Renewable Energy in Nevada

Potential impacts, design criteria, and mitigation of renewable energy in the Western U.S.

LITERATURE REVIEW
JUNE 2024

The Nature Conservancy
Nevada

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Introduction

Utility-scale renewable energy (primarily geothermal, solar, and wind) has been rapidly deployed over the past two decades in Nevada, and the rate of permit applications and construction is increasing to meet energy demands. This paper reviews the latest literature on renewable energy generation, storage, and transmission and its impacts on biodiversity and ecosystems with a focus on the ecosystems of Nevada (e.g., Mojave Desert and Great Basin). Several studies describe and summarize broad-scale impacts to biodiversity from the installation of renewable energy projects (e.g., Lovich and Ennen 2011; Hernandez et al 2014; Hernandez et al. 2015) from perspectives of impacts to species, land-use and land-cover, physical impacts, etc. However, new studies highlighting previously unquantified impacts of renewable energy facilities have been published. It is critically important to understand how the build-out of renewable energy in Nevada will impact both biodiversity and ecosystems so that developers, federal and state agencies, and the public understand the risks, what may be lost or compromised, how to better site and design facilities, and offset losses. There is a finite amount of undisturbed land and conserving the remaining undisturbed land for biodiversity is important (Cameron et al. 2012). Broad regional analyses of transmission and renewable energy site locations have been used to identify the least impactful locations (Wu et al. 2023), but gaps remain between these broad analyses and state and federal policies on siting.

The development and design of solar energy facilities has shifted in the past several years, and incudes changes in type of system used to generate energy as well as site preparation. All current solar permit requests with the Public Utilities Commission of Nevada (PUCN) and Bureau of Land Management (BLM) are for photovoltaic (PV). Recent advances in PV technology have made solar PV more economical than concentrated solar power (CSP) systems. During site preparation, there has been a shift away from blading and leveling solar facility sites and towards leaving sites vegetated to reduce impacts to vegetation, wildlife, and soils. Wind energy contributes approximately 200 megawatts (MW) of energy in the Spring Valley in Nevada but there have been proposed projects elsewhere throughout the state. Geothermal energy is prevalent in Nevada, but there is little published information on the impacts of geothermal energy production on ecosystems or species (e.g., Coates et al. 2023). Geothermal often has unique site-specific impacts as facility design is determined by the local hydrology and geology, however the infrastructure can be extensive and transmission from the power source to a substation is still required.

A common theme of utility-scale renewable energy projects throughout the literature is the unknown impacts and the need for more research (e.g., Hernandez et al. 2014; Smith and Dwyer 2016; Gibson et al. 2017). The development of projects has outpaced research and science on the environmental impacts, leading to ad hoc changes in design (e.g., Wilkening and Rautenstrauch 2019) and inconsistent mitigation requirements applied by regulatory agencies. Projects have also become larger, and proposals containing multi-project areas of >10,000 acres do not have comparable analogs. Further, a lack of before-after control studies on renewable energy designs has also limited the understanding of direct environmental impacts of renewable energy (Lovich and Ennen 2011; Agha et al. 2020). Project design has shifted with the intentions of building more wildlife-friendly facilities. However, without study results and consistent monitoring of outcomes there are still significant gaps in best management practices regarding system designs, regional siting and transmission planning, landcover changes, and wildlife impacts on both charismatic and cryptic species.

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[1] *Per Nevada Revised Statues, utility-scale means a resource which has a nameplate capacity of at least 50 megawatts and is interconnected directly to a substation of the electric utility through a generation step-up transformer.*

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Impacts common to all technologies

Fragmentation
Habitat fragmentation has been studied in many ecosystems and has been shown to negatively impact all systems and many species (Fahrig 2003). Fragmentation refers to the extent to which linear features, such as roads, powerlines, and railroads separate the landscape. More highly fragmented landscapes have more patches of habitat that are smaller in size and contain more edges. In comparison, less fragmented landscapes have fewer patches, and those patches are larger in size with less edges. Intact habitat is critically important for maintaining biodiversity (Haddad et al. 2015). As habitat becomes fragmented by roads, transmission lines, and other disturbances the conservation value is degraded, and many species are negatively impacted (Crooks et al. 2017). Further, disturbances become vectors for invasive species like cheatgrass (Bradley and Mustard 2006) or increase the foraging efficiency of predators like ravens which prey on greater sage grouse nests (Centrocercus urophasianus; Dinkins et al. 2014; Gibson et al. 2018) or increase predation on desert tortoise (Tuma et al. 2016). The impact of fragmentation has been studied more frequently in umbrella species such as greater sage grouse and desert tortoise, but likely similar impacts are found in other species (e.g., lizards, small mammals, insects, and arthropods) (Diffendorfer et al. 1995; Templeton et al. 2001), and native plant communities (Devitt et al. 2022). Further, in some desert environments, roads and other infrastructure can de-couple plant-soil-hydrology interactions (Devitt et al. 2022). Nevada has largely intact landscapes outside of its cities, towns, and other built areas. Understanding how large infrastructure projects will impact the ecosystem and intactness of ecosystems is important to future conservation values of an area and exploring alternatives. At the spatial scale of a project or series of projects, including permeability or connectivity through a site should reduce the barrier effect of a project. However, there has not yet been research comparing habitat use and connectivity of projects using designs that included permeability and projects that did not have permeability.

Ecosystem services
Ecosystem services can be difficult to quantify, particularly in shrublands like those that dominate Nevada. However, the ecosystem services provided by the shrublands of the Mojave Desert and the Great Basin sequester and store carbon (Arnone et al. 2005; Wohlfarht et al. 2008; Evans et al. 2014), have outsized biodiversity, reduce dust emissions and soil erosion, and provide natural fire breaks (Provencher et al. 2020). Soil loss and erosion are likely to increase on bladed/scraped sites as there is no vegetation or root structure to hold the soil. High winds will remove surface particles increasing atmospheric dust (Field et al. 2010). There are wide ranging consequences of increased dust emissions for human health (Nguyen et al. 2013), biogeochemical (Field et al. 2010), and climate (Jickells et al. 2005).

Renewable energy impacts

This section is split into the components and types of renewable energy systems and their impacts to species. For example, for each type of energy generation, transmission is required, and storage is often co-located. Breaking the components of a renewable energy facility or system into its components allows examination at the component-level to identify sources of particular concern that can be mitigated or re-designed for lower impacts. However, it is important to also understand the cumulative impacts of the entire system on the environment, and context is important as well (e.g., Table 1). For example, renewable energy facilities cause fatalities of birds (detailed synthesis below), however the context of quantities and rates of fatalities are important to understand relative to other causes of fatalities and power generation (Table 2; Sovacool 2009; Walston Jr. et al. 2016).

Table 1. Estimated amount of bird fatalities each year in the US by different sources (Sovacool 2009; Loss et al. 2015; Walston Jr. et al. 2016).

Fatality source	Mean	Lower (95% CI)	Upper (95% CI)
Cats	2.4 billion	1.3 billion	3.99 billion
Buildings	599 million	365 million	988 million
Automobiles	199.6 million	88.7 million	339.8 million
Transmission line collisions	22.8 million	7.7 million	57.3 million
Transmission line electrocutions	5.63 million	920,000	11.55 million
Wind turbines	573,093	467,097	679,089
Fossil fuel power plants	14.5 million		
Utility-scale solar	88,200	37,800	138,600

Wind
There is one large-scale wind facility in Nevada, built in Spring Valley in 2012. Additionally, wind farms have been proposed in Clark County and elsewhere in White Pine County. Impacts from wind farms include loss of habitat and habitat fragmentation, and over 500,000 bird fatalities and over 800,000 bat fatalities per year occur in the US from wind turbine strikes (Smallwood 2013; Gibson et al. 2017). There are conflicting data about the physical size of wind turbines and impacts on wildlife. For example, Smallwood (2013) suggest physically larger turbines caused fewer fatalities of birds and bats, and fatality of birds was 11 birds/MW and 17 bats/MW, however Barclay et al. (2007) found bat fatalities increased with height of wind turbine. Additionally, evidence suggests painting one of the three turbine blades black reduced visual smear and bird fatalities by over 70% (May et al. 2020). LeBeau et al (2017) identified a three-year lag response of seasonal habitat use from greater sage grouse in Wyoming at distances up to 1.2 km from wind turbines. Declining patterns 2-10 years after installation have also been observed in greater sage grouse lek activity in oil and gas fields (Harju et al. 2010), suggesting other species and infrastructure may have responses that go undetected due to study design and time length. The impact of wind farms on other terrestrial species is challenging to measure due to the many variables in habitat selection, but there is evidence that pronghorn antelope (Antilocapra americana) avoid wind turbines (Milligan et al. 2021), providing further evidence that siting should take migration routes, habitat value, and geography into consideration.

Table 2. Bird fatality rate at different types of power generation in Nevada.

Generation	Bird fatality/MW/year
Solar	2.7[a]
Wind	11.10
Fossil fuel	74.2

[a]Data from Walstrom et al. 2016, however fatalities/MW/year differ slightly based on location and datasets included in the analyses and range from 0.08-5.71 fatalities/MW/year on facilities built in ecosystems that occur in Nevada.

Solar
Since 2008, utility-scale solar projects have been developed with increasing frequency, especially in southern Nevada. Due to increases in state and federal mandates encouraging more renewable energy projects on federal lands, applications for renewable energy projects have increased dramatically throughout Nevada, including northern and southern Nevada. All new solar applications are for PV systems, but several CSP systems were built in the region, including Crescent Dunes in central Nevada and Ivanpah in southeastern California. The habitat loss from PV and CSPs are similar in that in some areas the vegetation is bladed and in other areas the vegetation may be mowed or left partially undisturbed within a facility. However, the impacts to birds and bats differ between PV and CSP systems. Birds and bats can strike both systems causing fatalities, but CSP systems can burn birds and bats if they fly through or near the concentrated solar areas (Hernandez et al. 2014).

Several studies summarize large datasets on bird and bat (volant species) fatalities at solar facilities in the Southwest (e.g., Koscuich et al. 2020; Smallwood 2022). These studies examined large datasets from multiple solar facilities, which span different types of generation systems (e.g., PV or CSP), size, and ecoregion. Fatalities at different components of the facility were also examined to understand how each part of the energy facility contributes. Components included in analyses were PV panels, CSP heat zone, transmission, and perimeter fencing (Koscuich et al. 2020; Smallwood 2022). There were 189 species of birds killed on solar facilities and eight species of bats (Appendix A). Bird fatalities on solar facilities in the Mojave Desert were highest during fall, a time when many bird species migrate to wintering ground, and included a mix of water birds, water associated birds, and other bird species (Koscuich et al. 2020). Throughout the US, the highest bird fatality rates at solar energy facilities occur during fall, but there is a bimodal distribution with another peak during spring (Loss et al. 2015). The bimodal peaks indicate increased bird fatalities during seasonal migrations, which can have negative population-level impacts on non-local (migratory) birds (Conkling et al. 2022).

Songbirds, mourning doves, western meadowlarks, and horned larks had the highest strike/fatality rate on solar facilities (Koscuich et al. 2020; Conkling et al. 2022, Smallwood 2022). There appeared to be no spatial pattern of which facilities have high numbers of water bird fatalities and which facilities do not. The size of the solar facility did not influence the fatality rate (Conkling et al. 2022), and mass mortality events were not recorded at PV facilities. Conkling et al. (2022) found deaths were from collisions with the solar panels, however Smallwood (2022) suggests perimeter fences had the highest fatality rates. Bird fatalities in the Mojave Desert ranged from 0.08 to 2.99 fatality/MW/yr and 5.71 fatality/MW/yr in the Great Basin (Walstron Jr et al. 2016; Koscuich et al. 2020). Smallwood (2022) calculated an annual mean bird fatality rate at 11.61 (95% CI = 8.37-17.56) birds/MW and bat fatality rate at 0.06 (95% CI = 0.01-0.10) bats/MW at solar PV facilities in California. Additionally, perimeter fence fatalities rates were 14.44 (95% CI = 10.88–20.34) birds/km and 2.56 (95% CI = 0.17–6.54) bats/km. Modeled data suggests 48% of 23 priority bird species are vulnerable to experiencing population-level impacts from fatalities caused by either solar energy, wind energy, or both in California (Table 3; Conkling et al. 2022).

Table 3. List of 23 priority bird species examined by Conkling et al. (2022). Species in bold are at risk of population-level impacts in California from either solar or wind energy.

Solar	Wind
American Kestrel	American Kestrel
American white pelican	**Bank swallow**
Common yellowthroat	**Barn owl**
Eared grebe	**Burrowing owl**
Greater roadrunner	Golden eagle
Horned lark	Horned lark
Mourning dove	Mourning dove
Rufous hummingbird	Red-tailed hawk
Western grebe	Swainson's hawk
Western meadowlark	Tricolored blackbird
Western Yellow-billed cuckoo	Western meadowlark
Willow flycatcher	White-tailed kite
Wilson's warbler	Wilson's warbler
Yellow warbler	
Yellow-rumped warbler	

Plants and plant communities are also impacted by the construction of solar facilities. Different designs during construction also impact the vegetation differently. For example, there are several site preparation designs in use, including: blading the vegetation and soil to level the site, mowing vegetation to reduce vegetation height, and crushing vegetation with vehicles and equipment during construction (Table 4). Methods using mowing or crushing are thought to leave plant roots intact with the expectation that vegetation will recover, and the site may retain the seedbank and some habitat value. However, few studies have document plant recovery or increased wildlife habitat value on either construction method. Grodsky and Hernandez (2020) showed blading has the most negative impact on the plant community followed by mowing. They do not test the crushing method to install solar infrastructure but do test leaving vegetation as is – which performed better than either blading or mowing and similar to control desert. Bladed areas had significantly higher cover of invasive annual grasses, and both blading and mowing significantly reduced cacti and yucca presence on the site (Grodsky and Hernandez 2020). Furthermore, disturbed areas in solar facilities disrupted the non-bee pollinator community compared to non-disturbed desert areas (Grodsky et al. 2021). Grodsky and Hernandez (2020) show that ecosystem services of plants are reduced by installation of utility-scale solar. Reduced species richness and flower visitation has several implications for ecosystem function, including: 1) lower biomass and diversity of pollinators may impact pollination rate of some species, favoring certain species at the expense of others, 2) reduced diversity of pollinators, and presumably biomass, may alter food-chain for insectivorous wildlife (Grodsky et al. 2021).

Solar panels at large facilities are installed in rows with spaces between rows for maintenance access, which creates three distinct microhabitats 1) shaded area beneath the panels with reduced sunlight and precipitation, 2) interpanel area receiving normal sunlight and precipitation, and 3) area under the dripline of panels which receive precipitation runoff from the panel (Figure 1). Each microhabitat provides a different moisture balance and sunlight amount for vegetation. Hernandez et al. (2020) show some plant species differentially germinate depending on which microhabitat their seeds are found. Further, the shaded areas under panels increased biocrust growth and production significantly (Herdia-Velasquez et al. 2023). Plant species richness in the three microhabitats was dependent on annual weather and soil conditions (Tanner et al. 2020). For example, during dry years microhabitats in shaded areas had higher species richness on more stressful soils likely from reduced evapotranspiration (Tanner et al. 2020). Additionally, two invasive annual plants, storksbill (Erodium cicutarium) and Mediterranean grass (Schismus arabicus), benefited from the shaded microhabitat and increased in abundance (Tanner et al. 2020). In a semi-agrivoltaic system, Graham et al. (2021) found solar panels delayed flowering and altered the pollinator community. Late-season floral abundance increased in partially shaded areas beneath solar panels which altered the species and composition of the community (Graham et al. 2021). Moore-O'Leary et al. (2017) highlight the lack of taxa specific data, but the current published data suggest most taxa are negatively impacted by utility scale solar facilities.

Table 4. Various disturbances that occur on utility scale solar facilities and the reported impacts to ecosystems.

Design component	Reported impact
Blading	had lower pollinator counts than undisturbed areas. Species richness was significantly lower at bladed sites compared to undisturbed, control sites (Grodsky et al. 2021). Significantly reduced cacti and yucca (Grodsky and Hernandez 2020).
Mowing	had lower pollinator counts than undisturbed areas. Species richness was significantly lower at mowed sites compared to undisturbed, control sites (Grodsky et al. 2021). Significantly reduced cacti and yucca (Grodsky and Hernandez 2020). Desert tortoise used site after construction, but as part of broader home range (Wilkening and Rautenstrauch 2019).
Panels over vegetation (e.g., shaded area)	Delayed flowering and altered pollinator community (Graham et al. 2021). Reduced population of rare plants in wet years (Tanner et al. 2021). Increased soil moisture and annual non-native species (Tanner et al. 2020). Increased seedbank survival (Hernandez et al. 2020). Increased biocrust under panels when vegetation was bladed (Herdia-Velasquez et al. 2023).
Run-off zone	Common annual plants increased in population (Tanner et al. 2021).
Perimeter fence	Most likely place for bird and bat fatalities to occur through collisions (Smallwood 2022).
Transmission	Bird fatalities occur from electrocution and collisions (Conkling et al. 2022; Smallwood 2022). Transmission can also provide perches for raptors that increase fatalities on nesting birds and juvenile desert tortoises (Tuma et al. 2016; Gibson et al. 2018).

Impacts from utility scale solar facilities also have Earth systems feedbacks and can extend beyond the project boundary of the facility. However, there are conflicting datasets with some indicating utility scale solar facilities provide a cool island effect and reduce temperatures of the surrounding ecosystems of several degrees C (e.g., Guoqing et al. 2021), while others report anomalously high temperatures 1.5-8 C above ambient temperatures extending beyond the facility and into the surrounding ecosystem (Broadbent et al. 2019; Devitt et al. 2022) - or nighttime temperatures were raised (Barron-Gafford et al. 2016). Wu et al. (2020) suggest there may be seasonality effects to changes in temperature. It is unknown why some studies report increasing temperature while other report decreasing temperature near facilities, perhaps the difference is related to method. For example, Guoqing et al. (2021) used remote sensing while others (e.g., Broadbent et al. 2019; Devitt et al. 2022) used field instruments. Regardless of the method, understanding temperature differences will be important to understanding broader Earth systems impacts. Changes in temperature have significant implications to the surrounding ecosystems. Reduced temperatures risk frost/freeze damage of some warm desert plant species in winter but reduce warm season moisture balance stress. Increased temperature of the surrounding ecosystem can place additional moisture/heat stress on animals and plants (e.g., Devitt et al. 2022). Additional research is needed to understand the Earth system feedbacks and dynamics of utility scale solar facilities, but current data show the impact extends beyond the boundary of the facility.

The impacts of utility scale solar on sagebrush ecosystems are not well known (Remington et al. 2020). Most utility scale solar energy facilities have been placed in the Mojave Desert, but there are increasing solar facilities proposed for development in the Great Basin which will likely occur in sagebrush vegetation, saltbrush/greasewood (Atriplex spp./ Sarcobatus spp.), or cheatgrass (Bromus tectorum) dominated sites. Small solar facilities have been developed in the semi-arid portions of Oregon, Washington, Idaho, and Utah often in conjunction with agricultural lands. Large utility scale solar projects in the thousands of acres have not been developed and present an important opportunity for study.

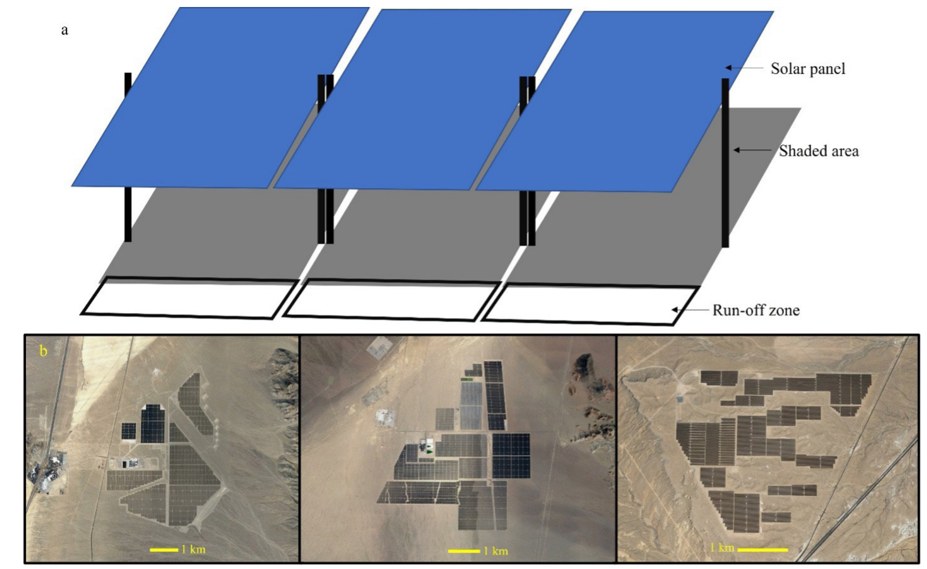

Figure 1. a) Zones of microhabitat associated with solar facility. Utility scale solar facilities often have between 10,000 and >100,000 panels. b) panels showing aerial photos of three solar facilities in southern Nevada. The yellow line measures 1 km.

Renewable energy in the past 20-years in the Great Basin has been dominated by geothermal and to a lesser extent wind. The environmental impacts of solar, wind, and geothermal are all different, but there will be some broad generalities of impacts. There will also be significant research opportunities to understand the potential impacts to ecosystems and where conservation values can be preserved or raised through appropriate siting and design. It is likely similar issues with bird/bat fatalities in the Mojave and solar facilities in other systems will be observed in the Great Basin (e.g., Smallwood 2022). Another major concern is the large land area required for utility scale solar and where the projects will be placed on the landscape and in which vegetation-type. Project siting will be critical to avoid migration routes, habitat fragmentation, and the loss of important habitat. For example, locating projects in areas with high greater sage grouse populations may lead to high mortality due to fence strikes (e.g., Stevens et al. 2012).

Geothermal

Utility-scale geothermal energy can have two main impacts on the environment: 1) the surface impacts to vegetation and wildlife through disturbance, habitat fragmentation, and noise caused by construction and facilities (e.g., Coates et al. 2023), and 2) hydrological impacts from exploration, production, and reinjection of groundwater – which may be manifested as surface impacts to nearby springs and groundwater dependent ecosystems (GDEs) depending on the hydrogeological connections (White 1991; Sorey 2000; Robins 2021). Surface impacts are similar to other disturbances where vegetation and soils are bladed and removed, wells and electricity generation facility infrastructure is built, and linear landscape disturbances are created by pipelines, roads, and electrical transmission lines. Additionally, hybrid geothermal-solar systems will have impacts from both the geothermal generation and solar generation, however the colocation of sites will reduce the overall disturbance footprint.

Geothermal facilities occur in both urban and rural settings, and siting options have historically been more limited than other renewable energy types because of hydrogeological requirements. However, the Basin and Range/Great Basin has significant geothermal resources (Garg et al. 2007). There is little research on the direct impacts of geothermal facilities on wildlife in rural settings. There have however been documented impacts to greater sage grouse abundance which declined by 24% within 5 km of geothermal energy facilities and lek absence rates increased by >700% within 2 km of a geothermal facility within 6-years of

construction (Coates et al. 2023). Declines in greater sage grouse did not occur when geothermal facilities were hidden by topography (Coates et al. 2023), suggesting facility site location and local topography is important for reducing impacts to greater sage grouse. Lek abandonment was attributed to noise and light pollution, and road traffic that reduced greater sage grouse ability to identify predators. Differences in topography dampened noise pollution and impacts from roadway traffic. Additionally, it is likely that birds and bats experience similar impacts as with other renewable energy generation types from basic infrastructure at geothermal energy facilities like areas with perimeter fencing and transmission lines; however, published data do not currently exist on these potential impacts. There is also less fencing on geothermal facilities compared to utility scale solar facilities.

Geothermal energy production can impact GDEs by lowering groundwater levels and drying springs (White 1991; Sorey 2000). Other hydrological or physical impacts may be manifested through land subsidence and the cessation of geysers (Sorey 2000). For example, in central Nevada, hot springs and a geyser system stopped flowing after geothermal exploration and energy production began in 1959 (White 1992). The geothermal exploration that stopped the geyser discharge was an open system with higher evaporative loss compared to modern closed-loop system. Geothermal energy can require large amounts of groundwater for cooling equipment (Robins 2021); however, most modern geothermal systems use a closed-loop system that pumps hot fluids from the geothermal reservoir or steam to the surface, heats a secondary fluid such as pentane, and reinjects cooler water/condensate back into the aquifer (Kaya et al. 2011). Pumping and reinjection rarely occur at the same location, and the pressure differences can cause a shift in the head pressure of the subsurface flow system which may impact hydrogeologic systems (Kaya et al. 2011). If there is connectivity between the geothermal reservoir and shallower groundwater system, there is the potential for the groundwater levels in the shallower system to decline with deeper groundwater withdrawal. Changes in groundwater levels could cause stress or die-off of phreatophytic vegetation associated with shallow groundwater. In some areas, evidence suggests a link between geothermal development activity and reduced spring discharge, including some springs that have completely dried (Sorey 2000), which can have significant consequences to wildlife, particularly if endemic species exist in impacted spring systems (e.g., FWS 2020). However, establishing a clear relationship between geothermal development and spring discharge is challenging because of the subsurface nature of the resource and multiple variables involved. These complexities highlight the uniqueness of each geothermal energy development. A challenge of geothermal energy is understanding the local and regional hydrogeology to predict impacts, which can range from minimal surface disturbance to drying of spring systems and wetlands. These potential impacts necessitate a strong monitoring system of springs and groundwater to detect the potential impacts of geothermal development, as well as a management plan should impacts be observed (Saito et al. 2021). Off-site mitigation is unlikely to be sufficient in the case of drying spring systems as springs hold high importance for biodiversity in the western US and each spring has unique physical characteristics (Kreamer et al. 2015; Love et al. 2022). Coates et al. (2023) underscores the importance of predevelopment monitoring for wildlife with 6-years pre- and post-development of geothermal energy facilities. Predevelopment monitoring of spring discharge is also important to understand the potential changes in spring discharge during geothermal energy development (Schaffer et al. 2018). Further, hydrogeologic studies focused on the groundwater – surface water interaction can also be valuable for providing context to the system. These often include studies on water quality, hydrogeologic tracers, recharge locations, flow paths, etc. Furthermore, a basic water balance, or Hydrogeologic Framework Model, can define potential vulnerabilities (e.g., Belcher 2019).

Enhanced geothermal systems (EGS) are an emerging technology that allow energy to be produced from geologic systems that contain hot dry rocks (Olasolo et al. 2016). In EGS, fluids are injected into hot dry rocks to fracture and expand the permeability of the subsurface. The fractured subsurface provides space for injected fluids to be warmed and then pumped to the surface to produce geothermal energy (Olasolo et al. 2016; Sharmin et al. 2023). The EGS can be contained as a closed loop through pumping and reinjecting of fluids while producing energy. The hydrogeology of areas suitable for EGS do not originally contain geothermally warmed groundwater and likely do not have a prior connection to local spring and wetlands, which should reduce some risks to these ecosystems. EGS also expands the potential locations where geothermal energy can be a viable renewable energy source, because it does not rely on existing heated groundwater. Because EGS have not been widely deployed, little research has been published on the potential environmental impacts. There have been reported concerns over increased seismic activity (Majer et al. 2012), but these concerns are generally for local communities and infrastructure. Potential concerns of EGS in arid ecosystems are the loss and/or use of water required for injection and other industrial processes. The amount of fluid, frequently referred to as water (Sharmin et al. 2023), injected into the fractured hot rocks is unknown. The amount of water required for injections is likely dependent on the size of the geothermal facility, but estimates have not been published. However, other fluids besides water can be used in EGS, such as CO_2 (Pruess 2006; Liu et al. 2023). Using CO_2 instead of water may be advantageous because CO_2 has better thermal qualities than water and if some CO_2 is trapped in the rocks and not recoverable, it is sequestered (Pruess 2006; Gao et al. 2022).

Energy storage impacts

Transitioning to renewable energy will require energy storage to balance energy supply and demand on the electrical grid. Energy is stored when production exceeds demand. Stored energy is used when demand exceeds production. Energy storage comes in several forms, and can consist of battery, gravity (e.g., pumped hydro), thermal, compressed air, or flywheel (EPA 2023). Others have outlined the life cycle of batteries, usually lithium-ion (e.g., Dai et al. 2019). In Nevada, battery storage is often proposed at new utility scale solar facilities and is more recently being proposed as stand-alone projects without associated on-site energy generation. Gravity storage has also been proposed at several locations throughout the state. Few studies have occurred on the environmental impacts of energy storage. No information was found on how the addition of battery storage at solar facilities changes the environmental impacts, but there is likely the need for a larger project area to accommodate the extra infrastructure and increased risk (e.g., fire, contamination) relative to projects without on-site batteries. Additionally, on-site batteries are often housed on concrete pads that will create additional impervious surfaces. Impacts from gravity storage also have little published information but need to be examined as individual projects that will require a land area footprint (habitat loss, fragmentation, etc.), water usage, and transmission to transport energy. Gravity storage projects have also proposed to pump and release water as a form of energy, which will also require additional understanding of the hydrology in the project area.

Transmission impacts

Utility scale renewable energy facilities require transmission lines to transport power to customers. Transmission lines vary in size depending on output, but create linear features on the landscape, have roads underneath the lines, and create vertical structures – each of which can have negative impacts to the ecosystem (Smith and Dwyer 2016). Transmission lines also kill 27 million birds each year in the US through strikes or electrocution (Gibson et al. 2017). Transmission lines may increase the risk of wildfire in certain vegetation-types, but it is unlikely that transmission increases wildfire risks in shrub dominated Great Basin and Mojave Desert because vegetation is not tall enough to contact lines or poles. The greater sage grouse is a species that requires large, intact landscapes and is susceptible to fragmentation and predation (LeBeau et al. 2019). Transmission lines can negatively impact multiple parts of the life cycle of greater sage grouse, notably lek occupation, nest success, chick survival, and general reduction of habitat quality (e.g., Coates et al. 2008; LeBeau et al. 2019; Kohl et al. 2019). LeBeau et al. (2019) observed reduced habitat suitability up to 3.1 km from transmission lines of the highest suitable habitat. Further, transmission lines negatively affected sage grouse lek trends by reducing chick survival 2.8 km away from transmission but did not affect lek persistence (Kohl et al. 2019), while nest and brood success was reduced up to 2.6 km and 1.1 km, respectively (Kohl et al. 2019). Additionally, data suggest presence of transmission lines can reduce sage grouse nest success up to 12.5 km away during years with average to above average raven densities (Gibson et al. 2018). Transmission lines provide perches for raptors that can increase predation on adult birds and increase nest predation by ravens on both sage grouse and desert tortoise (Coates et al. 2009; Tuma et al. 2016; O'Neil et al. 2018). While most information on predation risk is for specific species (e.g., greater sage grouse, desert tortoise), it is likely other species experience increased predation as well.

Design criteria, monitoring, and other recommended mitigation

Regional-scale optimization-type analyses can provide valuable insights into where and how renewable energy and the associated transmission can be sited to reduce negative environmental impacts (Stoms et al 2015; Wu et al. 2023). Regional-scale analyses take a holistic perspective, rather than a project-by-project ad hoc approach to building renewable energy facilities. Further, incorporating regional- or state-wide analyses into land-use plans are critical to providing state and federal agencies with the power to develop and re-assess renewable energy zones and exclusion zones based on important natural and cultural resources. While state-wide and regional plans partially exist (e.g., Solar Energy Development PEIS, West Wide Energy Corridors), site level design criteria and mitigation need to be developed based on science. Unfortunately, little information exists on appropriate design criteria in most ecosystems and federal agencies have been approving projects designed to limit impacts to wildlife based on small sample sizes, small sites, and anecdotal evidence. Past renewable energy developments have placed little emphasis on studying the impacts of different designs on wildlife. Most studies are developed post-construction to understand the potential of a project to disrupt or kill birds, bats, plants, or desert tortoise (e.g., Agha et al. 2020; Smallwood 2022).

General recommendations include:

- Avoid developing projects in areas of high bird usage, such as flyways, migration corridors, topography that provides uplift, etc. (Smith and Dwyer 2016).
- Employ deterrence technology (lights, sounds) to warn or scare wildlife away when necessary (Smith and Dwyer 2016).
- Reduce fencing. If fencing is needed, use visibility markers.
- Monitor impacts at least 3-years after facility installation and analyze data for lag effects on species.
- Standardize bird and bat fatality records to include all project components, such as transmission, storage, and fencing, as well as the energy generation.

Solar

- Construction should occur during certain times of the year (winter) to avoid desert tortoise and migrating birds.
- Translocations should not occur during severe to extreme drought years as measured by Palmer Drought Severity Index, instead the facility should build an onsite maintenance facility and desert tortoise should be translocated during an appropriate time of year.
- Develop additional methods to reduce bird fatalities at PV solar facilities.
- Bird and bat fatality monitoring should occur for at least 60 months to appropriately understand the number of species and individuals impacted by the facility (e.g., Smallwood 2022).
- Sites should be monitored for at least one year before construction to collect background bird fatality rates on the site.
- Breeding and non-breeding wildlife densities should be calculated prior to construction to understand the true loss of biodiversity and impacts to habitat (Smallwood 2022). A lack of before-after-control inhibits our understanding of site impacts (Agha et al. 2020).
- Understanding of how large-scale solar facilities cumulatively impact ecosystem in the Great Basin, which are likely sagebrush dominated or saltbrush/greasewood dominated.
- Projects should include connectivity corridors to allow wildlife to transit through the project site where appropriate.
- Perimeter fences should have large enough gaps to allow passage of small animals (e.g., kit fox, coyote, jackrabbit, desert tortoise, etc.).
- Projects should reduce soil erosion where possible. Restoring cryptobiotic soils or biocrusts will provide natural cover for soils.

Wind

- Sites should be monitored >1 year before construction to collect background bird and bat fatality rates on the site.
- Follow Wyoming State guidelines where no wind energy development should occur within greater sage grouse core areas, and development should be at least 0.4 km from the perimeter of occupied leks outside of core areas (Lebeau et al 2017).
- Construction should occur during certain times of the year (winter) to avoid desert tortoise and migrating birds.

Transmission

- Where appropriate, lines should be underground and vegetation restored to limit environmental impacts from transmission. Undergrounding lines causes temporary surface disturbance which can be restored like many pipeline projects. Over the longer term, undergrounding reduces bird/bat fatalities and predation risks to other species.
- Use perch deterrents on poles to limit perching of raptors.
- Use bird deterrent devices, such as flappers (Ferrer et al. 2020), on transmission lines, which can reduce bird collision fatalities by 70%.
- Transmission infrastructure should be placed more than 10 km from an active sage grouse lek (Gibson et al. 2018).
- Standardize wildlife fatality survey protocol and reporting for all renewable energy facilities, particularly for those in similar ecoregions.

Geothermal

- Develop a detailed and comprehensive groundwater model and plan to understand the potential impacts to GDEs and springs from geothermal exploration, production, and injection.
- Develop a baseline, local water budget, specifically a Hydrogeologic Framework Model.
- Require pre- and post-construction monitoring of springs that may be hydrogeologically connected with the geothermal resource, and development of an adaptive management strategy to address changes in spring temperature or flow.
- Avoid siting projects near wetlands with endemic and migrating species.
- Avoid siting wells and generation facilities within 10 km of greater sage grouse leks because of noise-related impacts on lek activity.
- Follow established guidelines on reserve pit design.
- Use closed-loop drilling to reduce the length of time fluids occur in the reserve pit, or eliminate the need for reserve pits.
- Require seismic monitoring for facilities using EGS.
- Disclose the fluid source for facilities using EGS.

Possible off-site mitigation opportunities

- Solar facilities off-set their bird fatalities by funding bird habitat enhancement projects.
- Funding revegetation efforts including a native seed/nursery at appropriate size for the scale, both the science and the broader effort, to restore burned areas in desert tortoise habitat.
- Funds provided by solar facilities to retrofit culverts and fencing for desert tortoise to provide better connectivity across highways and interstates.

Acknowledgements

We want to thank Laurel Saito and David Kreamer for their review and insightful comments on portions of this report.

[2]The BLM is expected to initiate an environmental impact statement in 2023 for the proposed White Pine Pumped Hydro Storage project.

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Appendix A

List of volant (bird and bat) species killed on utility scale solar facilities. List adapted from Smallwood (2022).

Common name	Species	Bird/bat	Native/non-native
American avocet	*Recurvirostra americana*	bird	native
American coot	*Fulica americana*	bird	native
American kestrel	*Falco sparverius*	bird	native
American pipit	*Anthus rubescens*	bird	native
American robin	*Turdus migratorius*	bird	native
American wigeon	*Mareca americana*	bird	native
Anna's hummingbird	*Calypte anna*	bird	native
Ash-throated flycatcher	*Myiarchus cinerascens*	bird	native
Band-tailed pigeon	*Patagioenas fasciata*	bird	native
Bank swallow	*Riparia riparia*	bird	native
Barn owl	*Tyto alba*	bird	native
Barn swallow	*Hirundo rustica*	bird	native
Belted kingfisher	*Megaceryle alcyon*	bird	native
Bewick's wren	*Thryomanes bewickii*	bird	native
Big brown bat	*Eptesicus fuscus*	bat	native
Black phoebe	*Sayornis nigricans*	bird	native
Black-and-white warbler	*Mniotilta varia*	bird	native
Black-chinned hummingbird	*Archilochus alexandri*	bird	native
Black-crowned night heron	*Nycticorax nycticorax*	bird	native
Black-headed grosbeak	*Pheucticus melanocephalus*	bird	native
Black-tailed gnatcatcher	*Polioptila melanura*	bird	native
Black-throated gray warbler	*Setophaga nigrescens*	bird	native
Black-throated sparrow	*Amphispiza bilineata*	bird	native
Blue-footed booby	*Sula nebouxii*	bird	native
Blue-gray gnatcatcher	*Polioptila caerulea*	bird	native
Blue-winged teal	*Spatula discors*	bird	native
Brant	*Branta bernicla*	bird	native
Brewer's blackbird	*Euphagus cyanocephalus*	bird	native
Brewer's sparrow	*Spizella breweri*	bird	native
Broad-tailed hummingbird	*Selasphorus platycercus*	bird	native
Brown pelican	*Pelecanus occidentalis*	bird	native
Brown thrasher	*Toxostoma rufum*	bird	native
Brown-headed cowbird	*Molothrus ater*	bird	native
Bullock's oriole	*Icterus bullockii*	bird	native
Burrowing owl	*Athene cunicularia*	bird	native
Bushtit	*Psaltriparus minimus*	bird	native
Cactus wren	*Campylorhynchus brunneicapillus*	bird	native
California gull	*Larus californicus*	bird	native
California myotis	*Myotis californicus*	bat	native
California quail	*Callipepla californica*	bird	native
Calliope hummingbird	*Selasphorus calliope*	bird	native
Canyon bat	*Parastrellus hesperus*	bat	native
Cassin's finch	*Haemorhous cassinii*	bird	native
Cassin's kingbird	*Tyrannus vociferans*	bird	native
Cassin's vireo	*Vireo cassinii*	bird	native
Cattle egret	*Bubulcus ibis*	bird	native
Cedar waxwing	*Bombycilla cedrorum*	bird	native
Chestnut-sided warbler	*Setophaga pensylvanica*	bird	native
Chipping sparrow	*Spizella passerina*	bird	native
Chukar	*Alectoris chukar*	bird	non-native
Cinnamon teal	*Spatula cyanoptera*	bird	native
Cliff swallow	*Petrochelidon pyrrhonota*	bird	native
Common gallinule	*Gallinula galeata*	bird	native
Common grackle	*Quiscalus quiscula*	bird	native
Common ground-dove	*Columbina passerina*	bird	native
Common loon	*Gavia immer*	bird	native
Common peafowl	*Pavo cristatus*	bird	non-native
Common poorwill	*Phalaenoptilus nuttallii*	bird	native
Common raven	*Corvus corax*	bird	native
Common yellowthroat	*Geothlypis trichas*	bird	native
Cooper's hawk	*Accipiter cooperii*	bird	native

Costa's hummingbird	*Calypte costae*	bird	native
Crissal thrasher	*Toxostoma crissale*	bird	native
Curve-billed thrasher	*Toxostoma curvirostre*	bird	native
Dark-eyed junco	*Junco hyemalis*	bird	native
Double-crested cormorant	*Phalacrocorax auritus*	bird	native
Eared grebe	*Podiceps nigricollis*	bird	native
Eurasian collared-dove	*Streptopelia decaocto*	bird	non-native
European starling	*Sturnus vulgaris*	bird	native
Fox sparrow	*Passerella iliaca*	bird	native
Gadwall	*Mareca strepera*	bird	native
Gambel's quail	*Callipepla gambelii*	bird	native
Golden-crowned kinglet	*Regulus satrapa*	bird	native
Gray flycatcher	*Empidonax wrightii*	bird	native
Great blue heron	*Ardea herodias*	bird	native
Great egret	*Ardea alba*	bird	native
Great horned owl	*Bubo virginianus*	bird	native
Greater roadrunner	*Geococcyx californianus*	bird	native
Greater yellowlegs	*Tringa melanoleuca*	bird	native
Great-tailed grackle	*Quiscalus mexicanus*	bird	native
Green heron	*Butorides virescens*	bird	native
Green-tailed towhee	*Pipilo chlorurus*	bird	native
Green-winged teal	*Anas crecca*	bird	native
Hermit thrush	*Catharus guttatus*	bird	native
Hermit warbler	*Setophaga occidentalis*	bird	native
Hooded oriole	*Icterus cucullatus*	bird	native
Horned lark	*Eremophila alpestris*	bird	native
House finch	*Haemorhous mexicanus*	bird	native
House sparrow	*Passer domesticus*	bird	non-native
House wren	*Troglodytes aedon*	bird	native
Inca dove	*Columbina inca*	bird	native
Killdeer	*Charadrius vociferus*	bird	native
Ladder-backed woodpecker	*Dryobates scalaris*	bird	native
Lapland longspur	*Calcarius lapponicus*	bird	native
Lark sparrow	*Chondestes grammacus*	bird	native
Lazuli bunting	*Passerina amoena*	bird	native
Least bittern	*Ixobrychus exilis*	bird	native
Least sandpiper	*Calidris minutilla*	bird	native
Lesser goldfinch	*Spinus psaltria*	bird	native
Lesser nighthawk	*Chordeiles acutipennis*	bird	native
Lincoln's sparrow	*Melospiza lincolnii*	bird	native
Loggerhead shrike	*Lanius ludovicianus*	bird	native
Long-billed curlew	*Numenius americanus*	bird	native
Long-eared owl	*Asio otus*	bird	native
Long-legged myotis	*Myotis Volans*	bat	native

Lucy's warbler	*Leiothlypus luciae*	bird	native
MacGillivray's warbler	*Geothlypis tolmiei*	bird	native
Mallard	*Anas platyrhynchos*	bird	native
Marsh wren	*Cistothorus palustris*	bird	native
Mexican free-tailed bat	*Tadarida brasiliensis*	bat	native
Mountain bluebird	*Sialia currucoides*	bird	native
Mourning dove	*Zenaida macroura*	bird	native
Nashville warbler	*Leiothlypis ruficapilla*	bird	native
Neotropic cormorant	*Phalacrocorax brasilianus*	bird	native
Northern flicker	*Colaptes auratus*	bird	native
Northern harrier	*Circus hudsonius*	bird	native
Northern mockingbird	*Mimus polyglottos*	bird	native
Northern pintail	*Anas acuta*	bird	native
Northern pygmy-owl	*Glaucidium gnoma*	bird	native
Northern rough-winged swallow	*Stelgidopteryx serripennis*	bird	native
Northern saw-whet owl	*Aegolius acadicus*	bird	native
Northern shoveler	*Spatula clypeata*	bird	native
Olive-sided flycatcher	*Contopus cooperi*	bird	native
Orange-crowned warbler	*Leiothlypis celata*	bird	native
Osprey	*Pandion haliaetus*	bird	native
Ovenbird	*Seiurus aurocapilla*	bird	native
Pacific loon	*Gavia pacifica*	bird	native
Pacific-slope flycatcher	*Empidonax difficilis*	bird	native
Pallid bat	*Antrozous pallidus*	bat	native
Peregrine falcon	*Falco peregrinus*	bird	native
Phainopepla	*Phainopepla nitens*	bird	native
Pied-billed grebe	*Podilymbus podiceps*	bird	native
Pine siskin	*Spinus pinus*	bird	native
Red-breasted merganser	*Mergus serrator*	bird	native
Red-breasted nuthatch	*Sitta canadensis*	bird	native
Redhead	*Aythya americana*	bird	native
Red-naped sapsucker	*Sphyrapicus nuchalis*	bird	native
Red-necked phalarope	*Phalaropus lobatus*	bird	native
Red-tailed hawk	*Buteo jamaicensis*	bird	native
Red-winged blackbird	*Agelaius phoeniceus*	bird	native
Ring-necked pheasant	*Phasianus colchicus*	bird	non-native
Rock pigeon	*Columba livia*	bird	non-native
Rock wren	*Salpinctes obsoletus*	bird	native
Rose-breasted grosbeak	*Pheucticus ludovicianus*	bird	native
Ross's goose	*Anser rossii*	bird	native
Ruby-crowned kinglet	*Regulus calendula*	bird	native
Ruddy duck	*Oxyura jamaicensis*	bird	native
Ruddy ground-dove	*Columbina talpacoti*	bird	native
Rufous hummingbird	*Selasphorus rufus*	bird	native

Rusty blackbird	*Euphagus carolinus*	bird	native
Sage thrasher	*Oreoscoptes montanus*	bird	native
Sagebrush sparrow	*Artemisiospiza nevadensis*	bird	native
Savannah sparrow	*Passerculus sandwichensis*	bird	native
Say's phoebe	*Sayornis saya*	bird	native
Scott's oriole	*Icterus parisorum*	bird	native
Semipalmated sandpiper	*Calidris pusilla*	bird	native
Short-eared owl	*Asio flammeus*	bird	native
Snowy egret	*Egretta thula*	bird	native
Snowy plover	*Charadrius nivosus*	bird	native
Song sparrow	*Melospiza melodia*	bird	native
Sora	*Porzana carolina*	bird	native
Spotted sandpiper	*Actitis macularius*	bird	native
Spotted towhee	*Pipilo maculatus*	bird	native
Summer tanager	*Piranga rubra*	bird	native
Surf scoter	*Melanitta perspicillata*	bird	native
Swainson's thrush	*Catharus ustulatus*	bird	native
Swamp sparrow	*Melospiza georgiana*	bird	native
Townsend's warbler	*Setophaga townsendi*	bird	native
Tree swallow	*Tachycineta bicolor*	bird	native
Varied thrush	*Ixoreus naevius*	bird	native
Vaux's swift	*Chaetura vauxi*	bird	native
Verdin	*Auriparus flaviceps*	bird	native
Vermillion flycatcher	*Pyrocephalus rubinus*	bird	native
Vesper sparrow	*Pooecetes gramineus*	bird	native
Violet-green swallow	*Tachycineta thalassina*	bird	native
Virginia rail	*Rallus limicola*	bird	native
Warbling vireo	*Vireo gilvus*	bird	native
Western grebe	*Aechmophorus occidentalis*	bird	native
Western gull	*Larus occidentalis*	bird	native
Western kingbird	*Tyrannus verticalis*	bird	native
Western meadowlark	*Sturnella neglecta*	bird	native
Western sandpiper	*Calidris mauri*	bird	native
Western small-footed myotis	*Myotis ciliolabrum*	bat	native
Western tanager	*Piranga ludoviciana*	bird	native
Western wood-pewee	*Contopus sordidulus*	bird	native
White-crowned sparrow	*Zonotrichia leucophrys*	bird	native
White-faced ibis	*Plegadis chihi*	bird	native
White-throated swift	*Aeronautes saxatalis*	bird	native
White-winged dove	*Zenaida asiatica*	bird	native
Wilson's snipe	*Gallinago delicata*	bird	native
Wilson's warbler	*Cardellina pusilla*	bird	native
Yellow warbler	*Setophaga petechia*	bird	native
Yellow-billed cuckoo	*Coccyzus americanus*	bird	native
Yellow-breasted chat	*Icteria virens*	bird	native
Yellow-headed blackbird	*Chrysomus icterocephalus*	bird	native
Yellow-rumped warbler	*Setophaga coronata*	bird	native

Appendix B

List of acronyms used.

Acronym	**Definition**
BLM	Bureau of Land Management
CO_2	Carbon Dioxide
CSP	Concentrated Solar Power
EGS	Enhanced Geothermal System
MW	MegaWatt
PUCN	Public Utilities Commission of Nevada
PV	Photovoltaic

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