Site Renewables Right: Accelerating a Clean and Green Renewable Energy Buildout in the Central United States

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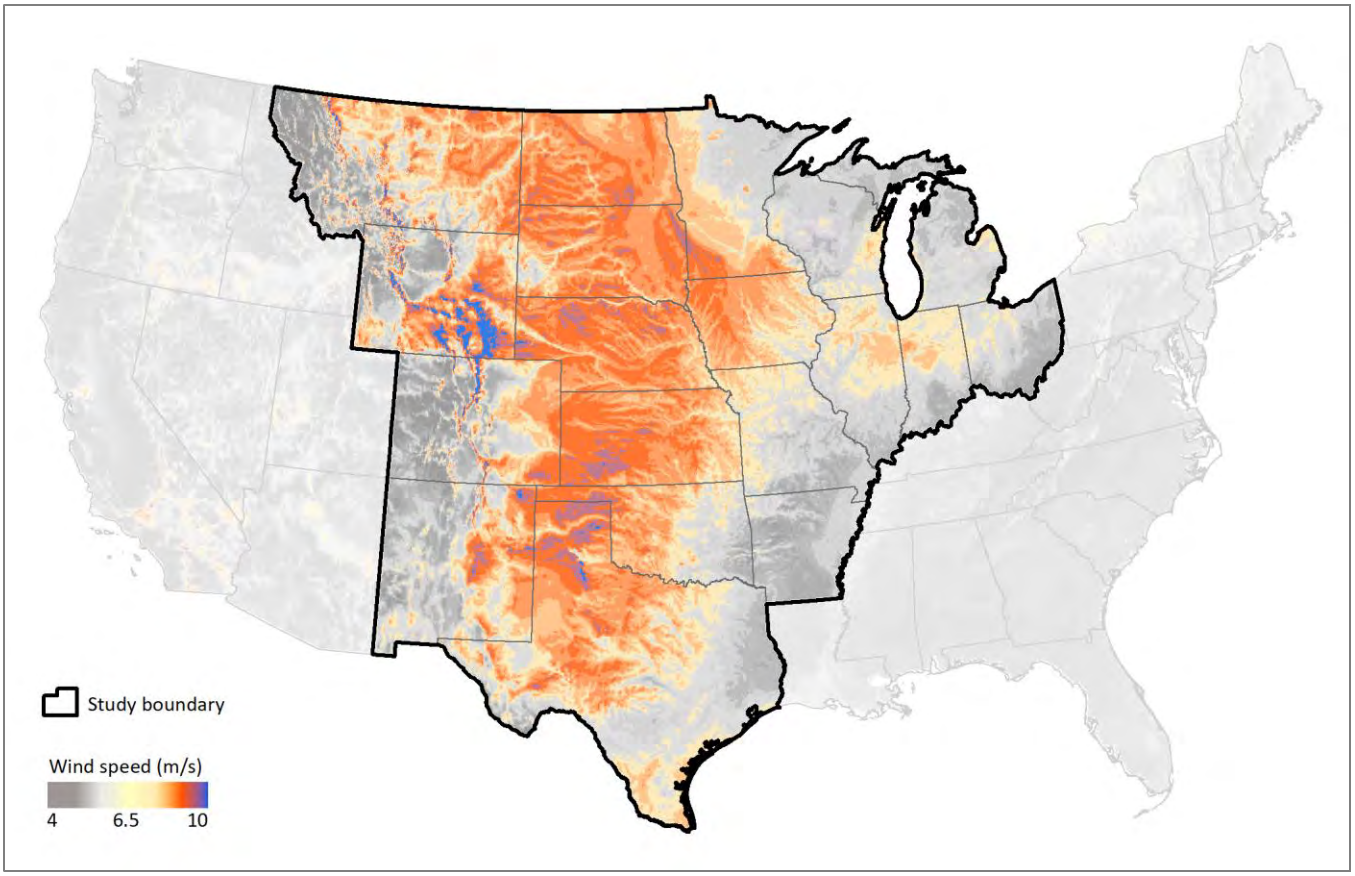
Introduction

The Nature Conservancy supports the rapid expansion of renewable energy while protecting wildlife and natural habitats. This paper summarizes the data and assumptions included in the Conservancy's Site Renewables Right analysis, as well as how we intend the results to be used. The Site Renewables Right analysis includes maps of key wildlife areas relevant to wind and photovoltaic (PV) solar energy development, which may be used to identify areas where projects are less likely to encounter significant wildlife-related conflict, delays, and cost overruns by prioritizing areas for avoidance. The maps were designed to serve as an important source of information to inform screening early in the project siting process. They can be used to inform due diligence analyses by power purchasers and to support application of state and federal renewable energy siting guidance, such as the U.S. Fish and Wildlife Service Land-Based Wind Energy Guidelines. By combining key wildlife avoidance areas for wind with other land suitability factors, we demonstrate that over 1,000 GW of wind energy may be developed in the central U.S. exclusively in areas of low conservation impact. The results indicate that we can accelerate a clean, low-impact energy future—one that advances energy and climate goals while avoiding impacts to wildlife and their habitats.

Figure 1. The central U.S. Wind Belt (resource data modified from AWS Truepower 2010)



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Background

Renewable energy development is essential to decarbonizing the electricity grid in the U.S. and reducing the impacts of climate change. Changing market conditions, improved technology, state policy, and federal action are all contributing to a transition to renewables at an unprecedented scale. Declines in capital costs for utility-scale wind and solar facilities are expected to drive continued growth, with solar projected to generate almost half of all the electricity produced from renewable sources by 2040 (USEIA 2020; Davis et al. 2021).

At the same time, energy development is the largest driver of land use change in North America, and poorly sited renewable energy projects can have significant impacts on wildlife and high-priority habitats (Trainor et al. 2016). In addition, siting in areas that would significantly impact wildlife and habitat can lead to conflict and slow the transition to a low-carbon energy future. These delays and increased costs can be minimized by evaluating siting considerations early in the project development process (Tegen et al. 2016). A study of solar projects indicated permitting was three times faster and project costs were 7-14% lower when projects were sited in areas of low biodiversity, compared to high biodiversity sites (Dashiell et al. 2019).

Demand is growing among corporate power purchasers for renewable energy that maximizes climate contributions and minimizes biodiversity impacts. Companies have shown increasing interest in the non-financial attributes of renewable energy projects, such as environmental impact and community acceptance (Lorenzen et al. 2020).

As a response to accelerating wind energy buildout and requests for guidance on potential wildlife impacts, in 2019 The Nature Conservancy released the Site Wind Right assessment as a resource to inform project siting. The 17-state study area encompasses approximately 80 percent of the country’s current and planned onshore wind capacity (AWEA 2019). This region is also home to North America’s largest and most intact temperate grasslands, which are among the most altered and least protected habitats in the world (Hoekstra et al. 2005).

In 2022, the wind assessment was updated to reflect new science, and its coverage expanded to 19 states. In addition, a companion analysis was developed to explore potential wildlife conflicts with utility-scale PV solar. Together, *Site Renewables Right* builds on previous studies by The Nature Conservancy (Kiesecker et al. 2011; Obermeyer et al. 2011; Fargione et al. 2012) and reflects the increasing scale of renewable energy development in the central U.S..

Existing Resources on Renewable Energy Siting and Wildlife

There are many sources of information that can be used to inform low-impact renewable energy development. Federal and state wildlife and natural resource agencies, science-based conservation organizations, and academic institutions have produced information on sensitive wildlife and habitats that can help steer renewable energy projects to areas of lower conservation value. The U.S. Fish and Wildlife Service has also developed the Land-Based Wind Energy Guidelines (WEGs), a voluntary framework for supporting “a structured, scientific process for addressing wildlife conservation concerns at all stages of land-based wind energy development” (USFWS 2012). The WEGs provide an appropriate framework to avoid, minimize and offset potential impacts from utility-scale, land-based wind energy. The effectiveness of the WEGs in supporting low-impact wind development, however, depends on the rigor of the analysis, input from appropriate state and federal fish and wildlife agencies, and whether the findings of the analysis translate into changes in the design and operation of a project.

While there are no similar national-level siting guidelines for solar energy, we understand that many renewable energy developers voluntarily utilize the framework outlined in the WEGs to guide solar siting decisions. We anticipate that as the solar industry matures, and the scientific understanding of its impacts on wildlife and habitat evolves, demand for national solar siting guidelines will increase. Many agencies and conservation organizations have also developed state-specific resources for wind and solar development (MNDNR 2016a; Maine Audubon 2019; IEC 2020; TNC 2020; TNC 2021a; TNC and DoW 2021; VDWR 2021; WGFD 2021).

The Nature Conservancy believes that the WEGs and other complementary resources can drive wind and solar facilities to low-impact sites when they are used early in the project development process, when rigorously applied, and when developers commit to abandoning projects that are deemed to have a high probability of significant adverse impacts to species of concern or their habitats that cannot be mitigated (USFWS 2012). We intend the Site Renewables Right analysis to complement the WEGs and state, local, and tribal-based siting guidelines to support low-impact siting.

Purpose, Methods, and Application of Site Renewables Right

The Nature Conservancy's Site Renewables Right analysis includes two key wildlife area maps – one relevant to wind energy projects, and the other for PV solar. The maps are designed to support screening early in the project siting process and intended to facilitate avoidance of important species and habitats. They can be used to inform application of the WEGs and other siting assessment frameworks, and to conduct due diligence screenings for power purchasers. The maps are particularly well suited to landscape-level site evaluations and site characterization analyses (i.e., Tier 1 and Tier 2 evaluations of the WEGs). The maps are not intended for use as "go/no-go" maps. Areas in white – those that have relatively low conservation value – are not "go areas" just as areas that are shaded are not "no-go areas." The maps can be used as <u>one</u> source of information to inform site evaluation and characterization analyses but should not be relied upon as the only source of information. The maps are not a substitute for undertaking robust assessment of anticipated impacts to species and habitat, such as the framework outlined in the WEGs. The maps also do not replace the need to consider the data and information outlined in the WEGs and other state guidelines, consult with state and federal wildlife agencies and tribal and local governments, or conduct detailed site-level analyses of conservation values and potential impacts. At the site level, areas with degraded soil, altered vegetation, and a history of prior human disturbance are preferable to intact natural areas for development. In addition, there are other social and cultural factors that may make utility-scale renewable development inappropriate at some sites. If, however, wind or solar projects are being considered in areas of high conservation value as depicted on the maps, we suggest a much more cautious and transparent approach to the next

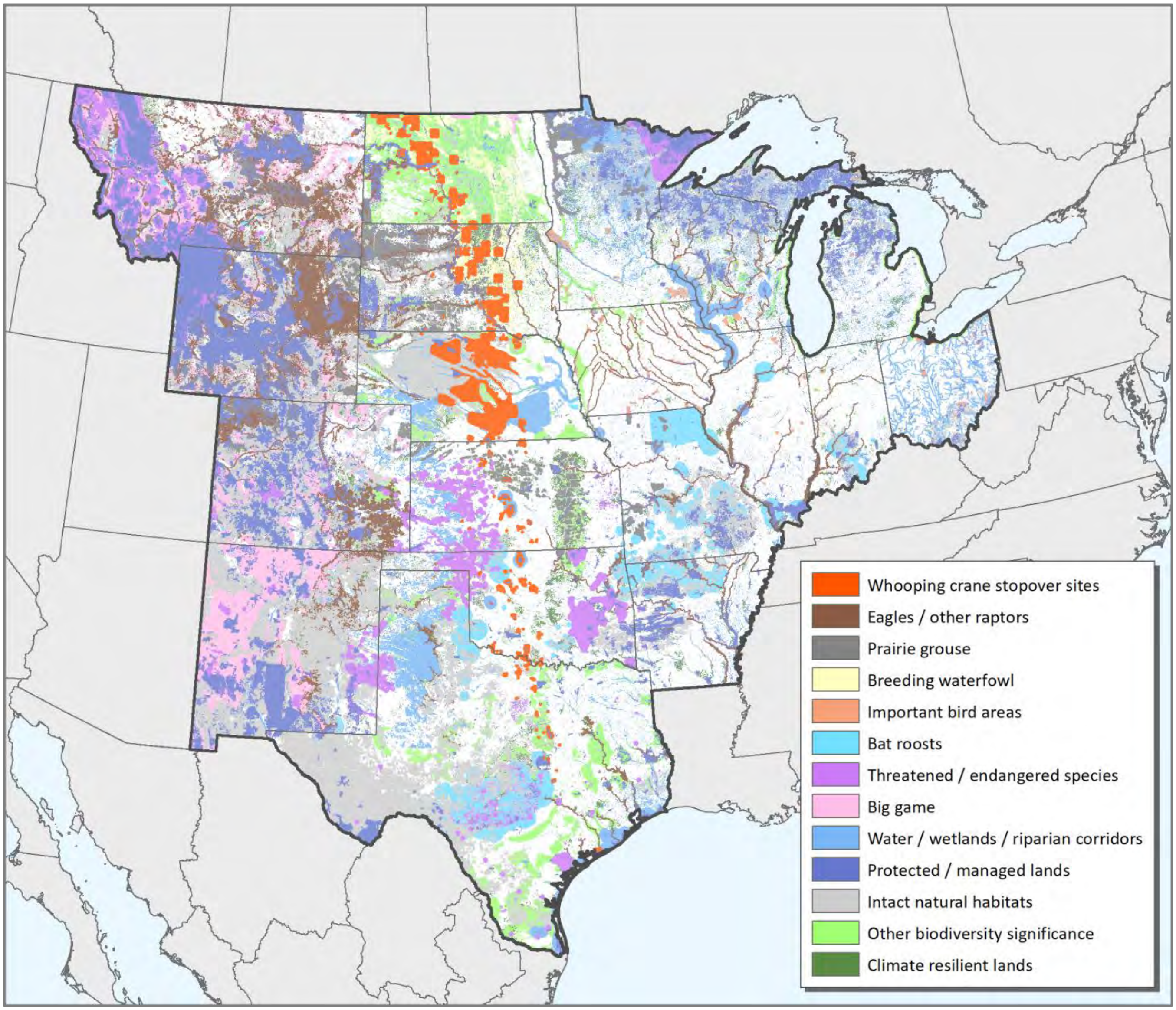
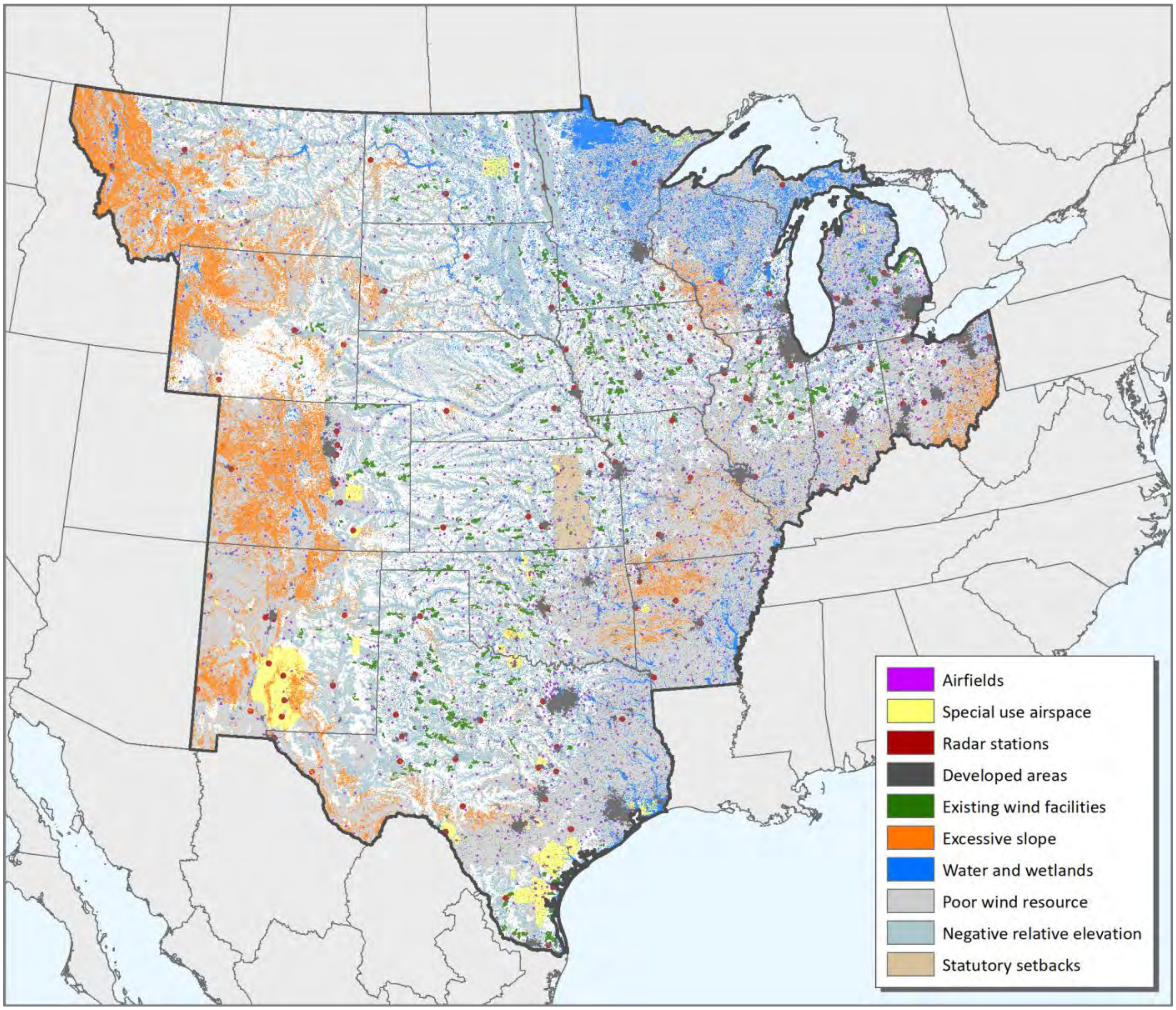


Figure 2. Map of key wildlife areas relevant to wind development

stages of project evaluation. Specifically, we recommend that such projects make the following information available to state and federal wildlife agencies and, to the maximum extent possible, to the public: 1) results of landscape-level site evaluations and characterization evaluations (e.g., Tier 1 and Tier 2 of the WEGs), specifically whether projects are anticipated to have a low, moderate, or high probability of significant adverse impacts to wildlife and habitat; 2) how determinations were made about the significance of impacts; 3) proposed measures for mitigating impacts to projects that will have a moderate or high probability of adverse impact to wildlife and habitat (USFWS 2012); and 4) the degree to which local, state, tribal, and federal wildlife professionals concur with these findings of impact and appropriateness of mitigation measures.

An interactive map and GIS datasets of the information described in this assessment are available to the public and may be accessed at http://www.nature.org/siterenewablesright.

Figure 3. Map of potential engineering and land use restrictions for wind development



Key wildlife areas map – wind

The key wildlife areas map for wind energy (Figure 2) identifies sensitive natural habitats and distributions of wildlife species that may be adversely impacted by wind development. These include:

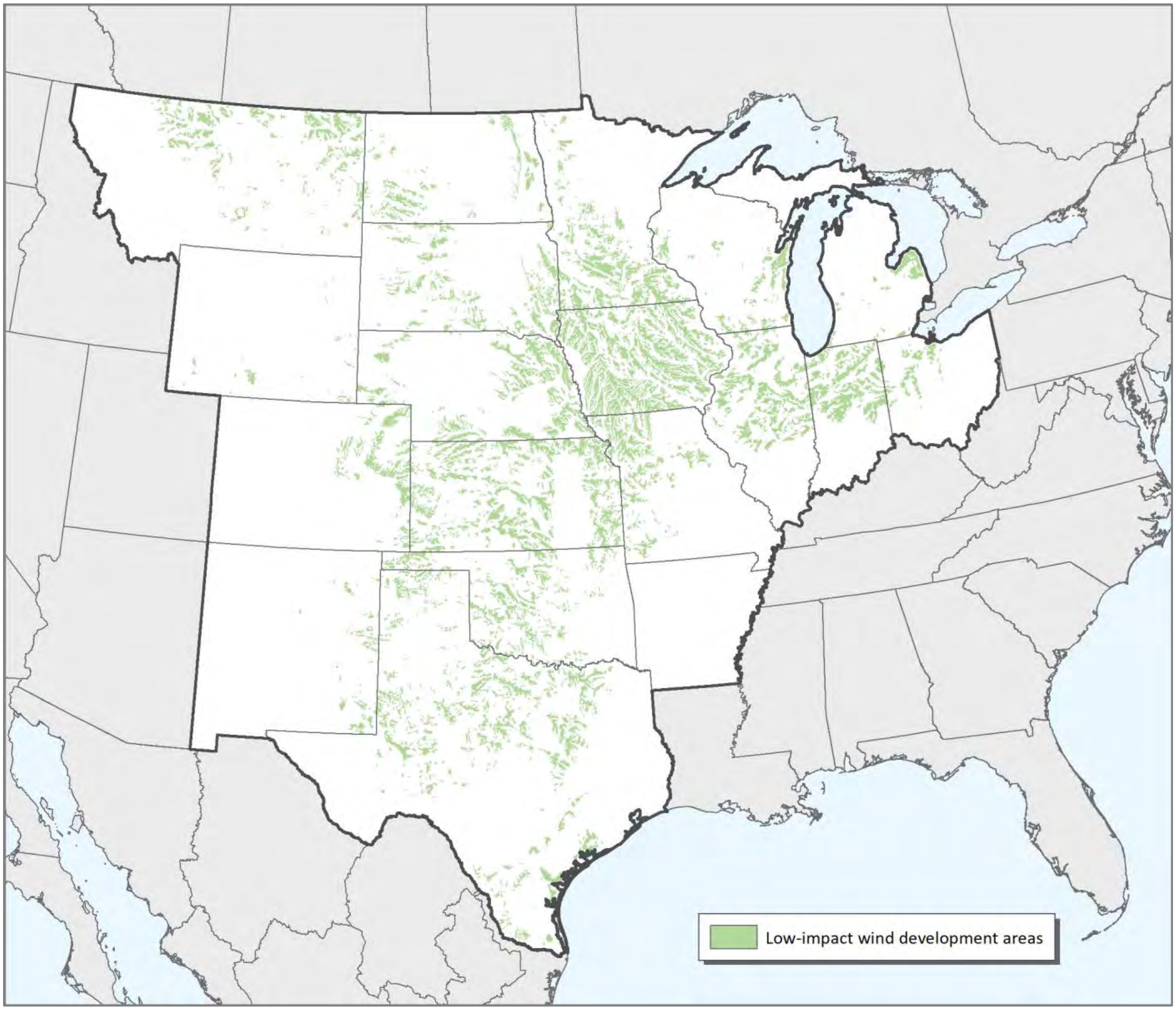
- Whooping crane stopover sites
- Eagle and other raptor nesting areas
- Breeding waterfowl habitats
- Important bird areas
- Bat roosts
- Threatened and endangered species
- Big game habitats
- Water, wetlands, and riparian corridors
- Protected and managed lands
- Intact natural habitats
- Other areas of biodiversity significance
- Climate resilient lands

Sources and delineation methods for component elements are detailed in Appendix A.

Low-impact wind assessment

To demonstrate the potential for low-impact wind development within the study area, we combined wildlife and habitats data (Figure 2) with spatial information on engineering and land use constraints (Figure 3) identified in published

Figure 4. Map of low-impact wind development areas



assessments of renewable energy potential and consistent with historical patterns of wind development in the Great Plains. Data sources and delineation methods for modeled restrictions are detailed in Appendix A. We recognize that additional factors may affect development potential in specific locations, including transmission capacity and the availability of willing landowners (Tegen et al. 2016; Oteri et al. 2018).

Input data were rasterized at a ground sample distance of 30 m. We generated a preliminary map of areas suitable for wind development by excluding lands with potential engineering and land use restrictions. To eliminate isolated areas too small to support commercial wind development, the results were smoothed using a 1 km radius moving window, and patches less than 20 km^2 in size were removed. The engineering and land use restrictions layers were then subtracted from the remaining smoothed patches to eliminate false positive values and other spatial artifacts introduced by the moving window analysis. To delineate suitable wind development areas with low potential for wildlife conflicts, wildlife and habitat data layers were subtracted from the preliminary suitability map, and the analysis was repeated as above (i.e., smoothing and reapplying the engineering and land use constraint layers). For each state and for the analysis area as a whole, we quantified wind development potential on all suitable lands, as well as the subset of suitable lands identified as low impact, based on a nameplate capacity density range of 3-5 MW/km^2 (USDOE 2008; Denholm et al. 2009).

Within the study area, we found that over 90 million ha (222 million ac) of land may be suitable for development (based on wind speed and terrain, excluding previously developed sites, statutory setbacks, unsuitable land use, and small/isolated sites). If all these areas were developed for wind energy, they could support approximately 2,707-4,512 GW of electrical

Table 1. Suitable land and low-impact wind development area statistics

State	Suitable land (ha)[1]	Percent of region[1]	Capacity on suitable land (GW)[2]		Low-impact suitable land (ha)[3]	Percent of region[3]	Capacity on low-impact suitable land (GW)[2]
Texas	15,945,276	23%	478-797		4,271,796	6%	128-214
Iowa	4,916,534	34%	147-246		4,179,950	29%	125-209
Kansas	7,583,374	36%	228-379		3,961,889	19%	119-198
Nebraska	7,868,623	39%	236-393		2,202,613	11%	66-110
Minnesota	3,503,389	16%	105-175		2,178,075	10%	65-109
Montana	8,059,881	21%	242-403		2,117,624	6%	64-106
Illinois	2,119,363	15%	64-106		1,924,567	13%	58-96
Oklahoma	3,595,162	20%	108-180		1,652,421	9%	50-83
South Dakota	6,878,777	34%	206-344		1,646,761	8%	49-82
Indiana	1,623,297	17%	49-81		1,534,308	16%	46-77
Missouri	2,318,808	13%	70-116		1,413,602	8%	42-71
Colorado	3,916,351	15%	117-196		1,059,786	4%	32-53
North Dakota	6,071,688	33%	182-304		950,010	5%	29-48
Wisconsin	1,172,347	8%	35-59		735,803	5%	22-37
Ohio	544,898	5%	16-27		434,145	4%	13-22
New Mexico	5,075,241	16%	152-254		420,152	1%	13-21
Wyoming	8,392,647	33%	252-420		178,785	1%	5-9
Michigan	620,168	4%	19-31		147,634	1%	4-7
Arkansas	34,834	0%	1-2		0	0%	0-0
combined area	90,240,658	21%	2,707-4,512		31,009,920	7%	930-1,550

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[1] Based on engineering and land use constraints discussed in "low-impact wind assessment."

[2] Calculated based on a nameplate capacity density range of 3-5 MW/km^2 (USDOE 2008; Denholm et al. 2009).

[3] Land identified as low impact for wildlife and habitat (Figure 2) without engineering or land use constraints (Figure 3). Depicted spatially in Figure 4.

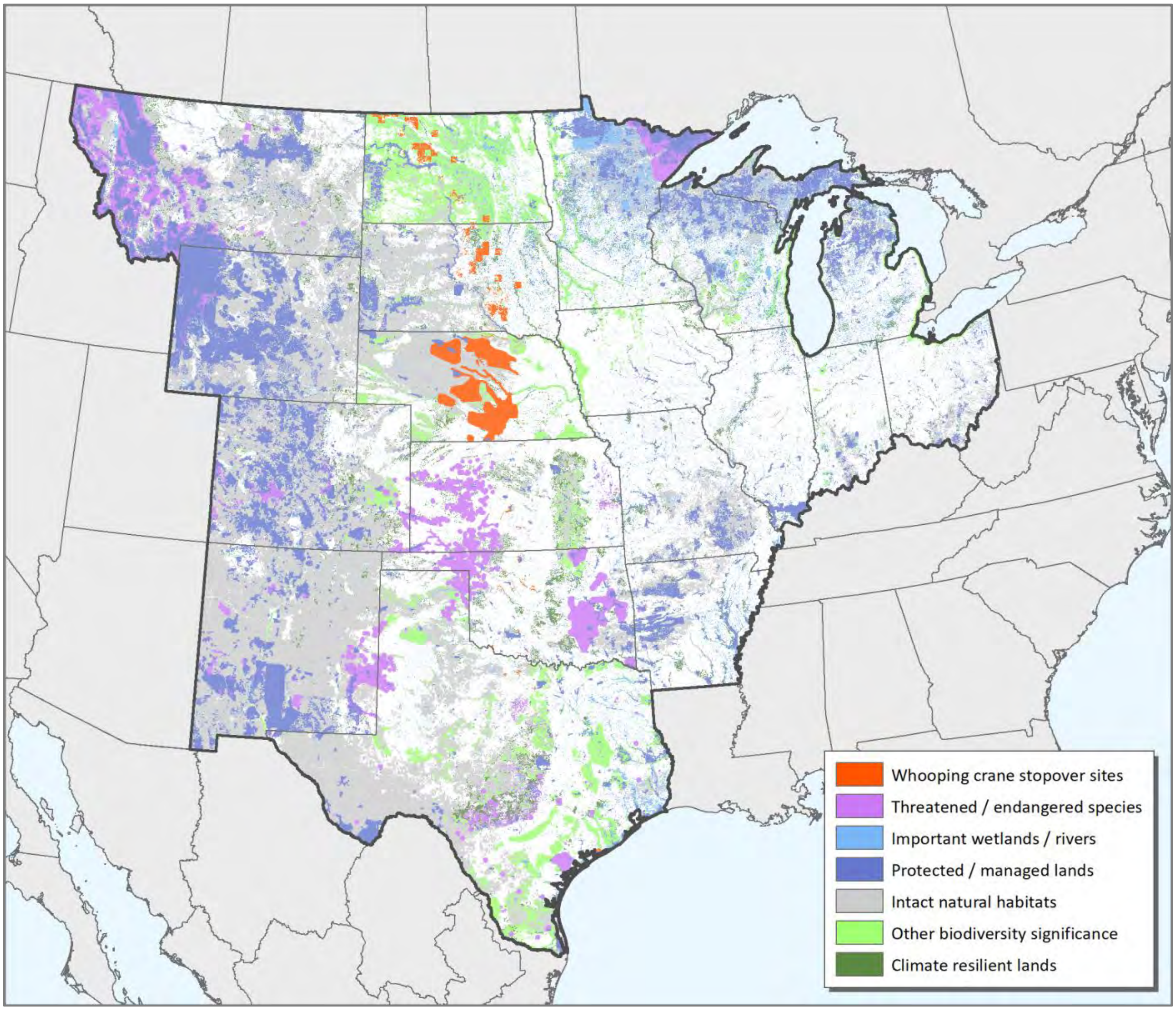
capacity. After removing sensitive wildlife habitats, approximately 31 million ha (77 million ac) remain as suitable for development (7% of the region) (Figure 4; Table 1). These low-impact areas are capable of yielding approximately 930-1,550 GW of electrical capacity. This is equivalent to 8-13 times current U.S. wind capacity (ACP 2021) and comparable to the total electrical generating capacity from *all sources* (USDOE 2021).

Key wildlife areas map – solar

To support site evaluations early in the project development process, we identified a subset of key wildlife areas from the wind map that may be relevant in the context of PV solar facility siting. The habitat elements featured in the solar map include:

- Whooping crane stopover sites (with 400 m avoidance buffer; cf. Baasch et al. 2019)
- Threatened and endangered species
- Water and wetland features (no buffers)
- Protected and managed lands
- Intact natural habitats
- Other areas of biodiversity significance
- Climate resilient lands

Figure 5. Map of key wildlife areas relevant to photovoltaic solar development



The impacts of PV solar development on wildlife in the central U.S. are poorly understood. While avian collision mortality has been documented at solar facilities in desert regions of the southwestern U.S. (Kagan et al. 2014; Walston et al. 2016; Kosciuch et al. 2020) with polarized light pollution (Horváth 2009) or “lake effect” as a hypothesized causal factor, it is unknown whether similar phenomena occur in bioregions with different patterns of bird use and abundance. Published reviews of potential solar impacts to other wildlife taxa and ecosystem processes (Tsoutsos et al. 2005; Turney and Fthenakis 2011; Northrup and Wittemyer 2013; Harrison et al. 2016; Taylor et al. 2019) are largely inferential, highlighting the dearth of empirical peer-reviewed research and the need for further study. In agricultural fields, restored vegetation within solar facility footprints may provide modest benefits to pollinator supply, carbon storage, and sediment retention (Graham et al. 2021; Walston et al. 2021). However, PV solar development in natural settings is likely to cause direct habitat loss and displacement of sensitive species due to land alteration and increased human activity. Large solar energy facilities and associated infrastructure may also disrupt wildlife movements and act as barriers in otherwise connected habitats (Bennun et al. 2021). As such, we believe the precautionary approach should be applied when siting solar projects near areas of known biodiversity significance, as is recommended with any large-scale industrial development.

A cursory evaluation of wildlife and habitats data along with basic land use requirements for PV solar facilities indicates the potential for low-impact solar development in the central U.S. is significantly greater than the stated figures for wind. A much higher average power density (Lopez et al. 2012) and smaller projected land use requirements (Larson et al. 2021) suggests that solar buildout will be less geographically constrained, with low-impact solar development opportunities found across the region. For example, within our 19-state study area approximately 283 GW of technical solar potential exists on current and formerly contaminated lands, landfills, and mine sites alone (USEPA 2018).

Discussion

Our analyses suggest that large areas of the central U.S. could be developed for wind and solar energy on sites with reduced risk of significant negative impacts to wildlife (Figure 4; Table 1). Because the availability of low-impact renewable energy resources far exceeds development projections, our conclusion that there is ample low-impact area should be applicable to any reasonable development scenario. Moreover, our estimates of development potential are likely conservative, as some of the areas that we identified as having engineering and land use constraints may be viable for wind energy due to improvements in technology (USDOE 2017).

We note that our delineation of sensitive wildlife habitats is not exhaustive. Spatial data on species of concern are missing or incomplete in some areas. With all development projects, wildlife concerns should also be addressed through careful micrositing. Operational mitigation may be required to reduce mortality, particularly for bats with wind development (Arnett et al. 2013). These issues highlight the importance of continued research to advance the science on low-impact wind and solar energy siting.

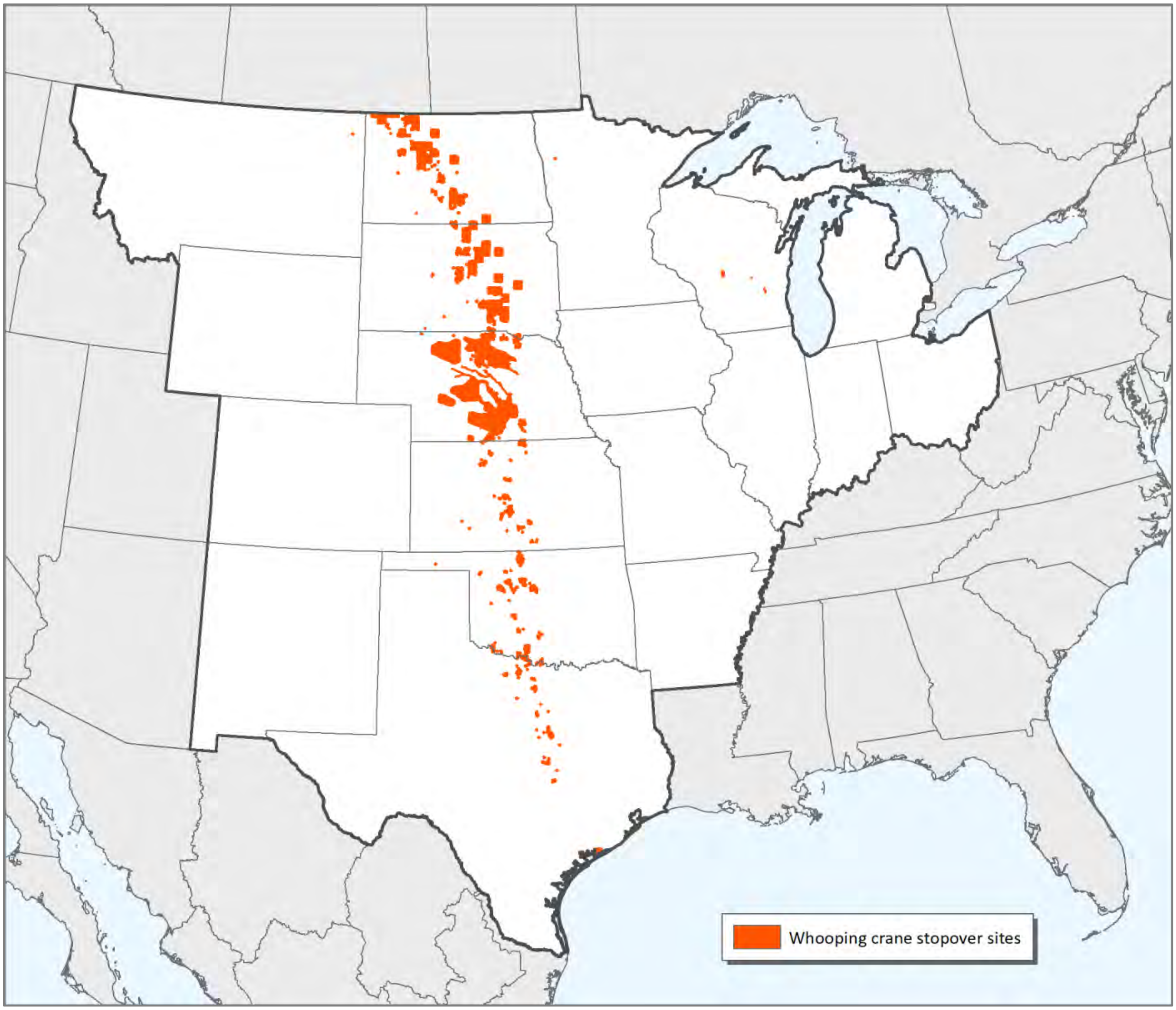
Our assessment provides a positive vision for accelerating a clean and green energy future. We can meet our climate goals and support the conservation of wildlife and natural habitats. While we recognize there is not a one-size-fits-all solution to “good” siting, the Site Renewables Right study can be a valuable source of information to identify project sites that support a clean and green future.

Appendix A – Component Element Descriptions

Whooping crane stopover sites

The federally endangered whooping crane (*Grus americana*), which has a current population of approximately 500 individuals, depends on wetlands in the central Great Plains during migration (USFWS 2021a). Whooping cranes exhibit aversion to wind turbines and may be displaced from suitable habitats near wind energy infrastructure (Pearse et al. 2021). In addition, whooping cranes may be at risk of turbine collisions in low light conditions when ascending or descending from high altitude migration flights, or when travelling between roost and foraging areas (USFWS 2009). To address these concerns, we delineated areas within 5 km of whooping crane stopover sites to be avoided by wind energy development. Stopover sites include locations with two or more confirmed whooping crane observations (USFWS 2010) since 1985, as well as modeled suitable habitat (cf. Austin and Richert 2001; Belaire et al. 2014) within portions of the migratory flyway frequently used by whooping cranes (Pearse et al. 2015). Modeled suitable habitat included contiguous areas >10 ha in size that met all the following criteria: <100 m from a non-forested, non-rocky wetland or perennial stream (USFWS 2016b) or playa lake (PLJV 2015), <1 km from cropland (Fry et al. 2011), <3% primary and secondary road land cover (ESRI 2010) within a 1 km^2 moving window, <10% urban land cover (USCB 2016) within a 1 km^2 moving window, and intersected core intensity or extended use core intensity areas within a defined migration corridor (Pearse et al. 2015). We also mapped critical habitat polygons designated by the U.S. Fish and Wildlife Service (USFWS 2018), whooping crane priority landscapes in Nebraska (NWWWG 2016), and whooping crane breeding areas in Wisconsin (USFWS 2021a).

Sources: data - USFWS (2010, 2016b, 2018, 2021a); ESRI (2010); Fry et al. (2011); Pearse et al. (2015); PLJV (2015); NWWWG (2016); USCB (2016); spatial analysis – TNC (2021b).



Eagles and other raptors

Raptors may be injured or killed by collisions with wind turbines (Stewart et al. 2007; Smallwood and Thelander 2008; Watson et al. 2018), and rates of mortality at commercial wind facilities may be underestimated due to lack of rigorous monitoring and reporting (Pagel et al. 2013). To reduce risk of population-level impacts to golden eagles (*Aquila chrysaetos*) in the western Great Plains, we mapped wind development avoidance areas corresponding to the highest modeled golden eagle densities in ecoregions assessed by the Western Golden Eagle Team (Bedrosian et al. 2018; top 2 of 7 area-adjusted frequency quantiles). Following general habitat management guidelines established by USFWS (1989), we recommend that developers avoid placing turbines within 1.6 km of streams and lakes with known high densities of bald eagle (*Haliaeetus leucocephalus*) nests. In states with available data, we delineated 3.2 km buffers of active golden eagle nests (CPW 2013) and occupied peregrine falcon (*Falco peregrinus*) habitat (WGFD 2004; CPW 2015a), and 1.6 km buffers of other active raptor nests (CPW 2013), raptor occurrences (MTNHP 2018a), and modeled prairie dog (*Cynomys* spp.) complexes (WGFD 2006; CPW 2009; MTNHP 2018b; TXNDD 2021a) due to their attraction of birds of prey.

Sources: WGFD (2004, 2006); CPW (2009, 2013, 2015a); Bedrosian et al. (2018); MTNHP (2018a, 2018b); TXNDD (2021a); unpublished TNC and USFWS data.

Prairie grouse

Grouse species in the central U.S. have experienced substantial population declines since the early 20th century (Vohdenhal and Haufler 2007) and may be further threatened by improperly sited energy development (Pruett et al. 2009; Van Pelt et al. 2013; Hovick et al. 2014; Winder et al. 2015; LeBeau et al. 2017). To prevent grouse displacement and potential impacts on vital rates, we mapped the following as wind development avoidance areas: Attwater's prairie-chicken (*Tympanuchus cupido attwateri*) known occurrence records (TXNDD 2021b) and the Refugio-Goliad Prairie Conservation Area in Texas (TNC 2009); Columbian sharp-tailed grouse (*T. phasianellus columbianus*) production areas and winter range in Colorado (CPW 2015b), and 5 km buffers of known leks in Wyoming (WGFD 2016); greater prairie-chicken (*T. cupido*) preliminary tier 1 and 2 habitats in South Dakota (Runia et al. 2021; T. Runia personal communication, September 20, 2021), modeled optimal habitat (Obermeyer et al. 2011) in Kansas and Oklahoma, production areas in Colorado (CPW 2015c), grassland conservation opportunity areas in Missouri (MDOC 2015), and priority habitat in Minnesota (MNDNR 2021); greater sage-grouse (*Centrocercus urophasianus*) rangewide biologically significant units (BLM 2018), state-designated core and connectivity areas in Wyoming (WGFD 2015) and Montana (MTFWP 2016), and 2 km buffers of known leks in Wyoming (WGFD 2017a); Gunnison sage-grouse (*C. minimus*) critical habitat (USFWS 2018), and production areas, brood areas, winter range, and severe winter range in Colorado (CPW 2011a); lesser prairie-chicken (*T. pallidicinctus*) rangewide conservation focal areas and 6.8 km buffers (following USFWS 2021b) of known leks (SGPCHAT 2021); plains sharp-tailed grouse (*T. phasianellus jamesi*) production areas in Colorado (CPW 2015d), 5 km buffers of known leks in Wyoming (WGFD 2017b), preliminary tier 1 and 2 habitats in South Dakota (Runia et al. 2021; T. Runia personal communication, September 20, 2021), and priority habitat in Minnesota (MNDNR 2021).

Due to lack of spatially explicit data, sharp-tailed grouse and greater prairie-chicken habitats in Illinois, Iowa, Nebraska, and North Dakota were not included in this assessment.

Sources: data – TNC (2009); CPW (2011a, 2015b, 2015c, 2015d); MDOC (2015); WGFD (2015, 2016, 2017a, 2017b); MTFWP (2016); BLM (2018); MNDNR (2021); Runia (2021); SGPCHAT (2021); TXNDD (2021b); spatial analysis – TNC (2021b).

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Prairie grouse (continued)

Bat roosts

Bat mortality has been documented at wind energy facilities across North America (Erickson 2002; USFWS 2003; Arnett and Baerwald 2013; AWWI 2018). Because bats concentrate in large numbers and have low reproductive rates, the viability of their populations is particularly vulnerable to adult mortality events (Kunz and Fenton 2003). Therefore, caution is warranted when undertaking any activity that may adversely affect known bat populations.

While knowledge of bat and wind turbine interactions in the southern Great Plains is limited, evidence suggests that the Mexican free-tailed bat (*Tadarida brasiliensis*) may be particularly susceptible to fatal injury during encounters with turbine blades. This species accounts for a large percentage of documented wildlife mortality at wind facilities across the Southwestern U.S. (Kerlinger et al. 2006; Miller 2008; Piorkowski and O'Connell 2010; AWWI 2018), including in states with extensive wind development. Moreover, regional populations are comprised primarily of reproducing females (Caire et al. 1989; Schmidly 2004); as such, each early season fatality in the area may result in the deaths of two individuals (mother and young). Recent population estimates in Oklahoma are markedly lower than historical figures, although the relative contribution of wind development is unknown. (Caire et al. 2013). Due to the large foraging range of this species (Best and Geluso 2003) and concerns regarding population-level impacts, we mapped avoidance areas that extend 32 km from Mexican free-tailed bat maternity roosts in New Mexico, Oklahoma, and Texas, as well as adjacent areas of Kansas.

In addition, we followed USFWS's (2016a) recommendation to avoid wind development within 32 km of Indiana bat (*Myotis sodalis*) priority 1 hibernacula, 16 km of priority 2 hibernacula, and 8 km of other current and historical sites. We apply the same rationale and avoidance distances to gray bat (*Myotis grisescens*) hibernacula and other known cave bat roosts across the analysis area.

We also included avoidance areas for mapped bat roosts in Montana (MTNHP 2018c), mapped hibernacula in Nebraska (NWWWG 2016), townships with documented northern long-eared bat (*Myotis septentrionalis*) maternity roosts and/or hibernacula in Minnesota (MNDNR & USFWS 2018), a 12-county region of northeastern Missouri near Sodalis Nature Preserve (Cole 2018), and important forest habitats in Indiana (TNC and Audubon 2010).

We acknowledge that migratory tree bat mortality (Arnett et al. 2016; AWWI 2018) is a significant concern with wind development in the central U.S. A recent study suggests that the hoary bat (*Lasiurus cinereus*) population of North America could decline by as much as 90% in the next 50 years at current wind energy-associated fatality rates (Frick et al. 2017). At present, spatial data and knowledge of behavior are insufficient to effectively inform project siting decisions for these species. New methods to track seasonal bat movements are in development (Weller et al. 2016); we encourage the support of these studies to improve understanding of tree bat migration routes. In addition, we strongly encourage the use of proven operational mitigation strategies (Arnett et al. 2013) and new approaches such as smart curtailment (Hayes et al. 2019) to reduce impacts to bat populations.

Sources: KSU (2002); TNC (2003, 2021b); TNC and Audubon (2010); Graening et al. (2011); INHDC (2014); KBS (2015a); NWWWG (2016); CNHP (2017a); MNDNR & USFWS (2018); MTNHP (2018c); TSS (2018).

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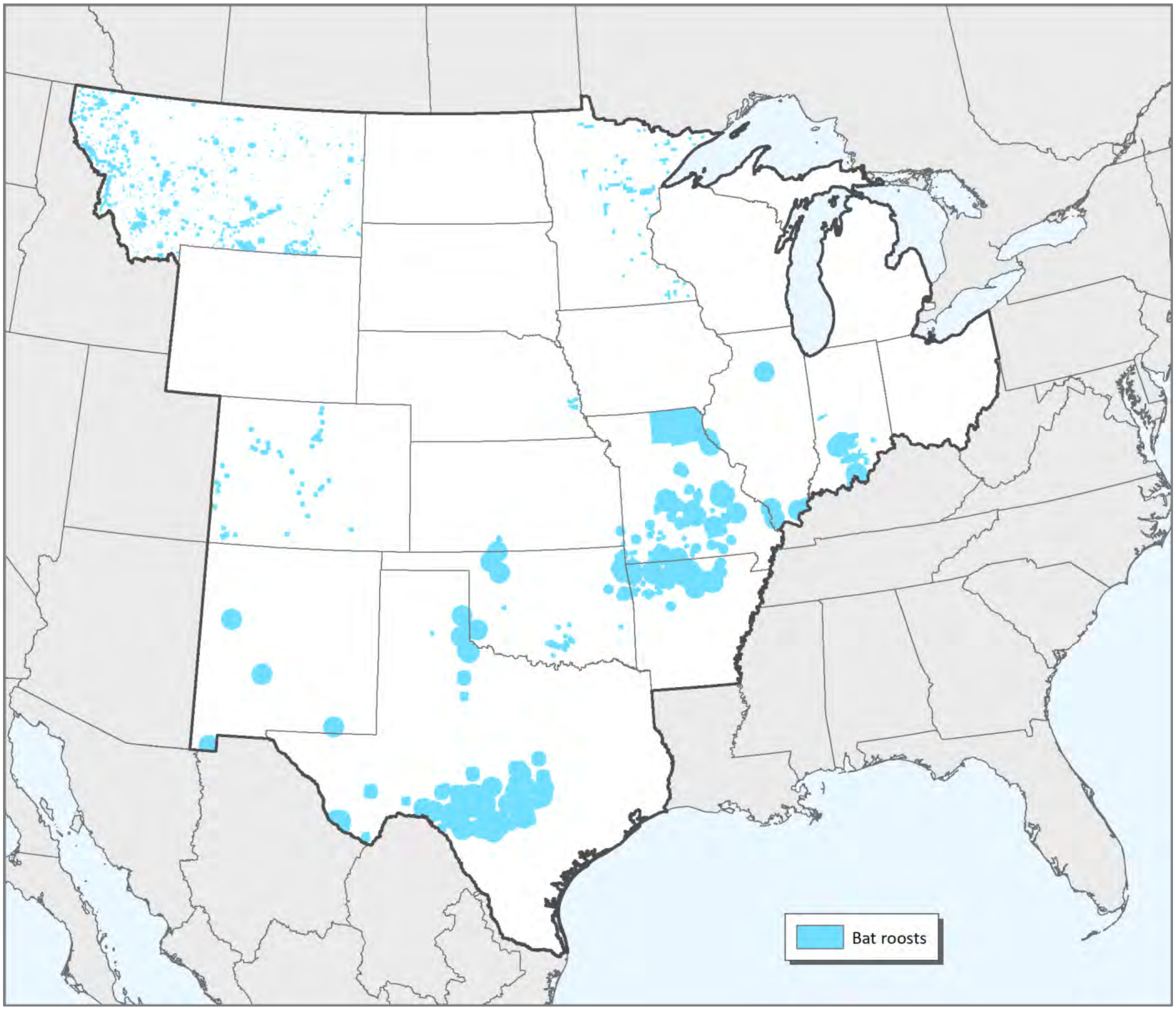
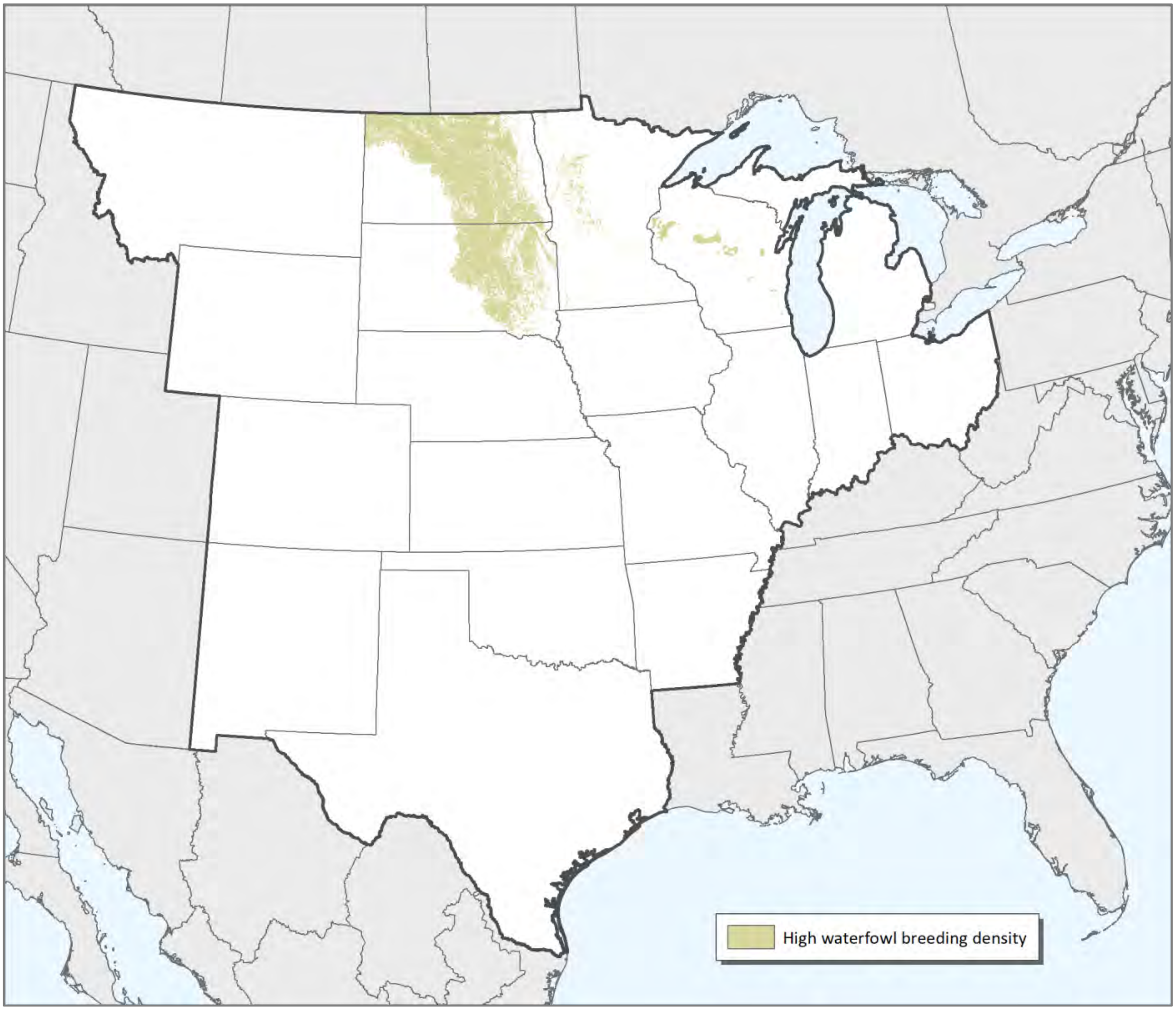
Bat roosts (continued)



Breeding waterfowl

Ducks and other wetland-dependent birds may be displaced from suitable habitats by wind energy infrastructure (Hötker et al. 2006; Loesch et al. 2013; Lange et al. 2018; Zhao et al. 2020). To minimize the risk of negative impacts to these species, we mapped areas important to breeding waterfowl in the northern portion of the study area to be avoided by wind development. In the Prairie Pothole region of Minnesota, North Dakota, and South Dakota, we identified areas where >100 estimated pairs of blue-winged teal, gadwall, mallard, northern pintail, and northern shoveler duck species are predicted to be attracted to wetlands (calculated using a 390 m pixel extent and based on long-term average wetland conditions (USFWS 2021c, following Shaffer et al. 2019) and buffered them by 800 m (Loesch et al. 2013). In Wisconsin, we included the 95th percentile of modeled habitat suitability for breeding ducks as identified in a statewide waterfowl conservation strategy (Straub et al. 2019).

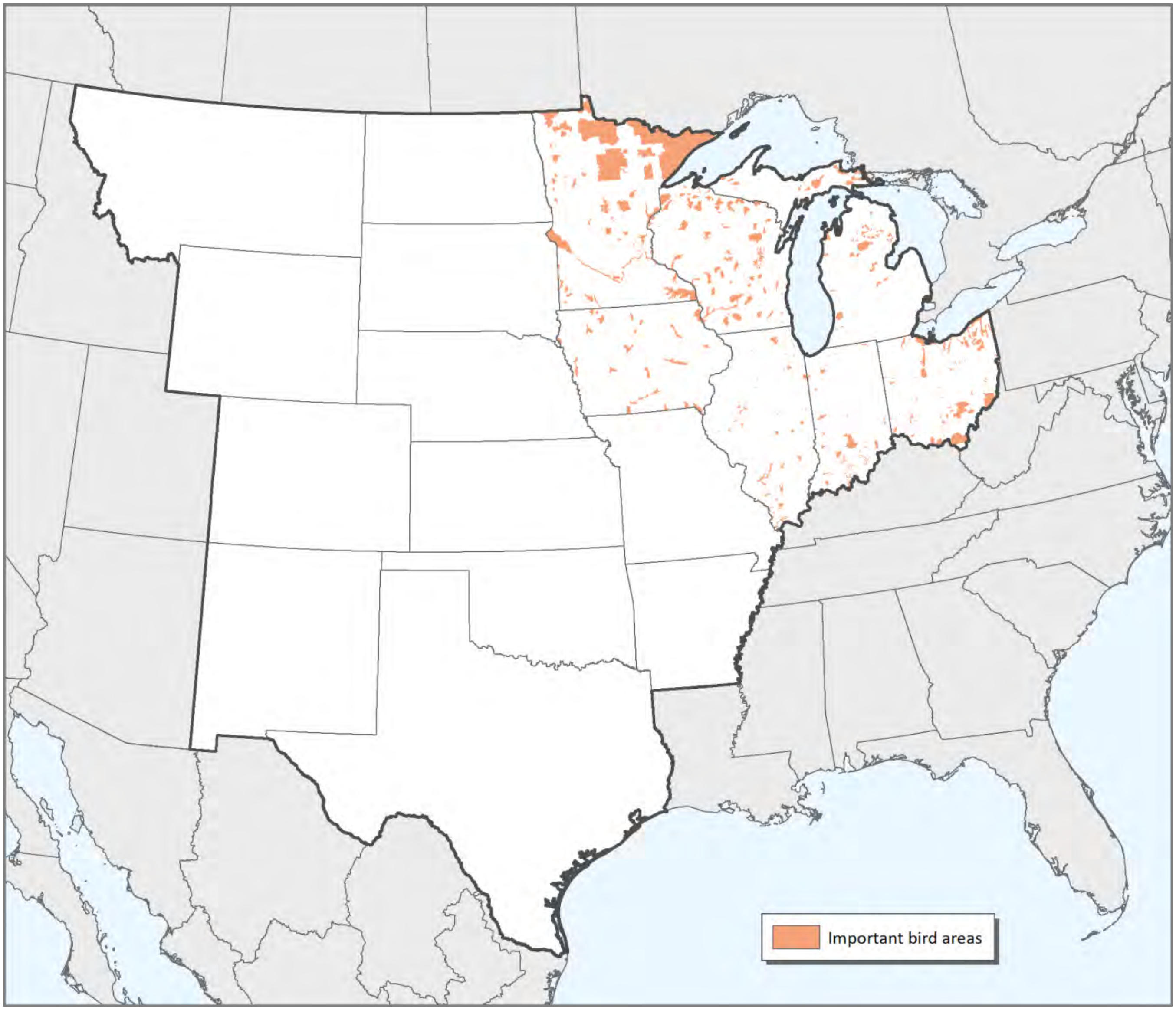
Sources: data – Straub et al. (2019); USFWS (2021c); spatial analysis – TNC (2021b).



Important bird areas

Important bird areas across the Great Lakes and Upper Midwest states may not be effectively captured by other spatial data layers used in this assessment. Therefore, we included state bird conservation areas in Iowa (IADNR 2017), Audubon important bird areas in Illinois, Indiana, Minnesota, Ohio, and Wisconsin (NAS 2018), and Great Lakes ecoregion bird portfolio sites in Michigan (Ewert 1999) as areas to avoid wind development.

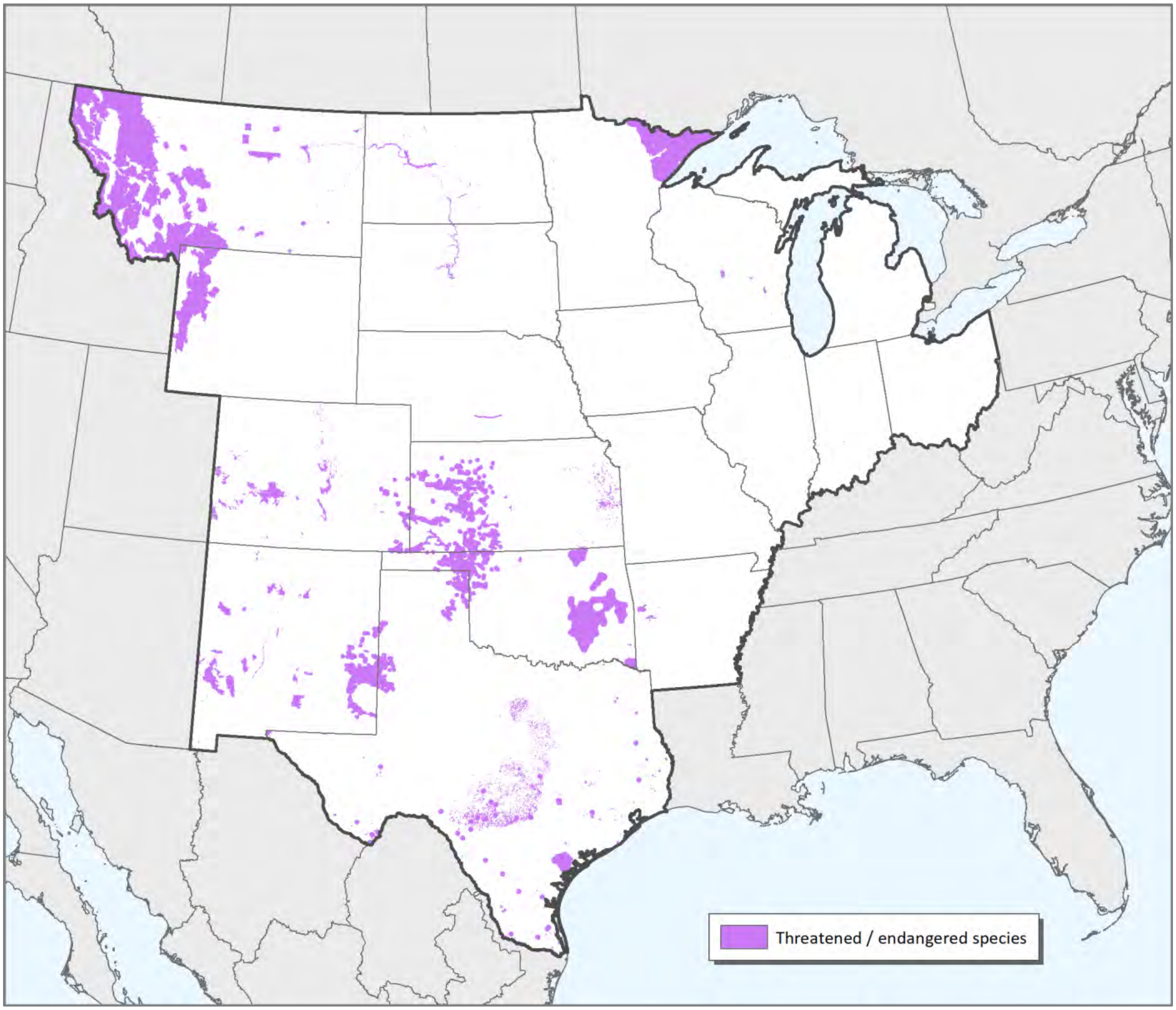
Sources: Ewert (1999); IADNR (2017); NAS (2018).



Threatened and endangered species (terrestrial)

Energy and infrastructure development are among the most significant threats to imperiled species in the U.S. (Wilcove et al. 1998). To prevent impacts to at-risk wildlife, we included terrestrial federally listed threatened and endangered species habitat as renewable energy avoidance areas. Mapped sites included critical habitat delineated by state and federal agencies, current/recent species distributions, modeled priority habitats, and occurrence records. We also included the lesser prairie chicken habitats described on page 12 above due to the proposed listing of this species (USFWS 2021d).

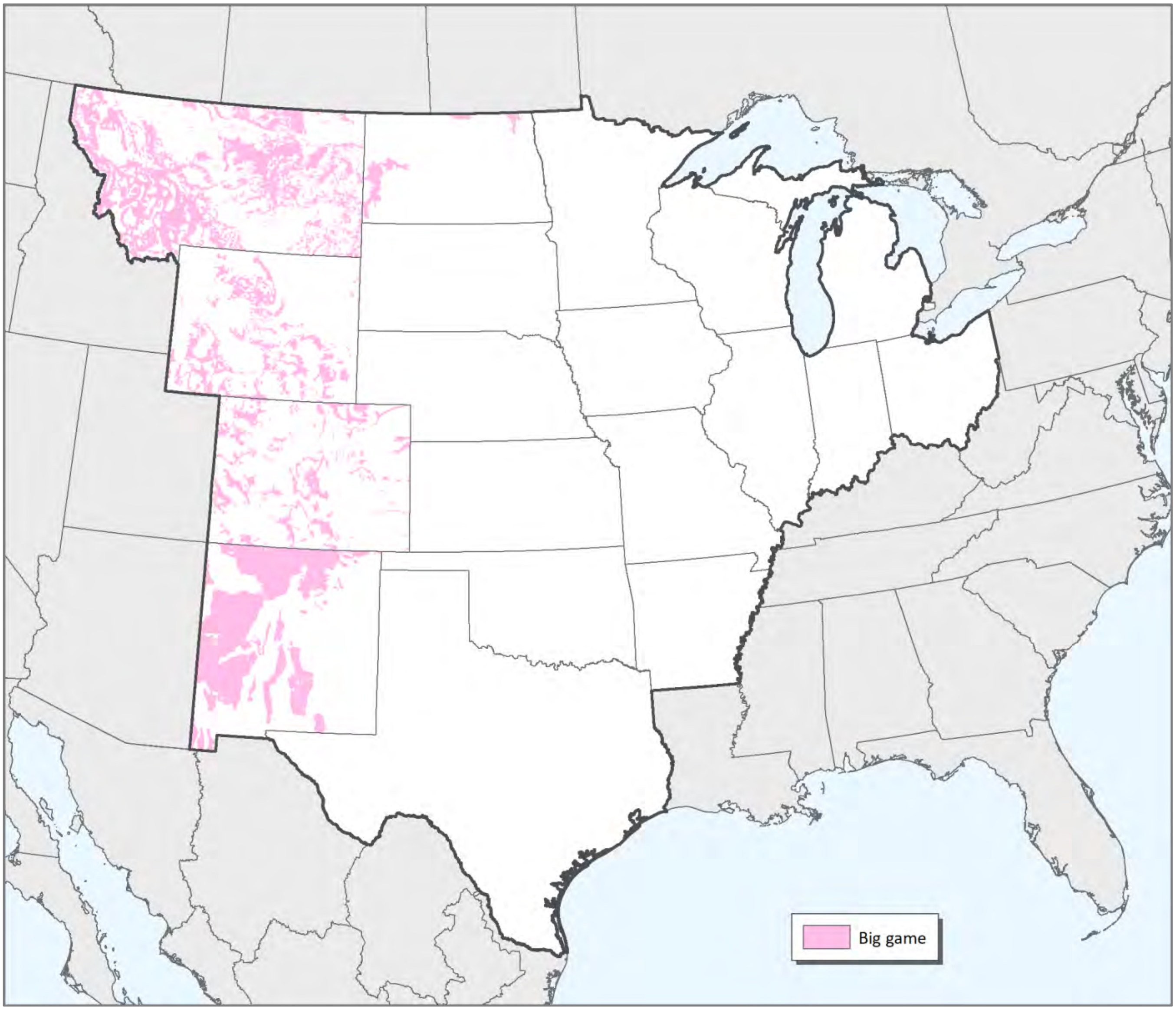
Sources: Masters et al. (1989); Diamond (2007); TNC (2009, 2021b); Laurencio and Fitzgerald (2010); CPW (2011a, 2011b, 2015e), USFWS (2014a); KBS (2015b); ODWC (2015); MTNHP (2018d); USFWS (2018); SGPCHAT (2021); TXNDD (2021c).



Big game

Roads and other anthropogenic features associated with energy development may alter the movement of big game animals and increase rates of mortality, particularly along migration routes and in crucial winter range in the western U.S. (Sawyer et al. 2006, 2009; WGFD 2011; Vore 2012; Taylor 2016). Based on the potential for loss and fragmentation of these vital habitats, we delineated wind development avoidance areas for big game in Colorado, Montana, New Mexico, North Dakota, and Wyoming using available spatial data (MTFWP 2010; WGFD 2011; CPW 2015f; WECC 2018; NDGFD 2021).

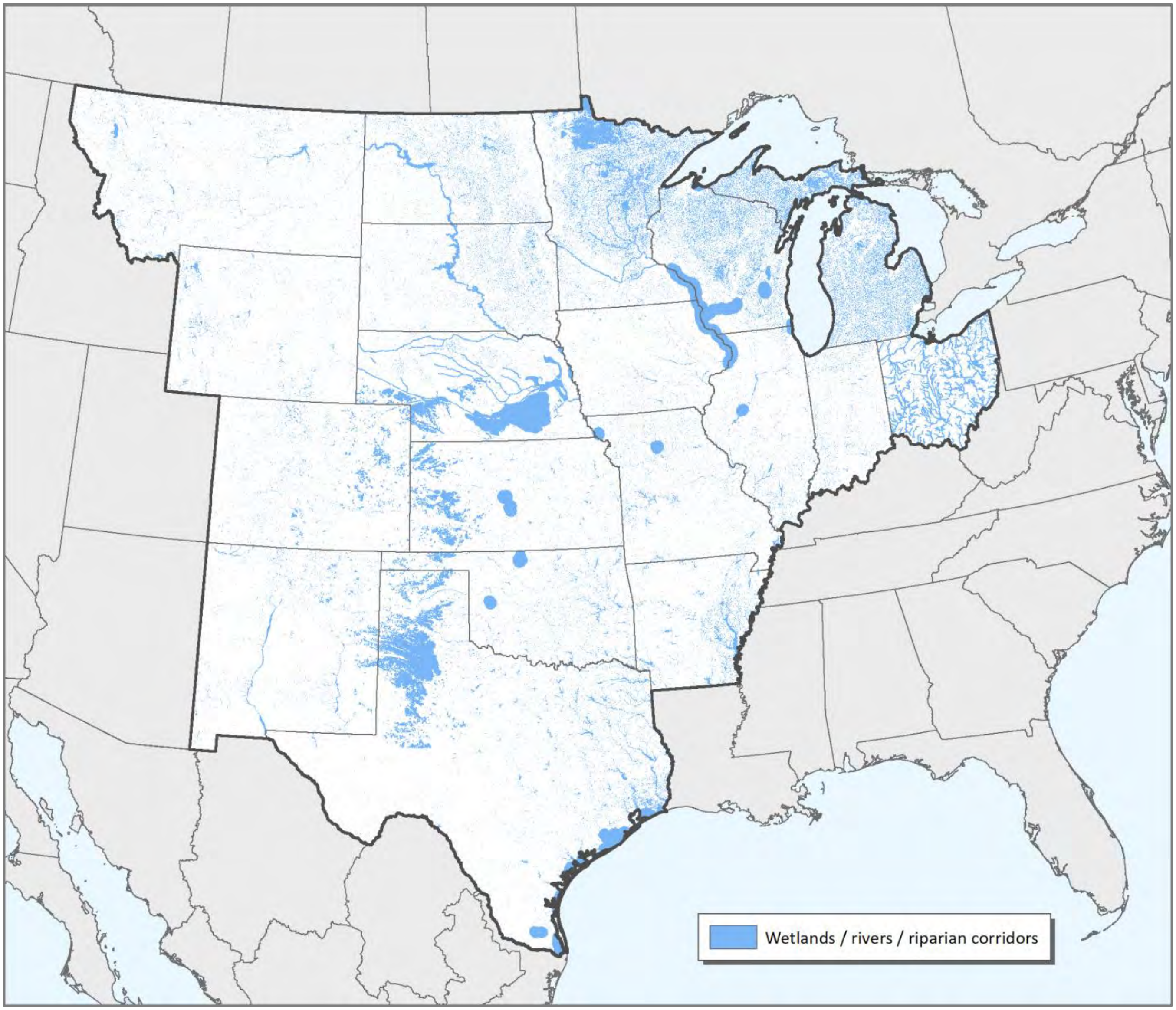
Sources: MTFWP (2010); WGFD (2011); CPW (2015f); WECC (2018); NDGFD (2021).



Wetlands, rivers, and riparian corridors

Renewable energy development near wetland complexes and riparian corridors may cause adverse impacts to migratory birds and other wildlife (Ewert et al. 2011; Obermeyer et al. 2011; Grodsky et al. 2013; PLJV 2017). Wetland features identified by TNC and partners to avoid development included National Wetlands Inventory sites (USFWS 2016b); open water areas (Fry et al. 2011); playa lakes and clusters (PLJV 2015); 1.6 km buffers of important rivers in Minnesota (MNDNR 2018a), Nebraska (NWWWG 2016), North Dakota and South Dakota (Fargione et al. 2012), and Ohio (TNC 2021b); 16 km buffers of Ramsar Convention wetlands (Ramsar 2021) in Wisconsin, Western Hemisphere Shorebird Reserve Network (WHSRN 2019) wetland sites in Illinois, Kansas, Missouri, Oklahoma, and Texas, and the Aransas and Washita National Wildlife Refuges (following Obermeyer et al. 2011); riparian habitats in New Mexico (Muldavin et al. 2020); 200-500 m buffers of streams (Ewert et al. 2011) and coastal wetlands (Battelle 2017) in Michigan; and wetlands of special significance (MTNHP 2016) and trumpeter swan (*Cygnus buccinator*) occurrence records (MTNHP 2018e) in Montana.

Sources: Ewert et al. (2011); Fry et al. (2011); Fargione et al. (2012); PLJV 2015; ABC (2015); MTNHP (2018e); NWWWG (2016); USFWS (2016b); Battelle (2017); MNDNR (2018a); Muldavin et al. (2020); WHSRN (2019); Ramsar (2021); TNC (2021b).

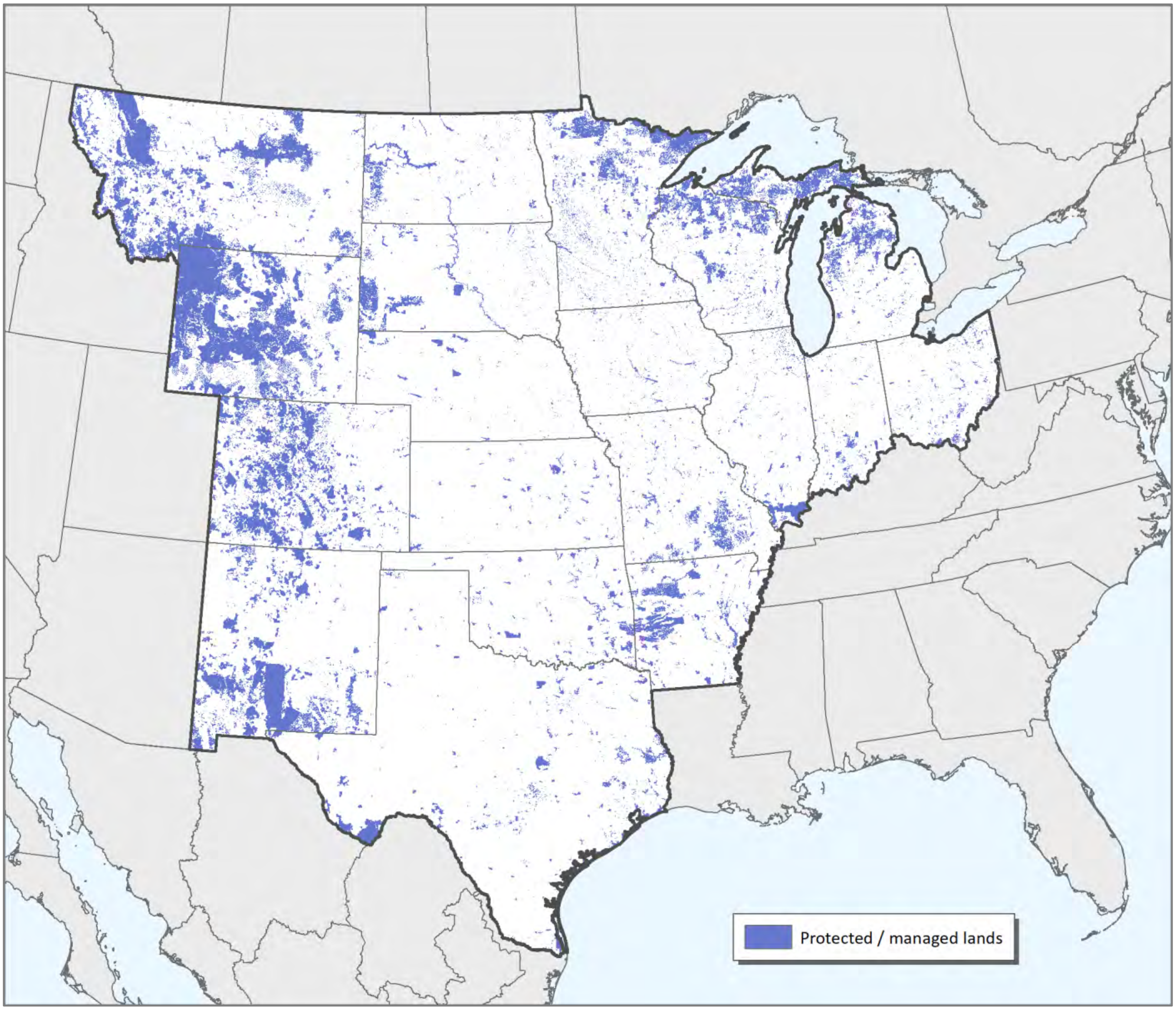


Protected and managed lands

We mapped renewable energy avoidance areas in locations managed for long-term conservation of natural features, including state parks and wildlife management areas; national monuments, parks, and wildlife refuges; military installations; other state and federal lands with development restrictions; private protected lands (including TNC preserves); and conservation easements.

Due to the relative scarcity and high conservation value of federal lands in the eastern portion the study area, all U.S. Forest Service properties outside of Colorado, Montana, New Mexico, and Wyoming were mapped regardless of planning designation status.

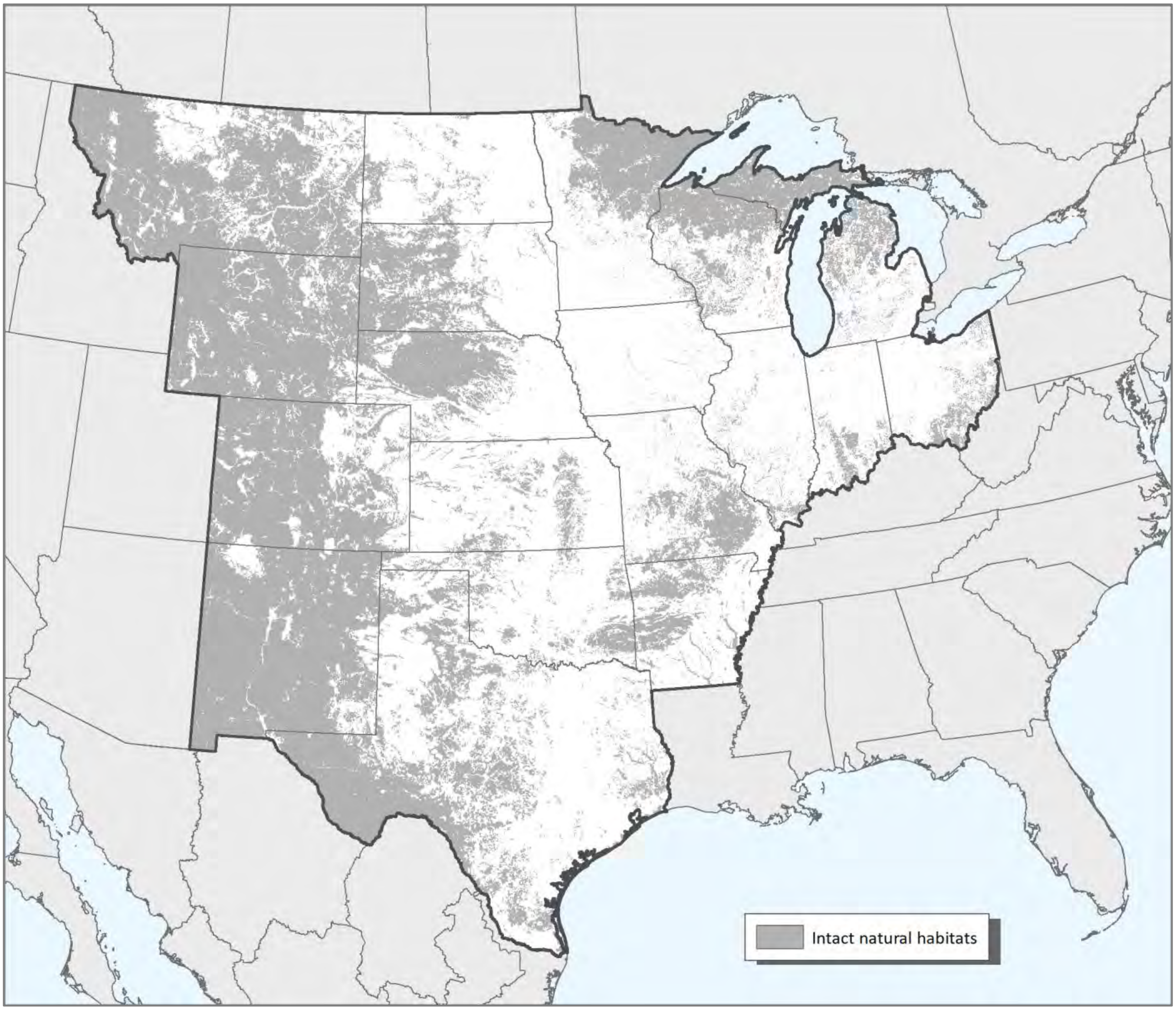
Sources: ANL (2016); USGS (2016); TNC (2021b).



Intact natural habitats

Agricultural conversion and other land use change across the central U.S. has significantly reduced the spatial extent of prairie ecosystems and contributed to the loss of many associated species (Comer et al. 2018). Remaining intact habitats provide the basis for long-term viability of many species of conservation concern. To delineate discrete patches of relatively undisturbed natural landcover for renewable energy avoidance, we processed the Theobald (2013) human modification (HM) model using a 1 km radius moving window and selected areas with HM index values less than 0.125. We then eliminated areas fragmented by oil and natural gas development (defined as sites with 1.5 active wells per km^2 or greater; see WGFD 2010). We also excluded lands in the Great Plains bioregion altered by past tillage or other landscape disturbances (Ostlie 2003). Finally, we added core forest and core wetland areas (TCF 2014) in Illinois, Indiana, Iowa, Minnesota, Missouri, and Ohio, and large intact forests in Michigan (LANDFIRE 2016, following Ewert et al. 2011) to capture additional, functionally intact habitats.

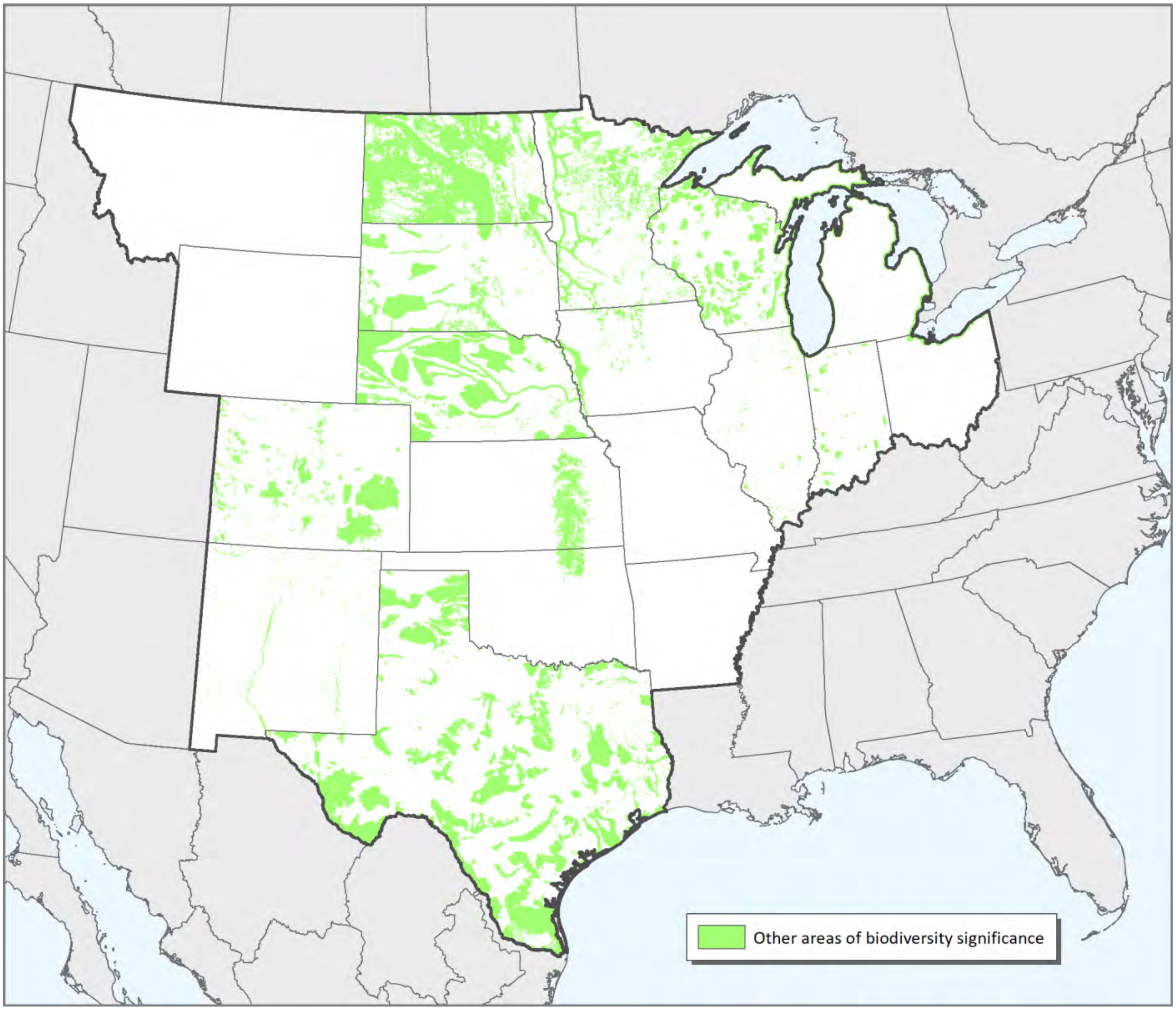
Sources: data - Ostlie (2003); Theobald (2013); AOGC (2014); TCF (2014); FracTracker Alliance (2016); LANDFIRE (2016); COGCC (2018); KGS (2018); MGS (2018); MTDNRC (2018); NOGCC (2018); NMEMNRD (2018); NDDMR (2018); SDDENR (2018); TXRRC (2018); WYGCC (2018); TNC (2021b); spatial analysis – TNC (2021b).



Other areas of biodiversity significance

We mapped renewable energy avoidance areas in other areas of conservation importance, including areas of moderate, high, or outstanding biodiversity significance (MNDNR 2015), and prairie conservation core areas, corridors, matrix habitat, and strategic habitat complexes in Minnesota (MNPPWG 2017); biologically unique landscapes, and medium and high sensitivity natural communities in Nebraska (NWWWG 2016); conservation opportunity areas in Wisconsin (WIDNR 2019); the Flint Hills landscape of Oklahoma and Kansas (TNC 2000, 2007; WHSRN 2019); areas within 8 km of Great Lakes shoreline (Ewert et al. 2011); natural areas inventory sites in Illinois (ILDNR 2021); potential conservation areas with high, very high, or outstanding biodiversity significance in Colorado (CNHP 2017b); Prairie Pothole Joint Venture priority areas, and the Loess Hills ecoregion in Iowa (IADNR 2018); riparian corridors in New Mexico (Muldavin et al. 2020); The Nature Conservancy's conservation priority areas in South Dakota (Fargione et al. 2012) and Texas (TNC 2013); areas of medium and high potential wind development impact in North Dakota (NDGFD 2021); and wind sensitive areas in Indiana (TNC and Audubon 2010).

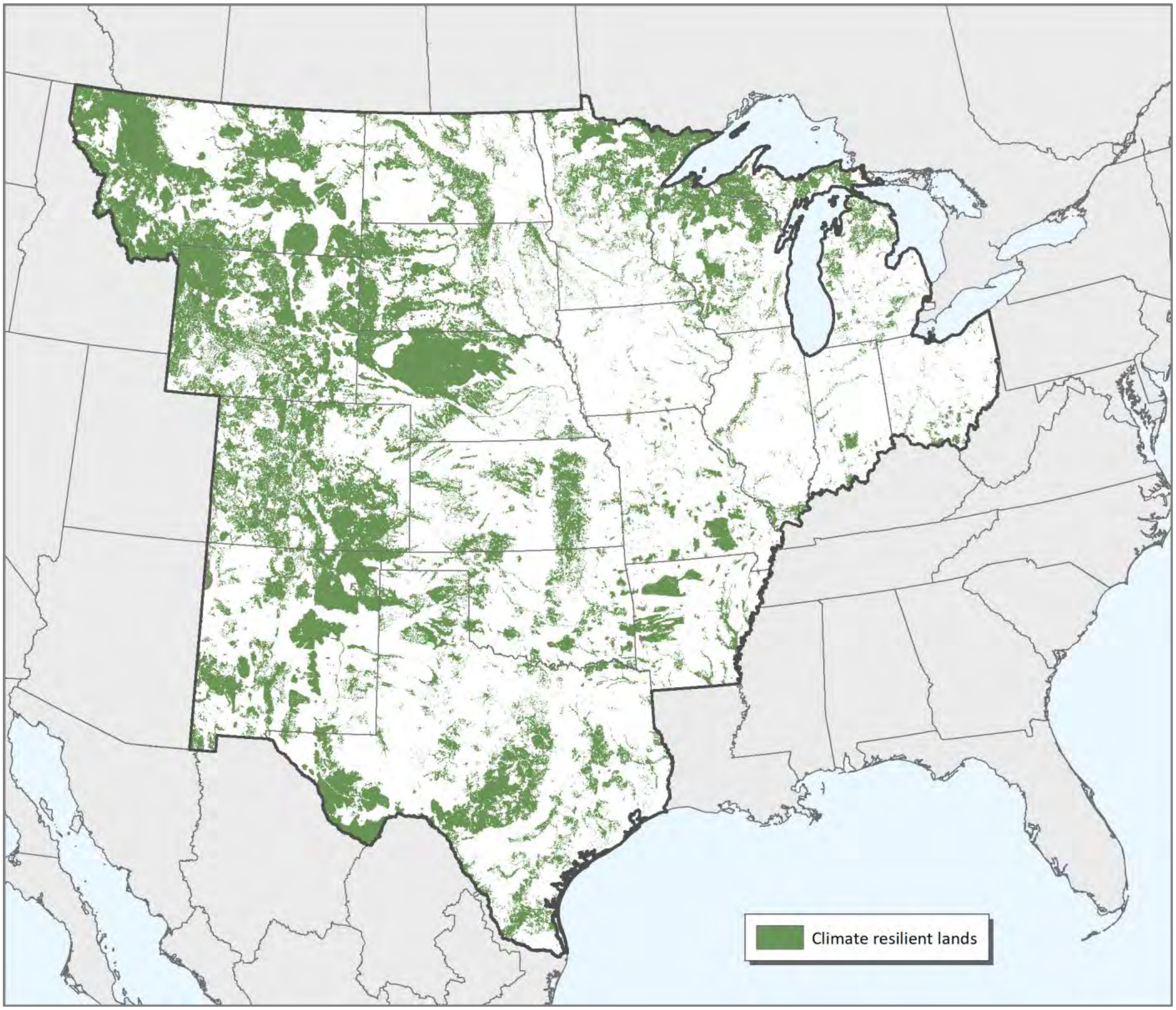
Sources: TNC (2000, 2007, 2013); TNC and Audubon (2010); Ewert et al. (2011); Fargione et al. (2012); MNDNR (2015); NWWWG (2016); CNHP (2017b); MNPPWG (2017); IADNR (2018); WHSRN (2019); WIDNR (2019); Muldavin et al. (2020); ILDNR (2021); NDGFD (2021).



Climate resilient lands

Over the next century, climate change is expected to drive shifts in species ranges and increase stressors to natural ecosystems. Renewable energy deployment may help mitigate climate change impacts; however, improperly sited facilities can fragment habitats and limit animal movements, further exacerbating threats to at-risk wildlife populations (IPCC 2014; IPBES and IPCC 2019). To identify areas important to sustaining species and natural communities in a changing climate, we mapped Resilient and Connected Landscapes with recognized biodiversity value (TNC 2021c) as development avoidance areas. These sites include representative geophysical environments and microclimates with relatively low levels of human modification, which comprise a network of lands most likely to retain ecosystem function in altered climate conditions (Anderson et al. 2014, 2018, 2019).

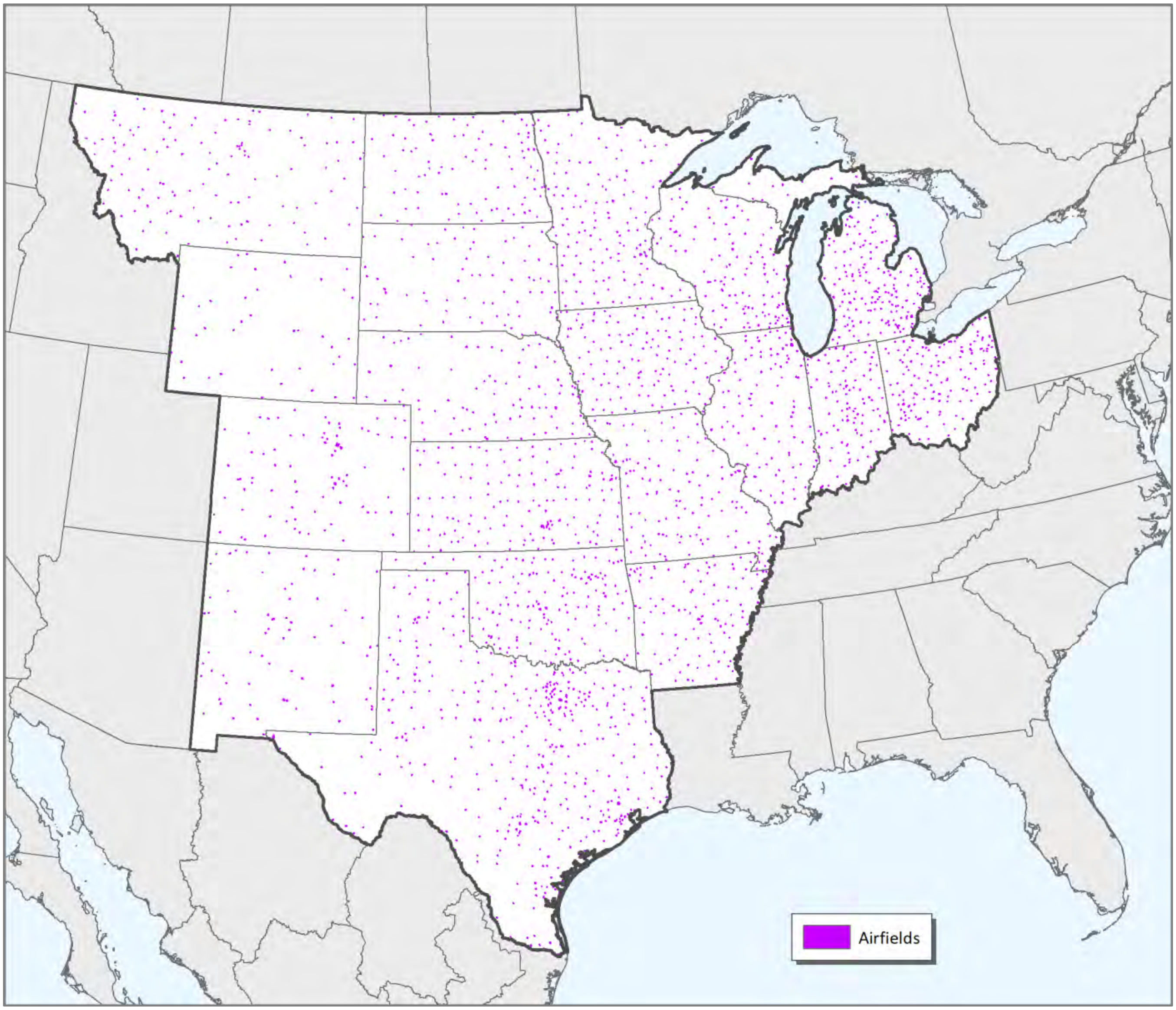
Source: TNC (2021b).



Airfields

Commercial wind turbines require undisturbed airspace for operation and may present hazards to air travel. Areas within 3 km of public use and military airfield runways are considered unsuitable for wind development (USDOE 2008).

Source: USDOT (2020).

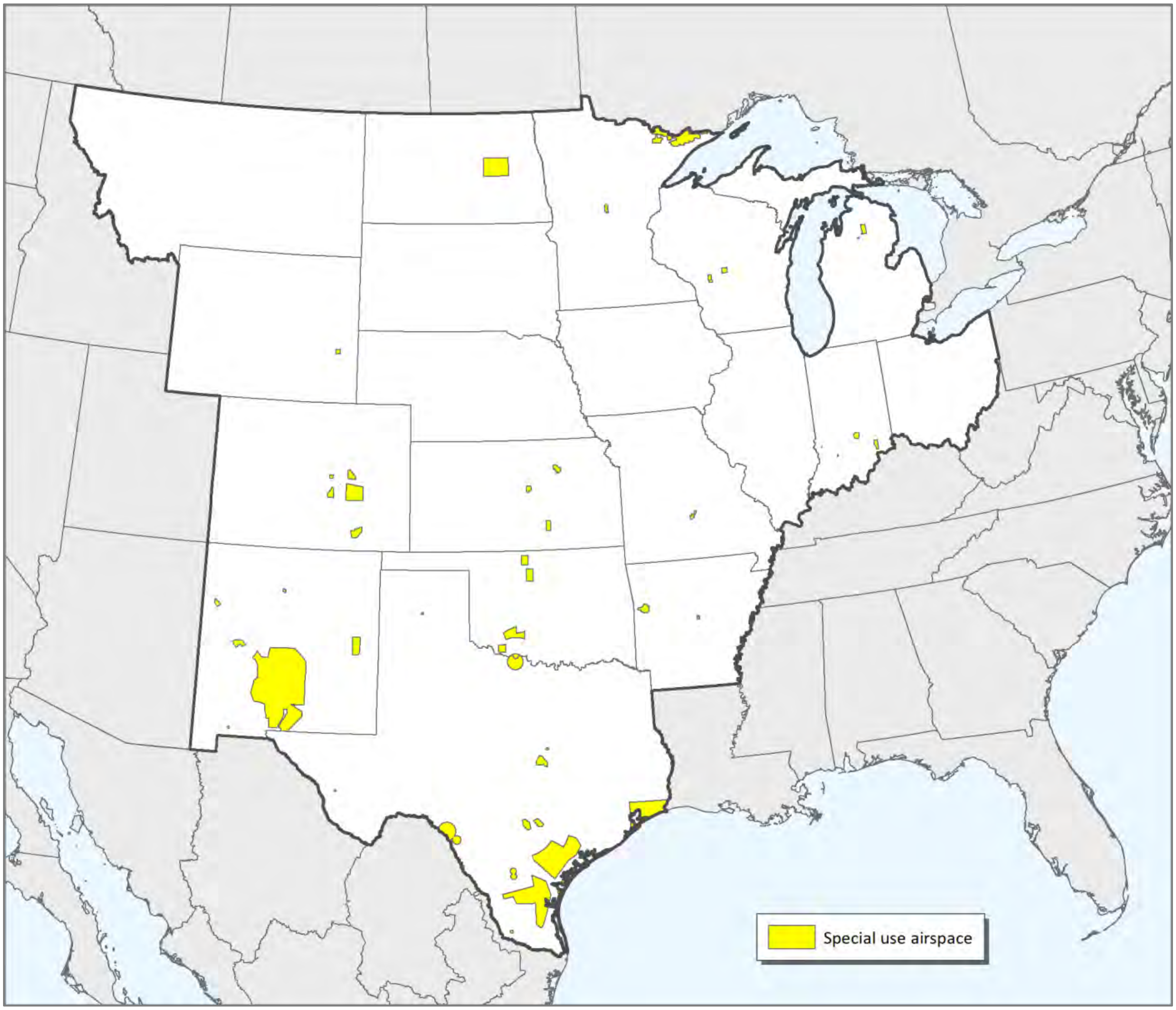


Special use airspace

Special use airspace areas managed by the Federal Aviation Administration contain unusual aerial activity, generally of a military nature. These include 'alert' areas which experience high volumes of training flights, 'restricted' areas near artillery firing ranges, and 'prohibited' areas with significant national security concerns (FAA 2010). Placement of wind turbines within these areas may create hazardous flight conditions and compromise military readiness (NRDC and USDOD 2013).

We consider alert, restricted, and prohibited airspace unsuitable for wind energy development. Outside of these areas, consultation with the U.S. Department of Defense may be required prior to constructing wind turbines within defined military operating areas, near low-level flight paths, and in areas that penetrate defense radar lines of sight.

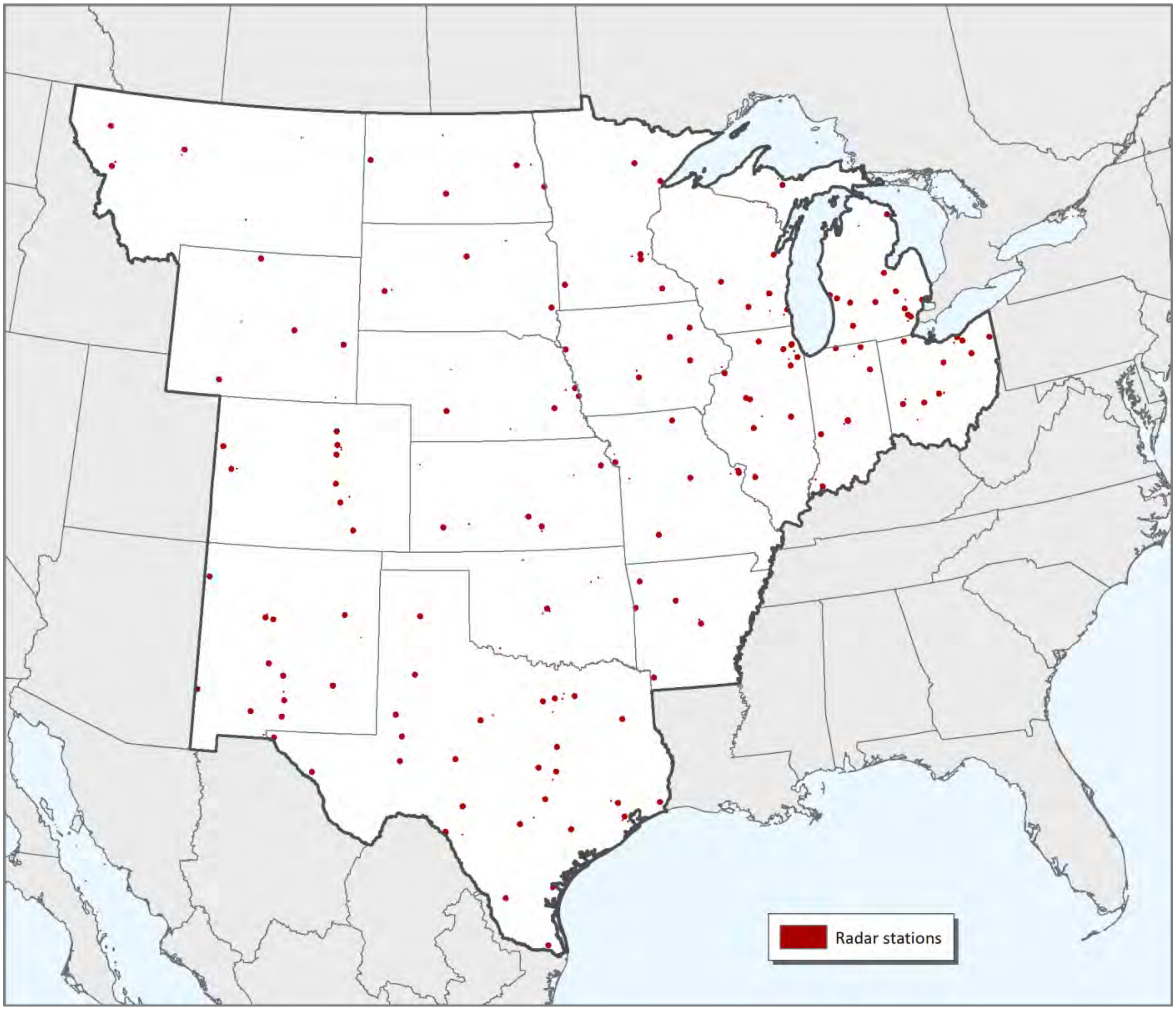
Sources: FAA (2017a, 2017b).



Radar stations

Wind turbines may cause interference with radar signals when sited in close proximity to weather stations and military installations (Vogt et al. 2011; NRDC and USDOD 2013). The National Oceanic and Atmospheric Administration requests that developers avoid constructing wind turbines within 3 km of NEXRAD radar installations (FAA 2021a); a larger avoidance distance of 9.26 km is assumed for Department of Defense radar sites (Tegen et al. 2016). Outside of these areas, mitigation may be required for wind turbines that penetrate radar lines of sight, particularly for structures within 36 km (FAA 2021a).

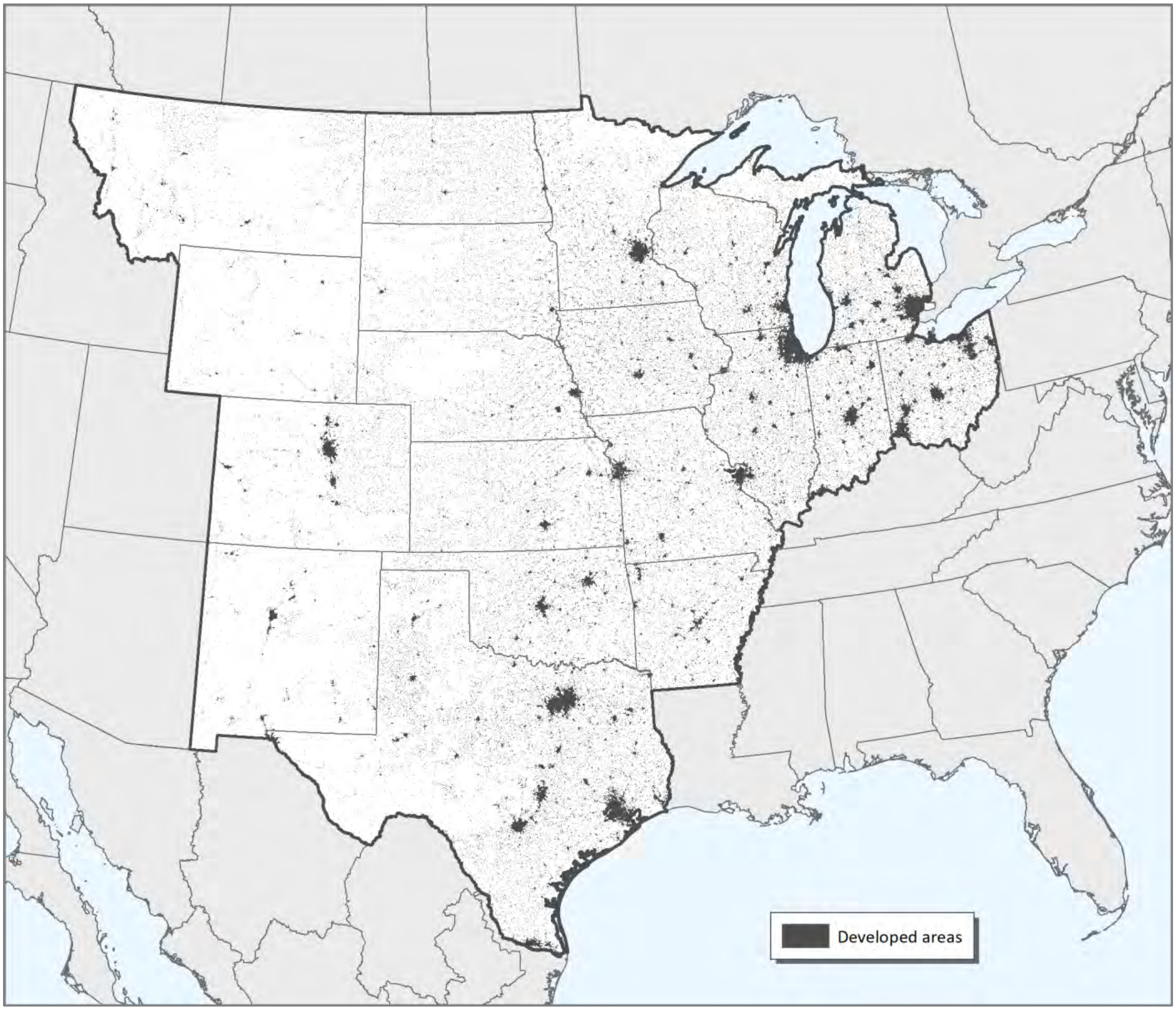
Sources: NOAA (2021); FAA (2021a).



Developed areas

Urban lands and other developed areas (including roads, industrial sites, etc.) are considered unsuitable for commercial wind development (USDOE 2008).

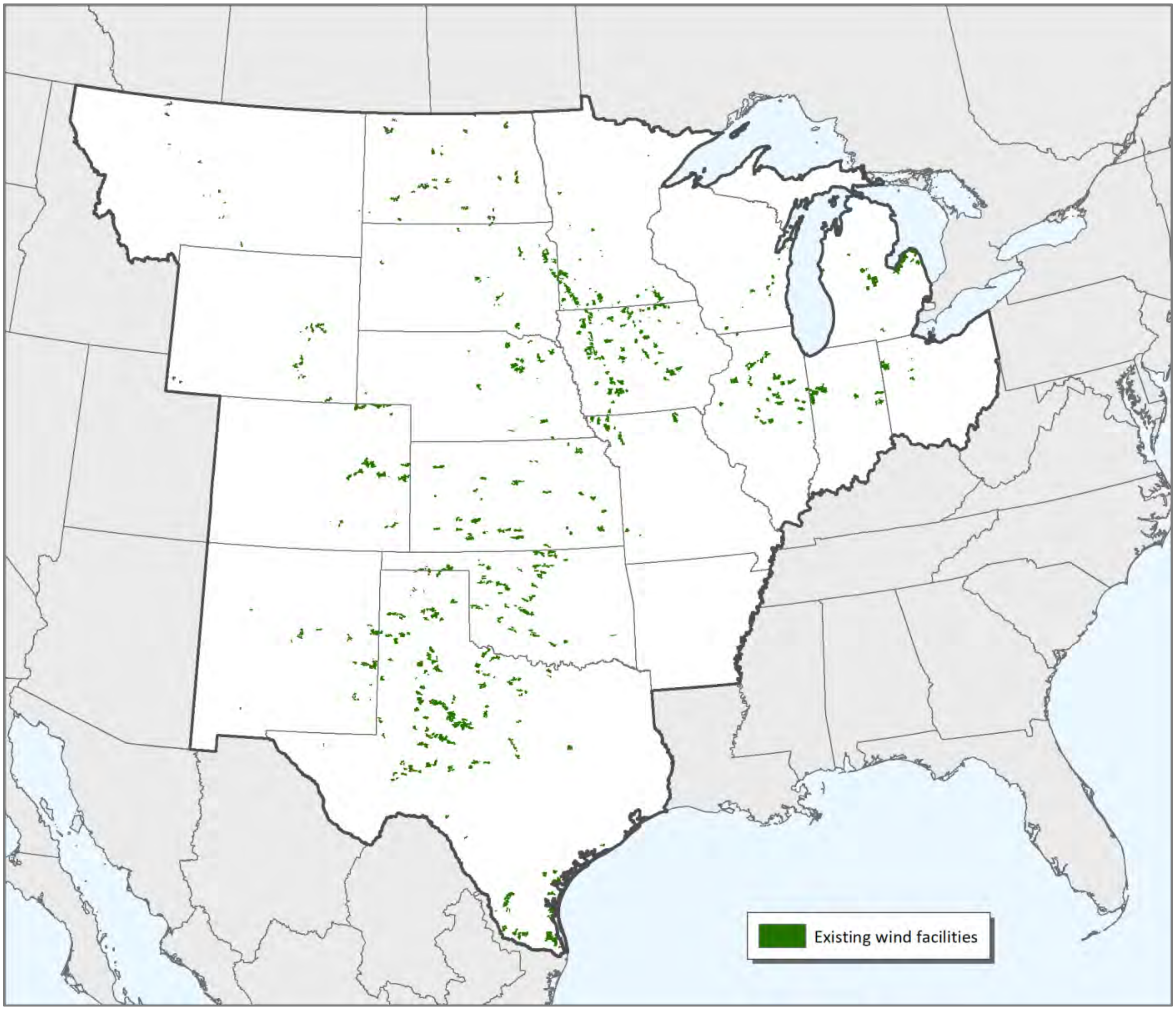
Sources: Fry et al. (2011); USCB (2016).



Existing wind facilities

Areas within 1.6 km of existing wind turbines are considered unsuitable for new wind development. This distance represents the typical spacing of turbine strings oriented perpendicularly to prevailing winds in the Great Plains.

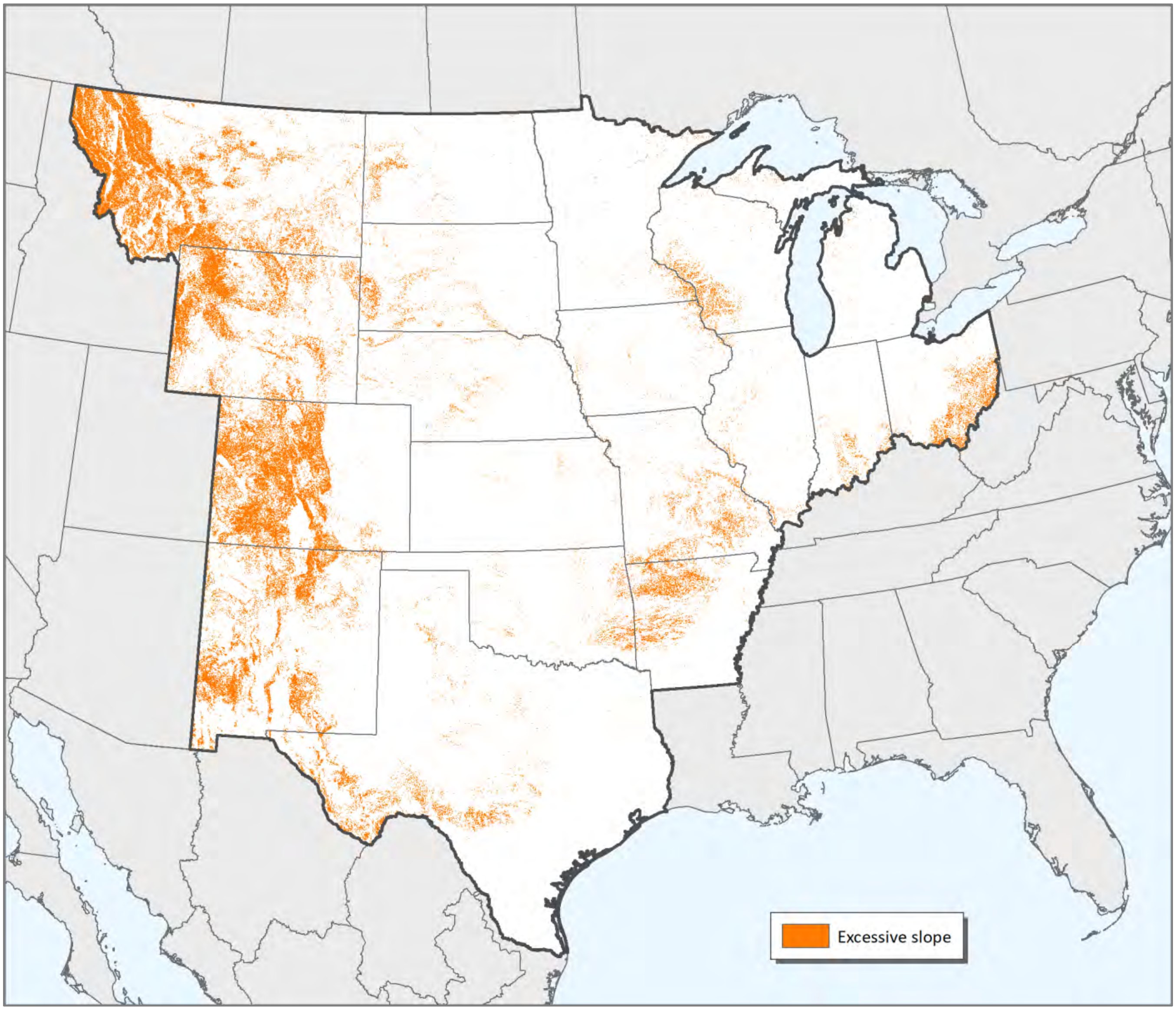
Source: FAA (2021b).



Excessive slope

Steeply sloping terrain may significantly increase capital costs associated with turbine construction. Areas of slope exceeding 20% are considered unsuitable for wind development (USDOE 2008).

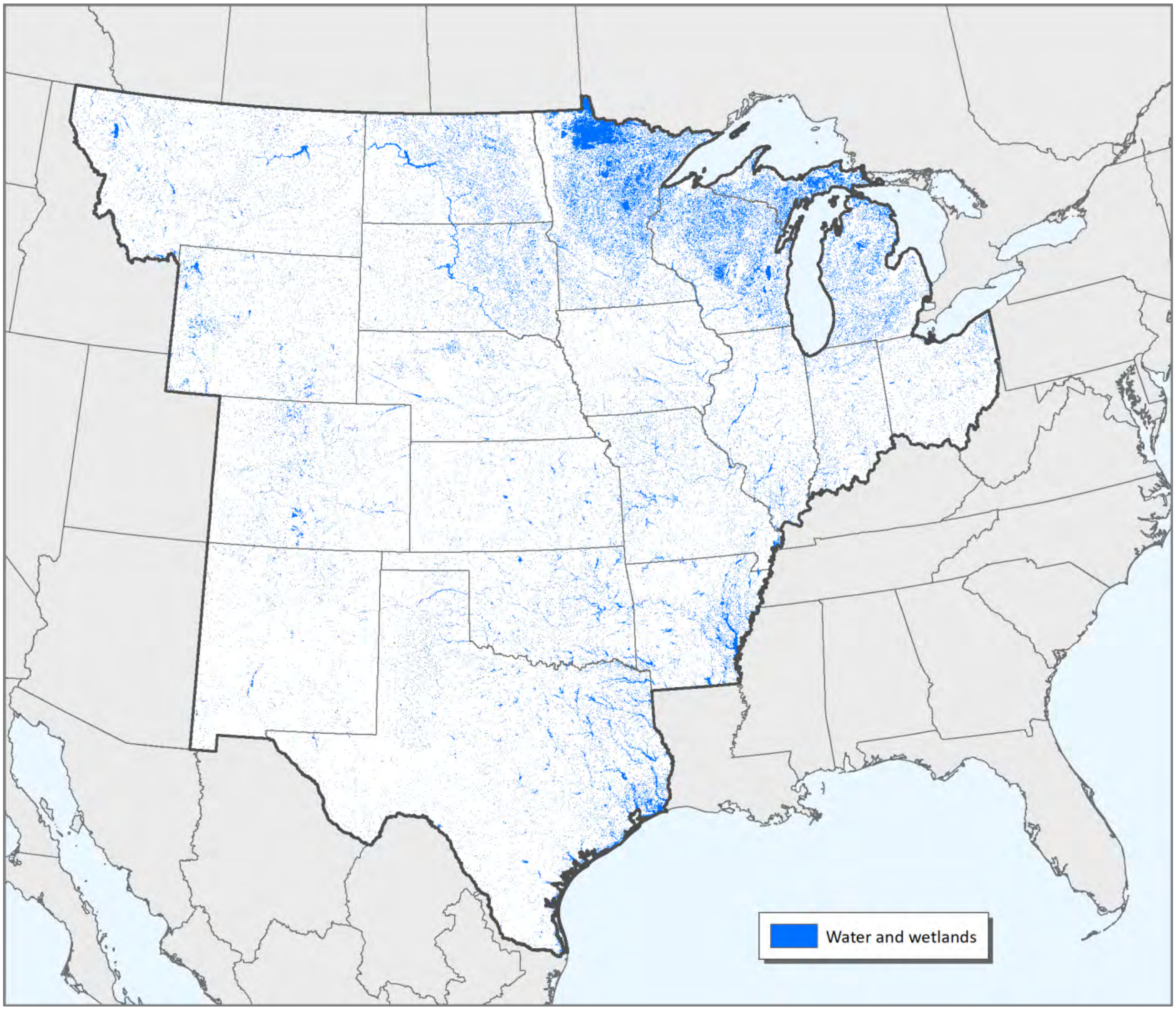
Source: USGS (2017a).



Water and wetlands

Open water and wetland areas are considered unsuitable for wind development (USDOE 2008).

Sources: Fry et al. (2011); PLJV (2015); USFWS (2016b).



Poor wind resource

Areas with annual average wind speeds of less than 6.5 m/s at 80 m height may be unsuitable for wind development (AWS Truepower 2010).

Source: AWS Truepower (2010).

Negative relative elevation

Mesoscale wind maps are often generalized and may not accurately depict wind energy potential at a given site (Bailey et al. 1997; Tennis et al. 1999). Wind developers employ a variety of computational models to assess local wind resources based on orography, measured wind speed, and other factors (Langreder 2010; Hau and von Renouard 2013). Most commercial wind facilities in the central U.S. are situated on topographic ridges which experience higher winds than the general surroundings. To identify terrain conducive to development, we calculated relative elevation based on the mean elevation of annuli extending 3, 6, 12, and 24 km from a given point (White et al. 2014). Negative values represent areas that lie below the adjacent landscape and thus have decreased wind exposure. Mountainous and coastal regions were not analyzed or excluded based on relative elevation as wind resources in these areas may be influenced by more complex topographic and meteorological factors.

Sources: methods – White et al. (2014); data – USGS (2017a); analysis – TNC (2021b).

Statutory restrictions

Wind development may be legally (or functionally) restricted in some areas of the central U.S., including within 2.8 km buffers of airport runways, public schools, and hospitals in Oklahoma (17 O.S., Section 160. 20, as amended); the "Heart of the Flint Hills" region in Kansas (Rothschild 2005; KBS 2015c); 1.6 km and 800 m buffers of certain state-protected properties in Illinois, as supported by the Illinois Natural Areas Preservation Act (525 ILCS 30/1-26); and 150 m buffers of state trails in Minnesota (cf. MNDNR 2018b).

Many additional state, county, and local regulations pertaining to wind development exist across the region (NREL 2021); however, a detailed examination of these constraints was beyond the scope of this assessment.

Sources: KBS (2015c); OKSDE (2015); PSCC (2015); MNDNR (2016b); USDOT (2017); USGS (2017b).

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