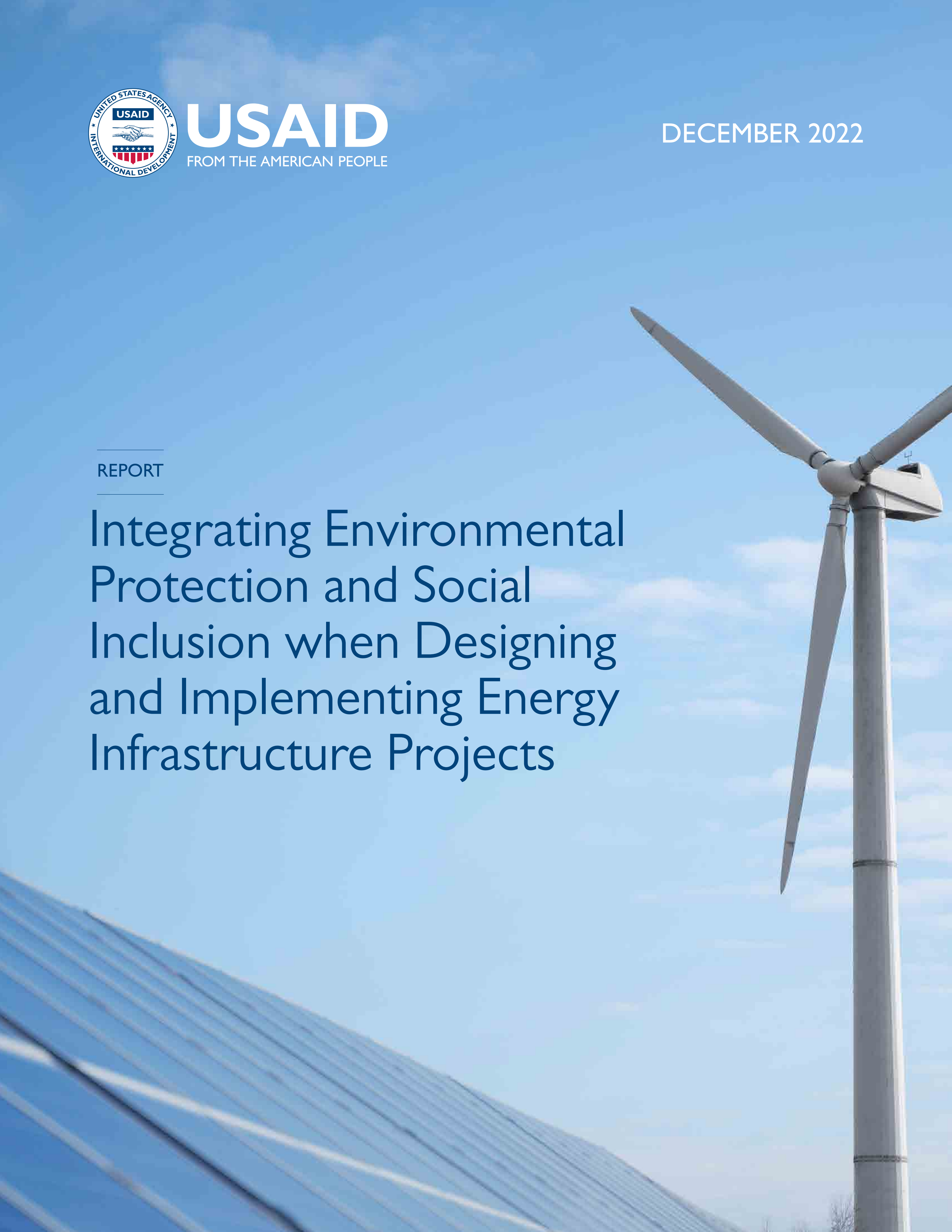

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DECEMBER 2022

REPORT

Integrating Environmental Protection and Social Inclusion when Designing and Implementing Energy Infrastructure Projects

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Integrating Environmental Protection and Social Inclusion when Designing and Implementing Energy Infrastructure Projects

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Front cover photo:	Solar panels and wind turbines provide clean energy but often have impacts on the environment and human communities. Photo by Freepik.
Back cover photo:	Wind turbines. Photo by Rabih Shasha on Unsplash.
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Contents

Acronyms & Abbreviations

CSF	Conservation Strategy Fund
EIA	Environmental Impact Assessment
ESIA	Environmental and Social Impact Assessment
ESOM	Energy System Optimization Model
EU	European Union
GESI	Gender equality and social inclusion
INRM	Integrated Natural Resource Management
IPCC	Intergovernmental Panel on Climate Change
SAEP	Southern Africa Energy Program
SEA	Strategic Environmental Assessment
USAID	United States Agency for International Development

Executive Summary

This synthesis report highlights the state of knowledge on interactions between energy infrastructure and the environment. Recent projections show that demand for energy will continue to increase worldwide. Governments, regulators, and utilities are working to meet this demand by increasing energy supply, often by improving efficiency and investing in new infrastructure, such as generation, transmission and distribution networks, and mini-grids. However, many projects still fail to adequately address tradeoffs between meeting energy needs and achieving broader environmental and social sustainability goals.

Global stakeholders agree that environmental and social considerations must be integrated in the design and implementation of energy infrastructure projects. This research study synthesizes evidence and best practices for USAID and its partners, drawn from an extensive literature review, which focused primarily on renewable energy sources, as well as interviews with five expert researchers and practitioners. Below are the key findings and recommendations, each of which is discussed in more detail in the main body of the report.

KEY FINDINGS

There is a lot of variation in the types and consequences of interactions between energy infrastructure and the environment. Not only do the types of vegetation, wildlife species, and other natural conditions vary widely in different regions of the world, but environmental policies and enforcement practices also vary, and different types of infrastructure will be more or less appropriate based on the setting. In most cases, the identified impacts and potential solutions will be best understood and most effective when considered in light of local context. This report provides suggestions for locally oriented assessments, solutions, research priorities, and best practices.

Impacts of wildlife and climate change on energy infrastructure

- The most common wildlife-caused impact on energy infrastructure is damage to equipment such as substations and transformers, usually resulting from wildlife coming into contact with infrastructure.
- Utilities tend to fix or replace damaged equipment instead of investing in better planning and data analysis to help predict and mitigate wildlife interactions prior to siting infrastructure projects.
- The most common climate-related impacts on energy infrastructure include damage to transmission and distribution lines from events like flooding, landslides, lightning strikes, and high winds, as well as reduced capacity of hydroelectric plants to produce electricity, for example, because of drought.

Impacts of energy infrastructure on the environment

- The most common negative impacts of energy infrastructure on the environment include loss and fragmentation of wildlife habitat and ecosystems, spread of invasive species, wildlife collisions with infrastructure, and wildlife electrocutions.
- There is significant variability among environmental impacts and their scale depending on the energy source (e.g., hydro, coal, or wind), type of energy infrastructure (generation, transmission, or distribution), and affected species and ecosystems.

Trade-offs among environment, economy, and society

- Climate-smart energy infrastructure and renewable energy production might cause unintended damage to local communities, wildlife, and ecosystem services.
- Countries deploying renewable energy sources often prioritize their energy production and climate benefits without addressing potential damage to wildlife and ecosystems.
- New electricity services may benefit urban consumers, while the associated infrastructure may cause damage in other–often rural–communities. This benefit and cost distribution imbalance often is not accounted for during the design phase of an infrastructure project.
- With weak enforcement of regulations to protect the environment, project developers generally do not have private incentives to invest in mitigation upfront, unless there are regulatory requirements or the potential for regulatory enforcement. Upfront mitigation measures and siting improvement during project planning almost always are less costly than mitigation measures during project construction or operation.
- Energy and environment regulators need to consider not only private costs to utilities and project developers but also costs of environmental and social externalities, including direct and unintended effects on third parties not involved in the activity.

RECOMMENDATIONS FOR BEST PRACTICES

- ✔ Conduct a rigorous, evidence-based Environmental and Social Impact Assessment (ESIA) early in the project design phase to avoid environmental and social impacts when possible, for example, as with the Kipeto Wind Farm project (Southern Africa Energy Program [SAEP]/EWT 2022). Project designers should assess energy alternatives, including improving existing energy infrastructure instead of constructing new infrastructure; integrate the ESIA team with the project design team; and monitor and enforce ESIA mitigation requirements.
- ✔ Invest in monitoring during the whole project lifecycle to help utilities and infrastructure managers understand appropriate mitigation techniques and minimize losses. Monitoring during the design phase helps define mitigation measures by identifying species and ecosystems that may be most impacted by infrastructure; monitoring during the implementation phase provides evidence of whether and how mitigation measures are working.
- ✔ Consider a strategic environmental assessment (SEA) that includes broad-focus, early-stage, regional planning and policy approaches that can help protect the environment and promote equitable development prior to implementing infrastructure projects.
- ✔ Invest in spatial analysis and data collection to determine the best locations for implementing an energy infrastructure project. This may include factors such as energy resource potential (e.g., wind speed, slope, land use/land cover, existing electric and road networks, and water bodies) and important natural resources to conserve (e.g., carbon-rich ecosystems, species of concern or particular value, such as endangered species, and wildlife movement corridors).
- ✔ Because energy infrastructure's impacts on wildlife and ecosystems vary widely, it is difficult to generalize mitigation strategies needed to avoid or limit these impacts. Targeted studies that consider local context are recommended to identify appropriate mitigation strategies. For example, a local wildlife survey may quickly reveal species-specific negative interactions that can be mitigated at a low cost.
- ✔ When designing infrastructure projects, conduct economic feasibility studies that assess not only financial costs and benefits but also environmental and social costs and benefits.
- ✔ To promote inclusive and equitable energy development, energy projects should create an intentional and deliberative process for engaging stakeholders during the design process, including affected communities that traditionally are marginalized. The social consultation process should be done at the earliest stages of project design; it is critically important and follows international best practices recommended for local communities to have the opportunity to provide free, prior, and informed consent.
- ✔ Energy projects should seek opportunities to amplify the voices and needs of women throughout design and implementation, particularly when the infrastructure may impact land or other resources that women depend on for livelihoods. Such involvement also can reduce gender-based violence, alleviate women's time poverty, create opportunities for women and girls to enter the labor force, and improve social norms through access to information.
- ✔ Project design teams can use the social conceptual framework presented in this report to guide consultations with affected communities, inform decision-makers about relevant trade-offs and questions to ask, and assess information needed to integrate social considerations into financial and environmental assessments for energy infrastructure projects.

Introduction

Energy infrastructure typically damages and fragments natural landscapes, causing greenhouse gas emissions, biodiversity loss, and ecosystem service decline. These negative impacts are counter to USAID's broader development objectives to protect biodiversity and other natural resources, open clean energy markets, and reduce air pollution and emissions. As USAID and its partners work to increase access to clean, reliable, and affordable energy in developing countries, the extent of power lines and other energy infrastructure will continue to increase, raising questions about how to reduce impacts on climate and the environment.

By failing to integrate environmental and social risks into siting and project design, energy infrastructure projects can inadvertently cause significant harm, human rights violations, project delays, and maintenance costs for power-sector utilities, donors, and communities. Conventional ESIAs often occur late in the design process, when it is more challenging to minimize environmental damage and social costs to local communities by altering or redesigning energy infrastructure projects.

At the request of USAID's Energy Division, this research report highlights the state of knowledge related to interactions between energy infrastructure and the environment, with three main goals:

1. Make a "business case" for integrating environmental protection and social inclusion into energy infrastructure planning and management by providing evidence of costs and benefits associated with environmental and social impacts.

2. Improve siting of new energy infrastructure by identifying potential benefits of and options to account for environmental and social risks at the early stages of energy projects.

3. Increase integration of gender equality and social inclusion (GESI) as well as local livelihoods into energy infrastructure development by highlighting approaches that allow infrastructure project designers to better understand how diverse communities access energy and other natural resources.

To develop this report, the research team considered energy generation, transmission, and distribution infrastructure, focusing mostly on renewable energy sources; and assessed interactions between infrastructure and the environment, including wildlife, habitats, and ecosystems. Research results and recommendations are focused on four main themes: (i) costs associated with interactions between infrastructure and the environment; (ii) existing mitigation measures to avoid or limit negative impacts associated with those interactions; (iii) trade-offs that decision-makers should consider when designing and implementing energy infrastructure projects; and (iv) social impacts associated with energy infrastructure.

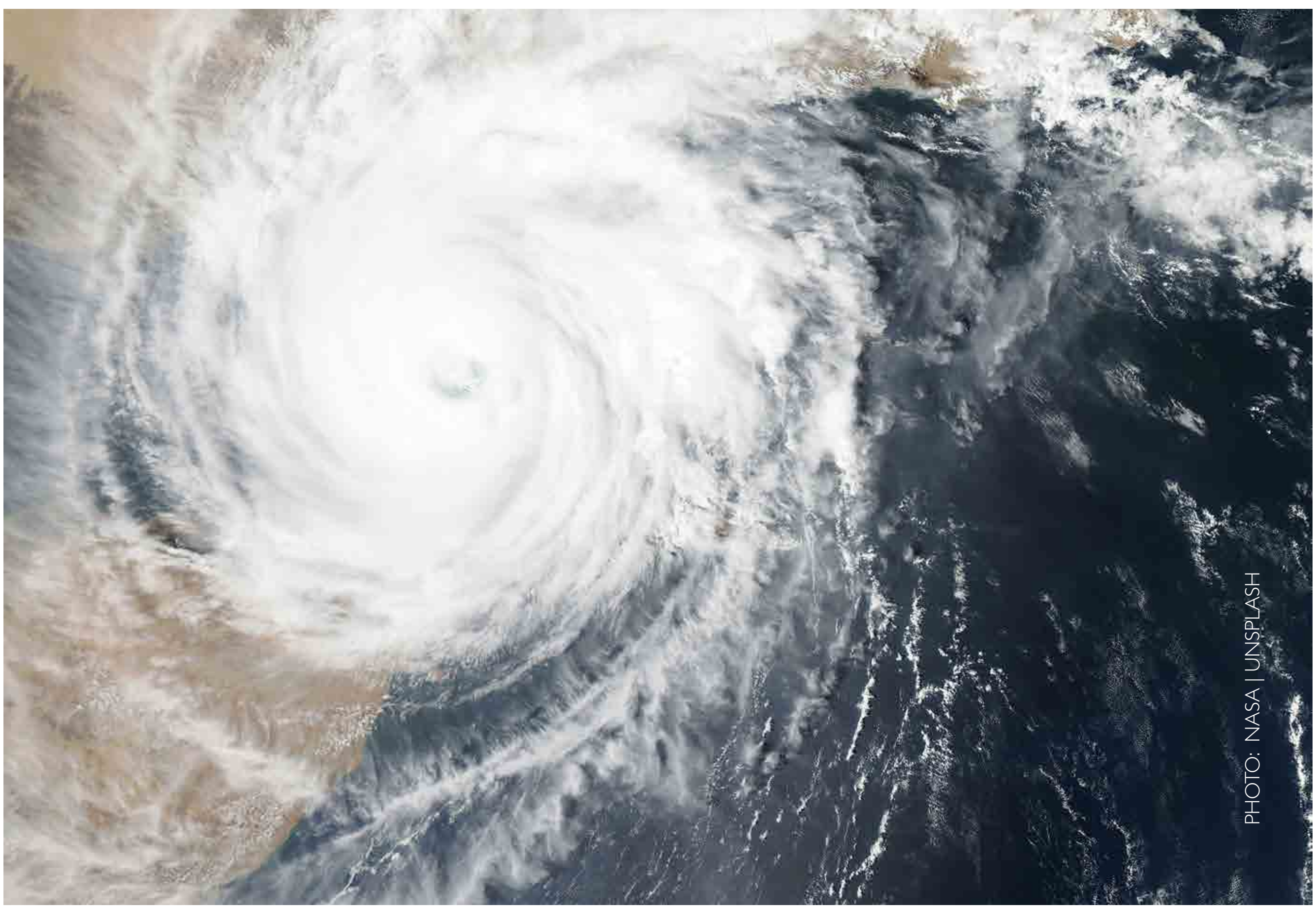
The overall objective of this report is to provide a snapshot of research insights related to energy infrastructure and the environment; it should not be considered an exhaustive synthesis of all the impacts and strategies available to limit these impacts.

This report has four main sections. The first section summarizes the most common issues related to interactions between energy infrastructure and the environment, including negative impacts caused by wildlife and climate change on energy infrastructure; energy infrastructure's negative impacts on wildlife and ecosystems; and measures to avoid or mitigate both. This section also describes trade-offs that decision-makers should consider when evaluating energy infrastructure and options for environmental protection.

The following section presents several solutions to avoid or mitigate negative interactions between energy infrastructure and the environment. This section introduces the commonly applied mitigation hierarchy approach and then discusses recommendations for better project design and implementation.

Next the report highlights social impacts that result from energy infrastructure development. This section summarizes the most common impacts and presents a conceptual framework that USAID and other energy project donors and developers may use to incorporate social considerations and community livelihoods into project design and implementation. Decision-makers can use the conceptual framework to: (i) better understand the relationship between infrastructure, society, and natural resources; (ii) guide the development, implementation, and monitoring of environmentally and socially sustainable energy projects worldwide, and (iii) encourage stakeholders to explicitly consider interactions between energy infrastructure and local communities when designing and implementing infrastructure projects.

The last section describes future research opportunities and best practices that USAID is well-positioned to promote.



The relationship between energy infrastructure and the environment

There is growing consensus in the literature on the importance of investing in energy infrastructure to meet an expanding worldwide demand (IRENA 2016 & 2019, IEA 2021a & 2022, Zhdannikov & Jones 2022). However, as demand for energy grows, new concerns arise about its impacts on the environment. Studies have shown that, along with power lines, even the greener sources of power generation can cause negative impacts on biodiversity and ecosystems and exacerbate climate change (Tere & Parasharya 2011, Jaber 2013, Hernandez et al. 2014, Sanchez-Zapata et al. 2015, Gasparatos et al. 2017, Sayed et al. 2021, Rabaia et al. 2021, Rahman 2022). Box 1 presents an example of the impact caused by power lines and wind farms on flamingos and other birds in India. This example illustrates some of the challenges faced by new infrastructure.

The expansion of energy infrastructure–especially the rapid growth of renewable sources–will continue for the foreseeable future (IEA 2021b, Jaeger 2021) as countries work to strike a balance between growing demand for energy and stricter conservation goals. Country commitments to reduce greenhouse gas emissions[1] and protect land and seascapes for conservation[2] will require governments, utilities, and other energy-related facilities to rethink investment strategies and targets. A recent report (McKinsey & Company 2022) considers a climate change scenario by which global temperature increases 2.4 degrees Celsius (significantly higher than the Intergovernmental Panel on Climate Change [IPCC] 1.5 degree target)[3] and finds that energy investments would need to increase by four percent per year for the next decade to meet growing demand and adapt energy systems for climate mitigation, reaching approximately US$1.5 trillion in 2035; most of these investments would need to be dedicated to non-fossil and decarbonization technologies. Although such investments will help countries reduce greenhouse gas emissions, infrastructure proponents also need to focus on avoiding damaging interactions with wildlife, on enhancing infrastructure's reliability and resilience to climate-related extreme weather events, and on protecting wildlife and ecosystems. A better understanding of the relationships between energy infrastructure and the environment can help correctly assess the costs and benefits of future investments.

This section presents impacts of wildlife and climate change on energy infrastructure projects; impacts of energy infrastructure on the environment; and trade-offs of energy infrastructure development to the environment, economy, and society.

BOX 1.

POWER LINES AND WIND FARMS CAUSE HIGH BIRD MORTALITY IN GUJARAT, INDIA

Wetlands in Gujarat, India are home to both greater and lesser flamingos; the latter is a near-threatened species. This region also contains power lines that were constructed within the breeding and feeding sites of both species, which tend to fly at night or early in the morning when visibility is low. As a result, there are frequent collisions between flamingos and power lines. The collisions are so frequent that local people have learned to look for power lines to collect dead birds for consumption (Tere & Parasharya 2011).

Gujarat is also one of the best places in India to establish wind farms. As a result, collisions with birds, not only flamingos, are becoming more common. Unfortunately, this type of infrastructure in India is exempt from requirements to conduct an environmental impact assessment (Parvatam 2019). Because of the growing number of animal deaths due to wind farms, some specialists are calling on India's government to reevaluate whether wind farms should be considered "green" energy infrastructure.

1 Examples of country commitments to reduce greenhouse gas emissions include The Paris Agreement, and the Net Zero Coalition.

2 Examples of country commitments to protect terrestrial and marine areas include Aichi Target 11 and the High Ambition Coalition for Nature and People.

3 Also noteworthy is that the McKinsey and Company (2022) report concludes that existing policies are insufficient to reduce global temperature to 1.5 Celsius degree or less.

Impacts of wildlife and climate change on energy infrastructure projects

WILDLIFE INTERACTIONS WITH INFRASTRUCTURE

Wildlife interactions with infrastructure are a common source of damage to infrastructure and power interruptions that can result in significant costs to infrastructure owners and society (see, for example, Dwyer et al. 2019, Barnes et al. 2022). In the United States, for example, wildlife is responsible for about 11 percent of power outages (Larsen 2016). The costs generally come from equipment damage, power outages, safety risks, lost revenue, and regulatory fines when animals such as reptiles, birds, bats, and other mammals collide or come in contact with infrastructure (especially power lines), frequently harming or killing the animals. Such interactions are not as well studied in the literature as climate-related extreme events, but utilities do have some information about their type, frequency, and associated costs. They typically are more local, shorter-term, and smaller in impact than damage caused by climate-related extreme events, which are less frequent but "high consequence disruptive events" (Elliot et al. 2019). Nonetheless, this literature review uncovered some studies that assessed costs associated with wildlife interactions and infrastructure.

California, United States

Two studies in the United States showed that wildlife was responsible for 10-15 percent of all power interruptions faced by utilities (Energy and Environmental Economics Inc. 2005, Larsen 2016). The first study, sponsored by the California Energy Commission, is considered a standard reference on the topic of wildlife-caused power outages (Energy and Environmental Economics Inc. 2005). It is one of the few studies that quantifies the costs of power outages directly caused by wildlife, using data from California utilities. Between the cost of unserved energy to California customers and costs incurred by utilities to restore electricity service, the authors found that wildlife-caused damage amounts to about US$34 million each year. Also using utilities' data, Larsen (2016) conducts a correlation analysis to identify the main factors affecting power outages of almost 200 utilities over a thirteen-year period. In both studies, wildlife-caused damage is presented as a well-known factor by utilities.

Guam, United States

The Pacific island of Guam is famous for military bases and tourist attractions, but it also is known for having one of the world's largest populations of invasive brown tree snakes. Interactions between snakes and power lines are frequent. Fritts (2002) estimates an average of 133 power outages per year–one every three days–as a result. To estimate the economic impact, Fritts (2002) calculates that the annual economic productivity loss is US$4.5 million, based on a seven-year measurement period. This cost is most likely underestimated as it does not include other expenses such as equipment repair and replacement.

Iran

Using information from 222 power outages caused by birds in Iran in 2018, Kolnegari et al. (2021) estimate the financial cost to restore power supply (i.e., fix or replace the equipment, and staff expenses) at approximately US$400 per incident. The authors also note additional costs not quantified in the study, including costs paid by utilities and distributors to commercial consumers such as factories due to production loss, and reputational costs from both consumers and the government. In Iran, energy facilities are scored according to their reliability; each time there is a power outage, the Ministry of Energy reduces the facility's score.

South Africa

In 2022, the Southern Africa Energy Program/Endangered Wildlife Trust (SAEP/EWT) published a report that describes detailed examples of wildlife interactions with energy infrastructure in South Africa. Wildlife species included not only birds, bats, reptiles, and small mammals but also large mammals such as elephants and rhinoceroses. In the report, the authors estimated that the costs of these interactions, particularly those incurred by Eskom (South Africa's largest electric public utility), could reach US$3.2 million per year. This estimate is most likely too low because the costs include only "resource deployment, hardware damage, and loss of income during outages" (SAEP/EWT 2022).

Several other studies that focus on costs are shown below in Table 1.

Table 1. Summary of costs related to wildlife-caused damage to energy infrastructure

Cause of damage	Cost	Year	Brief description	Source
Wildlife	US$33,873,000	2015	Annual cost for Californian utilities	Energy and Environmental Economics Inc. 2005
Wildlife	US$100,000,000	2022	Annual cost to African utilities	SAEP/EWT 2022
Wildlife	US$3,200,000	2022	Annual cost to Eskom in South Africa	SAEP/EWT 2022
Wildlife	US$4,500,000	1997	Annual cost of wildlife interruptions in Guam	Fritts 2002
Wildlife	US$384,000 - 2,1760,000	2011	Annual cost to Midwestern utility in the United States	Nelson et al. 2014
Wildlife	US$88,800	2018	Annual cost to consumers in Iran. About US$ 400 per incident	Kolnegari et al. 2020

There is consensus in the literature regarding some of the challenges related to these types of estimates.

1. Although utilities and distributors might have this information, they are not required to publish it.
2. When information is available, it is possible that the cost of damage caused by wildlife might be underestimated. Some dead birds and other animals that fall to the ground after colliding with infrastructure might be taken by scavengers. As a result, utilities and distributors are not able to attribute the power outage to wildlife.
3. As mentioned above, power outages caused by wildlife typically are local and of short duration. Utilities and distributors usually are able to quickly resolve the problem.

Because of these challenges, there is minimal data available to conduct research, and utilities' interest in the topic is usually secondary. Utilities often overlook wildlife-caused damage to infrastructure, for two main reasons: (i) the perception among utilities that wildlife-caused damage is unpredictable[4] and (ii) the additional perception that, for existing energy infrastructure, avoiding wildlife interactions may require expensive solutions. As a result, utilities tend to fix or replace damaged equipment instead of investing in better planning and data analysis prior to infrastructure siting, which could help predict and mitigate interactions with wildlife. However, this might be

4 People at utilities might have this perception, especially if they lack the expertise and time to fully understand wildlife patterns, but wildlife do frequently act predictably, and mitigation steps can be successful if project designers take time upfront to analyze and prevent negative interactions *(through personal communication with experts)*.

changing given the increasing number of studies showing the economic value of certain species that are affected by electricity infrastructure.

The examples from California, Guam, Iran, and South Africa, as well as the information in Table 1, show that costs to energy utilities, governments, and other infrastructure owners and managers may vary widely depending on the location, type of wildlife interaction, infrastructure equipment, and species involved. In common, studies agree that the costs related to wildlife are underreported worldwide (Barrett 2015). In addition, longer-term and larger-scale negative impacts and costs to energy infrastructure due to degraded landscapes and ecosystems are not commonly measured.

Lastly, although it is less frequently mentioned in the literature, there are some cases of positive interactions between energy infrastructure and wildlife. For example, there is much literature on offshore infrastructure benefitting marine biota and biodiversity (Degraer et al. 2020, Glarou et al. 2020). Positive interactions also may be observed with regard to terrestrial infrastructure. For example, some species of birds are known to use distribution lines for nesting and habitat (Hrouda & Brlík 2021, Morelli et al. 2014, Prather & Messmer 2010).

CLIMATE-RELATED EXTREME WEATHER EVENTS

As climate-related extreme weather events become more frequent, energy infrastructure must become more resilient (Zamuda et al. 2019). Damage to infrastructure and resulting power interruptions and outages[5] from events such as higher temperatures, heavy precipitation, high winds, landslides, and flooding (IAEA 2019) generate costs to companies and societies. For example, in the United States, the annual cost associated with power interruption caused by severe weather was estimated at US$2-3 billion (Larsen et al. 2018).

Damage to energy infrastructure from climate-related extreme weather events creates direct and indirect costs associated with investing in solutions to avoid or mitigate the damage. The direct costs mainly are related to fixing or replacing damaged infrastructure, revenue lost due to power interruptions, and higher utility bills for consumers. The indirect costs associated with investing in solutions often include rebuilding or redesigning older infrastructure and adopting best practices, such as improving governance, and other solutions to improve responsiveness. Several studies have quantified these costs (e.g., Gündüz et al. 2017, Hallegatte et al. 2019, Shin et al. 2021) (Table 2).

Table 2. ***Summary of costs resulting from climate-related extreme events to energy infrastructure***

Cause of damage	Cost	Year	Brief description	Source
Climate-related extreme weather	EUR 257,930,000	2005	Single storm event (Gudrun Storm in Sweden)	Gündüz et al. 2017
Climate-related extreme weather	US$ 101,000,000	2019	Annual cost related to floods and rain in Tanzania	Hallegatte, et al. 2019
Climate-related extreme weather	US$ 391 billion - 647 billion	2019	Annual cost related to extreme weather in low- to middle-income countries	Hallegatte, et al. 2019

5 Outages are defined as momentary (an outage of less than five minutes), sustained (an outage of more than five minutes), planned (when the company as provided notice to customers of an outage), and major event (a set of outages that, combined, exceed historically expected outage duration for at least one day) (PG&E 2020).

Cause of damage	Cost	Year	Brief description	Source
Climate-related extreme weather	US$ 28 billion to 169 billion	2021	Estimates on how much electric outages cost the United States economy	Shin et al. (2021)
Climate-related extreme weather	EUR 300,000,000	2003	Cost related to single heat wave event in France	Paskal (2009)
Climate-related extreme weather	US$ 5 billion to 7 billion	2011	Cost related to Hurricane Iris in the United States	Li et al. (2014)
Climate-related extreme weather	US$ 6 billion	2015	Annual cost to consumers	Larsen et al. (2017)

To avoid and mitigate impacts of climate-related extreme weather events, public and private utilities are investing in reliability and resilience. *Reliability* is defined by Clark-Ginsberg (2016) as "the ability of a power system to deliver electricity in the quantity and quality demanded by users." It refers to the "consistency" of electricity provision–the amount of times that electricity gets interrupted from utilities to consumers. *Resilience* can be defined as "the ability to reduce the magnitude and/or duration of disruptive events." According to the National Infrastructure Advisory Council (2009), "the effectiveness of a resilient infrastructure (...) depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event." In other words, once disruptive events occur, resilience measures the ability of an energy system to "bounce back quicker and stronger" (Clark-Ginsberg 2016). In the case of both reliability and resilience investments, rate-payers usually pay the costs (Larsen 2016).

Spending rate-payer funds on resilience usually requires utilities and distributors to show regulators and policymakers that the benefits outweigh the costs (Zamuda et al. 2019). As a result, there is a growing literature on (i) "resilience metrics" (Elliot et al. 2019) and (ii) the economic valuation of resilience (Rickerson et al. 2019, Zamuda et al. 2019). However, despite a growing number of studies, there is still a lack of consensus among utilities, regulators, and policymakers on the metrics for resilience and the analytical framework needed to assess the economic value of improving resilience (Elliot et al. 2019, Zamuda et al. 2019). These two research fields are complementary as "we measure what we value, and we value what we measure" (UN 2001). An accurate valuation of resilience is essential to inform decision-makers because it allows stakeholders to more easily compare the costs and benefits associated with resilience investments. Consideration of the "resilience dividend" (Rodin 2014) can help differentiate between a given scenario or intervention and a "business as usual" case.

Zamuda et al. (2019) created three categories of benefits associated with investing in resilience. Two are related to avoided costs, i.e., costs that are not incurred by utilities and consumers as a result of the investments. The third category consists of a more indirect benefit associated with *not* interrupting vital services and thus maintaining a utility's good reputation because of their investment to prevent power interruptions. The benefits measured as avoided costs usually are easier to quantify; the indirect benefits are more challenging to quantify monetarily (LaCommare et al. 2017).

Table 3 summarizes common categories used to quantify costs and benefits of improving resilience.

Table 3: ***Most common categories used to quantify costs and benefits of improving resilience***

Costs	Benefits
Cost to fix or replace damaged infrastructure	Avoided utility costs, e.g., avoided legal liabilities, and reduced cost of restoration, equipment repair, and/or replacement
Costs incurred by consumers due to power interruptions	Avoided customer interruption costs, e.g., avoided costs from short- and long-term duration to customers and to critical facilities such as hospitals and police
Reputational costs	Non-interruption-related social benefits, e.g., improved safety and/or avoided accidents and property damages caused by wildfires

Source: Zamuda et al. 2019 (benefits case).

OTHER DAMAGE INDUCED BY CLIMATE CHANGE

In addition to the increasing frequency and severity of extreme weather events, other damage to energy infrastructure could arise from the threat posed by climate change. An overall increase in air temperatures can lower the efficiency of generation, conversion, and combined-cycle processes of certain energy sources, reduce the carrying capacity of lines and transformers, and increase energy demand for cooling, which could result in overloads (Burillo 2018). Changes in precipitation patterns can reduce the combustion efficiency of coal, damage power lines from snow and ice, flood underground infrastructure, and damage towers due to erosion, as well as decrease the availability of freshwater for thermal cooling. Sea level rise also can damage coastal and low-lying infrastructure (Burillo 2018).

One particularly important and recent form of damage induced by climate change is permafrost thawing. According to Hjort et al. (2022), infrastructure costs related to permafrost degradation could rise to "tens of billions of U.S. dollars by the second half of the century," primarily in high-latitude and high-altitude regions. Permafrost thawing can cause various gradual and abrupt natural threats to infrastructure, increasing the risk of damage to buildings, impairing roads, affecting pipelines and other components (Hjort et al. 2022). At least 9,500 km of pipelines currently are located in permafrost areas of the Northern Hemisphere, and they are the most vulnerable type of infrastructure to these occurrences (Hjort et al. 2018). The lifecycle replacement costs to maintain them is expected to grow 60 percent (or US$1.83 billion) by 2059. Between one-third and one-half of critical high-latitude infrastructure could be at risk by mid-century, posing a particularly worrying cost scenario for energy utilities and project developers (Hjort et al. 2022).

IMPACTS OF ENERGY INFRASTRUCTURE ON THE ENVIRONMENT

Not only do wildlife interactions and climate change-related events damage energy infrastructure, but the infrastructure also has many negative impacts on the environment. Impacts associated with non-renewable energy sources, such as coal and other fossil fuels, are well known in the literature. They stem from generation, transmission, and distribution and include degradation of ecosystems, biodiversity loss, greenhouse gas emissions, acid rain, and smog (Dincer 1999, Jones et al. 2015, USAID 2018, Sayed et al. 2021). However, as countries work to reduce greenhouse gas emissions, more recent studies have focused on impacts associated with renewable energy sources such as wind and solar (Siler-Evans et al. 2013, Sayed et al. 2021). We know now that these sources, although important for reducing emissions, might cause significant environmental harm.

The impacts of infrastructure on the environment generate costs to society and the private sector. But there is an unfortunate lack of research focused on quantifying these costs, especially for renewable energy sources. Most studies included in this literature review estimate environmental and social costs related to hydropower and fossil fuels; typically they describe reputational and regulatory costs (e.g., to comply with regulations) and fines for lack of compliance. Even so, there is a paucity of data describing these costs. More research is needed to estimate costs and communicate the results.

Accordingly, rather than focusing on costs associated with impacts of energy infrastructure on the environment, this section focuses on summarizing those impacts, many of which are well known. The most common ones identified in the literature include: (i) loss and fragmentation of wildlife habitat; (ii) spread of invasive species; (iii) wildlife collisions with infrastructure, especially birds and bats; (iv) wind turbines causing air pressure changes, which also may kill bats; (v) wildlife electrocutions; (vi) damage impairing the functionality of marine and freshwater ecosystems; and (vi) degradation of ecosystem services, particularly those resulting from land conversion.

Table 4 highlights the most common impacts mentioned in the literature related to renewable sources– including wind, solar, geothermal, and bioenergy generation–and associated power lines as well as the scale of these impacts.

Table 4. *Common impacts of renewable sources and power lines on the environment*

Energy Infrastructure	Main Impacts	Scale of Impacts	Description of Impacts	References
WIND	Land use change impacts	Local and landscape	Wind facilities affect land use in many ways, but the impacts mentioned most in the literature relate to: (i) area requirements and (ii) the overlap between the area needed for energy production and ecologically sensitive areas, along with potential degradation of the latter.	Yong 2012, Lucas et al. 2012, Mcnew et al. 2014, Wang & Wang 2015, Thaxter et al. 2017, Diffendorfer et al. 2019, Nazir et al. 2019, Adeyeye et al. 2020, Turkovska et al. 2021, Harrison-Atlas et al. 2022, SEER 2022.
	Noise effects	Local	Noise from wind turbines can cause sleep and mental health problems for people. Infrasound windmill noise (at frequencies below what people can hear) can negatively affect birds and rodents.	
	Visual impact	Local	The visual impact of wind facilities is controversial – some studies present this impact as positive (e.g., the presence of wind farms attracts tourism), while other studies consider the impact to be negative (e.g., wind farms disrupt scenic views).	

Energy Infrastructure	Main Impacts	Scale of Impacts	Description of Impacts	References
SOLAR	Electromagnetic field effects	Local	Electromagnetic fields produced by wind facilities are usually low and limited in range. However, they might interfere with TV, radio, and microwave transmissions, mobile phones, and radar. In the case of offshore wind farms, it is possible that electromagnetic fields disguise or distort natural magnetic fields used by some aquatic animals.	Lovich & Ennen, 2011, Hernandez et al. 2014, Hernandez et al. 2015, Visser et al. 2019, Grodsky & Hernandez 2020, Zorzano-Alba et al. 2022
	Microclimate effects (e.g., temperature and precipitation)	Local	Wind facilities can alter local temperature and precipitation by lowering wind speeds and increasing turbulence.	
	Wildlife mortality	Local	Wildlife, mainly birds and bats, frequently collide with wind energy infrastructure. In addition, moving blades can create a drop in air pressure that causes bats' lungs to expand (known as barotrauma), typically killing the bats.	
	Land use change impacts	Local and landscape	The impact of solar facilities on land use is similar to the impact caused by wind facilities. However, in addition to area requirements and overlap with ecologically important areas, several studies note that solar facilities may fragment wildlife habitats and create a physical barrier to wildlife movement.	
	Pollutants	Local	At some solar facilities, hazardous chemicals are added to water used to cool the solar panels.	
	Water use	Local and regional	Water is used to wash dust from mirrors and panels and also may be used to cool solar panels.	
	Visual impact	Local	Solar facilities might disrupt scenic views.	
	Microclimate effects (e.g., temperature and precipitation)	Local	Solar facilities can alter rates of evapotranspiration and produce unused heat that can change local temperature and precipitation patterns.	

Energy Infrastructure	Main Impacts	Scale of Impacts	Description of Impacts	References
GEOTHERMAL	Dust and dust-suppression effects	Local	This impact tends to occur during the construction and decommissioning phases. The construction of roads and auxiliary infrastructure, as well as site preparation, produce dust, which can reduce solar mirror and panel efficiency. To reduce dust, solar facilities use suppressants that can negatively impact the environment (e.g., damage vegetation and alter water runoff volume and suspended solids in runoff).	Dhar et al. 2020
	Land use change impacts	Local and landscape	Impacts mentioned most in the literature relate to: (i) area requirements for geothermal infrastructure and (ii) the overlap between the area needed for energy production and ecologically sensitive areas, along with potential degradation of the latter.	
	Air quality	Local, regional, and global	Some geothermal plants emit carbon dioxide, ammonia, and volatile metals, among other pollutants.	
	Noise effects	Local	The drilling process can be noisy, potentially degrading quality of life for people living nearby.	
	Water use and quality	Local and regional	Water is required during all phases of geothermal energy production (construction, operation and maintenance, and decommissioning). To reduce water use, some facilities may use other fluids that can contaminate water and soil.	
BIOENERGY	Land use change impacts	Local and landscape	Producing corn-based biofuels requires land; land conversion degrades ecosystems.	Serra et al. 2017, Wu et al. 2018, Ale et al. 2019
	Water Use	Local and regional	Cultivation of bioenergy crops requires large amounts of water.	
	Chemical inputs and runoff	Local and regional	Some bioenergy crop producers use chemical fertilizers and pesticides to maximize yields.	

Energy Infrastructure	Main Impacts	Scale of Impacts	Description of Impacts	References
POWER LINES	Land use change impacts	Local and landscape	Power lines and their access roads and auxiliary infrastructure might be placed in undeveloped areas, disturbing natural areas and causing habitat fragmentation.	PSC (no date), Battaglini & Bätjer 2015, Biasotto & Kindel 2018
	Fire risk	Local and regional	Power lines sometimes spark fires.	
	Line as a resource	Local, national and global, e.g., for migratory species	Some bird species use power lines to increase home range and population size. However, power lines also are responsible for many bird fatalities due to collisions and electrocution.	

Notes: *This table does not explicitly consider impacts related to the construction phase of these energy infrastructures. Additional impacts might result, for example, from mining required to extract materials or from development of additional needed infrastructure, such as roads, to support the energy infrastructure. An influx of workers to the development area also may cause negative social impacts, especially on local women.*

Despite these impacts, there is no doubt about the benefits of renewable energy sources compared to fossil fuels. Among the advantages of renewable sources, three are highlighted in this study: (i) fewer greenhouse gas emissions and other air pollutants, (ii) fewer water pollutants, and (iii) lower reliance on foreign energy sources. Consider these examples: the Irish National Grid estimates that the displacement of CO_2 emissions from wind energy production ranges from 0.33 to 0.59 tonnes of CO_2 per MWh (Saidur 2011). For water consumption, the California Energy Commission estimates that 0.001 gallons per kWh are used for wind energy production, on average, and 0.030 gallons per kWh for solar, while fossil fuel energy sources use at least 0.250 gallons per kWh (Clark 2003).

Still, there is consensus in the literature that, as much as international organizations and national governments should continue to prioritize renewable sources, their environmental impacts should continue to be evaluated. Renewable energy benefits might be compromised if their environmental impacts are not better understood and avoidance and mitigation strategies are inefficiently implemented.

To contextualize some of the impacts summarized in Table 4, this study also surveyed the literature for metrics to quantify environmental damage from the generation, transmission, and extraction of materials for renewable energy. Although not an exhaustive survey, the study found that the most frequently reported metrics relate to biodiversity loss (typically measured in terms of mortality rates or areas where species habitat is compromised); climate change (usually reported as displaced greenhouse gas emissions or costs thereof); landscape impacts and deforestation (measured in hectares or acres affected, either as total or per energy unit); and ecosystem service losses (encompassing a broad set of metrics such as pollution concentration and other biophysical thresholds). This data and the measurement periods are summarized in Table 5, including some fossil fuel energy sources, which were included for comparison purposes.

Table 5. ***Quantified environmental damage metrics found in the literature review***

Energy Source	Country	Type	Impact	Quantified Impact Metric	Time Period	Study
Biofuels	USA	Generation	Landscape impact	54,740 km² affected	2007 - 2011	Trainor et al. 2016
Coal	Global	Generation	Landscape impact	17,710 km² affected	2007 - 2011	Trainor et al. 2016
Coal	EU (European Union)	Generation	Landscape impact	10 km²/TW/year		McDonald 2009
Oil and gas	USA	Extraction	Biodiversity loss (bird habitat)	3,275 hectares	2005 - 2015	Walker et al. 2020
Oil and gas	USA	Extraction	Biodiversity loss (bird mortality)	8.4 avian deaths per reserve pit		Trail 2006
Oil and gas	USA	Generation	Landscape impact	69,230 km² affected	2007 - 2011	Trainor et al. 2016
Oil and gas	Nigeria	Transmission	Deforestation	495 hectares	2014 (single event)	Agbagwa & Ndukwu 2014
Shale gas	USA	Generation & Transmission	Deforestation	11,527 hectares (loss of core forest)	2010 - 2016	Langlois et al. 2017
Coal (pit mining)	USA	Extraction	Landscape impact	515 hectares impacted per million short tons		Trainor et al. 2016
Coal (mountaintop removal)	USA	Extraction	Landscape impact	212 hectares impacted per million short tons		Trainor et al. 2016
Nuclear	USA	Generation	Landscape impact	2 km²/TW/year		European Commission 2015
Power lines	USA	Transmission	Biodiversity loss (bird mortality)	5.63 million electrocutions, 22.8 million power line collisions	2012 (annual)	Gibson et al. 2017
Power lines	USA	Transmission	Biodiversity loss (bird mortality)	0.01-174 million deaths	2009 (annual)	Saidur 2011
Power lines	USA	Transmission	Biodiversity loss (bat mortality)	4.6 deaths/MW/year	2009 (annual)	Saidur 2011
Power lines	USA	Transmission	Biodiversity loss (bird mortality)	12-64 million deaths	2014 (annual)	Richardson et al. 2017
Power lines	Global	Transmission	Biodiversity loss (bird mortality)	1 billion potential deaths	2002 (annual)	Richardson et al. 2017
Power lines	Global	Transmission	Biodiversity loss (mammal mortality)	14 species of carnivores		Kolnegari 2021
Power lines	Iran	Transmission	Biodiversity loss (bird mortality)	4,000 deaths (based on 6% reported electrocutions)	2018	Kolnegari 2021
Renewables (wind, biomass, PV and hydro)	Germany	Generation	GHG emissions	67 million tCO_2	2006 (annual)	Saidur (2011)

Energy Source	Country	Type	Impact	Quantified Impact Metric	Time Period	Study
Solar	South Africa	Generation	Biodiversity loss (bird mortality)	435 deaths (extrapolated)	Sep. - Dec. 2015	Visser et al. 2019
Solar	South Africa	Generation	Biodiversity loss (mortality)	9 species, 0.77 per hectare	Sep. - Dec. 2015	Visser et al. 2019
Solar	USA	Generation	Biodiversity loss (bird mortality)	38,000-138,000 deaths	2016 (annual)	Gibson et al. 2017
Solar	USA	Generation	Biodiversity loss (bird mortality)	3,500 deaths	Annual	Gibson et al. 2017
Solar	USA	Generation	Biodiversity loss (bird mortality)	70 deaths	40 weeks	Hernandez et al. 2014
Solar	USA	Generation	Biodiversity loss (habitat)	10,000 hectares of desert tortoise habitat	40 weeks	Hernandez et al. 2014
Solar	Europe	Generation	Landscape impact	37 km^2/TW/year	2009 (annual)	European Commission 2015
Submarine Power Cables	Spain	Transmission	Landscape impact	2.3 km^2 affected	Single event	Taormina et al. 2018
Submarine Power Cables	Denmark	Transmission	Ecosystem service loss	14-75 mg l-1 (mean particle concentration of mercury)	2005	Taormina et al. 2018
Submarine Power Cables	Wales	Transmission	Ecosystem service loss	178 dB re 1Pa (maximal noise emission)	2004	Taormina et al. 2018
Submarine Power Cables	France	Transmission	Ecosystem service loss	188.5 dB re 1Pa (maximal noise emission)	2004	Taormina et al. 2018
Wind	USA	Generation	Biodiversity loss (bat mortality)	600-888,000 deaths	2012 (annual)	Gibson et al. 2017
Wind	USA	Generation	Biodiversity loss (bird mortality)	573,000 deaths	2012 (annual)	Gibson et al. 2017
Wind	USA	Generation	Biodiversity loss (bird mortality)	27,000 deaths	2012 (annual)	Gibson et al. 2017
Wind	USA	Generation	Biodiversity loss (bird mortality)	0.15 million deaths	2009 (annual)	Saidur 2011
Wind	USA	Generation	Biodiversity loss (bird mortality)	234,000 deaths	Annual	Gasparatos et al. 2017
Wind	Norway	Generation	Biodiversity loss (bird mortality)	>25 species	2005 - 2010	May et al. 2012
Wind	Norway	Generation	Biodiversity loss	74 deaths (willow ptarmigan)	2005 - 2010	May et al. 2012
Wind	USA	Generation	Landscape impact	14,490 km^2	2007 - 2011	Trainor et al. 2016
Wind	EU	Generation	Landscape impact	72 km^2/TW/year		Science Communication Unit, European Commission DG Environment 2014
Wind	Norway	Transmission	Biodiversity loss (bird mortality)	39 deaths (white-tailed eagle)	2005 - 2010	May et al. 2012
Wind	Norway	Transmission	Biodiversity loss (bird mortality)	38 deaths	1980 - 2012	May et al. 2012

As noted above, this research did not identify many studies that quantify, in monetary terms, the environmental and social costs associated with renewable energy infrastructure (*this finding was validated by interviews*). There is considerably more information about the social cost of fossil fuel energy infrastructure, particularly for generation and transmission. Hassan et al. (2021), for example, estimate economic damage of more than US$157 billion from consumption of coal and oil in Pakistan every year. The few other studies we found–mostly related to hydropower–conclude that the environmental and social costs caused by developing the infrastructure projects were greater than their expected benefits (Vega et al. 2012, Jericó-Daminello et al. 2016, Gibson et al. 2017).[6]

The literature review also found studies quantifying social benefits of renewable energy infrastructure, but they, too, are scarce in the literature. Most compare monetary benefits associated with renewables versus conventional energy production. For example, Siler-Evans et al. (2013) estimate that the displacement of greenhouse gas emissions by adopting wind and solar energy in the United States generates a social benefit of around $40 to $100 per MWh. Wiser et al. (2015) find that the displacement of greenhouse gas emissions due to wind can represent a net gain of roughly $400 billion by 2050 (United States). The same study finds that health benefits from wind can accrue to $52–$272 billion when compared to conventional energy sources, as well as reduced water use in terms of withdrawals (15%) and consumption (23%). Nonetheless, not much is known about monetary benefits at the project level, including the benefits of mitigation strategies, which project proponents and developers often view exclusively as costs. Therefore, it is difficult to find examples of cost-benefit analyses of energy infrastructure projects that include social and environmental dimensions.

TRADE-OFFS AMONG ENVIRONMENT, ECONOMY, AND SOCIETY

Currently there is no "ideal commercialized energy source – one that is simultaneously low-cost, low-impact, zero-carbon emissions, non-polluting, completely safe, found everywhere, and always available on demand" (Brook & Bradshaw 2015). To make informed decisions, energy project stakeholders must consider the costs and benefits, including the financial, environmental, and social costs and benefits, associated with each alternative.

Trade-offs between energy production and environmental conservation

As countries work to meet new climate change goals (e.g., net zero emissions of CO_2 and other greenhouse gasses), there is great international and national pressure for governments to invest in renewable, low-carbon sources. Indeed, governments of many countries are prioritizing investments in renewable energy infrastructure (IEA 2021c). However, renewable sources, although beneficial for reducing greenhouse gas emissions, might generate significant impacts on local biodiversity and ecosystem services (Sawyer et al. 2022). For example, grid-scale solar and wind power generation facilities take up a relatively large amount of land; their installation and associated distribution networks can fragment wildlife habitats and disrupt or destroy wildlife corridors, reducing ecosystem services such as pollination, food provision, and ecotourism. These services directly affect local communities that depend on them for subsistence and livelihoods. Land degradation also deteriorates other ecosystem services that go beyond wildlife habitat, such as water supply, carbon storage, and soil retention, which also hinders sustainable development.

Countries deploying renewable sources often have prioritized their energy production and climate benefits without addressing potential damage to wildlife and ecosystems. It is important that regulators, utilities, and other stakeholders identify the trade-offs from a wide perspective, considering impacts on wildlife, landscapes, and seascapes, as well as the potential loss of natural resource benefits such as hydrological services, erosion prevention, and access to non-timber forest products that could potentially be lost because of new energy infrastructure.

6 It is possible that there is a bias in the literature toward the evaluation of "bad infrastructure projects."

Trade-offs between energy outcomes and social goals

New electricity services may benefit urban consumers, while the associated infrastructure may cause damage in other communities–for example, by violating land rights, destroying fishing and farming areas, or displacing and resettling people. There is a benefit and cost distribution imbalance that often is not accounted for during the design phase of an infrastructure project.

Trade-offs between the costs and benefits of implementing mitigation measures upfront

Several studies have shown the net benefit of investing in avoidance and mitigation early in project development. The costs of investing in upfront measures are almost always lower than costs associated with mitigation measures after project completion. Nonetheless, this must be evaluated on a case-by-case basis because of the complexity of energy infrastructure projects and their impacts. This can be difficult if environmental and social costs are not evident, e.g., if investors and developers are not penalized for causing environmental and social harms or required to internalize environmental and social costs. Thus, there may be a mismatch between the environmental and social protection values held by many project stakeholders and the values of the investors and developers. Watkins et al. (2017) show that unresolved conflicts among energy project stakeholders are responsible for most project cancellations and delays in Latin America and the Caribbean, and the earliest phases of project design are especially vulnerable to conflict. The authors conclude that "the consequences of such conflicts are increasingly detrimental for companies, investors, and national governments, as conflicts cause projects to fail and harm national economies." Adequate preemptive environmental and social mitigation actions may be a potential longer-term solution to these challenges.

It is important to consider not only private costs but also costs of environmental and social externalities, i.e., direct and unintended effects on third parties not involved in the activity. Unfortunately, private project developers often consider interactions between wildlife and energy infrastructure as secondary. In the case of wind facilities, for example, the private costs associated with bird collisions might be close to zero, as collisions do not necessarily damage wind turbines. More generally, ecosystem damage caused by energy infrastructure might degrade ecosystem services that provide a range of benefits to people. Which costs to consider will depend on external factors such as legislation, environmental policies, and social pressure.

Trade-offs between energy infrastructure requirements and scale

There is growing literature on off-grid, small- and mini-scale systems to improve equity and local development (IRENA 2019b, Gebreslassie et al. 2022). However, small-scale systems usually are not connected to a national electric grid and cannot access dispatchable resources outside their own territory to balance energy demand and supply (Trondle et al. 2020). As a result, there is a greater need for higher generation capacity relative to the size of the population served in these smaller systems, compared to large-scale systems, although there are less requirements in terms of transmission and distribution.

Trade-offs between different land use outcomes

Land is a limited resource, yet there is increasing demand for it to produce more energy; to meet national and international conservation commitments, e.g., the "30 by 30" initiative[7]; and to produce more food, fiber, and fuel for growing human populations. In many locations, these activities will be limited by lack of land available (Santangeli et al. 2016), and competition for land may represent a direct risk to the land rights of affected communities, including frequently marginalized groups such as women and Indigenous populations. In addition, environmental impacts of energy production may be intensified when there is limited land available (Poggi et al. 2018, van de Ven et al. 2021). It is important to define early in the decision-making process the environmental and social indicators that stakeholders will use to compare alternatives, as well as the distribution of impacts. Local communities, for example, often bear greater costs because of top-down decision-making that fails to account for local people's needs for different land uses that support their livelihoods (USAID 2019).

Trade-offs among stakeholders

It is important to acknowledge that different populations have different energy needs, are impacted by energy projects differently, and access energy within specific social and cultural contexts. These contexts are shaped by laws and regulations, cultural norms, gender roles, and customary practices, all of which reflect local values, experiences, knowledge, power dynamics, and behaviors (see Box 2). When developing energy policies and projects, implementers should ask themselves:

- Who is the intervention benefiting?
- How might it impact women, Indigenous populations, and other frequently marginalized groups?
- How might these groups be instrumental partners in helping to realize energy and natural resource management goals?

BOX 2.

WOMEN AND ENERGY PROJECTS: CRITICAL YET UNDERAPPRECIATED FINDINGS

The USAID-commissioned report, Women at the Forefront of the Clean Energy Future (USAID 2014), highlights that energy project developers have only recently begun to effectively address gender considerations, and gender-and-climate considerations, in energy projects. Many renewable energy policies and investments currently lack an understanding of the potential differences in impacts on women and men and opportunities for enhancing gender equality. Further, although women (particularly Indigenous women) may be disproportionately impacted by negative impacts of large-scale rural energy development, there is a lack of gender-related data in the energy sector, including women's participation. Where gendered approaches have been studied and considered in energy work, it has led to strong positive results. For example, micro-finance schemes that target women increase access to energy technologies; studies have demonstrated that women energy entrepreneurs often outsell their male counterparts and are more effective at de-escalating conflict in community engagement efforts; and gender-informed marketing strategies increase sales among women customers.

7 The "30 by 30" initiative was launched by the High Ambition Coalition for Nature and People in 2020. The aim is to conserve 30% of Earth's land and sea areas by 2030 through "area-based conservation measures" (Mukpo 2021).

Solutions to avoid or mitigate negative interactions between energy infrastructure and the environment

There are numerous tools and approaches available to avoid or mitigate the impact of energy infrastructure projects on the environment. Many are easy-to-install and low-maintenance tools, but most typically are infrastructure project-, site-, and species-specific. Thus each case needs to be evaluated independently. For example, using a Before-After-Control-Impact approach – a recommended approach in the literature – May et al. (2020) shows that painting one of a wind turbine's rotor blades black reduces bird mortality by 70 percent when compared to unpainted turbines. Nicholson et al. (2018) suggest using grating boxes around poles to reduce interactions with large mammals such as buffaloes and elephants, thereby avoiding damage to the poles and animal electrocution. Other common solutions include targeted technology to reduce wildlife collisions like spinners, lighting and curtailment; measures to reduce electrocutions such as undergrounding and insulation; constructing wildlife crossings over or under linear infrastructure; and at a landscape scale, maintaining wildlife corridors.

However, such solutions can be difficult to generalize to universal recommendations because project-specific information is needed, including the type of infrastructure, location, wildlife species affected, stakeholder preferences, and the amount of funding available. Consequently, this study focused on system-wide solutions that can help project designers gather the information needed to make informed decisions. Several guidelines on best practices and environmentally friendly approaches exist to support the development of new, more sustainable energy infrastructure (OECD 2012, IFC 2012, USAID 2018, UNEP 2021 & 2022). These guidelines typically do not focus on specific techniques, but instead focus on how project proponents can better plan and design new infrastructure to maximize benefits while minimizing financial and economical costs, including environmental and social costs.

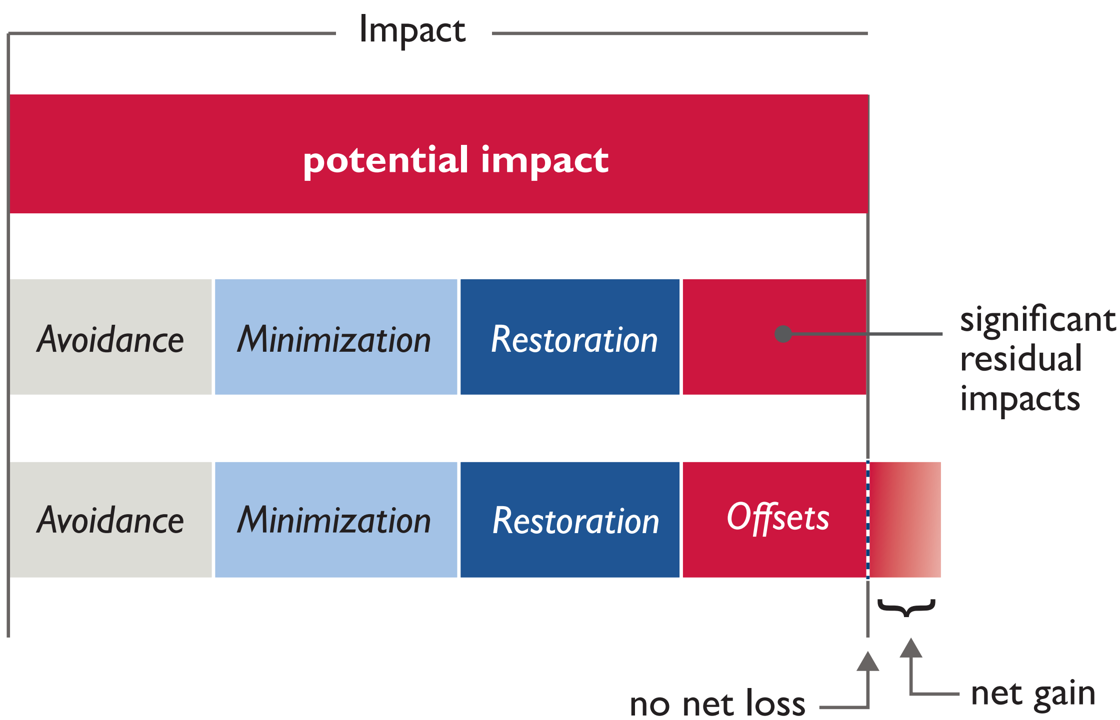
THE MITIGATION HIERARCHY APPROACH

The mitigation hierarchy is a commonly used approach to avoid or reduce the impact of infrastructure projects on people and the environment. It is fundamental to Environmental and Social Impact Assessment (ESIA, see next section), sometimes simply called Environmental Impact Assessment (EIA) (BBOP 2010) and may be defined as "the sequence of actions to anticipate and avoid impacts on biodiversity and ecosystem services; and where avoidance is not possible, minimize; and, when impacts occur, rehabilitate or restore; and where significant residual impacts remain, offset" (CSBI 2015).

For the sake of environmental and social protection, the most important step in the mitigation hierarchy decision process is for investors and project proponents to avoid negative impacts (Phalan et al. 2018, Jones et al. 2022). The second step, minimizing negative impacts that cannot be avoided, includes measures to reduce the damage, i.e., reduce the intensity and/or duration of the impact. When considered at the early stages of project design, these two steps will potentially lead to better conservation outcomes and save financial resources for utilities and distributors (CSBI 2015). Restoration, the third step, is recommended when environmental impacts may not be avoided or mitigated.

Project developers should plan to offset impacts that cannot be avoided, minimized, or restored at the site of infrastructure development. Offsetting typically is focused on conserving or restoring wildlife or ecosystems at a location other than the infrastructure site, to try to compensate for damage at the infrastructure site. However, offsetting residual impacts is not ideal. It usually is the most expensive option, and there is a growing literature on the challenges faced by restoration measures in capturing the ecosystem complexity and diversity that are lost as a result of development; offsetting also sometimes fails to involve local people (Gonçalves et al. 2015, Björnberg 2020, Simmonds et al. 2020, Tupala et al. 2022). Nonetheless, developers often favor offsetting as "an easier alternative than adherence to the earlier mitigation sequence steps, especially that of avoidance" (Hayes & Morrison-Saunders 2007). Figure 1 summarizes the mitigation hierarchy's four action steps.

Figure 1. Mitigation hierarchy components.



Source: CSBI 2015

Energy sector developers and other project proponents are increasingly using the mitigation hierarchy approach to reduce environmental impacts (Arlidge et al. 2018, Bennun et al. 2021, SAEP/EWT 2022), but researchers and practitioners also have published numerous studies highlighting the need for improvements. Arlidge et al. (2018), for example, stress several important and often overlooked considerations, such as the need to establish a conservation goal prior to implementing the mitigation hierarchy's action steps. The most common goal found in the literature is "No Net Loss," according to which negative impacts caused by a project are compensated by benefits resulting from measures to avoid or reduce those impacts. Less common is a goal to achieve "Net Gain." In this case, mitigation benefits outweigh project impacts. Both goals are valid, and project developers may include other goals. It also is critical that practitioners define the metrics and indicators they will use to quantify their goal(s) when using the mitigation hierarchy, as well as the expected impacts and benefits. Finally, when considering offsets for unavoidable impacts, practitioners should establish baseline and counterfactual scenarios to ensure that offsets are effective.

BETTER PROJECT DESIGN AND IMPLEMENTATION

Researchers and practitioners have published several guidelines on best practices to limit negative environmental and social impacts and improve resilience. These practices help energy project developers and other proponents, regulators, and national governments better understand trade-offs between development and conservation to make more informed decisions.

Environmental and Social Impact Assessment

There is substantial international consensus that the design and implementation of energy projects should include ESIA–a process that identifies a project's potential short- and long-term impacts on the environment and society and recommends solutions to avoid or mitigate those impacts. Nowadays, most countries, sometimes pressured by international funders, like Asian Development Bank, Inter-American Development Bank, International Finance Corporation (IFC), and the World Bank, require that project proponents conduct these assessments during the design stage. In particular, IFC Performance Standards have become international benchmarks for identifying and managing environmental and social risks (IFC 2012).

However, many countries follow different approaches, including whether to address social impacts (ESIA) or whether to focus only on environmental impacts (EIA), and they frequently have different regulations and quality standards for ESIA (Wood 2003, USAID 2013a, Gleason et al. 2014, UN Environment Programme 2018). For example, in India, many renewable energy infrastructure projects are exempt from such assessments, including wind power projects, solar photovoltaic power plants, biomass projects up to 15 MW, and hydropower plants that are less than 25 MW (Bhushan et al. 2013). In contrast, in Germany, wind projects with more than 20 turbines or that will clear more than ten hectares of forest need to present an EIA (ABO WIND 2021). Li (2008) provides a detailed overview of differences in EIA processes in developing countries and describes some international best- and worst-case performance scenarios (Table 6).


PHOTO: HERT NIKS | UNSPLASH

Table 6. ***Summary of international best and worst-case environmental assessment performance***

Best-case performance

The Environmental Impact Assessment (EIA) process:

- Facilitates informed decision-making by providing clear, well-structured, dispassionate analysis of the effects and consequences of proposed actions
- Assists in the selection of alternatives, including the selection of the best practicable or most environmentally friendly option
- Influences both project selection and policy design by screening out environmentally unsound proposals, as well as modifying feasible action
- Facilitates meaningful public engagement and review in at least two stages of the process: once when scoping the impacts and issues to be considered, and again during the presentation of initial findings of the EIA, including a non-technical summary
- Encompasses all relevant issues and factors, including cumulative effects, social impacts, and health risks
- Directs (not dictates) formal approvals, including the establishment of terms and conditions of implementation and follow-up
- Results in the satisfactory prediction of the adverse effects of proposed actions and their mitigation using conventional and customized techniques
- Serves as an adaptive, organizational learning process in which the lessons experienced are fed back into policy, institutions, and project designs

Worst-case performance

The Environmental Impact Assessment (EIA) process:

- Is inconsistently applied to development proposals with many sectors and classes of activity omitted
- Operates as a "stand-alone" process, poorly related to the project design and approval process, and consequently is of marginal influence
- Has a non-existent or weak follow-up process, lacking surveillance and enforcement of terms and conditions, monitoring impacts, etc.
- Does not consider cumulative effects or social, health, and risk factors
- Makes little or no reference to the public or public consultation is perfunctory, substandard, and takes no account of the specific requirements of affected groups
- Results in EIA reports that are voluminous, poorly organized, descriptive, generic and overly technical
- Provides information that is unhelpful or irrelevant to decision making
- Is inefficient, time-consuming, and costly in relation to the benefits delivered
- Understates and insufficiently mitigates environmental impacts and therefore loses credibility

Source: Li 2008

In addition to the worst-case performance scenarios highlighted in Table 5, there is a growing literature criticizing ESIA (or EIA) effectiveness in implementation (Jalava et al. 2010, Garrard et al. 2015, George et al. 2020). This study found examples of energy infrastructure projects that, despite having EIAs, should not be implemented given their environmental impact (e.g., Batang Toru Hydropower 510-MW project in North Sumatra [Rochmyaningsih 2020]). A recent study showed that projects are rarely rejected as a result of EIA (Fonseca & Gibson 2020). Below are some possible explanations found in the literature.

- **Timing of EIA's execution**. To be most effective, EIAs should be conducted early in the design stage of a project (Gleason et al. 2014). However, it is not uncommon to identify projects that were approved without conducting an environmental assessment at the early design stage.
- **Lack of time, financial resources, and capacity.** Project proponents often see EIA as a lengthy and costly process (Enríquez-de-Salamanca 2021) and, as a result, may seek to expedite the process, which can result in a check-box "green tape" sort of exercise (Morisson-Saunders et al. 2015).
- **Lack of public participation.** Some simplified EIAs do not include public participation (Enríquez-de-Salamanca 2021), or public participation might be highly political (O'Faircheallaigh 2010).
- **Lack of enforcement.** Project proponents might conduct poor quality EIAs to reduce costs or expedite the process, despite legislation that requires rigorous EIAs. India, for example, has strong regulations to protect the environment but weak enforcement policy (Jha-Thakur & Khosravi 2021).
- **Limited scope.** "EIA reports often fail to identify which species are at risk if the development intervention is to materialize or fail to examine the reasons why threatened species are threatened" (Wale & Yalew 2010). As a result, it is not fully possible to assess the project's impact on biodiversity.
- **Lack of consensus on the metrics and indicators to quantify the impacts, including cumulative impacts.** Studies highlight this point and the resulting inadequacy of EIAs to capture a wider range of impacts. This point is also related to the lack of data, including future trends and counterfactual scenarios. EIAs usually are conducted considering only a baseline scenario, i.e., the current situation. However, to accurately assess the impact of a proposed project, EIAs also should account for alternative scenarios in which environmental changes caused by the project are factored into predictions about future conditions.
- **Lack of transparency.** Many EIAs are not publicly available, reducing transparency in the decision-making process and allowing for corruption in countries with weak institutions (Li 2008).

To overcome these challenges, researchers and practitioners propose the following:

1. Conduct the ESIA at the early design stages of a project.
2. Conduct regular energy sector assessments to identify regional/national energy needs and prioritize projects.
3. Avoid quick assessments.
4. Provide enough financial support for the development of rigorous assessments.
5. Involve stakeholders throughout a project's planning and execution; ensure an inclusive process of consultation with affected communities, including women and other frequently marginalized groups.
6. For species conservation, define in advance of the project the types of species that should be prioritized, as well as the indicators used to quantify project impacts.
7. Invest in data collection, collaborative project design and monitoring, and information sharing.
8. Create not only the baseline scenario but also a counterfactual scenario.
9. Use an open and transparent process to reduce government corruption.

The first and second points might be two of the most important mentioned in the literature. There is consensus among researchers about the bad timing of most ESIAs, especially in developing countries, many of which have weak governance and inadequate enforcement of ESIA requirements. (*This point was confirmed in expert interviews*). Many development actors conduct ESIAs late in the project design process, and this timing inhibits communication between the project design and implementation teams and the ESIA team.

Regarding the second point, countries should "plan far ahead to ensure viable, least-cost, and low-impact combinations of technologies over time" (Carvallo et al. 2020). Currently, several Energy System Optimization Models (ESOM) such as SWITCH, MARKAL, OSeMOSYS, LEAP, NEMS, and PRIMES (Pfenninger et al. 2014, Johnston et al. 2019), exist to support countries' investment decisions (DeCarolis et al. 2017) and determine the portfolio of energy projects that are needed to achieve their energy needs while meeting conservation and social goals.

These proposed actions already are known by developers, but there is still a lack of support to adopt better practices for more effective ESIA, despite growing adherence from developers and practitioners in some countries. One explanation is that powerful project stakeholders, including utilities, often regard ESIA as an expensive process with minimal benefits. That belief may stem from a frequently skewed distribution of costs and benefits according to which project developers can reap financial benefits and achieve other development objectives, but too often are not required to internalize environmental and social costs; consequently, they might have minimal incentive to make investments to avoid those costs. Conducting more comprehensive cost-benefit analyses that take account of environmental and social costs could help rectify this situation and improve the ESIA process (see discussion below on economic feasibility analysis).

Strategic Environmental Assessment

Another commonly used tool to assess impacts and improve decision-making is the strategic environmental assessment (SEA) (World Bank 2012). While ESIA "occurs at the project level, (...) SEA is aimed more at the level of policy, planning, and programming. They differ both in the level of application and in the phase of planning," (Song et al. 2010) and they should not be understood as alternative tools, but rather as complementary ones. Table 7 shows the main characteristics of each type of assessment.

Table 7: Comparison between ESIA and SEA

ESIA (project-level)	SEA (policy, plans and programs)
Takes place at the end of the decision-making cycle	Takes place at the early stages of the decision-making cycle
Is a reactive approach to the proposal for development	Is a proactive approach to the proposal for development
Identifies specific impacts on the environment	Identifies environmental implications and issues of sustainable development
Considers a limited number of feasible alternatives	Considers a broad range of potential alternatives
Contains limited review of cumulative effects	Provides an early warning of cumulative effects
Emphasizes mitigating and minimizing impacts	Emphasizes meeting environmental objectives, maintaining natural systems
Has a narrow perspective with a high level of detail	Has a broad perspective with a lower level of detail to provide a vision and overall framework
Is conducted according to a well-defined process, with a clear beginning and end	Is conducted through a multi-stage, overlapping process
Focuses on a standard agenda, treats symptoms of environmental deterioration	Is iterative, focuses on a sustainability agenda, gets at sources of environmental deterioration

Source: Song et al. 2010.

Practitioners can use both ESIA and SEA to address not only environmental impacts but also social implications of project development. With both processes, the goal should be to ensure that project implementation promotes inclusive and effective participatory decision-making, community development, and empowerment.

The fact that SEA takes place at the early stages of infrastructure decision-making also can help avoid negative environmental and social impacts that might stem from investment decisions made before project design even starts. Frequently, infrastructure funders' investment decisions don't take into account alternatives or mitigation of environmental and social impacts, so some impacts might be "baked in" once decisionmakers begin to design individual projects. This can limit options for siting infrastructure in alternative locations or avoiding impacts, even if a rigorous ESIA is conducted in the design phase. Because SEA is focused more on policy and programming than on individual projects, decision-makers can use SEA to do more regional, longer-term planning.

One exceedingly important technique for conducting SEA is spatial analysis. Its use has increased in the last few years and is expected to "play a major role in the future" (Martínez-Gordón et al. 2021) as countries develop more energy infrastructure and transition to renewables (Stoeglehner 2020). Spatial analysis helps utilities, regulators, and other stakeholders to (i) define the best locations for the implementation of new energy infrastructure, considering energy, conservation, and socioeconomic outcomes, and (ii) identify biodiversity and ecosystems impacted by existing infrastructure and establish targeted mitigation measures.

For example, in 2015 Conservation Strategy Fund (CSF) conducted a study to evaluate the financial cost and environmental and social impacts related to construction of a transmission line between Colombia and Panama. Using spatial data and multicriteria analysis, CSF showed that the initial route not only was more expensive but also was less sustainable from an environmental and social perspective. Consequently, the project proponent identified an alternative route for the transmission line, in accordance with the national government (Campoverde et al. 2015).

Decommissioning Energy Infrastructure Projects

Finally, to better integrate environmental protection when planning energy infrastructure and guarantee that this infrastructure generates a net benefit over its whole life, it is important to consider the processes required for its decommissioning. These processes, which involve managing hazardous materials and reusing or disposing of other materials and components, often have been overlooked by stakeholders (Invernizzi et al. 2020).[8] The costs associated with decommissioning infrastructure are expected to increase in the coming years, but "few operators have put aside sufficient funds to effectively decommission their assets" (Invernizzi et al. 2020). One reason for this is the lack of clear policies and regulations worldwide for decommissioning energy infrastructure.

Some best practices for decommissioning include the following, taken from Brookes et al. (2019):

- Structural monitoring is essential to improve decisions on when to decommission.
- Sharing lessons across infrastructure decommissioning projects is essential to ensure that the current generation of infrastructure will be easier to decommission.

The transition from traditional stick-built infrastructure to modular infrastructure could facilitate and improve the performance of infrastructure decommissioning projects.

'Design for decommissioning' could ensure easier decommissioning, as well as reduce cost and risk to society, government, and industry.

Decommissioning could be part of an integrated national plan to, for example, reduce waste.

8 The exception is when analyzing nuclear power plants.

Integrating social impacts

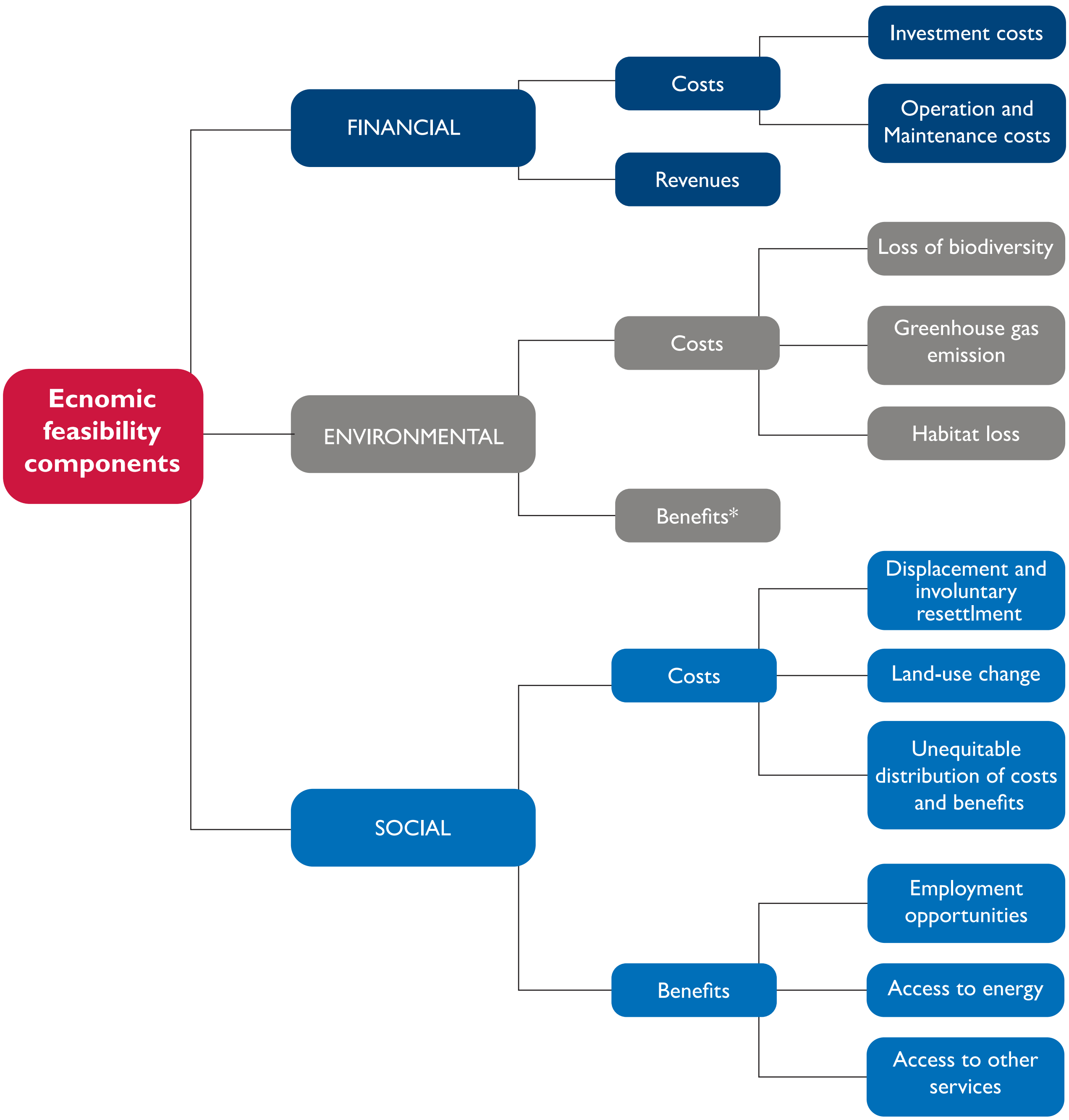
An energy infrastructure project's social impacts usually are considered as part of an Environmental and Social Impact Assessment (ESIA). Ideally, the ESIA or similar planning process should promote "empowerment of local people; enhancement of the position of women, minority groups, and other disadvantaged or marginalized members of society; development of capacity building; alleviation of all forms of dependency; increase in equity; and a focus on poverty reduction" (Vanclay 2003). Energy projects do produce many social benefits; there is no doubt that energy resources are fundamental to economic and social development; and there are several studies showing positive relationships between energy infrastructure and poverty alleviation (Schnitzer et al. 2014, Kammen 2020, Kemabonta & Kammen 2021).

There also is a growing literature showing that energy projects can exacerbate inequalities, especially between men and women and between socially dominant and marginalized communities (Snyder et al. 2018, USAID 2018, Stuner et al. 2019). The most common potentially negative social impact currently included in energy project planning is the possibility that local people might be displaced and/or resettled as a result of the project. Taken by itself, this consideration is insufficient. Without a more complete assessment of social costs and benefits associated with energy infrastructure projects, including a clear definition of who is bearing the costs and how they will be compensated in practice, it is difficult to determine a project's net benefit and viability.

ECONOMIC FEASIBILITY ANALYSIS

Part of the problem is that project design often is guided by financial feasibility studies, which are focused narrowly on financial costs and revenues. Authors like Branker et al. (2011) find that the majority of financial analyses are not suitable for renewable energy infrastructure, because they fail to consider risk and different actual financing methods available for these capital intensive projects. Conventionally, the ESIA is conducted as an additional assessment to the financial and technical feasibility of the project, mainly to identify mitigation strategies for environmental and social impacts. However, environmental and social components should be part of the project's discounted cost-benefit analysis (Okoye 2018) – in addition to factors such as competing energy rates, installation and operation costs, capital costs, capacity factors and technological improvements (Stockton 2004, Concolato et al. 2020). Bernal-Agustin and Dufo-Lopez (2006), for example, assess the economic feasibility of a photovoltaic system in Spain, by including both financial and environmental aspects, finding that the system is profitable and can attract investment but demands very long payback periods that can dissuade investors. Yang et al. (2012) conducts an economic feasibility analysis for wind farms in China, showing that the implications of energy savings and GHG emission reductions provide a substantial return for the project, when coupled with subsidies. Similar economic feasibility assessments have been conducted for the bioenergy sector and for hybrid renewable energy systems (Fantozzi 2014, Rinaldi, 2020). Incorporating costs and benefits from all three elements – financial, environmental, and social – produces a more complete economic feasibility analysis in an industry where public-private partnerships are necessary and frequently intended to promote sustainable development (Fantozzi 2014). Hence, besides traditional indicators such as the Net Present Value, Internal Rate of Return and Payback Periods, project design teams should look at the social costs and benefits arising from their energy infrastructure initiatives, which can have a direct economic impact on the project if they are internalized in the form of public taxes, incentives, or other imposed regulations. Figure 2 shows the components that should be included in an economic feasibility study, as well as some of the costs and benefits associated with each component.

Figure 2. *Economic feasibility components.*



**In the case of the environmental dimension, the benefits are usually measured as avoided costs and in comparison with other energy infrastructure projects. However, it is possible that as a result of an energy project some man-made structures (e.g., nests) may be created that generate a direct positive impact on the environment. In such cases, these benefits should be included as a component in the economic feasibility study.*

A SOCIAL CONCEPTUAL FRAMEWORK FOR ENERGY INFRASTRUCTURE PROJECTS

In previous sections we focused largely on environmental impacts, costs, benefits, and trade-offs associated with energy infrastructure. Here we highlight the social element of the decision-making process by recommending a social conceptual framework to promote greater integration of social costs and benefits with energy project design and implementation. We followed three steps to create a social conceptual framework based on Olander et al. (2018): (i) identify intermediary outcomes, (ii) identify social outcomes, and (iii) identify economic effects. We then divided the outcomes into four broad categories based on our review of energy infrastructure literature: (i) employment opportunities, (ii) access to energy, (iii) land-use change, and (iv) land rights and population displacement.

Table 8 shows intermediate outcomes, social outcomes, and economic effects of energy infrastructure projects organized into these four categories. A visual example of the social conceptual framework is presented in Figure 3.

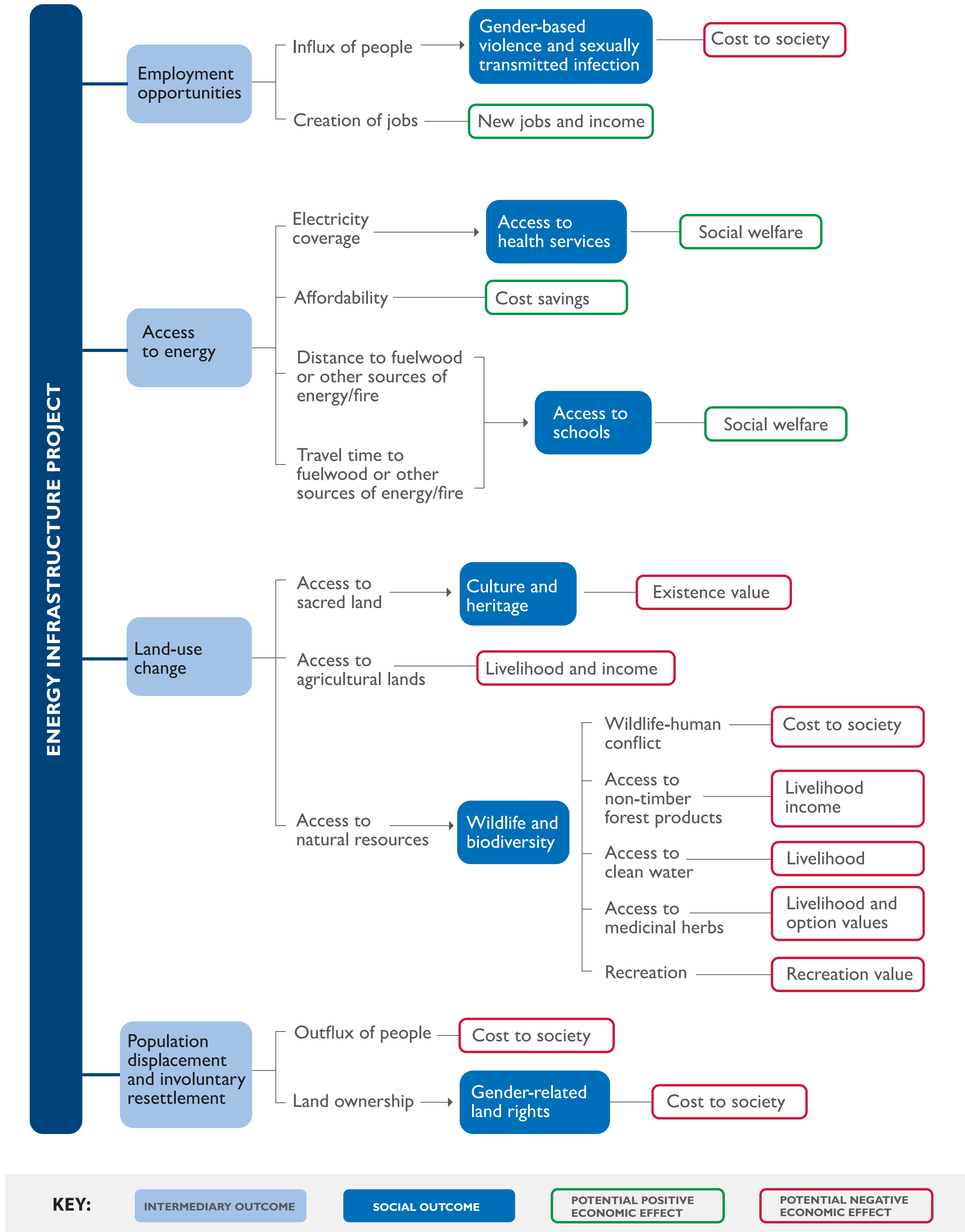
Table 8: *Social conceptual framework*

Intermediary outcome	Social outcome	Economic (well-being) effect	Potential direction of the effect
EMPLOYMENT OPPORTUNITIES			
Creation of jobs		New jobs and income (usually short-term)	Positive
Influx of people	Health impacts	Cost to society	Negative
	Gender-related violence		
ACCESS TO ENERGY			
Expanded electricity coverage	Increased access to health services	Social welfare (benefit to society)	Positive
Increased affordability		Cost savings	Positive
Reduced travel time to find fuelwood or other sources of energy/fire	Increased access to school	Social welfare (benefit to society)	Positive
LAND-USE CHANGE IMPACTS			
Reduced access to agricultural land		Livelihood and income	Negative
Reduced access to natural resources	Increased wildlife-human conflict	Cost to society	Negative
	Reduced access to non-timber forest products	Livelihood and income	Negative

Intermediary outcome	Social outcome	Economic (well-being) effect	Potential direction of the effect
	Reduced access to clean water	Livelihood	Negative
	Reduced access to medicinal herbs	Livelihood and option value	Negative
	Reduced access to recreation	Recreation value	Negative
Reduced access to sacred land	Culture and heritage	Cultural, existence, and bequeath value	Negative
LAND RIGHTS AND POPULATION DISPLACEMENT			
Outflux of people	Voluntary or involuntary resettlement	Cost to society	Negative
Land ownership	Land tenure changes, gender-related land rights	Cost to society	Negative

Note: The directions of the impacts given in this table result from a generalization based on the most common impacts found in the literature. In practical terms, the direction of a potential impact will be project-specific. Additionally, it is worth mentioning that the impacts will not have the same weights and will not be perceived in the same way by all stakeholders.

Figure 3. *Conceptual framework of the potential social impacts caused by energy infrastructure projects.*



Note: This figure shows the most common impacts identified in the literature. It should not be interpreted as an exhaustive list of potential social impacts caused by energy infrastructure projects.

The social conceptual framework provides a clear description of the most common relationships among energy infrastructure's social impacts and economic effects. Project design teams can use the framework to quantify and measure impacts (see Appendix B), guide consultations with affected communities, inform decision-makers about relevant questions to ask, and assess information needed to integrate social considerations with project financial and environmental assessments.

As Table 8 indicates, some general questions that apply to all energy infrastructure projects include:

- What are the expected intermediary outcomes?
- What are the expected social outcomes?
- Is it possible to estimate the economic value of the social impacts?
- How are social impacts distributed among affected communities?
- Will implementing the project enhance social equality or increase inequality?
- Are women and other frequently marginalized groups engaged in the project consultation and design process?

These questions should be asked at the earliest stages of project design. By answering, or at least discussing, these questions, regulators, utilities, affected communities, and other relevant stakeholders will have a better understanding of the social impacts associated with a project. Consequently, they will be better able to provide recommendations to minimize negative impacts and maximize positive ones (Power Africa 2018). The social consultation process is critically important and follows international best practices recommended for local communities to have the opportunity to provide *free, prior, and informed consent* (UN 2007).

Project design teams also should consider which indicators to use to measure social impacts. Table 9 lists potential indicators for each intermediary outcome included in the framework. These indicators are suggestions that stakeholders designing a project may consider during a process of consultation that includes gathering information from and building support among affected communities. To promote socially equitable energy infrastructure development, local communities should be informed and involved in weighing positive and negative impacts. Some of these may be subjective valuations that stakeholders value differently, so the consultation process should begin early and permit opportunities for negotiation and building consensus.

Table 9. *Potential indicators by intermediary outcome*

Intermediary outcome	Indicator
Creation of jobs	Number of local jobs created (by gender)
Influx of people	Number of workers moving to the local community (by gender) Change in incidence of gender-related violence * Change in incidence of sexually transmitted infections (by gender) *
Expanded electricity coverage	Percentage change of households within the community with electricity * Percentage change of households headed by women within the community with electricity *

Intermediary outcome	Indicator
Increased affordability	Electricity cost change relative to the average household income *
Reduced travel time to find fuelwood or other sources of energy/fire	Change in the time spent to access fuelwood or other sources of energy/fire *
	Change in the number of girls enrolled in elementary and middle schools *
Distance to fuelwood or other sources of energy/fire	Change in the distance to access fuelwood or other sources of energy/fire *
Reduced access to agricultural land	Number of hectares lost *
Reduced access to natural resources	Number of hectares lost *
Reduced access to sacred land	Number of hectares lost *
Outflux of people	Number of people moving to urban centers or other places (away from the community) (by gender) +
Land ownership	Percentage change of women who own land *

** A before-and-after assessment will be necessary to calculate values for these "change" indicators*

+ Some studies show that developers might pay less to compensate women when compared to men, and also women, especially those without husbands, might not be compensated with any land at all (USAID & IUCN 2018, Viña & Notess 2018).

Project designers also might wish to include other or additional indicators not listed here. Once the indicators are identified and quantified in their respective units, utilities, regulators, and other relevant stakeholders should attempt to estimate the economic value associated with each indicator. This task might not always be straightforward, e.g., for the economic valuation of recreation and existence values, but there are many studies on economic valuation of environmental and social impacts that could be used in these cases.

Conclusions

Although there are many publications describing the ways energy infrastructure can negatively affect the environment and communities, including guidelines and reports from researchers and practitioners around the world, many utilities and other project developers still fail to adequately address their negative impacts. To augment the research insights and recommendations presented in this report, this section highlights topics for future research and best practices that USAID is especially well positioned to promote.

FUTURE RESEARCH NEEDS

This literature review and interviews with experts uncovered significant gaps in knowledge about interactions between energy infrastructure and the environment. Future research to fill these gaps would further strengthen the evidence base, help make the "business case" for integrating environmental protection and social inclusion, and facilitate better design processes for more sustainable energy infrastructure.

In many locations and for numerous infrastructure projects, there is still a lack of evidence about:

- Costs of wildlife-caused damage to infrastructure.
- Costs of infrastructure-caused damage to wildlife and ecosystems, including both short-term and long-term cumulative impacts.
- Costs of infrastructure-caused damage to livelihoods in affected communities.
- Costs of large-scale, long-duration power interruptions.
- The economic feasibility of infrastructure projects, which would quantify not only financial but also environmental and social costs and benefits.
- The cost effectiveness of different mitigation strategies. Thus there is a lack of cost-benefit analysis of mitigation strategies and assessment of net benefits.
- Costs and benefits associated with trade-offs among different energy generation, transmission, and distribution options.

To help fill these gaps and improve infrastructure decision-making, USAID could sponsor research and data development initiatives, and USAID can work with utilities and other partners to collect (and gain access to) these kinds of data and information. For USAID-supported projects, in particular, it will be important to focus on research and evidence that informs existing Agency policies and directives such as USAID's Environmental Procedures, Gender Equality and Women's Empowerment Policy, guidelines for Effective Engagement with Indigenous Peoples: USAID Energy and Infrastructure Sector, and USAID Administrator Power's vision for global development that includes a focus on gender equity and inclusive development. USAID could make both "quick win" research investments–for example, a local wildlife survey may quickly reveal species-specific negative interactions that can be mitigated at low cost–as well as longer-term investments such as developing geospatial tools and analyses that would help the Agency and its partners identify environmental costs and plan to avoid larger landscape-level impacts.

There is consensus in the literature and among the interviewees we spoke to that utilities are facing more rigorous environmental and social regulations, as well as national and international pressure from regulators and societies around the world. However, we continue to identify energy infrastructure projects in which the environmental and social costs are greater than the financial benefits. This is especially true in developing countries where enforcement of environmental regulations tends to be weaker than in developed countries. USAID can help by sponsoring research to build the evidence base for environmental protection and social inclusion.

PROMOTING BEST PRACTICES

USAID also has many opportunities to promote best practices recommended in this report. One prime opportunity is to improve ESIA practices among USAID's partners. As noted above, there is substantial international consensus that the design and implementation of energy projects should include ESIA. USAID's own procedures for conducting ESIA–or, following USAID terminology, an Initial Environmental Examination or Environmental Assessment of proposed projects–are robust and thoroughly articulated (USAID Environmental Procedures 22 CFR 216). However, as this report has shown, many development actors encounter substantial challenges with ESIA implementation. USAID energy project designers, reviewers, and managers can help address these challenges, using the authority of USAID's Environmental Procedures and extensive network of USAID partners.

In addition to promoting more effective ESIA practices for individual projects, USAID also could use its convening authority to assemble partners to conduct strategic environmental assessments or other broad-focus, early-stage, regional planning initiatives in host countries. This could help alleviate problems stemming from the usual project-level efforts to avoid and mitigate impacts. For example, as noted above, infrastructure funders' investment decisions frequently do not take into account project alternatives or mitigation of environmental and social impacts, so some impacts might be "baked in" once decision-makers begin to design individual projects. Integrating environmental and social considerations into longer-term planning could avoid the most costly mitigation alternatives, such as relocating power lines. Because SEA is focused more on policy and programming than on individual projects, decision-makers can use SEA to do more regional, longer-term planning.

Finally, as a principal leader promoting gender equality and social inclusion in development projects, USAID could consider promoting the social conceptual framework presented in this report to encourage multi-stakeholder, inclusive project design; assess the social impacts of energy infrastructure projects; and monitor project implementation success.

References

ABO WIND. (2021, November 3). EIA Challenges in windfarm permission procedures [PowerPoint Slides]. https://energie-fr-de.eu/fr/manifestations/lecteur/conference-en-ligne-sur-leolien-terres-tre-et-les-procedures-dautorisations.html?file=files/ofaenr/02-conferences/2021/211102_Onshore%20Genehmigungsverfahren/Presentations/08_Urta_Steinhaeuser_ABO_Wind_OFATE_DFBEW.pdf

Adeyeye, K., Ijumba, N., & Colton, J. (2020). Exploring the environmental and economic impacts of wind energy: A cost-benefit perspective. International Journal of Sustainable Development & World Ecology, 27, 1–14. https://doi.org/10.1080/13504509.2020.1768171

Agbagwa, I. O., & Ndukwu, B. C. (2014). Oil and gas pipeline construction-induced forest fragmentation and biodiversity loss in the Niger Delta, Nigeria. Natural Resources, 5(12), 698.

Ale, S., Femeena, P. V., Mehan, S., & Cibin, R. (2019). Chapter 10—Environmental impacts of bioenergy crop production and benefits of multifunctional bioenergy systems. In J. C. Magalhães Pires & A. L. D. Cunha Gonçalves (Eds.), Bioenergy with Carbon Capture and Storage (pp. 195–217). Academic Press. https://doi.org/10.1016/B978-0-12-816229-3.00010-7

Arlidge, W. N. S., Bull, J. W., Addison, P. F. E., Burgass, M. J., Gianuca, D., Gorham, T. M., Jacob, C., Shumway, N., Sinclair, S. P., Watson, J. E. M., Wilcox, C., & Milner-Gulland, E. J. (2018). A Global Mitigation Hierarchy for Nature Conservation. BioScience, 68(5), 336–347. https://doi.org/10.1093/biosci/biy029

Barnes, T. A., Dwyer, J. F., Mojica, E. K., Petersen, P. A., & Harness, R. E. (2022). Wildland fires ignited by avian electrocutions. Wildlife Society Bulletin, 46(3), e1302. https://doi.org/10.1002/wsb.1302

Barrett, D. (2015). Wildlife induced outages and protection of overhead lines and substations. TE Connectivity.

Battaglini, A., & Bätjer, S. (2015). 9—Reducing the environmental impacts of power transmission lines. In J.-L. Bessède (Ed.), Eco-Friendly Innovation in Electricity Transmission and Distribution Networks (pp. 183–198). Woodhead Publishing. https://doi.org/10.1016/B978-1-78242-010-1.00009-4

BBOP. (Business and Biodiversity Offsets Programme). (2010). Biodiversity offsets and the mitigation hierarchy: a review of current application in the banking sector. https://www.unepfi.org/fileadmin/documents/biodiversity_offsets.pdf

Bennun, L., van Bochove, J., Ng, C., Fletcher, C., Wilson, D., Phair, N., & Carbone, G. (2021). Mitigating biodiversity impacts associated with solar and wind energy development: Guidelines for project developers. IUCN, International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2021.04.en

Bernal-Agustín, J. L., & Dufo-López, R. (2006). Economical and environmental analysis of grid connected photovoltaic systems in Spain. Renewable energy, 31(8), 1107-1128.

Biasotto, L. D., & Kindel, A. (2018). Power lines and impacts on biodiversity: A systematic review. Environmental Impact Assessment Review, 71, 110–119. https://doi.org/10.1016/j.eiar.2018.04.010

Bhushan, Chandra Sujit Kumar Singh, Swati Singh Sambyal and Kanchan Kumar Agrawal 2013, EIA Guidelines Wind Power Sector, Centre for Science and Environment, New Delhi

Björnberg, K. E. (2020). What, If Anything, Is Wrong with Offsetting Nature? Theoria, 86(6), 749–768. https://doi.org/10.1111/theo.12287

Branker, K., Pathak, M. J. M., & Pearce, J. M. (2011). A review of solar photovoltaic levelized cost of electricity. Renewable and sustainable energy reviews, 15(9), 4470-4482.

Brook, B. W., & Bradshaw, C. J. A. (2015). Key role for nuclear energy in global biodiversity conservation. Conservation Biology, 29(3), 702–712. https://doi.org/10.1111/cobi.12433

Brookes, N., Invernizzi, D. C., Locatelli, G. & Nikitas, N. (2019). Lessons from decommissioning. Highlights from the Major Projects Association event held on 7th March 2019. Retrieved from https://majorprojects.org/wp-content/uploads/2020/07/538highlightsde-commissioning.pdf

Carvallo, J. P., Feral, I., Kammen, D. M., Hartman, J., Sada, R., & Opperman, J. (2020). Paani Program | पानी परियोजना Energy Options Assessment. USAID Paani Program, USAID/Nepal.

Campoverde, D., Arrea, I. B., Díaz, M. C. V. & Bruner, A. (2015). Análisis comparativo de distintas rutas para la interconexión eléctrica Colombia–Panamá. Conservation Strategy Fund Technical Series 42.

Clark-Ginsberg, A. (2016). What's the Difference between Reliability and Resilience. Department of Homeland Security. March, 1932-4537.

Clarke, S. (2003). Electricity generation using small wind turbines at your home or farm.

Concolato, C. D. O. F., Cunha, M. R., & da Gama Afonso, H. C. A. (2020). Economic feasibility for photovoltaic solar energy projects: a systematic review. Revista produção e desenvolvimento, 6.

CSBI (Cross Sector Biodiversity Initiative). (2015). Mitigation Hierarchy Guide. Prepared by the Biodiversity Consultancy on behalf of IPIECA, ICMM and the Equator Principles Association: Cambridge UK. Retrieved July 13, 2022, from http://www.csbi.org.uk/our-work/mitigation-hierarchy-guide/

DeCarolis, J., Daly, H., Dodds, P., Keppo, I., Li, F., McDowall, W., Pye, S., Strachan, N., Trutnevyte, E., Usher, W., Winning, M., Yeh, S., & Zeyringer, M. (2017). Formalizing best practice for energy system optimization modelling. Applied Energy, 194, 184–198. https://doi.org/10.1016/j.apenergy.2017.03.001

Degraer, S., Carey, D. A., Coolen, J. W., Hutchison, Z. L., Kerckhof, F., Rumes, B., & Vanaverbeke, J. (2020). Offshore wind farm artificial reefs affect ecosystem structure and functioning. Oceanography, 33(4), 48-57.

Dhar, A., Naeth, M. A., Jennings, P. D., & Gamal El-Din, M. (2020). Geothermal energy resources: Potential environmental impact and land reclamation. Environmental Reviews, 28(4), 415–427. https://doi.org/10.1139/er-2019-0069

Diffendorfer, J. E., Dorning, M. A., Keen, J. R., Kramer, L. A., & Taylor, R. V. (2019). Geographic context affects the landscape change and fragmentation caused by wind energy facilities. PeerJ, 7. https://doi.org/10.7717/peerj.7129

Dincer, I. (1999). Environmental impacts of energy. Energy Policy, 27(14), 845–854. https://doi.org/10.1016/S0301-4215(99)00068-3

Dwyer, J. F., Harness, R. E., Gallentine, T., & Stewart, A. H. (2019). Bird-Caused Fires in ROWs. Environmental Concerns in Rights-of-Ways Management. 12th International Symposium.

Elliot, R., Aaronson, S. & National Rural Electric Cooperative Association. (2019). Utility Investments in Resilience of Electricity Systems (No. 1506414; p. 1506414). https://doi.org/10.2172/1506414

Energy and Environmental Economics, Inc. 2005. The Cost of Wildlife-Caused Power Outages to California's Economy. California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2005-030.

Enríquez-de-Salamanca, A. (2021). Simplified environmental impact assessment processes: Review and implementation proposals, Environmental Impact Assessment Review, 90, 106640, ISSN 0195-9255, https://doi.org/10.1016/j.eiar.2021.106640.

European Commission, Directorate-General for Environment, (2015). Wind & solar energy and nature conservation, Publications Office. https://data.europa.eu/doi/10.2779/54166 antozzi, F., Bartocci, P., D'Alessandro, B., Arampatzis, S., & Manos, B. (2014). Public–private partnerships value in bioenergy projects: Economic feasibility analysis based on two case studies. Biomass and bioenergy, 66, 387-397.

Fritts, T. H. (2002). Economic costs of electrical system instability and power outages caused by snakes on the Island of Guam. In International Biodeterioration and Biodegradation (Vol. 49, p. 93100). https://doi.org/10.1016/S0964-8305(01)00108-1

Fonseca, A & Gibson, R. B. (2021) Why are projects rarely rejected in environmental impact assessments? Narratives of justifiability in Brazilian and Canadian review reports, Journal of Environmental Planning and Management, 64:11, 1940-1962, DOI: 10.1080/09640568.2020.1852073

Garrard, G. E., Bekessy, S. A., McCarthy, M. A., & Wintle, B. A. (2015). Incorporating detectability of threatened species into environmental impact assessment. Conservation Biology, 29(1), 216-225.

Gonçalves, B., Marques, A., Soares, A. M. V. D. M., & Pereira, H. M. (2015). Biodiversity offsets: From current challenges to harmonized metrics. Current Opinion in Environmental Sustainability, 14, 61–67. https://doi.org/10.1016/j.cosust.2015.03.008

Gasparatos, A., Doll, C. N. H., Esteban, M., Ahmed, A., & Olang, T. A. (2017). Renewable energy and biodiversity: Implications for transitioning to a Green Economy. Renewable and Sustainable Energy Reviews, 70, 161–184. https://doi.org/10.1016/j.rser.2016.08.030

Gebreslassie, M. G., Cuvilas, C., Zalengera, C., To, L. S., Baptista, I., Robin, E., Bekele, G., Howe, L., Shenga, C., Macucule, D. A., Kirshner, J., Mulugetta, Y., Power, M., Robinson, S., Jones, D., & Castán Broto, V. (2022). Delivering an off-grid transition to sustainable energy in Ethiopia and Mozambique. Energy, Sustainability and Society, 12(1), 23. https://doi.org/10.1186/s13705-022-00348-2

George, T. E., Karatu, K., & Edward, A. (2020). An evaluation of the environmental impact assessment practice in Uganda: Challenges and opportunities for achieving sustainable development. Heliyon, 6(9), e04758. https://doi.org/10.1016/j.heliyon.2020.e04758

Gibson, L., Wilman, E. N., & Laurance, W. F. (2017). How green is 'green'energy?. Trends in ecology & evolution, 32(12), 922-935.

Glarou, M., Zrust, M., & Svendsen, J. C. (2020). Using artificial-reef knowledge to enhance the ecological function of offshore wind turbine foundations: Implications for fish abundance and diversity. Journal of Marine Science and Engineering, 8(5), 332.

Gleason, J., Arrea, I. B., Mitchell, E. and Bruner, A. 2014. Moving towards Greener Infrastructure: Innovative Legal Solutions to Common Challenges. Conservation Strategy Fund Discussion Paper No. 6. Conservation Strategy Fund & Environmental Law Alliance Worldwide. Retrieved from https://www.conservation-strategy.org/sites/default/files/field-file/CSF_eLaw_Moving_Towards_Greener_Infrastructure.pdf on June 10, 2022.

Grodsky, S. M., & Hernandez, R. R. (2020). Reduced ecosystem services of desert plants from ground-mounted solar energy development. Nature Sustainability, 3(12), 1036–1043. https://doi.org/10.1038/s41893-020-0574-x

Gündüz, N., Küfeoğlu, S., & Lehtonen, M. (2017). Impacts of Natural Disasters on Swedish Electric Power Policy: A Case Study. Sustainability, 9(2), 230.

Haddad, N. M., Brudvig, L. A., Clobert, J., Davies, K. F., Gonzalez, A., Holt, R. D., Lovejoy, T. E., Sexton, J. O., Austin, M. P., Collins, C. D., Cook, W. M., Damschen, E. I., Ewers, R. M., Foster, B. L., Jenkins, C. N., King, A. J., Laurance, W. F., Levey, D. J., Margules, C. R., … Townshend, J. R. (2015). Habitat fragmentation and its lasting impact on Earth's ecosystems. Science Advances, 1(2), e1500052. https://doi.org/10.1126/sciadv.1500052

Hallegatte, S., Rentschler, J., & Rozenberg, J. (2019). Lifelines: The resilient infrastructure opportunity. World Bank Publications.

Harrison-Atlas, D., Lopez, A., & Lantz, E. (2022). Dynamic land use implications of rapidly expanding and evolving wind power deployment. Environmental Research Letters, 17(4), 044064. https://doi.org/10.1088/1748-9326/ac5f2c.

Hayes, N., & Morrison-Saunders, A. (2007). Effectiveness of environmental offsets in environmental impact assessment: Practitioner perspectives from Western Australia. Impact Assessment and Project Appraisal, 25(3), 209–218. https://doi.org/10.3152/146155107X227126

Hernandez, R. R., Easter, S. B., Murphy-Mariscal, M. L., Maestre, F. T., Tavassoli, M., Allen, E. B., Barrows, C. W., Belnap, J., Ochoa-Hueso, R., Ravi, S., & Allen, M. F. (2014). Environmental impacts of utility-scale solar energy. Renewable and Sustainable Energy Reviews, 29, 766–779. https://doi.org/10.1016/j.rser.2013.08.041

Hernandez, R. R., Hoffacker, M. K., Murphy-Mariscal, M. L., Wu, G. C., & Allen, M. F. (2015). Solar energy development impacts on land cover change and protected areas. Proceedings of the National Academy of Sciences, 112(44), 13579–13584. https://doi.org/10.1073/pnas.1517656112

Hjort et al. 2022 https://www.nature.com/articles/s43017-021-00247-8

Hrouda, J., & Brlík, V. (2021). Birds in power-line corridors: effects of vegetation mowing on avian diversity and abundance. Journal of Vertebrate Biology, 70(2), 21027-1.

IAEA (International Atomic Energy Agency). 2019. Adapting the energy sector to climate change. IAEA, Vienna. https://www-pub.iaea.org/MTCD/Publications/PDF/P1847_web.pdf

IEA (International Energy Agency)a. (2021). Electricity Market Report–July 2021. IEA, Paris. https://www.iea.org/reports/electricity-market-report-july-2021

IEA (International Energy Agency)b. (2021). Renewables 2021. IEA, Paris https://www.iea.org/reports/renewables-2021

IEA (International Energy Agency)c (2021), Financing clean energy transitions in emerging and developing economies, IEA, Paris https://www.iea.org/reports/financing-clean-energy-transitions-in-emerging-and-developing-economies

IEA (International Energy Agency). (2022). Africa Energy Outlook 2022. World Energy Outlook Special Report, IEA, Paris.

IFC (International Finance Corporation). (2012.). Performance Standards on Environmental and Social Sustainability.

Invernizzi, D. C., Locatelli, G., Velenturf, A., Love, P. ED., Purnell, P., & Brookes, N. J. (2020). Developing policies for the end-of-life of energy infrastructure: Coming to terms with the challenges of decommissioning. Energy Policy, 144, 111677. https://doi.org/10.1016/j.enpol.2020.111677

IRENA (International Renewable Energy Agency) (2019a). Global energy transformation: A roadmap to 2050 (2019 edition). International Renewable Energy Agency, Abu Dhabi.

IRENA (International Renewable Energy Agency) (2019b). Off-grid renewable energy solutions to expand electricity access: An opportunity not to be missed, International Renewable Energy Agency, Abu Dhabi.

IRENA (International Renewable Energy Agency) (2016). Unlocking Renewable Energy Investment: The Role of Risk Mitigation and Structured Finance. International Renewable Energy Agency, Abu Dhabi

Jaber, S. (2013). Environmental Impacts of Wind Energy. Journal of Clean Energy Technologies, 251–254. https://doi.org/10.7763/JOCET.2013.V1.57

Jaeger, J. (2021). Explaining the Exponential Growth of Renewable Energy. World Resources Institute. Retrieved from https://www.wri.org/insights/growth-renewable-energy-sector-explained (June 23, 2022).

Jalava, K., Pasanen, S., Saalasti, M., & Kuitunen, M. (2010). Quality of Environmental Impact Assessment: Finnish EISs and the opinions of EIA professionals. Impact Assessment and Project Appraisal, 28(1), 15–27. https://doi.org/10.3152/146155110X488826

Jha-Thakur, U., & Khosravi, F. (2021). Beyond 25 years of EIA in India: Retrospection and way forward. Environmental Impact Assessment Review, 87, 106533. doi:10.1016/j.eiar.2020.106533

Jericó-Daminello, C., Seehusen, S. E., Arrea, I. B., Bruner, A., Ane, A. A., & Piontekowski, V. (2016). Impactos econômicos da construção da hidrelétrica de São Luis do Tapajós: uma análise do provimento de serviços ecossitêmicos. Conservation Strategy Fund.

Jones, N. F., Pejchar, L., & Kiesecker, J. M. (2015). The Energy Footprint: How Oil, Natural Gas, and Wind Energy Affect Land for Biodiversity and the Flow of Ecosystem Services. BioScience, 65(3), 290–301. https://doi.org/10.1093/biosci/biu224

Jones, K. R., von Hase, A., Costa, H. M., Rainey, H., Sidat, N., Jobson, B., White, T. B., & Grantham, H. S. (2022). Spatial analysis to inform the mitigation hierarchy. Conservation Science and Practice, 4(6), e12686. https://doi.org/10.1111/csp2.12686

Johnston, J., Henriquez-Auba, R., Maluenda, B., & Fripp, M. (2019). Switch 2.0: A modern platform for planning high-renewable power systems. SoftwareX, 10, 100251. https://doi.org/10.1016/j.softx.2019.100251

Kammen, D. M. (2020). Defeating Energy Poverty: Invest in Scalable Solutions for the Poor. In Health of People, Health of Planet and Our Responsibility (pp. 333-347). Springer, Cham.

Kemabonta, T., & Kammen, D. M. (2021). A community based approach to universal energy access. The Electricity Journal, 34(3), 106921.

Kolnegari, M., Conway, G. J., Basiri, A. A., Panter, C. T., Hazrati, M., Rafiee, M. S., ... & Dwyer, J. F. (2021). Electrical components involved in avian-caused outages in Iran. Bird Conservation International, 31(3), 364-378.

Krog, L., & Sperling, K. (2019). A comprehensive framework for strategic energy planning based on Danish and international insights. Energy Strategy Reviews, 24, 83–93. https://doi.org/10.1016/j.esr.2019.02.005

LaCommare, K., Larsen, P., & Eto, J. (2017). Evaluating Proposed Investments in Power System Reliability and Resilience: Preliminary Results from Interviews with Public Utility Commission Staff (LBNL—1006971, 1342947; p. LBNL—1006971, 1342947). https://doi.org/10.2172/1342947

Langlois, L. A., Drohan, P. J., & Brittingham, M. C. (2017). Linear infrastructure drives habitat conversion and forest fragmentation associated with Marcellus shale gas development in a forested landscape. Journal of Environmental Management, 197, 167-176.

Larsen, P. H. (2016). Severe weather, power outages, and a decision to improve electric utility reliability. Ph.D. Dissertation, Department of Management Science and Engineering, Stanford University.

Larsen, P. H., Boehlert, B., Eto, J., Hamachi-LaCommare, K., Martinich, J., & Rennels, L. (2018). Projecting future costs to U.S. electric utility customers from power interruptions. Energy, 147, 1256–1277. https://doi.org/10.1016/j.energy.2017.12.081

Li, J. C. (2008). Environmental Impact Assessment in Developing Countries: An Opportunity for Greater Environmental Security? FESS Working Paper 8. USAID & Foundation for Environmental Security and Sustainability

Li, Y., Stewart, M. G., & Bjarnadottir, S. (2014). Risk Assessment and Wind Hazard Mitigation of Power Distribution Poles. Maintenance and Safety of Aging Infrastructure: Structures and Infrastructures Book Series, Vol. 10, 10, 407.

Lovich, J. E., & Ennen, J. R. (2011). Wildlife Conservation and Solar Energy Development in the Desert Southwest, United States. BioScience, 61(12), 982–992. https://doi.org/10.1525/bio.2011.61.12.8

Lowery, S. & Vhugen, D. (2016). Land Tenure and Energy Infrastructure: Strengthening And Clarifying Land Rights In Energy Infrastructure Projects And Programming. USAID Issue Brief.

Lucas, M. de, Ferrer, M., & Janss, G. F. E. (2012). Using Wind Tunnels to Predict Bird Mortality in Wind Farms: The Case of Griffon Vultures. PLOS ONE, 7(11), e48092. https://doi.org/10.1371/journal.pone.0048092

May, R. F., Bevanger, K. M., Dijk, J. J. V., Petrin, Z., & Brende, H. (2012). Renewable energy respecting nature. A synthesis of knowledge on environmental impacts of renewable energy financed by the Research Council of Norway.

May, R., Nygård, T., Falkdalen, U., Åström, J., Hamre, Ø., & Stokke, B. (2020). Paint it black: Efficacy of increased wind turbine rotor blade visibility to reduce avian fatalities. Ecology and Evolution, 10. https://doi.org/10.1002/ece3.6592

Martínez-Gordón, R., Morales-España, G., Sijm, J., & Faaij, A. P. C. (2021). A review of the role of spatial resolution in energy systems modelling: Lessons learned and applicability to the North Sea region. Renewable and Sustainable Energy Reviews, 141, 110857. https://doi.org/10.1016/j.rser.2021.110857

McDonald, R. I., Fargione, J., Kiesecker, J., Miller, W. M., & Powell, J. (2009). Energy sprawl or energy efficiency: climate policy impacts on natural habitat for the United States of America. PloS one, 4(8), e6802.

Mcnew, L. B., Hunt, L. M., Gregory, A. J., Wisely, S. M., & Sandercock, B. K. (2014). Effects of Wind Energy Development on Nesting Ecology of Greater Prairie-Chickens in Fragmented Grasslands. Conservation Biology, 28(4), 1089–1099. https://doi.org/10.1111/cobi.12258

McKinsey & Company. (2022). Global Energy Perspective 2022–Executive Summary, April 2022. https://www.mckinsey.com/~/media/McKinsey/Industries/Oil%20and%20Gas/Our%20Insights/Global%20Energy%20Perspective%202022/Global-Energy-Perspective-2022-Executive-Summary.pdf

Moghaddam, N.B., Nasiri, M. & Mousavi, S.M. (2011). An appropriate multiple criteria decision making method for solving electricity planning problems, addressing sustainability issue. Int. J. Environ. Sci. Technol. 8, 605–620. https://doi.org/10.1007/BF03326246

Morelli, F., Beim, M., Jerzak, L., Jones, D., & Tryjanowski, P. (2014). Can roads, railways and related structures have positive effects on birds?–A review. Transportation Research Part D: Transport and Environment, 30, 21-31.

Morrison-Saunders, A., Bond, A., Pope, J. & Retief, F. (2015). Demonstrating the benefits of impact assessment for proponents, Impact Assessment and Project Appraisal, 33:2, 108-115, DOI: 10.1080/14615517.2014.981049

Mukpo, A. (2021). As COP15 approaches, '30 by 30' becomes a conservation battleground. Mongabay. Retrieved from https://news.mongabay.com/2021/08/as-cop15-approaches-30-by-30-becomes-a-conservation-battleground/ (on August 31, 2022)

Nazir, M. S., Mahdi, A. J., Bilal, M., Sohail, H. M., Ali, N., & Iqbal, H. M. N. (2019). Environmental impact and pollution-related challenges of renewable wind energy paradigm – A review. Science of The Total Environment, 683, 436–444. https://doi.org/10.1016/j.scitotenv.2019.05.274

NIAC. (National Infrastructure Advisory Council). (2009). Critical Infrastructure Resilience Final Report and Recommendations. National Infrastructure Advisory Council.

Nelson, J. P. & Lankutis, J. D. (2014). Accurate evaluation of cost for power reliability issues for electric utility customers. 2014 IEEE Rural Electric Power Conference (REPC), pp. C2-1-C2-11, doi: 10.1109/REPCon.2014.6842207.

Nicholson, S., Tate, G., Hoogstad, C., Murison, M., Diamond, M., Blofield, A., Pretorius, M., & Michael, M. (2018). Mitigating the Impact of Large Mammals on Wooden Electrical Distribution Poles in the Kruger National Park, South Africa. African Journal of Wildlife Research, 48, 023006. https://doi.org/10.3957/056.048.023006

OECD (2012), Strategic Environmental Assessment in Development Practice: A Review of Recent Experience, OECD Publishing, Paris, https://doi.org/10.1787/9789264166745-en.

O'Faircheallaigh, C. (2010). Public participation and environmental impact assessment: Purposes, implications, and lessons for public policy making, Environmental Impact Assessment Review, 30, (1) 19-27, ISSN 0195-9255, https://doi.org/10.1016/j.eiar.2009.05.001.

Okoye, C. O., & Oranekwu-Okoye, B. C. (2018). Economic feasibility of solar PV system for rural electrification in Sub-Sahara Africa. Renewable and Sustainable Energy Reviews, 82, 2537-2547.

Olander, Lydia, Sara Mason, Katie Warnell, and Heather Tallis. 2018. Building Ecosystem Services Conceptual Models. National Ecosystem Services Partnership Conceptual Model Series No. 1. Durham, NC: Duke University, Nicholas Institute for Environmental Policy Solutions. https://nicholasinstitute.duke.edu/sites/default/files/publications/building-escms-web.pdf

Pacific Gas and Electric Company. (2020). An Inside Look at Electric Reliability: 2019 Electric Reliability Report. https://www.pge.com/pge_global/common/pdfs/outages/planning-and-preparedness/safety-and-preparedness/grid-reliability/electric-reliability-reports/2020-Electric-Reliability-Presentation-for-2019-Reliability.pdf

Parvatam, S. (2019). Is the drive for clean energy throwing environmental caution to the wind? Nature India. https://www.nature.com/articles/nindia.2019.78

Paskal, C. (2009). The vulnerability of energy infrastructure to environmental change. London: Chatham House.

Pfenninger, S., Hawkes, A., & Keirstead, J. (2014). Energy systems modeling for twenty-first century energy challenges. Renewable and Sustainable Energy Reviews, 33, 74–86. https://doi.org/10.1016/j.rser.2014.02.003

Phalan, B., Hayes, G., Brooks, S., Marsh, D., Howard, P., Costelloe, B., Vira, B., Kowalska, A., & Whitaker, S. (2018). Avoiding impacts on biodiversity through strengthening the first stage of the mitigation hierarchy. Oryx, 52(2), 316–324. https://doi.org/10.1017/S0030605316001034

Poggi, F., Firmino, A., & Amado, M. (2018). Planning renewable energy in rural areas: Impacts on occupation and land use. Energy, 155, 630–640. https://doi.org/10.1016/j.energy.2018.05.009

Power Africa. (2018). Guide to community engagement for power projects in Kenya. USAID, Kenya. Available at: www.usaid.gov/powerafrica/kenya.

Prather, P. R., & Messmer, T. A. (2010). Raptor and corvid response to power distribution line perch deterrents in Utah. The Journal of Wildlife Management, 74(4), 796-800.

PSC (Public Service Comission). (n.d.). Environmental Impacts of Transmission Lines. Retrived on October 6th from https://psc.wi.gov/Documents/Brochures/Enviromental%20Impacts%20TL.pdf

Rabaia, M. K. H., Abdelkareem, M. A., Sayed, E. T., Elsaid, K., Chae, K.-J., Wilberforce, T., & Olabi, A. G. (2021). Environmental impacts of solar energy systems: A review. Science of The Total Environment, 754, 141989. https://doi.org/10.1016/j.scitotenv.2020.141989

Rahman, A., Farrok, O., & Haque, M. M. (2022). Environmental impact of renewable energy source based electrical power plants: Solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic. Renewable and Sustainable Energy Reviews, 161, 112279. https://doi.org/10.1016/j.rser.2022.112279

Richardson, M. L., Wilson, B. A., Aiuto, D. A., Crosby, J. E., Alonso, A., Dallmeier, F., & Golinski, G. K. (2017). A review of the impact of pipelines and power lines on biodiversity and strategies for mitigation. Biodiversity and Conservation, 26(8), 1801-1815.

Rickerson, Wilson & Gillis, Jonathan & Bulkeley, Marisa. (2019). The Value of Resilience for Distributed Energy Resources: An Overview of Current Analytical Practices. Report prepared for The National Association of Regulatory Utility Commissioners by Converge Strategies, LLC.

Rinaldi, F., Moghaddampoor, F., Najafi, B., & Marchesi, R. (2021). Economic feasibility analysis and optimization of hybrid renewable energy systems for rural electrification in Peru. Clean technologies and environmental policy, 23(3), 731-748.

Rochmyaningsih, D. (2020). Dam threatening world's rarest great ape faces delays. https://www.science.org/content/article/dam-threatening-world-s-rarest-great-ape-faces-delays

Rodin, J. (2014). The Resilience Dividend: Being Strong in a World Where Things Go Wrong. First Edition. PublicAffairs.

SAEP/EWT (2022). Mainstreaming Wildlife Incident Management into Utilities in Southern Africa. Johannesburg: USAID Southern Africa Energy Program and the Endangered Wildlife Trust.

Saidur, R., Rahim, N. A., Islam, M. R., & Solangi, K. H. (2011). Environmental impact of wind energy. Renewable and sustainable energy reviews, 15(5), 2423-2430.

Sánchez-Zapata, J. A., Clavero, M., Carrete, M., DeVault, T. L., Hermoso, V., Losada, M. A., Polo, M. J., Sánchez-Navarro, S., Pérez-García, J. M., Botella, F., Ibáñez, C., & Donázar, J. A. (2016). Effects of Renewable Energy Production and Infrastructure on Wildlife. In R. Mateo, B. Arroyo, & J. T. Garcia (Eds.), Current Trends in Wildlife Research (Vol. 1, pp. 97–123). Springer International Publishing. https://doi.org/10.1007/978-3-319-27912-1_5

Santangeli, A., Di Minin, E., Toivonen, T., Pogson, M., Hastings, A., Smith, P., & Moilanen, A. (2016). Synergies and trade-offs between renewable energy expansion and biodiversity conservation – a cross-national multifactor analysis. GCB Bioenergy, 8(6), 1191–1200. https://doi.org/10.1111/gcbb.12337

Sawyer, H., Korfanta, N. M., Kauffman, M. J., Robb, B. S., Telander, A. C., & Mattson, T. (2022). Trade-offs between utility-scale solar development and ungulates on western rangelands. Frontiers in Ecology and the Environment, 20(6), 345–351. https://doi.org/10.1002/fee.2498

Sayed, E. T., Wilberforce, T., Elsaid, K., Rabaia, M. K. H., Abdelkareem, M. A., Chae, K.-J., & Olabi, A. G. (2021). A critical review on environmental impacts of renewable energy systems and mitigation strategies: Wind, hydro, biomass and geothermal. Science of The Total Environment, 766, 144505. https://doi.org/10.1016/j.scitotenv.2020.144505

Schnitzer, D., Lounsbury, D. S., Carvallo, J. P., Deshmukh, R., Apt, J., & Kammen, D. M. (2014). Microgrids for Rural Electrification: A critical review of best practices based on seven case studies. United Nations Foundation.

Schöll, E. M., & Nopp-Mayr, U. (2021). Impact of wind power plants on mammalian and avian wildlife species in shrub- and woodlands. Biological Conservation, 256, 109037. https://doi.org/10.1016/j.biocon.2021.109037

SEER U.S. Offshore Wind Synthesis of Environmental Effects Research. (2022). Electromagnetic Field Effects on Marine Life. Report by National Renewable Energy Laboratory and Pacific Northwest National Laboratory for the U.S. Department of Energy, Wind Energy Technologies Office. Available at https://tethys.pnnl.gov/seer.

Serra, P., Giuntoli, J., Agostini, A., Colauzzi, M., & Amaducci, S. (2017). Coupling sorghum biomass and wheat straw to minimize the environmental impact of bioenergy production. Journal of Cleaner Production, 154, 242–254. https://doi.org/10.1016/j.jclepro.2017.03.208

Shin, J., Tiwari, A., Aweh, A., & Weishaeupl, S. (2021). Building a Resilient Grid to Combat and Adapt to Changing Climate Conditions. Climate and Energy, 38(3), 1-10.

Siler-Evans, K., Azevedo, I. L., Morgan, M. G., & Apt, J. (2013). Regional variations in the health, environmental, and climate benefits of wind and solar generation. Proceedings of the National Academy of Sciences, 110(29), 11768–11773. https://doi.org/10.1073/pnas.1221978110

Simmonds, J. S., Sonter, L. J., Watson, J. E. M., Bennun, L., Costa, H. M., Dutson, G., Edwards, S., Grantham, H., Griffiths, V. F., Jones, J. P. G., Kiesecker, J., Possingham, H. P., Puydarrieux, P., Quétier, F., Rainer, H., Rainey, H., Roe, D., Savy, C. E., Souquet, M., … Maron, M. (2020). Moving from biodiversity offsets to a target-based approach for ecological compensation. Conservation Letters, 13(2), e12695. https://doi.org/10.1111/conl.12695

Snyder, V., Carvalho Metanias Hallack, M., & Larrea, S. (2018). Gender and Energy: The Balance of Power. Inter-American Development Bank. https://policycommons.net/artifacts/304927/gender-and-energy/1222115/

Song, Y-I, Park, D., Shin, G., Kim, C. & Grigg, N. S. (2010) Strategic environmental assessment for dam planning: a case study of South Korea's experience, Water International, 35:4, 397-408, DOI: 10.1080/02508060.2010.506268

Stoeglehner, G. (2020). Integrated spatial and energy planning: A means to reach sustainable development goals. Evolutionary and Institutional Economics Review, 17(2), 473–486. https://doi.org/10.1007/s40844-020-00160-7

Sunter, D., Castellanos, S., & Kammen, P. D. (2019). Installing inequality: the racial disparities in solar deployment. The Beam, 63-65.

Sullivan, M., Schellenberg, J., & Blundell, M. (2015). Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States (LBNL—6941E, 1172643; p. LBNL—6941E, 1172643). https://doi.org/10.2172/1172643

Richardson, M. L., Wilson, B. A., Aiuto, D. A., Crosby, J. E., Alonso, A., Dallmeier, F., & Golinski, G. K. (2017). A review of the impact of pipelines and power lines on biodiversity and strategies for mitigation. Biodiversity and Conservation, 26(8), 1801-1815.

Rinaldi, F., Moghaddampoor, F., Najafi, B., & Marchesi, R. (2021). Economic feasibility analysis and optimization of hybrid renewable energy systems for rural electrification in Peru. Clean technologies and environmental policy, 23(3), 731-748.

Stockton, K. M. (2004). Utility-scale wind on islands: an economic feasibility study of Ilio Point, Hawai'I. Renewable energy, 29(6), 949-960.

Taormina, B., Bald, J., Want, A., Thouzeau, G., Lejart, M., Desroy, N., & Carlier, A. (2018). A review of potential impacts of submarine power cables on the marine environment: Knowledge gaps, recommendations and future directions. Renewable and Sustainable Energy Reviews, 96, 380–391. https://doi.org/10.1016/j.rser.2018.07.026

Tere, A., Parasharya, B.M. (2011). Flamingo mortality due to collision with high tension electric wires in Gujarat, India. J. Threatened Taxa 3, 2192

Thaxter, C. B., Buchanan, G. M., Carr, J., Butchart, S. H. M., Newbold, T., Green, R. E., Tobias, J. A., Foden, W. B., O'Brien, S., & Pearce-Higgins, J. W. (2017). Bird and bat species' global vulnerability to collision mortality at wind farms revealed through a trait-based assessment. Proceedings of the Royal Society B: Biological Sciences, 284(1862), 20170829. https://doi.org/10.1098/rspb.2017.0829

Trail, P. W. (2006). Avian mortality at oil pits in the United States: a review of the problem and efforts for its solution. Environmental management, 38(4), 532-544.

Trainor, A. M., McDonald, R. I., & Fargione, J. (2016). Energy sprawl is the largest driver of land use change in United States. PloS one, 11(9), e0162269.

Trondle et al. (2020). Trade-Offs between Geographic Scale, Cost, and Infrastructure Requirements for Fully Renewable Electricity in Europe. Joule. https://doi.org/10.1016/j.joule.2020.07.018

Tupala, A.-K., Huttunen, S., & Halme, P. (2022). Social impacts of biodiversity offsetting: A review. Biological Conservation, 267, 109431. https://doi.org/10.1016/j.biocon.2021.109431

Turkovska, O., Castro, G., Klingler, M., Nitsch, F., Regner, P., Soterroni, A. C., & Schmidt, J. (2021). Land-use impacts of Brazilian wind power expansion. Environmental Research Letters, 16(2), 024010. https://doi.org/10.1088/1748-9326/abd12f

UN. United Nations. (2001). Indicators of Sustainable Development: Guidelines and Methodologies. New York. https://www.un.org/esa/sustdev/natlinfo/indicators/isdms2001/isd-ms2001isd.htm

UN. United Nations. (2002). Guidelines on strategic planning and management of the energy sector. United Nations. Economic and Social Commission for Asia and the Pacific. https://repository.unescap.org/bitstream/handle/20.500.12870/2754/ESCAP-2002-MN-Guidelines-energy-sector.pdf?sequence=1

UN. United Nations. (2007). United Nations Declaration on the Rights of Indigenous Peoples. Available at https://www.un.org/development/desa/indigenouspeoples/wp-content/uploads/sites/19/2018/11/UNDRIP_E_web.pdf

UNEP. United Nations Environment Programme. (2002). Environmental Impact Assessment Training Resource Manual. Geneva

UNEP. United Nations Environment Programme. (2018). Assessing Environmental Impacts–A Global Review of Legislation. Nairobi

UNEP. United Nations Environment Programme. (2021). Integrated Approaches in Action: A Companion to the International Good Practice Principles for Sustainable Infrastructure. Nairobi

UNEP. United Nations Environment Programme. (2022). International Good Practice Principles for Sustainable Infrastructure. Nairobi

USAID. United States Agency for International Development. (2013a). EIA Technical Review Guidelines: Energy Generation and Transmission. Volume 1. Regional Document prepared under the CAFTA DR Environmental Cooperation Program to Strengthen Environmental Impact Assessment (EIA) Review

USAID. United States Agency for International Development. Environmental Compliance Procedures: Title 22, Code Of Federal Regulations, Part 216.

USAID. United States Agency for International Development. (2014). Women at the Forefront of the Clean Energy Future.

USAID. United States Agency for International Development. (2017). USAID Environmental Impact Assessment Tool.

USAID & IUCN. United States Agency for International Development & The International Union for Conservation of Nature. (2018). Advancing gender in the environment: making the case for gender equality in large-scale renewable energy infrastructure development. AGENT Thematic Energy Brief Series.

USAID. United States Agency for International Development. (2018). Environmentally sound design (ESD) sector environmental guidelines: small-scale energy

USAID. United States Agency for International Development. (2019). Effective engagement with indigenous peoples: USAID energy and infrastructure sector guidance document.

Vanclay, F. (2003). International Principles For Social Impact Assessment. Impact Assessment and Project Appraisal, 21(1), 5–12. https://doi.org/10.3152/147154603781766491 van de Ven, DJ., Capellan-Peréz, I., Arto, I. et al. (2021). The potential land requirements and related land use change emissions of solar energy. Sci Rep 11, 2907. https://doi.org/10.1038/s41598-021-82042-5

Vega, J. S., Malky, A., & Reid, J. (2012). Costos y beneficios del proyecto hidroelétrico del río Inambari. Documento de Discussión, (2).

Viña, C. S-L & Notess, L. A fair share for women: toward more equitable land compensation and resettlement in Tanzania and Mozambique. Working Paper, World Resources Institute.

Visser, E., Perold, V., Ralston-Paton, S., Cardenal, A. C., & Ryan, P. G. (2019). Assessing the impacts of a utility-scale photovoltaic solar energy facility on birds in the Northern Cape, South Africa. Renewable Energy, 133, 1285–1294. https://doi.org/10.1016/j.renene.2018.08.106

Wale, E. & Yalew, A. (2010) On biodiversity impact assessment: the rationale, conceptual challenges and implications for future EIA, Impact Assessment and Project Appraisal, 28:1, 3-13, DOI: 10.3152/146155110X492326

Walker, B. L., Neubaum, M. A., Goforth, S. R., & Flenner, M. M. (2020). Quantifying habitat loss and modification from recent expansion of energy infrastructure in an isolated, peripheral greater sage-grouse population. Journal of Environmental Management, 255, 109819. https://doi.org/10.1016/j.jenvman.2019.109819

Wang, S., & Wang, S. (2015). Impacts of wind energy on the environment: A review. Renewable and Sustainable Energy Reviews, 49, 437–443. https://doi.org/10.1016/j.rser.2015.04.137

Watkins, G., Mueller, S.-U., Ramirez, M. C., Meller, H., Blatsos, I., Carvalho Fernandes de Oliveira, J., Contreras Casado, C., Georgoulias, A., Georgoulias, N., & Rodriguez, J. (2017). Lessons from Four Decades of Infrastructure Project-Related Conflicts in Latin America and the Caribbean. Inter-American Development Bank. https://doi.org/10.18235/0000803

Wood, C. (2003). Environmental Impact Assessment: A Comparative Review. 2nd Edition, Longman, Harlow

World Bank. (2012). Strategic Environmental Assessment in the World Bank: Learning from recent experience and challenges. The World Bank. Washington, DC.

Wu, Y., Zhao, F., Liu, S., Wang, L., Qiu, L., Alexandrov, G., & Jothiprakash, V. (2018). Bioenergy production and environmental impacts. Geoscience Letters, 5(1), 14. https://doi.org/10.1186/s40562-018-0114-y

Yang, J., Chen, W., Chen, B., & Jia, Y. (2012). Economic feasibility analysis of a renewable energy project in the rural China. Procedia Environmental Sciences, 13, 2280-2283.

Yong, E. (2012). Vultures blind to the dangers of wind farms. Nature. https://doi.org/10.1038/nature.2012.10214

Zamuda, C. D., Larsen, P. H., Collins, M. T., Bieler, S., Schellenberg, J., & Hees, S. (2019). Monetization methods for evaluating investments in electricity system resilience to extreme weather and climate change. The Electricity Journal, 32(9), 106641.

Zhdannikov, D. & Jones, G. (2022, April 20). World needs an extra $1.3 trln energy investment by 2030–JP Morgan. Reuters. Retrieved from https://www.reuters.com/business/energy/world-needs-extra-13-trln-energy-investment-by-2030-jp-morgan-2022-04-20/ (June 21, 2022).

Zorzano-Alba, E., Fernandez-Jimenez, L. A., Garcia-Garrido, E., Lara-Santillan, P. M., Falces, A., Zorzano-Santamaria, P. J., Capellan-Villacian, C., & Mendoza-Villena, M. (2022). Visibility Assessment of New Photovoltaic Power Plants in Areas with Special Landscape Value. Applied Sciences, 12(2), Article 2. https://doi.org/10.3390/app12020703

Appendix A. Methodology

The research team that produced this report reviewed more than 200 published papers, including peer-reviewed and gray literature, and gave preference to synthesis and other review studies, to uncover evidence and highlight best practices for USAID and its development partners. The team conducted the literature review between March and April 2022.

Research strategy

The research strategy was divided into three groups following the outline of this paper. For each group, the researchers used a combination of key terms. The determination of these terms was based on three steps.

1. Determine the main topics of interest, e.g., energy infrastructure and wildlife and climate change.
2. Create a list of possible key terms for each topic.
3. Test a set of combinations of the key terms to be used to determine which final key terms should be included in the search process.

Key research element: A synopsis of costs associated with damage to energy infrastructure caused by wildlife interactions and climate-related extreme events.

Research question: What are the benefits and costs associated with damage from wildlife and climate-related extreme events on energy infrastructure?

The key terms used were:

- **Key terms (energy infrastructure)**

"transmission" OR "distribution" OR "transmission and distribution" OR "renewable energy" OR "wind turbines" OR "solar" OR "solar PV modules" OR "pipelines"

AND

- **Key terms (wildlife and climate change)**

"migration" OR " migratory birds" OR "bird strikes" OR "avian interactions" OR "collision" OR "wildlife" OR "biodiversity" OR " land use" OR "climate change" OR " climate risk" OR "climate resilience"

AND

- **Key terms (impact qualifiers)**

"outage" OR "outage cost" OR "customer cost" OR "prevention" OR "mitigation measures" OR "mitigation hierarchy" OR "avoidance" OR "compliance" OR "repairing damage" OR "sunk cost" OR "transactional costs" OR "reputational costs" OR "damage cost"

Key research element: A synopsis of energy infrastructure's common negative effects on biodiversity, ecosystems, and climate change—including, e.g., harm to wildlife, habitat fragmentation, and greenhouse gas (GHG) emissions caused by infrastructure development—along with solutions to avoid or mitigate these negative effects. The research done here also includes the section about trade-offs.

Research question: What are the impacts of energy infrastructure on biodiversity, ecosystems, climate change, and human well-being?

The key terms used were:

- **Key terms (energy infrastructure)**

"transmission" OR "distribution" OR "renewable energy" OR "wind turbines" OR "solar" OR "solar PV modules" OR "pipelines"

AND

- **Key terms (wildlife and climate change)**

"migration" OR " migratory birds" OR "bird strikes" OR "wildlife" OR "wildlife interactions" OR "biodiversity" OR "habitat loss" OR " land use" OR "greenhouse gas emissions" OR "climate change" OR " climate risk" OR "climate resilience" OR "gender" OR "women" OR "community engagement" OR "community stakeholders" OR "indigenous territory" OR "indigenous land" OR "protected areas" OR "rural areas"

AND

- **Key terms (impact qualifiers)**

"social cost" OR "economic impact" OR "tradeoff " OR "trade-off " OR "impact" OR "effect" OR "mortality" OR "cost-benefit" OR "valuation"

Key research element: Mitigation solutions to avoid or reduce the impact of energy infrastructure on the environment

Research questions: (a) What are the solutions that have been implemented or have been suggested to avoid or mitigate effects of energy infrastructure development on biodiversity, ecosystems, climate change, and human well-being? What are the benefits and costs that are associated with those solutions? (b) what types of tools have been used to help determine where, when, and how to implement these solutions?

The following key terms were used:

- **Key terms (energy infrastructure)**

"transmission" OR "distribution" OR "renewable energy" OR "wind turbines" OR "solar" OR "solar PV modules" OR "pipelines"

AND

- **Key terms (wildlife and climate change)**

"migration" OR " migratory birds" OR "bird strikes" OR "collision" OR "wildlife" OR "wildlife interactions" OR "biodiversity" OR "habitat loss" OR " land use" OR "climate change" OR " climate risk" OR "climate resilience" OR "gender" OR "women" OR "household" OR "community engagement" OR "community stakeholders" OR “indigenous territory” OR “indigenous land” OR “protected areas”

AND

- **Key terms (solutions)**

“mitigation” OR “solutions” OR “wildlife friendly” OR “safeguards” OR “environmental and social standards” OR “environmental and social policies”

- **Key terms (solution qualifiers)**

“tradeoff” OR “economic cost” OR “economic benefits” OR “cost-benefit” OR “ cost-effectiveness”

- **Key terms (tools)**

“Strategic Environmental Assessment” OR “spatial planning” OR “optimization” OR “tradeoff” OR “environmental impact assessment” OR “environmental and social framework” OR “environmental and social management system” OR “IFC performance standards”

Limitation and challenges of the research strategy

The main limitation is the limited time available to review a growing and broad literature about interactions between energy infrastructure and the environment. As mentioned above, the research focused on synthesis and review studies. Additionally, except for some seminal studies, we excluded studies published before 2010.

Studies on the following two categories were considered but less focus was given to them.

- Studies about the use of non-renewable energy sources (e.g., coal, natural gas, crude oil, etc.) to generate electricity and their social and environmental impacts
- Studies about hydropower plants and their social and environmental impacts

Interviews

In addition to the literature review and online search, the research team interviewed key experts from the power sector. The goals of the interviews were twofold:

1. To validate the information gathered during the literature review
2. To complement the report with additional data not reported online

Appendix B. Possible approaches to estimate social impacts

Two approaches can help project proponents easily identify the main impacts and groups of people most impacted and define appropriate mitigation measures.

A. RISK ASSESSMENT

When conducting risk assessment, only negative impacts should be considered. The goal of this approach is to provide a sense of the overall risk–in terms of cost and negative effects–associated with the project of interest. This methodology is based on two key factors: likelihood and severity of the impact. The definition of these two factors depends on multiple components such as the project, including best practices and requirements from funders; the country's context, including national legislation on best practices and safeguards; and stakeholder engagement. Table B1 presents a simple visualization of a risk matrix for a specific indicator.

Table B1. *Illustrative risk matrix*

		Severity of the impact				
		Very high (5)	High (4)	Medium (3)	Low (2)	Very low (1)
Likelihood	Very high (5)	25	20	15	10	5
	High (4)	20	16	12	8	4
	Medium (3)	15	12	9	6	3
	Low (2)	10	8	6	4	2
	Very low (1)	5	4	3	2	1

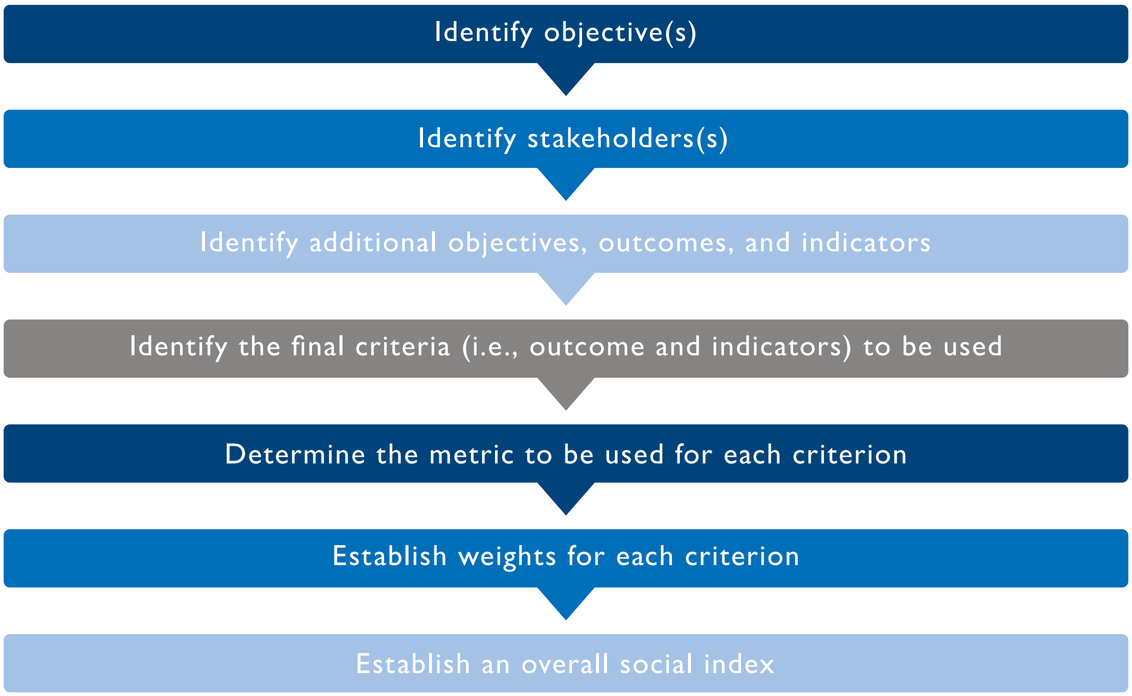
Note: Red corresponds to intolerable risk; yellow to moderate risk and green to tolerable risk.

Following this approach, all indicators can be associated with a "risk number" from 1 to 25, based on Table B1.

B. MULTI-CRITERIA ANALYSIS

Usually, the Multi-criteria approach is used to compare different alternatives (e.g., Moghaddam et al. 2011). However, this approach can also be used to assess the social risk of a project. Figure 2 shows the necessary steps to conduct a multi-criteria analysis. For a more detailed step-by-step, see Wang et al. (2009).

Figure B1. ***Steps to conduct a multi-criteria analysis.***



Source: Own elaboration based on Department for Communities and Local Government (2019). Multi-criteria analysis: a manual. ISBN: 978-1-4098-1023-0

Two main advantages of using this approach are (i) the assignment of criteria weights to reflect the relative importance or stakeholder preferences for each criterion or indicator, and (ii) the possibility to compare multiple impacts under different units of measurement, for example, US$ or non-monetary measures.

The formula used to combine the multiple metrics is as follows:

$$\text{Social impact index} = w_1 \cdot V_1 + \ldots + w_n \cdot V_n, w_i > 0 \text{ for all } i \text{ and } \sum_{i=1}^{n} w_i = 1$$

where *w* is the weight and *V* the standardized metric. It is important that the metric be standardized before the calculation of the overall social impact.

Table B2. ***Hypothetical estimation of the social impact***

Metric	Impact direction	Value	Standardized value (e.g., min impact = 1 and max impact = 5)	Weight	Weighted standardized value
Number of jobs created (men)	Positive	100	5	0.15	0.75
Number of workers moving to the local community (men)	Negative	90	-5	0.25	-1.25
Number of additional girls enrolled in elementary and middle schools	Positive	15	3	0.30	0.9
Number of people moving to urban centers or other places (away from the community) (men)	Negative	30	-2	0.30	-0.6
Social impact index					**-0.2**

Appendix C. Highlights from the interviews

Between July and August of 2022, the research team conducted four semi-structured interviews with experts in the field. Below we present the main points from the interviews:

ENERGY INFRASTRUCTURE AND CLIMATE CHANGE

- There are numerous impacts caused by extreme weather. These impacts affect transmission, distribution, and generation, including natural gas and coal power plants. It is not an impact restricted to hydropower dams.
- Extreme weather affects the energy power system reliability, which studies show is decreasing over the years. Currently, there is not an answer to this reduction. More studies are needed, especially to measure the cost of long-duration power outages, and estimate the avoided costs because of investment.

ENERGY INFRASTRUCTURE AND WILDLIFE

- At least in South Africa, most of the impacts are caused by existing/old infrastructures. They mentioned that because there is no quick fix to the problem of wildlife interaction and also because these interactions are infrequent, this situation is seen as secondary to utilities.
- For new projects, it seems that there is a little bit more concern with the environment. This is especially true in the case of projects funded by development banks.
- Their perception of wildlife is that national governments do not value it as much as they value climate change. Maybe because the international pressure towards the latter is bigger. As a result, countries are investing fast in renewable sources thinking only about greenhouse gas emissions, but not as much about all potential negative impacts that might be caused by renewable sources, which seems secondary at this point.
- In the case of power lines, the private cost of wildlife interaction is pretty straightforward. However, in the case of wind, that is not necessarily the case as interactions with wildlife might not cause any damage to the blade. This makes the challenge to convince small wind farm owners to invest in mitigation measures, for example, more difficult.
- Social pressure is definitely increasing but they mentioned that people sometimes tend to focus on the "wrong" things. For example, a lot has been said about the impact of wind turbines on birds, but the impact of transmission lines on birds is several orders of magnitude higher.

REGULATION

United States and Canada

- There is a strong regulation over power interruptions. Utility commissions require utilities to send reliability reports every year.
- Consumers pay for the interruptions. Utilities use the revenue from the rates to fix or solve the problem that caused the interruption. If it is something extreme or major, utilities may ask for money from the Public Utility Commission and increase the electricity rate.
- The environment is a big component in the decision-making process of utilities but only because of environmental regulations. Many utilities argue that the process is too onerous and too difficult. It's too time-consuming. And it's very expensive, they are incorporating wildlife in their decisions, or natural spaces in their decisions. But it's through the regulatory processes of state, local and federal agencies.
- There are multiple levels of legislation (e.g., national and state) that protect wildlife
- There are no penalties in the case of wildlife loss, but companies might be forced to shut down for a period of time depending on the impact (*Canada*).
- Regulator is the one making the final decision and not the company. The latter present the best route for a transmission line, for example, and a couple of alternatives. The regulator evaluates the options and chooses. It is too expensive, the regulator won't choose.
- In the US, companies tend to include environmental considerations at the early stages of project development. According to them, the process, including the Environmental Impact Assessment, tends to work well. Different from other countries, a key aspect is enforcement. They mentioned that other countries (e.g., India) have good regulations, but as a result of the lack of enforcement, companies do not follow best practices.

South Africa

- All new projects must conduct an environmental impact assessment, but this assessment is done late in the decision process and it is more to identify the impacts and provide recommendations on some mitigation measures.
- EIAs are very sensible to the specialist hired, i.e., usually, utilities hire someone focused on birds or an ecologist (with more broad knowledge of species and ecosystems). This means that the document won't have the level of detail required to fully understand and address the impacts related to many non-bird species, for example; different species generate different impacts and are impacted differently too.
- Currently, there is no legislation or penalties related to wildlife interaction. This is common across countries in Africa. There is public pressure, however, and this has motivated Eskom, South Africa's largest electric public utility, to adopt mitigation measures in the past.

DATA AVAILABILITY

- There is good information on the costs associated with short-term duration, but not so much on long-term duration. It is challenging to quantify long-term interruption's social and economic impacts.
- Utilities and distributors do have the cost of wildlife-caused damage, but the cost of energy infrastructure on the environment is much more difficult to obtain.
- There is information on the cost side but not as much on the benefit side regarding the implementation of mitigation strategies.
- They have access to good data that companies share with them, but these data are not publicly available.

MITIGATION MEASURES

- Utilities are constantly investing in mitigation measures to avoid power interruptions. They called it preventive investments. But they also mentioned that the amount invested by utilities is currently insufficient to increase and guarantee resilience. Preventive investment is difficult because "it is speculating on future risk."
- They mentioned that some utilities consider rerouting transmission lines, for example, if the environmental damage is extremely high. But it is difficult to estimate the economic impacts of damage to ecosystems. As a result, it is more difficult to justify investments motivated by environmental damage, i.e., "It's more difficult to get defensible estimates of damage to ecosystems and get them into a Commission's rulings."
- The underground option, for example, is currently too expensive as a substitute for aboveground transmission lines. Currently, there is no economic justification to invest in this option–even from an environmental perspective. They mentioned that it makes more sense to invest in micro generations that do not need transmission lines (only distribution lines).
- The main challenge that utilities have today to implement the best option in terms of the environment, for example, is restriction on lands. Often the best route (that would minimize the impact) goes over several private lands. Utilities have a whole team to negotiate with land owners, but usually, they have to rethink the route to avoid private lands.
- There is a structural difference between poles in the US and in most developing countries. While in the US, the poles are made out of wood, in developing countries, poles are made out of concrete. This distinction is important because it changes how interaction happens, as well as the solutions.
- Mitigation measures do not always represent additional costs, on the contrary, the benefits in terms of avoiding costs are many. However, there is a gap in terms of measuring the benefits of protecting wildlife and/or habitat.

TRADE-OFFS

- There is a constant trade-off between cost and reliability. According to them, consumers do not want to pay more than they do now to get a more reliable or resilient power system.
- An interesting trade-off that has no clear answer in the southwestern United States is the fact that the implementation of environmentally friendly distribution lines has benefited ravens, however, these ravens are eating endangered turtle species. What to do now? Relocate turtles and remove them from their natural habitat? No solution so far.

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