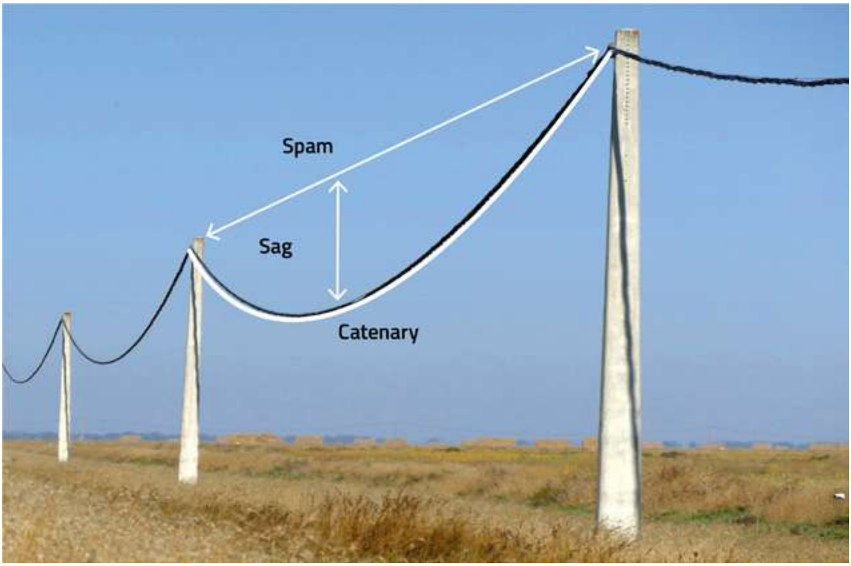

Figure 30. Names of the spaces and distances between supports. Electric power line with concrete poles and sheathed and twisted conductors. © Justo Martín

The support is made up of a tower body or a pole and a crossarm (the terms pole-top assembly or conductor configuration are also used). The various elements that make up the crossarm are the arms. The **tower body** is the vertical part that supports the crossarm, to which the conductors are attached (Figure 31). In the case of some special supports, such as pylons with branches (outlets to another line on the same support) a distinction is made between the **primary (or main) crossarm**, which holds the general circuit, and the **secondary (or auxiliary) crossarm**, where other elements (disconnectors, secondary circuit, etc.) are located (Figure 32).

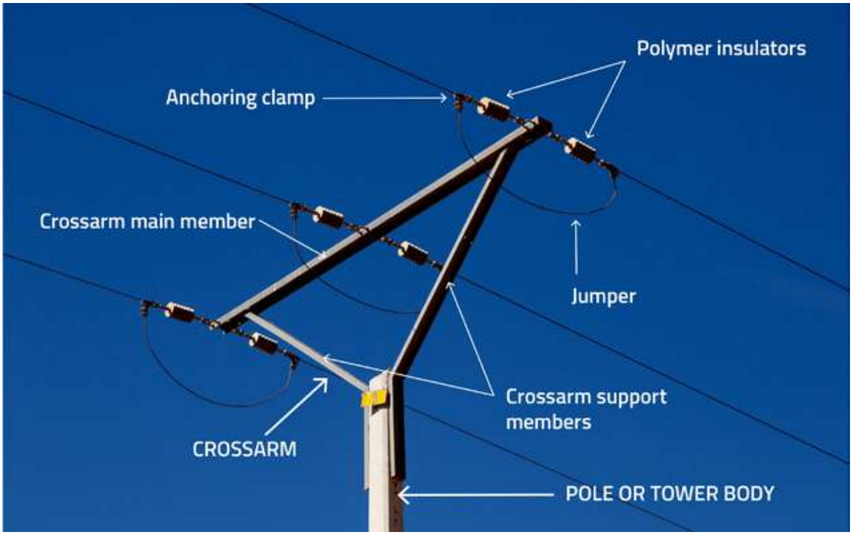

Figure 31. Parts of a support (anchor pole with a crossarm in a vault-type configuration and jumpers under the insulators). © Daniel Burón

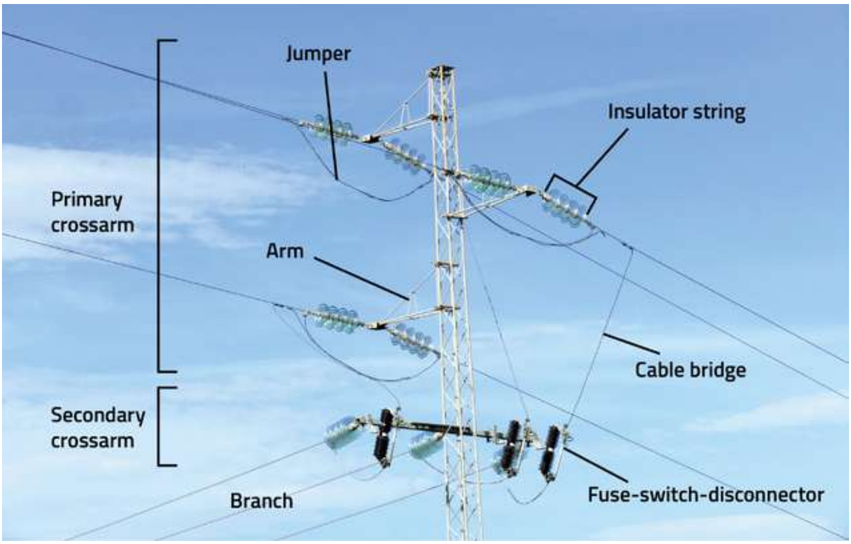

Figure 32. Parts of a support (anchor pylon with a crossarm in staggered configuration and a branch with fuse-switch-disconnectors). © Justo Martín

The conductors are attached to the insulators, and the latter to the towers by metal fittings, of which there are several types: **shackles, eyes, clamps, hooks**, etc. Other metal parts with different functions may also appear, such as Stockbridge dampers for ground wires or conductors, spacers and counterweights, all found on transmission lines, or various elements to protect against power surges, such as grading rings or **arcing horns** (Figure 33).

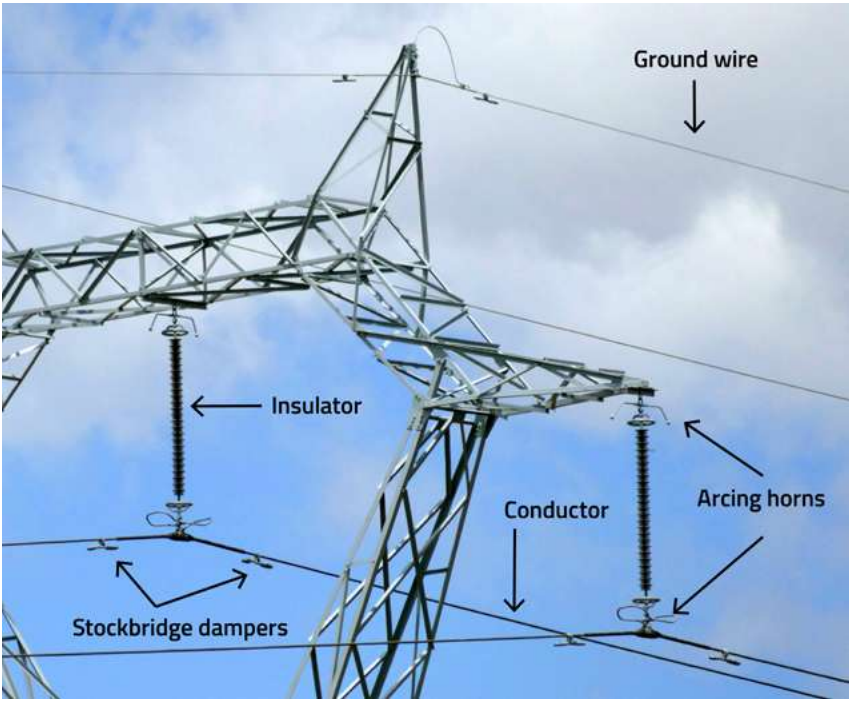

Figure 33. Parts of a support (transmission tower with suspension insulators). © Justo Martín

Depending on the layout of the insulators on the crossarm (Figure 34), they are called:

- **suspension insulators**, suspended beneath the crossarm;
- **pin insulators**, installed on top of the crossarm;
- **strain insulators**, attached to the crossarm in a horizontal direction, carrying the conductor and supporting the line under tension.

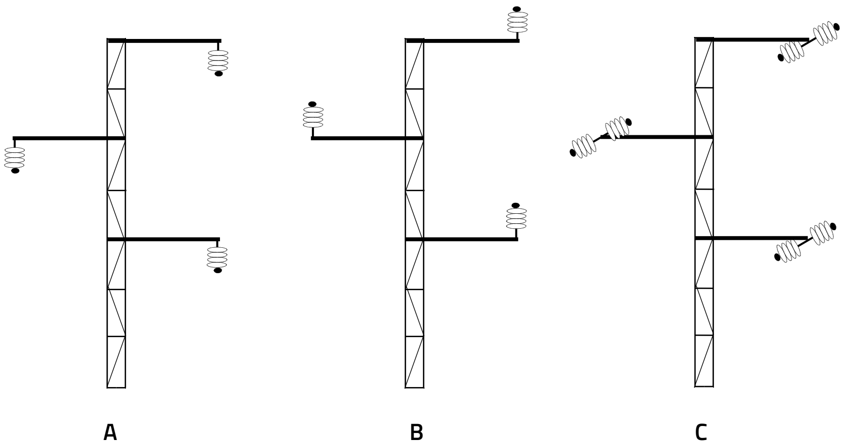

Figure 34. Basic support types based on the layout of the insulators on the crossarm. A: suspension insulators. B: pin insulators. C: strain insulators. Source: prepared by the authors.

In the case of strain insulators, the current is conducted from one conductor segment to the next through cables called **jumpers** (attached by means of **anchor clamps**), which are located above or below the insulator strings (Figures 31, 32 and 35). The connections between the jumper conductors are made using special metal wedge clamps (AMPACT).

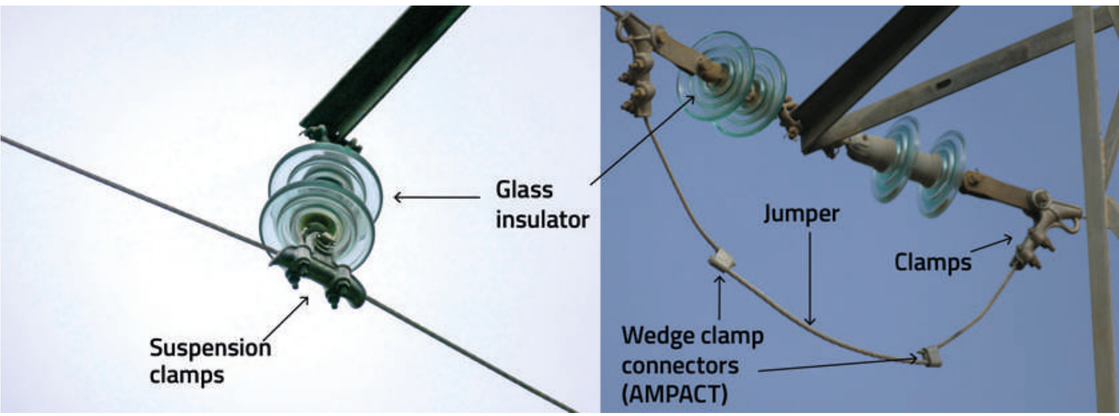

Figure 35. Fixation and connection systems. © Justo Martín

The length of the insulator string depends on the voltage in the conductors; if the voltage is high, a longer string is needed to ensure insulation and, consequently, to ensure greater separation between the cables in order to avoid electrical discharges. This in turn requires larger pylons. Support height varies between 10 m for small distribution lines to over 50 m for supports carrying 400 kV lines or over 100 m for ultra-high-voltage pylons, designed for 1,000 kV lines.

Supports can also carry **switching** and **protection devices**. Switching devices serve to discharge the voltage from parts of an installation or sections of a line so that it can be worked on safely. Protection devices protect against power surges and short circuits. Some devices perform both functions, switching and protection.

- **Disconnectors**. These are the most common switching devices. In single-phase circuits, single-pole disconnectors are used (Figure 36) and three-pole disconnectors are used in three-phase circuits. They include a variable number (2 or 3 per phase) of polymer or glass insulators, and can be mounted in a vertical position on the crossarm or suspended from it.

- **Fuse-switch-disconnectors (cut-out fuses)**. These devices often replace disconnectors; they allow for switching while at the same time protecting against power surges and short circuits (Figure 32).

- **Surge arresters or lightning arresters**. These are protection devices used alongside disconnectors on some types of support (e.g. those with transformers or supports where overhead cables are undergrounded); they serve as lightning conductors, protecting against atmospheric surge voltages (Figure 37).

- **Switch-disconnectors**. These replace disconnectors as switching devices. They are placed on the pole and are accompanied by several elements linked by cabling (Figure 36).

- **Recloser circuit-breakers**. Also on the pole, these are automatic reconnection switches. They are protection devices capable of detecting overvoltage, interrupting it and reclosing the circuit automatically to reconnect the line.

Other elements that appear on poles are **external transformers**. These devices convert medium voltage to low voltage. Like switch-disconnectors and recloser circuit-breakers, they are accompanied by various linked elements (Figure 37).

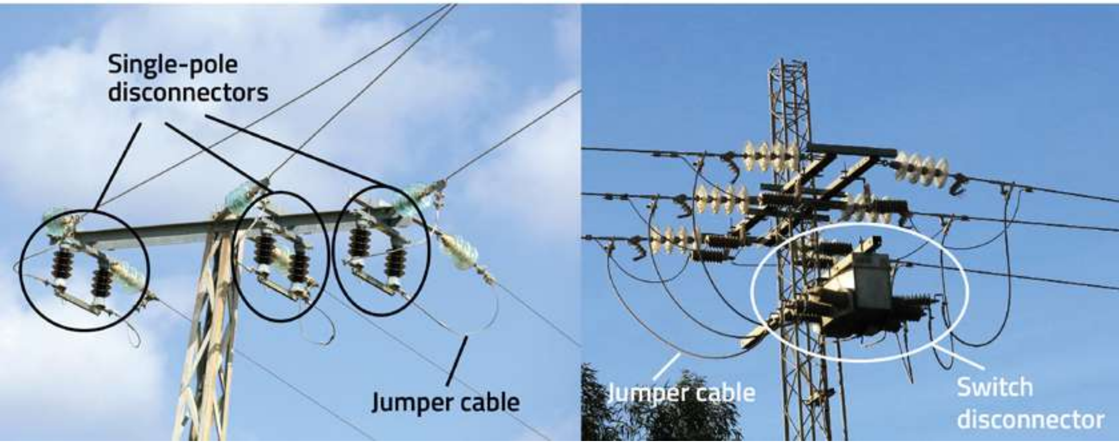

Figure 36. Switching and protection systems. Left: Pylon with single-pole suspended disconnectors. Right: Pylon with a switch-disconnector. © Justo Martín

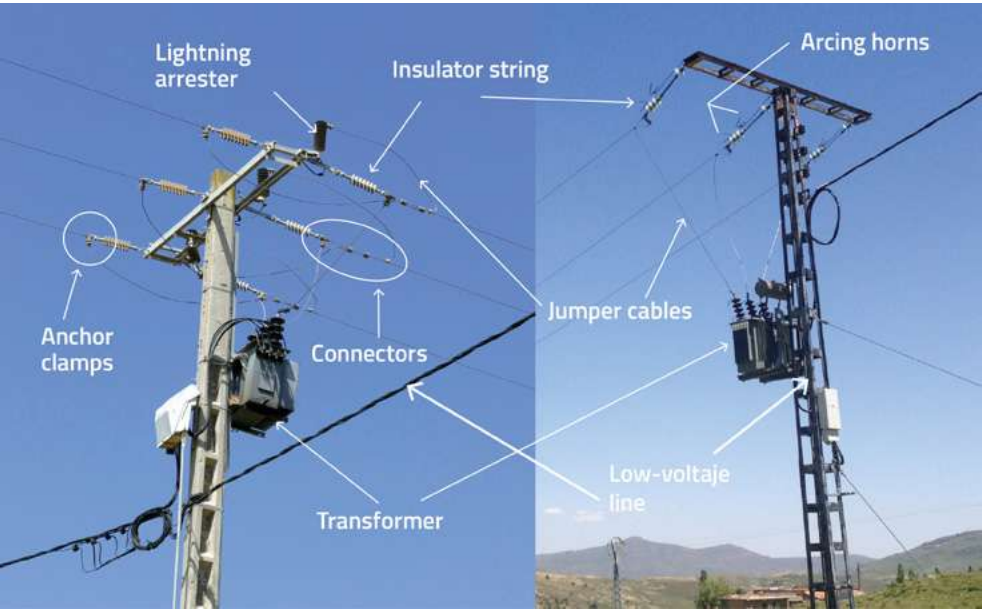

Figure 37. Supports with external transformers: left, on an anchor pole; right, on a termination pylon. © Justo Martín (left); Lahouari Djardini and Amina Fellous-Djardini (right)

After passing through the transformer or having reached a distribution substation housed in its own building (Figures 38 and 39), electric power lines often go underground. Overhead cables are undergrounded at special supports where the bare overhead cable becomes an insulated underground conductor. The connection structure in which this change takes place is called a **junction box** (Figure 40).

Figures 38 and 39. Examples of distribution substations located inside their own buildings. The (bare) medium-voltage line enters the building and the (sheathed) low-voltage lines carry electricity to the end consumers. © GREFA electric power line team

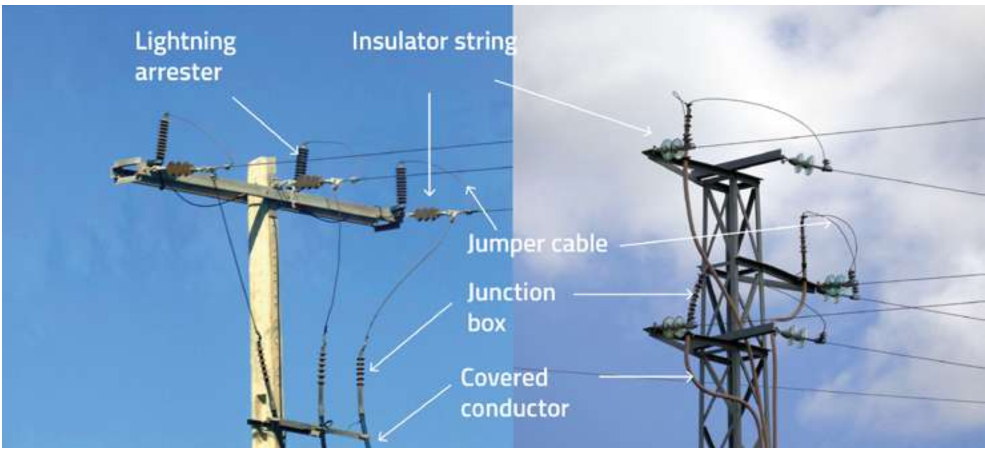

Figure 40. Parts of a dead-end tower. © Justo Martín

2.3. TYPES OF SUPPORTS

The structure and size of supports vary depending on voltage, topography, span length and tower type. Double-circuit structures are taller than single-circuit structures because the phases are arranged vertically and the lowest phase must maintain a minimum ground clearance, while the phases are arranged horizontally on single-circuit structures.

As voltage increases, the phases must be separated by a greater distance to prevent any chance of interference or arcing. Higher-voltage towers and poles are therefore taller and have wider horizontal crossarms than lower-voltage structures (Figures 41 to 43).

Figures 41, 42 and 43. Left: Pylons carrying a 220 kV transmission line. Centre: Pylon carrying a 66 kV high-voltage distribution line. Right: Pole with a 15 kV medium-voltage distribution line. © Justo Martín

Support heights vary from 10–12 m for medium-voltage distribution lines to more than 30 m for transmission line towers; in some cases (lines in special topographic conditions or carrying ultra-high voltages), towers may be more than 100 m high.

As shown in the following chapters, the risk to wildlife depends to a large extent on the size and structure of the supports, as we have already seen, conditioned by the voltage of the line they support. With lower-voltage towers, the main risk is electrocution on the supports, while with larger towers it is collision with the wires.

Supports can be classified in different ways:

Depending on their function on the line:

1. Supporting towers and poles. Their function is to support the conductors and ground wires and keep them off the ground. They are the most numerous kind of support used on straight stretches of line.

2. Anchor towers and poles. Supports with anchor insulator strings whose function is to provide solid points on the line, maintaining the tension of the cables and reducing the propagation of exceptional forces, so that the accidental breakage of a conductor or a support will not make the whole line collapse. Sometimes, a distinction is made between dead-end pylons located at the start or end of a line or at branch points, and strainer pylons in straight-line stretches replacing tangent supports at specific intervals depending on the terrain (Figures 44 and 45).

3. Special supports. Supports with a different function from those mentioned above. These include branch or derivation supports, which are used to carry the overhead line in different directions (Figure 46); junction supports, where a double-circuit line is separated into two single-circuit lines or where a branch starts from a line with two or more circuits; protection supports; supports with transformers; switching supports; overhead to underground conversion supports; etc. This group also includes crossing pylons, specially designed to cross railway lines, rivers, telecommunication lines, etc.

Depending on their relative position in the line layout:

1. Straight-line (or tangent) supports. Suspension, strainer or anchor supports on straight sections of line.

2. Angle supports. Suspension, strainer or anchor supports built at an angle in the layout of the line. They are special because, due to their location, they must withstand strong traction.

3. Termination supports. Equipped with anchor insulation strings, these supports are subject to strong lateral forces, which means they have to have special foundations.

Figures 44 and 45. Anchor pylons can be divided into strainer pylons (above), built in straight lines, and dead-end towers (below), at the start and end of a line and at branch points. © Daniel Burón (above) and Justo Martín (below)

Depending on the insulator layout and crossarm configuration, and the presence of other elements on the support (the letters correspond to the codes used in Section II of Appendix A):

A. Supporting towers and poles with suspension insulators.

B. Supporting towers and poles with pin insulators.

C. Anchor towers and poles with jumpers below the insulators.

D. Anchor towers and poles with jumpers above the insulators.

E. Switching supports with disconnectors or fuses, without any other devices.

F. Special supports with external transformers and/or other devices.

G. Termination or dead-end supports (overhead line to underground cable).

H. Branch or derivation supports.

As we shall see later, **crossarm configuration is an essential factor in assessing problems involving electric power lines and birds**. Therefore, the classification above is important reference material for the use of this manual; it is developed in greater detail in Appendix A.

Figure 46. Derivation pylon with a single crossarm assembly and without cut-out fuses or disconnectors. © Daniel Burón

3 Power lines and wildlife

Samantha K. Nicholson, Lourens Leeuwner, Gareth Tate and Constant Hoogstad

The Endangered Wildlife Trust, South Africa

Energy infrastructure (including power lines, power stations, wind turbines, solar developments, etc.) represents an important interface between people and wildlife, particularly in growing global economies where projects are often rolled out rapidly to meet the ever-increasing demands of industry and human development. Power line structures are generally tall (standing out in any landscape) and linear (crossing vast distances), increasing the opportunity for wildlife interactions and creating a barrier effect for many species, notably avifauna (Figure 47). Interactions can be negative or positive. Here we discuss some of the interactions and impacts that power lines have on local wildlife and landscapes. It is important to note that, considering the global grid of power lines, the full extent of the impact on ecosystem function is likely underestimated and, as with many other infrastructure impacts, information is lacking to truly quantify the large-scale effect.

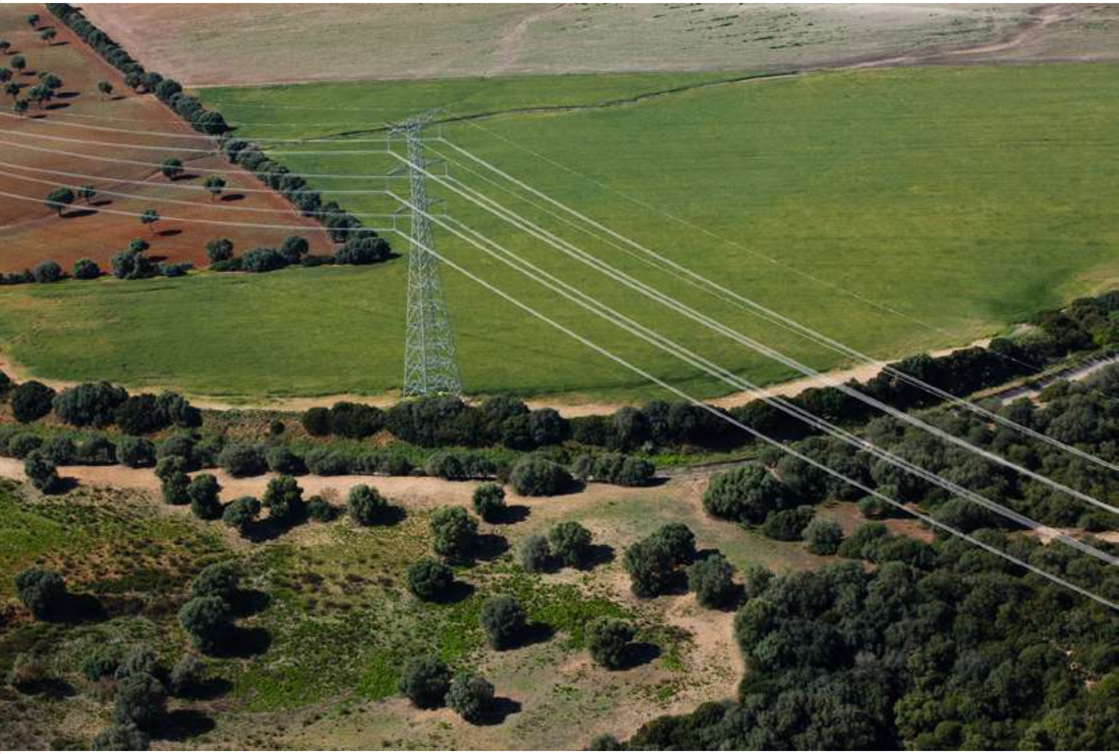

Figure 47. Power line structures represent a barrier for many species, notably avifauna. Bird–power line interactions are mostly negative. © Daniel Burón

3.1. EFFECTS OF POWER LINES ON ECOSYSTEMS

Impacts on landscapes and habitats

Power lines have considerable visual impact on natural habitats. The general geometric shapes of the structures themselves tend to contrast sharply with natural landscapes. During the construction of power lines, tall trees and vegetation are removed from large areas. Further, the long-term management of power line corridors may result in the complete **removal of vegetation** (largely due to the perceived fire hazard associated with corridor vegetation). While habitat clearing can allow otherwise uncommon plant communities to become established, providing suitable habitat for associated organisms too (Russell et al., 2005; Nekola, 2012; Garfinkel et al., 2022), it is detrimental to others that require environments with denser vegetation. These corridors are therefore generally seen as a cause of habitat fragmentation and loss for many bush- and forest-dependent species (Clarke et al., 2006). In any case, the benefits for some organisms (like edge species and open area species) are species-specific and localised and cannot be extrapolated to other species in different locations (Willyard & Tikalsky, 2008).

In addition, there is significant **risk of wildfires** in the surrounding habitat that result from electrocutions on power lines (Guil et al., 2018). These fires occur when an electrocuted animal burns and falls to the ground, where it sets light to vegetation, often causing significant damage to the area. This has been observed in Spain (Guil et al., 2018), in the USA (Barnes et al., 2022) and in South Africa (Figures 48 and 49; Eskom-EWT Strategic Partnership, Unpublished). In some cases, these incidents can directly affect human populations. For example, in Chile a fire ignited by an avian electrocution killed 15 people, injured more than 500 and destroyed almost 3,000 homes (Vargas, 2016).

> *Power lines may have different type of impacts and interactions on the territory they cross: changes in habitat structure, visual impact on landscapes, air and noise pollution, or interactions with wildlife.*

However, in certain cases, the habitat modification associated with the installation of power lines could have **some positive effects**. With proper management, power line corridors could contribute to the conservation of semi-natural grassland habitats in landscapes where these are altered or degraded (Dániel-Ferreira et al., 2021). Also, in very altered landscapes, local biodiversity could be increased by modifying the base of the transmission towers to increase the density and diversity of several species of invertebrates and small mammals as well as the numbers of birds and bird species; this could be used to facilitate the connection of fragmented populations (Ferrer et al., 2020).

Figures 48 and 49. A veld fire caused by the electrocution of five Cape vultures (*Gyps coprotheres*) on a distribution power pole (North-West Province, South Africa). © Eskom/Endangered Wildlife Trust Strategic Partnership

Electromagnetic fields

Power lines create an electromagnetic field (EMF) surrounding the lines themselves and the effects of this on wildlife are not yet well understood (Fernie & Reynolds, 2005; Balmori, 2015). However, much of the research that has been done has found that EMF exposure generally affects birds negatively, including through alterations to their behaviour, physiology, endocrine system and immune function (Fernie & Reynolds, 2005). Further, a study by Balmori (2015) found that EMF exposure may alter the receptor organs that animals use to orient in the Earth's magnetic field. This could have implications for migratory bird and insect species and, while this might be more evident in urban areas, it will also apply to animals in natural and protected areas (Balmori, 2015).

Figure 50. Golden eagle (*Aquila chrysaetos*) electrocuted by a power line in Morocco. © Daniel Burón

3.2. POWER LINES AND BIRDS

Birds interact with power line structures in various ways, either positively or negatively. Avifauna are by far the group of animals most severely impacted by the presence of power lines in the landscape (Angelov et al., 2013; Kagan, 2016; Bernardino et al., 2018; Chapters 4 and 5). This significant threat is likely to increase as a result of the expanding power line network and the growing demand for electricity (Figure 50).

> *Avifauna are by far the group of animals most severely impacted by the presence of power lines.*

Collisions and electrocutions

The best-known impacts are probably those related to direct bird mortality resulting from collision with cables and electrocution on pylons. **Electrocution can occur in two ways: by contact between two conductors or, more frequently, by contact between a conductor and an earthed metallic structure (the crossarm itself or a ground wire). Collisions occur when flying birds collide with overhead wires**. While larger, heavier bird species are prone to collisions, several species are also electrocuted when perching, roosting or nesting on infrastructure (Bernardino et al., 2018; Chapters 4 and 5; Figure 51). Globally, crane and bustard species are high on the collision risk list due to their low manoeuvrability, low and slow flight and in some cases flocking, roosting and feeding behaviour, with the latter also linked to visual fields that cause blind spots in these species (Shaw et al., 2010; Shaw et al., 2017). Environmental factors such as time of day, wind and topography also contribute to collisions (see Section 4.1), but the consensus is that visibility of the overhead line is a major factor as these larger species often only see the obstacle when it is too late to adjust their flight path (Table 3-1).

Large birds such as large raptors and storks are most affected by electrocutions on distribution line networks, with voltages of 132 kV and below posing the most apparent risk (Table 3-1; Dixon, 2016). Some of these species frequently use electricity poles and pylons as perching sites, which makes them very vulnerable to electrocution if they have large wingspans, as vultures and large eagles do, because they can easily make simultaneous contact with power line elements at different potentials. In the case of gregarious species, the risk of electrocution is also increased when several individuals perch on pylons with hazardous configurations, as multiple phases or earthed components on the structure may be contacted simultaneously, resulting in phase-to-phase or phase-to-earth electrocution of more than one individual at a time (see Section 5.3). On higher-voltage structures the risk is reduced as phase clearances exceed the wingspan of these birds, while medium-voltages pose the most significant risk due to insulator sizes, structure design and resultant clearances between phases and with the structure itself (Dixon, 2016; see Chapter 5).

Figure 51. Vultures are one of the groups of birds most severely impacted by electrocutions. Griffon vultures (*Gyps fulvus*) drying their feathers on a pylon. © Rachid El Khamlichi

Mortality is not evenly distributed throughout the electricity grid, but is concentrated in certain locations known as 'mortality hotspots' or 'black spots', as described in the following chapters.

Table 3-1. Severity of impacts (actual or potential) on bird populations: electrocution mortality and power line collisions for different bird families in Eurasia. 0 = no reported or likely casualties; I = reported fatalities, but no apparent threat to the bird populations of that family; II = high regional or local losses, but no significant impact on the overall conservation status of the species; III = casualties are a significant mortality factor, threatening an imperilled species regionally or on a larger scale.

Group of birds	(a) victims of electrocutions	(b) victims of collisions
Loons (Gaviidae) and grebes (Podicipedidae)	0	II
Shearwaters and petrels (Procellariidae)	0	II
Gannets (Sulidae)	0	I
Pelicans (Pelicanidae)	I	II–III
Cormorants (Phalacrocoracidae)	I	I
Herons and bitterns (Ardeidae)	I	II
Storks (Ciconidae)	III	II
Ibises (Threskiornithidae)	I	II
Flamingos (Phoenicopteridae)	0	II
Ducks, geese, swans and mergansers (Anatidae)	0	II
Diurnal birds of prey (Accipitriformes and Falconiformes)	II–III	I–II
Partridges, quails and grouse (Galliformes)	0	II–III
Rails, moorhens and coots (Rallidae)	0	II
Cranes (Gruidae)	0	III
Bustards (Otidae)	I	III
Plovers and waders (Charadriidae and Scolopacidae)	I	II–III
Skuas (Sterkorariidae), larids and gulls (Laridae)	I	II
Terns (Sternidae)	0–I	I–II
Penguins and guillemots (Alcidae)	0	I
Sandgrouse (Pteroclididae)	0	II
Pigeons and turtle-doves (Columbidae)	I–II	II
Cuckoos (Cuculidae)	0	I–II
Owls (Strigiformes)	II–III	II
Nightjars (Caprimulgidae) and swifts (Apodidae)	0	I–II
Hoopoes (Upupidae) and kingfishers (Alcedinidae)	I	I–II
Bee-eaters (Meropidae)	0–I	I–II
Rollers (Coraciidae) and parrots (Psittadidae)	I–II	I–II
Woodpeckers (Picidae)	I	I–II
Ravens, crows and jays (Corvidae)	II	I–II
Small and medium-sized songbirds (Passeriformes)	I	I–II

Source: Prinsen et al., 2011a; Derouaux et al., 2020

Figure 52. Egyptian vulture (*Neophron percnopterus*) populations in the Middle East have declined as a result of the impact of electrocutions on power lines in their wintering grounds in East Africa. © Íñigo Fajardo

While the threat is widespread and fairly well-studied, the extent of its impact on populations is difficult to quantify, although population declines in some species have been attributed to negative interactions with electric power infrastructure. For example, persistent electrocutions of Egyptian vultures (*Neophron percnopterus*) over 28 years in East Africa have contributed to a population decline of the species (Angelov et al., 2013; Figure 52). In South Africa, studies have shown that mortality rates of the threatened Ludwig's bustard (*Neotis ludwigii*) on power lines could be between 4,000 and 11,900 individuals killed annually on high-voltage transmission lines (Jenkins et al., 2011). It is expected that actual mortality rates will be higher than this when biases in carcass detection and mortality on low-voltage distribution lines are taken into account (Jenkins et al., 2011). When one considers the Ludwig's bustard population is estimated to be between 56,000 and 81,000 birds, it is clear that these levels of mortality are not sustainable for the population and will inevitably result in population declines (Jenkins et al., 2011; Shaw et al., 2017).

Between January 1997 and December 2019, 7,637 individual birds were reported killed on power line infrastructure in South Africa (Table 3-2). Most of the reported incidents (29%; n = 2,201) were of vulture species. Crane species are also very commonly reported to collide with power lines (22% of reported incidents) and this is thought to be a contributing factor in population declines.

Table 3-2. Numbers of reported bird fatalities (by species group) across the whole of South Africa recorded by the Endangered Wildlife Trust (January 1997 – December 2019).

Species group	Collision	Electrocution	Unconfirmed cause of death on power line	Total
Vultures	376	1,784	41	2,201
Cranes	1,631	39	3	1,673
Other bird species	299	565	58	922
Birds of prey	100	488	7	595
Bustards	582	7	5	594
Flamingos	464	-	-	464
Waterfowl	281	83	7	371
Storks	304	42	2	348
Owls	14	247	2	263
Secretary bird	104	1	-	105
Herons	47	52	2	101
Total	**4,202**	**3,308**	**127**	**7,637**

The data compiled in Table 3-2 by the Endangered Wildlife Trust (EWT, a South African-based non-governmental conservation organisation) resulted from a collaboration between EWT and Eskom (South Africa's state power company) under the Eskom–EWT Strategic Partnership (see Section 8.4). Incidents are reported directly by Eskom to the EWT, other conservation organisations or the public.

Source: compiled by the authors

Entanglement

Bird entanglements occasionally occur on power lines. They arise **when a bird gets caught in the cables or the metal structures of the line** (Figure 53). The bird inevitably ends up dying as it is often unable to untangle itself and sustains major injuries in its attempts to free itself. This can also interrupt the power supply as damage to the power structure can also occur. Although such incidents are generally rare, in some cases they may have implications for the conservation of threatened bird populations, as in the case of the Egyptian vulture (*Neophron percnopterus*) in one region of Spain, where entanglement was one of the main causes of the decline in the breeding population (Gangoso & Palacios, 2002).

Figure 53. Entangled lesser kestrel (*Falco naumanni*) on a medium-voltage covered wire. ©Íñigo Fajardo

Barrier effect

Power lines, by their nature, cause what is known as a barrier effect. The barrier effect results from roads, highways, power lines and other **linear structures which impact or alter an animal's movement pattern**. It has been observed that the barrier effect of power lines has caused birds to change their migratory behaviour and flight paths.

Individuals may respond to the presence of a barrier by altering their behaviour, for example, by avoiding the part of the landscape where there is a power line or changing their flight behaviour when approaching it (Pruett et al., 2009; Raab et al., 2011). This barrier effect due to avoidance behaviour has been described as extending from a few dozen metres to about one kilometre from overhead wires (as estimated by Benítez-López et al., 2010, from observations on 200 bird species). For example, transmission power lines are significantly avoided by little bustards (*Tetrax tetrax*) in Portugal (Silva et al., 2010), sage grouse (*Centrocercus urophasianus*) in the USA (Gillan et al., 2013) and pink-footed geese (*Anser brachyrhynchus*) in Denmark (Larsen & Madsen, 2000).

Nesting, perching and roosting opportunities

Despite the negative impact on birds documented globally, **power line infrastructure may provide benefits** for a variety of bird species or populations as they offer nesting, perching and roosting options (see for example Morelli et al., 2014; Figure 54). In landscapes where trees are scarce and there is limited availability of suitable nesting or perching sites, some bird species are able to exist largely because of the presence of power line structures. This applies only to selected species and estimation of the net impact at the population level requires an assessment of trade-offs between positive and negative impacts (Mainwaring, 2015; Moreira et al., 2017; D'Amico et al., 2018); the effects on species diversity and conservation may only be apparent in some situations (De Goede & Jenkins, 2001).

Figure 54. Power line infrastructure provides nesting, perching and roosting options to a variety of bird species. The net impact on these birds may be positive if anti-electrocution or anti-collision measures are adequate. White storks (*Ciconia ciconia*) nesting on a transmission line. © Justo Martín

Several species of birds are known to use pylons and towers for nesting; APLIC (2006) mentions 27 species, but there are probably more. Nesting opportunities provided by power line pylons have on occasion facilitated range expansion. This is the case, for example, of the martial eagle (*Polemaetus belicosus*) in South Africa (Figure 55). The South African population of this eagle is currently estimated at fewer than 800 adult birds, with the bulk of the known population believed to be residing in the country's larger protected areas. However, martial eagles also build nests and breed on pylons that support high-voltage power lines running through the largely treeless, semi-arid landscapes of the Karoo. In fact, it is estimated that over a third of the national breeding population nests on pylons in this region (Berndt, 2015). The provision of artificial nesting sites in the form of pylons or towers that support transmission and distribution lines is suspected to have facilitated, to some extent, the range expansion of the species. This finding, which is at odds with the generally held belief that the martial eagle is increasingly confined to large protected areas, has significant implications for our thinking around the conservation management of this globally threatened species. The EWT is currently undertaking a comprehensive study on the population dynamics of the pylon-nesting population of martial eagles in the Karoo and have identified over 80 active nests across 1,750 km of transmission lines. Other eagle species, including tawny eagles (A*quila rapax*) and Verreaux's eagles (*Aquila verreauxii*), also regularly nest and breed on pylons within this region.

> *The potential positive effects on certain bird species or populations (such as storks and birds of prey) can be furthered by ensuring that anti-electrocution and/ or anti-collision measures are adequate and the risk of fatalities is mitigated.*

When highly territorial birds such as corvids make use of these previously unavailable nesting and perching opportunities, regional prey species are unnaturally affected (Coates et al., 2020). Similarly, birds of prey use poles and pylons as hunting perches, which places rodents and other small mammals under additional pressure if no natural perches are present in the landscape (Bevanger, 1998; De Goede & Jenkins, 2001; Lasch et al., 2010), in addition to the danger that this behaviour poses to the birds if the pylon is poorly designed or insulated to prevent electrocutions (see Section 5.1).

Several weaver species are known to seek out transmission lattice towers as nesting sites, resulting in artificially large populations of these species (Harebottle & Oschadleus, 2014). In a landscape where only a few large trees would otherwise be suitable for these social species, a power line provides a series of artificial safe nesting sites, which in turn results in unknown pressure on plant diversity due to large-scale seed load reduction. Certain seeds may also be preferred, which may lead to an imbalance in plant community diversity.

Figure 55. The provision of artificial nesting sites in the form of pylons or towers that support transmission and distribution lines is suspected to have facilitated the range expansion of the martial eagle (*Polemaetus belicosus*) in South Africa. © Justo Martín

Impact of birds on power lines and electricity supply

The varied interactions between wildlife and power lines, including perching and nesting as discussed above, have **implications not only for the animals' safety but also for the operation and management of the lines**, as they are often the cause of power failures (Moreira et al., 2017). With the expansion of the electricity grid such interactions are becoming increasingly common, making recurrent outages in distribution networks more likely. Birds are generally high on the list of factors contributing to poor network performance and line faults (Minnaar et al., 2012). Line trips, damage to hardware and additional maintenance due to birds' negative interactions with infrastructure are a reality faced by electricity companies worldwide (Dixon, 2016). In some parts of the world, it is estimated that 10–23.5% of the power cuts in the electricity system are caused by incidents involving birds (APLIC, 2012).

There is a **variety of causes**:

- ➜ Contact between electrical components and nesting materials;
- ➜ Contact between conductors caused by a conductor swinging when a large flock of birds flies off it;
- ➜ Prey items or the remains of prey falling onto conductors or electrical equipment;
- ➜ Accumulation of excrement on parts of the conductors;
- ➜ Breaking of conductors or contact between conductors as a result of collisions;
- ➜ Damage to insulators or fuses caused by electrocutions;
- ➜ Contact with vegetation due to damage to pylons.

Electrocutions are the most serious source of problems. Some studies show that 10–55% of electrocution events cause short circuits, which can lead to more serious problems (APLIC, 2012). There have also been cases of electrocution and power cuts on railway lines, leading to interruptions in rail traffic, financial losses and other associated inconveniences.

For electricity companies, **the incidents caused by birds are costly**, both in financial terms (for repairing damaged assets, removing nests, spending time on administrative tasks, paying out compensation for cuts in power supply, etc.) and in terms of their own image, regarding consumers' opinions about their reliability and safety (APLIC, 2012).

Attention to structure design, line routeing and mitigation measures, such as insulation materials, isolation options and line markers (bird flight diverters), will vastly improve the performance of any network plagued by bird faults while ensuring the long-term survival of at-risk bird species.

A special case of bird damage to power lines is that caused by woodpeckers. A number of woodpecker species have been known to make hollows in wooden poles (Figure 56), which then provide shelter for other animal species such as insects and reptiles (Stemmerman, 1988; Harness & Walters, 2004; Murison & Leeuwner, 2018). The significance of this is often negligible; however, poles have been known to fail if multiple cavities are created (Murison & Leeuwner, 2018).

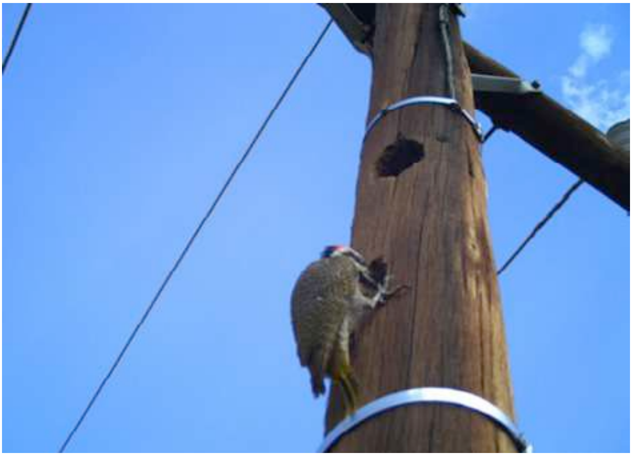

Figure 56. A woodpecker making holes in a wooden distribution pole. © Eskom/Endangered Wildlife Trust Strategic Partnership

Woodpeckers can thus cause severe damage to wooden power poles and this results in significant economic losses to electricity companies and occasionally an interruption in power supply (Harness & Walters, 2004). A previous study by Meyer and Maistry (2001) estimated that 5% of 16,000 poles (n = 800 poles) in Groblersdal and Marble Hall (two areas in South Africa) were damaged by woodpeckers and had to be replaced. The entire exercise was estimated to cost R 4,000,000 (~US$ 267,000) over a two-year period (Meyer & Maistry, 2001; Murison & Leeuwner, 2018). Damaged poles can cause safety concerns as there is a risk of live components making contact with vegetation. This can result in wildfires, increase the risk of electrocution for people and wildlife and cause power supply interruption (Murison & Leeuwner, 2018).

3.3. POWER LINES AND MAMMALS

It is often assumed that mammals rarely interact with electrical infrastructure due to their size, habitat preference, behaviour and nature. Although data show that large bird species are the group most impacted by electrical infrastructure, there are several records of mammals that have perished from electrocution. Climbing species, including primates, are the ones most affected (see Chapter 5 and the list compiled from the literature in Table 5-1).

Electrocutions

Electrocution of mammals takes many forms, from contact with overhead lines to electrocution on transformer boxes and live components in substations (Page-Nicholson et al., 2018).

The sheer size and height of species such as giraffe (*Giraffa spp*., up to 5.8 metres) and African elephant (*Loxodonta africana*, up to 3.8 metres) place them at particular risk of contact with lower-voltage overhead lines. A number of arboreal species and some primate species often use utility poles to climb up or use as refuges to escape from predators or other threats they might be exposed to, or to forage (Al-Razi et al., 2019). Certain species also roost on infrastructure such as box transformers and take refuge in substations where they are not exposed to the elements; this can bring them into contact with live components, leading to electrocutions. **While many mammal fatalities are due to electrocution, some occur as a result of the animal becoming entangled** in loose cables (Figure 57). This has been known to cause cattle and some giraffe deaths.

In some countries such as Costa Rica, the recorded cases of electrocuted mammals are more numerous than those of birds (see Case studies 4 and 16 about Costa Rica and primates, respectively), causing most of the interruptions in the electrical supply (Rodríguez et al., 2020).

In South Africa, between January 1996 and December 2019, approximately 432 individual mammals were reported killed on power line poles at the national level (Figure 58). Species ranged from small genets and mongooses to monkeys, ungulate species, large carnivores (e.g., lion *Panthera leo*, leopard *Panthera pardus*) and elephants. While this is a threat to a surprisingly wide range of mammal species, it is not thought that it could result in local population declines.

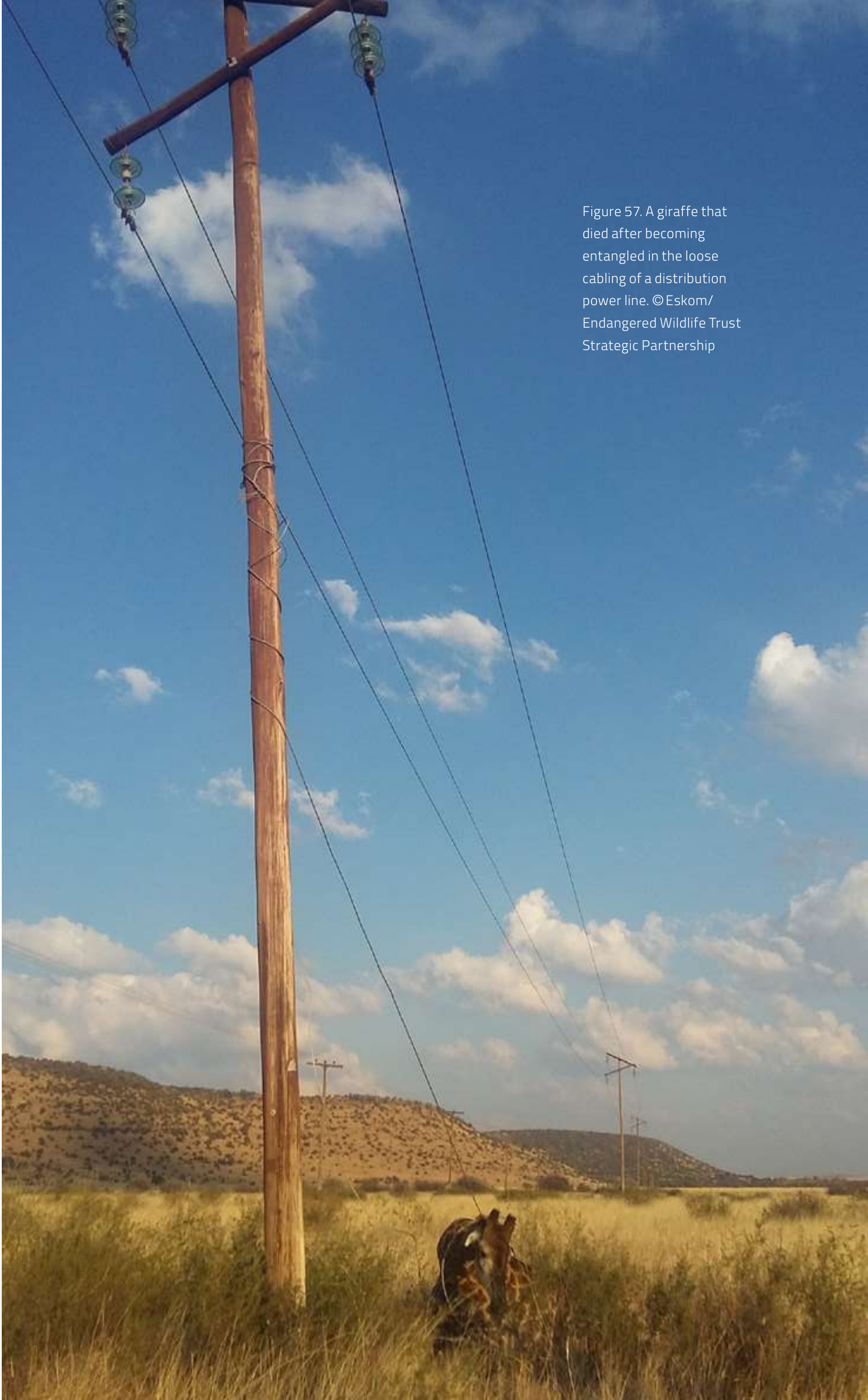

Figure 57. A giraffe that died after becoming entangled in the loose cabling of a distribution power line. © Eskom/ Endangered Wildlife Trust Strategic Partnership

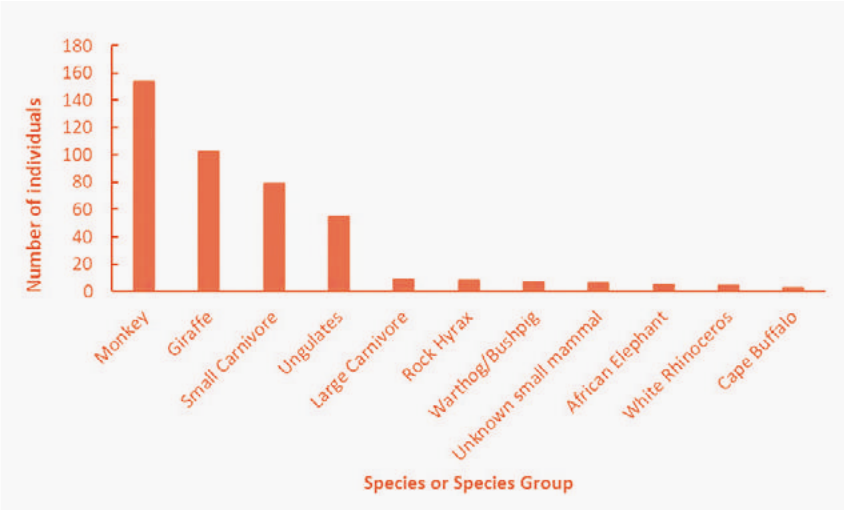

Figure 58. Number of reported mammal fatalities (by species or species group) across South Africa, recorded from January 1997 to December 2019. Source: Eskom-EWT Strategic Partnership (Unpublished)

Barrier effect

Power lines can also cause a barrier effect for some species of mammals, such as reindeer (*Rangifer tarandus*) and moose (*Alces alces*), which, in some areas, have changed their routes as a result (Colman et al., 2012; Bartzke et al., 2015).

Impact of mammals on power lines

Larger mammals are further at risk due to the fact that they use wooden poles to rub against, to clean/sharpen their horns or tusks on, to get rid of parasites and to mark their territories (Figure 59; Pretorius et al., 2016; Page-Nicholson et al., 2018). Over time this leads to **damage and weakening of the wooden poles**, which in turn leads to conductor height being lowered, increasing the risk of mammals interacting with these lines. Therefore, poles need to be replaced before they can become an electrocution risk or interrupt the power supply, which can often be a costly exercise.

Figure 59. Cape buffalo (*Syncerus caffer*) interacting with a wooden electrical distribution pole in the Kruger National Park, South Africa. © Eskom/Endangered Wildlife Trust Strategic Partnership

In addition, the **excavations** of Cape porcupines (*Hystrix africaeaustralis*) in South Africa around the foundation of steel lattice towers (Figures 60 and 61), for example, have been known to destabilise the structures and cause their eventual collapse (Letsoalo, 2019; Eskom-EWT Strategic Partnership, Unpublished). This is not only extremely costly to repair, but can cause significant safety issues and potential interruptions in power supply.

Figures 60 and 61. Damage around the steel lattice structures of a transmission power line caused by African porcupines. ©Eskom/Endangered Wildlife Trust Strategic Partnership.

3.4. POWER LINES AND OTHER SPECIES

Aside from birds and mammals, a surprising array of other animal groups also interacts with electrical infrastructure. Wooden gum poles widely used in distribution line networks are prone to **insect infestations**, despite treatment against these damages. Pole failures as a result of this are well documented in South Africa, where the state-owned utility company regularly implements wooden pole replacement programmes in the geographic regions where this occurs.

Some **climbing reptiles**, such as black and common iguanas (*Ctenosaura similis* and *Iguana iguana*) and **arboreal snakes** (*Boa constrictor*), and even some **amphibians** also seem to be susceptible to electrocution (Rodríguez et al., 2020; see Case study 4). The heat generated by some infrastructure components, such as transformers, may attract exothermic animal species such as these as well as a variety of invertebrates. This is seldom problematic due to the size of these creatures; however, snakes have been known to cause power losses when multiple phases are contacted simultaneously as the reptile slithers across the hardware. When some invertebrate species construct **nests** inside and around transformers the heat exchange efficiency of the hardware may be compromised, requiring additional maintenance for cleaning and removal.

Honey bees have been known to build hives in and around substations and although this seems to have little impact on utilities, research suggests that the proximity of high-voltage power lines will affect the health of nearby hives due to excessive exposure to electromagnetic fields (Shepherd et al., 2018).

> *The varied interactions between wildlife and power lines may have implications not only for the animals' safety but also for the operation and management of the lines.*

4 Collisions

James F. Dwyer[1], Richard E. Harness[1] and Justo Martín Martín[2]

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4.1. FACTORS THAT INFLUENCE AND DETERMINE THE RISK OF COLLISION

Figure 62. Although birds can usually see and avoid power lines while in flight, in conditions of poor visibility all types of line can present collision hazards. A Bonelli's eagle (*Aquila fasciata*) killed as the result of a collision. © Justo Martín

Of all negative interactions between birds and power lines, collisions are the most common because any overhead power line can constitute an obstacle for flying birds. When visibility is good, birds can detect power lines well in advance and avoid them, generally by flying over them. However, when visibility is poor (due to fog or rain, or at dawn, dusk, or night), birds appear less able to avoid power lines, either because they do not detect them at all or because they detect them too late to avoid them (Figure 62). Intrinsic factors are also influential in determining collision risk. For example, species-specific manoeuvrability in flight and social, predation, or predation-avoidance behaviours, on their own or in combination, cause some groups of birds to be at higher risk of collision than others (Ferrer, 2012). Most reported collisions (80%) involve transmission lines with ground wires (Bernardino et al., 2018). Ground wires are the thin wires at the top of transmission towers that provide lightning protection and other critical engineering functions for a transmission line. When visibility is poor, conductors are detected when the birds are close to the line. When trying to avoid the conductors by flying over them, the birds collide with the ground wires, which are much thinner and thus less visible.

> *Most reported collisions involve transmission lines with ground wires.*

The risk of a bird colliding with one of the components of an electric power line depends on three types of factors (see reviews by Prinsen et al., 2011a; Avian Power Line Interaction Committee (APLIC), 2012; Ferrer, 2012; Environmental Impact Services, 2013; Bernardino et al., 2018; Eccleston & Harness, 2018):

➜ Power line characteristics,

➜ Bird species,

➜ Environmental factors.

Power line characteristics. Several factors inherent to power lines affect the risk of collision. Most of these factors are driven by line voltage, which determines the structure and the configuration of the line. These characteristics are:

➜ *The number of horizontal planes in the layout of the cables.* Logically, presumably, the risk of collision depends on the number of horizontal planes of wires (conductors and ground wires) and the distance that separates them; complex structures with wires on several planes may create a kind of fence that is difficult for birds to cross through safely (Figure 63). Some studies support this hypothesis, although more research is needed to assess the relative weight of this factor in driving patterns of avian collision (Bernardino et al., 2018; Marques et al., 2020).

Figure 63. In areas with a high density of power lines, with many horizontal cable planes, the risk of collision is significant. © Justo Martín

➜ *Span length.* The distance between pylons is an element that appears to affect the risk of collision, since accidents are less frequent close to pylons than they are mid-span (Bernardino et al., 2018).

➜ *Line height.* Generally, the higher a structure is, the greater the risk of collision, in part because birds tend to fly up to pass over obstacles, and in part because birds flying above obstacles (like a tree canopy) may not be alert to potential anthropogenic obstacles. This may explain why collisions more frequently involve transmission lines than distribution lines (Marques et al., 2020).

➜ *Diameter of the conductors and ground wires.* This seems to be one of the main factors determining collision risk. The ground wire installed on transmission lines is much thinner than the conductors and hence less visible (Figure 64). Apparently, as birds approach power lines when visibility is poor, they only see the conductors when they are close to them and then fly up to avoid them, colliding with the ground wire above. In some specific studies, this is how as many as 80% of collisions occur (Bernardino et al., 2018).

Figure 64. Most collisions occur on lines with ground wires at the top of transmission pylons. Ground wires are typically far less visible than conductors. © Justo Martín

Bird species. It is important to consider avian characteristics, including physiology, morphology and ecology, to understand collision risk. One important factor is the gregarious nature of some species and their tendency to gather in large groups. Another important factor is the manoeuvrability of the flying bird, as well as its age and sex, which correlate with differences in experience, behaviour and size (for detailed information, see the compilation in Bernardino et al., 2018). Waterbirds and large steppe birds are particularly susceptible to collision due to their combination of high wing loading, high flight speeds, flocking behaviour, and tendency to encounter power lines crossing water features where natural obstacles are not present (Figure 65). In the case of waterbirds, another possible high-risk factor is their habit of flying at dusk (especially when returning to communal roosts). It should be borne in mind that collisions involving passerines may well be underestimated because of the difficulty of locating their corpses.

Figure 65. Large, heavy birds such as the great bustard (*Otis tarda*), with high wing loading and poor manoeuvrability, are particularly susceptible to collisions. © Justo Martín

➔ **Environmental factors.** Electric power lines cross all kinds of habitats and landscapes. This aspect, associated with other factors such as the weather and even direct human disruption, has an impact on the risk of collision in different ways.

➜ *Topography.* While migrating, birds tend to follow major geographical features (mountain ranges, coastlines), which help determine their migration routes. On these routes, topographical features such as ridges and mountain passes, river valleys and geological depressions concentrate flight routes. It is logical to assume that power lines that cross these points will pose a high risk of collision if birds fly over these areas at low altitude. However, studies are inconclusive on this point (Luzenski et al., 2016) and this risk probably overlaps with other effects, making it hard to generalise. What has been observed in some areas is that at a local level the topography can favour the formation of updraughts used by soaring birds during migration parallel to mountain ranges. These currents can be so strong that they literally push the birds upwards (Figure 66), causing collisions with power lines that are arranged both crosswise and lengthwise (G. Babiloni, pers. comm.).

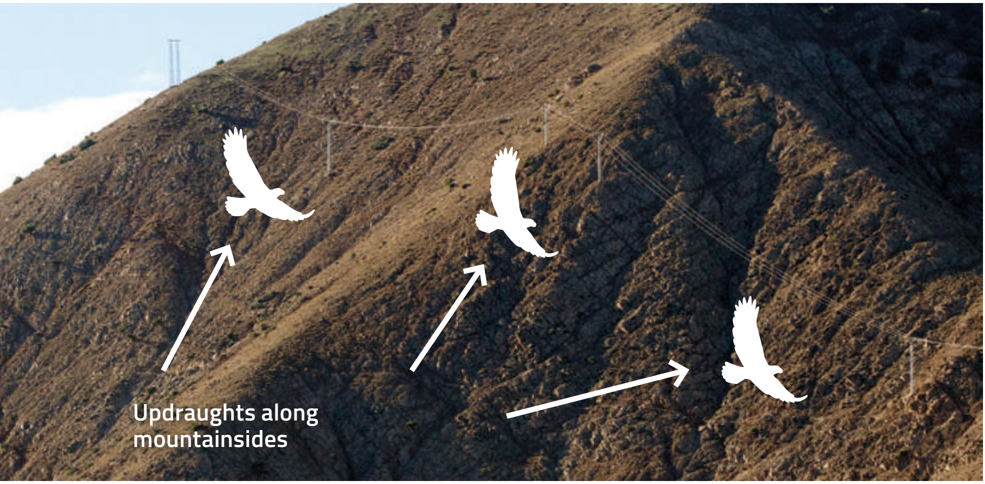

Figure 66. Updraughts can form at a local level, pushing the birds up until they find themselves at risk of colliding with power lines. © Daniel Burón

➜ *Habitat characteristics.* Vegetation plays an important role in the exposure of birds to power lines. In general, in their usual movements, birds tend to fly lower in open areas than in forested areas, and therefore the risk of collision can be greater for species such as geese (Shimada, 2001). Where electric power lines exceed the height of the forest canopy, collisions can occur when the birds' movements occur just above the trees (Figure 67); this is also the case where conductors hang beneath the lowest branches of trees, in the area in which forest birds move around. Moreover, where lines cross areas such as wetlands, coastal zones, steppes or other types of area where resident or wintering birds congregate, collisions tend to increase. This also occurs where lines cross over rivers (used by many birds as flight corridors) or are located near landfills used by numerous species as feeding sites.

When visibility is poor (in fog or rain, or at dawn, dusk or night), birds cannot see obstacles or only notice them when they are unable to manoeuvre in time to avoid them.

➜ *Weather and visibility conditions.* Weather conditions such as rain, snow, thick fog or very low cloud cover force birds to fly closer to the ground, while at the same time making power lines less visible. The most serious collision episodes are recorded in these conditions. In general, any circumstances involving reduced visibility lead to a higher risk of collision, notably dawn and dusk, as well as night time (Figure 68). Moreover, strong winds, in particular tailwinds or crosswinds, make it hard for birds to manoeuvre, thus increasing risk. In desert environments, dust or sand storms are also responsible for many soaring bird collisions (Shobrak, 2012; Al Nouri, pers. comm.).

➜ *Disruptions caused by humans.* Numerous human activities disturb birds, causing escape flights. If disruptions occur in areas that birds frequent or where they gather and there are power lines nearby, these changes in direction can lead to collisions. However, it is also true that when disruptions are permanent, for example, a busy road, birds typically avoid the area, so the risk of colliding with power lines is low.

In conclusion, the main factor that determines whether collisions occur is the presence of certain types of bird, whose biology and behaviour make them more susceptible to this kind of accident. In addition, certain habitat features and power line locations can make lines particularly dangerous.

Figure 67. In wooded areas, the risk of collision is higher when conductors pass just above the treetops. © Íñigo Fajardo

Figure 68. Many collisions occur at dusk and dawn, since the lines are less visible, and a large number of birds move around at these times. © Justo Martín

4.2. POWER LINES POSING A HIGH COLLISION RISK

Collisions are **typically concentrated along particular line sections** due to several factors that may influence their visibility and birds' ability to detect them. Such sections are located in areas where certain species are more abundant and congregate in large groups during the breeding and/or wintering seasons at their feeding or breeding grounds, as in the case of waterbirds, storks, bustards, cranes and certain passerines (Figure 69).

It is hard to set limits but, by applying the maximum precautionary principle, locations close to **bird aggregation sites, nesting platforms, breeding colonies, roosting sites**, etc. should be considered high-risk situations (Figure 70) (see Appendix A for a more detailed description of the situations).

Figure 69. Collisions are concentrated in some places due to several factors that influence power line visibility and birds' ability to detect them. A greater flamingo (*Phoenicopterus roseus*) killed by an electric power line perpendicular to the flight path generally used by these birds to fly between different wetlands. © Justo Martín

Even though this has not been proven, one aspect might be the position of the power lines in relation to **sunrise and sunset**; lines that run north–south could pose a greater potential risk than those that run east–west, depending on the birds' flight paths. When birds fly towards the sun at dawn or dusk, lines perpendicular to their path could be less visible to them because they are dazzled by the sun and cannot see the lines in front of them (Ferrer & Janss, 1999).

Seasonality and weather conditions must also be taken into account. The problem will be more common at times of the year when the largest congregations of susceptible birds (such as wintering waterfowl) occur and when visibility is often poor (especially in winter or rainy or foggy weather). In addition, as natural habitats or crops change over the seasons or as land use is altered over time, the risk will also change.

Finally, another environmental factor is the presence of **man-made structures** that might distract a bird's vision and ability to detect wires, like rotating wind turbines. A case study conducted within the Migratory Soaring Bird Project–Egypt (BirdLife International, 2021) has documented many soaring birds (especially pelicans and storks) colliding with power lines adjacent to operational windfarms in Egypt.

Figure 70. All power lines located near areas where birds congregate involve a greater risk of collision. Congregation of white storks (*Ciconia ciconia*) in a rice field. © Daniel Burón

4.3. ANTI-COLLISION MEASURES (PREVENTATIVE, MITIGATING AND CORRECTIVE)

There are different types of measures for avoiding collisions and they can be classified by the time at which they are applied into preventative measures and corrective and mitigating measures. The former are designed to avoid the problem before it occurs, while the latter resolve it totally or partially, permanently or temporarily depending on the sustainability of the solution adopted. Most preventative measures can also be used for correction or mitigation if they are applied a posteriori, when they may involve structural modifications to the power line (see reviews by Prinsen et al., 2011b; APLIC, 2012; Ferrer, 2012; Bernardino et al., 2018; European Commission, 2018). The selection of anti-collision measures should take into account not only the technical and economic possibilities of each location, so as to make the best use of available resources and efforts, but also the target species, which will be the most sensitive ones that suffer the greatest impact at local level.

Route planning. The best preventative measure is not to erect power lines in areas considered to be at high risk (Figure 71). This is possible with good planning when the routes for future power lines are designed, including during the environmental impact studies, the assessment of different routes and the choice of the most technically and economically viable and most environmentally friendly ones (see Chapter 8).

Undergrounding of electric power lines. This is the only totally effective and definitive way of avoiding collisions and it can be used with lines of all voltage levels. It can be adopted as a preventative measure or a definitive corrective measure on particularly problematic sites where other measures have proven ineffective and where the survival of threatened species is at stake. Once applied, it is quickly effective; in a region between eastern Austria and western Hungary, this measure reduced great bustard mortality due to collisions, and showed significant results in less than five years (Raab et al., 2012). Another example is the Stevin project, developed by the Belgian company Elia. The planned route of a new extra-high-voltage power line in the country ran for 5 km through a site of importance for both overwintering birds and breeding birds. It was determined that a significant effect on the birds could not be ruled out if overhead lines were used, so underground cabling would be the only option for this area (Renewables Grid Initiative, 2019). Apart from the environmental impact its installation entails (on the soil, vegetation, etc., at least during construction), and the technical problems involved in maintaining the line, the greatest disadvantage of undergrounding is its cost, 4–10 times higher than for overhead lines depending

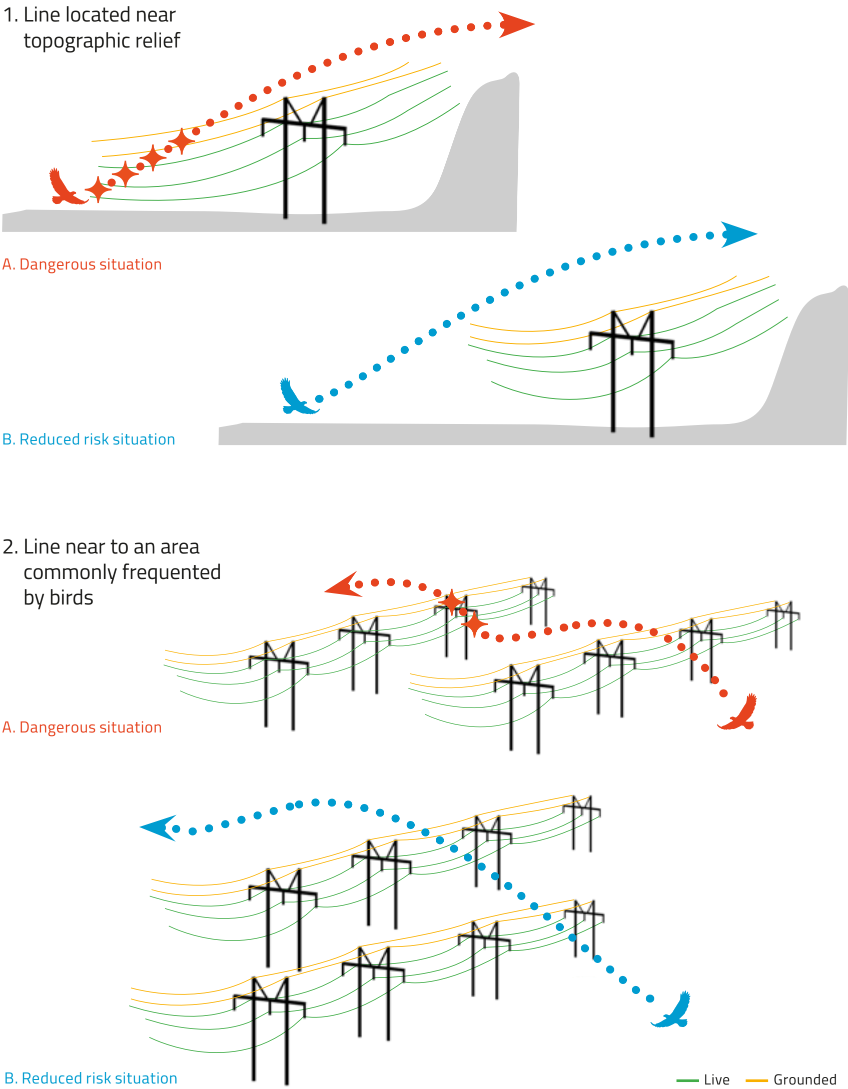

Figure 71. Route planning to avoid risky situations is essential to cut the collision risk to a minimum. Top: The route must consider flight paths and the local topography to avoid risky situations. Bottom: It is practical to combine the routes of neighbouring power lines to create a single obstacle and make it more visible; the efficiency is higher if the towers of the different lines are arranged alternately. Source: adapted from APLIC, 2012 and Pallet et al., 2022

on the terrain. If a line is not a new installation, but also involves the dismantling of an existing installation, the cost will soar. Maintenance costs are also higher. In addition, it is not always technically possible to bury the cables. Furthermore, as with any other measure, undergrounding must be considered in the framework of an overall environmental assessment. If it has a greater environmental impact than an overhead power line, it cannot be recommended.

> *Undergounding is a definitive solution for sites where other measures have proven ineffective and where the survival of threatened species is called into question.*

Habitat management. Given that the risk of collision is very directly linked to the passage of certain bird species, reducing their movements, for example, by creating new feeding and resting areas, may be a good means of prevention and mitigation a posteriori. However, besides the cost, it is not easy to change flight patterns and this measure should perhaps be reserved for very specific situations and species, and should always involve the marking of problematic lines.

Use of insulated and twisted conductors. This is a permanent measure; it consists of using insulated, twisted conductors to ensure that the risk of collision is very low, simply due to the presence of a single, very visible element. The cost of replacing an existing line is high; if the installation is new, such conductors require greater investment than bare cables. Moreover, there is a technical restriction because it is not possible to use this solution for voltages above 30 kV (Figure 72).

Modification of overhead line configuration. Taking into account the various structural factors affecting the risk of collision (presence of ground wires, conductors on different planes, increased danger mid-span), certain structural measures could theoretically be adopted and implemented to help reduce the risk. However, most of these measures are generally not technically and economically feasible and, in the rare cases where some of them have been applied, their effectiveness has not been proven (for more information, see the compilation in Bernardino et al., 2018).

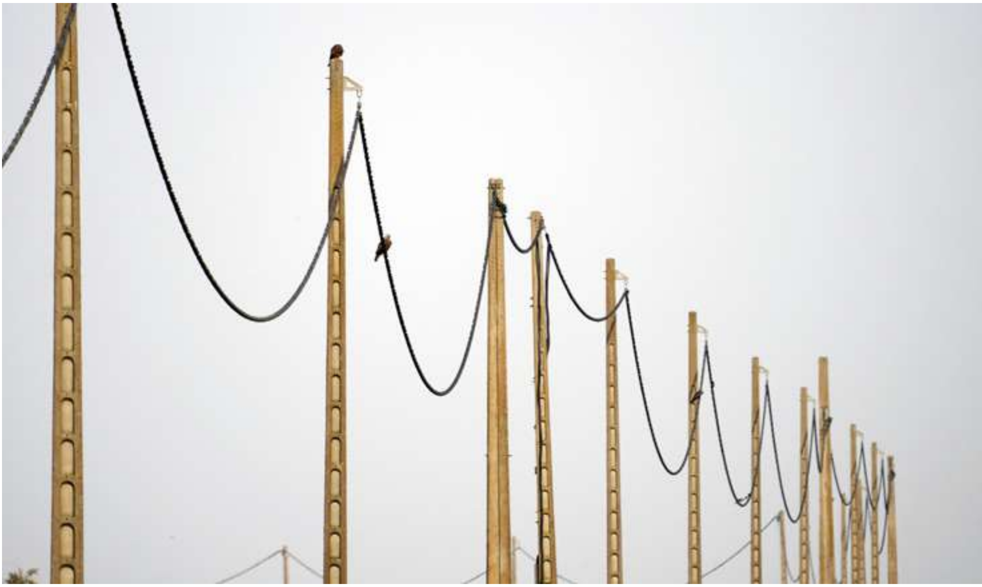

Figure 72. The use of insulated, twisted conductors is an effective measure against collisions, as it reduces the number of possible impacts and makes the conductors more visible. Distribution line with twisted cable. © Justo Martín

Installation of large-diameter ground wires. The use of OPGW (which have an optical fibre inner core) over 20 mm in diameter would help make them easier to distinguish from the conductors. This measure has been proposed (Bernardino et al., 2018), but no studies of its possible effectiveness have been carried out to date; this could be an interesting line of research to pursue in the future.

Marking of power lines. The addition of different types of marking device is the mitigation measure most frequently used to reduce collisions between birds and power lines. The generic term for these devices is line markers or bird flight diverters. Since they were introduced in the 1960s in some European countries, a variety of types of material have been tested: different sizes of PVC spiral, plastic or neoprene strips, fixed and rotating reflective hanging plastic plates, metal photoluminescent marker spheres ('aviation balls') in two contrasting colours, lighting devices powered by the conductor itself, etc. (Figure 73). These markers are installed on sections where collisions have occurred and preventatively on sections that are potentially dangerous or high risk (see previous section).

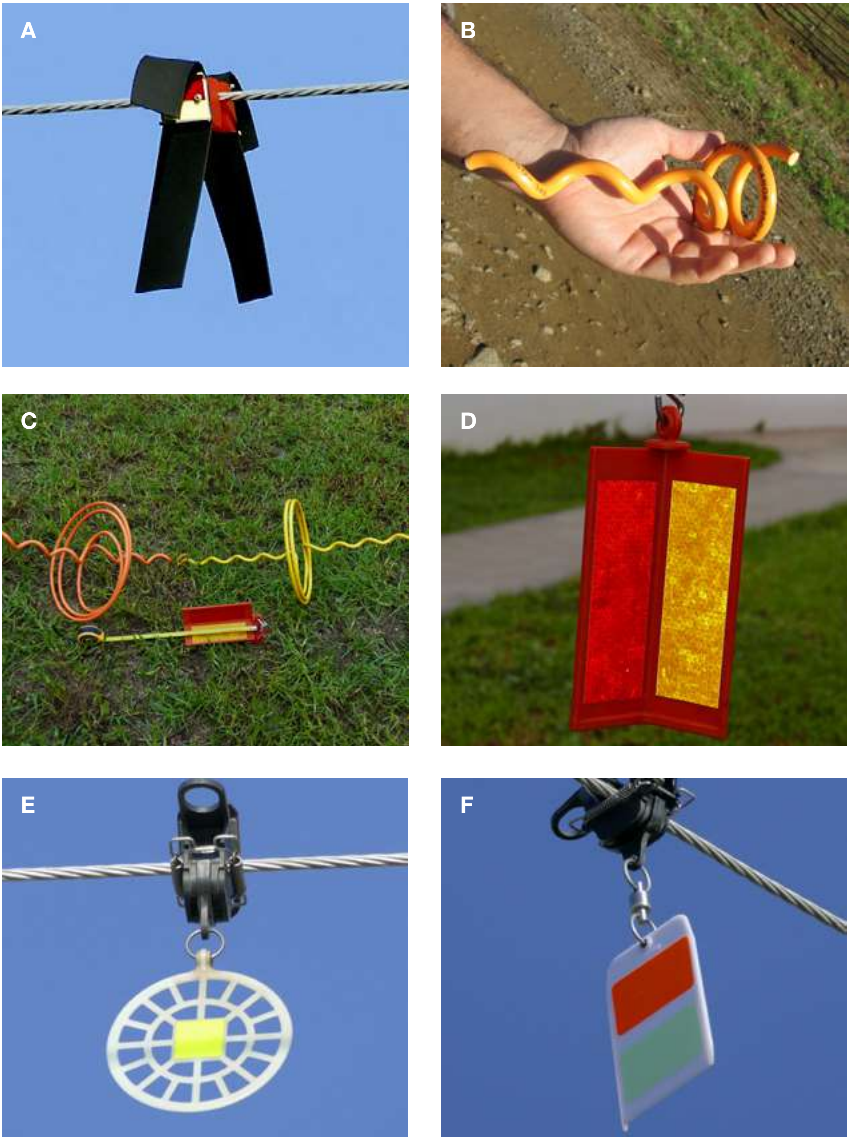

Figure 73. Types of bird flight diverter. A: neoprene strips. B: 'pig tail' spiral. C: types of spiral (tape measure and marker to compare the size). D: three-sided reflective rotating marker. E: double-sided reflective fixed marker. F: double-sided reflective rotating marker. © Justo Martín

4.4. EFFECTIVENESS OF ANTI-COLLISION MEASURES

Undergrounding power lines is the only way to eliminate all collision risk with certainty, but it is expensive and can create other detrimental environmental impacts. The efficacy of other anti-collision measures is harder to assess. Marking, one of the most popular measures, has been proven to reduce collisions. There are several types that vary widely in effectiveness. The reduction in risk reported in published studies and the grey literature ranges from under 10% to over 90%, with an average of about 50% (Barrientos et al., 2011; Bernardino et al., 2019). The most recent studies seem to indicate that devices with moving elements ('active' line markers) are more effective than 'passive' markers without movement (Bernardino et al., 2018; Ferrer et al., 2020; Figure 74). The **effectiveness of each type of marking depends on a number of factors**, including the kinds of birds involved (Bernotat et al., 2018; Liesenjohann et al., 2019); it is worrying that line marking appears not to work for bustards, which are often the most threatened species affected and for which there is, therefore, an urgent need to investigate other mitigation options (Marques et al., 2020; Shaw et al., 2021). This group of birds seems to have particularly poor forward vision in flight (Martin & Shaw, 2010).

In addition to movement, reflective and glow-in-the-dark surfaces and illumination make line markers more visible in low-light conditions, when the visibility of monochromatic markers is poor (Martin, 2011a). These types of line markers warrant further study however, in part to quantify their effectiveness, and in part to ensure there are no unintended consequences of the lighting.

Figure 74. Markers with mobile and reflective elements appear to be the most effective. They are also very simple to install and do not require the power to be interrupted. © Justo Martín

In most installations, line markers are placed every 5 m (Jenkins et al., 2010) (Figure 74). On distribution lines, this 5 m spacing is sometimes applied to the group of wires, so for example, if there are three conductors (A, B, C) and a ground wire (G), line markers are installed in the following pattern: conductor A, skip 5 m, conductor B, skip 5 m, conductor C, skip 5 m, ground wire G, skip 5 m, and back to conductor A (see Appendix A, recommendations). **Staggering line markers** on the wires in this way results in a line marker occurring at 5 m intervals across a marked span, but only at 20 m intervals on each individual wire (Figure 75). In other cases, line markers are placed only on the **upper conductors in an alternating pattern**. When multiple circuits are present, often only the outside wire on each circuit is marked (Cerezo et al., 2010; APLIC, 2012).

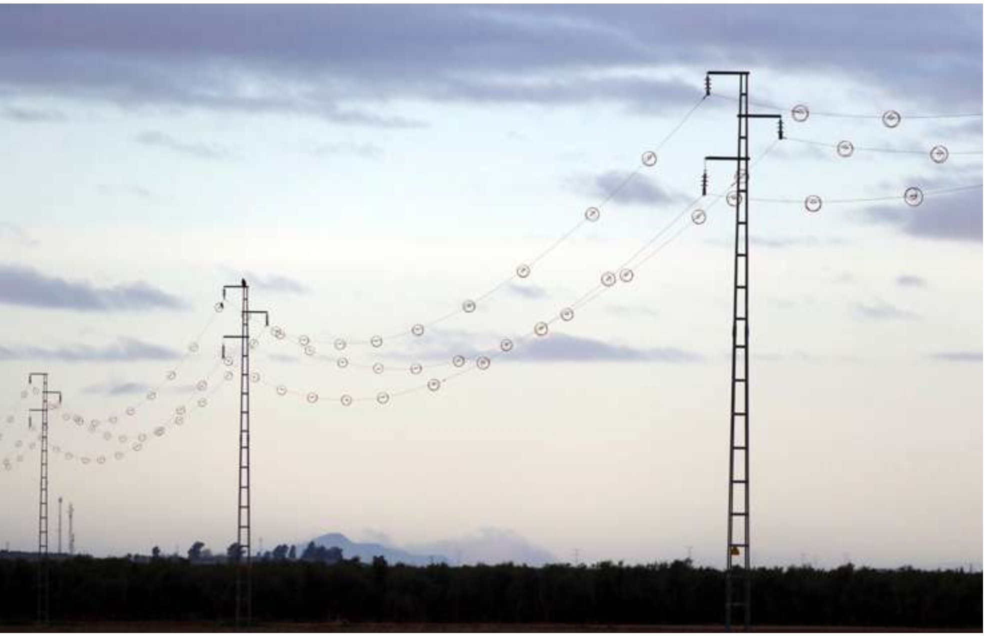

Figure 75. Line markers installed in an alternating pattern on the three conductors of a distribution line. © Justo Martín

On transmission lines, typically only the overhead ground wire(s) are marked (Figure 76). This results in a line marker fitted every 5 m if only one overhead ground wire is present or staggered every 10 m on each wire if two overhead ground wires are present.

Figure 76. Line markers installed in an alternating pattern on two overhead ground wires of a transmission line.

Line markers can fade, break, slip along the span or become obsolete as time passes. For these reasons, line markers **should not be considered a permanent, maintenance-free solution**. They may require periodic maintenance, and are often not 100% effective even then (Figure 77).

Figure 77. Although line markers reduce mortality, they are not 100% effective. A wing caught on a power line after a bird collided with a conductor equipped with an anti-collision system. © Íñigo Fajardo

The following table (Table 4-1) presents a summary of the main preventative and corrective anti-collision measures, as well as the various factors to consider when choosing which method to adopt:

Table 4-1. Characteristics of the main preventative and corrective anti-collision measures.

Measure	Type	Character	Duration	Cost	Effectiveness
Route planning	Non-structural	Preventative	Permanent	Medium–low	Medium–high
Habitat management	Non-structural	Preventative/ mitigating	Permanent	High–very high	Medium–high
Under-grounding	Structural	Preventative/ mitigating	Permanent	Very high	Total
Twisted cable	Structural	Preventative/ mitigating	Permanent	High–very high	High
Line configu-ration	Structural	Preventative/ mitigating	Permanent	High–very high	Low
Thicker ground wire	Structural	Preventative/ mitigating	Permanent	High	High
Line markers	Non-structural	Preventative/ mitigating	Non-permanent	Medium–low	Low to high

Source: compiled by the authors.

4.5. RECENT ADVANCES IN LINE MARKING AND MONITORING

Line marking

Line markers have **traditionally** been **installed on transmission lines manually** by specialised operators, by means of specially designed devices or even by helicopter crews (Figure 78). In this last case, teams of up to four highly trained experts (a pilot, two transmission linemen, and a helicopter refueller–maintenance specialist) work together to install line markers. The process is dangerous, involving the pilot manoeuvring a helicopter close enough to the ground wires for a transmission lineman to reach out from the aircraft to manually install each line marker. The process is also **logistically complex**, requiring coordination between an electricity company, a highly sought-after and expensive helicopter crew, an aviation regulatory agency, and an environmental regulatory agency needed to grant the permissions required for field refuelling and potential disturbance to wildlife. Electricity companies also must have contingency plans in place in case of accidents. Collectively, these challenges of safety, cost and logistics limit when and where line markers can be installed, and consequently they limit mitigation of avian collisions even in situations where collision mitigation is warranted and desired.

Figures 78 and 79. Helicopter installation of line markers (left). The UAS-deployed Linefly line marker installation robot (Fulcrum Air, Calgary AB) (right). © EDM International, Inc. (left) and James F. Dwyer and Richard E. Harness (right)

Figures 80, 81 and 82. Installation of flight diverters by drone. © James F. Dwyer and Richard E. Harness

Recently, research teams in the United States and Europe have developed **unmanned aircraft systems** (UAS) capable of deploying line markers (Figures 79, 80, 81 and 82; Acklen et al., 2020). UAS deployment eliminates the human risk associated with helicopter operations. UAS installations can also be less expensive and less logistically challenging, provided that the electricity company involved has already approved UAS operations generally. Another recent development in reducing avian collisions with power lines is **illuminating the lines** so that birds can see and avoid them. This approach was used in Hawai´i, USA, with lasers, and in Nebraska, USA with ultraviolet light. In Hawai´i, the approach was partially effective, but the green lasers were visible to people, which limits their likely utility in broader applications. In Nebraska, the approach was nearly 100% effective in reducing sandhill crane (*Grus canadensis*) collisions with a power line where previously hundreds of sandhill crane collisions occurred annually (Figure 83; Dwyer et al., 2019).

Figure 83. The Avian Collision Avoidance System shines ultraviolet lights on power lines to prevent sandhill crane (*Grus canadensis*) collisions, Nebraska, USA. © James Dwyer/EDM International, Inc.

Monitoring and reporting of collisions

It is expensive to manually monitor collisions as observers need to stay in the field for extended periods. Additionally, human observers have difficulties detecting events at night and during inclement weather. To address these challenges **automated devices** have been developed to assess bird mortality. These means of detection include:

- Bird Strike Indicators (BSI);
- Animal Activity Monitors (AAM).

A BSI (Figure 84) uses accelerometers to detect vibrations caused by bird strikes, and then records the signal data (Figure 85) and sends them to a base station, where the avian monitor can be remotely contacted via the internet or phone. BSIs have been used successfully on several projects, with results published by Pandey et al. (2007) and Harness et al. (2003). They have successfully detected crane collisions and outperformed visual observers at night (Murphey et al., 2009). They have also been used to test the efficacy of bird flight diverters (Luzenski et al., 2016).

The Electric Power Research Institute (EPRI; USA) is also developing an Animal Activity Monitor (AAM) which uses smart vision thermal cameras (Figure 86) to monitor and report collisions (Figure 87) (EDM International, Inc., unpublished data). These cameras use an algorithm to separate bird activity from other sources of background movement, such as clouds and wire movement due to wind.

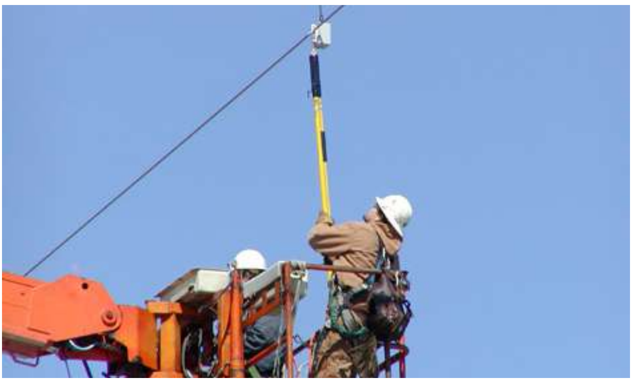

Figure 84. Line workers install a BSI on an overhead ground wire. © James F. Dwyer and Richard E. Harness

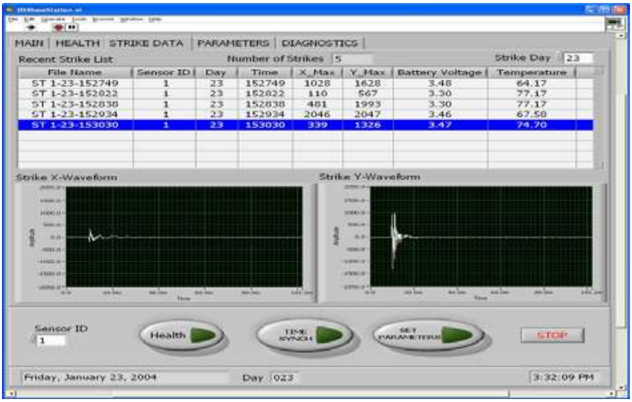

Figure 85. Bird strike signal captured and sent to base station. © James F. Dwyer and Richard E. Harness

Figure 86. Smart vision cameras installed on a transmission tower to monitor collisions. © James F. Dwyer and Richard E. Harness

Figure 87. Camera system capturing video footage of numerous passerines crossing the transmission line. © EDM International, Inc.

Such devices can be placed on power lines and help in the direct monitoring of collision mortality. In addition, **citizen science and new technologies** (including mobile phone apps and web platforms) can be very important tools for monitoring power line impacts and collecting information on fatalities (see Sections 7.1 and 7.5).

5 Electrocutions

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5.1. CAUSES OF ELECTROCUTION RISK

As mentioned in previous chapters, electrocution can occur in two ways: by contact between two conductors or, more frequently, by contact between a conductor and an earthed metallic structure (the crossarm itself or a ground wire), and birds are among the groups most seriously affected (Figures 88 and 89). Given the distance between supports, the spacing between conductors and the length of the insulators, **electrocutions are only frequent on power lines with voltages below 45 kV**. Death is usually caused directly by the electrical discharge, although in some cases in which the shock is not fatal the birds die as a result of falling from the top of a structure (Haas, 1980). The contact leaves characteristic burn marks on the animal (Haas, 1980; Oledorff et al., 1981; Ferrer et al., 1991). Electrocution occurs above all in **medium-to-large birds** that habitually perch on top of pylons. Unfortunately, this description precisely fits birds of prey, which, moreover, are generally scarce and in many cases threatened with extinction.

Figure 88. When a bird perches on a cable, there is no risk of electrocution; but if it perches on a metal part and there is a conductor nearby, the risk is much greater. Left, a Eurasian jackdaw (*Corvus monedula*); right, a black kite (*Milvus migrans*). © Daniel Burón

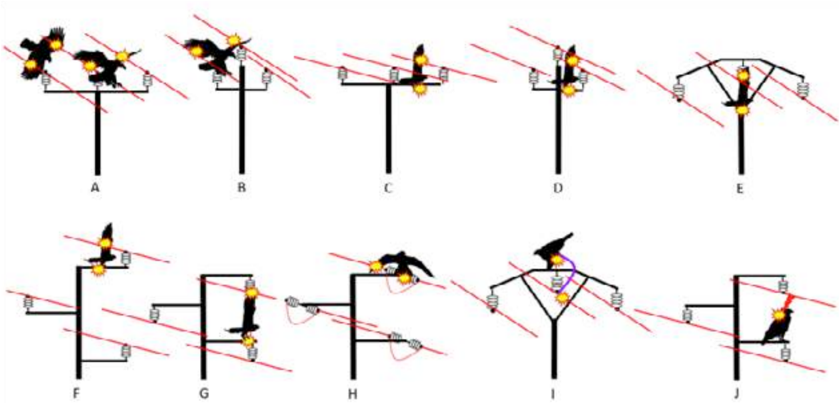


Figure 89. Electrocution usually occurs when the bird's body touches two conductors (A and B) or a conductor and a metal grounded part (C to H) at the same time. More rarely, electrocutions may result from defecation (I) or the formation of an electric arc (J). Note that in the case of ungrounded crossarms, electrocution can only occur by contact between two phases; i.e. cases A and B. Source: prepared by Justo Martín Martín based on Martín Martín et al., 2019.

Under normal conditions (dry plumage), feathers are very poor conductors of electricity, but this depends on atmospheric humidity. The most vulnerable point is usually the metacarpal bones (the bird's 'wrist'). In countries using metal lattice pylons, most electrocutions occur **when a bird touches a phase with one wing when perching on the crossarm;** in most cases, contact takes place between one wing and the opposite leg (GREFA, unpublished data). Contact may occasionally be made with the head or the bill depending on the pylon design (Ferrer & Janss, 1999; Figures 89, 90 and 91). The risk increases if the bird's plumage is wet, because water is a good conductor of electricity (APLIC, 2006).

Figure 90. The red area shows the extent of the skin (living tissue) on the underside of the wing; the rest is dead tissue (feathers). © Justo Martín

Figure 91. Electrocution generally occurs as a result of contact with areas of bare skin or sparse plumage. Area where electrical discharge exited on the underside of the wing of a short-toed snake eagle (*Circaetus gallicus*). © Justo Martín

In other cases, electrocution is the result of **indirect contact**, as sometimes occurs when a raptor takes its prey to a pylon to feed. The prey item may hang down and touch a conductor, allowing the electricity to flow through the bird, which is in contact with a metal part (Figure 89). This has been documented for species such as the Eurasian eagle owl, the black kite and the short-toed snake eagle (*Circaetus gallicus*). In the case of the short-toed eagle, the type of prey the species prefers (snakes) makes electrocution more likely (Ferrer et al., 1991; Ferrer, 2012).

Electrocution can have other, less frequent causes, but they also result in large numbers of victims (Ferrer & Janss, 1999; APLIC, 2006; Ferrer et al., 2012; Demerdzhiev, 2014; Garrido & Martín, 2015; Figure 89). They include:

- **Electrocution due to the formation of an electric arc.** An electric arc is formed when a current jumps between two conductors through a non-conducting medium like air (Ayrton, 2012). Since air is a poor conductor of electricity, it can be considered a good insulator. However, when the difference in electrical potential between two conductors exceeds a certain value, the air itself can become an electrical conductor causing a powerful electrical discharge between the two conductors. The distance at which the discharge occurs depends on the voltage difference and the atmospheric conditions: the wetter the environment, the longer the electric arc can be. So, on foggy or rainy days (particularly during light rain), in areas with high relative humidity, or when the bird has wet feathers, an electric arc can form between the bird and the conductor as the animal approaches the wire even without actually touching it. In saltwater environments (saltmarshes, or close to the sea), this risk is even higher (Figure 92).

> *Most electrocutions occur when a bird touches a phase with one wing when perching on a metal lattice pylon, usually when the bird lands or takes flight. Other causes, although less frequent, are also possible.*

Figure 92. Electrocution through the formation of an electric arc is rare, although it is possible when the relative humidity is high or the bird has wet feathers. Bonelli's eagle (*Aquila fasciata*) injured due to the formation of an electric arc. © Ernesto Ferreiro

➔ **Electrocution by 'unfortunate defecation'**. When large birds defecate, they produce a jet of excrement (a streamer) of considerable length, semiliquid in consistency and rich in salts, which is an excellent electrical conductor (Figure 93). If they defecate on a pylon, the jet can act as a line that connects the bird with the conductor below (apparently at a safe distance) before the other end has been completely expelled from the bird's cloaca. Electrocution is in this case the fatal result of an accident, which can occur quite frequently if the pylon in question is often used as a perch.

Figure 93. Defecation by large raptors in the form of a long jet leads to many electrocutions when the end of the jet comes into contact with a conductor below the metal crossarm. Bonelli's eagle. © Daniel Burón

5.2. FACTORS THAT INFLUENCE AND DETERMINE THE RISK OF ELECTROCUTION

Bird mortality on power lines has been observed globally wherever there are hazardous power lines and susceptible species (see Chapter 3). The risk of electrocution for a bird (or other groups affected) depends on **three types of factors** (see the reviews by APLIC, 2006; Lehman et al., 2007; Prinsen et al., 2011a; Ferrer, 2012; Environmental Impact Services, 2013; Eccleston & Harness, 2018):

- **The structure, configuration and presence of devices on the supports;**
- **The bird species;**
- **Environmental factors.**

As explained above, **the risk of electrocution is directly linked to the design of the support**, which determines the likelihood of the animal making contact with two conductors or with one conductor and ground at the same time. This is the main factor; crossarms in which the layout of the elements facilitates this contact pose a high risk (see Appendix A, where this aspect is discussed in detail, and Section 5.5).

Many other factors influencing the effect of power lines on birds are linked to the biology (size, morphology and behaviour) of the species involved (see Section 5.3). Finally, environmental factors such as topography, food availability, type of habitat and weather conditions have a variable impact, modifying the risk determined by the other two factors.

Figure 94. Electrocution is one of the main conservation problems for large eagles (golden, Spanish imperial and Bonelli's eagles). In the photo: golden eagle (*Aquila chrysaetos*). © Justo Martín

5.3. BIRDS SUSCEPTIBLE TO ELECTROCUTION

Some species or groups of species are more prone than others to either electrocution or collision with power lines (see reviews in APLIC, 2006; Lehman et al., 2007; Prinsen et al., 2011a; APLIC, 2012; Ferrer, 2012; Bernardino et al., 2018; Eccleston & Harness, 2018).

Susceptibility factors

Three main types of factors (Bevanger, 1994) determine a bird's susceptibility to electrocution:

- ➜ The bird's morphological characteristics, which determine how easily contact can take place;
- ➜ The bird's behaviour, since a species' tendency to use power lines will determine how susceptible it is to this problem;
- ➜ Other factors that may have an impact, such as the bird's sex or age.

Morphological characteristics. It is obvious that larger birds have a higher risk of electrocution, because they can make a dangerous contact more easily (APLIC, 2006; Lehman et al., 2007). Birds that stand over 1 m tall (medium-sized or large raptors, storks, etc.) are considered the most vulnerable (Figure 94). On some pylons with transformers or disconnectors or a large number of conductors, electrocutions can affect almost any bird species. There are reported cases involving peregrine falcons and common kestrels, small nocturnal raptors including owls, such as the Eurasian scops owl (*Otus scops*), and even passerines such as starlings and finches.

Behaviour. Among medium-sized or large species, those that tend to use power line poles and pylons as hunting look-out spots, perches or roosts are the most susceptible. Of these species, raptors are probably the group most affected (Ferrer et al., 1991; Ferrer & Hiraldo, 1991, 1992; Ferrer & Negro, 1992; Janss & Ferrer, 1998, 1999, 2001; Sergio et al., 2004; Ferrer, 2012), in particular large eagles, vultures, buzzards and kites, which look for food in relatively unobstructed areas. Species that prefer forests, such as falcons, hawks, the short-toed snake eagle and the booted eagle, tend to be less susceptible, because in their environments there are many natural perches as alternatives to electricity poles. Nocturnal birds of prey deserve special attention here because, despite the fact that they hunt from perches, they are generally less likely to be affected by this problem (Figure 95). Since they use their hearing to find and locate prey, they need lower perches than those provided by medium- and high-voltage power line supports. Only larger species (e.g. the Eurasian eagle owl), whose larger size and more sensitive hearing allow them to use higher supports, display high electrocution rates (Taylor, 1994; Fajardo, 1998).

Figure 95. Small and medium-sized nocturnal raptors are not seriously affected by electrocutions. They typically use lower perches than those provided by medium- and high-voltage power line supports. Barn owl (*Tyto alba*). © Justo Martín

It should be kept in mind that the constant use of a support increases the risk by pure probability, so electrocutions can be also recorded on relatively safe supports if they are used intensively (Godino et al., 2016; Garrido et al., 2018a).

In the case of gregarious species that use power line pylons and poles as roosts or just as resting places (cattle egret – *Bubulcus ibis*, griffon vulture – *Gyps fulvus,* kites and storks, for example), a large number of simultaneous electrocutions can occur if the birds come into contact with the cables, so that if one of them receives an electric shock, the whole group will be electrocuted (Figure 96). This risk is clearly higher on rainy or foggy days, because of both their wet plumage and the increased risk of electrical arcing. The behaviour of species like kites and vultures that perch on pylons with outspread wings to warm up in the sun or to get dry after rain increases the risk of group electrocutions.

Figure 96. Gregarious species that use power lines as resting places are at risk of multiple electrocutions. Group of northern bald ibises (*Geronticus eremita*) resting on a power line support. The whole group is at risk of electrocution. © Francisco Peña

This type of accident even occurs on transmission line pylons, which are generally safer due to the greater spacing between conductors. In these cases, electrocution occurs because different birds in close contact touch the conductors, closing the circuit and electrocuting them all (Ferrer, 2012). Another group of species at risk includes those that use pylons as nesting platforms, such as storks, certain eagles (Spanish imperial eagle – *Aquila adalberti,* Bonelli's eagle – *Aquila fasciata*, see Section 3.2), corvids, falcons and kestrels.

Other factors. Sex can be a risk factor, due to both the difference in size (in raptors, the female tends to be bigger; Ferrer & Hiraldo, 1992) and differences in behaviour between males and females (Dwyer, 2009). The bird's age also plays a role. In some species, such as the Spanish imperial eagle (Figure 97), young individuals have been shown to be more susceptible to electrocution (Ferrer & Hiraldo, 1991).

The risk of electrocution depends not only on the design of the support, but also on the frequency of use by animals.

Figure 97. Young Spanish imperial eagles (*Aquila adalberti*) are more susceptible to electrocution than adults. © Daniel Burón

Susceptible bird groups

In general, the bird groups most affected by electrocution are storks, medium-sized and large raptors (diurnal and nocturnal) and corvids (Lehman et al., 2007; see Chapter 3). In coastal zones, members of the family Laridae may account for a large proportion of victims – up to almost 30%, according to studies carried out in Menorca, Spain (de Pablo, 2017). Parrots, with many colonial, gregarious and medium to large-sized species, are another sensitive and perhaps underestimated group (Galmes et al., 2008; Tinoco et al., 2022).

Deaths caused by power lines have different consequences according to the demographic and biological characteristics of the affected species. If the species is abundant and the effect is local, its impact on the population may be almost negligible. However, if the effect is widespread and concerns a rare species, it becomes the species' main mortality factor, jeopardising its future survival or recovery (see Chapter 3).

In general, the species most seriously affected are those with one or more of the following characteristics:

- ➜ Species present at **low population densities** and thus with a limited ability to replace individuals;
- ➜ Species with **low breeding potential**, in which an increase in adult mortality prevents population losses being replaced;
- ➜ Species with **low fertility rates, low natural mortality rates and long life expectancy**, in which the stability of the population depends on a high adult survival rate;
- ➜ **Rare and threatened species**, in particular if other unfavourable characteristics also apply (low density, low fertility rates, etc.).

5.4. OTHER VERTEBRATES SUSCEPTIBLE TO ELECTROCUTION

Although data shows that large bird species are most impacted by electrocution, there are also other groups affected. Some climbing **reptiles**, such as black and common iguanas (*Ctenosaura similis* and *Iguana iguana*), arboreal snakes (boa constrictor – *Boa constrictor*) and even some **amphibians**, also seem to be susceptible to electrocution on distribution power lines (Rodríguez et al., 2020). Among **mammals**, several primate species have been involved in such accidents (Boinski et al., 1998; Lokschin et al., 2007; Ferrer, 2012; Kumar & Kumar, 2015; see Case studies 4 and 16). However, while electrocution of birds is a well-known problem worldwide, there is little information on the impact of power lines on mammalian species, especially carnivores. Here we have compiled reports of electrocuted mammals from around the world, which suggests that this is indeed a global problem, the true extent of which is far from well known (Figure 98; see Chapter 3).

Figure 98. Records of electrocuted mammals, including carnivores, from around the world suggest that this is a global problem, the true extent of which is far from well known. A pair of electrocuted Eurasian lynxes (*Lynx lynx*) photographed in Sayin-dareh, Abyek County, Iran. © Mahmood Kolnegari

Reports of electrocuted mammals include large herbivores such as the Asian elephant (*Elephas maximus*) in India and the African elephant (*Loxodonta africana*) and giraffe (*Giraffa camelopardalis*) in South Africa; large carnivores such as the cougar (*Puma concolor*) in the USA, lion (*Panthera leo*) in South Africa, leopard (*Panthera pardus*) in India and South Africa and striped hyaena (*Hyaena hyaena*) and Eurasian lynx (*Lynx lynx*) in Iran; and some cases of medium-sized carnivores such as the common genet (*Genetta genetta*) and mongoose (*Herpestes ichneumon*) in Spain (Thompson & Jenks, 2007; Ferrer, 2012; Vedamanickam et al., 2015; Menon et al., 2017; Kolnegari et al., 2018; Talukdar et al., 2018; Eskom-EWT Strategic Partnership, Unpublished;

see Chapter 3). Another climbing mammal reported as a victim of electrocution is the woolly opossum (*Caluromys derbianus*) in Central and South America (Saavedra-Rodríguez et al., 2013; Rodríguez et al., 2020). There are also data on large bats of the genus *Pteropus* that sometimes use electricity cables for resting (Martin, 2011b; Chouhan & Shrivastava, 2019; Tella et al., 2020). All these records support the idea of a widespread but poorly known impact of power lines on mammalian species (Figure 99 and Table 5-1).

Figure 99. Climbing carnivores are particularly susceptible to electrocution. Common genet (*Genetta genetta*) electrocuted on a medium-voltage support in northern Africa. © Justo Martín

Two main scenarios account for electrocutions of animals that it would be difficult to imagine climbing a power pole. Some, like elephants, deer and hyaenas, were electrocuted by bare wires (without insulation) near the ground. Some authors have suggested that this kind of incident is more likely on wooden-pole lines due to deterioration of the wood or because other animals, like wild boar (*Sus scrofa*), knock down the poles, leaving bare wires close to the ground. Other animals like cougars, lynxes and genets are usually found on poles where there is already another electrocuted animal, typically a bird, at the top of the pole, suggesting that they had tried to climb up to get the previous victim (see Chapter 3).

There is not much information about how these accidents happen but if in some cases the mammal tries to climb the pole, some **anti-climbing system** would be an effective measure to mitigate this problem (see Case study 4 and Appendix B). Other mitigation measures to tackle the electrocution of non-climbing animals on the ground due to fallen wires could focus on **renewing wooden poles or replacing them with more resilient types**, e.g. concrete or metal poles. Because birds face the risk of phase-to-earth electrocution on non-wooden poles, the design of the replacement poles should be safe for both birds and other animals.

Table 5-1. Reports of mammals (non-primates) and reptiles electrocuted in different countries.

Species	Country	Source
Australian flying fox (*Pteropus* spp.)	Australia	Martin (2011b)
Indian flying fox (*Pteropus giganteus*)	India Sri Lanka	Chouhan & Shrivastava (2019) Tella et al. (2020)
Straw-coloured fruit bat (*Eidolon helvum*)	Zimbabwe	Skinner & Chimimba (2005)
Asian elephant (*Elephas maximus*)	India	Menon et al. (2017), Talukdar et al. (2018)
African elephant (*Loxodonta africana*)	South Africa	Eskom-EWT Strategic Partnership (Unpublished)
Giraffe (*Giraffa camelopardalis*)	South Africa	Eskom-EWT Strategic Partnership (Unpublished)
Cape buffalo (*Syncerus caffer*)	South Africa	Eskom-EWT Strategic Partnership (Unpublished)
White-tailed deer (*Odocoileus virginianus*)	USA	DePerno et al. (2005)
Cougar (*Puma concolor*)	USA	Thompson & Jenks (2007)
Lion (*Panthera leo*)	South Africa	Eskom-EWT Strategic Partnership (Unpublished)
Leopard (*Panthera pardus*)	India South Africa	Vedamanickam et al. (2015) Eskom-EWT Strategic Partnership (Unpublished)
Eurasian lynx (*Lynx lynx*)	Iran	Kolnegari et al. (2018)
Red fox (*Vulpes vulpes*)	Iran	Kolnegari et al. (2018)
Striped hyaena (*Hyaena hyaena*)	Iran	Kolnegari et al. (2018)
Common genet (*Genetta genetta*)	Spain Morocco	Ferrer (2012), Martín Martín (Unpublished) UICN & DEF (2020)
Mongoose (*Herpestes ichneumon*)	Spain	Ferrer (2012)
Stone marten (*Martes foina*)	Iran Spain	Kolnegari et al. (2018) Martín Martín (Unpublished)
Northern raccoon (*Procyon lotor*)	Costa Rica	Rodríguez et al. (2020)
Kinkajou (*Potos flavus*)	Costa Rica	Rodríguez et al. (2020)
Black-eared opossum (*Didelphis marsupialis*)	Costa Rica	Rodríguez et al. (2020)
Central American woolly opossum (*Caluromys derbianus*)	Costa Rica	Saavedra-Rodríguez et al. (2013), Rodríguez et al. (2020)
Grey four-eyed opossum (*Philander opossum*)	Costa Rica	Rodríguez et al. (2020)
Brown-throated three-toed sloth (*Bradypus variegatus*)	Costa Rica	Rodríguez et al. (2020)
Western tamandua (*Tamandua mexicana*)	Costa Rica	Rodríguez et al. (2020)
Mexican hairy dwarf porcupine (*Sphiggurus mexicanus*)	Costa Rica	Rodríguez et al. (2020)
Variegated squirrel (*Sciurus variegatoides*)	Costa Rica	Rodríguez et al. (2020)
Spiny tail iguana (*Ctenosaura similis*)	Costa Rica	Rodríguez et al. (2020)
Green iguana (*Iguana iguana*)	Costa Rica	Rodríguez et al. (2020)
Boa constrictor (*Boa constrictor*)	Costa Rica	Rodríguez et al. (2020)

Source: compiled by the authors

5.5. POWER LINES POSING A HIGH ELECTROCUTION RISK

Electrocutions do not occur randomly on supports but tend to be concentrated on certain ones. **Support design and the surrounding habitat are the main factors** accounting for the distribution of fatalities in a power line network (Ferrer et al., 1991; Janss & Ferrer, 2001; Guil et al., 2011; Ferrer, 2012; Figure 100).

Figure 100. Electrocutions are concentrated on supports with a dangerous configuration and/or where the topography and habitat favour their use by birds or by other animals, and where food is plentiful. Power line with very dangerous pylons, raised above the surrounding vegetation. © Daniel Burón

In general, the power line supports posing the highest electrocution risk to birds have the following **characteristics** (Ferrer et al., 1991; Janss & Ferrer, 2001; Mañosa, 2001; Ferrer, 2012):

- Supports with an exposed loop of wire or jumpers above the insulator;
- Supports with pin-type insulators;
- Supports with special designs, such as transformer poles;
- Supports located in transitional areas between ecosystems (ecotones);
- Supports in areas with a high density of prey and few natural perches;
- Supports in areas with a high concentration of birds: landfill sites, wetlands, recently harvested fields, etc. (Figure 101);
- Supports close to water sources during the dry season or in semi-arid or arid areas.

The support design characteristics are developed in greater detail in Appendix A.

Figure 101. Wetlands characterised by large concentrations of birds are areas where the risk of electrocution is high. Glossy ibises (*Plegadis falcinellus*) congregating in a rice field. © Daniel Burón

Accidents are therefore **concentrated on a very small number of supports** that meet these conditions; in some overhead lines, 13% of the supports are responsible for more than 90% of the electrocutions (Ferrer et al., 1991; Janss & Ferrer, 2001; Mañosa, 2001; López-López et al., 2011; Ferrer, 2012; García-Alfonso et al., 2021).

It is important to note that the electrocution risk depends not only on the support design but also on **how frequently such supports are used** by birds. In some habitats, the intensity of use may be higher due the lack of alternative natural perching sites (on cultivated land and in desert areas, for example). In such circumstances, a configuration that is not very dangerous but is used intensively is very likely to cause a higher mortality rate than a structurally dangerous configuration that is used only occasionally (Ferrer, 2012, Godino et al., 2016; Garrido et al., 2018a). Local meteorological conditions are a further factor influencing frequency of use.

Environmental factors include:

Characteristics of the surrounding habitat. The vegetation around power lines determines both their use as perches by raptors and the presence of prey species. The risk is higher in ecotone areas, which tend to be richer in food, or in areas with no trees or very scattered trees, while the risk is lower for power lines that run across wooded areas with trees that are taller than the pylons. Studies mentioned above in Morocco (Godino et al., 2016; Garrido et al., 2018a), Sudan (Angelov et al., 2013) and Mongolia (Dixon et al., 2017) are notable examples of this. One particular case is that of power lines located near wetlands; not only do some species in these environments use the supports as perches, but they may do so with wet plumage and even spread their wings to help dry them, which puts them at greater risk. In dry climates, lines located near water sources are particularly hazardous and cause many electrocutions (Izquierdo et al., 1997). Conversely, the existence of urban areas, houses or linear infrastructure such as busy roads or paths close by reduces the potential use of power lines, at least by the species most sensitive to human presence and activity (Figure 102).

Figure 102. Power lines located close to roads or transport routes are generally less frequently used by birds, in particular by species more sensitive to human presence. Road in southern Morocco. © Justo Martín

Weather. Electrocutions are more common on rainy days or when there is persistent fog, because wet plumage increases the conductivity of the bird's body, which also facilitates electrical arcing. This means that the number of electrocutions is higher during wet months. Strong winds can also increase the risk, as they make it hard for birds to control their flight and force perched birds to move to adjust their balance, which requires them to open their wings more often.

Other factors affecting the probability of electrocution are: (1) the **season** of the year (Lehman et al., 2007), the risk increasing at the end of spring and in autumn due to breeding and dispersal of species prone to electrocution; (2) the **passage of migratory species** (Godino et al., 2016; Dixon et al., 2017).

5.6. ANTI-ELECTROCUTION MEASURES (PREVENTATIVE, MITIGATING AND CORRECTIVE)

As in the case of collisions, a distinction can be made between preventative measures and corrective and mitigating measures; of these, corrective measures can be permanent or provisional depending on the sustainability of the solution adopted. Similarly, efforts must be focused on the most sensitive species that suffer the greatest impacts at local level; a measure that is necessary in one place may be completely useless in another. And just as importantly, measures must be realistic and take into account the technical and economic possibilities of each location so as to make best use of available resources and efforts.

The adoption of permanent measures on power lines with dangerous supports may involve the total or partial modification of the line, which is a very costly solution, but it may be the only effective one in certain cases (Figure 103).

> *Apart from wildlife considerations, economic cost is therefore another reason why new lines must be designed with permanent anti-electrocution measures from the outset.*

Figure 103. The modification of pylons and power lines is very costly, hence the importance of good planning and a safe configuration from the outset. Technicians modifying a pylon. © Justo Martín

The following are the measures most commonly used (APLIC, 2006; Prinsen et al., 2011b; Ferrer, 2012; European Commission, 2018; Guil et al., 2021):

Route planning. As in the case of collisions (see Section 4.3).

Undergrounding of electric power lines. As in the case of collisions (see Section 4.3).

Use of insulated and twisted conductors. This is a permanent measure but also expensive if an existing power line needs to be replaced. It consists of the use of insulated and twisted conductors, so that the risk of electrocution is reduced to zero (Figure 104). As with undergrounding lines, this is also an effective means of avoiding collisions. Twisted conductors are only viable for lines with a voltage below 35 kV. For higher voltages, up to 132 KV, it is possible to use separate insulated conductors.

Figure 104. The replacement of bare conductors with sheathed, twisted conductors eliminates the problem of electrocution permanently. Black stork (*Ciconia nigra*), short-toed snake eagle (*Circaetus gallicus*) and lesser kestrel (*Falco naumanni*) on a medium-voltage line with twisted cables. © Íñigo Fajardo

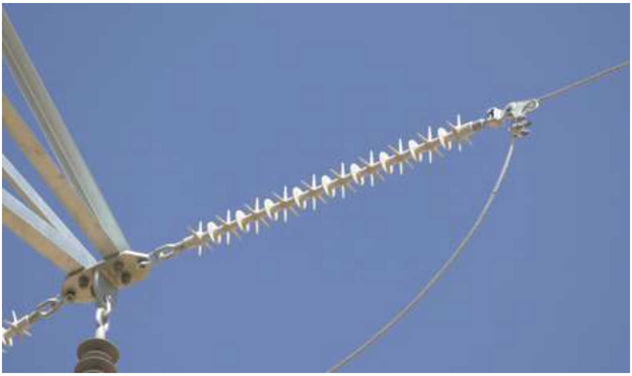
Use of supports with safe crossarm configurations. This is a permanent measure consisting of installing crossarm configurations that minimise electrocution risk (Figure 105). Where supports are known to cause electrocutions, total or partial replacement of the crossarm in order to make it safe is the only effective and permanent solution if the measures described above are not possible. Changing existing configurations is very costly, so safe configurations should always be used when building new power lines. The basic characteristics of these safe configurations must comply with the minimum safety distances (see Appendix A). Whenever possible, it is highly recommended to use supports with suspended insulators that move the phases away from the perching area.

Figure 105. The use of a bird-safe design is the best measure to minimise the risk of electrocution. Crossbar with suspended insulators in alternating arrangement, with safety distances between critical points. © Justo Martín

Appendix A includes a series of structural recommendations aimed at making the crossarm configurations most commonly used by electricity companies safe.

Installation of insulating elements and deterrent devices. This can be a temporary or permanent corrective measure (although it can also be preventative). It consists of increasing the distance between danger points or preventing their use by birds without making structural changes to the crossarm. There are several measures that can achieve this, and they can be used simultaneously or combined in different ways:

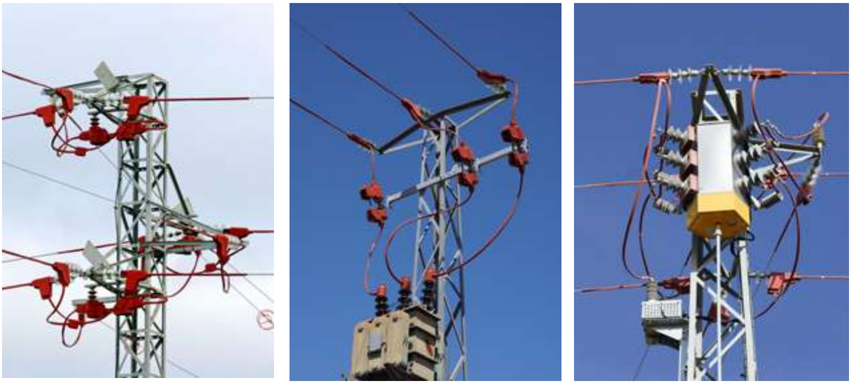
a) *Installing elements that increase the gap between the conductors on the crossarm.* This can be done by increasing the number of glass or porcelain insulators in the string, or even by using polymer insulators. These insulators either have a special shape to prevent birds landing on them or they are used with devices that stop them landing (Figures 106 and 107).



Figures 106 and 107. Polymer insulators can provide a greater horizontal safety distance from the perch area. This configuration either directly prevents birds using them (top) or else it is fitted with accessories that perform this function (bottom). © Justo Martín (top) and GREFA Power Lines Team (bottom)

b) *Covering the conductors and other live elements (surge arresters, fuses, disconnectors) with insulating materials, to ensure minimum safety distances.* Covered wires, insulating tape or preformed materials (sheaths and coverings) are used for this purpose; these preformed items made of plastic, PVC or silicone are specific to each type of element and interlock to form an insulating assembly (Figure 108). These coverings are also used in building new power lines with safe configurations, because some support types (supports with disconnectors or a transformer, termination supports, supports with a switch-disconnector, etc.) preclude a totally safe structure (Figures 109, 110 and 111). On metal crossarms, another possible type of insulation consists of placing rigid plastic sheaths on the parts where birds perch, so that they avoid contact with the ground connection of the pylon (Figure 112). To increase their efficiency, they can be combined with other insulating elements such as anti-perching devices. Adoption of this measure will depend on the configuration of the crossarm and insulators and the species present in the region. Currently, prefabricated insulated wires provide a permanent solution for jumpers, cable bridges and other connections on a pole or pylon. Use of these materials can lower the installation and maintenance costs of anti-electrocution measures.

Figure 108. Coverings consisting of preformed parts are the type of insulation most commonly used. Silicone is one of the materials used to make these pieces, since it provides high strength and durability. © Imad Kanouni

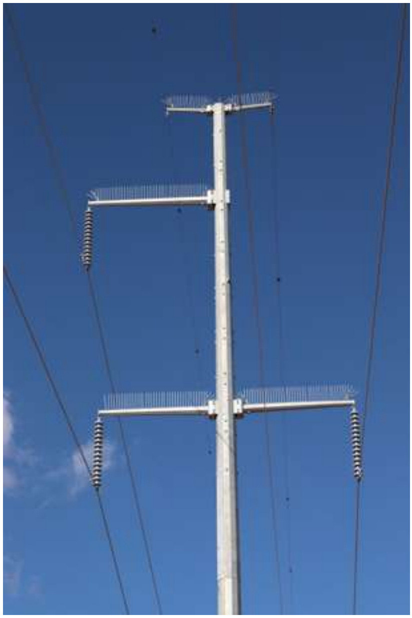


Figures 109, 110 and 111. Insulators with preformed parts are also used on lines with safe configurations, since they are necessary on supports with disconnectors (left), transformers (centre) or control and protection systems (right), for example. © Justo Martín

Figure 112. In some configurations, fitting rigid plastic sheaths on the crossarm is a good way of making them safe. Upland buzzard (*Buteo hemilasius*). © Mohamed bin Zayed Raptor Conservation Fund project – Mongolia

c) *Installing elements that discourage or prevent birds from perching on dangerous parts (anti-perching devices).* The purpose of these elements is to stop birds using the pylons for building their nests or perching, or at least to force them to do so in safer areas only. There are several different types of anti-perching devices, including perches and supports installed above crossarms, vertical rods, vertical metal plates, rods with swivel heads that turn in the wind (with or without mirrors), and supports with reflective elements similar to those used to prevent collisions. To prevent nesting, it is common to combine anti-perching devices with the provision of alternative artificial nests nearby (Figures 113 to 120).

Figures 113 to 116. (From left to right, top to bottom). Examples of perching deterrents. Figure 113. Rigid metal plates. © Justo Martín. Figure 114. Fixed "umbrella-shaped" metal anti-bird spikes. © Justo Martín. Figure 115. Combination of anti-perching deterrents. © James Dwyer. Figure 116. Rotating cups with anti-perching extension. © Álvaro Camiña

Figures 117 to 120. (From left to right, top to bottom). Further examples of anti-perching deterrents. Figure 117. Raised perch on top of the pylon combined with anti-perching deterrent; white stork. © Justo Martín. Figure 118. Anti-perching spikes. © James Dwyer. Figure 119. Raised platform for nesting; white stork nest. © Justo Martín. Figure 120. Combination of perching deterrents with an alternative artificial nest nearby. © Justo Martín

Figure 121. Mortality can be reduced considerably by only modifying supports where deaths are concentrated. © GREFA Power Lines Team

5.7. EFFECTIVENESS OF ANTI-ELECTROCUTION MEASURES

In addition to support configuration, factors such as density of prey or food, location, surrounding habitat and relief also influence the electrocution risk. This explains why electrocuted birds are concentrated in certain areas and on certain supports. In fact, most electrocutions occur on just a few supports, while most of them never claim any victims. This implies that taking indiscriminate corrective action on all power poles will not result in a decrease in mortality by electrocution. Tintó et al. (2010) found this in their study in Catalonia (Spain), where corrective measures applied to 64% of the power poles did not significantly decrease bird deaths by electrocution, because the corrected poles already posed a low electrocution risk.

Much greater reductions in mortality can therefore be achieved by modifying a relatively small number of carefully-selected dangerous supports (Figure 121).

Some studies found that modifying only 13% of power line supports would reduce mortality by 82% (López-López et al., 2011; Ferrer, 2012). Other studies suggested that 99% of the deaths in a given area could be eliminated by modifying just 23% of the pylons (Mañosa, 2001).

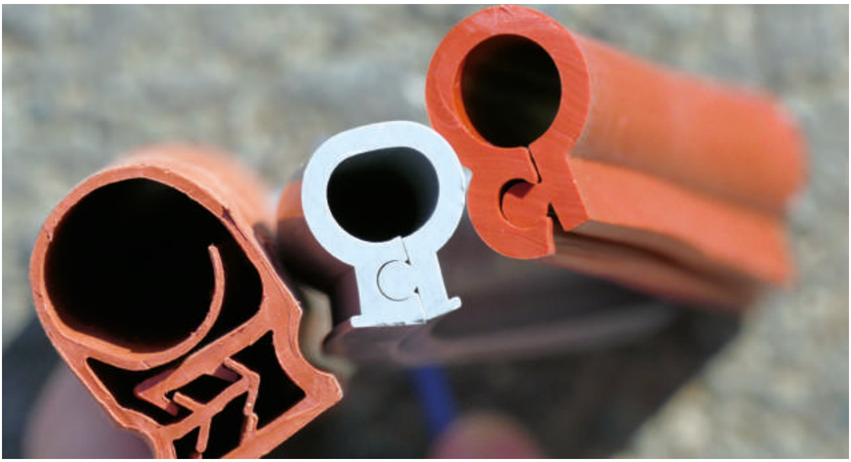


Figure 122. The quality of the materials and parts used in making the insulation determines its effectiveness and above all its durability. The insulation on the left is more robust and has a safer fixation system. © Justo Martín

Leaving aside definitive measures such as undergrounding, use of twisted cables or structural modifications, the effectiveness of insulation systems, often used in combination with anti-perching devices, **tends to be very high with success rates of over 80%**. Although these measures cannot be considered permanent, some manufacturers guarantee device lifespans of over 20 years under extreme climatic conditions. However, the reality is that their effectiveness is **often much lower and decreases far earlier for a variety of reasons**, including the following (Dwyer et al., 2017; Martín Martín et al., 2017):

- *Use of poor-quality or non-durable materials.* The quality of the materials used by manufacturers varies greatly, as does the design of the various devices. Even if they appear very similar, there may be great differences in strength and effectiveness. To reduce costs, some manufacturers use plastic materials with low tensile strength (Figure 122) or unreliable fixation systems. As a result, the devices may break, open or become detached in a short time, leaving the dangerous parts of the installation uncovered (Figure 123).
- *Poor installation.* Several problems may occur at the time of installation, such as the installers' lack of specialised training, poor choice of components, mixture of components from different manufacturers in the same assembly, or a lack of inspection at the end of the work. Faulty fitting of insulating elements may include fragments of non-insulated conductors, unprotected screws, faulty connections between parts, etc. (Figures 124 and 125). In these cases, the insulation is not completely safe after installation or it is soon lost, long before the theoretical lifespan of the materials (Figures 126 and 127).

Figure 123. If poor-quality materials are used, defects can quickly appear. Fixation system becoming detached from the conductor just months after it was installed. © Justo Martín

Figure 124. Installation of insulating devices in which numerous metal parts remain uncovered close to the area where birds perch. © Justo Martín

Figure 125. Faulty installation; the insulation does not cover the entire live metal part. © Justo Martín

Figure 126. Insulation sheath that has become detached at the end due to poor fitting. © Justo Martín

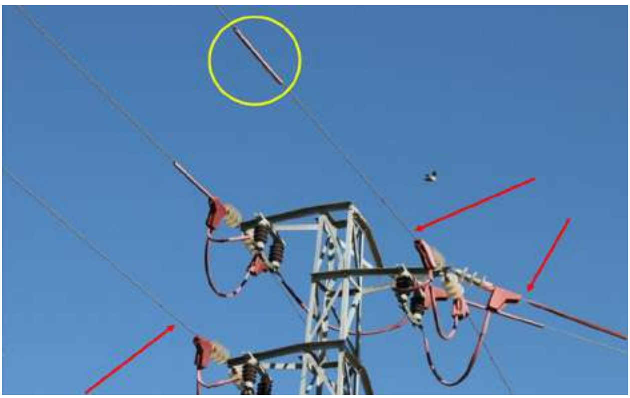


Figure 127. Poorly connected insulation sheaths that have become detached and have moved along the span, exposing the conductors close to the areas where birds perch. © James Dwyer

➔ *Non-insulated live parts on supports with disconnectors, transformers and other equipment.* Supports with disconnectors and/or other elements on the crossarm or on the post often have secondary crossarms or structures that provide alternative perches to the upper crossarm, but pose a risk of electrocution through contact with the various parts present. Sometimes, the upper arm may even have anti-perching devices that make the birds look for perches on other, riskier parts of the pylon. In these cases, the insulation should not be restricted to the conductors and jumpers, but should also include the connections to the equipment (surge arresters, fuses, disconnectors, etc.), including the connection terminals (Figures 128 and 129). This is very important because many cases of electrocution occur on supports of this type where the connecting cables have been insulated but the end points (terminals) are left bare.

Figure 128. Dead-end tower with bare connections to surge arresters on conductors. © Justo Martín

Figure 129. Insulated termination pylon with a transformer, in which the connections between the transformer and the fuses are bare. The upper parts are not correctly fitted, leaving the metal elements uncovered. © Justo Martín

➔ *Installations that do not take into account the risk of electrocution through defecation.* Electrocution through contact with bird excrement is not frequent but the risk of it occurring on frequently used supports should be taken into account. Electrocutions often occur on properly insulated pylons that comply with the recommended minimum distances but do not allow for this risk. Insulation of the conductor below the perching area solves this problem (Figure 130).

- *Poor execution of maintenance work.* When power lines require maintenance operations that involve the removal of insulation, this insulation is sometimes not replaced afterwards. It is essential to provide electricity company technicians with special training about insulation devices, how they work and how they should be installed to maximise their efficacy.

Figure 130. Pylon with vault crossarm configuration on which the central conductor is insulated in order to avoid the electrocution of birds that perch on the base. The risk of defecation is also avoided in this position, but not at the ends of the crossarm, where the layout allows birds to perch. © GREFA Power Lines Team

The effectiveness of these insulation systems is proven, provided they are well designed and installed (Tintó et al., 2010; Chevallier et al., 2015). However, it would be useful to carry out studies on their design and the durability of the various insulating materials used (polymer plastics and silicone) to find out which are the most durable and efficient, especially under extremes of temperature, humidity and wind strength. To our knowledge there have been no long- or medium-term studies on this subject to date.

To be effective, insulation systems must be installed and monitored by specialised personnel and, above all, they must be periodically inspected after installation, both to ensure they are suitable and properly installed and to check the extent to which the materials deteriorate over time.

A study carried out in the USA (Dwyer et al., 2017) discovered 56 electrocuted birds belonging to 10 different species on 52 insulated pylons, revealing that in all cases corrective measures were not applied correctly. Similarly, a citizen science project carried out in Hungary (Demeter et al., 2018) identified over 3,400 cases of electrocution of 79 species during the inspection of over 57,000 pylons, where 3% of the remains were found under pylons with insulation systems; the authors concluded that the corrective measures used did not guarantee total protection against electrocution.

Figure 131. Old, deteriorated insulation in which metal parts (circled) are currently uncovered, posing a risk of electrocution if a bird perches on the crossarm (red arrows). © Justo Martín

Recent studies carried out in southern Spain showed that over 12% of the raptor electrocutions recorded in the last 20 years occurred on pylons that had been properly insulated (Garrido et al., 2018b). Other studies in the same geographical area revealed higher mortality rates in large eagles on pylons with insulation systems than on other pylons with similar characteristics but without this protection. A good number of these accidents involved old devices and materials that had deteriorated over time, had become degraded or had lost part of their insulating capacity and thus the protection they offered (Guil et al., 2011; Figure 131).

Given that power lines must be inspected after a few years to check that they are still in good condition and working properly, ideally these checks should also include the condition of the anti-electrocution (and anti-collision) systems installed.

Moreover, **anti-perching devices tend to be less effective than insulation systems**. Birds may carry on trying to perch again and again, sometimes sustaining injuries on devices with sharp points, or they might be forced to flap their wings or make sudden movements to try to balance or to move to another location, which could lead to electrocution (Figure 132). Sometimes, the devices do not prevent birds building nests on pylons, which extends the electrocution risk throughout the entire breeding season for both adults and their young (Figures 133 and 135). The choice of the most appropriate anti-perching model in each case must be combined with proper installation because it may even increase the electrocution risk if not done correctly (Dixon et al., 2017; Orihuela-Torres et al., 2021; Figure 134).

Figure 132. Anti-perching devices alone are less effective than insulation systems. White stork (*Ciconia ciconia*) electrocuted on a support with metal plate anti-perching devices. © Justo Martín

Figures 133, 134 and 135. (Clockwise). In many cases, anti-perching devices do not prevent birds building nests on pylons. Figures 133 (top left) and 135 (bottom). White stork nests on pylons with anti-perching devices. © Justo Martín. Figure 134 (top right). Anti-perching device installed in such a way that it would not prevent a small bird perching near the conductor; its position may even increase the risk. © Andrew Dixon

Providing **supplemental perches** may be a useful and efficient way to mitigate the electrocution risk. However, many factors influence their success, and they are not equally effective with all species groups. Their effectiveness may be limited if the support provides other attractive but dangerous perches. Some studies show higher electrocution rates for certain species and devices; therefore, their efficacy has to be validated (Sánchez et al., 2020).

Table 5-2 presents a summary of the most common measures adopted to prevent or mitigate electrocutions, as well as their efficacy and other characteristics.

Table 5-2. **Characteristics of the main preventative and corrective measures against electrocutions**.

Measure	Type	Character	Duration	Cost	Effectiveness
Under-grounding	Structural	Preventative/ mitigating	Permanent	Very high	Total
Sheathed, twisted conductors	Structural	Preventative/ mitigating	Permanent	Very high	Total
Safe crossarm configuration	Structural	Preventative/ mitigating	Permanent	High	Total
Insulation of dangerous parts	Non-structural	Preventative/ mitigating	Non-permanentt	Low–medium	High
Anti-perching devices	Non-structural	Preventative/ mitigating	Non-permanent	Medium–low	Low–medium

Source: Martín Martín et al., 2019

6

Diagnosis and assessment of injuries or deaths of animals due to power lines

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6.1. SIGNS OF COLLISION ON THE BODIES OF INJURED BIRDS

Collision with power line cables causes **different types of traumatic injury to a bird's body and can lead to the animal dying instantly**. However, **on numerous occasions the bird does not die immediately** after the collision and falls to the ground, still alive (Figures 136 to 139). If the bird has only broken a wing, it can move away from the power line on its feet (distances exceeding 2 km from the point of collision have been recorded). Carcasses and seriously injured birds are often preyed on by scavengers and opportunist predators such as dogs, foxes, jackals, wild boar, corvids, kites and others (Ferrer, 2012), and this should be taken into account when estimating mortality rates, as indicated in Point 6.4.

Figures 136 to 139. Signs on the bodies of birds involved in collisions. Figure 136 (top left). Often, the collision does not kill the bird, but it is seriously injured and exposed to predators. Cattle egret (*Bubulcus ibis*) injured as a result of a collision. © Daniel Burón. Figures 137 (top right) and 138 (bottom left). Booted eagle (*Aquila pennata*) and grey heron (*Ardea cinerea*) killed by a collision, with an open fracture of the wing. © Justo Martín. Figure 139 (bottom right). Damage to plumage due to a collision; it forms a linear band at the same height on each feather. © CAGPDS/CAD

If a seriously injured bird is found under a power line, the competent authority should be notified so that it can take charge of the animal. However, even if the injured bird is rescued and treated, the injuries are generally serious and the bird often ends up dying or having very little chance of being totally rehabilitated and released into the wild. The most common injuries correspond to certain characteristic signs on the animal (Table 6-1).

Table 6-1. Types of injury and signs of collision on a bird's body.

Type of injury	Signs
Broken bones	Broken bones in extremities (wings and legs) and the back; fractured vertebrae and skull; amputation of limbs.
Damaged plumage	Mechanical damage (torn or split feathers); rarely burns.
Skin injuries	Tears, pieces of torn skin; exposed muscles, tendons or bones; without immediate treatment, they rapidly develop infections and necrosis.
Secondary injuries to extremities	Oedemas and localised necrosis around wounds, exposed bones, tendons and muscles; signs of bacterial infection.
Bruises in the impact area	Large bruises on wing and pectoral muscles.
State of surviving birds	**Initially in a state of shock. Unable to fly or even move, depending on the wounds and secondary injuries.**

Source: prepared by the authors based on Haas et al., 2003, and Fajardo & Zorrilla, 2016 (see the latter publication for further illustrations).

6.2. SIGNS OF ELECTROCUTION ON THE BODIES OF INJURED ANIMALS

Electrocution **normally causes the instant death of the animal**. However, **sometimes the electric shock itself is not fatal and death is caused by the fall** from the pole or pylon, the carcass being found at its base. As in the case of collisions, the carcass is generally very quickly eaten by scavengers.

Quite frequently, the animal does not die but is seriously injured, although it generally dies soon after as a result of its injuries or is killed by an opportunist predator looking for carcasses. It is rare for the animal to survive, recover from its wounds and return to the wild, although this can happen if it receives quick and appropriate treatment from specialists in these kinds of injury (Figure 140).

Figure 140. It is rare for electrocuted birds to survive and for it to be possible to release them into the wild. Egyptian vulture (*Neophron percnopterus*) that has survived electrocution; its feet have wounds caused by the electric shock. © Justo Martín

The electric current passing through the animal's body produces **certain signs that indicate the cause of death or the type of accident** (Table 6-2). These signs may be very obvious on the outside of the body (in 80% of cases) or almost undetectable unless a necropsy is performed on the corpse (in 15% of cases) (Figures 141 to 143). In the remaining 5% of cases the body is totally charred, because sometimes a bird left hanging on the wire causes an electric arc so intense that the sparks burn the bird's feathers and then the entire body (Fajardo, pers. comm.). In mammals, signs can be obvious, but sometimes loss of consciousness causes the animal to fall and die from the subsequent trauma, especially in cases of low-voltage electrocution (Di Maio & Dana, 2013).

Evaluation of injuries and signs on the animal's body is essential to determine the cause of death.

Table 6-2. Types of injury and signs of electrocution on an animal's body.

Type of injury	Signs
Broken bones	Fractured vertebrae with paraplegia. Fractured skull. Fractured pelvis. Amputated legs or wings.
Burns on the plumage or skin	The burns are visible on the edges and tips of the burnt feathers which are blackened with irregular edges In the event of an electric arc, as the current passes externally through the animal's body, large burns may occur on the plumage but without internal injuries to the body (see Figure 92). In the case of a mammal, patches of fur are charred.
Burns on the bones	Sometimes visible on the bone remains.
Burns on feet and other parts	Burns comprising small wounds or areas of dry tissue at the current entry and exit points (especially on the wings, legs, bill or breast). Burns in the bird's cloaca too if the electrocution was caused by defecation. Electroporation; generalised cell disorganisation with a loss of consistency and muscular structure caused by the sudden high temperature as the electricity passed through the tissues. In these cases, there are white spots of viscous appearance on the skin of the legs. If the animal survives and does not receive treatment, necrotic areas develop on the skin of its extremities.
Perimortem bruises	The animal may show bruises on the parts of the body where it is hit when falling, even if it is already dead, as the blood continues to circulate for a short period of time.
Internal injuries	Signs of fibrosis in the heart; congestion in internal organs (liver, spleen, kidneys); in birds, congestion lines in the subcutaneous tissue in the feet. In the case of electrocution due to defecation, necropsies reveal a wrinkled, blackish digestive tract.

Source: prepared by the authors based on Haas et al., 2003, and Fajardo & Zorrilla, 2016 (see the latter publication for further illustrations).

Figure 141. Signs on the bodies of animals that have been electrocuted. Top left: Carcass of a lanner falcon (*Falco biarmicus*) electrocuted without any apparent signs at first glance. © Daniel Burón. Top right: Spanish imperial eagle (*Aquila adalberti*) with partially burnt plumage. © CAGPDS/CAD. Bottom left: Griffon vulture (*Gyps fulvus*) entirely charred. © Íñigo Fajardo. Bottom right: Common genet (*Genetta genetta*) electrocuted with its whiskers burnt. © Justo Martín

Figure 142. Signs on the bodies of birds that have been electrocuted (continued). Left to right, top row: Golden eagle (*Aquila chrysaetos*) with an amputated wing. © Íñigo Fajardo; Spanish imperial eagle (*Aquila adalberti*) with an irregular edge on its primary feathers; Burnt and blackened feather ends and edges. © CAGPDS/CAD. Middle row: Booted eagle (*Aquila pennata*) with an electric shock mark on the wing. © Íñigo Fajardo; Same individual as in the previous photo, with signs of the electric shock on the right leg (on the left in the photo). © Justo Martín; Foot with skin torn open by the electric shock. © CAGPDS/CAD. Bottom row: Spanish imperial eagle foot with electroporation; Spanish imperial eagle in which the edges of the cloaca were burnt through electrocution by defecation; Digestive tract of the previous individual, blackened by the electric shock it received. © CAGPDS/CAD

Figure 143. Signs on the bodies of birds that have been electrocuted (continued). Left to right, top row: (the two photos on the left) Bone with burn mark found among the highly degraded remains of an Egyptian vulture carcass; Signs of electrocution in the feathers around the eye of a short-toed eagle. Middle row: Eagle owl electrocuted with prey in its claws; Haematoma on the skull of an electrocuted red kite (*Milvus milvus*). Bottom row: (the two photos on the left) Congestion lines in subcutaneous tissue of the foot; Broken feathers with burnt rachis. © CAGPDS/CAD except for GREFA (middle row, left).

6.3. DIAGNOSIS OF THE CAUSE OF DEATH

Although most carcasses found under a pylon or near a span are the result of electrocutions or collisions, death can sometimes be due to other causes.

A sick, injured, poisoned or shot animal may decide to perch on a pylon and die there, remaining upright as if the cause of death were electrocution; it would usually be easy to reject that as a cause because the body would not show the typical signs (see Table 6-2). However, sometimes the body of an animal that has just died receives a blow when it falls and crashes into parts of the pylon (for example, one with a transformer), resulting in a case that can only be resolved through laboratory analysis. Normally, this is not necessary and experienced personnel can determine the cause of death (Figure 144).

Figure 144. It is sometimes hard to diagnose the cause of death in situ. Griffon vulture (*Gyps fulvus*) found dead on a pylon; its position (the bird died falling forward, apparently in a position where there would be no contact) indicates that it might not have been electrocuted. © Íñigo Fajardo

Likewise, a similar situation can occur in the case of collisions, because individuals that are also injured, sick or poisoned, with their faculties diminished, would have greater difficulty manoeuvring and avoiding a collision, so it should almost be considered a secondary cause.

On other occasions, poachers or poisoners throw carcasses under pylons or power lines in order to draw suspicion away from their activities, a type of behaviour frequently recorded in different parts of the world (Fajardo & Zorrilla, 2016).

Apart from the signs of collision or electrocution mentioned above, there are other **elements that can be used to judge whether death was due to an incident with a power line or to poisoning or shooting**. These elements can basically be divided into two types: the general position in which the carcass is found and a few characteristic external signs, as well as the type of pylon (Fajardo & Zorrilla, 2016).

➔ **Position**. When a bird dies as a result of electrocution or a collision, as it falls the dead body adopts a 'droplet' posture determined by its anatomy (its mass is concentrated in the upper part of its body) and gravitational attraction so that, when it reaches the ground, it lands on its back, meaning the head of the carcass is on top in an apparently relaxed posture (Figure 145). The same thing occurs with shot birds when they fall from sufficient height.

Figure 145. The natural position of a bird that dies in the air and falls to the ground from a certain height is a 'droplet' shape during the fall, and then it lands on its back with the body appearing relaxed. Left: Booted eagle (*Aquila pennata*) carcass falling, adopting a 'droplet' shape. ©Íñigo Fajardo. Right: Individual of the same species, killed by electrocution. ©Justo Martín

However, birds that die as a result of poisoning normally do so lying on the ground. When the bird eventually dies, it falls forwards due to the position of its centre of gravity, which is displaced towards the front, meaning the carcass ends up with its head facing downwards. Moreover, poison causes death accompanied by contractions, convulsions and spasms which are reflected in the carcass, which has its wings spread or half open, the tail raised and upright and the feet completely stiff. In the case of long-necked species such as vultures and storks, the bird appears to be curled up as a result of sudden pain. In medium-sized raptors, the 'fan' posture is typical, with the wings and tail fully spread. In mammals poison signals can also be clear, such as the extensions of the limbs, bristly hair or *risus sardonicus* (facial expression characterised by raised eyebrows and grinning distortion of the face resulting from spasm of facial muscles) among others. (Figures 146 to 153).

If an animal dies on the ground as a result of something other than poisoning, for example following injuries caused by a firearm, it also has its head facing downwards but in a different position, without any signs of the contractions or convulsions described above.

In all cases, it should be borne in mind that a carcass may have been moved from its original position by strong winds, especially in the case of long-winged species (e.g. storks), or by scavengers.

> *When a bird dies after being electrocuted or as the result of a collision, the lifeless body adopts a 'droplet' position as it falls to the ground.*

External signs. Poison leaves other signs, such as vomit (next to the bird or nearby), a full crop or loose or bloody faeces, which leave obvious stains around the cloaca. Foot stiffness is a common sign in electrocution, poisoning by pesticides that affect the nervous system (carbamates and organophosphates), trauma and even acute illness that produces shock. Therefore, contractions of the feet are not a diagnostic character but one more sign to be considered. In electrocuted birds the claws are clenched so tightly that the prey remains held by them after death (Figures 143 (middle row, left), and 148). This is also the reason why a bird carcass is sometimes left hanging on the pole.

Figures 146 to 153. Signs of death from poisoning. Figure 146. Griffon vulture (*Gyps fulvus*) with its wings slightly open and contracted; Figure 147. Griffon vulture lying face down on the ground with its tail raised; Figure 148. Contracted toes of a poisoned red kite (*Milvus milvus*); Figure 149. Cloaca of a bearded vulture (*Gypaetus barbatus*) with the remains of loose faeces; Figures 150 and 151. Poisoned black kite (*Milvus migrans*) and common kestrel (*Falco tinnunculus*) in a 'fan' position; Figure 152. Poisoned red fox (*Vulpes vulpes*); the marks produced by the animal's convulsions before death can be seen on the ground; Figure 153. Poisoned dog, showing *risus sardonicus* grimace. Figures 146, 147 and 151 © Justo Martín; Figures 148, 149, 150, 152 and 153 © Íñigo Fajardo

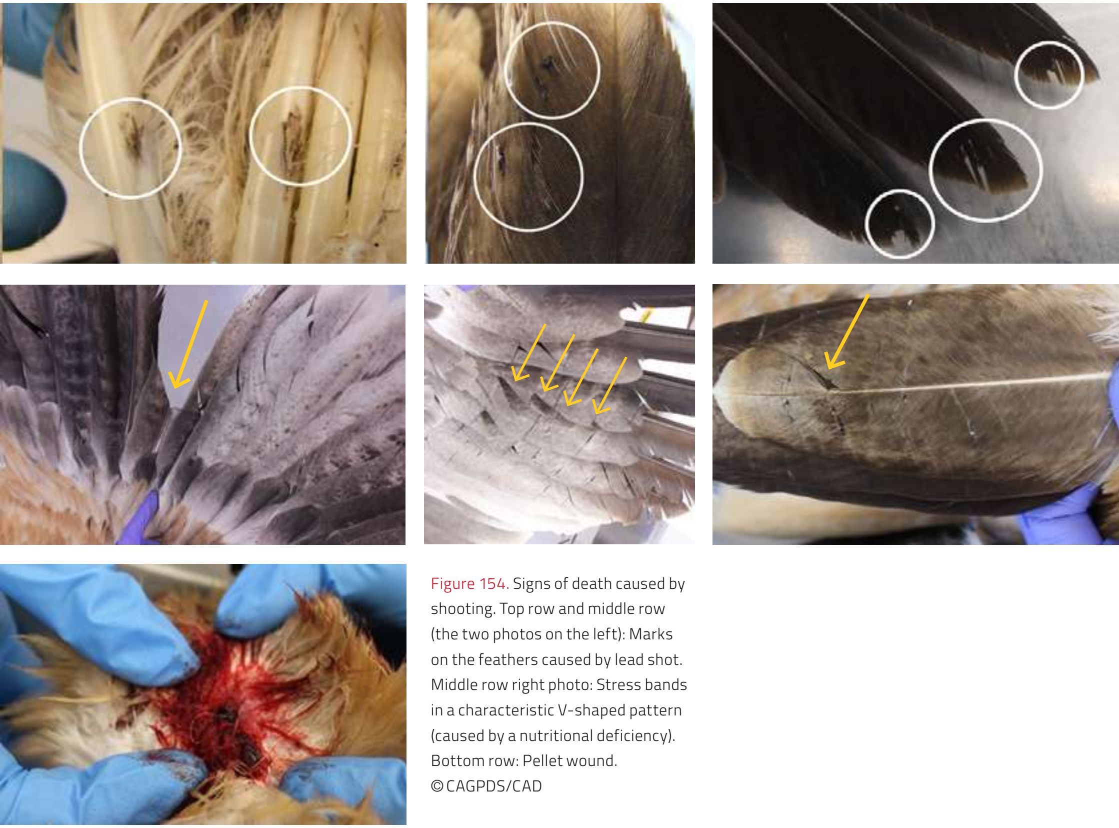

Figure 154. Signs of death caused by shooting. Top row and middle row (the two photos on the left): Marks on the feathers caused by lead shot. Middle row right photo: Stress bands in a characteristic V-shaped pattern (caused by a nutritional deficiency). Bottom row: Pellet wound. ©CAGPDS/CAD

Shooting also leaves obvious signs. Although the injuries are not too visible, pellets break and cut feathers and pierce quills if fired at fairly close range, or cause rounded marks if fired from further away; the two types of feather damage are easy to identify on the body and in the surrounding area (Figure 154).

These marks on the feathers should not be confused with those produced by collisions or electrocution or with stress bands (caused by nutrient deficiencies during feather development). Collisions produce linear breaks located at the same height on several feathers; electrocution can break feathers, but they are split into groups and usually show burnt rachis and frayed edges, or at least changes in colouring due to heat; breaks due to stress bands have a characteristic V-shaped pattern.

6.4. ASSESSMENT OF MORTALITY CAUSED BY ELECTRIC POWER LINES

As discussed above, collisions and electrocutions are concentrated at certain points or in specific parts of the electricity network, depending on a number of variables, especially those linked to their structure, the environment and the biological and behavioural characteristics of the species present.

Studies carried out in different parts of the world show that there is considerable variability in bird mortality rates for these sections or mortality hotspots. In the case of collisions, the figures ranged from less than one dead bird per kilometre of power line per year to as many as 170 victims or more per kilometre per year, with extreme cases of almost 500 victims per kilometre per year in the USA. In the case of electrocutions, figures of 0.001 to 2.1 victims were recorded per pylon per year in Greece (Loss et al., 2014, compares bird mortality rates in different circumstances in different countries).

When establishing actual mortality rates based on data collected in the field, it should be noted that **in a search for carcasses, only some of the remains are found**. By conducting different experiments, Ferrer (2012) discovered that even experienced researchers were not capable of finding all the carcasses or remains present; the success rate was only 25% when the researchers were not very experienced (Ponce et al., 2010; Figure 155). Search effectiveness can be increased by using dogs trained to search for carcasses, especially for small birds in areas of dense vegetation (Homan et al., 2001; Paula et al., 2011; Domínguez del Valle et al., 2020).

In addition to the variability in search effectiveness, the action of **scavengers** must be mentioned. For them, carcasses are an important food source, which may even be predictable and abundant at these mortality hotspots or black spots. They even appear to learn to identify the areas where pylons have the highest death rate and visit them more frequently. Animal corpses and remains therefore disappear once they are discovered by scavengers; moreover, it has been noted that the smaller the bird species in question, the higher the **disappearance rate** (the speed at which bodies and remains are removed) (Ferrer, 2012; Borner et al., 2017). Conversely, the term **persistence rate** can be used in this context to indicate the percentage of carcasses that persist for a given time; it is related to the **persistence time** (the time for which a carcass remains detectable).

Figure 155. The technical and field personnel's experience is important in obtaining accurate mortality data. Characterising power lines and searching for carcasses in Morocco. © Daniel Burón

The smaller the bird species in question, the higher the carcass disappearance rate.

The disappearance (or persistence) rate is very variable, and even though it can be influenced by factors such as the type of vegetation, season or the weather (e.g. heavy rain makes carcasses degrade faster), it mainly depends on the composition and density of the scavenger community (Ponce et al., 2010; Barrientos et al., 2018). Scavengers include both mammals and birds, although the former are responsible for most disappearances. The most common species are foxes, wild boar (*Sus scrofa*), feral dogs and cats, rats, corvids (ravens, jackdaws, crows), kites (black and red – *Milvus migrans* and *M. milvus*), white storks (*Ciconia ciconia*), gulls, vultures and even large eagles (Ferrer, 2012).

Disappearance rates (one month after death) ranging from 10% to over 70% have been recorded, with very rapid disappearance just after death and a progressive decrease thereafter (Figure 156; Ponce et al., 2010). Carcasses of small birds disappear quickly (almost 90% by the second day for the smallest), given that they tend to be consumed without any remains being left behind, unlike larger species, which are frequently consumed in situ but only partially eaten, with the remains sometimes being left for months (Ponce et al., 2010; Schutgens et al., 2014; Uddin et al., 2021).

The disappearance rate is established **based on experiments** in which dead birds of different sizes are placed under or near a power line. The carcasses are checked periodically by observers for a set time in order to quantify and measure the actions of the scavengers present in the study area. Persistence rates should not be calculated on the basis of experiments using carcasses of other taxa as rates seem to be taxon-specific. Nevertheless, carcasses of domestic animals can be used because they have persistence rates similar to those of their wild relatives. Thawed carcasses are suitable for trials as their persistence rates are similar to those of fresh ones (Barrientos et al., 2014).

These experiments provide another corrective statistic that is essential for determining the actual mortality rate; this is the **detectability rate**, since observers will not find every carcass even where there are no scavengers. The detectability rate varies considerably from one observer to another, with recorded values of 25–85% (Borner et al., 2017). In addition to the skills of each observer, which can vary, other factors should be taken into account such as the size of the bird (larger corpses are more easily detected), its state of decomposition and the density and height of the vegetation (it is harder to find carcasses in dense scrub or grassland) (Borner et al., 2017; Gómez-Catasús et al., 2021).

Figure 156. Scavengers quickly remove carcasses, with disappearance rates of over 70% being recorded. Feral dog eating remains of a white stork. © Justo Martín

The disappearance and detectability rates depend to a great extent on the geographical location of the power line, which ultimately determines factors such as the presence and density of scavengers and how easily they (and observers) find the carcasses; this also varies with the time of year (Borner et al., 2017).

Consequently, carcasses found during the inspection of a power line only confirm the problem and give an idea of its possible severity, depending on the quantity of remains found and the species affected. It is **impossible to obtain a good estimate of actual mortality rates without carrying out local studies** to determine the disappearance and detectability rates in the study area. Monthly sampling may be enough to establish these rates for medium-sized and large birds, but for small birds weekly or even more frequent visits are necessary to obtain values that can be considered reliable (Borner et al., 2017).

Mortality rates that are as realistic as possible should be obtained for each site with a view to establishing priorities for implementing correction measures in areas in which a large number of accidents occur (Figure 157).

Methods are now available for correcting bias and assessing mortality. A good case is the robust GenEst suite of statistical models and software tools for generalised mortality estimation, developed by the U.S. Geological Survey (Dalthorp et al., 2018a). It was specifically designed for estimating the number of bird and bat fatalities at solar and wind power facilities, but both the software and the underlying statistical models are general enough to be useful in various situations to estimate the size of open populations when detection probabilities and search coverages are less than 100% (Dalthorp et al., 2018b).

Figure 157. The carcasses discovered only reveal signs of the problem and give an idea of its possible actual severity. Electrocuted Bonelli's eagle (*Aquila fasciata*) and short-toed snake eagle (*Circaetus gallicus*). © Justo Martín

7

Collection and analysis of data on dangerous power lines

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The starting point for adopting measures aimed at reducing the mortality caused by power lines is to have data indicating where and how action should be taken. The effectiveness of the measures to adopt and their cost/benefit ratio are directly linked to the quality of the initial data collected in field studies, including the inventorying and monitoring of the existing wildlife populations. This chapter outlines the main aspects to be taken into account when identifying areas with dangerous power lines for birds, but these aspects can be extrapolated to other faunal groups.

7.1. BASELINE INFORMATION

Given that power lines stretch across a large part of the land surface in any given region or country, **it is essential to prioritise areas where efforts should be concentrated in the search for dangerous power lines and the implementation of corrective and mitigating measures** (Figure 158). Basically, this requires precise information on species distributions and movements and the location and characteristics of existing power lines in a given geographical area (project area, region, country, etc.).

If no specific information is available, as a starting point generic mapping programmes such as Google Maps, Google Earth, Bing Maps or Apple Maps can be used in combination with other **resources**, such as websites that plot marked birds' movements or the location of major electricity transmission lines across countries and continents. Some examples are the following:

- AviStep - the Avian Sensitivity Tool for Energy Planning (https://avistep.birdlife.org/) to identify where renewable energy could impact birds and should therefore be avoided, developed by BirdLife International.

- Movebank (https://www.movebank.org/cms/movebank-main), an online database of animal tracking data hosted by the Max Planck Institute of Animal Behavior. It helps animal tracking researchers to manage, share, analyse and archive their data. Animal movements can be tracked on an interactive map (Figure 159).

- The European Network of Transmission System Operators website (www.entsoe.eu/data/map/) has maps that can be viewed and downloaded of the main power lines in Europe and North Africa, including those under construction.

- The Soaring Bird Sensitivity Map tool (https://maps.birdlife.org/MSBtool/), for plotting bird migration routes in the Mediterranean Basin or the Middle East, also developed by BirdLife. Although it only contains information on soaring birds, it does provide details of their flight routes, on which it is possible to overlay maps of protected or important bird areas, make selections by country, etc.

Figure 158. It is essential to determine the areas in which survey and correction work should be focused. Landscape near Annapurna, Nepal. © Justo Martín

These resources allow you to **cross-reference information about the areas where birds move and congregate with information on the power line network** and discover where there may be areas of potential conflict.

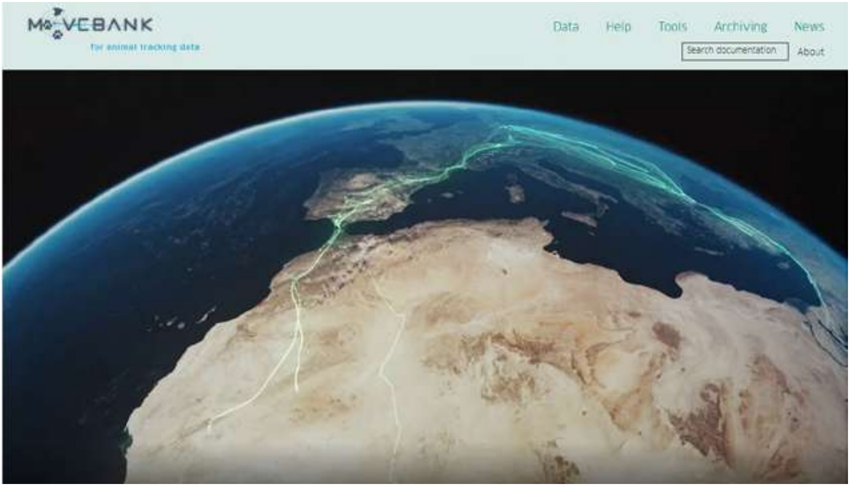

Figure 159. Movebank is a free, online database of animal tracking data hosted by the Max Planck Institute of Animal Behavior. It helps animal tracking researchers to manage, share, protect, analyse and store their data. © Movebank

Other websites can also provide information on the occurrence of certain bird species and points of interest inside or outside protected natural areas. **Citizen science platforms** for collecting and consulting data on biodiversity are also useful. These platforms collect data continuously from millions of users around the globe who upload their field observations via the website or a mobile app. The data are stored on the developer's server for consultation and use. For example, mortality data can be looked up and used to detect mortality hotspots where action needs to be taken. Currently, the platforms with the largest numbers of users are ebird (https://ebird.org), created by the Cornell Lab of Ornithology in the USA, Observation (https://observation.org; Figure 160), developed by the Observation International Foundation, based in the Netherlands, and iNaturalist (https://www.inaturalist.org), a joint initiative of the California Academy of Sciences and the National Geographic Society. These and other platforms are available through GBIF, the Global Biodiversity Information Facility (https://www.gbif.org), an international network and data facility funded by the world's governments which aims at providing anyone, anywhere, with open access to data about all types of life on Earth.

Other sources of information of interest are the Integrated Biodiversity Assessment Tool (https://www.ibat-alliance.org/) and Critical Sites Network (CSN) Tool (https://criticalsites.wetlands.org). The first hosts and maintains the three key global biodiversity datasets: the IUCN Red List of Threatened Species, the World Database on Protected Areas (WDPA) and the World Database of Key Biodiversity Areas (KBA). The second provides access to information on over 300 migratory waterbird species, their migration routes and the key wetland sites these birds use in the African–Eurasian region.

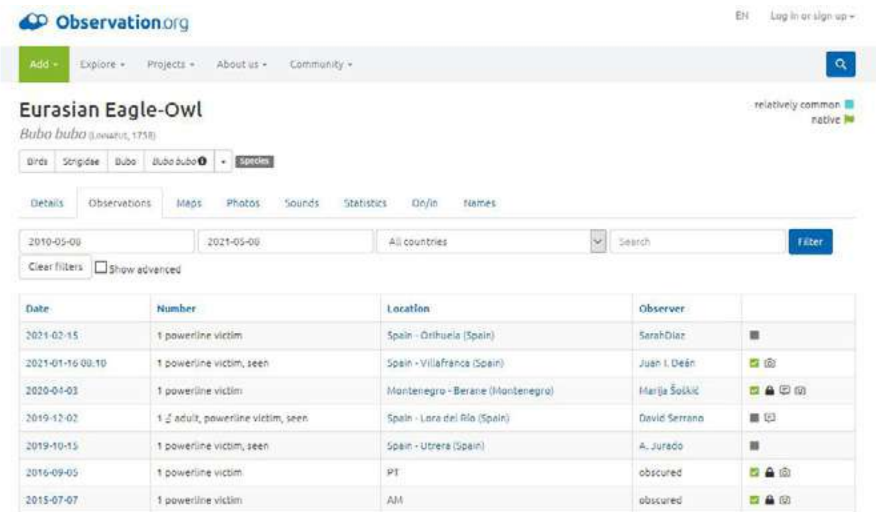

Figure 160. Page from the Observation.org website showing information on eagle owl electrocutions. © Observation.org

For new power line projects, highly accurate information is needed to facilitate the environmental assessment procedures, to help in selecting the best options to eliminate wildlife impact and to meet technical and financial requirements. In these cases, existing information has to be supplemented with information gathered in the area affected by the project. Good mapping of habitats and characterisation of existing power lines are essential. To assess the presence of sensitive species, monitoring has to take into account both the breeding and wintering seasons and migration times. In addition, breeding events, numbers present, daily and seasonal movements and possible areas of concentration also need to be studied. These studies should cover at least one full year.

7.2. SPECIES AND PRIORITY AREAS

Priority areas can be determined in several ways. One simple method is to identify the **number of priority species present and their population sizes** (European Commission, 2018). Priority species[1] are those that the IUCN Red List of Threatened Species™ lists as threatened (in the Vulnerable, Endangered and Critically Endangered categories) at global, regional or national levels (Figure 161).

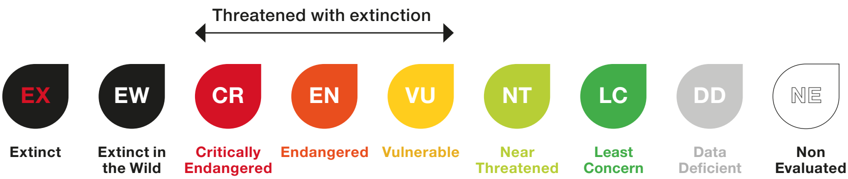

Figure 161. Priority species can be defined as those considered threatened according to the IUCN Red List of Threatened Species™. Source: IUCN, Standards and Petitions Committee, 2019

These areas can be classified as **priority I, II and III areas**, depending on the abundance and temporary or permanent density of the priority species found in them.

Inventory and monitoring programmes covering the birds' nesting (or other species' breeding), wintering and dispersal areas are essential in determining priority areas. Internationally important bird areas would be priority I areas, nationally important areas would be priority II, and regionally or locally important areas would be priority III. Table 7-1 presents some criteria for classifying priority areas.

[1] Priority species can also include those whose conservation (in the broad sense of the term) can meet objectives that transcend the conservation of the individual species, such as conserving habitats and other important aspects of biodiversity at various geographical scales and levels of biological integration (March et al., 2009).

Inventory and monitoring programmes for priority species are essential in determining priority areas on which to focus preventative and/or corrective efforts.

Figure 162. The network of protected natural areas should be included among the priority areas for studying and resolving problems involving power lines and birds. Jebel Zaghouan National Park (Tunisia). © Justo Martín

Table 7-1. Priority levels and corresponding types of areas of importance for bird species sensitive to electrocution and collision.

Priority level	Type of area of importance
Priority I areas, e.g. Important Bird Areas (IBAs)	'World Hotspots' for several priority species with a high density of individuals or for one globally threatened species at least: • Key breeding, wintering and dispersal areas; • Key sites where many individuals congregate, such as stopovers on migration routes or feeding points (e.g. wetlands or garbage dumps); • Bottleneck areas on migration routes; • Important migration routes; • Important flyways between breeding or roosting sites and foraging areas.
Priority II areas	Nationally important areas for one or more priority species: • Important breeding, wintering and dispersal areas; • Important flyways between breeding or roosting sites and foraging areas; • Nationally important congregation sites.
Priority III areas	Regionally or locally important areas for priority and non-priority species: • Local flyways; • Important areas for breeding, wintering or dispersal at a local level, acting as 'sources' for other peripheral areas nearby; • Locally important congregation sites.

Source: prepared by the authors based on European Commission, 2018

Within priority areas, efforts should be focused on the points or areas where the species most susceptible to the impacts of power lines (see Sections 4.1 and 5.3.) are concentrated, and thus where their conservation status is of greatest concern. Logically, the measures proposed will benefit them, as well as the rest of the susceptible species present (Moleón et al., 2007).

Similar criteria can be used in the case of mammals or other groups; data can be combined, if necessary, to determinate priority areas.

7.3. SENSITIVITY AND RISK MAPS

Provided good data have been collected from the outset, sensitivity and risk maps can then be created.

Sensitivity maps are based on a specific sensitivity score determined for each species, which weights and evaluates characteristics linked to the problem to be assessed. These scores are **combined with species distribution data** to create sensitivity maps showing the areas with the highest concentrations of sensitive species, by identifying areas of importance according to their sensitivity (high, medium or low). This methodology was used, for example, to create bird sensitivity maps for wind farms, as a tool to help in the planning of new installations that take bird conservation into account (Garthe & Hüppop, 2004; Bright et al., 2008; McGuinness et al., 2015).

Figure 163. Knowledge of the bird community at a given location is used to determine the areas at highest risk. Red kite (*Milvus milvus*). © Justo Martín

In the case of power lines, there are examples of maps prepared for bird sensitivity to electrocution (Pérez-García, 2014) and collisions (Red Eléctrica Española, 2017; D'Amico et al., 2019; Biasotto et al., 2021). The sensitivity scores were based on characteristics such as the species' conservation status, anatomy, behaviour, preferences and habitat use (Figure 163).

In countries where mortality caused by power lines is poorly documented, this methodology can be used to generate information at large scales. The resulting maps will allow for a preliminary assessment aimed at identifying areas where electrocutions and/or collisions may be having a significant impact on wildlife (for example, in UICN, In press). This will then be useful for the development of regional management strategies (Biasotto et al., 2021).

Where information is available not only on the distribution of sensitive species but also on the factors that lead to accidents involving power lines, risk maps can be prepared. This requires the combined analysis of many different types of data, such as information on land use, topography, bird congregation areas (landfill sites, wetlands, water sources, etc.), weather factors (e.g. fog frequency) and fatal incidents (Pérez-García, 2014; Silva et al., 2014).

By associating sensitivity maps and risk maps, priority areas for mitigation measures or measures to protect birds from dangerous power lines can be identified and the most suitable areas for the installation of new lines can be determined more precisely, together with the criteria for building them. A good example of such analysis is that carried out in Belgium on the collision risk for the high-voltage grid, which establishes eight levels of risk (Derouaux et al., 2012; Derouaux et al., 2020; Figure 164).

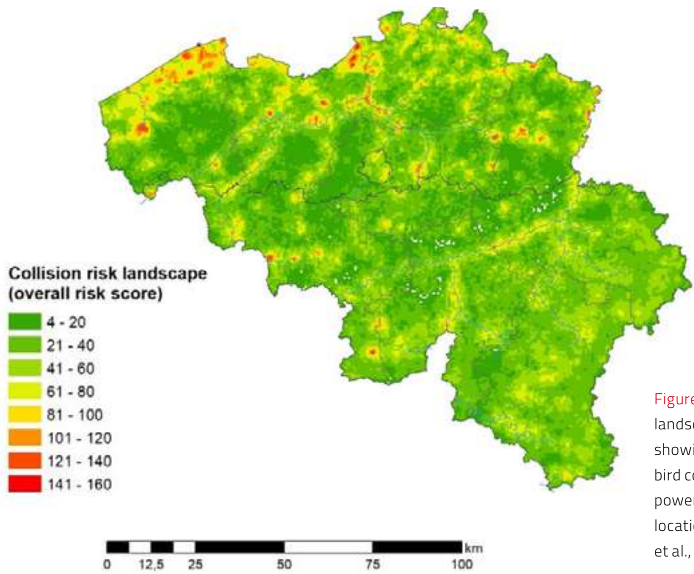

Figure 164. Collision risk landscape for Belgium, showing a gradient of bird collision risk should a power line be built in any location. Source: Derouaux et al., 2020

7.4. PRIORITY LINES AND SUPPORTS

Once the priority and/or risk areas have been determined, a digital map database of the area and the power lines it contains makes it possible to **prioritise the supports and line sections that require action** (Figure 165). It should be noted that most electrocutions occur on a small number of supports; it is therefore of paramount importance to **identify them so that efforts can be focused** on those that most need attention. Similarly, in the case of collisions, the power line spans where most collisions occur must be ascertained so that remedial action can be planned.

Predictive models of danger levels can be used, based on variables linked to the characteristics of the power line (type of insulator, presence and configuration of jumpers, use of line markers, etc.) and its location (in terms of habitat and topography). The danger levels of the supports or sections of a line can thus be categorised and the potentially most dangerous ones selected (de la Cova, 1997; Tintó et al., 2010; Guil et al., 2011; Dwyer et al., 2014; Hernández-Lambraño et al., 2018; Mojica et al., 2018).

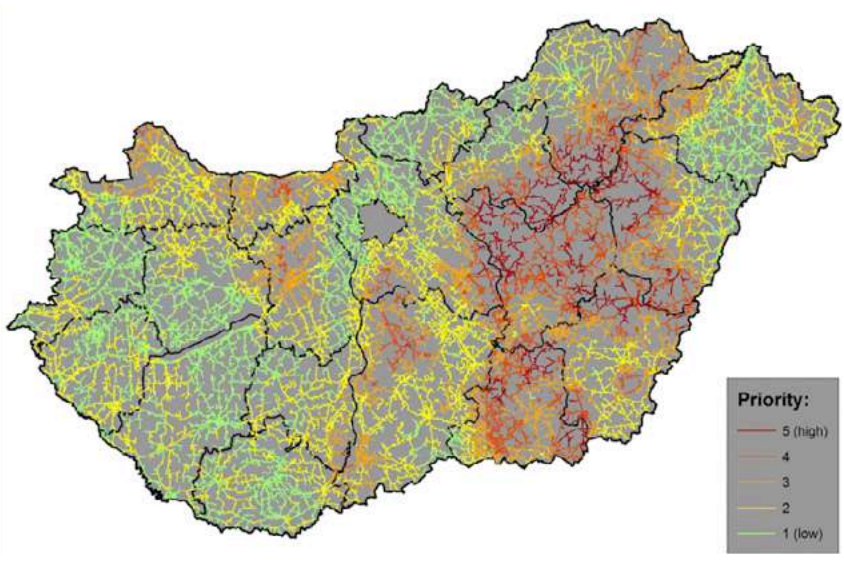

Figure 165. Map of bird conservation priorities on the medium-voltage power line network in Hungary with regard to electrocution. Source: MME Birdlife Hungary, 2008

Predictive models that include the characteristics of the supports work very well, but they have the disadvantage of requiring a lot of very detailed information, and thus their use on relatively large geographical scales is complicated. Moreover, in these cases, it appears that other factors such as land use, the density of power lines and the abundance of water sources could be even more important for assessing mortality and therefore for selecting priority action areas (Pérez-García, 2014; Guil et al., 2015).

In the case of black spots with high mortality rates and a large concentration of potentially dangerous supports on which actons have to be prioritised (for operational reasons or because of a lack of financial resources), it is advisable to design an **action plan** establishing these priorities (Figure 166).

Figure 166. An action plan must be drawn up for black spots, indicating the priorities and the order of execution. Power line where numerous electrocutions have occurred in the Guelmin region (Morocco), where an action plan was prepared. © Daniel Burón

Figure 167. The system used for data collection in the field and data processing must be standardised and centralised. Characterisation of power lines in Morocco. © Justo Martín

The **criteria for prioritising the supports to be corrected** could be as follows (according to the action plan prepared for corrective work in the Guelmin area: UICN, CAGPDS & HCEFLCD, Unpublished):

1. Mortality rate (number of electrocuted individuals found on the support);
2. Use of the support as a perch;
3. Proximity of the support to other supports that meet the previous criteria;
4. Configuration of the support, according to specific criteria that determine the intrinsic danger it poses to birds.

Mortality detected at black spots may affect a single species, several species or one or more groups of species. This will depend on the species present in the area (see Sections 4.1 and 5.2) and the use they make of the power line supports. Any impact will be more significant in the case of **threatened species** that are particularly sensitive to power line-related mortality. If good information is available on their distribution and main demographic parameters, priority should be given to populations of threatened species identified as ‘sinks’, i.e., where mortality exceeds productivity, and to those areas in their range where the highest mortality is detected. Here the priority will be to identify the areas used most intensively by the species and to locate those points (line sections or supports) that pose a greater mortality risk, where work will be focused (Hernández Matías et al., 2020; see Table 7.2 for the main steps to be taken in the selection and priorisitation process).

7.5. DATA COLLECTION

Given the numerous technical details and the large number of power lines and supports that may need to be assessed, it is essential to have a standardised data collection and processing system that is homogeneous, comparable, and can be used uniformly, irrespective of the person who collects the data or the place where they are collected (Figure 167).

The best way to achieve this is to **design data collection protocols** in the form of data-entry reports or sheets, both for identifying and characterising dangerous power lines and supports, and for recording wildlife fatalities. The basic information that these protocols should collect is shown in Table 7-3.

Table 7-2. Steps in the selection and prioritisation process.

The steps to be taken in a given geographical area to determine which supports or sections to prioritise for retrofitting would be as follows:
1. Selection of the area to be surveyed, based on criteria that can be cumulative, such as distribution of species susceptible to electrocution or collision, presence of threatened species, presence of areas where there is a known or suspected impact of electrocution or collision, presence of known or suspected individual concentration sites (e.g. wetlands), or of protected areas. A list of criteria can be prepared and will help establish priority areas.
2. Identification of the power lines to be assessed. Firstly, it is advisable to get a map of the layout of the power lines in the selected area, or to create one in GIS format if one does not exist. Secondly, it is recommended to obtain specific cartographic information about the power line supports and their design, as well as about the distribution of the habitats and species at risk. This information can be obtained through deskwork if there is sufficient literature and baseline cartographic information, or by combining deskwork with fieldwork. If necessary, the supports can be mapped and information collected on their design (or on the type of power line, wires, etc. when assessing the risk of collision) and other technical details as well as detailed data on electrocution and/or collision fatalities.
3. Assessment of the risks of power line supports and sections and prioritisation of corrective measures. In the next step, the information previously obtained through deskwork or fieldwork will be used to establish the danger level of each support and/or the parameters of the identified power line sections: design, habitat and potential presence of species at risk. One of several models published in the scientific literature (Tintó et al., 2010; Dwyer et al., 2014; Bedrosian et al., 2020) can be used for this purpose or a model could be developed for the analysis in question. Once the level of danger has been established, correction work can be prioritised in those parts of the line where the risk is greater, and where measures are urgent due to the impact on the target species.

Source: compiled by the authors

Table 7-3. Basic information to be collected by and included in protocols for identifying and characterising dangerous power lines.

General data. Basic information to identify the document (the data-entry report or sheet), the person collecting the information, the location, etc. • Identification code of the power line. • Person collecting the data: full name and contact details (telephone, e-mail). • Date and time. • Brief description of weather conditions. • Identification of the location: name of the place, municipality, etc. • Location: geographical coordinates of the pylon or accident location. • Habitat: general habitat type, e.g. forest, garrigue, herbaceous crops, tree crops.
Identification and characterisation of the power line and supports. The power line and its supports should be described using the basic terminology given in Chapter 2 of this manual. • Ownership of the line (information generally obtained later). • Name of the power line (as with ownership). • Rated voltage (if currently unknown, to be filled in later). • Line code (found on a panel on the support or added later). • Support code (found on a panel on the support or added later). • Description of the support(s) or line: presence and number of ground wires, type of crossarm, presence and layout of any strain insulators and jumpers, presence of disconnectors or transformers, number and arrangement of phases and other relevant characteristics described in Chapters 4 and 5. • Location (taken at the base of the support; for a section posing a collision risk, take the locations of the two supports at either end of the span). • Retrofitted devices: if a support has been corrected, describe the corrective devices and the condition of their parts, paying particular attention to any defects. • Deterrent devices: the same applies if there are anti-perching devices, supports, platforms, etc. • Line markers: the same applies to any anti-collision marker system.
Detected fatalities. Detailed information on fatalities if detected during the survey: • Species. • Number of individuals. • Sex and age (if possible). • Condition of the individual (injured or dead). • Condition of the carcass (fresh, decomposing, skeleton). • Apparent injuries (in accordance with Tables 6-1 and 6-2, Chapter 6).
Actual mortality. If actual mortality estimates are to be obtained, it is necessary to carry out experiments and studies at a local level to obtain specific values for the disappearance and detectability rates (see section 6.4 and literature cited there).

Source: compiled by the authors

The sampling unit must be the power line support in the case of electrocutions or the line section in the case of collisions. In the case of the latter, in order to optimise the **search for collision spots**, it is important, as mentioned, that sampling is carried out according to a standardised methodology. Some basic recommendations are as follows (Lazo et al., 2016; Figure 168):

- The width of the observation strip is set at 30 m and 60 m for the sampling strip.
- The observer should move forward in a zig-zag fashion within the observation strip, at an angle of approximately 50º to the line, to maximise the chance of encountering carcasses.
- The observer should maintain a speed of approximately 2 km/h; at this speed, the average length of a sampling sector to be covered by an observer in a single field day would be about 4–5 linear km of power line, or about 16 km of actual zig-zagging, always depending on the trafficability of the terrain.
- The use of trained dogs is recommended for habitats with dense vegetation (see Section 6.4).

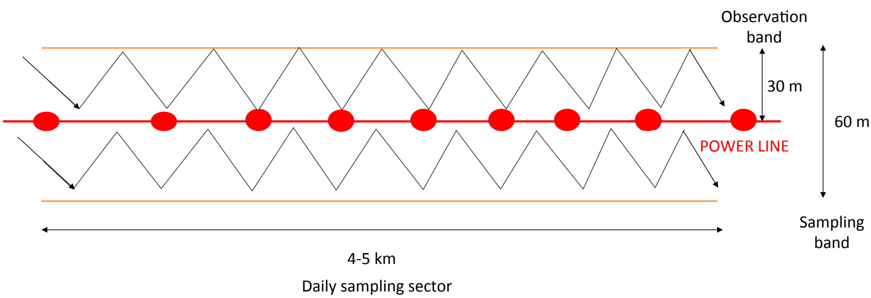

Figure 168. Basic distances recommended for collision surveys. Source: prepared by the authors based on Lazo et al., 2016.

The data should be accompanied by **photographs** of the support, especially the crossarm (when assessing electrocution risk), the section of the power line and cables (when assessing collision risk), and, in the case of incidents, the condition of the carcass and its remains. Many cameras and mobile phones can include geolocation information with the photos taken, and it is advisable to activate this option (Figure 169).

Figure 169. The data must always be accompanied by photos taken with a camera or a mobile phone. Survey of power lines in Morocco. © Carlos Torralvo

It is advisable for all data collectors to use the same **coordinate system** – UTM or degrees of latitude and longitude – to facilitate subsequent data processing. If UTM coordinates are chosen, it is vital to check that the map datum and geographic zone used are correct. Because of its coverage and ease of use, the most practical datum to use is the WGS84 global geographic coordinate system (the one used by Google Earth). The maximum precision possible is required for the data; errors of a few dozen metres can lead to erroneous support identification, resulting in mistakes being made in the execution of mitigation work.

The reports and data-entry sheets must be designed in such a way that data collection and subsequent interpretation are as simple as possible, through the use of diagrams and drawings, 'yes/no' checkboxes, specific spaces for each piece of information, etc.

It is practical to include a 'Notes' field for any relevant aspect that cannot be added elsewhere in the report or for any supplementary information deemed necessary, such as whether there are nests, how many there are, the species they belong to, their status, etc., together with their location or a photograph, or references to other incidents that may have occurred in the past. This space can also be used to mention any other power lines nearby that may be of interest, etc. (Figure 170).

The effectiveness of the measures to adopt and their cost/benefit ratios are directly linked to the quality of the data collected, including data on the existing wildlife populations.

Figure 170. When birds are discovered, it is important to search the area for any signs that may indicate the cause of death or provide other relevant information. The carcass of a white stork (*Ciconia ciconia*) near a power line in Morocco. ©Íñigo Fajardo

It is a good idea to add useful reference information on the report or data sheet, such as a glossary of the technical elements of power lines, details of a contact person to receive information, an address (physical or electronic) to which information can be sent.

Filling in reports or data-entry sheets in the field requires a great deal of effort, and collecting data also involves covering several kilometres of power lines on foot. New technologies have made this a lot easier and more effective. There is a wide variety of **mobile applications for field data collection**, which allow custom forms to be designed for any particular study. Some apps have even been developed for collecting power line data directly on a mobile phone (Harness et al., 2016; GREFA, pers. comm. 2018). IUCN-Med has developed a free mobile application, e-faunalert (https://e-faunalert.org/), specifically for collecting data on dangerous power lines around the world, in collaboration with the *Fundación Amigos del Águila Imperial, Lince Ibérico y Espacios Naturales Privados*; it is available in several languages (Figure 171).

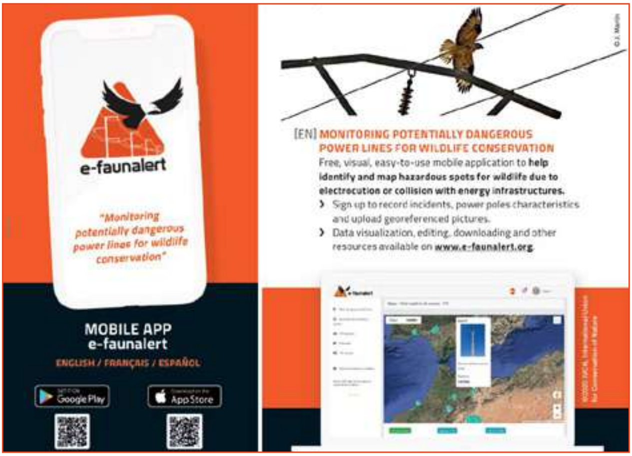

Figure 171. e-faunalert is the mobile application developed by IUCN-Med. The use of mobile applications makes it easier to collect, check and process data. e-faunalert promotional flyer. ©IUCN-Med

There are also various **citizen science platforms** for collecting data on biodiversity that can be useful for this purpose (see for example those mentioned in Section 7.1). Some of them have been created specifically to monitor mortality caused by electricity infrastructure, in collaboration with electricity companies. In Europe some initiatives of this type are operating, such as the 'Vogelfundportal'/'Bird Portal', an online portal which allows users to report dead birds found around power lines in Germany (a joint endeavour by Renewables Grid Initiative – RGI, the Nature and Biodiversity Conservation Union – NABU/BirdLife Germany, and German grid operators. For further information, see: https://renewables-grid.eu/activities/ird/bird-portal.html, https://www.nabu.de/tiere-und-pflanzen/voegel/gefaehrdungen/stromtod/25433.html; interactive online map available at: https://www.nabu.de/tiere-und-pflanzen/voegel/gefaehrdungen/stromtod/25541.html).

Another use of new technologies is checking and characteriseing overhead lines and their supports with **drones** (Mulero-Pázmány et al., 2014; Yang et al., 2020). These devices are now used by electricity companies for power line monitoring and inspection; they can be very useful in the case of potentially dangerous supports and lines located in areas that are difficult to access.

One aspect that is often neglected is the evaluation of the effectiveness of the measures employed and, if necessary, periodic reviews of the condition of installed devices. Ideally, protocols for such evaluation and review should be developed and implemented (see Section 8.1).

7.6. DATABASE AND MAP CREATION

All the **information collected**, whether through reports or by any other means, must be **digitised and entered into a database**. Given the large amount of data that can be collected, it is advisable to **centralise** the database as far as possible, or at least to keep multiple existing databases (by department, region, natural area, etc.) while maintaining the **same structure** in each one to facilitate data transfers and comparisons.

The fields in the database must logically match those in the report, although other fields may be included, such as the correction date, the company responsible, the review date, etc. Each entry should correspond to one observation or one specific support, in accordance with the design of the database.

Instructions for use (or the equivalent) should also be developed, so that there are no divergences in the way information is collected and entered, even if the database is managed by different people.

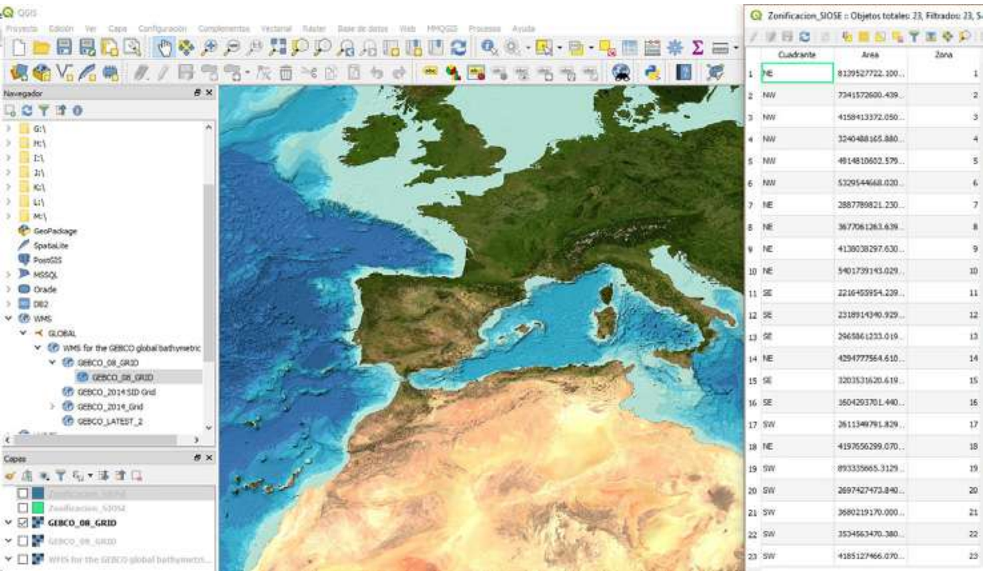

Figure 172. The association of data collected in a geographic information system facilitates data analysis and decision making. The QGIS interface, with associated maps and data. Source: prepared by Justo Martín.

The database can be designed using a database management programme or spreadsheets. The important thing is that it should be **compatible with a geographic information system** (GIS) to work directly in map format. One good tool is Quantum GIS (QGIS), a free, open-source-code GIS for GNU/Linux, Unix, Mac OS, Microsoft Windows and Android platforms (Figure 172); there are other free tools such as gvSIG, GRASS, SAGA GIS and Kosmo. ArcGIS is perhaps the best-known GIS and offers greater possibilities, but a user licence has to be purchased.

Google Earth and its KMZ file format can be used to display, send or receive the data, so they can be used by people who are not familiar with using a GIS; the data processed in the GIS can be exported to this programme.

GIS software can be used not only to manage the data collected, but also to associate them with other sources of information available for consultation. In the absence of prior information, these sources can also be used to establish a starting point for studies.

7.7. IMPORTANCE OF SHARING DATA AND INFORMATION

Just as important as the production, collection and management of data is the **sharing of the information and making it available to help in decision-making processes at all stages**, from the planning of new line development projects to the design and implementation of mitigation measures.

The most efficient approach to reducing electrocution and collision risk is to undertake strategic environmental assessments (SEAs) and environmental impact assessments (EIAs) at proposed power line locations during the planning stage and to adopt safe designs and structures. In the case of existing lines, companies should carry out monitoring studies – collecting data about the species present, fatalities and the effectiveness of any mitigation techniques that may have been implemented.

Some companies already perform studies of this type and collect at least some of these data during the construction and/or monitoring phases (see Kettel et al., 2019). These studies are of great value, as they gather first-hand information on how effective the mitigation and prevention systems adopted have been, and they should be disseminated and used to improve power line management (Figure 173). In some cases, companies publish these studies or some of the data collected, and/

or they provide their data for use in scientific publications or in conservation initiatives in partnership with non-governmental organisations (Kettel et al., 2019); examples of this type of partnership are the Eskom-EWT Strategic Partnership, https://www.ewt.org.za/what-we-do/wildlife-and-energy-programme/, and the French National BirdLife Committee, http://rapaces.lpo.fr/cna-oiseaux-et-lignes-electriques. However, except in rare cases like these, the information is often not published and data are not yet fully centralised or systematically made available for wider use.

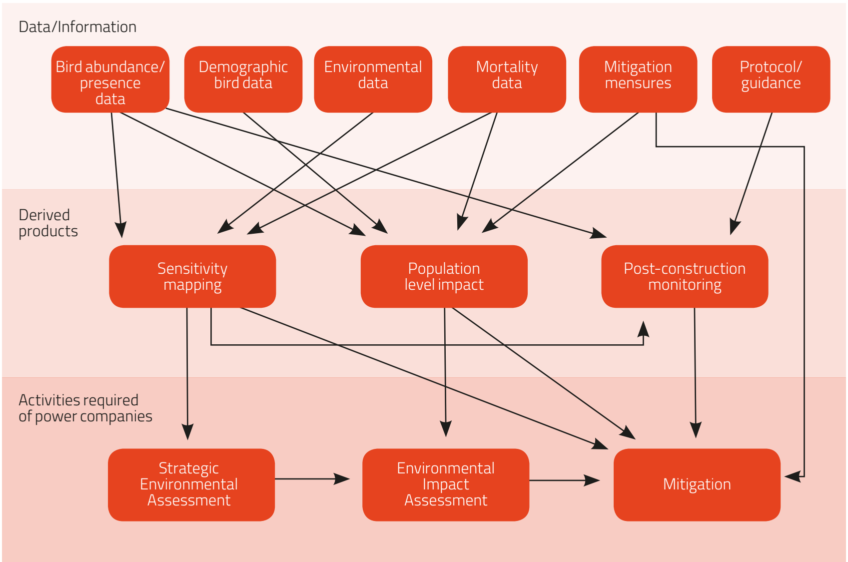

Figure 173. Conceptual framework for how data/information (top) informs derived products (middle) and activities required of power companies (bottom). Source: adapted from Kettel et al., 2019.

The systematic collection and dissemination of all such information would be invaluable for other electricity companies and stakeholders when assessing the vulnerability of species to power lines and also during the planning stage and when developing mitigation measures through mapping the sensitivity and vulnerability of species. This would not only help **avoid power line construction in the highest-risk areas and identify priority locations for mitigation** measures, but also minimise costs (Kettel et al., 2019).

Furthermore, electricity companies could demonstrate their commitment to society and nature conservation by making the results of their reports available to everyone and contributing to the creation of national databases, and even developing citizen science initiatives to collect data and information (see Section 7.5). Some companies are already doing this, as mentioned above. To power companies, collisions and electrocutions can also have financial consequences resulting from power outages. It is therefore in the companies' interest to adopt best mitigation practices for the sake of their reputation, public acceptance and compliance with national and international laws.

On the other hand, scientists do not always widely disseminate their evidence and results or share them with companies, authorities and other relevant decision makers. **Much of the scientific literature is difficult for external stakeholders to access, evaluate or understand**. As a result, information on best practice for reducing the impact of power lines on wildlife is not always widely known and electricity companies or governments might not have the resources to conduct extensive literature searches (Kettel et al., 2019). For companies to plan and design low-impact infrastructure and implement mitigation measures when needed, and for governments to develop the appropriate regulatory frameworks and/or the necessary agreements with companies, they both need to have the best existing information at their disposal, but they also must do their part to obtain it and make good use of it.

It would be **useful for all stakeholders to agree on and adopt uniform methodology and guidelines for the conduct of studies**, together with standardised data formats, to ensure that studies conform to high standards, produce comparable and/or homogeneous results, and meet their required objectives (for suggestions see Section 7.5). One outcome of this should be a more integrated database containing all the available data and study results, which can be used for the planning and management of power lines and their impacts.

Publishing and sharing such information can certainly help develop trust among the various stakeholders, while also raising awareness of the studies being carried out and of the data and information that is already available.

8

Bases for power line action plans and their incorporation into general conservation strategies

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[4] SaharaConservation, France

Given the extent and complexity of the problem of the impact of power lines on wildlife, a definitive solution must involve the adoption of several measures allowing for an integrated and effective approach.

Figure 174. The definitive solution to the problems involving wildlife and power lines lies in the preparation and implementation of a specific action plan. Long-legged buzzard (*Buteo rufinus*). © Justo Martín

Ideally, this set of measures should be implemented in a systematic, organised manner through **action plans aimed at preventing, avoiding and mitigating the impact of power lines on wildlife**. Such plans should situate the issue in time and space and detail the methods of execution and the timeframe. The territorial and temporal scale of an action plan and its scope will depend on the specific needs and capacities of each situation; it may encompass one species or several, and operate at a local, regional, national or even transnational scale. It would be up to the international, national or local authorities involved (with responsibility for the environment, industry, energy and spatial planning) to start designing and developing the action plan or plans, in collaboration with the electricity companies and civil society, through NGOs involved in nature conservation and with advice from experts.

> *Measures to protect biodiversity must be identified early in the project planning stages.*

Action plans should contain **different types of measures**, including at least those presented below (from Antal, 2010; Prinsen et al., 2011a; BirdLife International, 2015, 2021; Dwyer et al., 2017; European Commission, 2018; CIBIO, 2020):

- Collection of information about power lines, sensitive species and mortality;
- Identification of priority sites and planning processes;
- Establishment of a specific legal framework;
- Establishment of mechanisms for stakeholder participation and cross-sector collaboration;
- Development of awareness-raising and training plans.

Likewise, the set of measures aimed at avoiding and mitigating the impacts of power lines on wildlife should be integrated into the processes of strategic spatial planning and environmental assessment, to ensure that they are taken into account at all stages in the development and implementation of projects. Considerations on the protection of these species should also be included in more comprehensive policies and strategies (for nature protection or energy development), to ensure greater coherence and long-term sustainability of the measures.

8.1. INFORMATION ON POWER LINES, SENSITIVE SPECIES AND FATALITIES

The first step in addressing the problem of these impacts in a specific area is to acquire adequate reliable information about the situation, which means **collecting and compiling data** on any wildlife fatalities due to electrocution or collision and the technical characteristics of any dangerous power lines detected (Figure 175; see Chapter 7).

Figure 175. The ultimate objective of the action plan is to establish an electricity grid with the lowest possible impact on sensitive species in the country. The collection of field data is the first step towards this end. Inspection of power lines and bird fatalities in southern Morocco. © Íñigo Fajardo

In this respect, **fatality monitoring and reporting systems** should be implemented, especially by electricity companies. Such systems are used to observe problematic areas where electrocutions and collisions are concentrated. This information should be shared with the authorities and civil society so that they can collaborate in finding effective ways to minimise the impact. As mentioned in Section 7.5, citizen science tools can play a very important role in this kind of data collection. The development of new monitoring technologies, such as those mentioned in Section 4.5, can also help in this regard. Environmental authorities should perform a supervisory role to ensure the information is gathered correctly and made available, as well as participating in the data collection.

> *Standardised procedures need to be set up for inspecting preventative and corrective measures and monitoring their status and effectiveness.*

To facilitate the management of the information gathered, a centralised **national or regional register** should be set up to record **power lines that are dangerous or potentially dangerous** to birds or other susceptible groups found in the territory, as well as related fatal incidents. The register should be based on field data and scientific knowledge about the supports and lines that pose high electrocution and collision risks (those located in areas used intensively by susceptible species, supports and lines that have caused fatalities, and supports with dangerous configurations). The register will provide information on where the greatest impacts occur or might occur so that mitigation measures can be implemented to prevent them. It will also enable construction plans for new power lines to take into account the lessons learned from existing lines.

In conjunction with fatality monitoring systems, **on lines where preventative and/or corrective measures have been implemented**, power companies should establish mechanisms both to check that the measures have been properly implemented and to periodically monitor their status and effectiveness, using standardised procedures (see Section 7.5). Retrofitted devices should be subject to **regular inspections** to assess their condition and address any deterioration. These inspections could be combined with monitoring of the devices and their effectiveness for research and information purposes, for example to check the durability of the materials under different weather conditions (see Sections 4.4 and 5.7). In any case, any non-functional device found should be replaced as soon as possible (Figure 176). The inspections should take place at least as frequently as the inspections of the condition and safety of the power line itself, and not less than once every three years. These technical inspections must ensure that the compulsory retrofitting of any supports or lines where electrocutions or collisions have been recorded is carried out.

Figure 176. Non-functional devices should be replaced as soon as possible. Pole retrofitted with insulating sheaths which have become detached. © Justo Martín

Similar monitoring and inspection work should also be carried out by specialised government technicians, in addition to the work done by electricity companies to comply with regulations and to meet their quality criteria (Figure 177).

These assessments should be **published** to make their findings on the effectiveness of the measures, whether positive or negative, accessible to everyone, thereby adding to a pool of common knowledge for all stakeholders (as discussed in Section 7.7). Assessment results can be published in peer-reviewed journals and on freely accessible online platforms such as https://renewables-grid.eu/.

Figure 177. Electricity companies' technicians and workers need to be trained in the correct procedures for inspecting preventative and mitigation measures and monitoring their effectiveness. © Justo Martín

8.2. PRIORITY SITES AND PLANNING PROCESSES

Analysis of the data recorded in the register together with information on the presence of sensitive species and the existence of areas important for these species or protected areas, among other factors, makes it possible to **identify and delimit at-risk, sensitive and priority areas**. GIS and **sensitivity mapping tools** can be used to map areas where potential collisions and electrocutions might be expected, and/or where poorly planned and dangerous power lines may have significant impacts on the conservation of the most susceptible species present (for bird sensitivity maps see, for example, Pérez-García, 2014; Red Eléctrica Española, 2017; D'Amico et al., 2019; Derouaux et al., 2020; Biasotto et al., 2021; UICN, In press). See Sections 7.2–7.4 and Case Study 17 for more details.

Sensitivity mapping is an important decision-making support tool for project developers, authorities and donors. It can be carried out across the whole territory or in the areas of greatest importance for target species. It should initially focus on the natural areas protected in national or regional legislation. Important Bird Areas (IBAs) meeting BirdLife International's criteria, specifically for birds, and Key Biodiversity Areas (KBAs – IUCN, 2016), for vertebrates of conservation concern, should be also be included if they have not been already (Figure 178).

These maps should be used **early in the planning process** to identify areas where new overhead lines (or other energy infrastructure such as solar photovoltaic or wind farms; Figure 179) should be avoided or where underground or at least safe power line designs should be prioritised. Such maps should show at least two categories of area:

- **Main areas** – areas in which it is advisable to avoid erecting power lines as far as possible; if this is not possible, the installation of underground lines or twisted cables should be considered. If aerial wires are the only feasible option, these areas must be regarded as secondary.

- **Secondary areas** – areas in which newly created routes avoid particularly sensitive locations for species and their habitats, and are as short as possible. It is especially important to use safe posts or pylons for new installations in such areas and to retrofit existing supports with insulating sheaths; the potentially most dangerous spans should be fitted with markers. It is also advisable to avoid routes near wetlands, rivers and the areas they run through; ridges, hills and cliffs and their surrounding areas; as well as forest zones and steppes of importance for birds.

Figure 178. The entire IBA network should be considered a priority for the application of preventative and corrective measures to mitigate the impact of power lines. Lake Nakuru National Park IBA, Kenya. © Justo Martín

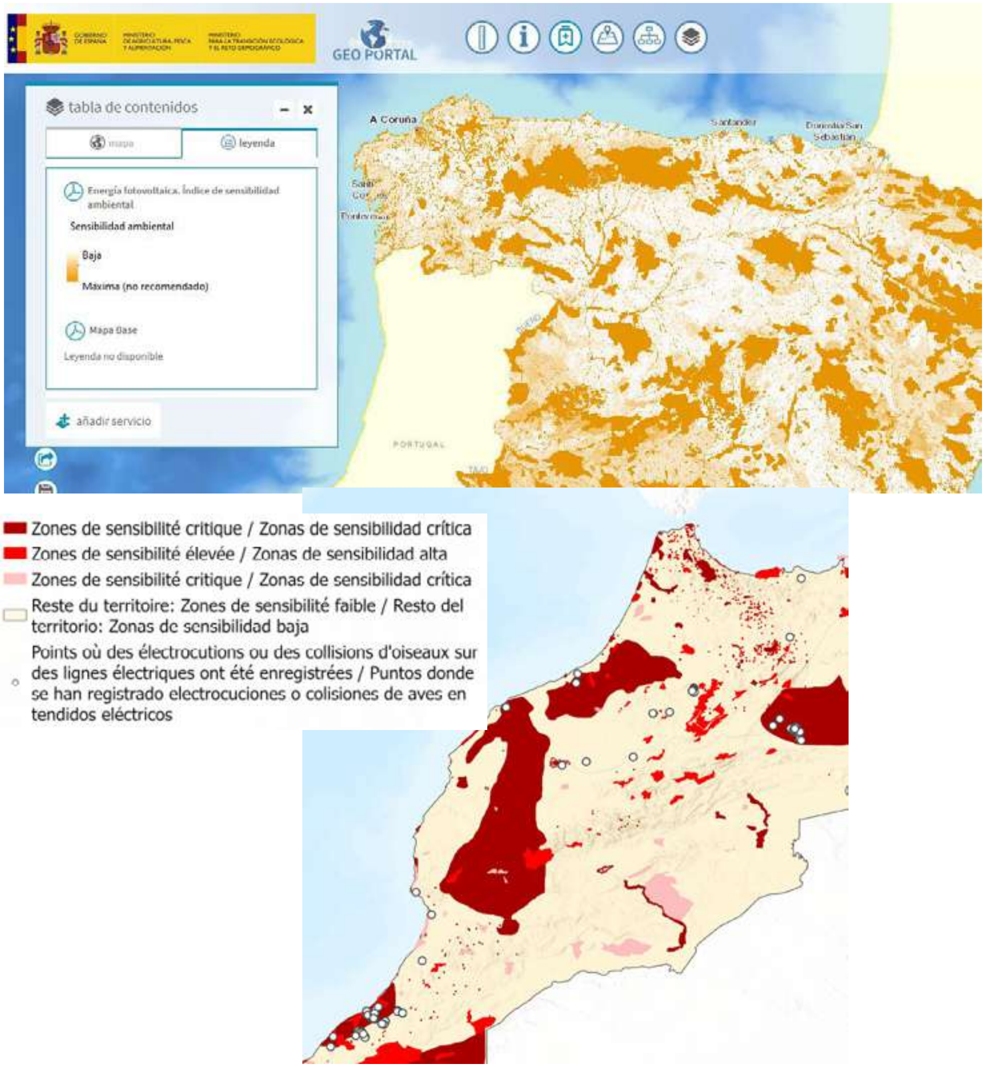

Figure 179. Two examples of sensitivity maps. Top: Environmental sensitivity map developed by the Spanish Government to identify the areas of the country that are most sensitive to new solar and wind energy projects. Available at https://sig.mapama.gob.es/geoportal/. © Ministry for the Ecological Transition and the Demographic Challenge, Spain. Bottom: Map of sensitive areas in Morocco (detail), where power lines can represent a threat (greater or lesser) to the populations of sensitive bird species. Source: UICN, In press

Planning of all new power lines should follow the identification of suitable routes based on technical, ecological, social and economic criteria, bearing in mind the presence of previously identified at-risk, sensitive and/or priority areas, and factors affecting the number of accidents involving wildlife on power lines, inter alia. The **best available impact-avoidance and prevention measures** should be put in place at the route planning stage and during the design and construction of a new line. If this is not feasible, **mitigating measures** should be implemented; failing that, some means of offsetting the impact will need to be adopted (see Table 8-1 for examples of measures).

Table 8-1. Examples of measures to avoid or reduce environmental and landscape impacts of new power lines.

• If technically possible, install new lines over existing ones, creating double circuit lines (unless they are in areas of importance for wildlife, in which case it would be better to build the line in another, non-sensitive area).
• Try to build the new lines near transportation routes (roads, paths, railway lines, other power lines), creating integrated infrastructure corridors.
• Avoid routes that run along summits, ridgelines, dominant points, river valley crossings, coastlines or migration corridors ('bottlenecks'), or near rocky areas, whether isolated or in mountainous areas.
• Avoid areas where birds congregate regularly, temporarily or seasonally (landfill sites, some agricultural areas, etc.) and community roosts.
• In environmental impact studies, include restoration and offsetting measures (measures that compensate for environmental impacts that are unavoidable or too costly to avoid, once all avoidance and mitigation measures have been taken) aimed at improving the habitat (shelters for small vertebrates, nest boxes for small and medium-sized birds, improvements in the vegetation, etc.).
• During the nesting, breeding and chick-rearing period, try to avoid carrying out maintenance work on power lines that have nests on supports or that are located near nests or breeding sites used by priority species.

Source: compiled by the auhors

Sensitivity mapping provides valuable information for planning and for directing funding towards actions that mitigate current impacts, for example by identifying areas where existing power lines should be proactively retrofitted. Sufficient resources should be allocated in such areas to avoiding or mitigating existing or potential impacts caused by power lines.

8.3. SPECIFIC LEGAL FRAMEWORK AND AGREEMENTS

To ensure power lines are safe for wildlife, it is recommended that an appropriate, specific legal framework be established at national or regional level, and/or collaboration agreements be set up between the parties involved to facilitate good relations and cooperation. The following aspects need to be included:

- In general, the **protection of wildlife** against potential negative impacts of power lines, considering the adoption of the safest preventative measures in each case;

- **The obligation to adopt wildlife-safe configurations on future power lines**, so that it is not necessary to install insulation systems, except where safer designs are not possible;

- **The obligation to install anti-collision and/or anti-electrocution devices on existing power lines** in cases where collected data show that these specific support designs are dangerous to wildlife (see Appendix A and B); a reasonably short maximum timeframe should be specified to ensure that the necessary corrective measures are adopted rapidly;

- **The inclusion of aspects relating to the protection of vulnerable species in legislative procedures** and in power line inspection protocols, at the same level as technical safety aspects and other particulars of environmental protection, requiring that the non-adoption, poor application or poor maintenance of proposed measures constitute grounds for shutting down the operation and use of the power line.

In addition, the legal framework or collaboration agreement should set out the mechanism for **financing preventative, corrective and offsetting measures** according to the polluter-pays principle.

Governments that operate grids and/or issue permits for grid development should work with electricity companies to implement such regulatory frameworks and measures, with the collaboration of expert advisors and all other stakeholders. This will facilitate electicity network operations, ensuring both the electricity supply and the minimisation of risks to infrastructure and fauna.

Although establishing such a regulatory framework is important, it is not essential for the implementation of an action plan. It is sufficient to establish working and action protocols that include the basic content of these points, agreed on by the government authorities and the electricity companies, together with a firm commitment by all stakeholders to fulfil them (Figura 180).

Figure 180. An effective action plan must be agreed on by government authorities and the electricity companies. Power lines in Tunisia. ©Íñigo Fajardo

At the same time, the action plans and measures implemented must take into consideration both existing national legislation and the regional and global obligations on signatory countries arising from international agreements and treaties (e.g. Convention on Biological Diversity (CBD), Convention on Migratory Species (CMS), Agreement on the Conservation of African–Eurasian Migratory Waterbirds (AEWA)), that address the conservation of wildlife or the energy sector's impact on biodiversity.

8.4. CROSS-SECTOR COLLABORATION AND STAKEHOLDER PARTICIPATION

The complex and multi-faceted nature of the energy sector overall is currently characterised by fragmented planning practices and a lack of cross-sector action in many parts of the world (Fischer et al., 2020). **Cross-sector collaboration and cooperation mechanisms involving the various relevant authorities and electricity companies** can foster efficient, environmentally friendly management of energy infrastructure. Likewise, **stakeholder participation** in electricity grid development and operation projects is also a very important aspect. To ensure effective participation and cooperation, environmental information sharing in the planning and operating phases (see Section 7.7) and stakeholder consultation are both essential.

National committees that include members from the relevant authorities and electricity companies, as well as technical experts, scientists and civil society representatives, can be set up to facilitate communications and the coordination of efforts among all parties.

The main function of these committees is to optimise efforts aimed at reducing impacts, ensure consistency between current and future actions, and establish implementation priorities. Their work should also include disseminating studies and their results, as well as exchanging experiences between different regions in a country or between different countries. National committees should ideally be sponsored and financed by the electricity companies as one way of offsetting some of the adverse effects of dangerous power lines.

As mentioned in Section 7.7, there are some good examples of collaborations in this regard. In France, there has been a committee of this type since 2004, the Comité National Avifaune (CNA, French National Birdlife Committee; http://rapaces.lpo.fr/cna-oiseaux-et-lignes-electriques), which has achieved very satisfactory results (Figure 181).

Another way to encourage stakeholders to work together is to create **partnerships** between two or more of them. This is the case, for example, in South Africa, where in 1996 the Endangered Wildlife Trust (EWT – the national conservation NGO) and the country's state-owned power company Eskom established the Eskom-EWT Strategic Partnership (EWT-ESP). Its goal is to minimise negative interactions between wildlife and the electricity grid in the country by analysing incidents and undertaking corrective and preventative work on the infrastructure (EWT, 2020). For further information see: https://www.ewt.org.za/what-we-do/what-we-do-people/wildlife-and-energy-programme/, https://www.ewt.org.za/our-news/our-news-integrated-reports/.

Involving civil society organisations and citizen groups provides benefits in terms of **increased transparency and engagement** with citizen science data collection efforts. It should be noted that, whether or not mechanisms exist for the participation of civil society, conservation NGOs and other stakeholders can play a very important role in advocacy and environmental monitoring.

Figure 181. Screenshot from the website of the CNA. © Comité National Avifaune

8.5. AWARENESS RAISING AND TRAINING

An important step in developing the action plan is to assess the ability of the various sectors directly involved to implement the measures effectively. **If gaps in experience, capacity, skills or knowledge are identified, the plan should include initiatives to design and implement awareness raising and training** for all stakeholders likely to be involved. Such actions must have a clearly defined schedule and be updated regularly.

Training in the public sector. As in some of their other lines of action, the environmental authorities should employ full-time technical staff who are specially trained to address the problem of wildlife electrocutions and collisions, combining technical knowledge of power lines with scientific expertise on birds (and/or other susceptible groups of fauna), their biology and their behaviour (Figure 182).

This training should be extended to other civil servants responsible for the environment or who work in associated areas, such as forest rangers, engineers and lawyers. A customised training plan should be drawn up for each of them in accordance with their responsibilities and working practices. It is important, for example, that environmental agents or rangers know how to proceed in the event of an electrocution or collision and how to collect data on the accident. Likewise, the technical staff in charge of reviewing environmental assessments for new power line projects should be aware of their potential impacts and see if these issues are adequately addressed in the evaluation. It is also valuable if there are legislators, judges and prosecutors who have had specific experience and training.

Figure 182. Raising awareness of the problem among environmental authorities and electricity company technicians and training them is a priority for ensuring the success of the measures to be implemented. Work meeting during the workshop organised in Tunisia in 2017. © Justo Martín

Training of electricity companies' technicians and workers. All individuals working on the design, assembly and retrofitting of power lines should receive specific training on problems involving power lines and wildlife. Their training programmes must ensure that they understand the problems, the various kinds of preventative and mitigation measures, the effectiveness of these measures, best practice regarding use and installation, and how to collect the relevant data when inspecting the lines. In addition to ensuring that devices are correctly fitted and checked, this training will also have benefits in terms of monitoring, as it will enable participants to account precisely for accidents involving animals on power lines, and to fill in their own fatality reports with the help of pre-prepared forms and mobile phone applications designed for this purpose.

8.6. MAINSTREAMING WILDLIFE CONSERVATION IN SPATIAL PLANNING AND GENERAL POLICIES AND STRATEGIES

In order to minimise the impact of power lines on wildlife, the issue needs to be included in general **strategic spatial and environmental planning** and in proposals for energy development projects. These planning processes should be based on **strategic environmental assessments (SEAs)**, which enable governments and companies to **identify potential long-term, large-scale, cumulative risks and impacts** on wildlife, society and the economy of single large or multiple smaller power line projects at the pre-planning and planning stages. Sensitivity mapping tools can be used to identify areas where significant impacts may occur, as mentioned previously; high-risk areas can then be identified and the risks avoided or substantially reduced.

The SEA process should also optimise land use, reduce the overall environmental and social footprint of power line projects, and cut potential impact costs into the future (Figure 183). These planning tools should take into account the current context of increasing reliance on renewable energy to combat climate change. Climate change adaptations will require the development of renewable energies in places suitable for electricity production; these locations are usually not in conventional energy-producing areas and require power lines to be installed in remote and sometimes pristine areas such as forests and deserts (Figure 184).

Figure 183. The SEA process should optimise land use and reduce the overall environmental and social footprint of power line projects. Power line in a forested area in Spain; the central pylon has a Bonelli's eagle (*Aquila fasciata*) nest. © Justo Martín

Figure 184. The development of renewable energies requires the construction of new power lines. Thermosolar plant and associated power lines in Spain. © Justo Martín

Environmental Impact Assessments (EIAs) are **essential at the level of individual projects** and help to identify the extent of the threats to wildlife at that level. They must assess the biodiversity value of the proposed route of a new power line. Several routes should be investigated in parallel, and the risks associated with each one should be evaluated and appropriately addressed. The route involving the lowest possible risk should be the preferred option. These assessment procedures enable specific risks and impacts on wildlife to be addressed and can put forward specific avoidance and mitigation actions. A detailed pre-construction baseline survey is an essential part of an EIA. As the area occupied by power lines will be large, a stratified random sampling approach could be adopted.

Governments should ensure that the ecological data generated by EIAs is widely accessible, including abroad, so that it can feed into strategic analyses and add to the pool of knowledge on the impacts of power lines on wildlife. This information can then serve to improve SEAs. Competent authorities should have dedicated trained technical staff to work on these processes and ensure that potential impacts are fully included and addressed (as already mentioned in Section 8.5).

For their part, power companies should also have dedicated staff to carry out /manage SEAs and EIAs, as well as fully trained members of senior management who devote their time to making power lines safer for wildlife; otherwise, no resources will be allocated to this issue.

Figure 185. A detailed pre-construction baseline survey is an essential part of an EIA to detect the presence and status of sensitive species. Bearded vulture (*Gypaetus barbatus*). © Justo Martín

Governments and the relevant authorities should ensure that **mechanisms** are in place throughout the development and assessment stages of projects and plans **for all stakeholders** – local communities, conservationists, experts, researchers and civil society in general – **to be appropriately consulted and to participate effectively**. This is especially important in the earliest stages of project development so that expert and local knowledge can feed into the detailing and route selection process. The principle of free, prior and informed consent must be observed.

A lot of useful information about SEAs and EIAs concerning power lines as well as practical guidelines for partners, civil society, governments, development banks, financiers, project developers and consultants are available on the website of the Migratory Soaring Birds Project (https://migratorysoaringbirds.birdlife.org/en/sectors/energy/electrical-power-lines-toc#gsc.tab=0).

As discussed in Section 3.1, power lines can play a role as ecological corridors, at least for some species, especially if the land over which they run is managed for improving habitats, adding secure nesting sites, etc. These possibilities should therefore be incorporated into power line projects. There is already some experience in how such areas can be used for **habitat improvements favouring certain species**, as in the case of the EU LIFE Elia-RTE Project "Creating green corridors under overhead lines" (2011–2017). The aim of this project was to create green corridors under overhead electrical lines in wooded areas in Belgium and France. Various innovative actions were undertaken to enhance biodiversity and to raise people's awareness of natural habitats and the species associated with such corridors. The project is also an example of joint work by various stakeholders. More information and documents are available at: www.life-elia.eu.

Furthermore, it is important to ensure that the measures aimed at avoiding and mitigating the impacts of power lines on wildlife are **consistent and aligned with sectoral policies** (such as energy and spatial planning) and with environmental and sustainability strategies and goals. To achieve this, governments, power companies, donors and the energy and environmental sector in general should **incorporate them into more comprehensive policies and strategies**.

> *Mainstreaming species conservation measures within broader policies in all the sectors involved can help ensure that energy needs are met while the most susceptible species are unaffected by electrocutions and collisions.*

We hope that with the collaboration and firm commitment of all, and with the help of tools such as this manual, these species may be able to coexist safely with all power lines around the world in the near future.

9 Case studies from around the globe

This chapter presents a compilation of case studies written by international experts. They provide a systematic assessment of the current situation on the ground across five continents from a local point of view.

9.1. Africa

CASE STUDY 1

The impact of power lines in Morocco

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Over the past few decades, Morocco has launched a large-scale integrated programme to increase electricity production capacity by diversifying sources of supply, from coal- and gas-fired power stations (in Lasfar, Safi, Tahaddart and Beni Mathar) to large renewable energy projects. The country has implemented ambitious renewable energy projects and is planning several more, with the target of increasing the contribution of renewables to 52% by 2030 (ONEE, 2016). These efforts have led to significant growth in the high-, medium- and low-voltage electricity networks, which now total 27,516, 94,243 and 244,514 km, respectively (ONEE, 2020a). This has made it possible not only to export electricity but also to achieve near-total grid coverage of the rural parts of the country, reaching 99.78% in 2020 (ONEE, 2020b).

In 2016, a major electrocution mortality hotspot was identified in the region of Guelmin (in south-western Morocco) thanks to collaboration between the Action Plan for the Spanish Imperial Eagle in Andalusia, IUCN-Med and the Kingdom of Morocco (Godino et al., 2016). In order to reconcile the development of the electricity network with current biodiversity conservation issues, the National Water and Forests Agency (ANEF, in French), in collaboration with IUCN-Med and other partners (the Government of Andalusia and European NGOs), has developed knowledge transfer activities related to the conservation of birds threatened by electrocution.

Since then, the ANEF and IUCN-Med have organised four workshops and several training courses with more than 200 participants from North African countries and

Europe on identifying and mitigating the impact on bird species of collisions and electrocutions on electricity infrastructure. One outcome of these initiatives has been the production of a practical guide to the identification and prevention of dangerous power lines to birds, published in French for the North African region (Martín Martín et al., 2019).

At the same time, national NGOs [Research Group for the Protection of Birds in Morocco (GREPOM, in French)/BirdLife, Moroccan Ornithology Group (GOMAC, in French), Moroccan Association for Raptor Protection (AMPR, in French), Association of Friends of Raptors (ASARA, in French) and Moroccan Association for the Protection of Birds and Wildlife (AMPOVIS, in French)] have conducted field surveys to characterise and identify dangerous power lines at regional level (in Guelmin in 2016–2018, and in Missour and Ifrane-Azrou in 2019). The data collected on the impact of power lines on birds, in particular raptors, revealed significant mortality of several species of birds and mammals (eagles, vultures, buzzards, falcons, storks, crows and genets) in the surveyed regions, with 59 electrocuted animals in 2016, 43 in 2017, 98 in 2018 and 213 in 2019. At the country level, this mortality is an underestimate given that other potentially dangerous regions have not yet been surveyed and that a considerable effort remains to be made to ensure full coverage of Moroccan territory.

In 2020, NGO initiatives led by GREPOM and AMPR in collaboration with the ANEF included:

➜ Organisation of webinars;

➜ Production of articles (Amezian et al., 2015) and guidelines for collecting electrocution data on birds in the field (Aourir & Radi, Unpublished);

➜ Installation of GPS transmitters on Bonelli's eagles (*Aquila fasciata*) and Rüppell's vultures (*Gyps rueppellii*) (in the framework of the Small Scale Initiative Programme for Civil Society Organizations in North Africa – PPI-OSCAN, in French) to assess individuals' ranges and mortality (Figure 186 C);

➜ Assessment of threats to birds of prey in north-western Morocco (also in the framework of the PPI-OSCAN) and

➜ Establishment of a national network of observers and organisation of surveys to identify further black spots throughout the country (https://www.grepom.org/electrocution-safe-flyways/).

Additionally, to determine the real extent of this threat to raptor populations, the ANEF and IUCN-Med launched the Atlas Programme for inventorying and monitoring raptor populations in Morocco (UICN & DEF, 2020; Figure 186 A and B).

All actions to protect birds against electrocution must be accompanied by preventative, mitigating and corrective measures. The involvement of the managing bodies of the electricity network in Morocco, such as the *Office National de l'Électricité et de l'Eau Potable* (ONEE)-*Branche Électricité*, in this endeavour is fundamental. We hope that those in charge and decision makers within the grid operators are committed to participating in this effort to conserve and protect birds, particularly birds of prey, in the face of what national and international experts consider to be the main threat to birds of prey in Morocco.

Figure 186. A: Remains of electrocuted birds collected during a sampling survey in the Guelmin area. B: Survey of raptors in the High Atlas. C: Tagging a Bonelli's eagle (*Aquila fasciata*) with a GPS transmitter. © Justo Martín

CASE STUDY 2

Mitigating large mammal impact on wooden distribution poles in the Kruger National Park, South Africa

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As human populations expand and developments encroach into protected areas, it is inevitable that interactions between wildlife and electrical infrastructure will increase. This is the case in protected areas where mammal electrocutions often occur as a result of damaged electrical infrastructure. In a previous study conducted by the Endangered Wildlife Trust, a camera trap survey on a problematic power line in the Kruger National Park (Kruger) revealed that large mammals (particularly Cape buffalo, *Syncerus caffer*, and African elephant, *Loxodonta africana*) damaged wooden utility poles by rubbing/pushing against them. The study (Hoogstad & Diamond, 2012) and field observations reveal that mammal species utilise the wooden poles as rubbing/scratching posts. In some cases, up to 400 wooden poles have been replaced within the Kruger per annum (Arthur Blofield, pers. comm.). Since power lines within protected areas such as the Kruger often stretch over long distances and through various habitats, they create a challenging environment for maintenance. Damaged and weakened power line poles are a threat to the wildlife that interacts with them. The continuous rubbing action from large mammals on such poles results in the weakening of the pole. This can lead to electrocution of the large mammals which rub against them as it results in the sagging of the conductors when the pole breaks, posing a high electrocution risk (for example, at least 112 giraffes, *Giraffa camelopardalis*, three buffaloes and five African elephants have been reported electrocuted in the last 21 years in South Africa; Eskom-EWT Strategic Partnership, Unpublished). Damaged poles need to be replaced on a regular basis in order to prevent such electrocution events and to maintain a regular supply of electricity to users.

Four mitigation measures (steel sleeve, VB Rhino, Grating box and Polefix industrial cast) were tested for their effectiveness in reducing contact between mammals and poles (Figure 187). Camera traps were set up along the Foskor-Kruger 22 kV power line in the Kruger National Park over 16 months to monitor wildlife interactions at experimentally treated (n=9) and control (n=8) utility poles. Direct contact between large mammals (buffalo: 64%, elephant: 11%) and poles made up 71% of pole–wildlife interactions.

A cost–benefit analysis was undertaken to determine the most cost-effective mitigation measure. Although VB Rhino is the most expensive solution, wildlife-pole interactions were completely prevented. The Grating box significantly reduced contact from buffalo and deterred elephant and other species from utilising it. The Grating box is also designed in such a way that when an animal makes contact with the product, it rotates around the pole. This acts as a further deterrent for an animal to rub against it. This method of mitigation is easy to install and the pole can still be inspected for damage and infestations. While it is not the cheapest method of mitigation, it is potentially the most suitable and, in the long run, the most cost-effective. An added benefit is that these boxes installed on wooden poles do not have a visibility impact in nature as they can be coloured to blend with their surroundings. Further benefits of the Grating box include: it is lightweight, easy to assemble, low maintenance, corrosion resistant and fire resistant. Based on these findings, it is suggested that the Grating box is the most feasible solution to limit wildlife interaction on wooden poles.

It is evident that installing mitigation products will reduce annual costs to the power company significantly. Implementing mitigation will not only allow for a more reliable, consistent supply of electricity to camps and facilities in and around Kruger, but will prevent potential mammal electrocutions in the future.

Figure 187. The four mitigation products tested to limit/prevent contact between wildlife and poles in the Kruger National Park: A: Steel pole sleeve; B: Polefix industrial cast; C: FRP Grating box; D: VB Rhino. © Endangered Wildlife Trust

9.2. Americas

CASE STUDY 3

Power lines and wildlife in South America

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Power line impacts on wildlife are a global conservation issue. In Europe and North America, wildlife collisions and electrocutions on power lines have been extensively addressed and are recognised as a growing threat to biodiversity. However, this problem has been largely overlooked in other parts of the world, such as South America. As a result, and with few exceptions, there is a lack of systematic assessments of the impact of this source of mortality on wildlife populations in these areas (Lehman et al., 2007; Bernardino et al., 2018).

One of the groups of animals most frequently affected by electrocution on power lines is raptors, due to their behaviour and size. South America harbours almost a third of the globally recognised raptor species (Sarasola et al., 2018), but recorded electrocution incidents are anecdotal, with few events in Chile, Brazil and Argentina (Valenzuela, 2009; Alvarado-Orellana & Roa-Cornejo, 2010; Ibarra & De Lucca, 2015; Sarasola & Zanón-Martínez, 2017; Galmes et al., 2018; Gusmão et al., 2020; Sarasola et al., 2020). In these countries, electrocutions mainly occur on three-phase medium-voltage (12–13.2 kV) distribution lines. Additionally, in central Argentina incidents have also been reported on single-phase low-voltage (7.2 kV) lines, even though these are less common (Figure 188 C). Electrocution incidents are also linked to poles and crossarms made of conducting materials (e.g. steel-reinforced concrete or metal), and with jumpers above the crossarms. On these lines, birds perch directly on the top of the grounded pole with little clearance between themselves and a jumper wire attached to the top of the pole (Galmes et al., 2018; Sarasola et al., 2020; Figure 189 E).

In Argentina, species affected by electrocution on power lines include at least two parrots, one owl and five diurnal raptor species: black-chested buzzard eagle

(*Geranoetus melanolecus*), variable hawk (*Buteo polyosoma*), turkey vulture (*Cathartes aura*), black vulture (*Coragyps atratus*) and Chaco eagle (*Buteogallus coronatus*) (Sarasola & Zanón-Martínez, 2017; Galmes et al., 2018). The Chaco eagle (Figure 188 A and D) is the only species of conservation concern in South America for which electrocution is considered a major threat to its populations, due to the high number of incidents in comparison with local abundances (Galmes et al., 2018) but also with regard to its global population size (Sarasola et al., 2020).

In Chile, apart from a single mention of an owl species, avian electrocution events are restricted to the black-chested buzzard eagle (Valenzuela, 2009; Alvarado-Orellana & Roa-Cornejo, 2010), which is also the species most affected by electrocution in Argentina (Ibarra & De Lucca, 2015; Sarasola & Zanón-Martínez, 2017). Notably, in both countries, juveniles comprised the bulk of the electrocution incidents involving this eagle species, which are probably related to the large aggregations of juveniles that form during dispersal in areas with high-risk poles (Figure 188 B).

In both Argentina and Chile, increased social awareness of avian electrocution resulted in the implementation of mitigation measures, which included retrofitting of power line pylons (Figure 189 F). However, such measures were implemented at a local scale (on particular poles) and not as part of conservation strategies at regional or country levels, with the exception of La Pampa province in central Argentina, where a power line of over 40 km was constructed to avian-friendly designs (Figure 189 G and H).

Electrocution has been reported for harpy eagles (*Harpia harpija*) in Brazil (Gusmão et al., 2020). Two juveniles and one adult died on rural overhead distribution lines operating at a standard low voltage of 13.8 kV.

Reports of wildlife collisions with power lines in South America are even more scarce than those for avian electrocution. Avian collision is mentioned for a swan species in Chile (Valenzuela, 2009), harpy eagles (Aguiar-Silva et al., 2014) and two species of terns (see below) in Brazil, Andean condors (*Vultur gryphus*) in Argentina, Chile and Peru (Plaza & Lambertucci, 2020) and turkey vultures on high-voltage transmission lines in central Argentina (Sarasola, unpub. data).

Besides birds, other vertebrate taxa may be involved in power line incidents. For instance, primates and bats are potential victims of electrocutions (Al-Razi et al., 2019; Tella et al., 2020). However, in spite of their high diversity and abundance in tropical forests of South America, there are only a few published records of these vertebrates being electrocuted in Brazil and Colombia (Lokschin et al., 2007; Pereira et al., 2019; Montilla et al., 2020).

Although power lines may not pose a risk to all types of wildlife, the lack of incidents registered for potentially affected species, and more importantly for those categorised as threatened with extinction, is likely a consequence of inadequate survey efforts at a regional scale. Future research in this region should focus on effectively assessing the impact of power line electrocutions and collisions on biodiversity.

Figure 188. A: A juvenile Chaco eagle perched on a power line pole in western La Pampa province, Argentina. B: Juvenile black-chested buzzard eagles are among the raptor species most affected by electrocution mortality in southern South America, probably due to individual aggregations related to juvenile dispersal movements. C: Raptor electrocution is often reported on single-phase low-voltage lines in Argentina, particularly on steel-reinforced concrete poles with jumper wires, which are more dangerous for raptors. D: Note talons and part of tarsus of an electrocuted Chaco eagle that remained on the energised cable. © J.O. Gjershaug, José Hernán Sarasola and Maximiliano Galmes/CECARA

Figure 189. E: An electrocuted variable hawk in central Argentina on a pole combining wire jumpers above the crossarm with a dangerous construction material (steel-reinforced concrete). F: Black-chested buzzard eagle flying from a retrofitted pole where jumper wires were moved below the crossarm to reduce electrocution risk. G and H: Bird-friendly pole designs over 40 km of a newly built power line in Argentina. © José Hernán Sarasola and Maximiliano Galmes/CECARA

Migratory birds and power line collisions in Brazil

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In the case of Brazil, information on bird collisions and power line impacts is still limited to individual energy sector environmental impact studies and some monitoring studies from research bodies. A national overview has not yet been published; thus, the question of which species and biomes are most affected has only been unsatisfactorily answered and merits broader and more detailed studies in near future. This need is urgent especially because Brazil has witnessed a rapid expansion of the energy sector and the resulting installation of new power transmission lines, making birds increasingly exposed to the risk of death through interaction with these structures.

The impacts of power lines on migratory birds through collision have been recorded in Brazil mainly for the roseate tern (*Sterna dougallii*) and common tern (*S. hirundo*) in the order Charadriiformes. Both interact with power lines in the municipality of Galinhos, state of Rio Grande do Norte, in the Brazilian Northeast (Silva et al., 2019; Figure 190). These species migrate from North America to South America during the northern winter. The roseate tern is classed as 'Vulnerable' on the Brazilian List of Endangered Species (Lima, 2018) and is included in the National Action Plan for the Conservation of Seabirds. Mortality in both species has been detected and monitored by the State University of Rio Grande do Norte within a long-term project monitoring marine biota strandings. Since 2014, a significant increase has been seen in migratory bird mortality in the region. Fracture and amputation patterns on one or both wings and the spatial distribution of the animals found suggest that the accidents can be attributed to collision with local power lines. The problem was reported to the company responsible for the power line and the institutions have jointly sought mitigating measures to solve it. The results obtained by the university show a total of 307 individual roseate and common terns were affected in the period 2010–2020. As a mitigating measure, preformed bird protectors were installed in 2018, and 15 flags were added to power lines to scare the animals away and avoid collisions. However, data collected by the project show that the measures have proved ineffective in preventing new accidents, since 83 new cases had occurred by May 2020. Other possible mitigating measures have been discussed and alternatives are still in the process of being implemented by the company. Researchers from the State University of Rio Grande do Norte, the Federal University of Bahia, the National Centre for Bird Conservation and Research (CEMAVE, in Brazilian) and the Audubon Society are involved in the survey.

CEMAVE is a decentralised unit of the Chico Mendes Institute for Biodiversity Conservation (Instituto Chico Mendes de Conservação da Biodiversidade – ICMBio) linked to the Ministry of Environment of Brazil. CEMAVE's work addresses the Brazilian commitment to international agreements on migratory species research and conservation. The Brazilian federal government also consults CEMAVE on matters related to the licensing of renewable energy schemes and their potential impacts on birds.

Figure 190. Remains of terns killed by collision. © Camila Gomes/CEMAVE

CASE STUDY 4

Biodiversity loss due to power lines and actions to address the problem in Costa Rica

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Costa Rica is a megadiverse country with more than 5% of the world's biodiversity. Protected Areas cover 27% of its land and wooded and forest agroecosystems cover 26% (MINAE et al., 2018). Wild fauna belongs to the public domain and is protected by the Government of Costa Rica, which, through the Ministry of Environment and Energy, has the duty to ensure that human activities do not affect vital ecological processes. Developers of infrastructure projects are liable for any damage caused to the environment and for any impact on wildlife and must adopt measures to minimise that impact. Directive MINAE 013-2018 created an intersectoral working group known as 'Electrificación Sostenible' (Sustainable Electrification), involving the government, electricity companies, civil society and academia, and officially endorsed the *Guide to the prevention and mitigation of wildlife electrocution by overhead power lines in Costa Rica* (Rodríguez et al., 2020).

There are eight power companies regulated by the government, which operate more than 30,000 km of power lines. Arauz-Abrego (2002) identified the points most prone to electrocution at national level for the years 1998–2001. Díaz (2014) found that in one year there were 774 electrocutions of fauna in Guanacaste province, with mammals (monkeys and kinkajous) being most affected. During 2018–2019, annual data on the electrocution of wild fauna was officially systematised for the country for the first time, with a total of 7,154 animals reported. Mammals were the worst affected group with 3,401 deaths, particularly squirrels (*Sciurus* spp.) with 993 and monkeys (family Cebidae) with 947. In birds, more than 2,827 individuals of various species died; the great-tailed grackle (*Quiscalus* spp.) with 724 individuals and pigeons (family Columbidae) with 627 were the most affected. In addition, 438 reptiles of various species were reported killed. More than 450 animals could not be taxonomically identified (Rodríguez et al., 2020). These data do not show the total number of electrocutions during the period because the information collected came from only six of the eight companies. In addition, it is only when the electrocution causes an electrical failure that the company sends a technician to the site to confirm it, and there is also no continuous research on the subject. When injured animals survive, they are taken to rescue centres, which absorb much of the expense of veterinary care in electrocution cases, as well as the costs of maintenance, release and ongoing care for animals that cannot be released.

In 2020 this issue was included in the National Energy Plan, and it has also been identified as a negative interaction that requires attention within the framework of the National Biodiversity Policy and Strategy. The electricity companies in Costa Rica have been carrying out preventative work for more than 15 years, since the issuance of directive DM 013-2018. They have proactively accepted the recommendations of the *Guide to the prevention and mitigation of wildlife electrocution by overhead power lines in Costa Rica* by acquiring and installing barriers and insulating devices on distribution lines, including anti-climbing devices for guy wires, electrostatic devices for porcelain insulators and insulating devices for transformers in the electricity network and substations. In addition, aerial crossings for wildlife have been installed in vulnerable areas and, as preventative measures, vegetation is pruned or controlled on a regular basis.

Figure 191. A: Mother and baby golden-mantled howler monkeys (*Alouatta palliata*) electrocuted in northern Costa Rica. The mother died of electrocution injuries a few days later. This is the monkey species most affected by electrocution in Costa Rica. © International Animal Rescue Costa Rica, Nosara. B and C: Two-toed sloth (*Choloepus hoffmanni*) using a power line to move between patches of trees. This is the sloth species most affected by electrocution in Costa Rica. More than 300 sloths were electrocuted in one year. © Efraín González/Empresa de Servicios Públicos de Heredia

Figure 192. Environmental responsibility of electricity companies. A: Monitoring and using prevention equipment for electric power lines. © Diego Carballo/Empresa de Servicios Públicos de Heredia. B: Anti-climbing device to prevent fauna from climbing up a guy wire to the electric cable. © Dinnia Ramírez

CASE STUDY 5

Power lines and birds in the USA

James F. Dwyer and Richard E. Harness

EDM International Inc, USA

Power lines are ubiquitous throughout the United States with approximately 322,000 km (200,000 miles) of transmission lines (≥ 240 kV) in 2010 (Weeks, 2010), increasing to 386,000 km (240,000 miles) by 2020 (Edison Electric Institute, 2020). Much of this 10-year 20% increase has been driven by the need to deliver electric power to urban and industrial load centres from recently developed renewable wind energy (Figure 193 A) and solar energy generation facilities (Weeks, 2010). Distribution lines (< 69 kV), are also abundant, with over 8.8 million km (5.5 million miles) in 2010 (Weeks, 2010), increasing to 10.1 million km (6.3 million miles) by 2016 (Warwick et al., 2016). Additionally, there are estimated to be over 3,300 electric utility companies in the United States (Alves, 2021), ranging from small rural electric cooperatives to large investor-owned companies. Although utility companies are required to build lines per specific safety codes, these codes are designed for human safety and not wildlife. Thus, lines can be constructed in a way that results in animal contacts. Avian collisions (Figure 193 B) and animal-caused outages are a persistent utility issue (Frazier & Bonham, 1996; EPRI, 2001; Smith & Dwyer, 2016). The decentralised ownership can result in a reluctance to share geospatial or other data among utilities. This coupled with the vast numbers of utilities makes coordinated efforts to resolve animal interactions difficult. This results in a constant need to 're-invent the wheel' as different electric utilities successively encounter similar problems but are unable to benefit from the experience of other companies in the same situations.

The Migratory Bird Treaty Act implements various international treaties requiring protection of migratory bird species and protects most birds in the United States, except for non-native and upland game species. Eagles receive additional protection under the Bald and Golden Eagle Protection Act. Penalties for violating these acts, which include bird electrocutions and power line collisions, can result in substantial fines for individuals and organisations (Suazo, 2000). For example, in 1999 an electric utility was fined US$ 50,000 and had to develop an avian protection plan to address how they would mitigate the problem. After this case, mitigation activities increased substantially in the United States (Suazo, 2000). This led to the development of formal guidelines by the U.S. Fish and Wildlife Service (USFWS) and Avian Power Line Interaction Committee (APLIC; USA/Canada) on how to prepare an avian protection plan (APLIC & USFWS, 2005).

Despite a wealth of information on avian electrocutions with power lines and much positive action on the part of electric utilities, avian electrocutions and collisions remain abundant. For example, the USFWS estimates 504 golden eagles (*Aquila chrysaetos*) are electrocuted annually in North America (95% confidence interval: 124–1,494; U.S. Fish and Wildlife Service, 2016). Golden eagles are frequently electrocuted throughout their range in the U.S. (Mojica et al., 2018). And this level of mortality is deemed unsustainable for long-term stability of the North American population when combined with other anthropogenic causes of mortality (USFWS, 2016). Although many new lines are constructed avian-friendly, electrocutions persist because: (1) many older avian-unfriendly poles exist and utility budgets limit how many poles can be retrofitted (Lehman et al., 2007); (2) dangerous poles are not retrofitted within regionally cohesive mitigation strategies (Dwyer et al., 2020); and (3) retrofitting is sometimes applied incorrectly (Dwyer et al., 2017). Thus, mitigation efforts are inconsistent between adjacent electric utilities, leading to clear lines of demarcation separating areas where, for example, electrocution mitigation is prioritised from areas where it is not. To address these concerns, management and regulatory agencies are renewing their management efforts to prevent electrocutions and collisions through retrofitting power lines (USFWS, 2013, 2016; Figure 193 C and D). The USFWS also allows wind energy companies to compensate for the illegal take of eagles by retrofitting other companies' electric utility poles. For example, one golden eagle mortality can be offset by around 16 retrofitted poles (USFWS, 2012).

Figure 193. A: A golden eagle (*Aquila chrysaetos*) perched on a new transmission line constructed for a wind facility. B: Unmanned Aircraft System installing a line marker to increase the visibility of a power line to birds in flight. C: An orange-crowned warbler (*Vermivora celata*) dead after colliding with a power line during spring migration. D: Electric utility linemen installing insulated jumpers and insulated links on conductors to reduce avian electrocution risk. © James F. Dwyer and Richard E. Harness

9.3. Asia

CASE STUDY 6

Avian electrocution in China

Xiangjiang Zhan[1] and Andrew Dixon[2]

[1] *Institute of Zoology, Chinese Academy of Sciences, China*
[2] *Reneco International Wildlife Consultants, United Arab Emirates*

Electrocution of raptors has been recorded in open landscapes of western and northern China in the provinces of Qinghai, Xinjiang and Inner Mongolia. Electricity distribution lines posing a threat to birds in China are those with metal or steel-reinforced concrete poles that present a phase-to-ground electrocution risk. In addition to distribution lines connecting to the transmission grid, power supply infrastructure associated with oil derricks, wind turbines and mobile telecommunications masts also present an electrocution risk.

Surveys of electricity distribution lines in the grasslands of the Qinghai–Tibet Plateau in 2007–2008 indicated that anchor poles and poles with additional hardware connected by jumper wires presented the greatest risk of electrocution (Dixon et al., 2013; Figure 194 A). However, repeat surveys of the same lines in 2015 found no cases of electrocution because of marked land use changes in the vicinity of the lines, with the construction of a major highway and the erection of a transmission line with taller pylon structures in parallel with the distribution lines. Disturbance associated with road construction and the option for raptors to use higher, safe perching sites on transmission line pylons resulted in fewer birds using dangerous perch sites on the distribution line. This indicates that amalgamating electricity distribution infrastructure with other anthropogenic linear landscape features, such as transmission lines and roads, can potentially reduce perching rates, and thus exposure to electrocution risk, at dangerous poles.

Avian electrocution is undoubtedly under-recorded in China as few surveys have been carried out at power lines, many of which traverse remote tracts of land. However, the use of GSM and satellite-received tracking devices on saker falcons (*Falco cherrug*) from breeding areas in Russia and Mongolia have revealed cases of electrocution in China. A juvenile male was electrocuted while wintering in agricultural habitats in Xinjiang, 1,169 km from its natal area in Russia (Karyakin et al., 2018). During post-breeding dispersal, the tag deployed on an adult female transmitted stationary GPS locations from below a power pole on a distribution line in steppe rangeland of Inner Mongolia (Figure 194 C and D). These cases demonstrate that electrocution in China can affect migratory birds from populations in other countries.

The extensive electricity distribution network in open rangeland and plateau ecosystems is responsible for the electrocution of many raptors in China, and so retroactive mitigation should be implemented on existing lines (Figure 194 B) and regulations adopted to ensure that new lines are constructed to be bird safe. China has the scientific, engineering and industrial capacity that can be harnessed to implement mitigation measures and pioneer the production of bird-safe electricity infrastructure both nationally and globally.

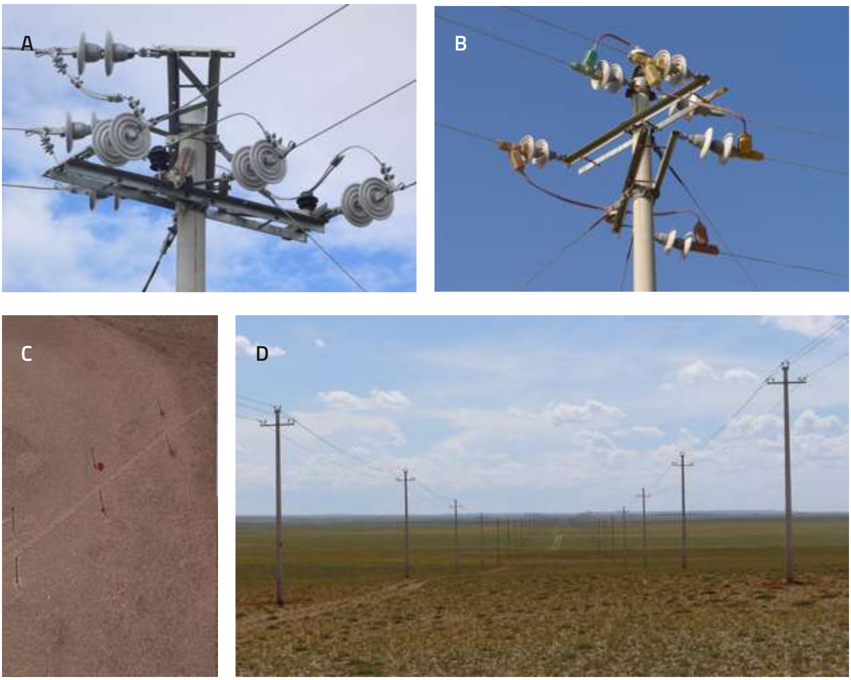

Figure 194. A: Saker falcon electrocuted after contact with a jumper wire on an electricity distribution line in Qinghai, China. B: Chinese insulation covers deployed on jumper wires at a deviation point on a distribution line in Inner Mongolia. C and D: Stationary GPS location from a satellite transmitter deployed on a saker falcon, which was subsequently recovered at a dangerous power line in Inner Mongolia, China. © Andrew Dixon

CASE STUDY 7

Power lines and wildlife in India

Pranay Juvvadi

Raptor Conservation Foundation, India

Indian biologists have not studied avian interactions with power lines with the detail deserved. However, some studies carried out in recent years indicate that the impact on bird populations can be high.

There are few records of bird electrocutions in India and those that exist lack detail on the mode of electrocutions. A couple of exploratory surveys in Andhra Pradesh (2006) noted that certain 11 kV pole configurations (corner poles, poles with exposed jumpers and transformer poles) resulted in more mortalities compared to similar 33 kV poles.

We noted the metal pin on which the insulators were attached on the pole-tops had varying clearances. This inconsistency resulted in variable spacing between the grounded pole-top and the energised wire (Figure 195 A and B). In cases where the pin was mounted close to the pole-top, even small birds such as red-vented bulbul (*Pycnonotus cafer*) bridged the gap between the live phase and the grounded pole-top resulting in mortalities (Figure 195 C). These concrete/steel poles with grounded metal crossarms and the widely varying pole-top mounted pins had the potential to kill both large and small birds (Figure 195 E and F).

In 2011, with EDM International, Inc. (EDM), we surveyed 624 11 kV concrete poles and found 160 carcasses (Figures 195 D, E and F; Harness et al., 2013). The carcass detection rate was very high, with one per every three poles (Harness et al., 2013). The most common configuration on the landscape consisted of three-phase tangent units without any equipment (Figure 195 D). This configuration comprised 83% of all energised poles (n=407) and was associated with 93 bird carcasses (58%). This configuration had 267 poles with the centre pin mounted low, which was associated with 96% of the birds found under all tangents (n=89, 0.33 carcasses/pole).

Some species of raptors use power lines for nesting. Between March 2002 and March 2007 around Hyderabad, Andhra Pradesh, a total of 25 nests of eight raptor species were recorded on power lines (Juvvadi, 2009). Twenty-two nests (88%) were on transmission towers, and 21 of these (95.4%) were on vertically configured designs. On these towers, all nests were situated within the main lattice, between the crossarms in non-critical areas of the towers, posing no threat to the power supply (Figure 196 A). The state electricity provider had a policy of actively destroying nests (Figure 196 B), which was not only illegal and labour intensive, but also pointless, as the birds built the nests back. Accommodating nests on power lines and managing operational concerns without destroying nests is a better practice.

Recent great Indian bustard (*Ardeotis nigriceps*) fatalities due to collision with power lines has brought this issue to the forefront; the expansion of the electricity network is one of the major factors contributing to the species population decline (BirdLife International, 2018; Uddin et al., 2021).

With India ramping up renewable energy stations across India, the number of new power lines criss-crossing the landscape will put many bird species at risk of electrocutions and collisions. Policy decisions will be needed to make India's power line infrastructure bird safe. Burying power lines removes the problem of electrocution and collision, but where this is not feasible, making small design changes can go a long way in making the lines avian-friendly.

For example, power lines with suspended insulators will safely accommodate small and large birds, minimising the risk of electrocution (Hunger et al., 2006). Existing lines could be remedied based on:

➜ areas with high bird use, such as nesting, roosting and migratory congregation sites;
➜ pole/line sections with high mortality rates and/or animal-caused outages;
➜ poles with dangerous configurations (exposed jumpers, low-mounted pole-top pins, equipment) (Figures 195 C and D, and 196 C and D).

We need more specific guidance to avoid unnecessary bird mortality.

Acknowledgements: We would like to thank Richard E. Harness at EDM International, Inc. for looking at this paper and suggesting important changes and additions. We would also like to thank Tejah Balantrapu for editing and revising multiple drafts.

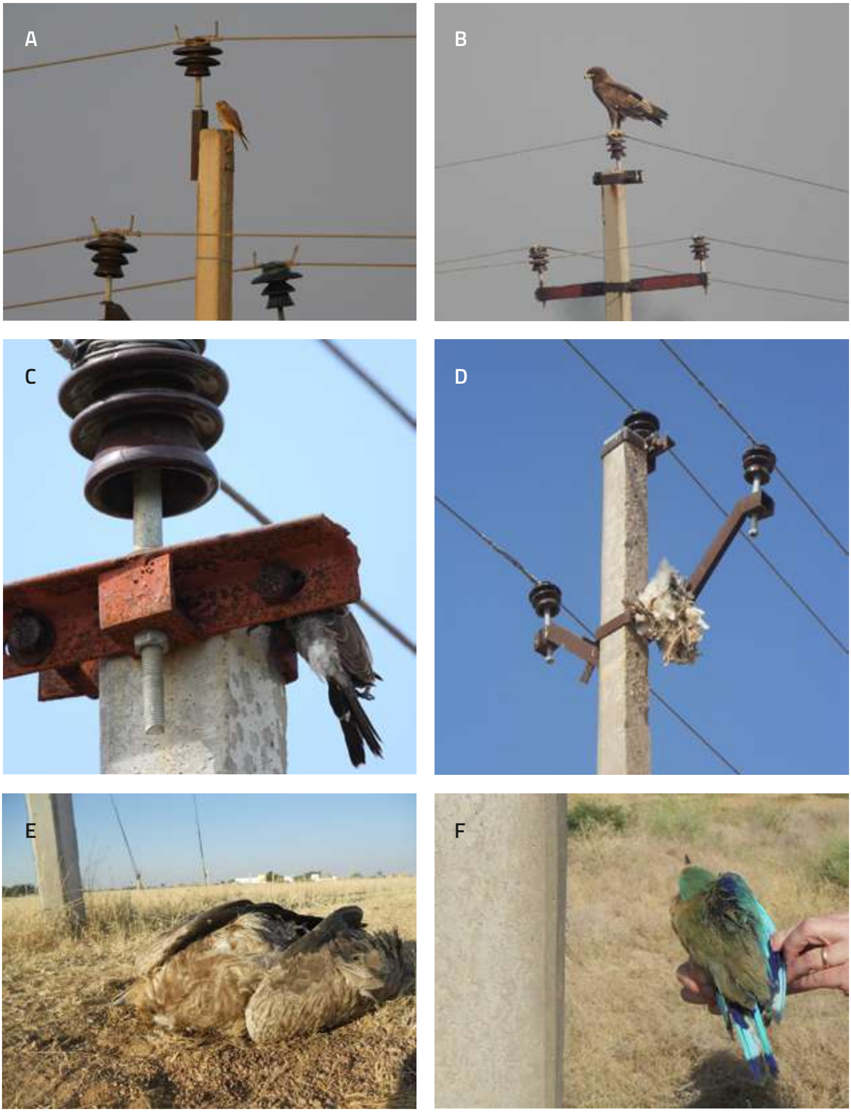

Figure 195. A–D: Three-phase tangent units without any added equipment are the most common configuration. They have the potential to kill both large and small birds (E and F). A: Common kestrel (*Falco tinnunculus*) and B: Indian spotted eagle (*Clanga hastata*) perched on 33 and 11 kV power poles respectively. C: Red-vented bulbul (*Pycnonotus cafer*), D: Indian eagle owl (*Bubo bengalensis*), E: Tawny eagle (*Aquila rapax*) and F: Indian roller (*Coracias benghalensis*) killed on 11 kV power poles. © Pranay Juvvadi

Figure 196. A: Nest of Bonelli's eagle (*Aquila fasciata*) on transmission pylon. B: Nest knocked down by electricity company workers. C and D: Poles with exposed jumpers (C) or equipment poles with bare jumpers (D) are dangerous configurations; C: Indian spotted eagle; D: Red-necked falcons (*Falco chicquera*). © Pranay Juvvadi

CASE STUDY 8

Birds and power lines in Iran

Mahmood Kolnegari[1] and Richard E. Harness[2]

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Iran has a diverse avifauna with more than 550 bird species in varied habitats (Kolnegari & Hazrati, 2018) and widespread power lines, including 127,581 km of transmission lines and 815,367 km of distribution lines, growing at 2% per year (Ministry of Energy, Iran, 2020). Historical surveys and reports from linemen and wildlife rangers suggest a severe conflict between birds and power lines (Kolnegari & Harness, 2020; Kolnegari et al., 2020a, 2020b; Figure 197 A and B). Despite an abundance of power line interactions with birds on the Iranian Plateau (Kolnegari et al., 2019), studies on power line conflicts are at a preliminary stage and under-represented in English-language publications (Kolnegari et al., 2020a). Recently, the establishment of a national group of power technicians and conservationists, Iran's Birds and Power Lines Committee (IBPLC), along with the implementation of corrective measures on dangerous power structures, have raised public awareness of the issue, placing Iran in a leading position in the Middle East (Kolnegari et al., 2019, 2020b).

Iranian power companies have historically tried to avoid bird electrocutions to reduce the economic impacts of avian-derived faults. Such faults are costly and disruptive and can result in damage to equipment (NRECA, 1996; EPRI, 2001) and fires (Lehman & Barrett, 2002). Additionally, there are non-economic consequences, such as receiving negative electricity reliability scores from Iran's Ministry of Energy and incurring negative public perception (Kolnegari et al., 2020b). In contrast, companies do not act in a similar fashion to resolve avian collisions because wire strikes are difficult to detect and do not typically result in outages or damaged facilities (APLIC, 2012).

When action is taken, it is typically based on the number and duration of faults. Recently, groups like IBPLC have been working to get power companies to also consider the conservation status of at-risk bird species by, for example, focusing mitigation efforts on lines near important natural areas such as wetlands and artificial sites attracting large numbers of sensitive birds, such as steppe eagles (*Aquila nipalensis*) congregating at landfills. Progress has been made by involving the highest government authority (i.e.

Iran's Department of Environment) in the evaluation of power lines. Local NGOs have also been engaged to help power companies address conservation threats.

Power line surveys in Iran reveal some promising consequences, such as the utilisation of red marker balls (Figure 197 C) reducing whooper swan (*Cygnus cygnus*) collisions with a transmission line (Kolnegari et al., 2020a). Additionally, some protection also exists on distribution lines. For example, in a study of transformer electrocutions, some units had already been proactively covered (Kolnegari & Harness, 2020). Power facilities have also been altered in some cases to benefit wildlife. For example, in a survey on nest box installations on distribution pylons (Figure 197 D), there was an increase in common kestrel (*Falco tinnunculus*) nesting, thus decreasing the need to remove nests built on the pylons to prevent power failures (Kolnegari et al., 2020c). Surrogate nest boxes also result in fewer negative interactions due to fewer nests on structures.

Despite some progress, Iran faces significant avian-interaction mitigation challenges. For example, although EPRI (2019) notes 347 commercially available products designed to mitigate animal-caused outages, few products are available in Iran. Furthermore, retrofitting is expensive and often must be accomplished with an outage, making scheduling difficult. IBPLC is working to improve the situation locally and regionally. IBPLC's goal is to establish a regional committee bringing together Middle Eastern countries to develop regional avian protection plans guidelines based on international findings, and to develop and promote novel regional measures compatible with Middle Eastern power infrastructure.

Table 9-1. **Estimated bird mortality related to power line infrastructure in Iran per year**.

Cause of mortality	Estimated toll*	Note
Collision	10,000–60,000 individuals	Primarily on transmission lines associated with wetlands
Electrocution	3,700–25,000 individuals	Primarily on 20 kV distribution lines
Annual nest destruction	5,000–50,000 eggs/ chicks	Data only available for transmission lines (63–400 kV)
Entangled in utility equipment (not electrocutions)	30–240 individuals	On both transmission and distribution equipment

Source: compiled by the authors

*General estimates were derived by reviewing records of known issues and then extrapolating these data across the electricity network.

Figure 197. A and B: Bird mortality due to electrocution. A: Electrocution of three Eurasian magpies (*Pica pica*) on arcing horns of a 20 kV pole-mounted transformer. © IBPLC. B: Electrocution of a white stork (*Ciconia ciconia*) on a 63 kV power pole. © Mohammad Sadegh Arshadi. C and D: Retrofitted power lines in Iran. C: Retrofitted transmission line with red bird balls, Mazandaran province, Iran. © Mohammadali Yektanik. D: A wooden nest box installed on a distribution power pole, Markazi province, Iran. © Mahmood Kolnegari

CASE STUDY 9

➔ Impact of transmission lines in Japan

Masaki Shirai

Central Research Institute of Electric Power Industry, Japan

In Japan, 11 privately-owned transmission system operators (TSOs) are in charge of regional power supply services and are responsible for supplying electricity in their respective service areas (Shirai et al., 2020). The TSOs manage approximately 250,000 transmission towers in total and deal with extra-high-voltage power, mainly between 66 kV and 500 kV. The total length of the lines exceeds 100,000 km and 85% of the system consists of overhead lines.

Common and threatened bird species in Japan are protected by the Wildlife Protection and Hunting Management Law and the Conservation of Endangered Species of Wild Fauna and Flora Act, respectively. The Ministry of the Environment has listed over one hundred threatened bird species in the Red Data Books.

Although the Environmental Impact Assessment Act does not include electrical transmission line projects in Japan, several prefectures and cities require environmental impact assessments (EIAs) under local government regulations when transmission lines are constructed. TSOs carry out EIAs according to the local government regulations or voluntarily even where there is no local government EIA requirement for transmission lines.

During a pre-construction stage, TSOs conduct field surveys to investigate the existence and home range of the threatened bird species while listening to opinions from experts and local governments. In order to avoid the impact of noise and vibration, considerate methods are often used in the construction of pylons located near the nests of threatened bird species, such as temporarily suspending work. Construction material transportation routes also avoid crossing their habitats as much as possible.

Transmission lines include the risk of bird collision and electrocution. Several bird species have been reported to collide with or be electrocuted on transmission lines: oriental stork (*Ciconia boyciana*), grey heron (*Ardea cinerea*), red-crowned crane (*Grus* *japonensis*), white-naped crane (*Grus vipio*), whooper swan (*Cygnus cygnus*), tundra swan (*C. columbianus*), greater white-fronted goose (*Anser albifrons*), bean goose (*A. fabalis middendorffii*), Steller's sea eagle (*Haliaeetus pelagicus*), white-tailed eagle (*H. albicilla*), mountain hawk-eagle (*Nisaetus nipalensis*) and Blakiston's fish owl (*Ketupa blakistoni*). To increase the visibility of transmission lines and prevent bird collisions, bird flight diverters (coloured tags or rings) are used on overhead ground lines near important wintering or breeding habitats (Murata, 1997; Figure 198). TSOs also install artificial perches on the tops of transmission towers or bird perching deterrents on electrical transmission lines to reduce bird electrocution (Saito & Watanabe, 2006).

Transmission towers can provide nesting sites for birds. In Japan, several bird species use them: jungle crow (*Corvus macrorhynchos*), carrion crow (*C. corone*), Eurasian magpie (*Pica pica)*, osprey (*Pandion haliaetus*), common kestrel (*Falco tinnunculus*), Eurasian hobby (*Falco subbuteo*), black kite (*Milvus migrans*), oriental stork and great cormorant (*Phalacrocorax carbo*). Since their nest materials can cause power outages, TSOs often remove the nests from risky parts of transmission towers. To reduce the conflict between bird conservation and electricity supply, artificial nests are sometimes installed on the safer parts of transmission towers (Takeuchi & Kobayashi, 2012).

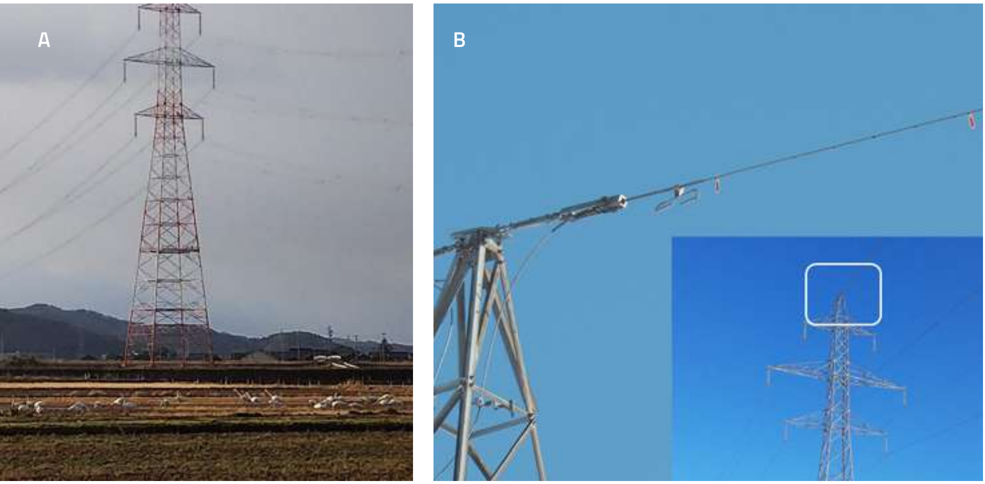

Figure 198. A: Swans and power lines. B: A bird flight diverter for swans and geese in Japan. © Masaki Shirai

CASE STUDY 10

➔ Raptor electrocution in Mongolia

Andrew Dixon

Reneco International Wildlife Consultants, United Arab Emirates

Much of the Mongolian landscape comprises vast, open areas of steppe rangeland that support an extensive, seasonal nomadic pastoral system of livestock grazing. Mongolian pastoralism is organised around widely dispersed settlements in district centres known as *soums*, of which there are around 330 across the country, and each one requires a reliable electricity supply. Electricity distribution lines connecting *soums* with the transmission grid are typically lengthy (average ca. 50 km) and are often the only structural features in otherwise open landscapes. Since the turn of the century these distribution networks have been considerably expanded and renewed using pole designs that pose a high risk of electrocution for raptors.

The feature that makes Mongolian 10–15 kV distribution lines so dangerous for birds is that the conductor cables are carried on grounded support structures, i.e. steel-reinforced concrete poles with galvanised steel crossarms and brackets holding pin insulators. This kind of pole is the most cost-effective (i.e. cheapest) option for electricity distribution; moreover, the risk of damage to the power line caused by grassland steppe fires precludes the use of wooden support structures (Figure 199 A). Consequently, any contact with a live conductor by a bird perched on the pole or crossarm will result in phase-ground electrocution, with every pole in the network posing the same mechanistic risk. However, it is not only pole structure that contributes to electrocution risk for raptors, as the likelihood of a bird being killed is also influenced by topography of the landscape and food supply in the surrounding habitat. Power poles attract perching raptors in open, featureless landscapes and this is particularly true when there are high densities of small-mammal prey species in the vicinity (Dixon et al., 2017). There are colonial small mammals in the Mongolian steppe that exhibit irregular, but massive, spatial and temporal fluctuations in abundance; the unpredictability of these outbreaks makes it difficult to risk-prioritise lines that are structurally similar across comparable landscapes. Consequently, all dangerous lines in the steppe zone pose a broadly similar electrocution risk over an extended timescale. Following postfledging dispersal, large numbers of raptors, particularly juveniles, aggregate in areas with high densities of small mammals; if such areas coincide with a dangerous line, electrocution rates can be enormous, with a bird killed at virtually every pole over a few months (Figure 199 C).

Currently, ca. 20% of *soums* are connected to the transmission grid via dangerous distribution lines, but renewal of old wooden poles involves the installation of grounded concrete poles, so the extent of dangerous lines continues to grow across the country. Retrospective mitigation of dangerous lines is imperative in Mongolia as the scale of electrocution is so large, with an estimated 18,000 raptors killed annually. Given the large numbers of the threatened saker falcon electrocuted annually in Mongolia, our study suggests electrocution may be an important driver of demographic trends, which may potentially result in population declines (Dixon et al., 2020). Research in the country has focused on the relative efficiency of different mitigation techniques, and the most cost-efficient and effective methods include the installation of insulation to prevent grounding (Dixon et al., 2018, 2019). In an initiative to address the problem at a national scale, the Mohammed bin Zayed Raptor Conservation Fund (MBZRCF; Abu Dhabi) has developed 'failsafe' insulation equipment that poses no risk to power supply or transmission efficiency (Figure 199 B). Furthermore, cost is a major consideration in Mongolia when commissioning a new electricity distribution line and the insulation equipment developed by the MBZRCF can be integrated with new infrastructure at little additional cost.

Figure 199. A: Dangerous distribution lines for birds in Mongolia. © D. Scott. B: ‘Failsafe’ insulation equipment developed in Mongolia by the Mohammed bin Zayed Raptor Conservation Fund (MBZRCF). © Andrew Dixon. C: Birds electrocuted in Mongolia. © G. Purev-Ochir

9.4. Europe

CASE STUDY 11

Birds and power lines in Hungary

Márton Horváth and Szabolcs Solt

MME BirdLife, Hungary

The magnitude of the problem

The overhead electricity system in Hungary consists of 11,000 km of high-voltage transmission lines and 54,000 km of medium-voltage distribution lines. Since the 1980s, electrocutions and collisions have caused significant mortality of protected birds in the country – similar to many other areas around the world. The geographical extent of the electricity system's impact on birds and the approximate number of electrocuted birds began to be explored in the mid-2000s, when *Magyar Madártani és Természetvédelmi Egyesület* (MME, in Hungarian; MME/BirdLife Hungary), organised citizen scientists and national park rangers to collect systematic data nationwide. From 2004 until 2014, these volunteers searched 8% (57,486) of the 700,000 distribution pylons in Hungary. They found 3,400 electrocuted avian carcasses of at least 79 species (Demeter et al., 2018; Figure 200 A), including four species of conservation concern: red-footed falcons (*Falco vespertinus*), European rollers (*Coracias garrulus*), saker falcons (*Falco cherrug*) and eastern imperial eagles (*Aquila heliaca*) (Figure 200 B). Based on the survey results and the total number of dangerous electricity poles, MME estimates that a minimum of 42,000 birds (especially raptors and corvids) are electrocuted in Hungary annually (Horváth et al., 2010). Collision mortality involving birds and overhead power lines is much less understood, but substantial numbers of deaths have been detected among large migrating species like common cranes (*Grus grus*) and waterbirds. Collision with power lines is also the main cause of mortality for the globally threatened great bustard (*Otis tarda*) (Vadász & Lóránt, 2015) and great Indian bustard (*Ardeotis nigriceps*) (Uddin et al., 2021).

Mitigating avian mortality

MME, in cooperation with electrical engineers, developed a plastic cross arm cover designed to fit the most common electric pylon types in 1991. The intent of the cover was to reduce the frequency with which birds contacted energised wires while perched on grounded crossarms, the most common mechanism of electrocution in Hungary.

Over 20 years, approximately 90,000 pylons were fitted with these covers (Fidlóczky et al., 2014). Although plastic covers did reduce electrocutions, the reduction was not as substantial as hoped. To address that, since 2008 MME has worked to identify and install jumper covers, conductor covers, and equipment covers that prevent birds from contacting energised wires and equipment (Fidlóczky et al., 2014). When installed correctly, these methods have been effective in reducing electrocutions on treated pylons, but only a fraction of the dangerous pylons have been addressed, so significant electrocution mortality persists in Hungary. Since 2009, MME has also partnered with Hungarian ornithologists and with Hungarian electricity companies to develop and study new bird-friendly pylon designs intended to reduce avian electrocution risks. Several new pylon designs developed in the MME program are now in use, although complete replacement of old pylons will require several decades.

Future perspectives

An optimistic voluntary agreement called 'Accessible Sky' was signed between the Hungarian Ministry of Environment and Water, all Hungarian electricity companies and MME in 2008. Accessible Sky aimed to facilitate the conversion of all dangerous power lines in Hungary to bird-friendly configurations by 2020. As a first step, MME prepared a detailed conflict map of birds and power lines, suggested a prioritisation schedule and calculated the budget needed for further steps (Horváth et al., 2010). Although bird-friendly conversions have been undertaken within several projects in key bird habitats in the last decade, unfortunately neither the government nor the electricity companies allocated sufficient budget or effort to meet the 2020 deadline. Recently the parties to the agreement have begun to discuss how Accessible Sky may be continued so avian electrocutions and collisions in Hungary can be minimised or eliminated in the near future.

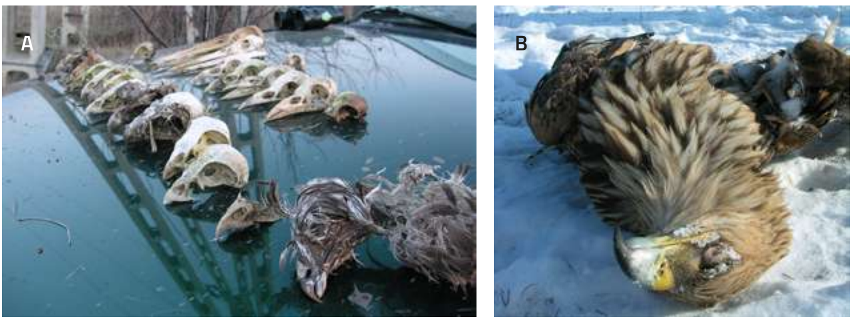

Figure 200. A: Dead specimens of different bird species collected under a single pole (Tiszasüly, Hungary). B: Eastern imperial eagle (*Aquila heliaca*) found dead from electrocution. © Márton Horváth

CASE STUDY 12

Birds and power lines in Russia

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As early as the 1930s, Russian scientists began talking about the problem of bird electrocution, but only since the second half of the 1970s has it been seen as a threat to raptors (Galushin, 1980). The first Methodological Recommendations on Preventing Bird Electrocution on Power Line Posts were published in 1980. The Ministry of Energy of the former Union of Soviet Socialist Republics (USSR) issued an order 'On the development and implementation of measures to prevent bird deaths on overhead power lines...' (1981), which applied to steppe, semi-desert and desert areas of the USSR, including Russia, where the mortality risk for rare birds of prey was highest. From then onwards, research on bird deaths on overhead power lines began to be published (Pererva & Blokhin, 1981; Zvonov & Krivonosov, 1981, 1984). In the 1990s, on the back of the growing public environmental movement in Russia, several environmental laws were adopted: the Russian Federation Laws 'On Environmental Protection' (1991) and 'On wildlife' (1994) were designed to protect wildlife, prohibiting damage from the operation of communications and electricity transmission lines. Recommendations on the organisation and implementation of measures to prevent the death of birds of prey on 6–35 kV power lines are being developed by the Russian Government. The Russian Ministry of Energy explicitly prohibits the use of power transmission line supports with pin insulators in areas with large bird populations (Ministry of Energy of the Russian Federation, 2003).

However, the problem is still profoundly serious. Only 20 of 85 Russian regions (23.5%) have information on the species composition and scale of bird electrocutions on power lines. Traditionally, the focus of researchers has been on bird deaths in arid zones and there is information about the deadly impact of electrocutions and collisions in some regions of the country, affecting mainly steppe eagles (*Aquila nipalensis*), which have catastrophically decreased in numbers in European Russia from 20,000 to 1,100 pairs since 1980 (Gorban et al., 1997; Karyakin, 2013), mainly due to the impact of power lines (Karyakin & Novikova, 2006; Karyakin, 2012), with 3,420 individuals dying annually in Kalmykia region (Matsyna et al., 2012). Other affected species include saker (*Falco cherrug*) and peregrine falcons (*Falco peregrinus*), common (*Falco tinnunculus*) and lesser kestrels (*Falco naumanni*), rough-legged (*Buteo lagopus*) and common buzzards (*Buteo buteo*), golden (*Aquila chrysaetos*), eastern imperial (*Aquila heliaca*) and white-tailed eagles (*Haliaeetus albicilla*), black kites (*Milvus migrans*), Eurasian eagle owls (*Bubo bubo*), hooded crows (*Corvus cornix*), Eurasian jackdaws (*Corvus monedula*), magpies (*Pica pica*), and even pipits (*Anthus* spp.) (Saltykov, 2003; Barbazyuk et al., 2010; Matsyna et al., 2011; Gadzhiev & Melnikov, 2012; Melnikov & Melnikova, 2012; Saltykov, 2012b; Gadzhiev, 2013; Karyakin et al., 2013; Karyakin & Vagin, 2015; Pavlov & Senator, 2015).

Vast numbers of birds have died. In the Republic of Tatarstan, 130,000 individuals of more than 20 bird species are estimated to have died because of power lines (Saltykov, 1999); in the Nizhny Novgorod region 185,500 birds died annually (Matsyna & Zamazkin, 2010), of which 13,800 were birds of prey (Matsyna, 2005); in the Republic of Altai and Altai Territory, it is estimated that at least four million birds are killed annually, 10,000–15,000 of which are raptors (Karyakin et al., 2009); in Khakassia about 3,500 are killed, including 700 raptors (Nikolenko, 2011). Based on the results of these studies, a list of vulnerable bird species has been compiled, which includes 266 of the 789 bird species in Russia (Saltykov, 2016), the steppe eagle and the saker falcon being the most threatened species due to electrocution (Karyakin, 2012). It should be noted that the death of a large number of individuals is not the only factor to be taken into account when assessing the problem. In species with large populations, high mortality rates on power lines may have a very small impact, whereas in threatened species, the death of a few individuals may have very serious consequences.

To minimise the problem, since 2000 Russian institutions have developed many actions, including meetings and workshops and the publication of methodological guidelines, with some support from the United Nations Development Programme–Global Environment Facility (UNEP–GEF) (Saltykov, 2000, 2012a; Matsyna & Zamazkin, 2010; Saltykov & Dzhamirzoev, 2015; Karyakin, 2016; Saltykov & Medzhidov, 2016; Saltykov & Gugueva, 2017; Saltykov, 2018; Russian Raptor Research and Conservation Network, 2020). Power companies have retrofitted and rebuilt dangerous lines following the recommendations of the Russian Raptor Research and Conservation Network (Nikolenko & Karyakin, 2012), which reduced the mortality of key species (the golden, imperial, steppe and white-tailed eagles, saker falcon and eagle owl) in the Altai-Sayan region and Transbaikalia (Karyakin et al., 2013; Goroshko, 2016a, 2018). Some large power line companies were able to retrofit and re-equip power lines with effective devices (Goroshko, 2016b).

Underground cable lines are a priority for bird protection in Russia, but companies are reluctant to switch to these lines. Less dangerous wooden pylons are used only in Siberia, but they are being replaced with concrete poles. Of the effective retrofitting devices, the most common, in accordance with accepted standards, are plastic caps with corrugations to insulate the wires at the support head.

Although the length of dangerous power lines has been reduced, the existence of a very good legal framework in Russia does not correlate with law enforcement, so new bird-dangerous power lines continue to be built and operated in the country and there is still a huge length of bird-dangerous power lines inherited by grid companies from the USSR. Cooperation continues between large public organisations (WWF Russia, the Russian Raptor Research and Conservation Network, and the Russian Bird Conservation Union) and the major energy companies (Rossetti, Gazprom and Rosneft), and it is hoped that in the next decade we will come closer to some tangible results in addressing the problem of bird deaths on power lines in Russia.

Figure 201. The most common types of 6–10 kV power lines that are dangerous for birds in Russia. Source: Collage from the Russian Raptor Research and Conservation Network (RRRCN) website (http://rrrcn.ru/ru/electrocutions/popl)

Figure 202. A: Golden eagle (*Aquila chrysaetos*) electrocuted on 10 kV power line. Amur region, Russia. © I. Ishchenko. B: Steppe eagle (*Aquila nipalensis*) perching on a bird-safe 10 kV power line. The potentially dangerous bare wires near the pole have been insulated with a plastic device to protect birds. Ulyanovsk region, Russia. © A. Saltykov

CASE STUDY 13

The Spanish story

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Up to 1977, only a few isolated records of cinereous vultures (*Aegypius monachus*) dying by electrocution on power lines in Extremadura (western Spain) were published in general works on this species. The first proper review of birds dying on power lines in Spain was reported by Jesús Garzón in a communication at the International Council for Bird Protection (ICBP) World Conference on Birds of Prey in Vienna in 1975 (report of proceedings published in 1977). Garzón reported that electrocution could be a very important factor in the mortality rates of large birds such as the cinereous vulture, Eurasian eagle owl (*Bubo bubo*) and Spanish imperial eagle (*Aquila adalberti*) (Chancellor, 1977). Nevertheless, the first systematic study on the real effect of electrocution on power lines started in 1982 in Doñana National Park (Ferrer et al., 1986, 1987, 1988, 1991; Ferrer & De la Riva, 1987). This pioneer study showed that more than 2,000 birds died per year, among them 400 birds of prey, on only 100 km of distribution power lines in Doñana National Park (Figure 203 A). Those studies also showed that for some species, like the Spanish imperial eagle, electrocution was the most important mortality factor, driving this species towards extinction. As a consequence of these studies, power lines in Doñana and surrounding areas were properly retrofitted, increasing the first-year survival rate of young Spanish imperial eagles from 17.6% to 80%, and resulting in the most successful conservation measure ever undertaken to protect this species (Ferrer & Hiraldo, 1991).

After these studies, in June 1990, the regional government of Andalusia in southern Spain passed the first executive order in Europe regulating the construction of power lines to make them safe for birds (Decree 194/1990). The text of the Decree describes the types of safe pylons allowed for new power lines as well as the obligation to correct pylons with dangerous designs along existing lines. As a consequence, bird mortality by electrocution in Andalusia decreased by 82% when selective correction measures affecting 13% of the pylons were implemented (López-López et al., 2011). During the following years, almost all the autonomous communities (regions) in Spain adopted similar decrees (Ferrer, 2012). However, the federal government, whose role is to introduce basic legislation at a national scale, ignored the accumulated scientific knowledge and did not publish the Spanish decree until 18 years later (RD 1432/2008). Unfortunately, this decree included the provision that the government, rather than the power companies, must pay for the retrofitting of dangerous power poles, even if they belonged to private companies, consequently slowing down the retrofitting process. According to this decree, retrofitting must be done only in protected areas and without any kind of prioritisation, with all pylon designs being considered equally dangerous for birds.

Additionally, in recent years there has been public pressure in Spain to pass laws regulating the construction of power lines to make them safe for birds, and imposing penalties and substantial fines under the polluter-pays principle if electrocutions and collisions are not avoided. However, some local governments and NGOs have been collaborating with electricity companies to identify and modify existing dangerous power lines and to install new bird-friendly power lines. Thus, more than 30,000 dangerous pylons were made safe along 5,000 km of power lines in Andalusia through simple remediation techniques and a redesign of power lines, thanks to a collaboration agreement between the main electricity company and the regional government based on scientific recommendations. Mitigation measures included construction of new pylons with suspended insulators, avoiding the use of pylons with exposed jumpers above the insulator and ensuring that new power lines were constructed away from breeding areas. Retroactive mitigation measures included replacing exposed insulators with the suspended type and installing protective systems on pylons to prevent birds coming into contact with wires (Figure 203 C). This work has produced a 62% reduction in mortality rates in the region despite a continuous increase in overhead power line construction; this has helped the population of Spanish imperial eagles in Andalusia to increase from the 22 breeding pairs recorded in the early 1970s to the 123 pairs recorded in 2020 (CMS, 2020). Similarly, the Spanish NGO GREFA, the lead organisation in the EU LIFE Projects LIFE Bonelli and AQUILA a-LIFE, has modified hundreds of dangerous power lines to make them safe for raptors, especially Bonelli's eagle (*Aquila fasciata*), thanks also to agreements made with electricity companies (GREFA, 2020) (Figure 203 B).

Fortunately, following the example of Andalusia and due to pressure from the public and from specific projects and NGOs (PIE Project, Migres Foundation, SOS Electric Power Lines Platform, AQUILA a-LIFE, etc.), the major power companies in Spain are using selective models and prioritisation criteria as the best way to reduce this problem as quickly as possible (Ferrer et al., 1991; Ferrer, 2012; GREFA, 2020).

Collaboration between power companies and scientific research institutions (CSIC, Endesa, Iberdrola and Red Eléctrica) is critical for optimising and testing the effectiveness of electrocution correction measures and for determining retrofitting prioritisation criteria.

Figure 203. A: Dangerous power line in Doñana National Park (Spain). © Daniel Burón. B: Bonelli's eagle (*Aquila fasciata*) found electrocuted by the AQUILA a-LIFE team. C: Electricity company technicians modifying a dangerous pole. © AQUILA a-LIFE-GREFA

CASE STUDY 14

The Andalusian Wildlife Analysis and Diagnosis Centre

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The Andalusian Wildlife Analysis and Diagnosis Centre (CAD, in Spanish) is the reference laboratory for fauna of the regional environment ministry of the Andalusian Government (Spain). It was created in 2001 in the southern Spanish city of Málaga in response to the need to resolve incidents that directly and indirectly affect wildlife.

The main objective of the CAD laboratory is to apply forensic analysis to solve emergencies and incidents that directly and indirectly affect wildlife. It achieves this by diagnosing diseases, determining causes of death and assessing the health of wild fauna, using means such as necropsies, genetics, toxicology, pathological anatomy, forensic entomology, microbiology, parasitology, biochemistry, serology and haematology. This work is carried out in the CAD facilities by a multidisciplinary team made up of veterinarians, biologists and analysts. The analyses they carry out meet the quality standards necessary for compliance with current legislation on nature conservation.

The CAD laboratory supports a number of regional projects for the recovery, conservation and management of wildlife, including protected and threatened species, hunting, species recovery programmes, reintroductions, captive breeding, control of wildlife poisoning, etc. The results it generates are an indispensable tool in the management of all these programmes and therefore help ensure the survival of threatened species.

The laboratory's work is very diverse:

➜ Assessing health and pathologies in populations of protected or threatened species and game animals, both free-living and in recovery centres and game species reference stations;

Figure 204. A: Microbiology laboratory. B: DNA processing. C: Forensic study. D: Analysis of partridge chick stuffed with poison. ©CAD

➜ Studying the cause of death in necropsies of free-living and captive wild species; conducting specialist forensic studies on bone remains, genetic studies to relate poisoned samples with other seized items, ballistics studies, and determining the date of death by means of forensic entomology;

➜ Analysing samples collected during waterbird and fish mortality episodes in Andalusian wetlands;

➜ Diagnosing cases of poisoning for the eradication of the illegal use of poisoned baits in the Andalusian region (Action Programme for the Fight against Poison in Andalusia);

➜ Genetic monitoring through the study, evaluation and control of aspects related to the purity and genetic variability of game species and other species of interest. Molecular sexing of new-born chicks from samples (blood, feathers, remains of hatched eggs, etc);

➜ Monitoring the transmission of animal diseases, with particular attention to diseases common to wild animals, domestic livestock and human beings (zoonoses), and responding to health emergencies.

The work of the CAD is essential in the fight against wildlife crime. Its results allow the enforcement of sentences against environmental criminals, who consciously or unconsciously are in many cases responsible for poisoning protected fauna and even endangering the lives of people who use hunting reserves, protected areas, etc.

Between 2001 and 2021, the CAD carried out 537,228 tests from 212,126 samples.

9.5. Oceania

CASE STUDY 15

Managing bird interactions with power distribution assets in Australia

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There is no systematic measuring of the impact on bird populations of power transmission and distribution lines and their poles in Australia. Nor is there a national database on electrocutions and/or collisions of birds or an entrenched reporting process for asset managers to identify impacts on wildlife generally. Only one State/Territory – Tasmania – has a statewide database of incidents and then only involving threatened species: the Tasmanian wedge-tailed eagle (*Aquila audax fleayi*), white-bellied sea eagle (*Haliaeetus leucogaster*), grey goshawk (*Accipiter novaehollandiae*) and masked owl (*Tyto novaehollandiae*). New South Wales (NSW) has a regional database for incidents involving the threatened powerful owl (*Ninox strenua*).

Despite maintenance staff attending outages on power lines, birds are rarely recorded as a cause of an outage – about 40% of outages have no assigned cause. Anecdotal evidence suggests this may be because inspections are focused on overhead conductors rather than the ground. While most incidents actually observed are simple collisions, there is a likely heavy bias of records towards electrocutions since they are more likely to cause an outage than collisions and thus more likely to be recorded. Thus, records of fatalities and injuries are uncalibrated indices of incidents, developed from anecdotal records. These indices are used to identify apparent mortality hotspots and monitor numbers of incidents involving particular birds after mitigation, which may include installation of flappers, pole perches or insulation or changed conductor configurations (from three-phase to bundled or sheathed, for example).

The only Australian States/Territories that routinely apply bird mitigation after incidents (and then only with particular threatened species) are Tasmania and parts of NSW. In the late 1990s, in reaction to ongoing electrocutions of grey goshawks and wedge-tailed eagles, the Tasmanian power distribution network provider (TasNetworks) changed pole-top configurations at poles near known nests and other places of high risk, reducing electrocutions by more than 80% (Hess et al., 1996; Figure 205). Since 2017 similar work continues for wedge-tailed eagles, mainly involving flappers since the issue is usually electrocution by an eagle touching multiple conductors in a mid-span collision. A recent partnership between TasNetworks and Raptor Refuge incorporates post-mortem examination, tailored, timely mitigation and a shared database. It is intended to progress this management by identifying high-risk line sections and bird-safeing them proactively. BirdLife Australia Raptor Group has begun independent assessment of wedge-tailed eagle densities in various Tasmanian habitats to assist this. Construction and maintenance of lines in Tasmania also involves distance buffers between lines and eagles breeding at known nests, and TasNetworks provides some funds to assist raptor rehabilitation and research.

In 2019 BirdLife Australia secured support from one NSW power distribution network provider to begin mapping their infrastructure in relation to known powerful owl territories in the Sydney Basin. In one known strike zone this company applied bird-safeing to lines. The current conservation risk assessment process required by National Parks and Wildlife in NSW requires all line managers to consult with BirdLife to assess impacts of works involving vegetation disturbance, to ensure least impact upon birds, but does not assess the risk of the power lines themselves.

In Victoria, power lines built to service windfarms are now subject to development permit conditions and this will allow regulators to have those lines bird-safed.

Figure 205. A: Wedge-tailed eagle (*Aquila audax*) on power pole. B: Adult and juvenile wedge-tailed eagles perched on a pole-top perch added to keep raptors from pole-top wires, near Ross in central Tasmania, July 2020. © Peter Thorpe

9.6. Other case studies

CASE STUDY 16

Primate electrocutions

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Electrocution of primates climbing on power lines is a widespread but largely overlooked conservation concern. For example, golden-mantled howler monkeys (*Alouatta palliata palliata*) are frequently electrocuted in Costa Rica (Figure 206). Black-tufted marmosets (*Callithrix penicillata*) and howler monkeys (*Alouatta guariba clamitans*) are also electrocuted in Brazil (Printes, 1999; Lokschin et al., 2007; Pereira et al., 2020), as are squirrel monkeys (*Saimiri oerstedii oerstedii* and *S. o. citrinellus*) in Costa Rica – 'electrocution being arguably the major source of direct mortality for [squirrel monkeys]' (Boinski et al., 1998). Outside of the Americas, Angolan black-and-white colobus (*Colobus angolensis palliatus*), Sykes monkeys (*Cercopithecus mitis albogularis*), vervet monkeys (*Chlorocebus pygerythrus hilgerti)*, northern yellow baboons (*Papio cynocephalus ibeanus*) and white-tailed small-eared galagos (*Otolemur garnettii lasiotis*) are electrocuted in Kenya (Katsis et al., 2018), as are Barbary macaques (*Macaca sylvanus*) in Algeria (UICN & DGF, 2019). Rhesus macaques (*Macaca mulatta*) and Hanuman langurs (*Semnopithecus entellus*) in India (Kumar & Kumar, 2015; Ram et al., 2015), Indonesian slow lorises (*Nycticebus* spp.) in Indonesia (Moore et al., 2014) and purple-faced langurs (*Trachypithecus vetulus nestor*) in Sri Lanka (Moore et al., 2010) are also electrocuted. In Bangladesh, where most primate populations are threatened and declining, Phayre's leaf monkeys (*Trachypithecus phayrei*) and Bengal slow lorises (*Nycticebus bengalensis*) have been documented in electrocutions (Al-Razi et al., 2019). Additional citations describing a wide variety of electrocuted primate species are summarised in Katsis et al. (2018) but omitted here in the interest of page space. These events not only injure and kill primates, but also result in electric outages causing economic disruption and damage to power equipment. For example, in 2006 a vervet monkey caused a four-hour nationwide blackout in Kenya after contacting a station transformer (BBC News, 2006).

Primate electrocutions are likely increasing in part because power lines are being expanded to provide electricity service to widely distributed human populations in developing countries, and because overhead power systems in developing countries typically use grounded steel or concrete configurations that reduce long-term maintenance costs compared to wood construction, but increase electrocution risks for wildlife (Slater et al., 2020). Though some primate-specific electrocution prevention techniques have been developed, including a rope ladder to allow primates to cross open areas without using power lines (Lokschin et al., 2007) and a cover for a specific piece of equipment called a 'fused cut-out' (Midsun Group, Southington, CT, USA), the effectiveness of this equipment has not yet been quantitatively tested, nor is it widely applied. Most power pole retrofitting techniques are driven by efforts to prevent electrocution of raptors, but solutions effective for raptors may not be effective for primates due to differences in behaviour and body morphology. Burns on the prehensile tail of arboreal primates are common in electrocutions, and there is no analogue for that body configuration in avian biology. Additional research is needed on primate-specific techniques and equipment focused on preventing primate electrocutions (see Appendix B).

Figure 206. Electrocuted golden-mantled howler monkeys. The Monkey Farm is a monkey care and rehabilitation facility located on Camino del Cielo, Playa Ocotal, Guanacaste, Costa Rica. © The Monkey Farm. Additional images are available at https://themonkeyfarm.org/transformer-project.

CASE STUDY 17

Reconciling power line developments with the conservation of soaring bird species: the importance of early planning and spatial mapping tools

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Safe Flyways – Reducing energy infrastructure-related bird mortality in the Mediterranean is a joint six-year initiative of the Vulture Conservation Foundation (VCF), the Society for the Protection of Biodiversity in Thrace, IUCN-Med, EuroNatur, the University of Barcelona, WWF Spain and WWF Greece, and is coordinated by BirdLife International and funded by the MAVA Foundation.

Collisions and electrocutions on energy infrastructure are significant threats to migratory birds in the Mediterranean region. Phase II of the Safe Flyways project focuses on the reduction of power line-associated bird mortality through targeted international, national and local work with partner NGO's in close collaboration with the industry.

The project strongly advocates the importance of early planning for energy infrastructure deployment, so as to avoid future impacts through careful site selection (the most effective mitigation measure available to renewable energy stakeholders). A number of important wildlife mapping tools have been developed so that biodiversity can be mainstreamed into the strategic planning and site selection processes for energy infrastructure.

A Mediterranean-wide survey was conducted by researchers, government officials, experts, partners and other stakeholders to reveal the extent of the bird collision and electrocution problem in 2017 and 2019. Its results are being used to guide future actions, and it is planned to repeat this work in Phase II of the project.

Sensitivity mapping is an effective spatial planning tool at regional and national levels that can guide decision making on the siting of new energy developments and is the first step in identifying suitable sites away from sensitive features. Project partners recognise that sensitivity mapping is an essential prerequisite for wildlife-friendly spatial planning. The Soaring Bird Sensitivity Mapping Tool (Figure 207) is an example of the effort to provide developers, planning authorities and other stakeholders with access to information on the distribution of soaring bird species. More information may be found on the Migratory Soaring Bird Project website (http://migratorysoaringbirds.undp.birdlife.org/).

Further risk screening can be undertaken at the early planning stage to support site characterisation and to help assess biodiversity sensitivities for one or more potential project sites. The Integrated Biodiversity Assessment Tool (IBAT) is a web-based spatial mapping and reporting tool that can support this process at a finer scale (Figure 208). The tool can help energy stakeholders to incorporate biodiversity considerations into key project planning and management decisions, by indicating protected and important areas (including Important Bird and Biodiversity Areas) and species or habitats which may be present along a route. For further information, visit Integrated Biodiversity Assessment Tool (IBAT; https://www.ibat-alliance.org/).

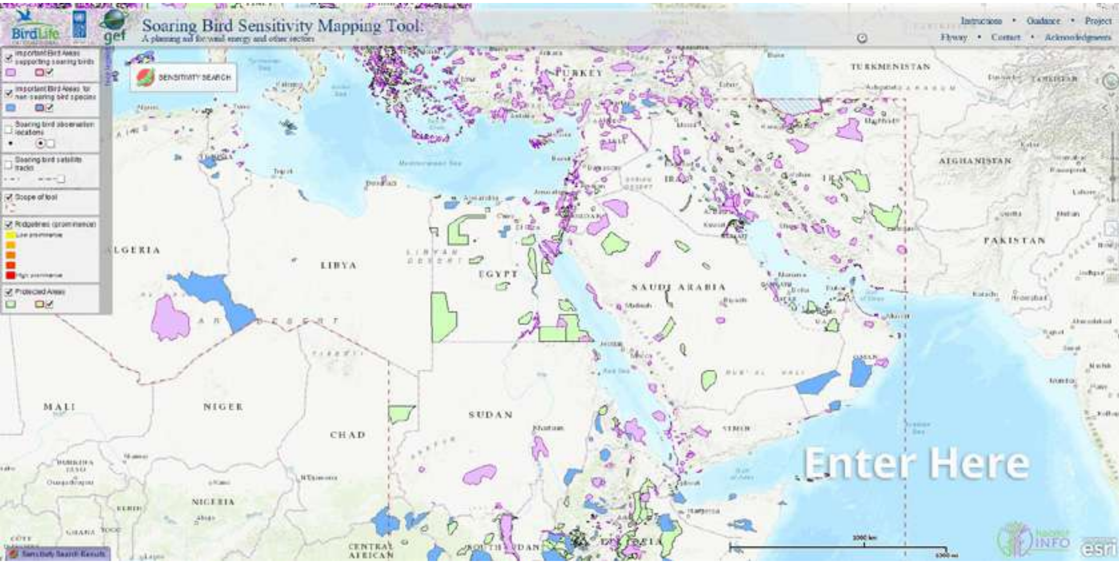

Figure 207. Screenshot of the Soaring Bird Sensitivity Mapping Tool. © Migratory Soaring Bird Project

The use of these tools and associated guidance is also being promoted through international forums and networks. The project calls for countries to join key platforms, especially the Convention on Migratory Species (CMS) Energy Task Force (ETF), which is a multi-stakeholder platform that works towards reconciling renewable energy developments with the conservation of migratory species. The ETF brings together governments, multilateral environmental agreements, investors, the private sector and non-governmental organisations, with the aim of avoiding and minimising the negative impacts of energy developments on migratory species. Further information can be found at The CMS Energy Task Force website (https://www.cms.int/en/taskforce/energy-task-force).

The project partners are open to collaboration with project countries, power companies and regional and international organisations. For more information, please contact the project coordinator: Osama.alnouri@birdlife.org.

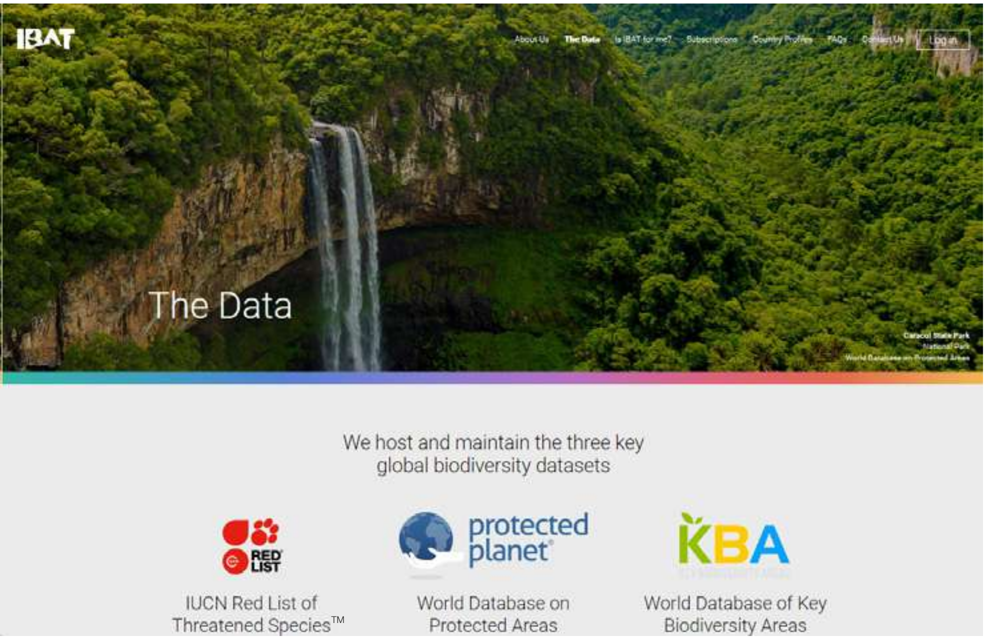

Figure 208. IBAT website. © IBAT

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Appendices

Introduction

The general objective of these appendices is to show in detail the preventative and mitigating measures presented in Chapters 4 and 5, as well as recommendations for their correct implementation. Their content may be summarised as follows:

Appendix A covers anti-electrocution and anti-collision measures directed at birds in general.

- Section I explains which support designs are the most dangerous and what safety distances between elements must be adopted for the designs to be safe.

- Section II gives a typology of supports, classifying them according to the arrangement of elements in the crossarm, presented in the form of factsheets. This classification can be used to characterise power lines anywhere in the world. The danger level is assessed for each type and the most effective corrective measures to reduce the risk are shown.

- Section III is a photo gallery showing examples of the different support types and corrective measures.

- Section IV includes recommendations for anti-electrocution measures. It sets out the characteristics that new electrical lines must have to be safe and makes recommendations on the correct use and installation of insulation devices.

- Section V includes recommendations for anti-collision measures, describing the lines on which they should be installed and making recommendations for the installation of visual markers.

Appendix B covers specific measures for power lines and installations located in forest environments, where climbing animals present an additional problem to that of bird interactions.

- Section I outlines preventative measures for securing substations and transformer stations.

- Section II deals with preventative measures for securing supports and wires.

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Appendix A

Power lines and birds: safe and dangerous designs and recommendations for preventative and mitigating measures

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I. SUPPORT CONFIGURATION AND ELECTROCUTION RISK

As electrocution depends on the bird contacting two points with different potential simultaneously, the risk of electrocution on a given pole or pylon depends on the configuration and the structure of the crossarm. Crossarm layouts that facilitate such contact (vertical insulators and disconnectors, jumpers above them, transformers, etc.) pose a high risk. In general, due to the grounding connections, the risk is greater if the crossarm is made of metal rather than wood and if the pole is also metal and not made of wood or unreinforced concrete. Likewise, the perching opportunities offered by the crossarm configuration have a considerable influence (Figure A1).

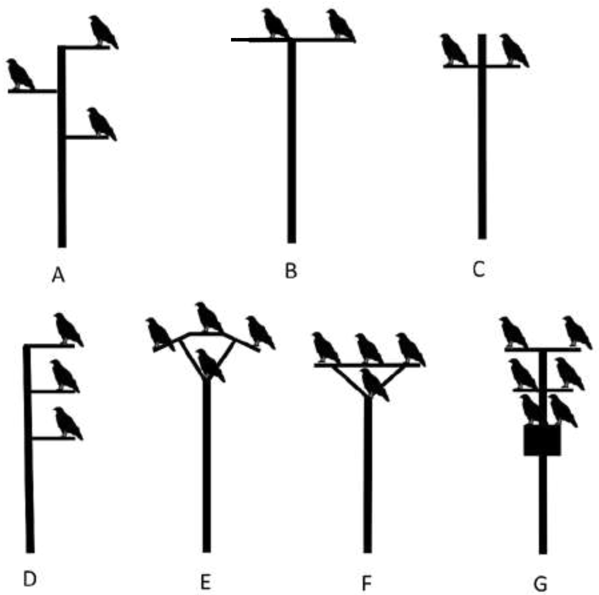


Figure A1. Potential perching points on different crossarm configurations. A: alternating (or staggered) configuration. B: horizontal configuration. C: cross-shaped configuration. D: vertical configuration. E: vault configuration. F: flat vault configuration. G: special support (with a transformer in this example). Source: prepared by the author.

A typology of poles based on crossarm configuration (see Chapter 2) allows them to be classified according to how dangerous they are. Transmission line pylons are not taken into account here because their large size and considerable separation between conductors generally do not lead to electrocutions. Although they have occasionally been found to cause electrocutions – due to electric arcing, defecation or simultaneous contact with two conductors – these incidents are rare and, in practice, unpredictable and unavoidable.

It should also be noted that all configurations and measurements included in the classification correspond to metal crossarms with a ground (earth) connection; the risk is generally lower for wooden or fibreglass crossarms because these materials are poor conductors (unless they are wet) and are often not grounded. If it exists, grounding takes place through a separate wire connected to the crossarm. Its position must also be taken into account in assessing the danger level of a support. For crossarms without a ground connection, electrocution can only occur by contact between two conductors, so the risk is high when the distance between conductors (and/or jumpers) is very small, as on crossarms with pin insulators or on anchor supports with jumpers above the insulators. As a result, the critical distances vary compared with the same configurations on metal crossarms.

> *For a support to be considered safe, the critical distances must be large enough to avoid electrocuting the largest birds likely to use it, bearing in mind their wingspan and height.*

On the basis of these premises and how electrocutions occur in accordance with crossarm configuration, five basic critical distances and their relation to the size of the bird should be considered in order to assess how dangerous they are (Figure A2).

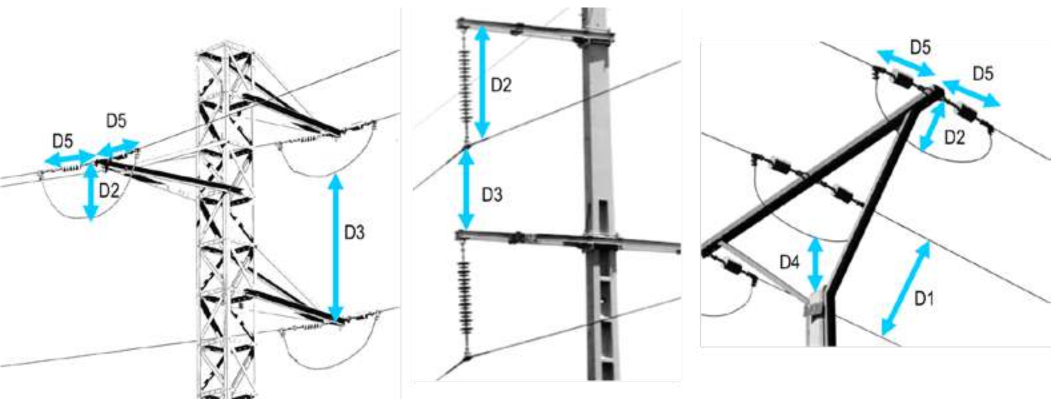


Figure A2. Critical distances for some common crossarm configurations. Source: prepared by the author.

As we have seen (Chapter 5), electrocution normally occurs as a result of contact involving two bare parts of the bird that are not covered in feathers (wrists, head, legs); therefore, these critical safety distances should relate to the measurement between the two wing wrists and the distance between the wrists and the legs. In humid climates where the bird's plumage may often be damp, larger distances should be considered, taking the wing tips as reference points (Figure A3).

Figure A3. The wingspan and vertical reach of the bird determine critical distances. Griffon vultures (*Gyps fulvus*) landing. ©Íñigo Fajardo

Critical distances depend on the largest birds present susceptible to being electrocuted. Most birds susceptible to electrocution are raptors; therefore, the size of the larger raptors (Accipitridae and Cathartidae) should be considered. Some species such as the Andean condor (*Vultur griphus*), cinereous vulture (*Aegypius monachus*) and lappet-faced vulture (*Torgos tracheliotos*) have wingspans of around 3 m, corresponding to a wrist-to-wrist length of around 1.7 m (Figure A4).

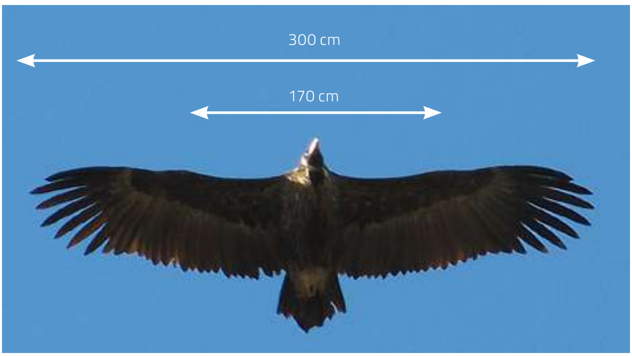


Figure A4. Wingspan and wrist-to-wrist distances in the cinereous vulture (*Aegypius monachus*). © Justo Martín

Bearing in mind these dimensions, safe values of critical distances for the different configurations are given in the following table:

Table A-1. Safe values of basic critical distances for assessing the danger level of a crossarm configuration, taking into account the largest birds that may be electrocuted.

DISTANCE	CROSSARM CONFIGURATION	BASIC CRITICAL DISTANCE	SAFE VALUE
D1	ALL CONFIGURATIONS	Distance between the conductors. *Depends on the bird's wingspan.*	1.5 m
D2	ALL CONFIGURATIONS	Vertical distance between the point where the bird perches and the nearest live element at a lower level (conductor or jumper). *Depends on the risk caused by defecation and the distance between the bottom of the legs and the tip of a wing spread out downwards.*	1 m (0.7 m)*
D3	ALTERNATING (STAGGERED) CONFIGURATION VERTICAL CONFIGURATION	Vertical distance between the point where the bird perches and the nearest live element at a higher level (conductor or jumper). *Depends on the vertical reach of the bird, i.e. the distance between the foot and the tip of a wing spread out upwards.*	1.5 m
D4	VAULT CONFIGURATION	Vertical distance between the bottom of the crossarm and the nearest live element at a higher level. *Depends on the vertical reach of the bird.*	1 m
D5	ALL CONFIGURATIONS (ANCHOR SUPPORTS)	Horizontal distance between the point where the bird perches and the nearest live element. *Depends on the distance between the foot and the tip of a wing spread out sideways.*	1 m (1.5 m)**

Source: compiled by the author.

*A vertical safety distance of 1 m (D2) may be difficult to achieve in some configurations, but at least 0.70 m must be guaranteed.

**A horizontal safety distance of 1 m (D5) is sufficient in most cases, since electrocution occurs when there is contact between the bare parts of the wing and not with the feathers. However, as mentioned above, in regions with a very damp climate where large eagles or vultures are present, this distance should be increased to 1.5 m, in particular if the anchor device (a smooth polymer insulator or insulator string with extensions) allows birds to perch on it.

Based on these minimum basic distances and the type of support, the potential hazard of each type of configuration can be determined. In general:

- The least dangerous crossarms are those with a horizontal layout or an alternating configuration with suspension insulators, as long as the separation between a side arm and the conductor suspended from the side arm above is more than 1.5 m. Note that a horizontal configuration poses a lower collision risk due to the lower number of planes in which the wires are arranged.
- Vault configurations with suspension insulators are not very dangerous either, as long as the distance between the fork, where a bird can perch, and the central conductor is more than 1 m. If the top of the vault is close to the conductors, the risk of electrocution through defecation is significant.
- Poles equipped with any type of devices pose increased electrocution risks to birds of all sizes because of short phase-to-ground and phase-to-phase distances.

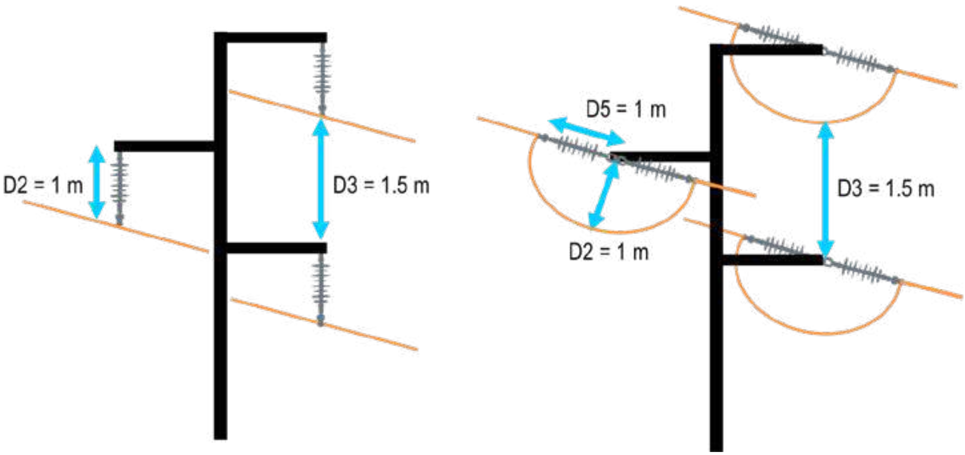


Figure A5. Safe distances for an alternating conductor configuration with suspension insulators (left) and jumpers (right). Source: prepared by the author.

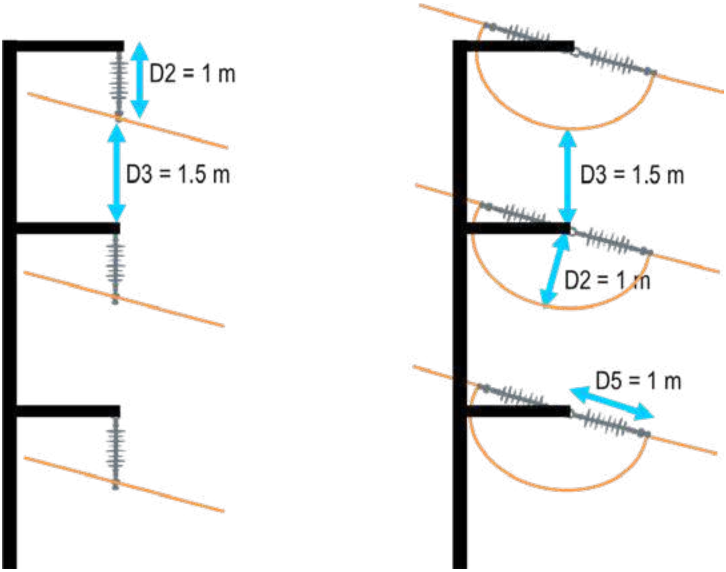


Figure A6. Safe distances for vertical crossarm assemblies with suspension insulators (left) and jumpers (right). For horizontal conductor configurations, the measurements should be the same as for the upper side arm. Source: prepared by the author.

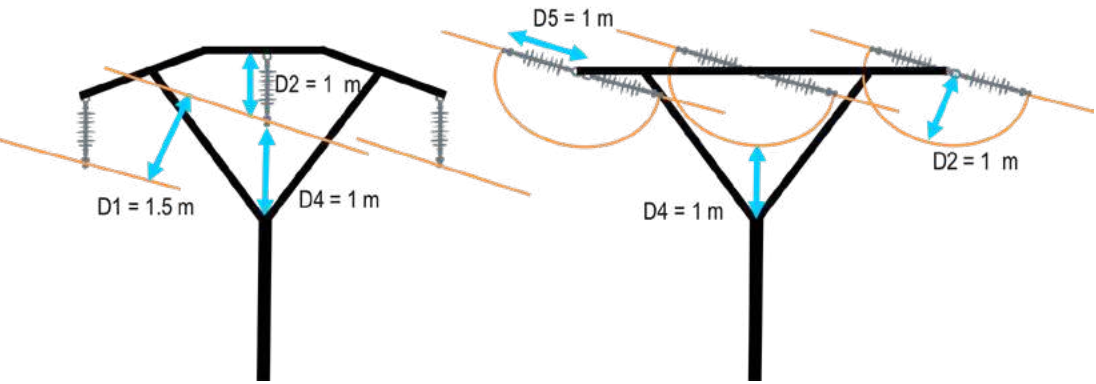


Figure A7. Safe distances for a vault configuration with suspension insulators (left) and jumpers (right). The same applies to a horizontal configuration (except that D4 does not exist). Source: prepared by the author.

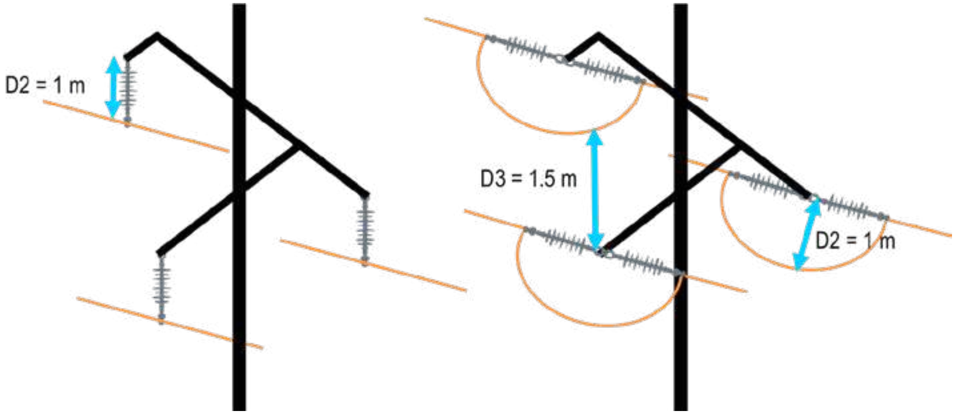


Figure A8. Canadian configuration, with supension insulators (left) and jumpers (right). This is an unusual but safe configuration. Source: prepared by the author.

In the case of crossarms without ground connections, safety depends on the spacing between conductors. Configurations where the central conductor is above the crossarm and the lateral conductors are below pose a lower risk of electrocution (Figure A9).

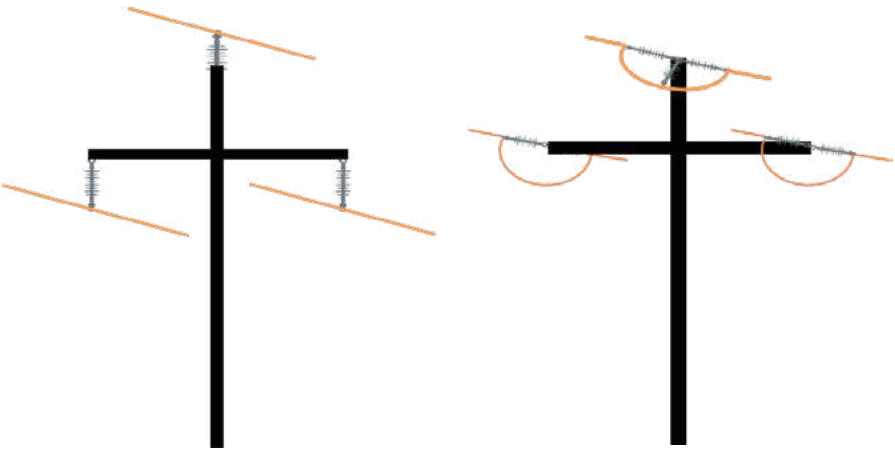


Figure A9. Safe configuration crossarms without ground connection. Source: prepared by the author.

The classification and the measures described below refer to supports for medium-voltage lines of up to 35 kV in general; most electrocutions occur on these lines, since the distances between their elements are conducive to this type of accident.

All configurations and measurements included in the classification correspond to metal crossarms and grounded supports; for ungrounded poles, the risk is generally lower and depends on other factors such as the presence and position of ground or neutral wires.

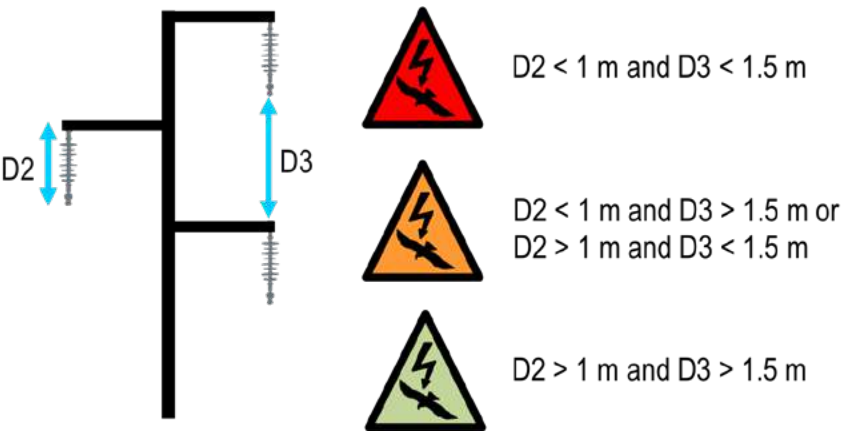
For ease of reading, computer graphics and colour coding are used to indicate how dangerous each type of support is and its corresponding level of risk.

Given that the same type of support can pose various kinds of danger depending on the distances between its constituent elements, the colour is associated with values that determine how dangerous it is.

➔ The DANGER LEVEL for supports is as follows:

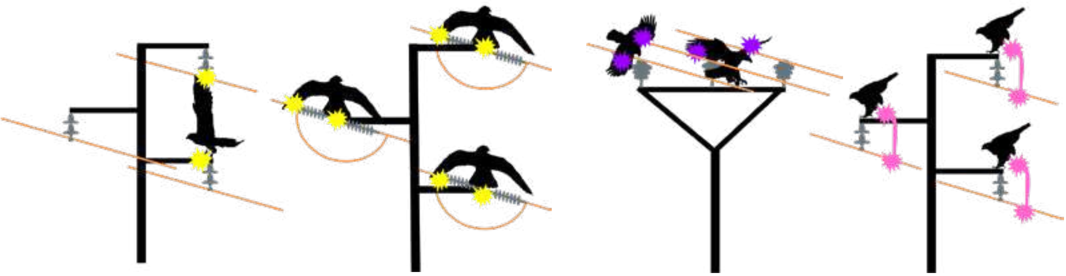
High or Very High **Moderate** **Low**

The danger level for each type of support depends on the basic critical distances. For example:



The 'High or Very High' category includes configurations and models with different danger levels. It is assumed there are relative differences in level between the various types, but it was decided to combine them in a single category in the interest of simplification.

➔ With regard to the RISK, three possibilities are considered for each type of support, each one indicated by a different colour (Figures A10, A11 and A12). The risk points are as shown:



Figures A10, A11 and A12. Left (2 figures): Phase–earth contact (yellow). Centre: Phase–phase contact (purple). Right: Contact through defecation (pink). Source: prepared by the author.

A series of corrective measures is proposed below for each type of power line support, with the aim of achieving safe distances at the points where birds can potentially perch. Materials and designs now exist that make it possible to build supports with very safe configurations for birds or to make hazardous configurations less dangerous, so that the risk of electrocution is very low. Structural measures involve the replacement of part or all of the crossarm. Non-structural measures involve the addition of insulating elements that reduce or eliminate the electrocution risk.

Applying structural measures to existing power lines is costly and may not even be technically feasible; these measures would be more suitable for newly constructed lines, although the possibility of installing them on old lines should always be evaluated.

In any case, mitigation measures need to be targeted specifically at the most sensitive species that are affected at a local level; a measure may be necessary in one place but completely useless in another. In addition, the technical and economic possibilities of each location must be taken into account so as to make the best use of available resources and efforts.

The effectiveness of the proposed measures has been proven, although the literature review that has been carried out suggests that many of them are not backed up by scientific studies quantifying their effectiveness and durability.

Section III of this annex includes a photo gallery of many of the support types described in these factsheets to make them easier to understand and identify on the ground.

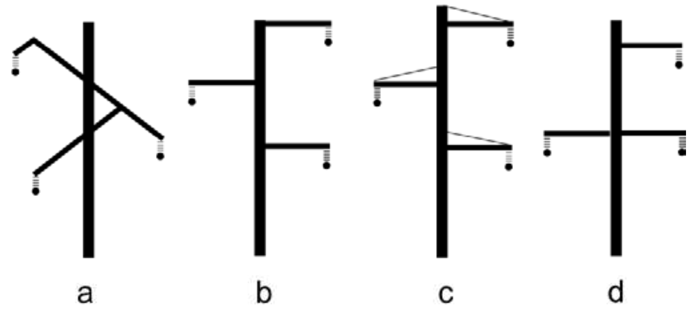
A1 SUPPORTING TOWERS OR POLES WITH SUSPENSION INSULATORS IN A STAGGERED OR ALTERNATING CONFIGURATION

Description

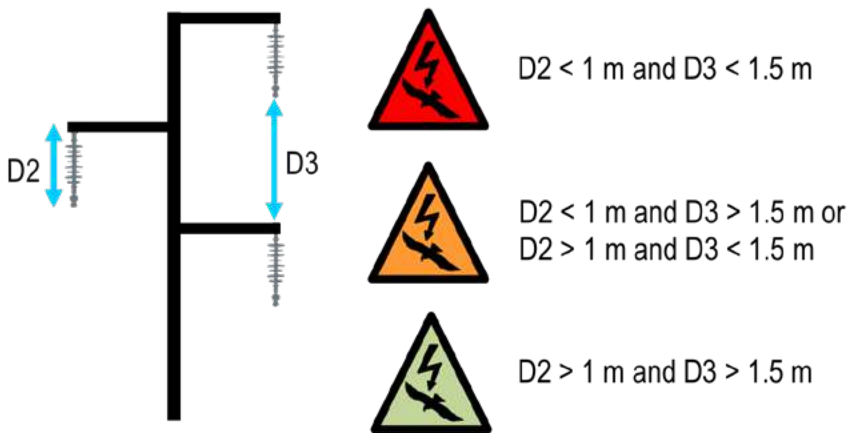
The phases are held in two vertical planes, alternating between them on three horizontal levels, or with one phase on an upper level and two on a lower level.

Variations

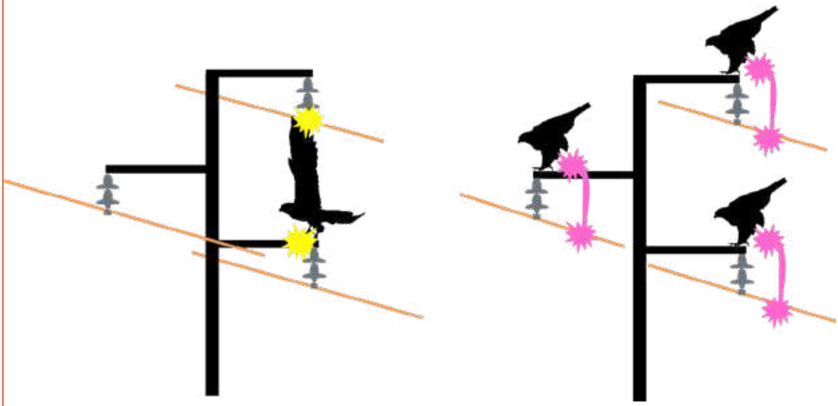
a) Canadian-type; b) simple staggered; c) staggered with tie members; d) false staggered crossarm



Danger level

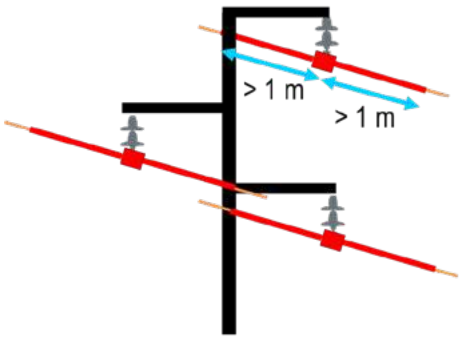


Risk

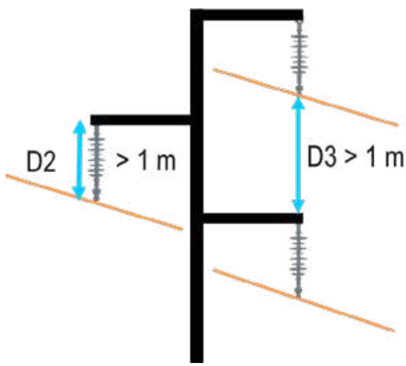


Corrective measures

Non-structural



Structural



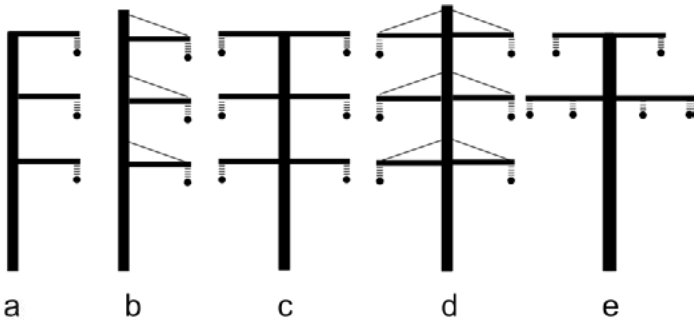
A2 SUPPORTING TOWERS OR POLES WITH SUSPENSION INSULATORS IN A VERTICAL CONFIGURATION

Description

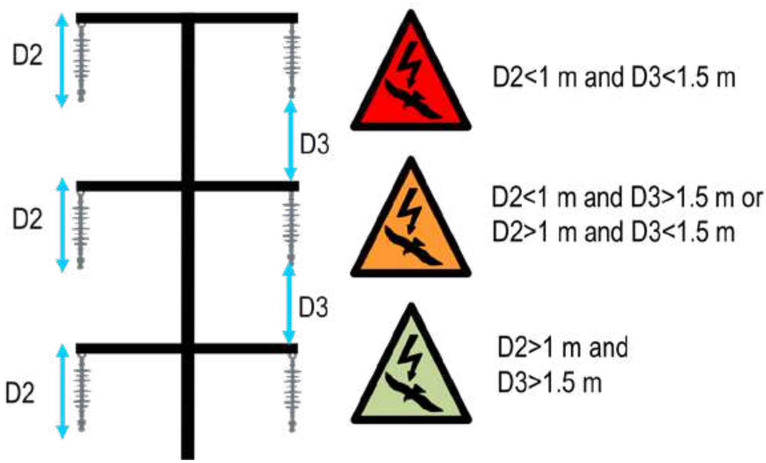
The phases of a circuit are held in the same vertical plane on three horizontal levels, with a single circuit (single or vertical conductor configuration with three phases) or a double circuit (with six phases), or on two levels with one circuit on each side.

Variations

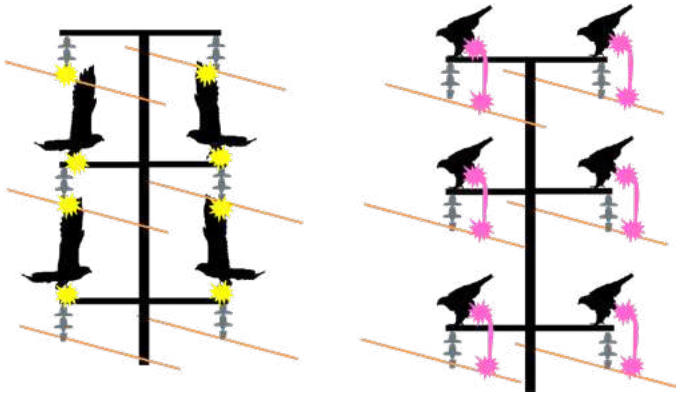
a) single circuit (the three phases on one side); b) single circuit with tie members; c) double circuit with phases on three levels; d) double circuit on three levels with tie members; e) double circuit on two levels



Danger level

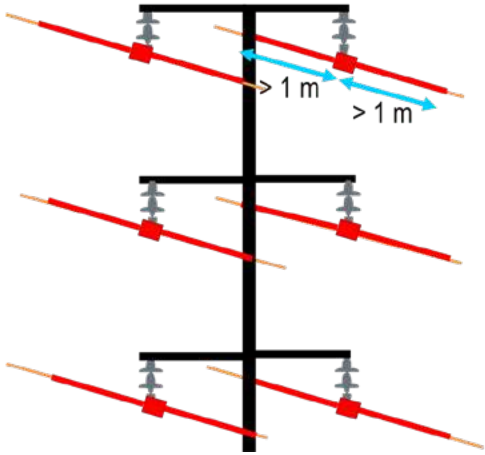


Risk

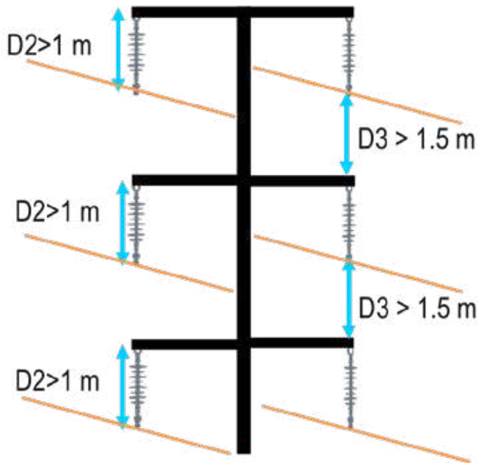


Corrective measures

Non-structural



Structural



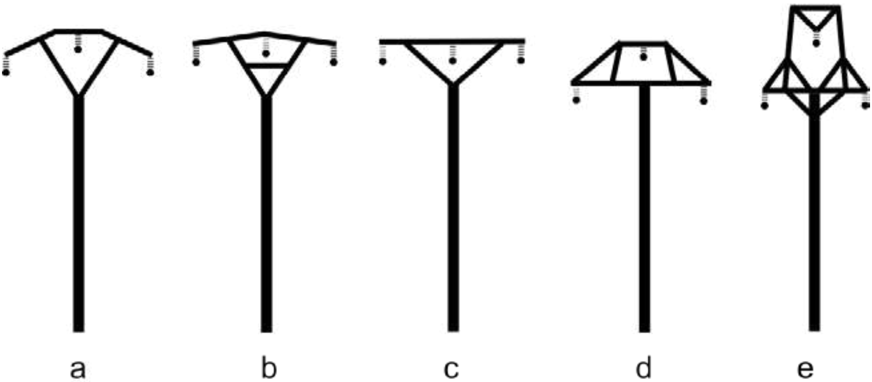
A3 SUPPORTING TOWERS OR POLES WITH SUSPENSION INSULATORS IN A VAULT CONFIGURATION

Description

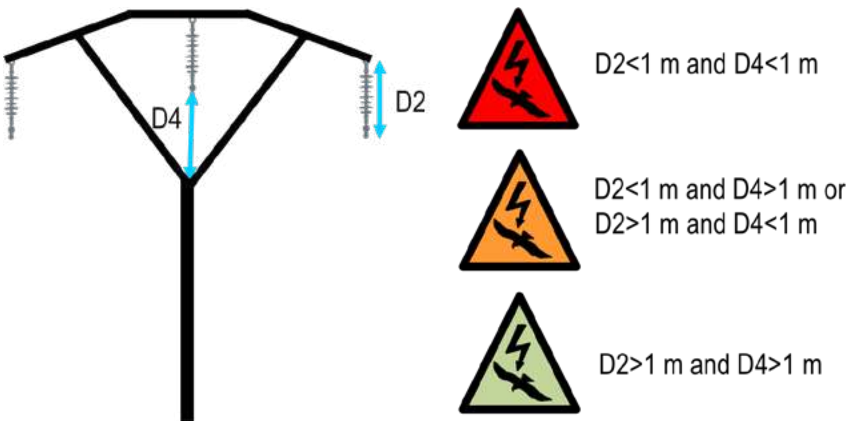
Arrangement with the central phase higher than the lateral phases, usually on an angled structure with a lower vertex, or with all phases on a single horizontal plane on a triangular structure.

Variations

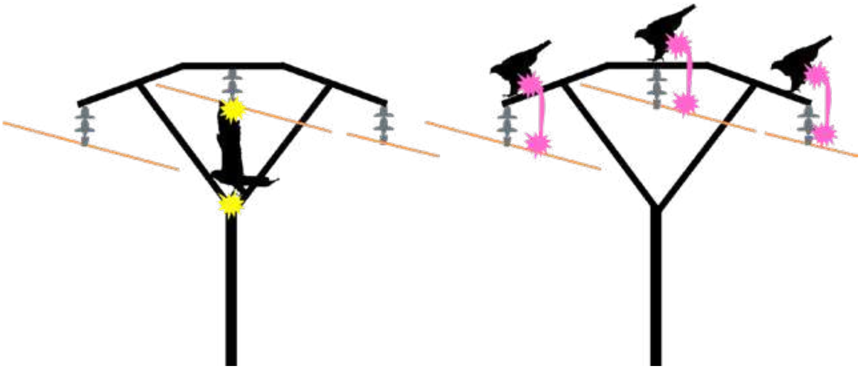
a) simple (vault configuration on two planes); b) with central crossbar (vault configuration on two planes and central crossbar joining the diagonal members; c) flat (vault configuration on a single plane); d) lattice vault; e) upper or superimposed vault



Danger level

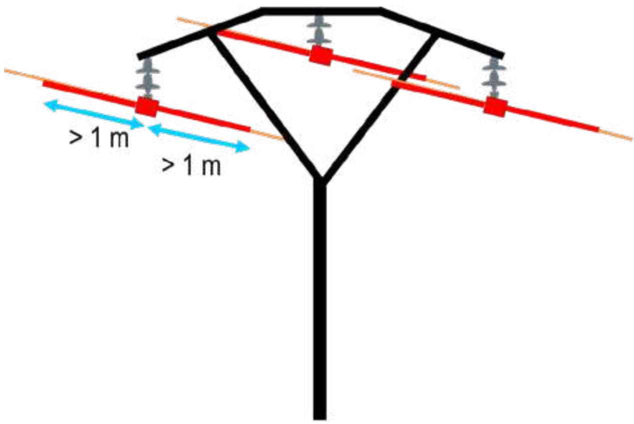


Risk

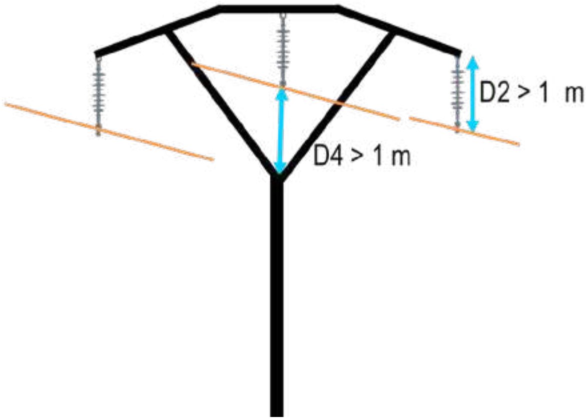


Corrective measures

Non-structural



Structural



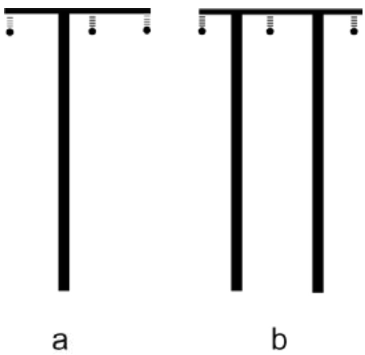
A4 SUPPORTING TOWERS OR POLES WITH SUSPENSION INSULATORS IN A HORIZONTAL CONFIGURATION

Description

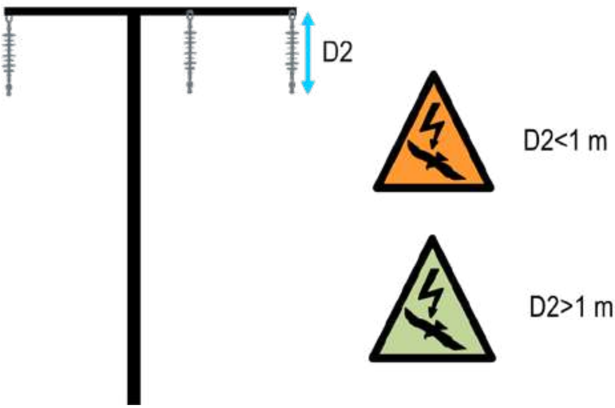
The three phases are suspended on the same horizontal plane from a horizontal crossarm. The crossarm sometimes rests on more than one pole, in which case it is referred to as an 'H' pole assembly or H-frame.

Variations

a) simple (one pole); b) ‘H’ pole configuration (more than one pole)



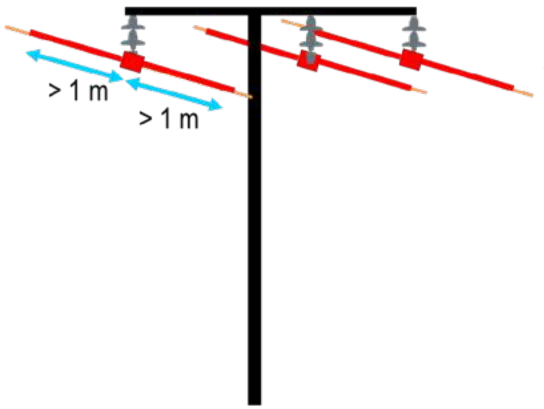
Danger level



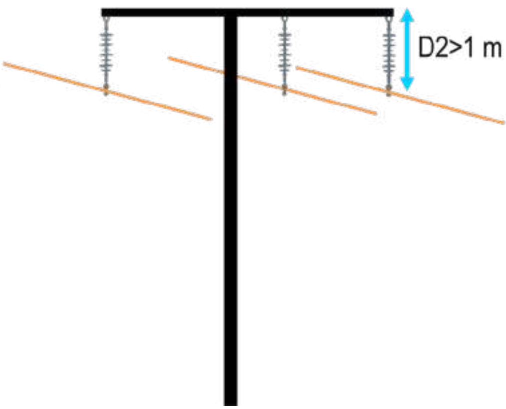
Risk

Corrective measures

Non-structural



Structural



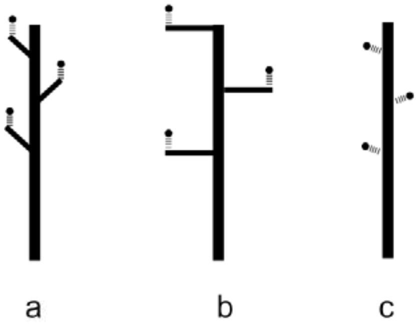
B1 SUPPORTING TOWERS OR POLES WITH PIN INSULATORS IN A STAGGERED OR ALTERNATING CONFIGURATION

Description

The phases are held in two vertical planes, alternating between them on three horizontal levels, or with one phase on an upper level and two on a lower level.

Variations

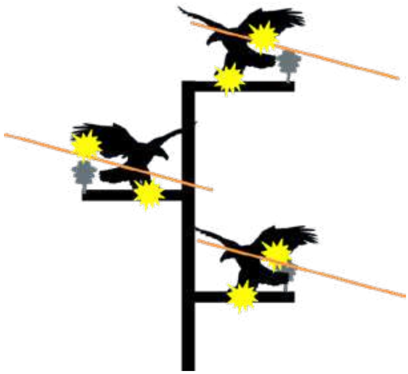
a) arms angled upwards; b) horizontal arms; c) no arms



Danger level

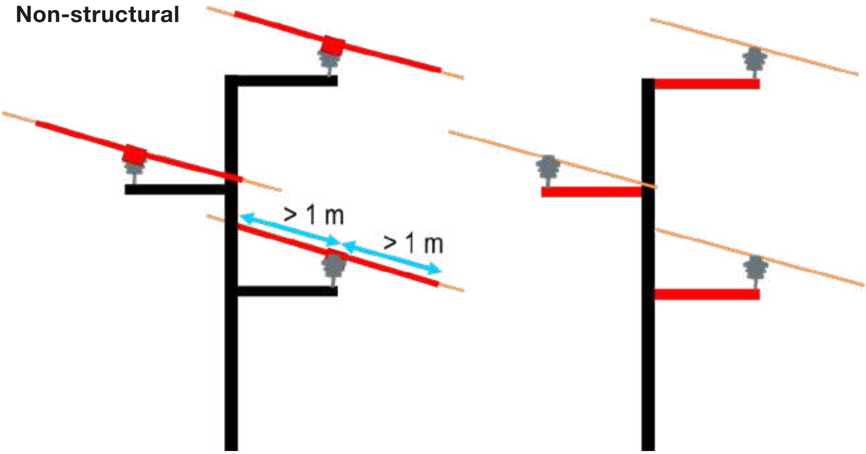
Very dangerous in all circumstances

Risk

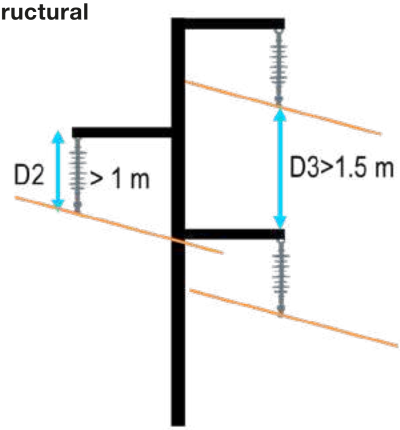


Corrective measures

Non-structural



Structural



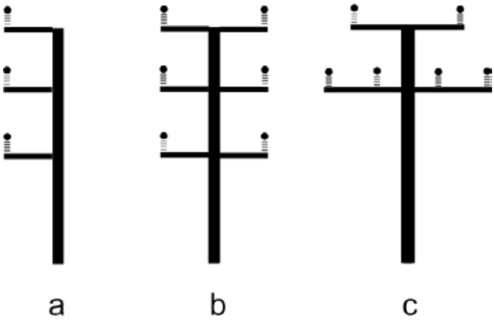
B2 SUPPORTING TOWERS OR POLES WITH PIN INSULATORS IN A VERTICAL CONFIGURATION

Description

The phases of a circuit are held in the same vertical plane on three horizontal levels, or on two levels with one circuit on each side.

Variations

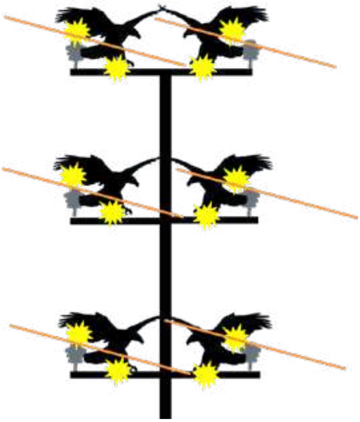
a) single circuit (the three phases on one side); b) double circuit; c) double circuit on two levels



Danger level

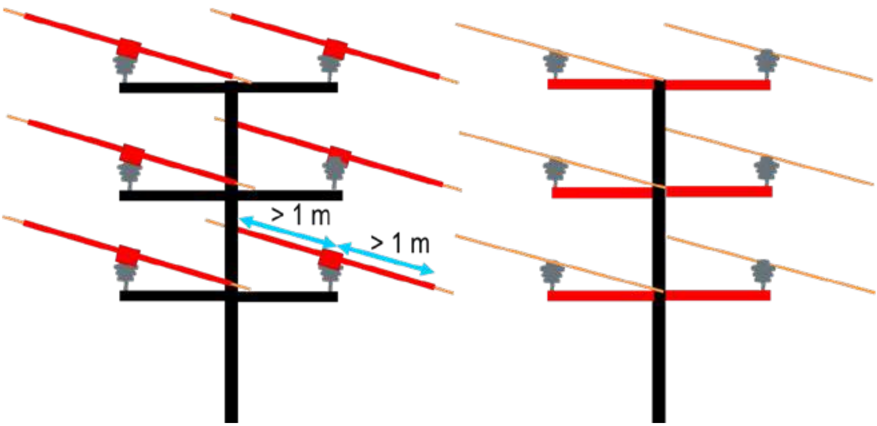
Very dangerous in all circumstances

Risk

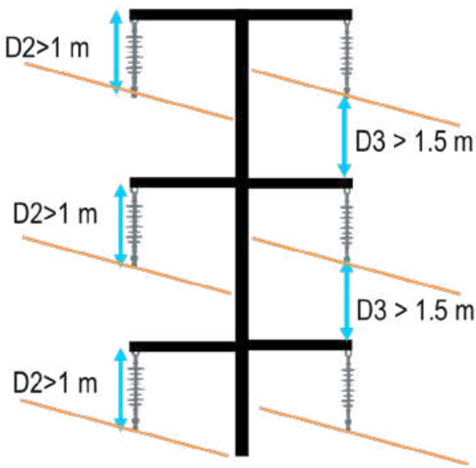


Corrective measures

Non-structural



Structural



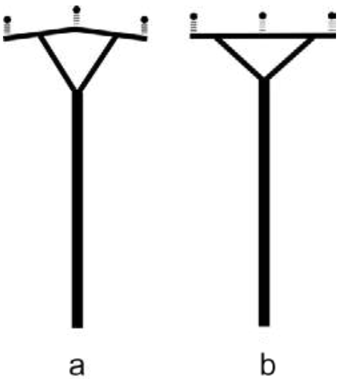
B3 SUPPORTING TOWERS OR POLES WITH PIN INSULATORS IN A VAULT CONFIGURATION

Description

Arrangement with the central phase higher than the lateral phases, usually on an angled structure with a lower vertex, or with all phases on a single horizontal plane on a triangular structure.

Variations

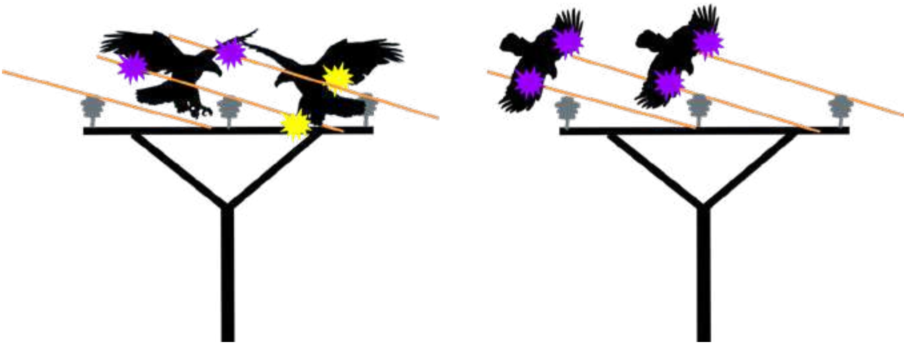
a) simple (vault configuration on two planes); b) flat (vault configuration on a single plane)



Danger level

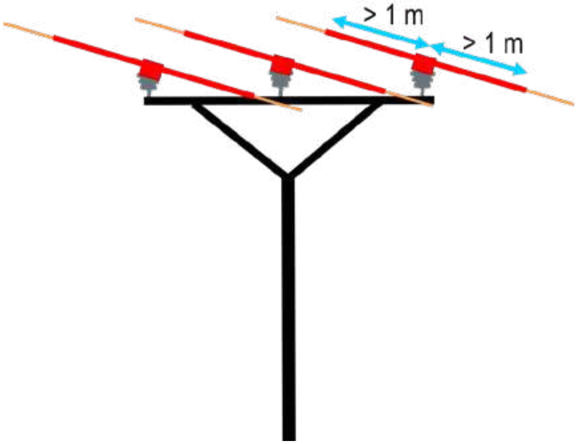
Very dangerous in all circumstances

Risk

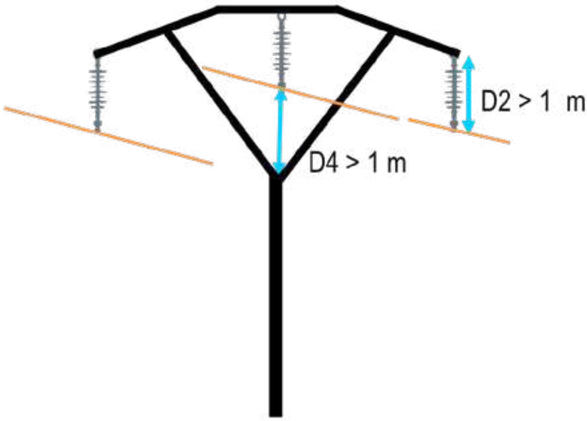


Corrective measures

Non-structural



Structural



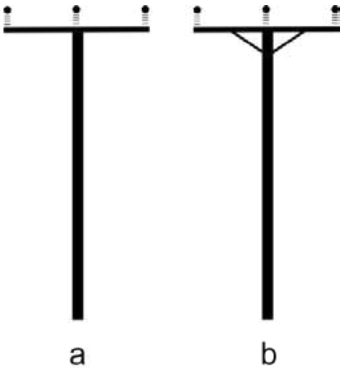
B4 SUPPORTING TOWERS OR POLES WITH PIN INSULATORS IN A HORIZONTAL CONFIGURATION

Description

The three phases are held on the same horizontal plane, on a horizontal crossarm.

Variations

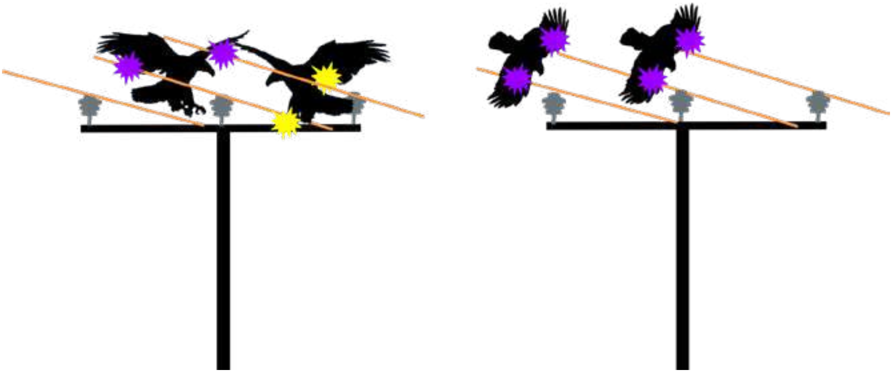
a) simple; b) braced



Danger level

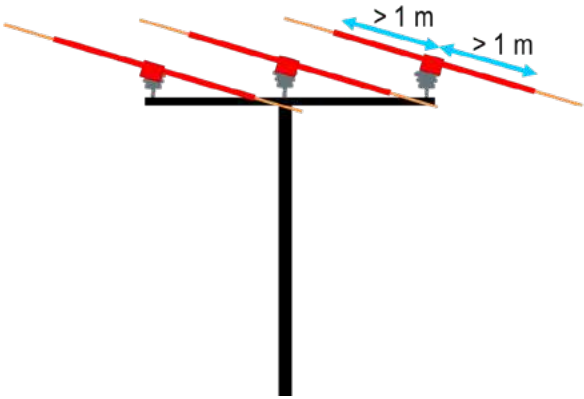
Very dangerous in all circumstances

Risk

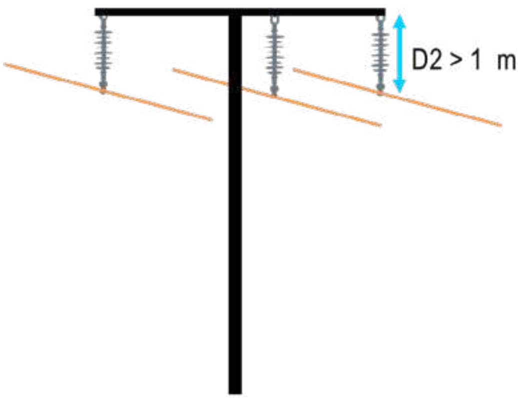


Corrective measures

Non-structural



Structural



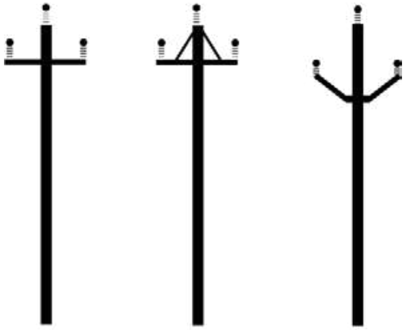
B5 SUPPORTING TOWERS OR POLES WITH PIN INSULATORS IN A CROSS-SHAPED CONFIGURATION

Description

The phases are held on two levels, with the central phase higher than the lateral phases; the assembly is cross-shaped.

Variations

a) simple; b) braced; c) side arms angled upwards



a b c

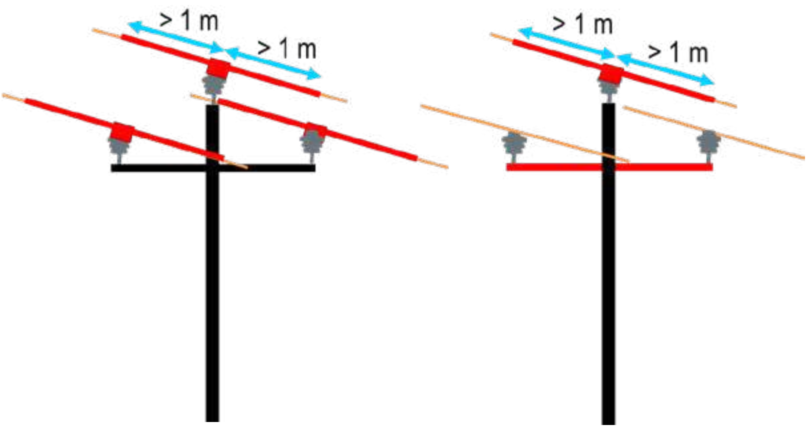
Danger level

Very dangerous in all circumstances

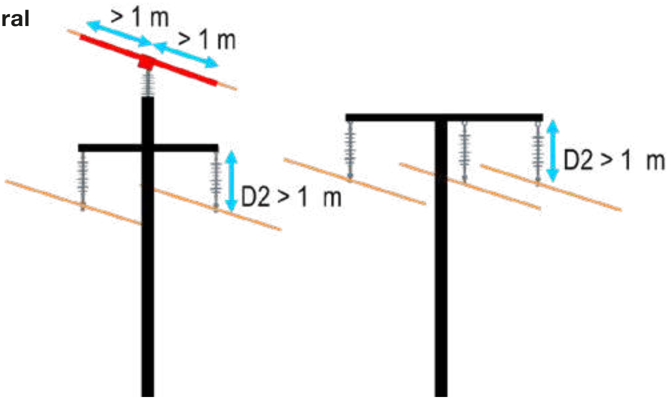
Risk

Corrective measures

Non-structural



Structural

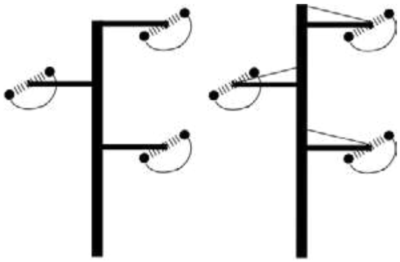


C1 ANCHOR TOWERS OR POLES WITH JUMPERS BELOW INSULATORS IN A STAGGERED CONFIGURATION

Description	The phases are held in two vertical planes, alternating between them on three horizontal levels, or with one phase on an upper level and two on a lower level.

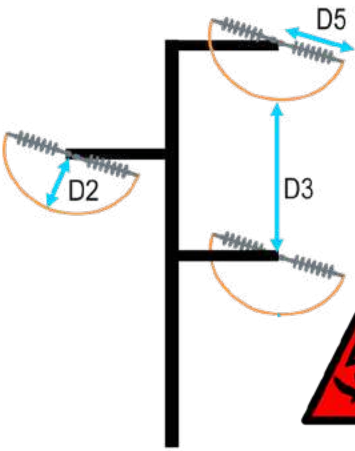
Variations

a) simple staggered; b) staggered with tie members



a b

Danger level

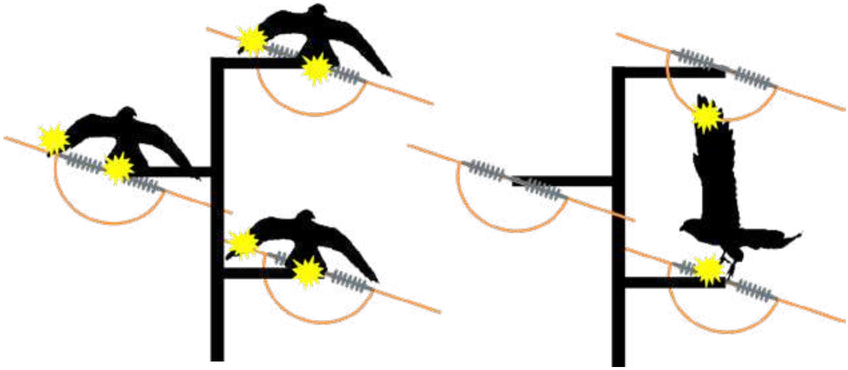


D2 < 1 m, D3 < 1.5 m and D5 < 1 m or
D2 < 1 m, D3 < 1.5 m and D5 > 1 m or
D2 > 1 m, D3 < 1.5 m and D5 < 1 m or
D2 < 1 m, D3 > 1.5 m and D5 < 1 m or
D2 < 1 m, D3 < 1.5 m and D5 > 1 m
(2 or 3 distances under D reliable)

D2 < 1 m, D3 > 1.5 m and D5 > 1 m or
D2 > 1 m, D3 < 1.5 m and D5 > 1 m or
D2 < 1 m, D3 > 1.5 m and D5 < 1 m or
(1 distance under D reliable)

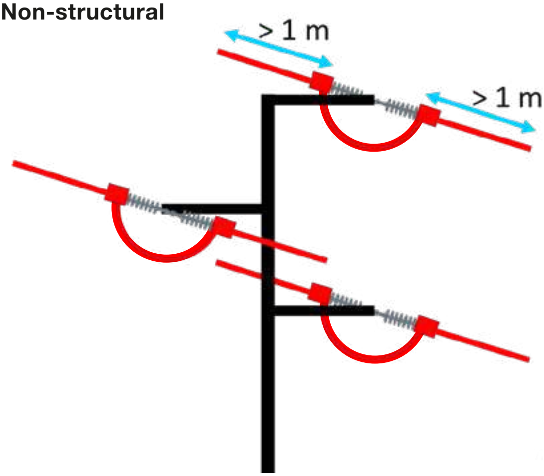
D2 > 1 m, D3 > 1.5 m and D5 > 1 m

Risk

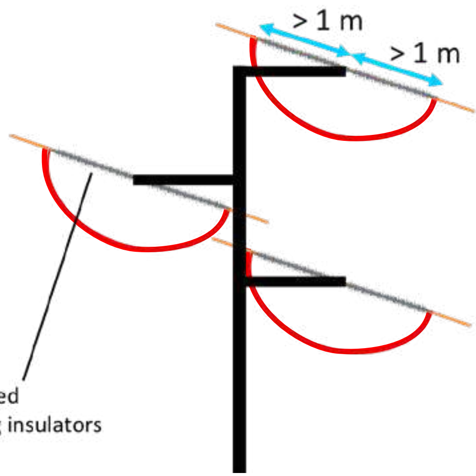


Corrective measures

Non-structural



Structural



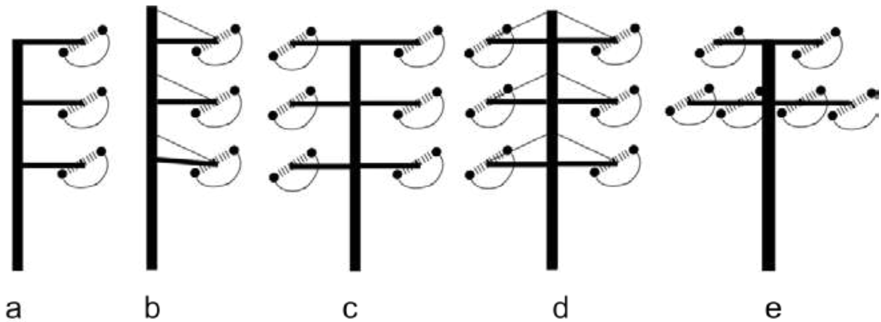
C2 ANCHOR TOWERS OR POLES WITH JUMPERS BELOW INSULATORS IN A STAGGERED CONFIGURATION

Description

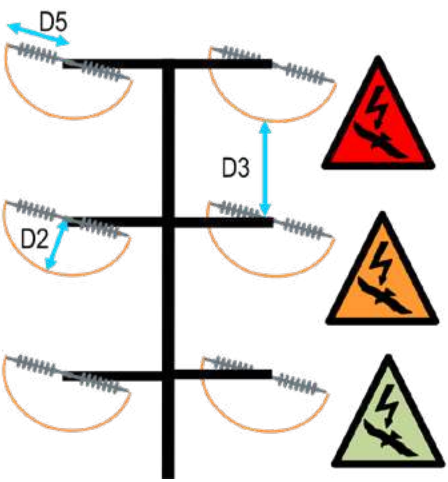
The phases are held in the same vertical plane on three levels

Variations

a) single circuit (the three phases on one side); b) single circuit with tie members; c) double circuit with phases of each circuit on three levels; d) double circuit on three levels with tie members; e) double circuit on two levels



Danger level

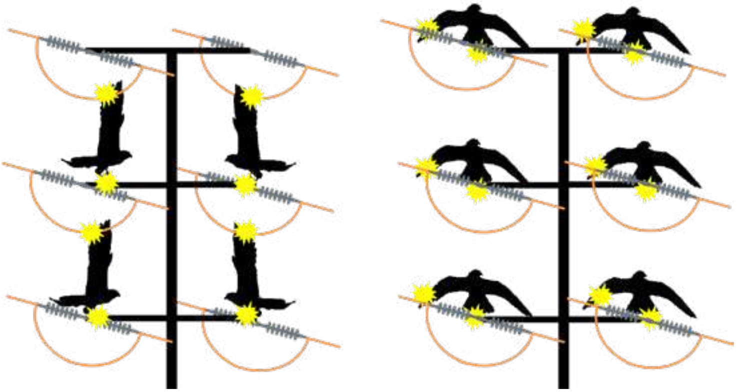


D2 < 1 m, D3 > 1.5 m and D5 > 1 m or
D2 > 1 m, D3 < 1.5 m and D5 > 1 m or
D2 < 1 m, D3 > 1.5 m and D5 < 1 m
(2 distances under D reliable)

D2 < 1 m, D3 > 1.5 m and D5 > 1 m or
D2 > 1 m, D3 < 1.5 m and D5 > 1 m or
D2 < 1 m, D3 > 1.5 m and D5 < 1 m
(1 distance under D reliable)

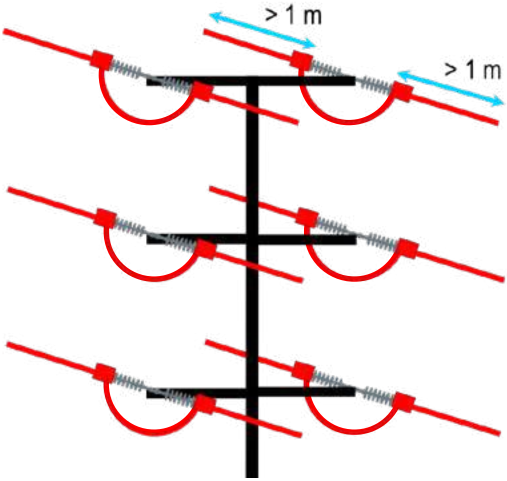
D2 > 1 m, D3 > 1.5 m and D5 > 1 m

Risk

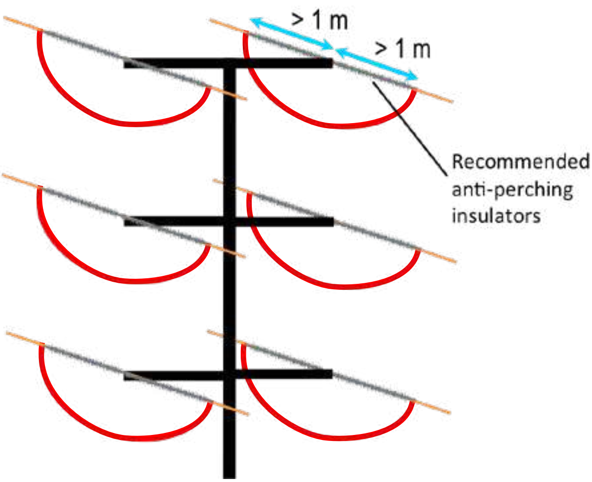


Corrective measures

Non-structural



Structural



C3

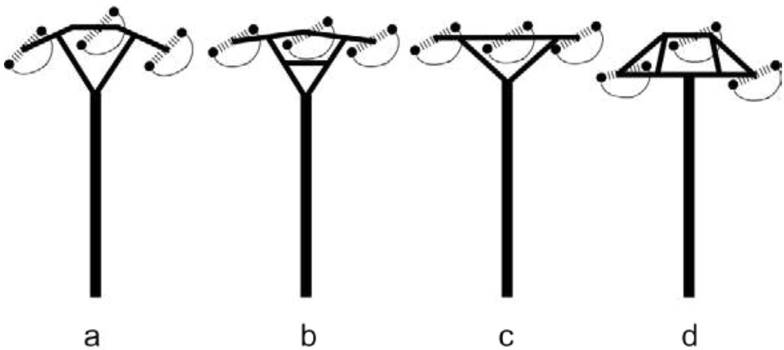
ANCHOR TOWERS OR POLES WITH JUMPERS BELOW INSULATORS IN A VAULT CONFIGURATION

Description

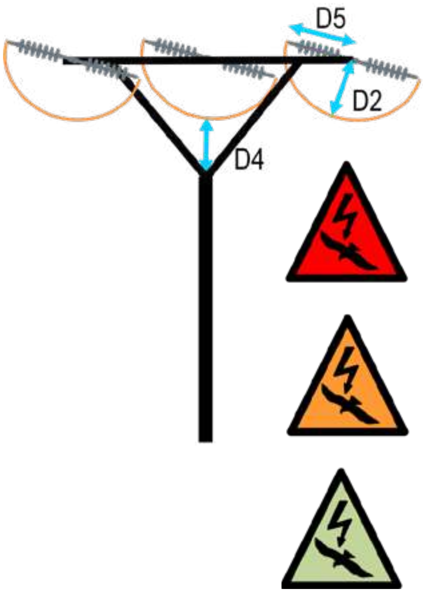
Arrangement with the central phase higher than the lateral phases, usually on an angled structure with a lower vertex, or with all phases on a single horizontal plane on a triangular structure.

Variations

a) simple (vault configuration on two planes); b) with central crossbar (vault configuration on two planes and central crossbar joining the diagonal members; c) flat (vault configuration on a single plane); d) lattice vault



Danger level

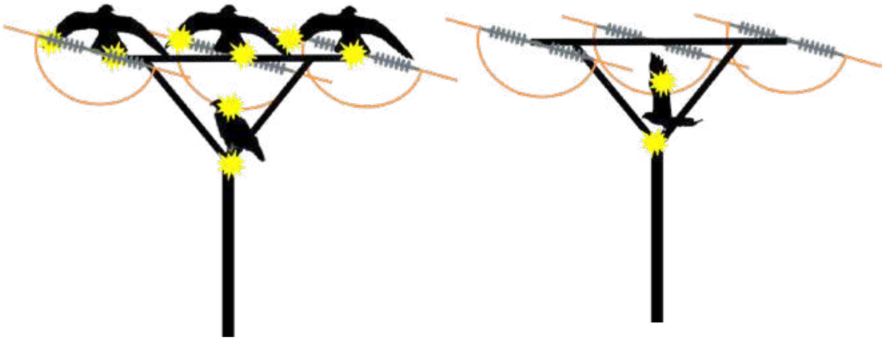


D2 < 1 m, D4 > 1 m and D5 > 1 m or
D2 > 1 m, D4 < 1 m and D5 > 1 m or
D2 < 1 m, D4 > 1 m and D5 < 1 m
(2 distances under D reliable)

D2 < 1 m, D4 > 1 m and D5 > 1 m or
D2 > 1 m, D4 < 1 m and D5 > 1 m or
D2 < 1 m, D4 > 1 m and D5 < 1 m or
(1 distance under D reliable)

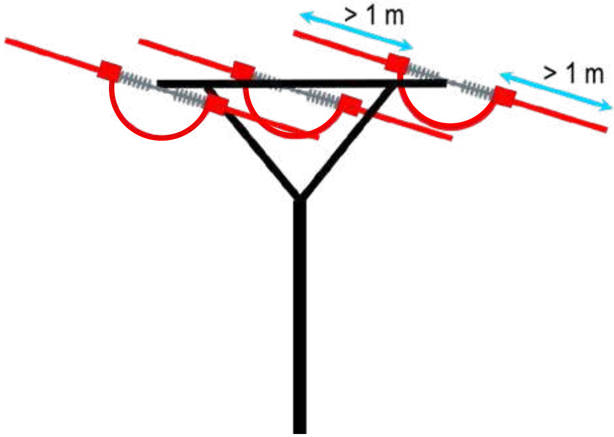
D2 > 1 m, D4 > 1 m and D5 > 1 m

Risk

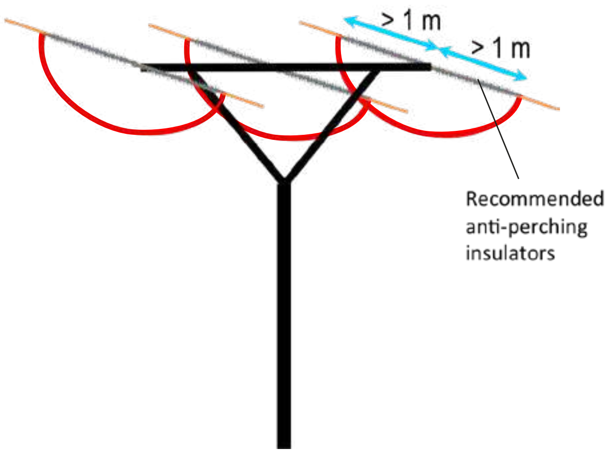


Corrective measures

Non-structural



Structural



C4

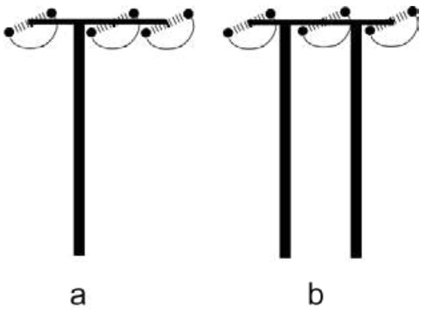
ANCHOR TOWERS OR POLES WITH JUMPERS BELOW INSULATORS IN A HORIZONTAL CONFIGURATION

Description

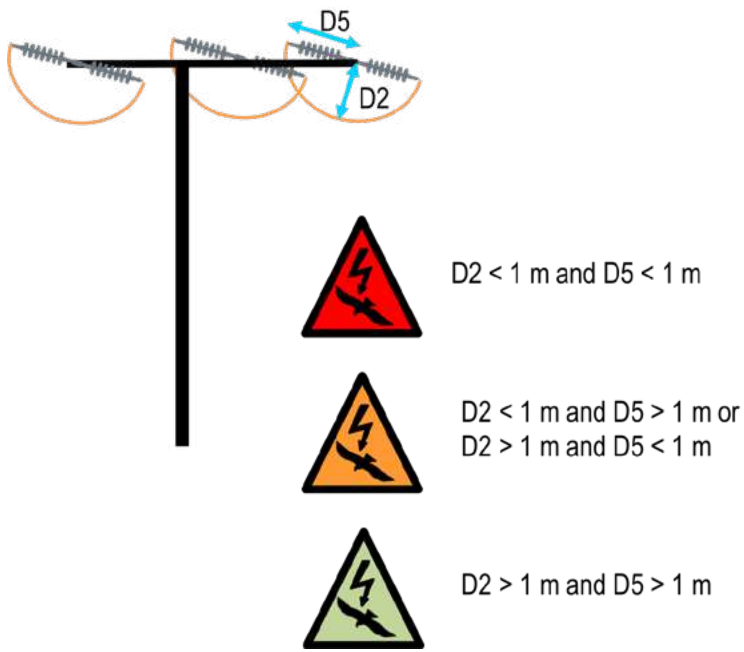
The three phases are held on the same horizontal plane, on a horizontal crossarm. The crossarm sometimes rests on more than one pole, in which case it is referred to as an 'H' pole configuration or H-frame.

Variations

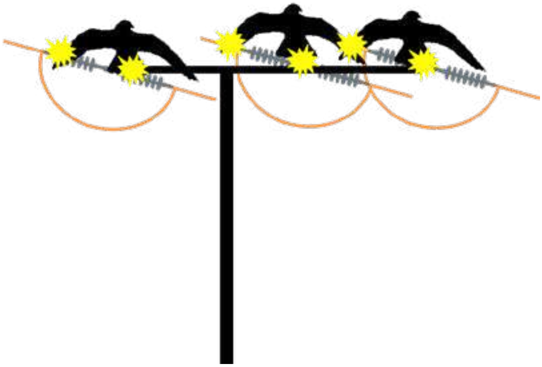
a) simple (one pole); b) ´H´ pole configuration (more than one pole)



Danger level

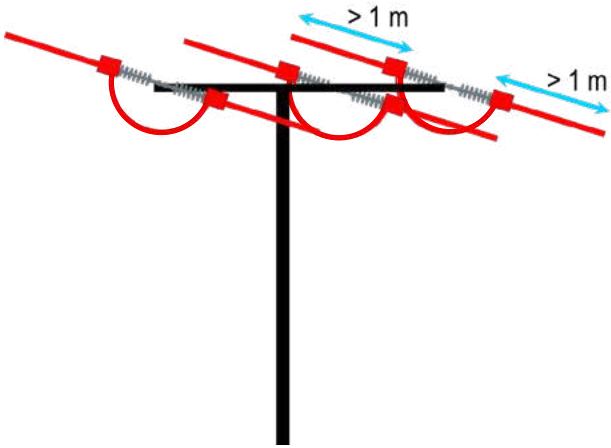


Risk

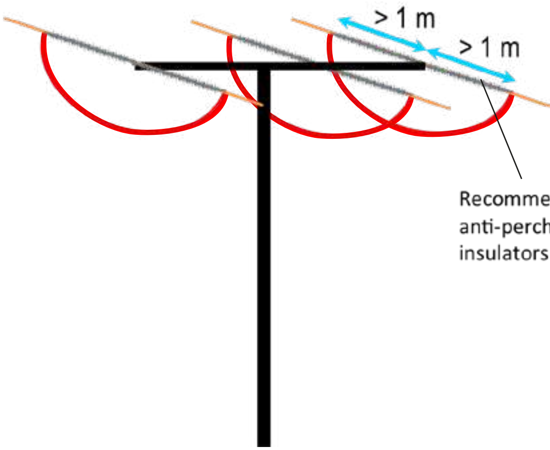


Corrective measures

Non-structural



Structural



D1

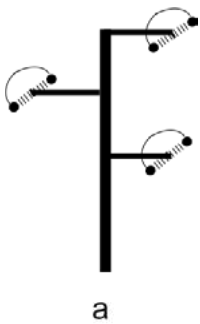
ANCHOR TOWERS OR POLES WITH JUMPERS ABOVE INSULATORS IN A STAGGERED CONFIGURATION

Description

The phases are held in two vertical planes, alternating between them on three horizontal levels, or with one phase on an upper level and two on a lower level.

Variations

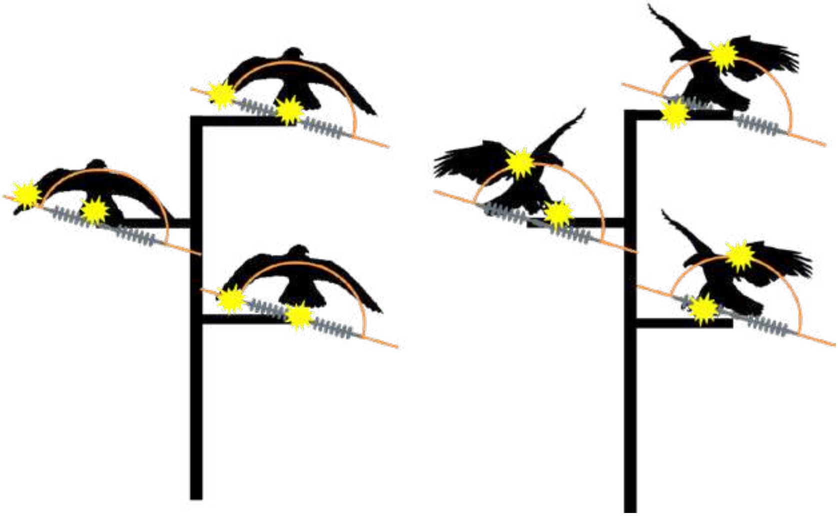
a) simple



Danger level

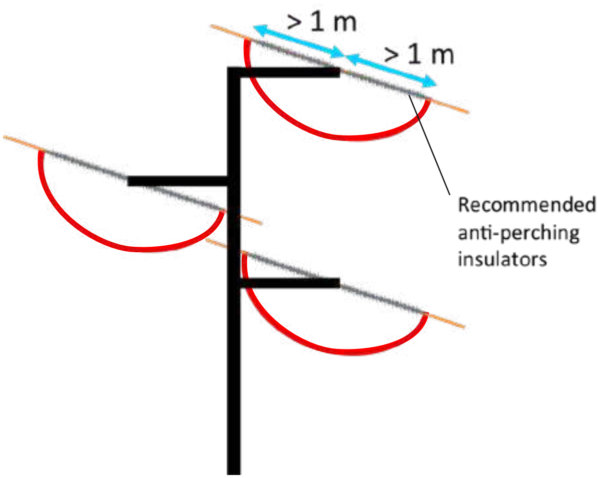
Very dangerous in all circumstances

Risk



Corrective measures

Structural



D2

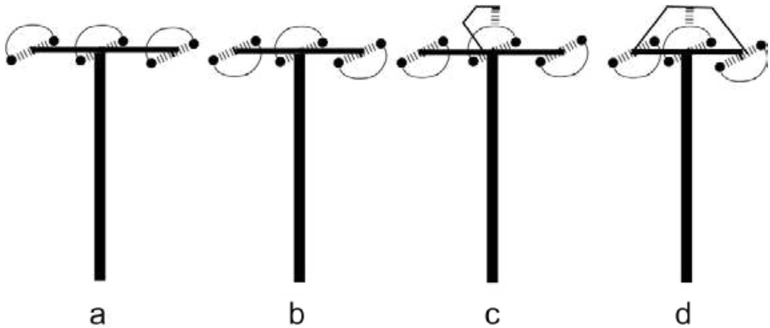
ANCHOR TOWERS OR POLES WITH JUMPERS ABOVE INSULATORS IN A HORIZONTAL CONFIGURATION

Description

The three phases are held on the same horizontal plane, on a horizontal crossarm, with jumpers above at least one of the anchor insulator strings.

Variations

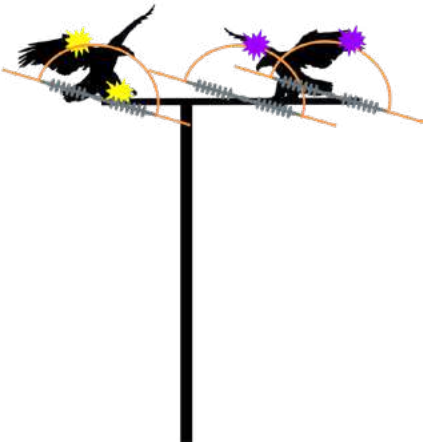
a) all three jumpers above; b) central jumper above and lateral jumpers below; c) central jumper suspended above from a rod; d) central jumper suspended above from an arch.



Danger level

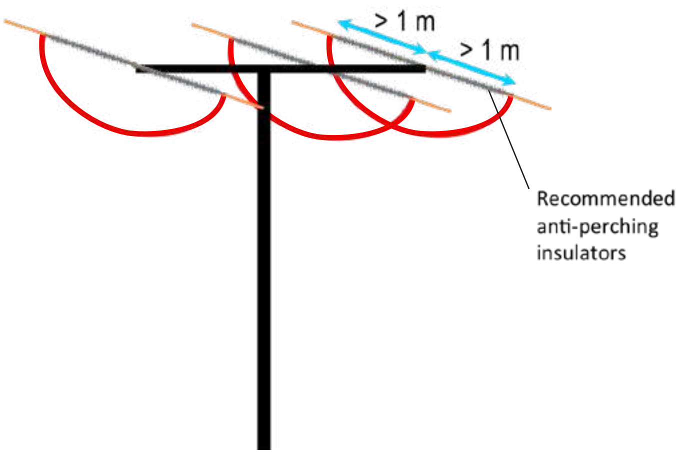
Very dangerous in all circumstances

Risk



Corrective measures

Structural



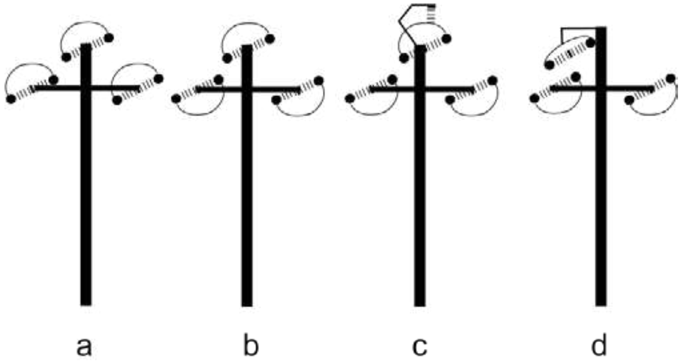
D3 ANCHOR TOWERS OR POLES WITH JUMPERS ABOVE INSULATORS IN A HORIZONTAL CONFIGURATION

Description

The phases are held on two horizontal planes, with the central phase higher than the lateral phases, with jumpers above at least the central anchor insulator string; the assembly is cross-shaped.

Variations

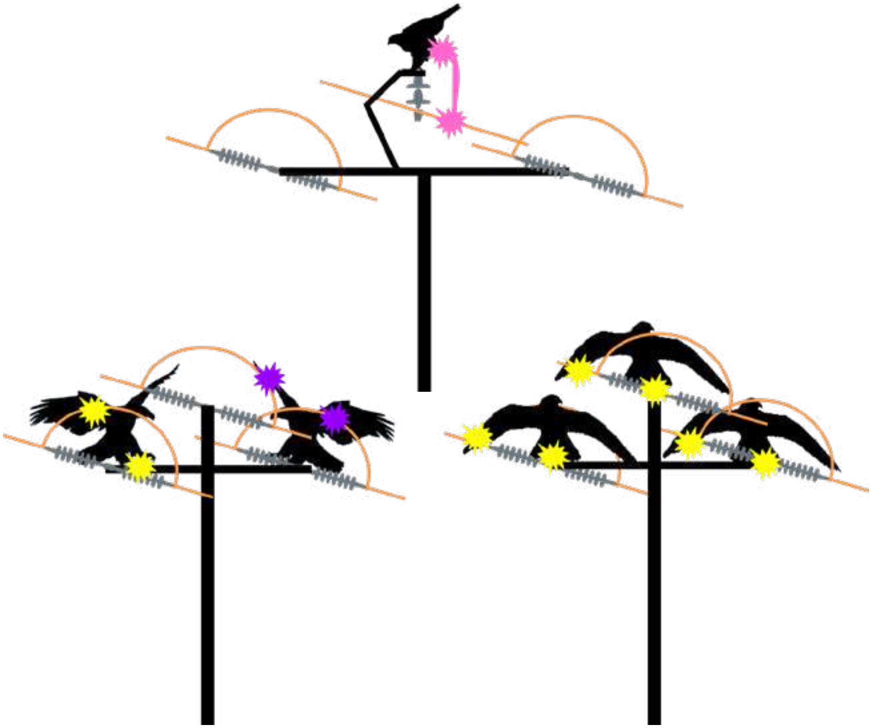
a) all three jumpers above; b) central jumper above and lateral jumpers below; c) central jumper above suspended vertically; d) central jumper above suspended laterally.



Danger level

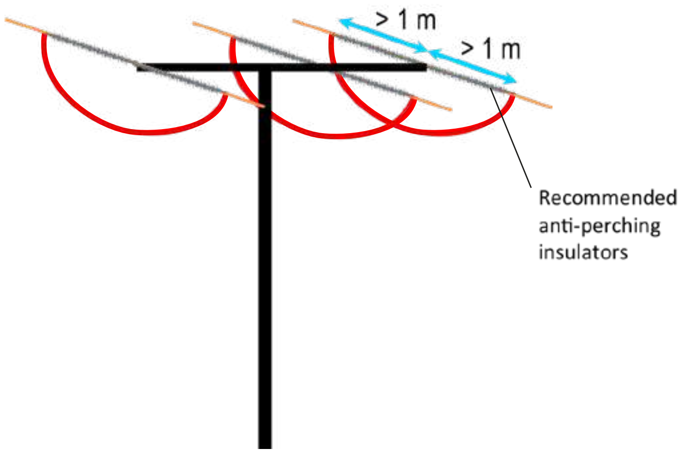
Very dangerous in all circumstances

Risk



Corrective measures

Structural



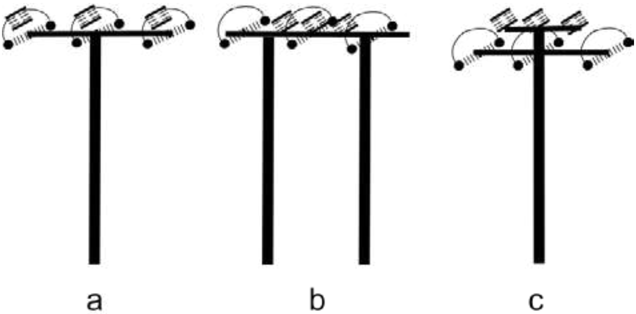
E1 SWITCHING SUPPORTS WITH DISCONNECTORS OR FUSES ABOVE, WITHOUT ANY OTHER DEVICES

Description

Special supports in variable configurations, generally horizontal; they have single-pole or three-pole disconnectors or cut-out fuses, above the crossarm, without any other elements.

Variations

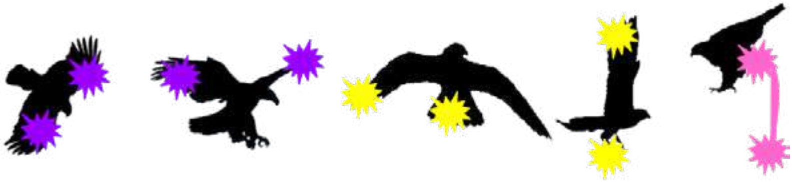
a) simple horizontal; b) ´H´ pole configuration; c) on an additional arm at the top of the pole



Danger level

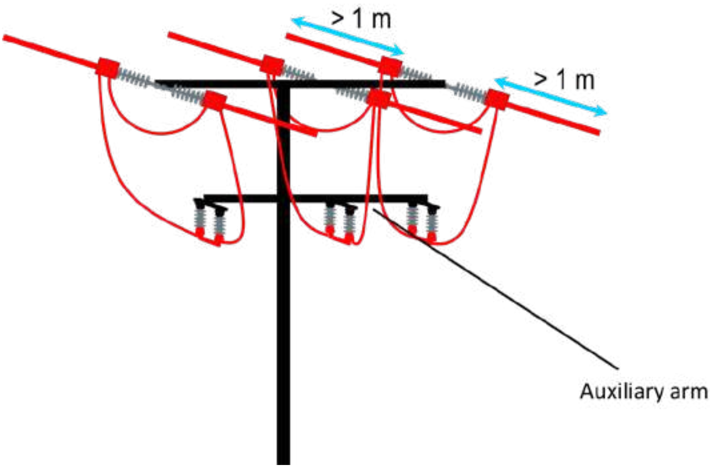
Very dangerous in all circumstances

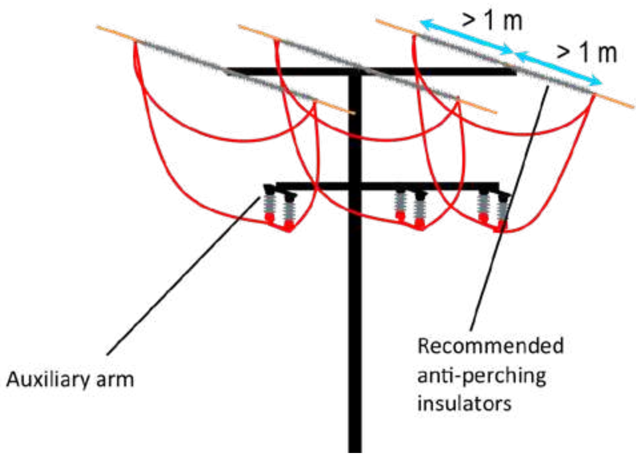
Risk



Corrective measures

The most advisable measure is a **structural change** to a horizontal anchor support with large insulators and disconnectors or fuses mounted on a lower auxiliary arm, protected with preformed insulators and covered wires for jumpers and connections. If the existing structure is retained, all disconnectors or fuses, jumpers and connections must be protected.





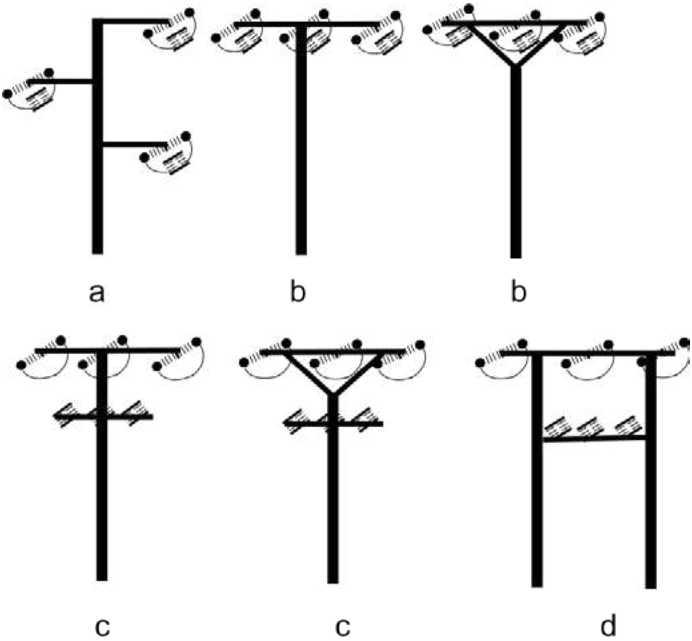
E2 SWITCHING SUPPORTS WITH DISCONNECTORS OR FUSES BELOW, WITHOUT ANY OTHER DEVICES

Description

Special supports in variable configurations, generally in a staggered, horizontal or vault arrangement; they have disconnectors or cut-out fuses suspended from the crossarm or on a lower arm, without any other elements.

Variations

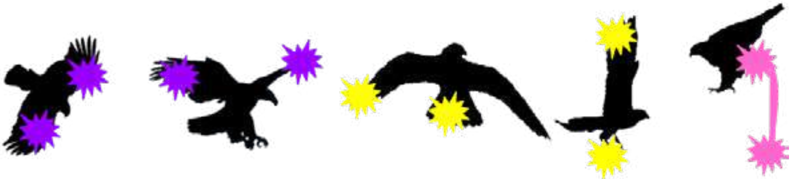
a) at different levels (staggered, etc.); b) at the same level, different assemblies (horizontal, vault, etc.); c) on a lower additional arm (horizontal, vault, etc.); d) on a lower crossbar in a horizontal ´H´ pole configuration



Danger level

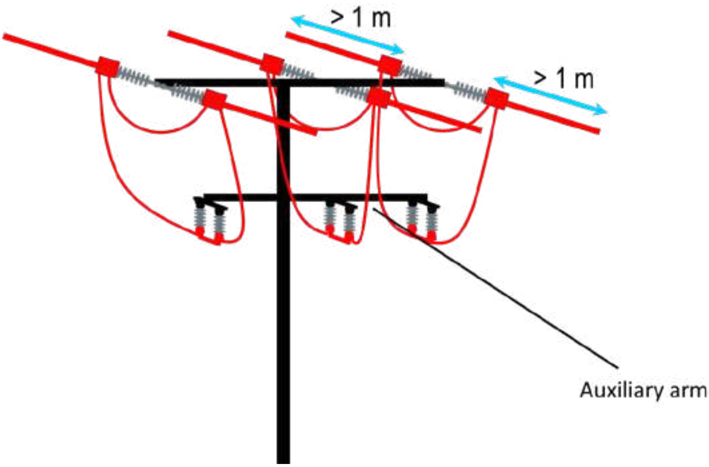
Very dangerous in all circumstances

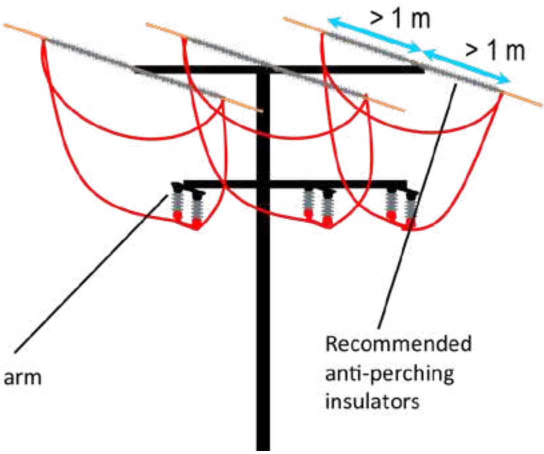
Risk



Corrective measures

The most advisable measure is a **structural change** to a horizontal anchor support with large insulators and disconnectors or fuses mounted on a lower auxiliary arm, protected with preformed insulators and covered wires for jumpers and connections. If the existing structure is retained, all disconnectors or fuses, jumpers and connections must be protected.





F

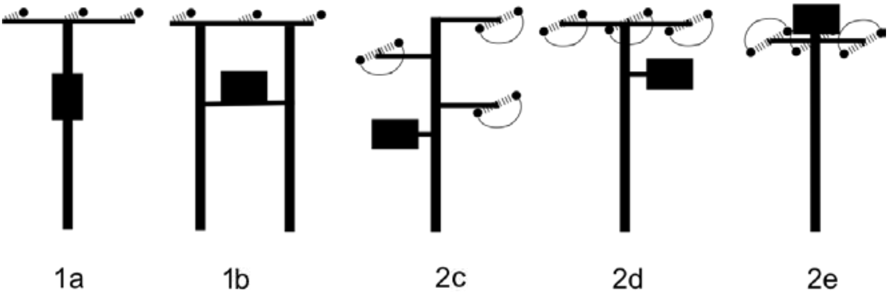
SPECIAL SUPPORTS WITH EXTERNAL TRANSFORMERS AND/OR OTHER DEVICES

Description

Special supports in variable configurations, generally anchor supports with a horizontal assembly (also with staggered or ´H´ pole configurations), with different types of elements installed. These can be an external transformer (usually at the end of a line), a switch-disconnector, a recloser circuit breaker, etc., complemented by control and/or protection devices (disconnectors, cut-out fuses, lightning arresters).

Variations

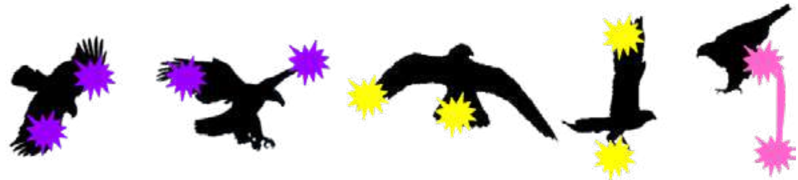
1: a) external transformer on the pole, horizontal configuration; b) transformer on the central crossbar, ´H´ pole configuration. 2: c) control device on a supplementary arm, in a staggered arrangement; d) control device on a lower arm, in a horizontal configuration; e) control device on the crossarm. Other arrangements are also possible.



Danger level

Very dangerous in all circumstances

Risk



Corrective measures

They depend on the configuration of the support. In general:
-Removal of jumpers above the main crossarm.
-Insulation of the dangerous points and jumpers and connectors between elements, preferably using preformed insulators for devices and covered wires for jumpers and connectors.
-Insulation to a safety distance of at least 1 m around places where birds may perch.

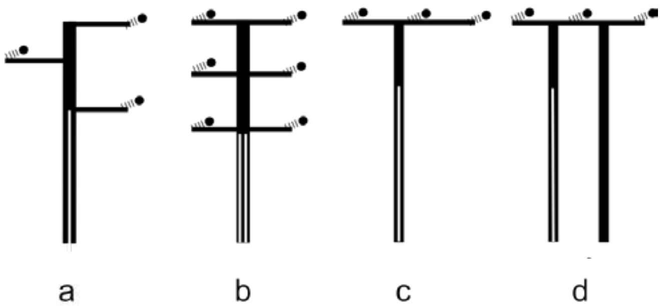
G TERMINATION SUPPORTS

Description

Special supports in variable configurations, generally anchor supports in a horizontal configuration (also staggered or vertical), where the overhead line is undergrounded. They usually also have control and/or protection elements (disconnectors, cut-out fuses, lightning arresters).

Variations

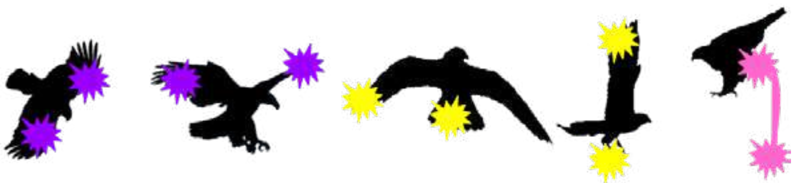
a) staggered arrangement; b) vertical arrangement with double circuit; c) horizontal arrangement; d) ´H´ pole configuration



Danger level

Very dangerous in all circumstances

Risk



Corrective measures

They depend on the configuration of the support. In general:
- Removal of jumpers above the main crossarm.
- Insulation of the dangerous points and jumpers and connectors between elements, preferably using preformed insulators for devices and covered wires for jumpers and connectors.
- Insulation to a safety distance of at least 1 m around places where birds may perch.

H BRANCH OR DERIVATION SUPPORTS

Description

Special supports in variable configurations, generally anchor-type with jumpers below, from which a branch line starts. Disconnectors or fuses are commonly installed between the main line and branch line, on a lower arm. The branch line is sometimes undergrounded.

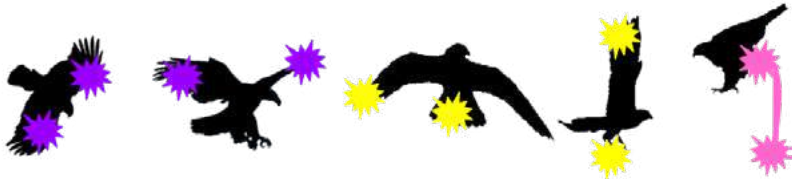
Variations

A large number of possible combinations and arrangements. The code for a branch combination begins with ´H-´ before the code for the other support type. For example, ´H-A3a´ would be a derivation that starts from a support pylon with suspension insulators in a simple vault configuration.

Danger level

Very dangerous in all circumstances

Risk



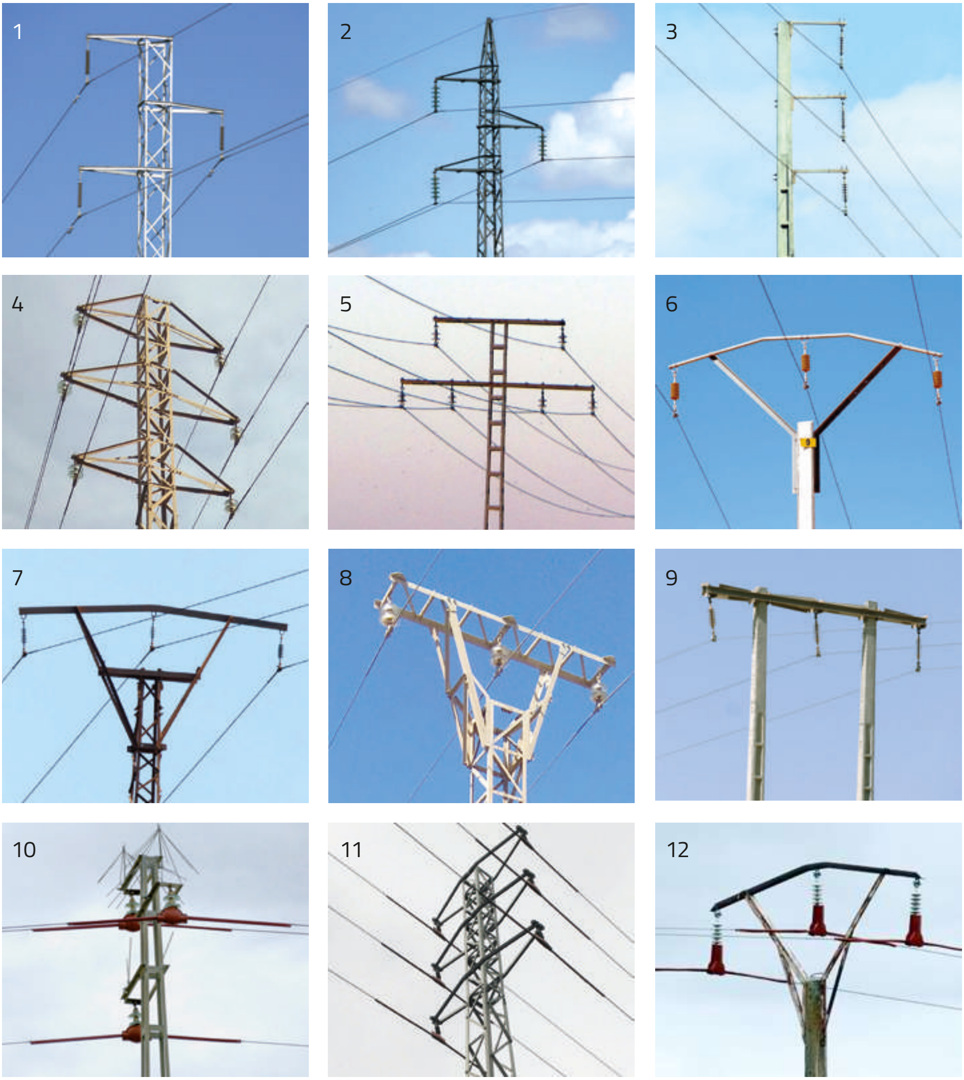
Corrective measures

They depend on the configuration of the support. In general:
-Removal of jumpers above the main crossarm.
-Insulation of the dangerous points and jumpers and connectors between elements, preferably using preformed insulators for devices and covered wires for jumpers and connectors.
-Insulation to a safety distance of at least 1 m around places where birds may perch.

III. PHOTO GALLERY: EXAMPLES OF SUPPORT TYPES AND ANTI-ELECTROCUTION MEASURES

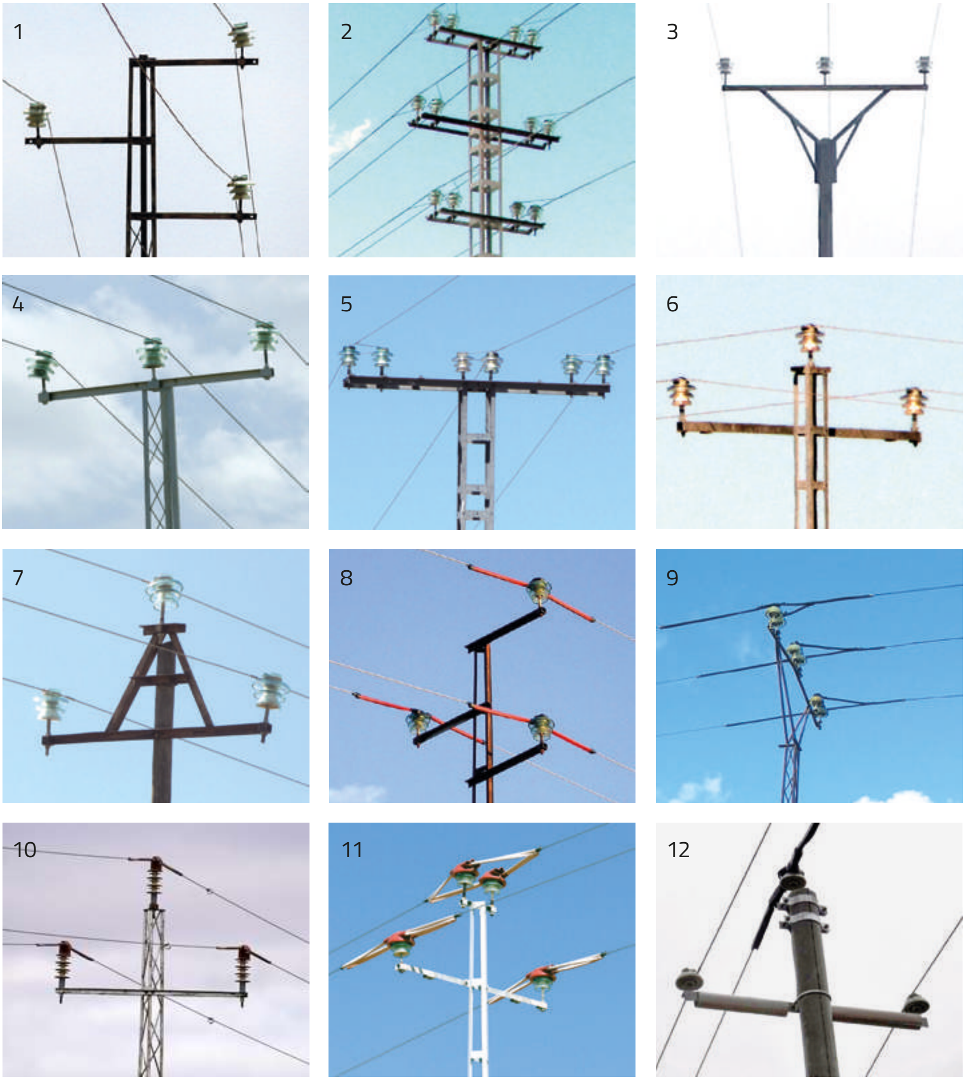
Note: the codes used in the photo captions correspond to the codes used in Section II of this Appendix A (e.g. A1b corresponds to factsheet A1, SUPPORTS WITH SUSPENSION INSULATORS IN A STAGGERED OR ALTERNATING CONFIGURATION, variation b) simple staggered).

A TANGENT SUPPORTS WITH SUSPENSION INSULATORS



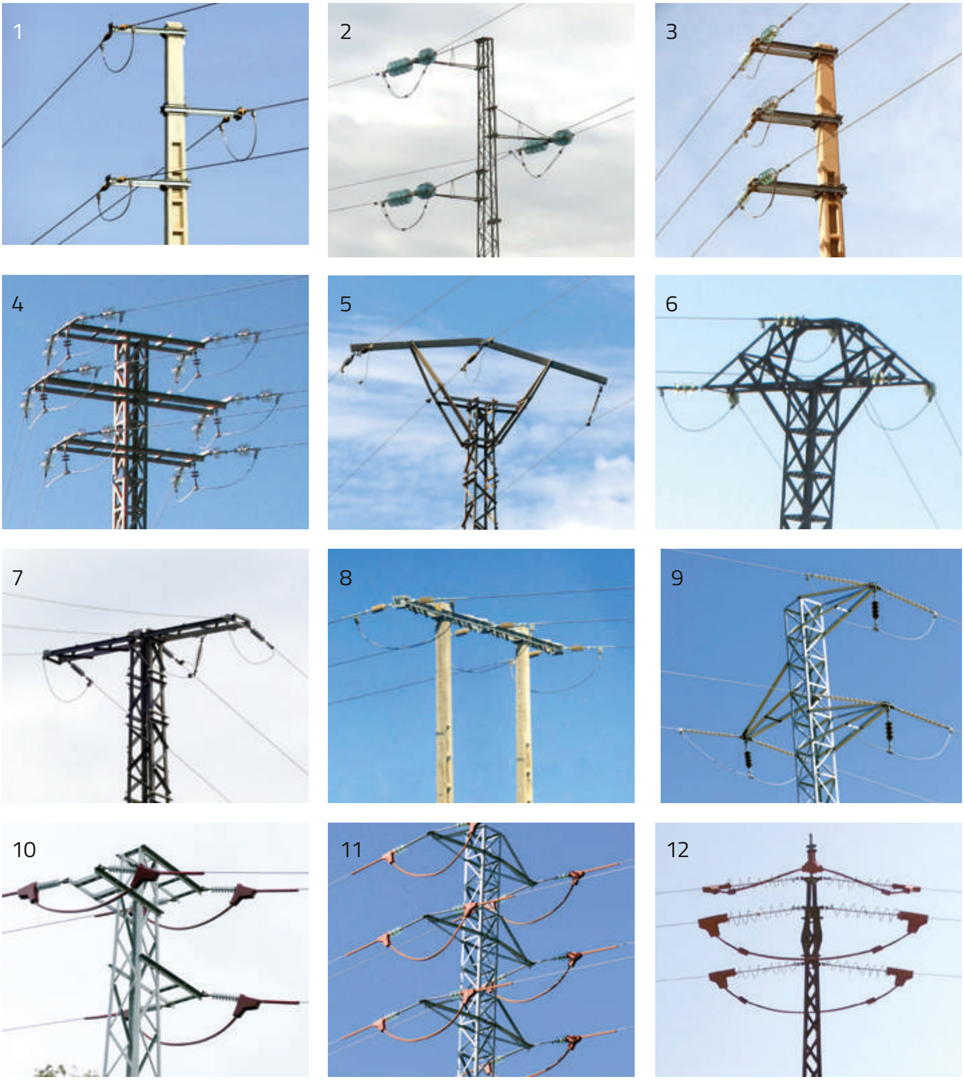
1: Simple staggered crossarm (A1b); 2: staggered crossarm with tie members (A1c); 3: vertical arrangement, single circuit (A2a); 4: vertical arrangement, double circuit on three levels with tie members (A2d); 5: vertical arrangement, double circuit with phases on two levels (A2e); 6: simple vault (A3a); 7: vault with central crossbar (A3b); 8: flat vault (A3c); 9: horizontal “H” pole assembly (A4b). 10, 11 and 12: examples of non-structural corrective measures, insulation of conductors, clamps and anti-perching devices (10). © Justo Martín except for GREFA (4, 8 and 11).

B TANGENT SUPPORTS WITH PIN INSULATORS



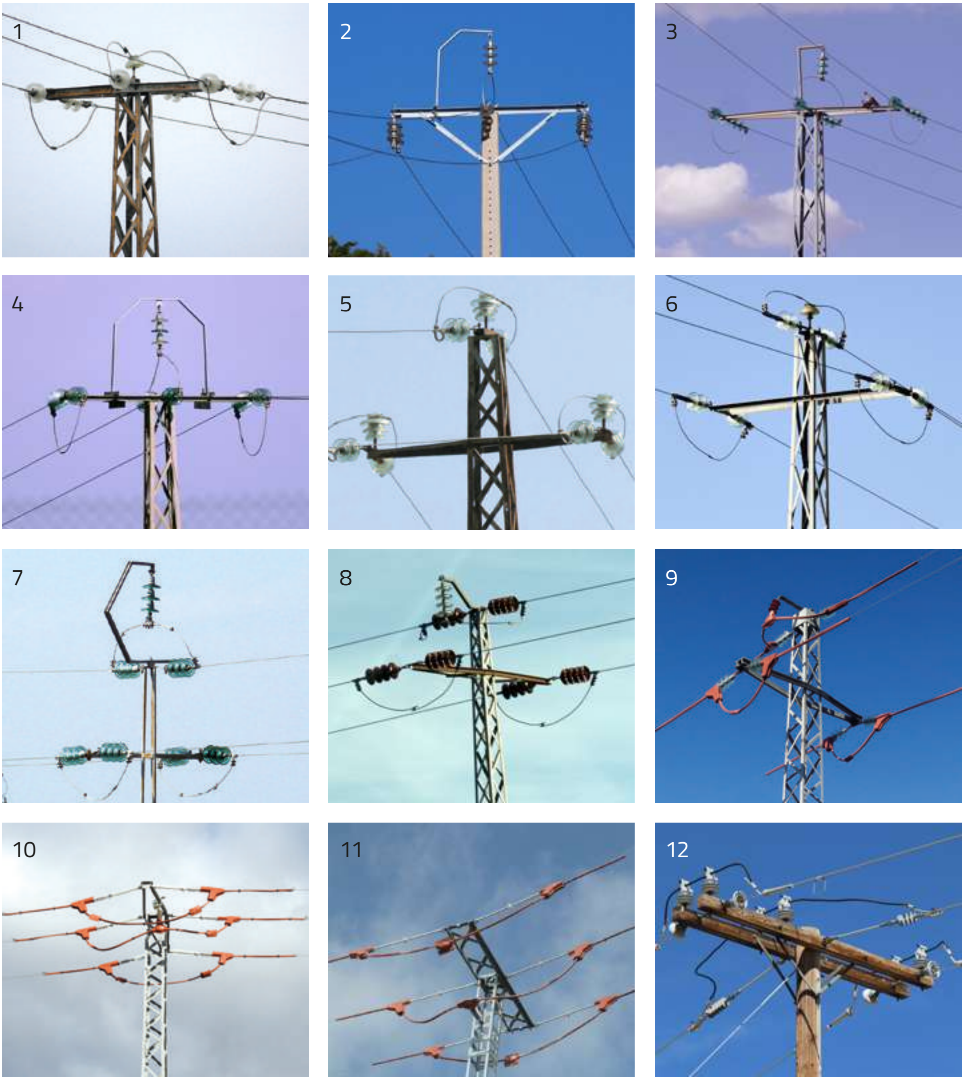
1: Staggered crossarm (B1b); 2: vertical arrangement, double circuit on three levels (B2b); 3: flat vault (B3b); 4 and 5: simple horizontal assembly (B4a); 6: simple cross-shaped assembly (B5a); 7: braced cross-shaped assembly (B5b). 8-12: examples of non-structural corrective measures, insulation of conductors (all), insulators (11) and crossarm (12). © Justo Martín (1-7, 9-11), J.R. Garrido (8) and Andrew Dixon (12)

C ANCHOR SUPPORTS WITH JUMPERS BELOW THE INSULATORS

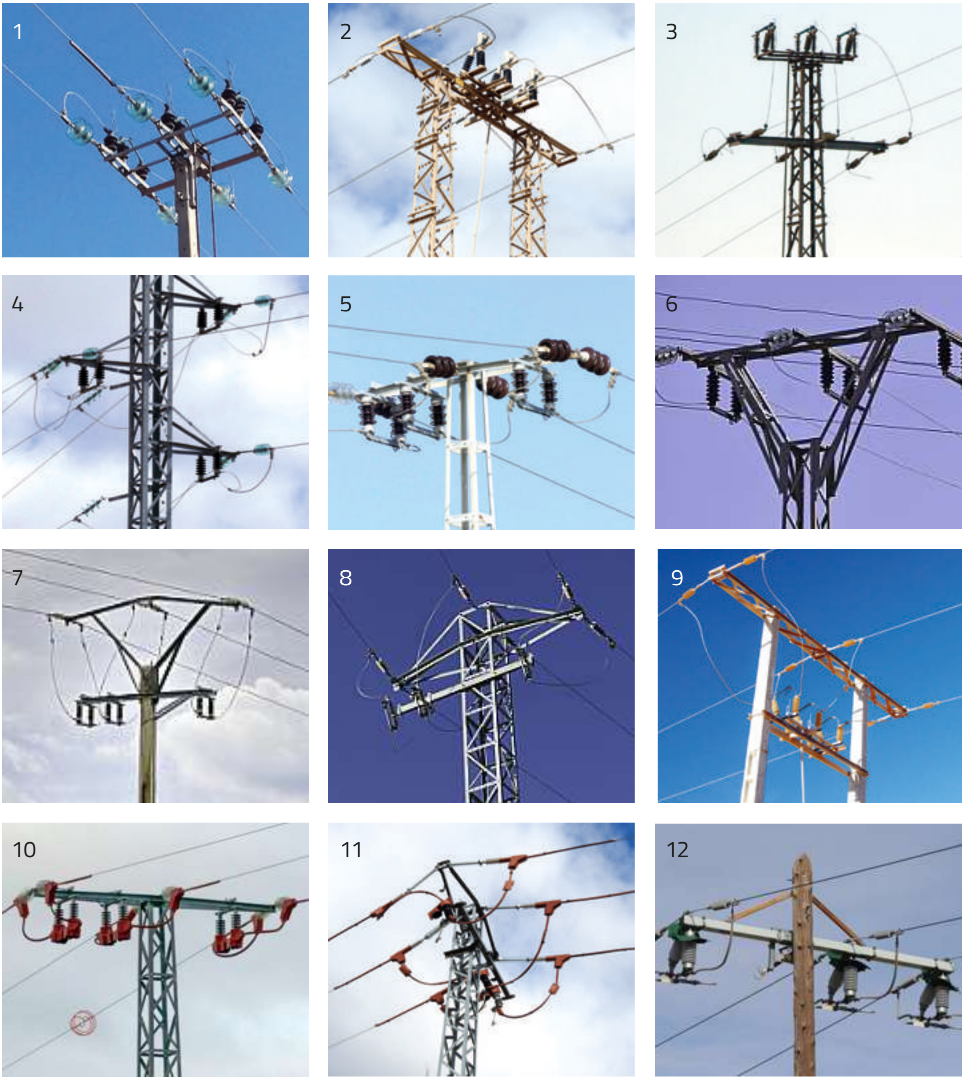


1: Simple staggered crossarm (C1a); 2: staggered crossarm with tie members (C1b); 3: vertical arrangement, single circuit (C2a); 4: vertical arrangement, double circuit on three levels (C2c); 5: vault with central crossbar (A3b); 6: lattice vault (C3d); 7: simple horizontal assembly (C4a); 8: horizontal "H" pole assembly (C4b). 9-12: examples of corrective measures; 9: insulators longer than 1 m; 10: insulation of jumpers, clamps and conductors; 11: insulation of jumpers, clamps and conductors and installation of metal extensions between crossarm and insulators; 12: insulators longer than 1 m with anti-perching system and insulation of clamps and jumpers. © Justo Martín except for GREFA (12).

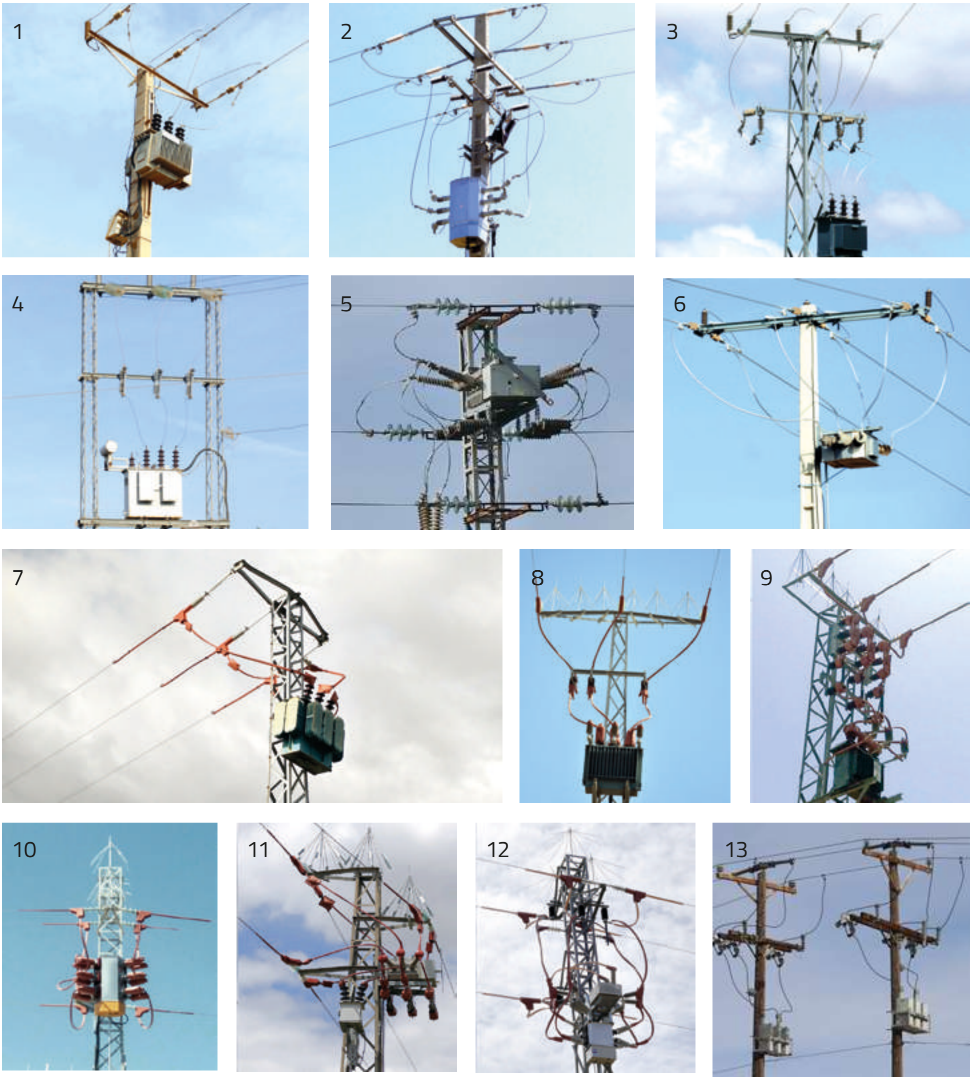
D ANCHOR SUPPORTS WITH JUMPERS ABOVE THE INSULATORS



1: Horizontal arrangement, central jumper above and lateral jumpers below (D2b); 2 and 3: horizontal arrangement, central jumper suspended above (D2c); 4: horizontal arrangement, central jumper suspended above in an arch (D2d); 5: cross-shaped arrangement, three jumpers above (D3a); 6: cross-shaped arrangement, central jumper above (D3b); 7: cross-shaped arrangement, central, jumper above suspended from rod (D3c); 8: cross-shaped arrangement, central jumper above suspended laterally (D3d). 9-12: examples of corrective measures; 9 and 10: insulation of conductors, clamps and jumpers; in 10, in addition, installation of metal extensions between crossarm and insulators; 11: insulators longer than 1 m and insulation of conductors, clamps and jumpers; 12: horizontal wooden crossarm, with fibreglass extensions on the central phase, and insulation of jumpers and clamps. © Justo Martín except for GREFA (9 and 10) and James Dwyer (12).



1: Disconnectors above, horizontal arrangement (E1a); 2: disconnectors above, horizontal “H” pole assembly (E1b); 3: disconnectors above, on auxiliary arm at the top (E1c); 4: disconnectors below, at different levels, staggered crossarm (E2a); 5: disconnectors below, at the same level, horizontal arrangement (E2b); 6: disconnectors below, at the same level, flat vault; (E2b); 7: disconnectors below, on a lower crossbar, vault; (E2b); 8: fuses below, on a lower crossbar, lattice vault (E2b); 9: disconnectors below, on a lower crossbar, horizontal “H” pole assembly (E2d); 10-11: examples of corrective measures; 10: insulation of jumpers, clamps, connectors, conductors and disconnectors; 11: insulation of jumpers, clamps, connectors, conductors and disconnectors and installation of metal anti-perching extensions between crossarm and insulators; 12: fibreglass crossarm, disconnectors below, covered jumpers and switch base isolating disks. © Justo Martín except for GREFA (1 and 11) and James Dwyer (12).



1, 2 and 3: Supports with external transformers in a horizontal assembly accompanied by switch devices and lightning arresters, at the end of the line (F1a); 4: external transformer ‘H’-pole assembly with fuses and lightning arresters above (F1b); 5: control device in a staggered assembly (F2c); 6: control device on a lateral branch, horizontal assembly (Fd); 7-12: examples of corrective measures, with insulation of jumpers, connectors, conductors, disconnectors and fuses; 7: installation of metal extensions; 8-12: with anti-perching devices on crossarm. 7-13: examples of corrective measures, with insulation of jumpers, clamps, connectors, conductors, disconnectors and fuses; 7: installation of metal extensions; 8-12: with anti-perching devices on crossarm; 13: conductor covers, jumper covers, arrester caps, cutout covers and bushing covers. © Justo Martín except for GREFA (7) Manuel Muñoz (8, 9 and 10) and James Dwyer (13).

1: Staggered assembly (Ga); 2: vertical arrangement, double circuit (Gb); 3, 4 and 5: horizontal assembly (Gc); 5 with control device (Gc); 6: 'H'-pole assembly (Gd). Support 1 has no control or protection devices; supports 2 and 4 carry disconnectors or fuses and lightning arresters; supports 3 and 6 only have lightning arresters; and support 5 has fuses and a control device. 7-12: Examples of corrective measures, with insulation of jumpers, clamps, connectors, conductors, disconnectors and fuses; 7, 8 and 11 with anti-perching devices on crossarm; 9 with metal extensions between insulators and crossarm; 10 with insulators and anti-perching devices. © Justo Martín except for GREFA (9 and 11) and J.R. Garrido (12).

1: Anchor support, staggered assembly (H-C1a); 2: anchor support, vertical arrangement, simple circuit (H-C2a); 3: anchor support, vertical arrangement, simple circuit with tie members (H-C2b); 4: anchor support, simple vault assembly (H-C3a); 5: suspension support, simple vault assembly (H-A3a); 6: anchor support, horizontal assembly (H-C4a); 7: termination support (H-Ga). Derivations 1 and 3 have fuses, 7 disconnectors, 2, 4 and 5 have no switching devices. 8-12: Examples of corrective measures, with insulation of jumpers, clamps, conductors, connectors, disconnectors, fuses and other dangerous points; 9 insulators with anti-perching devices; 12 anti-perching devices on crossarm and use of covered wires for connectors (in black). © Justo Martín except for Daniel Burón (2) and GREFA (9 and 10).

General recommendations for newly built lines

a) Supporting towers and poles

➜ In general, supports with pin insulators must not be installed; they are very dangerous in most cases.

➜ If it is only possible to install pin insulators, the crossarm must be made of wood or concrete in a cross-shaped configuration, and the distance between conductors must be as large as possible, ideally 1.5 m or more, with the ground wire covered for at least the first metre below the crossarm. Smaller distances, even in horizontal configurations, can be safe if the central pin and conductor are covered.

➜ The length of the insulator strings installed must provide the recommended safety distances; if they do not, then the longest possible insulators should be installed according to the crossarm design and the support materials.

➜ Horizontal and Canadian-type (alternating configuration with diagonal arms) assemblies are the safest configurations if the safety distances cannot be achieved.

b) Anchor towers and poles

➜ The length of the insulator strings installed must provide the recommended safety distances; if they do not, then the longest possible insulators should be installed according to the crossarm design and the support materials.

➜ Do not install jumpers above the crossarm or the arms, and avoid configurations that make that arrangement necessary. Anchor clamps and especially jumpers should be insulated with preformed elements.

c) Special supports

➜ In order to avoid live elements above the crossarm, it is recommended that a lower arm be installed to carry the additional devices – surge arresters and junction boxes on terminal supports; disconnectors or fuses on supports with transformers; and surge arresters on the transformers themselves.

➜ All connections between live components of the various devices (transformers, disconnectors, fuses, lightning arresters, underground conversions, junction boxes, etc.) must be insulated:

• All jumpers or connections with a bare wire between live components and their connection terminal;

• Connections from insulators to disconnectors or fuses and lightning arresters;
• Connections to transformer terminals;
• Terminals of disconnectors, fuses, lightning arresters and transformers (to be fitted with preformed parts made of insulating material);
• Jumpers between anchor clamps and the other attachment clamps on branch crossarms.

➜ Insulation of connectors on such supports should be achieved preferably by using insulated wires or by covering them with effective preformed insulators made of rubber, solid silicone or another similar material; the use of insulating tapes is not recommended because they have a far shorter lifespan.

d) In general

➜ Metal anti-perching or anti-nesting systems should be avoided, particularly if they are upright and not mobile, because they can injure birds with their projecting parts and sharp edges.

➜ If anti-perching or anti-nesting systems are used, they must be installed in conjunction with insulation systems, especially if birds have other places to perch that may be dangerous.

General recommendations for the installation of protective insulation to avoid electrocution

➜ In general, the insulation should be installed using preformed parts, coatings and sheaths made to fit each element to be insulated and fixed in place; they should fit together and not leave spaces or uncovered live parts.

➜ Similarly, it is generally not recommended to use insulating tape to join insulating parts covering devices or live components (e.g. connections between jumpers and devices such as disconnectors or lighting arresters). The use of tape is only justified in cases where there are no preformed parts for a particular device or point, and only tape that provides maximum support and optimal longevity should be used.

➜ During the installation of protective sheaths on the conductors, the sheaths must be fixed in such a way that they do not separate and slip down the curve of the conductor towards the middle of the span, leaving live parts uncovered. It is preferable to use fixing clamps to keep them attached to the insulator string. The fitting of rings (preformed rods, or metal flanges) is a less efficient solution, because over time they can become unscrewed due to vibration, and even damage the end of the sheath. It is not recommended to use insulating tape for this purpose, because it is the least effective solution in the long term.

➜ During the insulation of conductors and clamps, both anchor and suspension, the insulating sheath covering the cable must extend 3 or 4 cm inside the preformed insulating device on the clamp once closed; as in the previous case, must be securely fixed in place.

➜ On anchor supports, make the connections between the conductors constituting the jumper at the lowest point using wedge pressure clamps (AMPACT or similar), and insulating them as well as the conductors with a preformed part that fits their shape and size.

➜ When fitting the sheath on the conductors, ensure there is no gap between the insulated end of the jumper and the sheath, to make sure no metal element or live part of the conductor remains uncovered.

➜ When using preformed parts, it is important to avoid mixing elements from different manufacturers, since they may not match and thereby lead to faulty assemblies that would be less efficient. Similarly, it is advisable to check that the parts cover the live elements effectively and, if any area is not covered, to ensure it is insulated by applying a double layer of insulating tape.

➜ In the case of supports with a vault configuration with suspension insulators and a risk of electrocution through birds defecating, it is essential to insulate not only the central conductor but also the lateral conductors 1 m to each side of the connection with the insulator string; if it is an anchor support, all three jumpers should be insulated.

➜ On branch supports, pay attention to the layout of the cables in relation to the stayed areas, in particular the secondary crossarm in relation to the conductors on the main crossarm. Even if the minimum required insulation has been achieved, there could be dangerous sections on the lower arm where birds might perch. It is advisable to take safety distances into account with regard to the horizontal and vertical points and to insulate the required length.

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V. RECOMMENDATIONS FOR ANTI-COLLISION MEASURES

Priority power lines for the installation of anti-collision measures

Although a specific study of the collision risk should be carried out for each power line, in general the installation of anti-collision measures should be prioritised in the following cases:

➜ Power lines **located less than 1 km** from wetlands, urban solid waste landfill sites, sites where dead animals and their remains are stored, or crops, since these areas attract large numbers of birds that go there to feed each day;

➜ Power lines **within a 1.5 km radius of nesting platforms** used by priority species (e.g. vultures, eagles) in particular in mountainous or wooded regions or near rocky ridges;

➜ Power lines **within a 1.5 km radius of nesting sites** of colonial birds such as herons, storks and other waterbirds and certain raptors;

➜ Power lines **within a 1.5 km radius of nest boxes used by gregarious birds** such as herons, storks, cranes, colonial raptors, etc;

➜ Power lines on **which threatened or gregarious species build their nests** (certain raptors and storks, for example);

➜ Power lines located **in areas with a large number of breeding or wintering steppe birds** (e.g. bustards, houbaras), as well as in areas that these species use as corridors;

➜ Power lines **crossing watercourses** that act as corridors for seabirds and migratory birds;

➜ Power lines that cross bird flyways in **migratory corridors or bottlenecks**, or in other situations in which the topography gives rise to risky situations;

➜ Power lines within a 1 km radius of locations where bird collisions have already been reported.

These lines should also be prioritised in the search for mortality black spots.

Recommendations for the installation of visual markers

➜ Visual markers should be placed on ground wires; if the power line does not have ground wires, these devices should be placed on the conductors.

➜ On the ground wires, bird protection devices should be fitted at 5 m intervals if there is only one ground wire, or alternating at 10 m intervals if there are two parallel ground wires.

➜ Conductors should be marked so as to generate a visual effect equivalent to one marker every 5 m. That is why the markers are fitted in an alternating pattern on the two conductors and with a maximum distance of 10 m between adjacent markers on the same conductor.

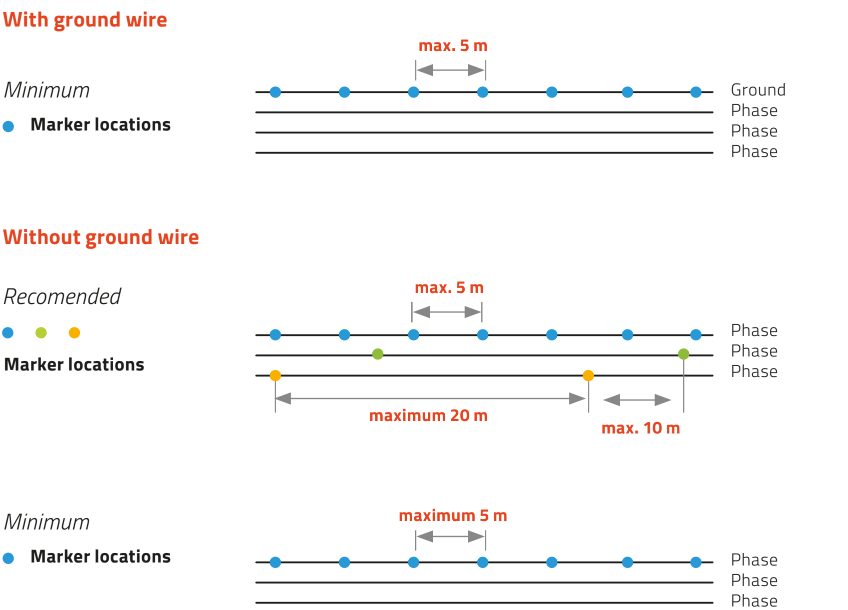

Figure A13. Recommended spacing between markers, taking into account the presence of ground wires. © Endesa

Appendix B

Power lines and forest wildlife: prevention and mitigation of impacts in forest environments

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Electrical installations that run through wooded areas present a special problem. Forests all over the world, especially in tropical areas, are home to various species of climbing vertebrates, especially mammals (monkeys, squirrels, etc.), but also some reptiles and even amphibians. These animals regard power lines and supply installations as elements of the ecosystem on which they can move, take refuge or search for food. Therefore, they climb up the poles and try to move along the conductors or enter substations, risking electrocution. Incidents can lead to major power cuts, especially if they take place in transmission or distribution substations, affecting regions or even entire countries.

Prevention of wildlife electrocution in forested habitats begins with the proper planning and design of electric power lines. Critical considerations include the analysis of the species composition and behaviour of animals that live around the project area and in nearby protected areas, ecological corridors and environmentally fragile habitats. If necessary, infrastructure designs must be modified to account for the environmental fragility of these habitats. Adequate maintenance of the surrounding vegetation and forest cover is the most effective mitigation measure to prevent wildlife electrocution. Technically designed pruning management schemes require knowledge of vegetation growth rates and should be integrated into pruning schedules to successfully keep vegetation cover at a suitable level around power lines. Additionally, stakeholder participation is crucial for successful implementation of prevention and mitigation measures, particularly when a lack of power failures prevents companies from detecting when and where fauna is electrocuted. Given the proper means of communication, people can report cases of wildlife electrocution or report areas with a high electrocution risk.

Measures to prevent these incidents also include preventing animals from accessing electrical installations, preventing them from climbing the supports, and installing bridges and other means that allow animals to get around them. These measures must be supplemented with anti-electrocution and anti-collision measures designed for birds already discussed in previous chapters of this manual. Prevention and mitigation measures must be monitored and carefully analysed. This information is critical to improve the conservation of wildlife and to reduce the maintenance costs of electricity distribution infrastructure.

This Appendix presents some general recommendations for the installation and design of substations and transformer stations in these environments, as well as examples of preventative measures to avoid the impacts of power lines on forest wildlife.

I. PREVENTATIVE MEASURES FOR MAKING SUBSTATIONS AND TRANSFORMER STATIONS SAFE

a) When a substation has to be built, the selected area must have enough space, so there must be no trees within at least 30 metres of the perimeter fence.

b) Switchgear and transformer stations must be designed with a perimeter fence made of electrowelded mesh barrier, or similar material, with a mesh size no greater than 2.5 cm (one inch), with a metal sheet about 100 cm high at the bottom. At the top, a metal sheet with a smooth finish must be placed at an angle towards the outside (like a visor), to prevent animals from entering easily. An electric fence may be placed on top (Figure B1).

c) If a concrete perimeter wall is planned, it must have a fine plaster finish on the outside, up to a height of at least 100 cm from the bottom, with columns designed in such a way that they are not external; to prevent wildlife from entering the substation by climbing the walls or columns (Figures B2 and B3).

d) The substation gates must be designed in such a way that wildlife cannot access the substation. Gaps between closing parts must be less than 2.5 cm (one inch). One option is to install a sliding door or gate.

e) Barrier devices (preferably rotating) must be installed on overhead conductors that enter the substation.

f) The vegetation around the substation should be kept under control as part of routine maintenance, so as not to allow the growth of shrubs or trees that might facilitate wildlife access.

g) If wildlife access cannot be fully controlled, insulating and barrier devices should be installed on the most sensitive parts of the electrical system.

Figures B1-B3. Examples of perimeter walls and fences ideal for switching stations and substations. © CNFL

II. PREVENTATIVE MEASURES FOR MAKING SUPPORTS AND WIRES SAFE

The chapters on electrocution and collision have shown a variety of measures that can be applied in forest environments. The aim of this section of the Appendix is to cover in more detail some of the measures aimed at non-flying arboreal fauna.

Table B-1 shows the most commonly used preventative measures in forest environments. The fact sheets that follow provide greater detail on those measures that have not been covered in previous sections.

Table B-1. Measures to prevent wildlife accidents on power lines in forest environments.

TYPE	MEASURE
Barrier-type protection devices (see below)	Anti-climbing devices Rotating barrier devices Barrier discs and electrostatic protectors
Accompanying measures (see below)	Artificial aerial bridges
Anti-collision devices (see Chapter 4 and Appendix A)	PVC spirals Neoprene or plastic strips Reflective devices
Insulating materials (see Chapter 5 and Appendix A)	Preformed insulators Insulated conductors and wires
Deterrent devices (see Chapter 5 and Appendix A)	Plastic triangles Non-metal spikes (various designs)

Source: compiled by the authors

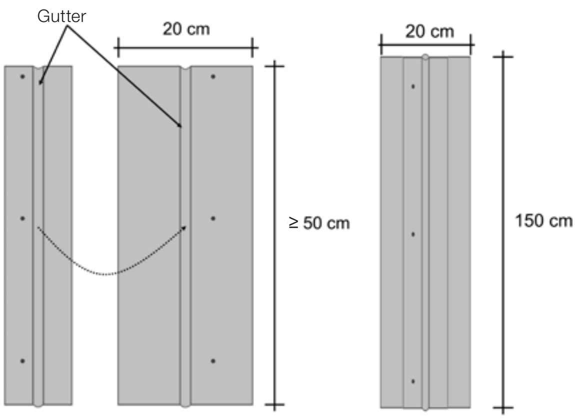
A . Barrier-type protection devices

A1. ANTI-CLIMBING DEVICES

➜ Description

These rectangular stainless-steel sheets (also called pallet-type anti-climbing devices) are fitted on the guys of the poles that support overhead lines. The devices are intended to prevent animals from climbing up the guys to the power lines.

The minimum dimensions are 20 cm x 50 cm, although for animals such as squirrels or monkeys the length must be at least 1.5 m. The device is made up of two pieces with a gutter in the middle that wraps around the cable and allows the device to rotate, supported by a metal ring that holds it in place. The two pieces are assembled separately and riveted together.



Figures B4 and B5. (Top). Examples of these types of devices on guys. © Luis R. Lara/CNFL

Figure B6. (Left). Basic design and minimum size (left). Recommended size for squirrels and monkeys (right). © Luis R. Lara/CNFL

➜ Placement

The device must be placed at a height of more than three metres, with all devices at the same height to prevent the animal from zig-zagging.

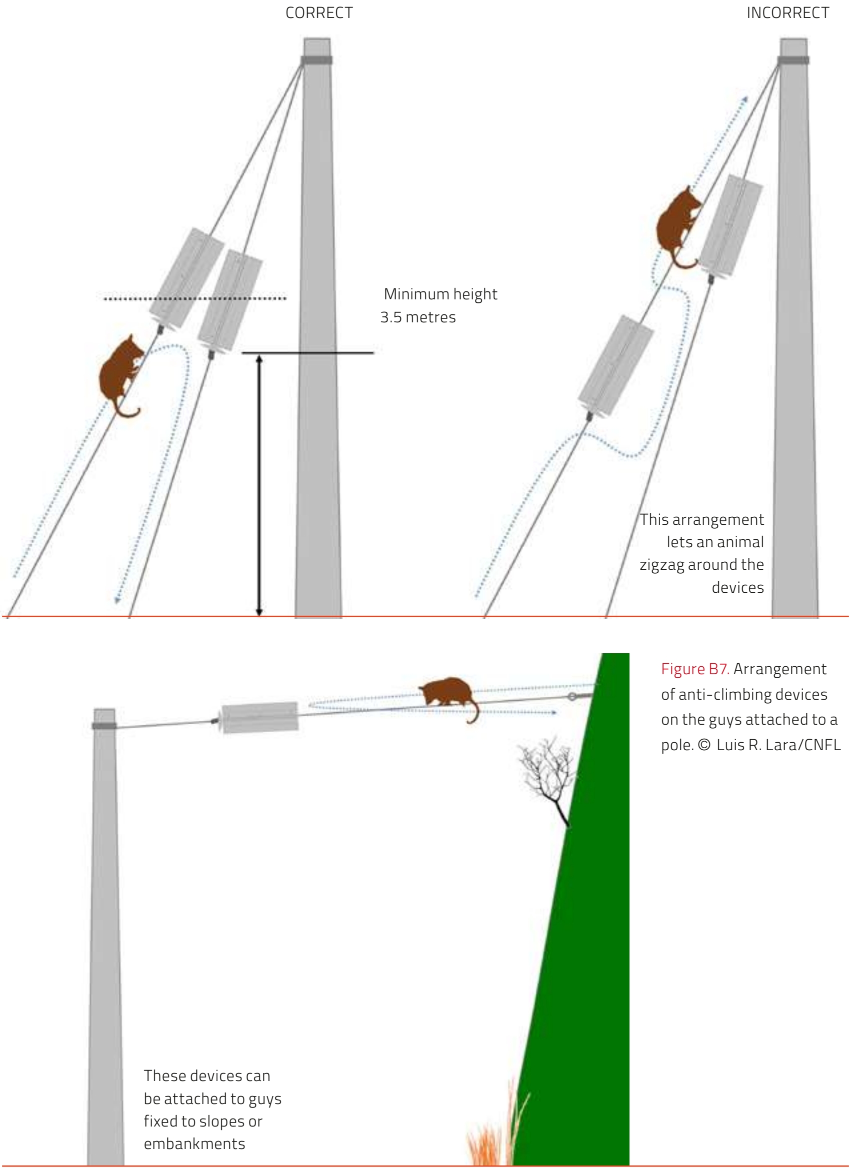


Figure B7. Arrangement of anti-climbing devices on the guys attached to a pole. © Luis R. Lara/CNFL

A2. ROTATING BARRIER DEVICES (LINE ROLLERS)

➜ Description

These rotating devices are fitted on conductor cables, guys or electrical connections. They prevent fauna from reaching the electric lines, since their revolving design and spikes (in some models) prevent animals from holding on to them firmly.

They can also be used to prevent fauna from entering substations, as they can be placed on energy output or input cables that feed the substation or the cables of the lighting system.

They must be made of a polymer that allows them to be installed with the lines energised, if necessary, and they must be longer than 1.5 m to prevent some animals from jumping over them.

Figure B8. Rotating barrier with spikes.
© Raychem WLG

➜ Placement

They are placed on electrical lines, guys, electrical connections, electrical lighting cables, communication cables, etc. These devices must be fitted on the line at a maximum distance of 1 m from the pole to prevent the animal from coming into contact with the electrical line.

Figure B9. Arrangement of spikeless rotating barriers on conductors.
© Luis Diego Carballo (Electrificadora ESPH)

A3. BARRIER DISCS AND ELECTROSTATIC PROTECTORS

➜ Description

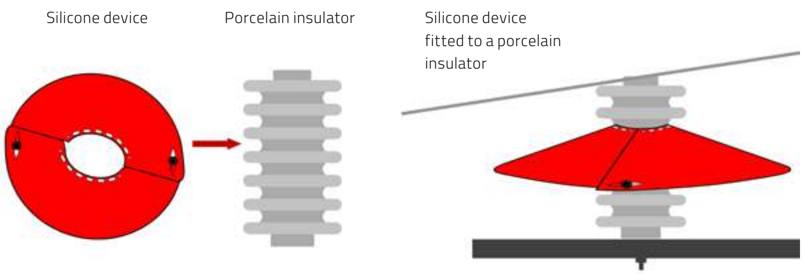
They act as a physical barrier that prevent animals from climbing or moving along the insulator strings and reaching the power line.

There are two types, conical and disc-shaped. The former are made of smooth silicone material and are arranged horizontally. This design prevents birds from perching and/or building their nests on the device and also protects the insulator from bird excrement, thus favouring the long-term functionality of the insulator.

Rigid discs, made of a weather-resistant polymer, can be installed either horizontally or vertically at points where animals need to be excluded.

Some models are made of polymers that can be electrostatically charged; they pick up a charge from the energised bushing that the product is mounted on and deliver a non-lethal electrostatic discharge when touched by an animal. The discharge is comparable to the electric shock generated by electrified livestock fences.

The normal diameter is 45–65 cm, although this may vary depending on where it is to be installed.



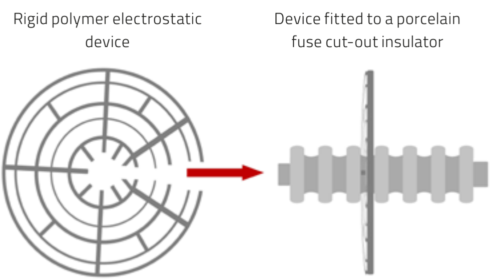


Figure B10. (Top) Silicone conical device and arrangement on a suspension insulator. © Luis R. Lara/CNFL

Figure B11. (Left). Polymer disc and vertical arrangement on a porcelain insulator. © Luis R. Lara/CNFL

➜ Placement

Rigid discs are installed in both vertical and horizontal arrangements on suspension and strain insulator strings. They can also be used between elements in substations where animals need to be excluded. Conical devices are fitted to the insulators of tangent supports or to transformer bushings, but only in a horizontal position because of their shape. Both types can be installed with the lines energised, with no need to interrupt the supply.

Figure B12. Electrostatic devices fitted to the porcelain fuse cut-out insulators in a substation: design and correct installation. © Ezequiel Herrera/CNFL

B. Accompanying measures: artificial aerial bridges for arboreal wildlife crossings

➜ Description

Bridges are installed between wooded areas that have been fragmented by the construction of roads or power lines, connecting points where wildlife crossings have been recorded or are probable. These artificial bridges reduce the need for wildlife to use the power line as a corridor or to descend to the ground to cross the road, reducing the risk of being run over.

The designs are very variable; simple ones may consist of a single rope greater than 15 mm in diameter, or two or three interlaced ropes stretched taut.

Other more elaborate designs include a 'hammock' type, made of plastic mesh supported by ropes or cables, with wooden or PVC crosspieces to provide stability.

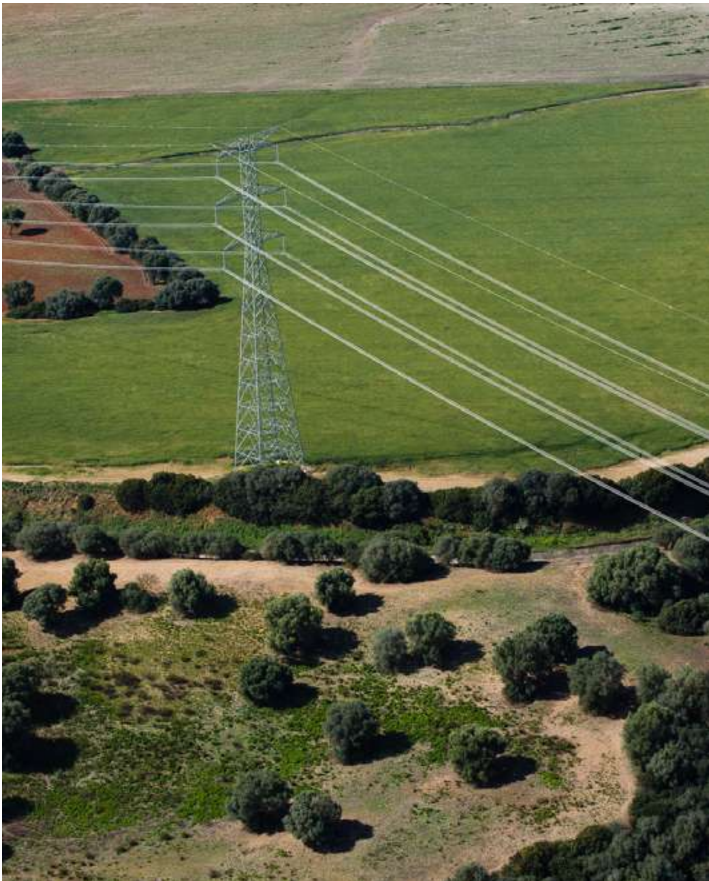
➜ Placement

The bridge ropes are tied to tall trees inside the forest, at least 10 m from the edge of the cleared area to increase the likelihood of use by wildlife. They can be installed above or below the electricity line, but always with sufficient clearance so that the animals do not try to climb onto it, and at a minimum height of 10 m above the ground.

It is important to choose strong trees and non-breakable branches for installation.

Figure B13. Left to right and top to bottom: Aerial bridge with a single rope; Design with two ropes; 'Hammock' type; A bridge crossing a road. © CNFL

Figure B14. The use of insulated conductors is particularly suitable in forest environments to prevent wildlife accidents and avoid interruption in power supply. Southern pig-tailed macaque (*Macaca nemestrina*) in a tropical rainforest, Malaysia. © Justo Martín



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