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Impacts of Renewable Energy Sources on Biological Diversity and Conservation: An Overview

Said. A. Saad[1] Ibrahim M. Abou El Leil[2]

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Authors affiliation
[1]*Zoology Department, Faculty of Science, Tobruk University*[1]
[2]*Department of Geology, Faculty of Science, Tobruk University*
[2]ibrahim.aboueleil@tu.edu.ly

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ABSTRACT

Nowadays, renewable energy is regarded as a clean and different kind of energy. This study attempts to demonstrate how renewable energy sources, such as solar photovoltaic (PV), wind farms, and hydropower generation, impact the biological diversity of terrestrial and aquatic animal habitats. In 55% of previous research on wind farm turbines, bird death rates range from 0.0 to 2.0 fatalities/turbine/year, whereas raptor mortality rates range from 0.0 to 0.1 fatalities/turbine/year in 79.4% of the studies. This is contingent upon the location and method of turbine installation. The most often mentioned threats were migratory birds (migrant goose, crane, lapwing, golden plover), water birds (geese species), grassland birds (common quail, corn crake, lapwing, ringed plover), and raptors (common buzzard, common kestrel, and red kite). Bat mortality rates range from 0.0 to 47.5 fatalities per turbine per year at different wind farms. The study also looks at the deleterious impacts of hydroelectric reservoirs on biodiversity, including freshwater turtles and aquatic and terrestrial species, as well as the negative effects of PV installations on ecosystems and wildlife. However, the loss of habitats and the regular migration paths of the wildlife animals were indicative of these consequences.

آثار مصادر الطاقة المتجددة على التنوع البيولوجي والحفاظ عليه، نظرة عامة

سعيد أ. سعد إبراهيم .م. أبو الليل

في الوقت الحاضر، تُعتبر الطاقة المتجددة نوعًا نظيفًا ومختلفًا من الطاقة. تحاول هذه الدراسة توضيح كيفية تأثير مصادر الطاقة المتجددة، مثل الألواح الشمسية الكهروضوئية (PV)، ومزارع الرياح، وتوليد الطاقة الكهرومائية، على التنوع البيولوجي لمواطن الحيوانات البرية والمائية. في 55% من الأبحاث السابقة حول توربينات مزارع الرياح، تتراوح معدلات وفاة الطيور بين 0.0 إلى 2.0 حالة وفاة/توربين/سنة، في حين تتراوح معدلات وفاة الطيور الجارحة بين 0.0 إلى 0.1 حالة وفاة/توربين/سنة في 79.4% من الدراسات. هذا يعتمد على موقع وطريقة تركيب التوربينات. أكثر التهديدات المذكورة كانت الطيور المهاجرة (الإوز المهاجر، الكركي، الدراج، الدراج الذهبي)، الطيور المائية (أنواع الإوز)، الطيور العشبية (السُمانة المشتركة، الدراج الذهبي، الدراج، الدراج ذو الخاتم)، والطيور الجارحة (الباز المشترك، الشاهين المشترك، والنسر الأحمر). تتراوح معدلات وفيات الخفافيش من 0.0 إلى 47.5 حالة وفاة لكل توربين سنويًا في مزارع الرياح المختلفة. تبحث الدراسة أيضًا في التأثيرات الضارة للخزانات الكهرومائية على التنوع البيولوجي، بما في ذلك السلاحف العذبة والمخلوقات المائية والبرية، بالإضافة إلى التأثيرات السلبية لتركيبات الطاقة الشمسية على النظم البيئية والحياة البرية. ومع ذلك، كانت فقدان المواطن والمسارات الهجرية المنتظمة للحيوانات البرية تشير إلى هذه العواقب.

INTRODUCTION

This special issue includes research on the impact of renewable energy on biodiversity. To slow down the fast extinction of species brought on by climate change, we must move from fossil fuels to renewable energy sources (Bellard et al. 2012; Maclean and Wilson 2011; Malhi et al. 2020; Ohashi et al. 2019). For instance, an empirical study of American breeding bird trends (Figure 1) reveals a negative link with rising atmospheric ozone concentrations brought on by the burning of fossil fuels (Liang et al. 2020). In recent decades, the world has witnessed a rapid transition toward renewable energy as a sustainable alternative to fossil fuels, driven by the

urgent need to address climate change and reduce greenhouse gas emissions. Renewable energy sources—such as solar, wind, and bioenergy—play a crucial role in achieving global sustainability goals and mitigating environmental degradation. By limiting global warming, these energy systems can help protect ecosystems and biodiversity from the adverse effects of climate change (Abdel-Sanad, 2024).
However, the relationship between renewable energy and biodiversity is complex and not entirely positive. Recent studies indicate that the large-scale and poorly planned deployment of renewable energy projects can have negative impacts on ecosystems. For instance, renewable energy infrastructure often requires extensive land use, which may lead to habitat loss and fragmentation, thereby threatening biodiversity. Wind energy projects, in particular, have been associated with bird and bat mortality due to collisions with turbines (Karmi, 2024).

Moreover, bioenergy production raises additional environmental concerns, especially regarding land-use competition with agriculture and natural habitats. Unsustainable practices in bioenergy development may result in deforestation, loss of species diversity, and ecosystem imbalance. On the other hand, renewable energy remains essential for reducing reliance on fossil fuels, which are a major driver of climate change one of the most significant threats to global biodiversity (Al-Ramah, 2024).

Therefore, the impact of renewable energy on biodiversity can be described as dual in nature: it offers significant environmental benefits by mitigating climate change, yet it may also pose ecological risks if not properly managed. This highlights the importance of adopting integrated planning approaches and environmentally sensitive policies to ensure that renewable energy development aligns with biodiversity conservation objectives (Al-Masry, 2025).

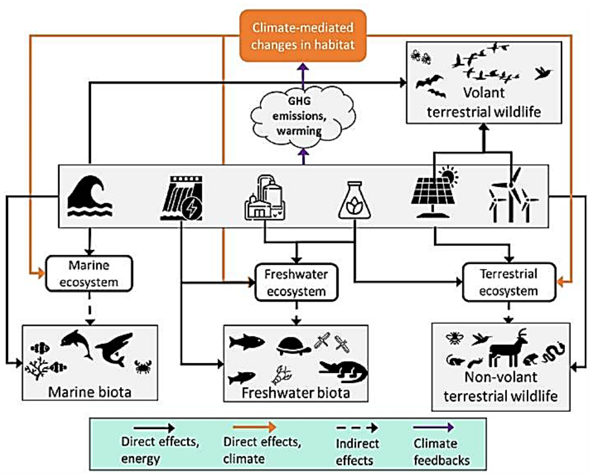

Fig. 1 Effects of renewable energy production

Additionally, Figure 1 illustrates the impact of renewable energy generation on freshwater, marine, and terrestrial biota (from left to right, symbols indicate wave energy, hydropower, renewable natural gas, biopower, sun, and wind). The term "direct consequence" refers to mortality resulting from interactions with energy infrastructure. Degradation of habitat or the use of fossil fuels to delay climate change are examples of indirect repercussions. Observe the purple arrows that show how the renewable energy sectors are responding to climate change.
However, Table 1 gives an statistical analysis of renewable energy adverse on the biodiversity.

Table 1 Statistical analysis of renewable energy impacts

Energy Source	Type	Estimated Animal Deaths per Year	Animals Affected	Notes
Wind Power	Renewable	140,000 – 500,000	Birds, bats	Collisions with turbines
Solar Power	Renewable	10,000 – 100,000+	Birds (especially desert species)	“Solar flux” burns at large plants
Hydropower (Dams)	Renewable	Millions	Fish, aquatic life	Habitat disruption, turbine injuries
Biomass Energy	Renewable	Thousands – Millions	Small animals, birds	Habitat destruction, combustion
Fossil Fuels	Non-renewable	Millions – Billions	Birds, fish, mammals	Oil spills, pollution, climate change
Nuclear Energy	Non-renewable	Relatively Low	Minimal direct impact	Rare accidents (e.g., radiation events)

Moving to renewable energy can mitigate greenhouse gas emissions but may also threaten biodiversity. This study emphasizes the need to understand the impacts of renewable energy technologies on biodiversity while offering an overview of energy technologies and renewable sources. It explores the potential of transitioning to a low-carbon future with variable renewable energy sources like solar, wind, and hydropower, and introduces the "blue economy," which involves utilizing marine renewable energy resources.
To meet the decarburization goals set forth in the Paris Agreement, the share of electricity in total energy should rise from 26% to 57% in 2030 and 86% in 2050 (IRENA 2020). The need or hydropower will increase by 17.7% by 2030 and 34.7% by 2050. To reach the Paris climate commitments, wind energy should account for 35% of global power production by 2050, which would reduce emissions by 6.3% (IRENA, 2019b). In Figure 2, IRENA (2020) forecasts the demand for renewable energy

generation using the International Energy Agency baseline for 2018.

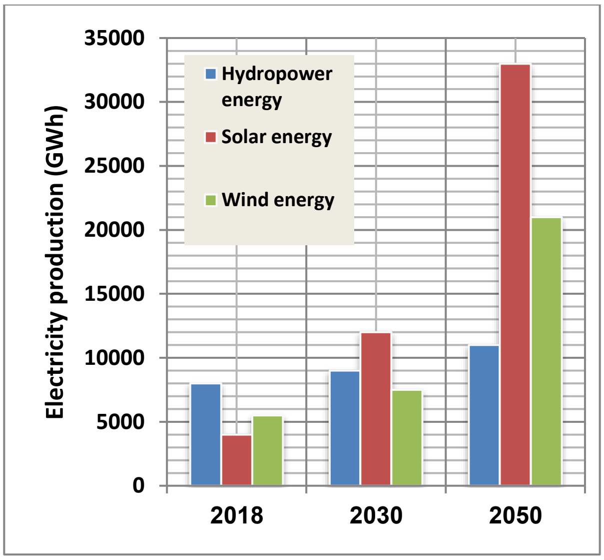

Fig. 2 Projections of renewable energy (Modified after IRENA, 2020)

Biological conservation studies standardize ecological indicators, typically assessing energy impacts on a per-kWh basis. However, this method overlooks operational stability and grid resilience contributions of various energy sources. For instance, while biomass can substitute fossil fuels, it may contribute less to the electrical grid compared to more variable renewable sources like sun and wind, which, despite their higher energy densities, pose trade-offs regarding power density and intermittency. Fossil fuels have a greater energy density than renewable energy sources when assessed in terms of the areal footprint, or the area required to produce power. In Figure 3. However, it is very challenging to assess how different ecosystem types and species are affected by energy sources that serve global markets using the notion of an ecological footprint (Wachs and Engel 2021). We talk about documented energy footprints in the Supplemental Information (SI). Another great overview of the sustainability concerns associated with different renewable energy sources is provided by Gasparatos et al. (2017).

The environmental effect indicators include air quality, land footprint, water footprint, air pollution, and climate regulation. For the six renewable energy sources—biopower, conventional hydropower, marine hydrokinetic (MHK), concentrated solar power (solar CSP), photovoltaic solar power (solar PV), and wind energy value indicators such as energy return on investment, levelized cost, capacity factor, dispatch index, and storage index are presented.

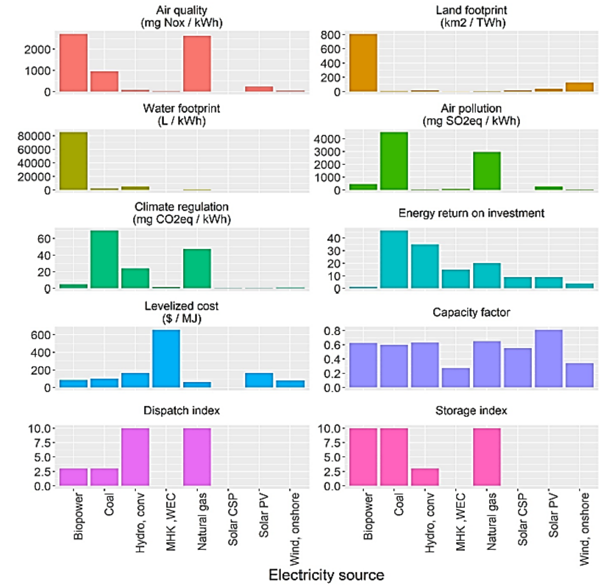

Fig. 3 Indicators of environmental impact (IRENA, 2020)

STUDY OBJECTIVES

The following is an expression of the study's primary goals:

1. Examine the effects on biodiversity of using renewable energy sources.
2. Determine which energy source affects ecosystems and wildlife the most.
3. Distinct deterioration of aquatic and terrestrial ecosystems.

METHODOLGY

The material included in this review research was gathered from a variety of literature sources that were relevant to these investigations, including:

1. The Wildlife Institute for Renewable Energy (REWI, 2023).
2. The Documents Library of the American Wind and Wildlife Information Centre.
3. Database of Energy Literature Reviews.
4. The Energy and Wildlife Program of the USGS.

RENEWABLE ENERGIES EFFECTS ON BIODIVESITY

Wind Power Energy Effects

According to IRENA's "TES" scenario, to achieve the climate goals of the 2015 Paris Agreement, wind energy will need to provide 25% of global electricity by 2050. This requires increasing installed capacity from 624 GW in 2018 to 2526 GW by 2030, and further to 6044 GW by 2050.

Most studies on the effects of wind energy on wildlife have focused on habitat displacement and bird and bat mortality (Agha et al. 2020). According to Cook et al. (2018) and Fernandez-Bellon et al. (2019), the degree to which a bird species is displaced by wind energy installations depends on its habitat associations, post-construction land management changes, and the distance to turbines. For example, raptors' vulnerability to collision with turbines is correlated with species abundances (Garvin et al., 2011; Strickland et al., 2011) and landscape features (Fernandez-Bellon et al., 2019).

According to O'Shea et al. (2016), the number of bat deaths reported worldwide has exceeded intentional killings brought on by accidents with wind turbines. Bats are affected by direct collisions with wind turbines and the ensuing barotrauma (Grodsky et al. 2011). Many studies have looked at the causes of bat mortality near turbines and whether or not bats are attracted to them (Cryan et al. 2014; Kunz et al. 2007).

Land-based wind energy projects can have indirect effects on wildlife because infrastructure (roads, substations, turbine pads, and service buildings) dislodges habitat. The land used for wind turbines in a wind facility often replaces more space suitable for wildlife and has significantly less impact on birds than an area mined for coal producing a comparable quantity of power (Denholm et al. 2009).

Offshore Wind Energy Impacts on Marine Species

The maritime environment and related animals may be impacted by offshore wind farms. Certain impacts like the artificial reef effect, which is covered below may be advantageous rather than negative. OWF operations can generally affect animals in the following ways:

1. modification of maritime ecosystem,
2. danger of collision,
3. power cable-related electromagnetic field (EMF) impacts;
4. noise effects; and 5. water quality (such as pollution).

Floating structures, which are not anchored to the ocean floor (Figure 4), are being used by the offshore wind sector (NOWRD, 2019). Instead of being supported by a foundation, these floating constructions are attached to the bottom by cables or legs. Projects located in deep water (around 60 meters, or 200 feet) such as those in the Gulf of Maine, off the Pacific Coast, and in Hawaii frequently utilise floating buildings.28 The majority of proposed floating projects are used.

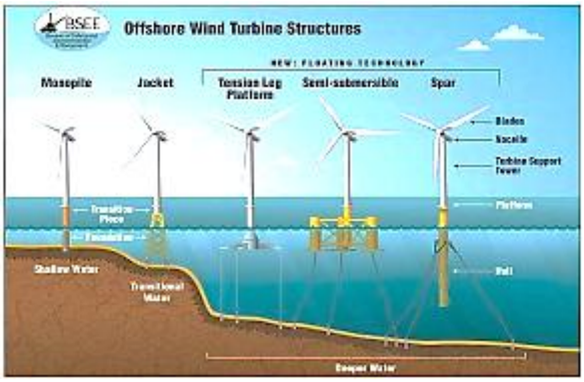

Fig. 4 Offshore wind turbine components and foundation structures

The scientific literature examines the short-term detrimental and beneficial impacts of offshore wind development on fish, birds, bats, sea turtles, marine mammals, invertebrates, and other components of the marine environment (Table 2). Modelling and observational research (mostly from the North Sea) show that most effects (such as habitat alteration) occur in the immediate vicinity of the wind turbine array. Beyond the array, other effects (such as noise effects) can extend up to tens of miles. While some of these evaluations use land-based wind energy data to predict potential offshore wind scenarios, others extrapolate findings from existing offshore wind farms (OWFs), mostly in the North Sea, to planned offshore wind energy projects. Laboratory studies that replicate variables (such as noise levels) frequently found in offshore wind farms provide information on additional possible effects.

Table 2 Potential impacts associated with offshore wind energy projects

Animal type	Oceanic change	Habitat alteration	Collision risk	Electromagnetic field (EMF) effects	Noise effects	Water quality
Marine mammals	--	Y	Y	--	Y	Y
Invertebrates	Y	Y	--	Y	Y	Y
Fish	--	Y	Y	Y	Y	Y
Sea turtle	--	Y	Y	--	Y	Y
Birds	Y	Y	Y	--	--	Y

However, wind farms are constructed in many places without considering the existence of protected animal species. In troubled areas, certain mitigating measures have been put in place. In 55% of the studies, bird death rates range from 0.0 to 2.0 fatalities/turbine/year. 79.4% of the raptors' estimated yearly mortality rates lie between 0.0 and 0.1 fatalities per turbine. The only species designated as an endangered species and wind turbine mortality is the red kite (Milvus milvus). The most commonly considered threatened species include raptors (common buzzard, common kestrel, and red kite), migratory birds (migrant goose, crane, lapwing, golden plover), grassland birds (common quail, corn crake, lapwing, ringed plover), and waterbirds (geese species). At various wind farms, bat mortality rates vary from 0.0 to 47.5 deaths per turbine annually. According to reports, the bat species Laisurus cinereus, Lasiurus borealis, Lasionycteris noctivagans, and Nyctalus noctula had the greatest fatality rates. Table 3 summarizes the yearly fatality rates from North American and European research to help understand the scope of the issue (Arnott et al., 2016).

Table 3 Wind turbine annual mortality rates for bats from different habitats and geographical regions

Region	Habitat	Annual death rate per MW installed capacity
USA and Canada	Northeastern deciduous forest	6.1–10.5
USA and Canada	Midwestern deciduous forest – agricultural	4.9–11
USA and Canada	Great Plains	6
USA	Great Basin/Southwest Desert region	1–1.8
Germany	Black Forest	10.5
Europe	Agricultural land	0.6–5.3

Threats to Wildlife

Fast-moving turbine blades have killed a number of animal and avian species. Early studies in California indicate that raptors have high mortality rates, especially when compared to their low rates of reproduction and population levels (Smallwood and Thelander, 2004; Hunt, 2002). Numerous studies have indicated high death rates at some wind farms that use antiquated technology and are situated along migratory routes in areas with substantial bird populations (Smallwood and Thelander, 2004; Hunt, 2002; Thelander and Rugge, 2000).

More recent studies have focused on bat fatalities at wind energy plants. Particularly in the United States, where wind turbines are situated on wooded, eastern slopes, it has been shown that migratory, tree-roosting species are especially vulnerable. According to estimates, the mortality rate per turbine in the eastern United States ranges from 20.8 to 69.6. According to scientists, bat populations are significantly impacted by these losses (Arnett et al., 2008).

Songbirds can also be involved in collisions, although the number of deaths is frequently too low to have an impact on healthy populations (Erickson et al., 2001; Strickland et al., 2001; Kuvlesky et al., 2007). Wind turbines may increase the mortality of migratory and resident species that are declining or of particular concern if they are situated in high concentration areas or important habitat (Arnett et al., 2007).

The red bat (Lasiurus borealis) and other migratory birds are most affected by wind turbines (Figures 5, 6, & 7). Every year, thousands of insectivorous bats are killed as they migrate south over turbine-lined ridges to their winter homes (Arnett et al., 2007).

Fig. 5 Red bat (*Lasiurus borealis*) is killed by wind turbines

Fig. 6 A Greater flamingo dead due to collision with power lines

Fig. 7 Birds pass through power lines in wetlands

Habitat Degradation

Wind energy may permanently alter a comparatively small amount of habitat when compared to other land uses (Bureau of Land Management, 2005). But in both the short and long term, the surrounding ecology is nevertheless harmed by roads, buildings, noise, human activity, and fragmentation. 10. It has been shown that grassland birds and some animals, such elk and mule deer, avoid turbine pads, especially during construction (Leddy, 1996; Leddy et al., 1999; Johnson et al., 2000). Species that intentionally avoid human activity or that rely on intact, coherent environment are particularly vulnerable (Johnson, 2000). Entire wind farms and the large buffer surrounding them are unsuitable for species such as prairie grouse that avoid houses, roads, and power lines (Braun et al., 2002; Robel et al., Pitman, et al., 2005).

Figure 8 shows how the construction of roads, wind turbines, and other infrastructure has damaged and fragmented habitat. Loss of habitat and related deterioration may be detrimental to many animal species.

Fig. 8 Habitat destruction from the construction of wind turbines

Research indicates that bat species that are most vulnerable to wind turbines are frequently most active in low wind conditions, before and after storms, and during fall migration (Reynolds, 2006; Johnson, 2005). One study found that almost 90% of bat deaths occur between mid-July and late-September during the fall migration20, whereas other studies found that most bat deaths occur on low-wind nights (Fiedler, 2004; Horn, et al., 2008). Bat mortality can be considerably reduced by turning off wind turbines during these high-risk times (Baerwald et al. 2009). Turbines can be placed outside of migratory pathways in locations with lower bird abundance to reduce high bird death rates. Raptor mortality was far lower in wind farms with fewer birds than in sites with large numbers. (Thelander and Smallwood, 2004; Anderson et al., 2004, 2005).

To reduce the impact of wind energy development on wildlife, landscape-level planning is essential. Wind farms can be placed to avoid critical habitat, such as sage grouse leks or migratory pathways. 10. Developers can also work out how to build turbines with the fewest roads, transmission lines, and other infrastructure in order to mitigate the effects of fragmentation (Kuvlesky et al., 2007). Turbines are often best placed on already developed land in order to make use of existing infrastructure and avoid disturbing intact habitat zones (Kuvlesky et al., 2007).

A wind farm in Columbia Hills is viewed by mule deer (Figure 9). The noise, building, and human activity that come with wind energy development can displace wildlife.

Fig. 9 The effect of wind turbines on wildlife

Marine Renewable Energy

Offshore wind and marine hydrokinetic energy (MHK) represent emerging sources of power, with a particular focus on the conservation of migrating seabirds, especially rare species, raising notable concerns (Copping et al. 2021; Mendel et al. 2019). Mitigation of negative impacts on aquatic organisms, such as noise disturbances typically associated with construction activities, may be feasible by planning construction to avoid critical periods for the at-risk species (Astariz and Iglesias 2017; Best and Halpin 2019; Mooney 2020). Additionally, wave energy technologies deploy wave energy converters to harness electricity, which is transmitted to the grid through underwater cables installed along the ocean floor. It is estimated that there are over two terawatts of potential wave power available globally (Khan et al. 2017; Gunn and Stock-Williams 2012).

Changes in the flow patterns around MHK installations may have an effect on the dispersion and colonization-extinction dynamics of marine larvae. Changes to the flow fields around MHK installations may impede animal movement to and from neighbouring habitats (Hooper and Austen 2013). These impacts are thought to be greatest for tidal barrages and lowest and most fleeting for tidal-stream turbines (Langhamer et al., 2010).

Hydro Power Energy Effect

About 80% of the energy generated in many nations comes from hydroelectric power generation, making it the most significant source of electric energy.

Hydropower is a major and growing energy source on a global scale (He et al. 2021). Hydropower may help integrate other renewable energy sources and contribute to the transition to a low-carbon future by storing water for future generation. Reduced greenhouse gas emissions and higher hydropower production are causally related (Xia and Wang 2020). Hydropower also stores energy in reservoirs, has minimal operating costs, is fairly flexible in reaction to demand, and offers the greatest energy-return-on-investment (EROI) of all renewable energy sources.

The well-known ecological effects of hydropower are covered in this special issue, along with potential global ramifications (Anderson et al. 2021; He et al. 2021). Even though the addition of lentic reservoir habitat may increase overall freshwater variety, dams can jeopardise lotic species with fragile life cycles, especially when they are placed too close to one another.

The development of reservoirs significantly impacts biodiversity through habitat loss and alteration. Large reservoirs inundate land and disrupt riverine ecosystems, particularly affecting riparian vegetation. The typically stagnant (lentic) water in reservoirs changes water quality, adversely affecting aquatic life, including freshwater species and aquatic animals, unlike the flowing water of rivers. Moreover, dams interrupt the natural hydrological cycle of rivers, comprising a dry season, rising water season, wet season, and falling phase, which influences the movement patterns of freshwater and aquatic turtle species that are aligned with these natural cycles. Consequently, the transformation from a dynamic river system to a static water-holding reservoir restricts the seasonal movement of aquatic species seeking biological resources, altering their ecological dynamics.

Effects of Hydropower Reservoirs wildlife

Reviewing the detrimental effects of hydropower reservoirs on biodiversity, this study includes freshwater turtles and aquatic and terrestrial animals in various locales.

Effects of Reservoirs on Terrestrial Mammals

Generally speaking, the type of habitat an animal chooses has an impact on the extent of its home range. Densities of wild mammals are often impacted by habitat elements that impact population abundance and perhaps spatial and social organisation. Every mammal species is thought to occupy a range within the environmental gradient, which may have an impact on behavioural interactions and population growth. Among other requirements, mammals actively choose their habitat based on environmental signals that provide appropriate feeding and reproductive niches. Furthermore, the natural hydrological phases of the river where the reservoir dam is constructed determine how the habitat resources fluctuate seasonally (Alho et al. 2000).

As a result, the creatures that have been displaced by the reservoir's impacts will either die or relocate, causing the former biological densities to reappear. Ultimately, this will lead to the displaced species' futile attempt to establish themselves in a new location.

As one of the most serious human-caused factors in habitat alteration and biodiversity loss, the reservoir's existence exacerbates the negative effects of forest reduction with habitat fragmentation (Laurance & Bierregaard, 1997, 2009; Alho and Oecol, 2011.(

Effects of Hydropower Dams on freshwater biodiversity

Hydropower has a wide range of effects on biodiversity, depending on the size and kind of plant. The degradation of habitat is the most significant consequence. Furthermore, the construction of several plants fragments the river network, making it impossible for fish to migrate upstream or downstream to meet their lifecycle requirements.

Effects of Hydropower Plants on iconic marine species

Proposed plantings in Europe threaten iconic species such as the Atlantic salmon, European eel, and sturgeon, particularly in the biodiversity-rich southern Europe and the Balkans. If these plantings occur, unique fish species in the Balkans face the risk of significant population declines.

Insects play a crucial role in the riverine food chain, and hydropower development significantly impacts various species. Beyond fish, these dams affect semi-aquatic animals like fish otters and numerous fish-eating birds such as pelicans and kingfishers. The fragmentation caused by dam construction disrupts the migratory routes of animals like lynxes, wolves, and local deer species, leading to population declines (Figure 10).

Solar Energy Effect

Globally, solar-generated power is rapidly growing due to increased demand. The two main solar technologies utilised at the utility level are photovoltaic (PV) and concentrated solar-thermal power (CSP).

According to future scenarios developed to meet the climate objectives of the 2015 Paris Agreement, solar systems will supply 36% of the world's electricity needs by 2050 (IRENA 2020). The installed capacity would have grown from 582 GW to 8,828 GW by 2050 (IRENA 2019a, 2020). These are ambitious goals.

Over the past 20 years, solar energy facilities have expanded in both size and quantity (Chock et al. 2020; Hernandez et al. 2014).

Large-scale solar energy plants are expected to have a significant impact on wildlife due to habitat loss, particularly fragmentation by access roads, despite the fact that there is presently little study on the consequences on wildlife (Lovich and Ennen 2011). Indirect land use and land demand might vary significantly (Hoffacker et al. 2017; Van De Ven et al. 2021). Furthermore, solar energy installations are usually found in grasslands or natural ecosystems (Hernandez et al. 2015b).

Fig. 10 Dead fish, jumping trout and migratory pathways near hydropower dam

Species and Habitat Impacts

The regions most affected by solar PV growth are species of concern, taxonomy, or important natural groups. Responses about species of concern were generally divided into five major groups:

1. Ungulates that have solar sites within their geographic ranges;

2. Avian species that migrate, nest, or browse in and around solar sites;

3. Aquatic species that are heavily reliant on water quality;

4. Small animals and reptiles that burrow in or near solar sites; and

5. Pollinators that can engage with the flora at a solar site.

Respondents characterised habitat loss, habitat fragmentation, habitat degradation, and collision danger as possible effects of solar development on species. The following categories apply to the impact of solar radiation on wildlife:

Habitat changes: The surface area required for utility-scale solar development to help meet decarbonization goals will require some level of habitat loss, habitat fragmentation, and changes in land use.

On-site plant and animal habitat: Solar energy facilities can implement strategies to manage on-site habitat for the benefit of native wildlife communities (e.g., seeding with native plants).

Construction impacts: The development of utility-scale solar projects, as is the case with all forms of development.

Collisions with supporting infrastructure: The various structures needed to operate a solar energy facility (e.g., PV panels, overhead transmission lines, CSP towers) have the potential to pose a collision risk to wildlife, which may lead to injuries or fatalities.

4.3.2. Species Potentially Impacted by Solar Energy

The following species can be affected by scale solar energy projects for both wildlife and Habitats (Table 3).

Table 3 wildlife and habitats solar energy impacts

wildlife impacts	
Species	Examples
Amphibians	Gopher frog Striped newt
Aquatic species	Black creek crayfish Endangered or threatened mussels Fairy shrimp
Birds	Bald eagle Golden eagle Gray flycatcher
Insects	Monarch butterfly Rusty patched bumble bee
Mammals	Bats Desert burro deer Elk
Reptiles	Blunt-nosed leopard lizard Eastern box turtle Garter snake
Habitats impacts	
Desert	Aeolian sands Desert wash Sand flat and dunes
Forests and woodlands	Joshua Tree woodlands Mesquite woodlands

The detrimental effects that PV facilities have on animals and environments have been the subject of several studies. These studies emphasise how PV infrastructure at the landscape level reduce connection between appropriate ecosystems or populations.

Nonetheless, these effects were reflected in the loss of habitat and the migration of species (Figure 11).

Fig. 11 Sheep grazing below solar panels (right) and habitats reduction (left)

Nonetheless, there have been reports of wildlife remains which are classified as fatalities at PV projects and the infrastructure that goes along with them.

Complementarity among renewable energy sources

Each renewable energy source has pros and cons, and the synergistic deployment of complementing generating assets often results in the most dependable grids (Shove 2020). Generators must have faster ramping cycles, or the ability to quickly raise or decrease power, in order to include fluctuating renewables. Due to increased emissions and shorter working component lifespans due to thermal stress, these operational changes will likely have an effect on the environment (Heptonstall and Gross 2020). However, it is evident that the many types of renewable energy negatively impact biological diversity in a number of ways.

CONCLUSION

Based on the previous study the following conclusions can be drawn:

1. Nowadays renewable energy regards as an alternative and clean source for energy.
2. The study highlights the impacts of renewable energy sources such as solar photovoltaic (PV), wind farms and hydropower generation on the biological diversity for both terrestrial and aquatic animals environments.
3. About 55% of previous studies for turbines of wind farms indicated that bird mortality rates ranges from 0.0 to 2.0 fatalities/turbine/year. 79.4% of the evaluated mortality rates for raptors range from 0.0 to 0.1 fatalities/ turbine/year.
4. This turbine installation and location has a negative impacts on the wildlife.

5. The most commonly considered threatened are the raptors (common buzzard, common kestrel and red kite), grassland birds (common quail, corn crake, lapwing, ringed plover), migrating birds (migrant goose, crane, lapwing, golden plover) and water birds (geese species). Bat annual mortality rates range from 0.0 to 47.5 fatalities/turbine/year at different wind farms.
6. Also, the study reviews the adverse impacts of hydroelectric reservoirs on biodiversity, taking terrestrial and aquatic mammals and freshwater turtles.
7. Many species are impacted by hydropower, including lots of insect life.
8. Hydropower dams do indeed affect fish directly but also riverine life more broadly – such as semi-aquatic wildlife (like fish otters) and a wide array of birdlife, particularly fish-eating birds like kingfishers or pelicans.
9. The hydropower projects also affect the terrestrial landscape, including species like the lynx, wolf and local deer species, as they can't carry out their normal migratory pathways and died due to the fragmentation caused by the construction of the plants and reservoirs

The adverse effects of PV ffacilities on wildlife is represented by habitats reduction and the migratory pathways of wildlife animals.

RECOMMENDATIONS

In light of the previous study the following recommendations can be suggested:

1. Smart Site Selection

The biggest biodiversity impacts come from where projects are built.

a. Avoid ecologically sensitive areas like wetlands, old-growth forests, and migration corridors.
b. Use degraded lands, deserts (with caution), rooftops, or already-developed areas instead.
c. Apply tools like environmental impact assessments (EIAs) before construction.

2. Wildlife-Friendly Design

Renewables can be modified to reduce harm to animals.

Wind energy:

a. Adjust turbine speeds during peak bird/bat activity.
b. Use radar or AI systems to detect flocks and temporarily shut down turbines.
c. Paint one blade black to reduce bird collisions (proven in studies).

Solar energy:

a. Design panels with space underneath for vegetation or small wildlife.
b. Avoid creating "solar heat islands."

3. Reduce Marine Impacts (Offshore Energy)

Offshore wind and tidal energy can disturb marine life.

a. Schedule construction outside breeding seasons.
b. Use noise-reduction technologies during installation (e.g., bubble curtains).
c. Monitor impacts on species like whales and fish.

4. Habitat Restoration & Offsetting

If impacts are unavoidable, compensate by improving ecosystems elsewhere.

a. Restore native vegetation around solar farms or wind sites.
b. Create pollinator habitats (wildflower meadows).
c. Invest in conservation projects that exceed the damage caused.

5. Grid & Infrastructure Optimization

Energy infrastructure (not just generation) affects biodiversity.

a. Bury power lines where possible to reduce bird collisions.
b. Retrofit existing infrastructure instead of building new corridors.
c. Use wildlife-safe designs for transmission lines.

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