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EXECUTIVE SUMMARY

The United States has abundant wind resources, such that only about 3% of the resource would need to be developed to achieve the goal of producing 20% of electricity in the United States by 2030. Inappropriately sited wind development may result in conflicts with wildlife that can delay or derail development projects, increase projects costs, and may degrade important conservation values. The most cost-effective approach to reducing such conflicts is through landscape-scale siting early in project development. To support landscape scale siting that avoids sensitive areas for wildlife, we compiled a database on species distributions, wind resource, disturbed areas, and land ownership. This database can be viewed and obtained via http://wind.tnc.org/awwi. Wind project developers can use this web tool to identify potentially sensitive areas and areas that are already disturbed and are therefore likely to be less sensitive to additional impacts from wind development.

The United States' goal of producing 20% of its electricity from wind energy by the year 2030 would require 241 GW of terrestrial nameplate capacity. We analyzed whether this goal could be met by using lands that are already disturbed, which would minimize impacts to wildlife. Our research shows that over 14 times the DOE goal could be produced on lands that are already disturbed (primarily cropland and oil and gas fields), after taking into account wind resource availability and areas that would be precluded from wind development because of existing urban development or because of development restrictions. This work was published in the peer reviewed science journal PLoS ONE (a free online journal) and can be viewed here: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0017566.

Even projects that are sited appropriately may have some impacts on wildlife habitat that can be offset with offsite compensatory mitigation. We demonstrate one approach to mapping and quantifying mitigation costs, using the state of Kansas as a case study. Our approach considers a range of conservation targets (species and habitat) and calculates mitigation costs based on actual costs of the conservation actions (protection and restoration) that would be needed to fully offset impacts. This work was published in the peer reviewed science journal PLoS ONE (a free online journal) and can be viewed here: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0026698.

SUMMARY OF PROJECT ACTIVITIES AND ACCOMPLISHMENTS

We compiled and analyzed data for use in wind energy development to avoid and mitigate impacts to wildlife. Below we present methods and results for each of three products that resulted from this overall effort. The first product is a publically available, online Landscape Assessment Tool for use in landscape-scale siting (referred to as Tier 1 assessment in the Fish and Wildlife Service's Land-Based Wind Siting Guidelines). The second product is an analysis, using data compiled and distributed in the Landscape Assessment Tool, of how much wind energy can be produced on disturbed lands in the United States. This provides guidance for how wind energy development could avoid most impacts to wildlife. However, it will not be possible to avoid all impacts. Consequently, to mitigate remaining impacts, compensatory offsite mitigation would be required. To illustrate how such an approach could effectively and efficiently be implemented, our third product is the application of our "Development by Design" approach to wind energy development in Kansas. The approach, methods, and findings are described for each of these three products below.

Product 1: Landscape Assessment Tool (http://wind.tnc.org/awwi)

We compiled to four types of data for the lower 48 United States: 1) the spatial distributions of species that may be impacted by wind development, 2) wind resource, 3) protected areas and other land ownership, and 4) disturbed areas. We describe the methods and data sources for each below before describing how these data layers were incorporated into the publically available online Landscape Assessment Tool.

Species Distributions.

We identified vertebrate species that have the potential to be impacted by wind development. These include species that are critically imperiled, imperiled, or vulnerable at the population level, typically based on habitat loss. In addition we consider species with repeated observed mortality, and species known to be impacted by fragmentation from roads and towers. This results in a list of approximately 480 species for the lower 48 states. We acquired spatial data on these species distributions from all of the lower 48 states. Data were not available for every species on our list, in every state in which that species occurs. We were able to obtain species models for over 60% of the state by species combinations for which they were sought. This includes over 2,300 different models, most of which cover only one state. We reprojected the models so that they are all in the same geographic projection. We mosaiced the data so that instead of having a separate data layer for each species in each state, we now have one layer for each species that covers all the states in which that species occurs. Species distribution models were acquired primarily from the U.S. Geological Survey Gap Analysis Program (GAP). These models are commonly generated through expert elicitation of species habitat relationships, with maps generated by land cover data layers depicting the distribution of habitats where these species are expected to occur.

For wind power in the United States, we used wind power class modeled at 50 meters above the ground (National Renewable Energy Lab 2011). These data are provided at a resolution of 200 x 200 meter pixels. Land ownership, including protected areas, was obtained from the Protected Area Database of the United States (Conservation Biology Institute 2010b).

We created a binary disturbed/undisturbed classification that considers areas with any of the following human impacts to be disturbed. Specifically, we compiled spatial data on the footprint of human disturbance, including developed areas, cropland, roads and other impervious surfaces, oil and gas development, and surface mines. Disturbance data were compiled from four sources: 1) National Land Cover Dataset, 2) USGS impervious surfaces dataset, 3) USGS topographic change dataset, and 4) a national oil and gas field dataset. All data layers are available in 30 meter rasters. The National Land Cover Dataset (NLCD) is a federal multi-agency effort that applies standard class schemas, methodologies, and error assessments to quantify landcover patterns across the entire lower 48 U.S. states (Multi-Resolution Land Characteristics Consortium 2010). The following NLCD classes were considered to be disturbed lands: Cultivated Crops, Developed-High Intensity, Developed-Low Intensity, Developed-Medium Intensity, Developed-Open Space, and Hay/Pasture. The Hay/Pasture class included planted forage grasses, but did not include natural (i.e. unplanted) grasslands used for grazing. We used a Landsat derived impervious surface classification produced by USGS (Yang et al.

2003) to identify areas with reduced percolation such as pavement. The USGS topographic change data was used to identify significant topographic change, representing surface mines and other major human-based changes in topography (United States Geologic Survey 2008). The USGS used a threshold for identifying significant topographic change of 10.21-17.57 meters, depending on the land cover type. Oil and gas fields were identified with a kernel density analysis of well locations using IHS energy© data (Copeland et al. 2009).

LAT functionality

The web tool is designed to view, download, and query data, in addition to linking to data sources. The web map service allows users to view different data layers and to easily link to the metadata and the source GIS data for each data layer, with hyperlinks in the legend associated with each data layer. This ensures transparency of data sources, because users can link from the viewable data layers to the data layer sources. The LAT also contains an “identify tool” that allows users to click anywhere in the country and obtain a list of species that are found in that vicinity. We are able to execute this query in real time because, rather than querying the 30 meter pixel data, which would be prohibitively slow, we pre-process all of the data to assess presence absence in nationwide 7.5-minute quadrangle grid (approximately 50 square miles). When a user selects a given location with the identify tool, the LAT quickly queries the presence/absence quadrangle database in order to determine which species are present in a given vicinity. The LAT also contains a reporting feature that allows users to draw a custom project area and generate a custom report that lists the species likely present in that vicinity. The LAT’s reporting feature also uses the processed quadrangle data to provide a real-time report.

To assess the quality of the species distribution data, when used at the 7.5-minute quadrangle scale, we obtained species observation data for as many species and states as possible. This data was obtained from state natural heritage programs. We used Cohen’s Kappa statistic, a spatial statistic that evaluates goodness of fit, to assess data quality (Landis and Koch 1977). The kappa statistic corrects for the number of correct predictions that are due to chance alone. For example, if a species distribution model predicts that a species will occur over 90% of the state, we would expect 90% of species observations in the state to be predicted successfully by the model, even if the species observations were actually randomly generated. The kappa statistic corrects for this bias in percent correct predictions that occurs in widespread species. We have conducted this analysis for >200 species distribution models for which we could obtain species observation data. We found that 80% of the models passed the Kappa test (i.e. had a Cohen’s Kappa value of >0.6), when used at the coarse resolution at which the web tool is designed to be used.

Since its public release in January 2011, we have continued to update the LAT. We have added data on lesser prairie chicken habitat in Oklahoma and added raptor count data from HawkWatch International and the Hawk Migration Association of North America. We have updated the software to ArcGIS 10 and Adobe Flex 4. Using funds beyond this DOE grant, we hope to continue to update the LAT to ensure that it continues to be a useful and relevant tool for developers.

Product 2:

Win-Win for Wind and Wildlife: A Vision to Facilitate Sustainable Development

The Department of Energy’s (DOE) envisions the US producing 20% of its electricity from wind by 2030, as outlined in their report “20% wind energy by 2030,” hereafter “20% vision”

(Department of Energy 2008). However, wind energy has, per unit energy, a larger terrestrial footprint than most other forms of energy production (McDonald et al. 2009) and has known and predicted adverse impacts on wildlife (Kunz et al. 2007, Arnett et al. 2008, AWEA [American Wind Energy Association] 2009). Meeting the DOE 20% vision (~ 241 Gigawatts of on-shore wind with an additional 64 Gigawatts of off-shore wind) would result in 5 million hectares of impacted land, an area roughly the size of Florida, with an additional 18,000 kilometers of new transmission lines (Department of Energy 2008). While environmental concerns over wind development have focused primarily on direct strike mortality of birds and bats (Kunz et al. 2007, Arnett et al. 2008, Kunz et al. 2008) it is the increase in fragmentation and habitat loss associated with development that creates an important conservation challenge (National Research Council 2007, Pruett et al. 2009b). In the US the Federal Endangered Species Act currently protects over 1300 species and another ~250 species are under consideration for protection. The majority of these species list habitat loss and fragmentation as the primary cause for federal protected status (http://www.fws.gov/endangered/). Siting of wind development that avoids habitats important for biodiversity reduces the potential for significant habitat loss and fragmentation and corresponding listing of additional species.

In this study we examine patterns of wind energy potential in terrestrial landscapes that are already disturbed by human activities (e.g., agriculture, oil and gas development). Although other studies (Lu et al. 2009) have estimated the total amount of potential wind-energy production available in the US and globally, this is the first to examine if renewable energy goals can be met on disturbed lands that could reduce conflict with wildlife. Our goal is to estimate the potential electricity generation capacity of lands of low value for biodiversity conservation rather than estimate impacts associated with wind farms and associated transmission. Our scenarios (Figure 1) are based on the DOE forecast of wind energy production for each state to meet the 20% vision. The DOE projections outline a spatial and temporal roadmap for meeting wind energy goals, with specific GW projections for each of the lower 48 states. Here we focus on the 31 states that comprise the majority of the DOE 20% vision, excluding states which have < 1 GW of projected development: AL, AR, CT, DE, FL, GA, KY, LA, MA, MO, MS, NH, NJ, OH, RI, SC, VT (1). We calculated the area needed to meet DOE wind energy scenarios within each state, providing a broad overview of the potential for wind energy generation on disturbed lands, but did not attempt to predict where within each state wind energy development will take place. The land area needed to meet the 20% vision depends on the wind potential of any given area, as characterized by its wind power class. Foregoing development of undisturbed land with high wind classes in favor of disturbed lands (with potentially lower wind classes) may require more land to generate the same amount of energy. Therefore, we examined if meeting DOE goals solely on disturbed lands would require an increase in land area over that needed when the highest wind classes are exploited regardless of disturbance. Finally, we discuss the likelihood that targeting development to already disturbed lands will reduce impacts to biodiveristy, and potential limitations to this conclusion.

MATERIALS AND METHODS

To develop a disturbance data layer that is relevant and comparable across the conterminous United States we utilized data that were consistently derived across large geographical/regional scales (Theobald 2010). We used the National Land Cover Dataset (NLCD), classified into disturbed lands using the following classes: Cultivated Crops, Developed-High Intensity, Developed-Low Intensity, Developed-Medium Intensity, Developed-Open Space and

Hay/Pasture (http://landcover.usgs.gov/natllandcover.php). We recognize that rangelands often serve as important wildlife habitat despite their intensive use by domesticated livestock. For this reason we have excluded these lands in our index. We used a LandsatTM derived impervious surface classification (Yang et al. 2003) to identify areas with reduced percolation, such as pavement. The USGS topographic change dataset (http://topochange.cr.usgs.gov/) was used to identify mines and other major human-based changes in topography. Oil and gas fields were integrated into the analysis using IHS energy© data (Copeland et al. 2009). While we have confidence in the ability of individual data layers to accurately predict disturbance patterns misclassification error for individual data layers can be found in their respective data sources. We created a binary disturbance dataset by defining any 30-meter pixel classified as disturbed across the four independent datasets (landcover, mined, impervious, and oil & gas) as disturbed, otherwise undisturbed. We calculated the square kilometers (km^2) of each wind power class within each state. Following the DOE 20% vision, we estimated the amount of GW per unit area across the US and in each state by assuming that average nameplate capacity (44.5%) is installed at 11.24 MW/km^2 and adjusting turbine nameplate capacity with capacity factors specific to each wind power class (WPC 7 = 53%; WPC 6 = 49%; WPC 5 = 46%; WPC 4 = 43%; WPC 3 = 38%). These area requirements assume efficiency increases as predicted for 2030 by the DOE (Department of Energy 2008).

We estimated the amount of land in each state needed to meet DOE projections by selecting the largest contiguous blocks of disturbed lands in the highest wind power class in that state and repeating that process in successively smaller disturbed patches and lower wind power classes until the DOE projection was reached. The smallest patch sizes selected were all within the size range of existing or proposed wind developments. To generate an “unconstrained” development scenario, we repeated this process without restricting the selected areas to disturbed lands. We compared the amount of land needed to meet the DOE projection under the disturbance restricted and unconstrained scenarios. Once the land area needed to meet the DOE projection was determined, we measured the amount of undisturbed land that would need to be developed to meet goals in the unconstrained scenario. Throughout our analysis, we excluded certain areas as being protected or restricted from development, modeling our decision rules on those used in the DOE’s report (Department of Energy 2008). We excluded areas having a protected status precluding wind development using the Gap Analysis Program code 1 or 2 (i.e., permanent protection excluding development), based on the Protected Area Database of the United States, version 1.1 (Conservation Biology Institute 2010a). To avoid counting areas where land is not protected but large-scale wind will likely not be developed, we excluded urban-core areas (U.S. Census Bureau 2009), and wetlands and water bodies identified in the NLCD data. All spatial analyses were performed in ESRI’s ArcGIS 9.3 (http://www.esri.com/) and all statistical analyses were performed in R (R Development Core Team 2009).

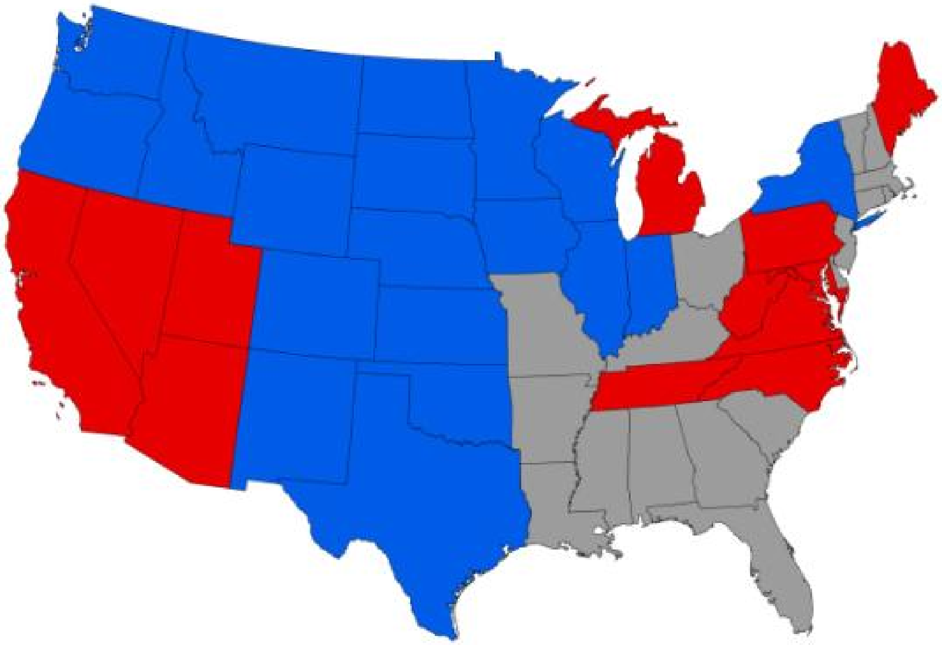
RESULTS

Croplands cover 1,954,821,517 ha, planted hay/pasture 521,779,323 ha, impervious surfaces 380,885,661 ha, oil and gas fields 365,236,244 ha, surface mines 1,212,619 ha and urban-developed lands 480,230,891 ha. Total disturbed lands were 3,218,665,150 ha, with some disturbances overlapping. After removing urban areas, permanently protected lands and areas with wind power classes less than three, there were 1,450,443,444 ha considered suitable for wind.

Our analysis indicates that a network of land-based turbines, accounting for areas inappropriate for their placement, has the potential to generate 7,705 GW in the lower 48 United States, with potential for 3,554 GW in areas already disturbed by human activities (Figure 2). Given a DOE projection of 241 terrestrial GW, there is ample opportunity to meet this goal in areas likely to have relatively low wildlife value. Despite the extensive wind resources across the US, nine states (CA, AZ, NV, UT, WV, PA, VA, NC, & TN) are unable to meet DOE projections within areas already disturbed (Figures 1 & 2). There are also three states (MD, MI & TN) that are unable to meet DOE terrestrial projections even if wind development is not confined to disturbed lands. Given the distribution of wind power classes, an additional nine states (CO, ID, MT, NY, OK, OR, SD, WA & WY) would require an increased land base to generate the same amount of GW if development is focused solely on disturbed lands (Figure 3). Notwithstanding these tradeoffs, a disturbance-focused development strategy would avert the conversion of ~2.3 million hectares of undisturbed lands relative to the unconstrained scenario in which development is based solely on maximizing wind potential.

DISCUSSION

Wind energy production will result in reduced CO2 emissions and reduced water demand for electricity generation (Department of Energy 2008) but it will result in broader terrestrial (McDonald et al. 2009) and aerial impacts (4-6). The increase in wind production forecasted by DOE may be compatible with wildlife if properly sited, but will still pose a challenge for conservation, both because of the threat of bird and bat mortality (Kunz et al. 2007, Arnett et al. 2008, Kunz et al. 2008) and because of the large area impacted which may cause habitat loss, fragmentation, and avoidance (National Research Council 2007) (Pruett et al. 2009b). There are multiple ways to balance the tradeoffs between emissions reduction and increased fragmentation resulting from wind energy development. First, energy conservation can help reduce the new energy needed by the U.S., reducing the area impacted by new energy development (McDonald et al. 2009). Many impacts can be mitigated or eliminated with appropriate siting and planning for energy development (Kiesecker et al. 2010). Planning for the siting and mitigation of industrial scale wind development will require that we examine tradeoffs at an appropriate landscape scale. Harnessing the power of systematic conservation planning (Kiesecker et al. 2010) will allow stakeholders to examine cumulative impacts associated with wind and other development as well as balance other land use needs and issues (e.g. view sheds) that will be important in addition to wildlife.



State	DOE (GW)	Total (GW)	Disturbed (GW)	% DOE goal on Disturbed Land	Averted Loss (KM^2)
AZ	**2.72**	**27.37**	**0.36**	**13%**	**534**
CA	**15.82**	**108.22**	**6.18**	**39%**	**2719**
CO	**2.51**	**290.25**	**105.20**	**4197%**	**420**
IA	**19.91**	**490.62**	**450.56**	**2263%**	**0**
ID	**2.82**	**55.75**	**5.33**	**189%**	**496**
IL	**14.68**	**343.66**	**304.60**	**2075%**	**91**
IN	**6.77**	**16.46**	**16.15**	**238%**	**0**
KS	**7.16**	**838.21**	**518.70**	**7246%**	**16**
MD	**1.82**	**1.59**	**0.28**	**15%**	**297**
ME	**1.11**	**11.09**	**0.63**	**56%**	**194**
MI	**20.34**	**15.51**	**10.76**	**53%**	**1092**
MN	**9.94**	**195.31**	**173.69**	**1747%**	**110**
MT	**5.26**	**902.04**	**245.27**	**4662%**	**884**
NC	**1.89**	**5.35**	**0.82**	**44%**	**339**
ND	**2.26**	**724.14**	**457.19**	**20201%**	**126**
NE	**7.88**	**698.73**	**291.35**	**3697%**	**482**
NM	**6.45**	**297.29**	**25.68**	**398%**	**1193**
NV	**7.49**	**36.17**	**0.22**	**3%**	**1431**
NY	**2.19**	**48.52**	**25.64**	**1179%**	**381**
OK	**38.48**	**259.72**	**141.81**	**369%**	**3058**
OR	**7.92**	**70.04**	**8.10**	**100%**	**1297**
PA	**3.10**	**5.97**	**0.79**	**25%**	**579**
SD	**8.06**	**854.48**	**350.53**	**4349%**	**1163**
TN	**1.09**	**0.37**	**0.01**	**1%**	**78**
TX	**20.46**	**733.77**	**320.63**	**1567%**	**765**
UT	**2.45**	**26.61**	**0.33**	**14%**	**451**
VA	**1.78**	**5.63**	**0.57**	**32%**	**330**
WA	**9.87**	**58.14**	**10.77**	**109%**	**1772**
WI	**1.54**	**5.22**	**3.52**	**228%**	**0**
WV	**1.96**	**9.51**	**0.80**	**41%**	**347**
WY	**12.77**	**569.93**	**63.23**	**495%**	**2146**
Low wind	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**

Figure 1. Map of continental US with states where DOE targets can (blue) and cannot (red) be met on disturbed lands. We exclude states (grey) with less than 1 GW of projected development. Inset table with DOE projections (in GW), total available wind energy (in GW), wind energy available on disturbed lands (in GW), percent of DOE vision that can be met on disturbed land and amount of undisturbed lands that a disturbance focused development scenario would avert (in square kilometers).

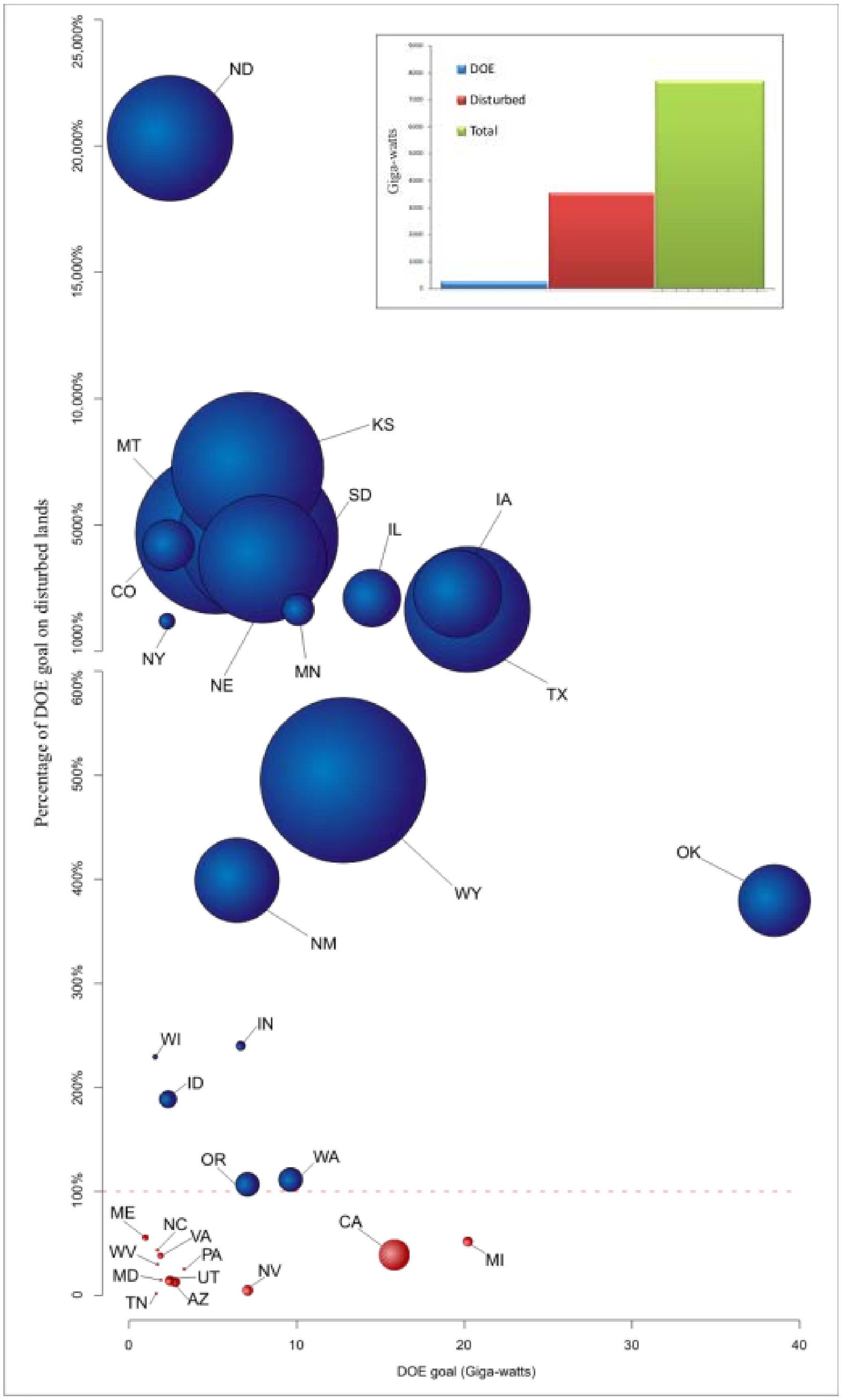


Figure 2. *Available wind-generated Giga-watts (GW) in each state as a function of the DOE goal and percentage of the DOE goal that can be met on disturbed land. Bubbles indicate where DOE goals can (blue) and cannot (red) be met on disturbed lands. Bubble area indicates total GW of wind potential available in the state (Range 0.37 GW in TN to 902 GW in MT). Inset graph shows potential GW wind production for the entire US and potential on disturbed lands relative to the DOE 20% projection.*

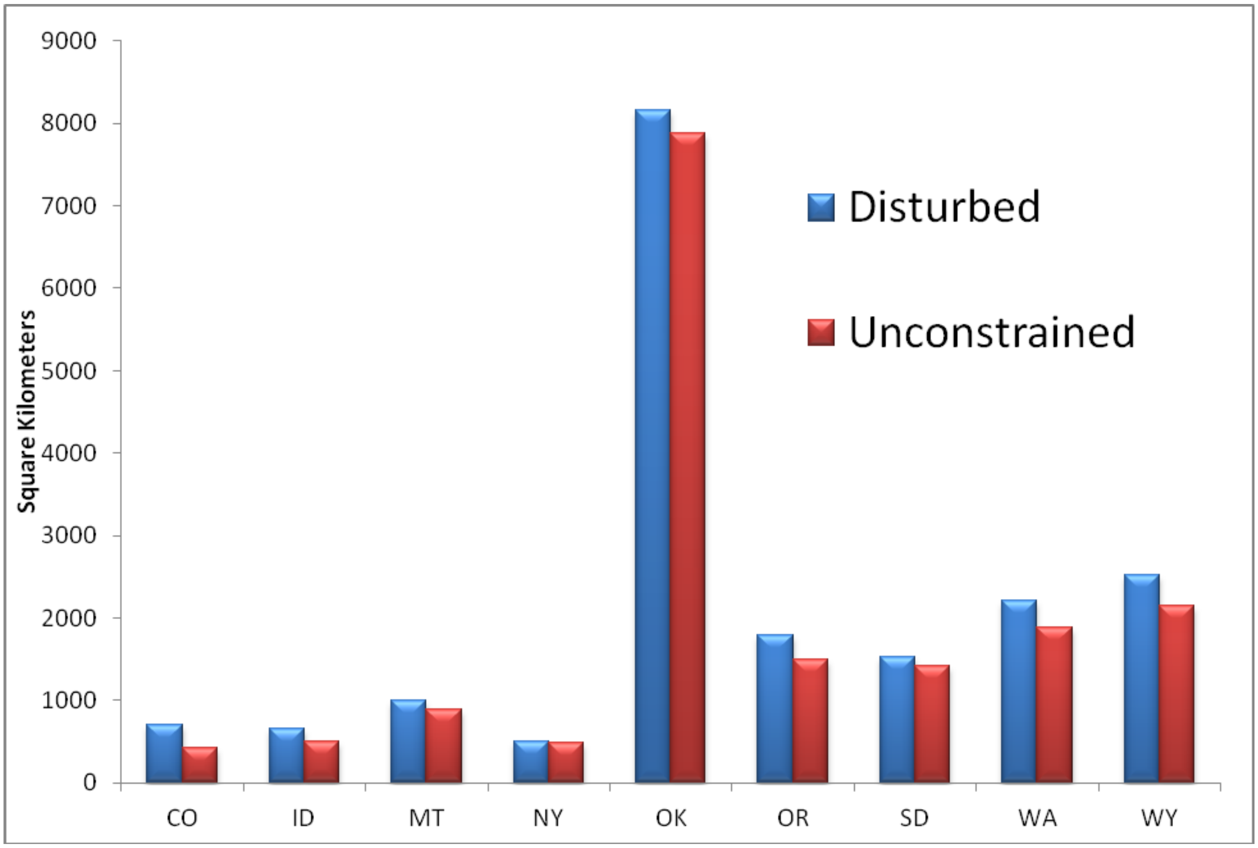


Figure 3. *Minimum number of square kilometers needed to meet DOE projections for disturbance restricted (blue) or unconstrained (red) scenarios. For simplicity we have only included states where disturbance focused development would result in an increased area needed to meet the DOE projections. For all other states there is either not an increase in land needed or the state is unable to meet DOE projections on disturbed lands.*

The disturbed areas used in this analysis represent low-quality habitats incapable of supporting populations of imperiled species and are altered to the point of no longer supporting natural community assemblages (Stein et al. 2000, Fletcher et al. 2010). Disturbance is also consistently associated with reduced biological integrity and increased probability of extirpation for many species (Johnson et al. 2005), such that areas of high disturbance generally have low value for biodiversity (Forman et al. 2003). Patterns of disturbance have historically played a significant role in the design and development of conservation priorities (Margules and Pressey 2000). From a conservation perspective, the types of species that accumulate in disturbed landscapes does not compensate for the loss of biodiversity resulting from fragmentation of once large and intact landscapes (Stephens et al. 2008).

Conversely, areas of low disturbance are disproportionately valuable for biodiversity. Species of conservation concern that require large intact shrubland or grassland habitats, such as sage grouse and greater and lesser prairie chickens, are sensitive to human activity and may be evolutionarily adapted to avoid large vertical structures such as wind turbines, and are therefore thought to be particularly vulnerable to wind energy development. These grouse exhibit 90% reduction in nesting up to 1.25 miles away from vertical structures such as wind turbines (Pruett et al. 2009a). For these and other species that require large unfragmented habitat, improperly sited wind turbines may be incompatible with maintaining viable wild populations.

The approach we outline here is not intended to prescribe exactly where turbines should be located, but instead to demonstrate that there are many options for wind development. Site-specific characteristics or landowner preferences may limit the ability to develop any particular piece of disturbed land. However, given the large area of disturbed lands that have suitable wind resource, most of the projected wind development in the US could be targeted onto existing disturbed lands. New wind development would likely have minimal potential to impact terrestrial wildlife if sited in disturbed areas. In addition to reduced wildlife impacts, a disturbance-based development strategy is largely compatible with current land uses. For example, given turbine spacing needs, wind farms typically utilize only 2-4% of an area, making it compatible with agricultural production (AWEA [American Wind Energy Association] 2009). Moreover, compensation associated with development increases profitability of lands that balance agriculture and wind development (Department of Energy 2008). While land in corn production yields profits of less than $1,000 per ha (FAPRI [Food and Agriculture Policy Research Institute] 2010), farmers may receive $4,000 - $6,000 per year per turbine (Aakre and Haugen 2009). A turbine and associated infrastructure have a per turbine footprint of less than a ha, thus farmers receive more than adequate compensation to encourage them to convert some of their (already disturbed) cropland to wind energy development. The other types of disturbance used in our analyses are also physically compatible with wind development, within or adjacent to these lands. Although wind developments on oil and gas fields is currently often limited by land rights and competing interests, these two forms of development are physically compatible and co-location could be facilitated and incentivized with targeted policies and subsidies. Agriculture and oil and gas make up the vast majority of the disturbed lands identified in our analysis, such that removal of other disturbed lands would not qualitatively change our results. However, we believe that ridges surrounding abandoned surface mines and areas adjacent to existing roads also constitute disturbed areas where wind energy development should be considered.

Placing turbines on disturbed lands may also benefit the expansion of transmission lines and associated infrastructure that will be critical to facilitate wind development. Because disturbed lands are already in areas of high road and transmission line density they may ease the development of new or expanded transmission capacity. As transmission capacity is expanded, consideration should be given to its design to ensure its placement considers wildlife conservation and can encourage development of wind on disturbed lands. Given the nationwide surplus in wind energy, it is conceivable that states that cannot meet goals on disturbed lands could import electricity from states where there is a surplus of disturbance-based wind energy. A number of states (MT, SD, KS, TX, ND, NE, WY, IA & IL) have a significant surplus of wind potential on disturbed lands where additional development would not likely cause significant loss of wildlife (Figure 2). Moving development to states where there is a surplus of wind potential on disturbed lands may alleviate some of the conflict over impacts to wildlife, if feasible given transmission and political constraints.

Targeting state and federal subsidies to favor low-impact developments and creating avoidance and mitigation requirements that raise the costs for projects impacting undisturbed lands could maximize public value for wind energy and wildlife conservation. Steering development to already disturbed landscapes may increase the spatial extent of wind energy (Figure 3) but will also decrease resulting impacts to wildlife by limiting habitat fragmentation (Figure 1). Even for the nine states where wind development sufficient to meet the DOE target on disturbed lands requires more turbines, would result in an 11% increase in the land area required to meet the 20% vision in these states, an increase of less than 2,000 km2. We recognize that in these nine states a disturbance-focused development strategy may require increased investment to produce the same amount of electricity. However as wind development increases, conflicts over impacts to wildlife are likely to become increasingly important. Thus, a proactive approach that seeks to avoid impacts to wildlife will reduce overall costs and facilitate wind development.

Several caveats limit our ability to conclude that a given disturbed area has low wildlife values. First, we are measuring terrestrial disturbance, which may not be correlated with use of the aerosphere by birds, bats, and insects. In particular, birds require migratory stopover sites, and these may occur along rivers, wetlands, or playa lakes that are embedded within heavily disturbed agricultural landscapes. Second, even terrestrial species may require migratory corridors through disturbed areas to access undisturbed habitat. Although, currently, quantitative nationwide data on airspaces with high bird/bat use do not exist, available regional and local information on migratory corridors, stopover sites, and aerospace use will be important to incorporate into local siting decisions. Additional research on land-cover and landscape features associated with bird and, particularly, bat mortality is needed to confidently identify areas where wind development would cause low mortality. In spite of this limitation, several factors suggest that a disturbance-based approach to wind siting will reduce overall impacts to wildlife. First, strategies other than siting may be the most appropriate for addressing bird and bat strike mortality. For example, mitigation measures, such as feathering blades (which stops their rotation) or reducing operations during lower winds speeds during times of when bat mortality is known to be high (fall migration nights when wind speeds are less than 5.5 m/s) could reduce bat mortality independent of where wind energy is sited (Arnett et al. 2010); micrositing of turbines can reduce bird mortality (Barrios and Rodriguez 2004). These strategies can be applied on both disturbed and undisturbed lands. Second, there is no reason to expect that siting wind turbines on disturbed lands would increase direct mortality to birds and bats. Even in cases where targeting disturbed lands requires the use of lower wind power classes and therefore more turbines to produce the equivalent amount of energy, these turbines would have reduced movement (i.e. would spend a smaller fraction of the time moving). It is likely that mortality at turbines that are not moving will be negligible (Barclay et al. 2007). Finally, even with 241 GW of on-shore wind energy, wind energy would kill less than 1 million birds per year. This is a very small proportion of the direct human-caused mortality to birds, which has been estimated at 300 – 2,300 million birds per year due to (in descending order of importance) cats, windows in buildings, poison, transmission lines and communication towers, cars, and oil and waste water pits (Barclay et al. 2007). At worst, wind energy would be responsible for a fraction of a percent of all human-caused bird mortality, although bat mortality has the potential to be have a much more significant population-level impact. Because species of conservation concern are preferentially found in native habitat versus cropland and other disturbed areas (Doherty et al. 2008, Fletcher et al. 2010), we expect that targeting wind energy development in disturbed areas would be more likely to impact birds that are not of conservation concern. In total, we believe that the identification of large areas of disturbed lands that are suitable for wind energy development and the targeting of wind energy and transmission line construction in these areas offer the potential to dramatically reduce the wildlife impacts associated with increased wind energy generation.

Our analysis may under-estimate the amount of wind resources available on disturbed lands. To estimate wind production potential we utilized 50-meter above ground wind data that is publically available and was used by the DOE to create the 20% vision. However, current turbine design places wind turbine hub heights at 80 meters where wind speeds are higher, allowing the economic development of wind on disturbed lands not identified as suitable in our analysis. Further, our analysis may not identify all areas with disturbed lands. Although we have a high degree of confidence in our ability to predict areas impacted by disturbance, we recognize that areas characterized as undisturbed in our analysis do not represent “pristine wilderness”. Although undisturbed areas are free of overt disturbance, they may be impacted by other factors (i.e., invasive weeds) or other land-use practices that reduce the wildlife value (i.e., over-grazing), neither of which are included in our definition of disturbed areas. This suggests that there may be moderately disturbed areas that are suitable for wind development but are not captured in our analysis, although disturbance caused by poor land management can often be addressed through management and/or policy changes within otherwise intact and functioning ecosystems. In total, our estimate of the potential for developing wind on disturbed lands is likely conservative, such that the potential for avoiding impacts to biodiversity is even greater than indicated by our analysis.

Avoiding impacts to undisturbed areas will be critical to maintain wildlife in the face of climate change and future development (Mawdsley et al. 2009). Maintaining large and intact natural habitats and maintaining or improving the permeability of land for the movement of both individuals and ecological processes may provide the best opportunity for species and ecological systems to adapt to changing climate (Mawdsley et al. 2009). The push to develop renewable energy is motivated in part due to the negative impacts that climate change would have on biodiversity. However, the potential benefits to biodiversity from wind energy’s contribution to climate change mitigation will be realized only if development can avoid and mitigate impacts to remaining habitat (Kiesecker et al. 2009). Our analysis provides a first step toward a national blueprint to facilitate sustainable wind development in a manner that maintains areas important for wildlife.

Product 3:
Development by Design: Mitigating Wind Development’s Impacts on Wildlife in Kansas

The DOE estimates that it will require about 5 million ha of land and nearly 18,000 km of new transmission lines in order for the U.S. to generate 20 percent of its electricity from wind (Department of Energy 2008). Given the distribution of wind resources across the continental United States, certain states, such as Kansas, are likely to experience a disproportionate amount of development.

Regulatory agencies often require that developers follow the mitigation hierarchy (Council on Environmental Quality 2000), which requires developers to avoid and minimize site impacts before utilizing offsets for negative impacts. We use a landscape-level approach to mitigation, referred to as “Development by Design” (Kiesecker et al. 2009, Kiesecker et al. 2010, Kiesecker et al. 2011), which provides a quantitative approach to development that achieves no net loss for wildlife. Although the term “mitigation” has sometimes been used to refer only to the payments designed to offset or compensate for impacts, we restrict the use of “mitigation” to refer to the whole mitigation hierarchy sequence, which starts with avoidance of impacts. In the final step of the mitigation hierarchy, mitigation payments are required to offset or compensate for remaining impacts that cannot be avoided or minimized. We refer to this final step of the mitigation hierarchy as “compensatory mitigation” or “offsets.”

Our Development by Design approach to landscape-scale mitigation offers three distinct advantages over traditional project-by-project approaches: 1) it allows consideration of the cumulative impacts of current and projected development projects; 2) it provides a regional context to better determine which step of the mitigation hierarchy should be applied (i.e. avoidance versus offsets); and 3) it adds flexibility for choosing offsets to maximize conservation benefits by targeting the most threatened habitats or species. This method allows for mitigation funding to be pooled and allocated toward the highest conservation priorities, resulting in a higher conservation return on investment. This should lead to reduced development costs and improved conservation outcomes compared to project-by-project approaches to offset impacts.

Here we apply Development by Design to wind energy development in Kansas. This framework identifies areas where impacts to important habitats cannot be offset and, therefore, should be avoided. The framework also provides a method to identify areas where development may proceed without significant ecological concerns, as well as areas where ecological impacts will be significant, but can be offset. Importantly, this approach provides a mechanism to quantify expenditures necessary for offsets where they are appropriate. Finally, we discuss possible incentives to encourage the use of this framework.

Methods

We next describe the scientific basis for the following recommendations: 1) which areas to avoid in Kansas, 2) how to quantify impacts that need to be offset, and 3) how to offset impacts. These recommendations form the basis for the GIS analyses and mitigation cost calculations presented in the results.

Identifying Areas Where Wind Energy Development Should be Avoided

Kansas contains many unique habitats and associated wildlife populations. Our analysis follows best practices for conservation planning (Margules and Pressey 2000) by considering multiple conservation targets designed to preserve both whole landscapes and particularly sensitive areas (Figure 4; Table 1). Specifically, we include key habitats (intact grasslands and playas), umbrella species (greater and lesser prairie-chickens), imperiled species (whooping crane), and areas of wildlife congregation for taxa that may be vulnerable to wind energy impacts (bat roosts and playas). We make use of over a dozen pre-existing spatial datasets of habitat, land cover, land use, wind speed, protected areas, roads, transmission lines, wind turbines, soils, and species occurrence. Complete descriptions of methods and sources of error in these datasets is beyond the scope of this paper, but can be found in the relevant citations. However, each dataset is of sufficient quality for use in our landscape-scale assessment.

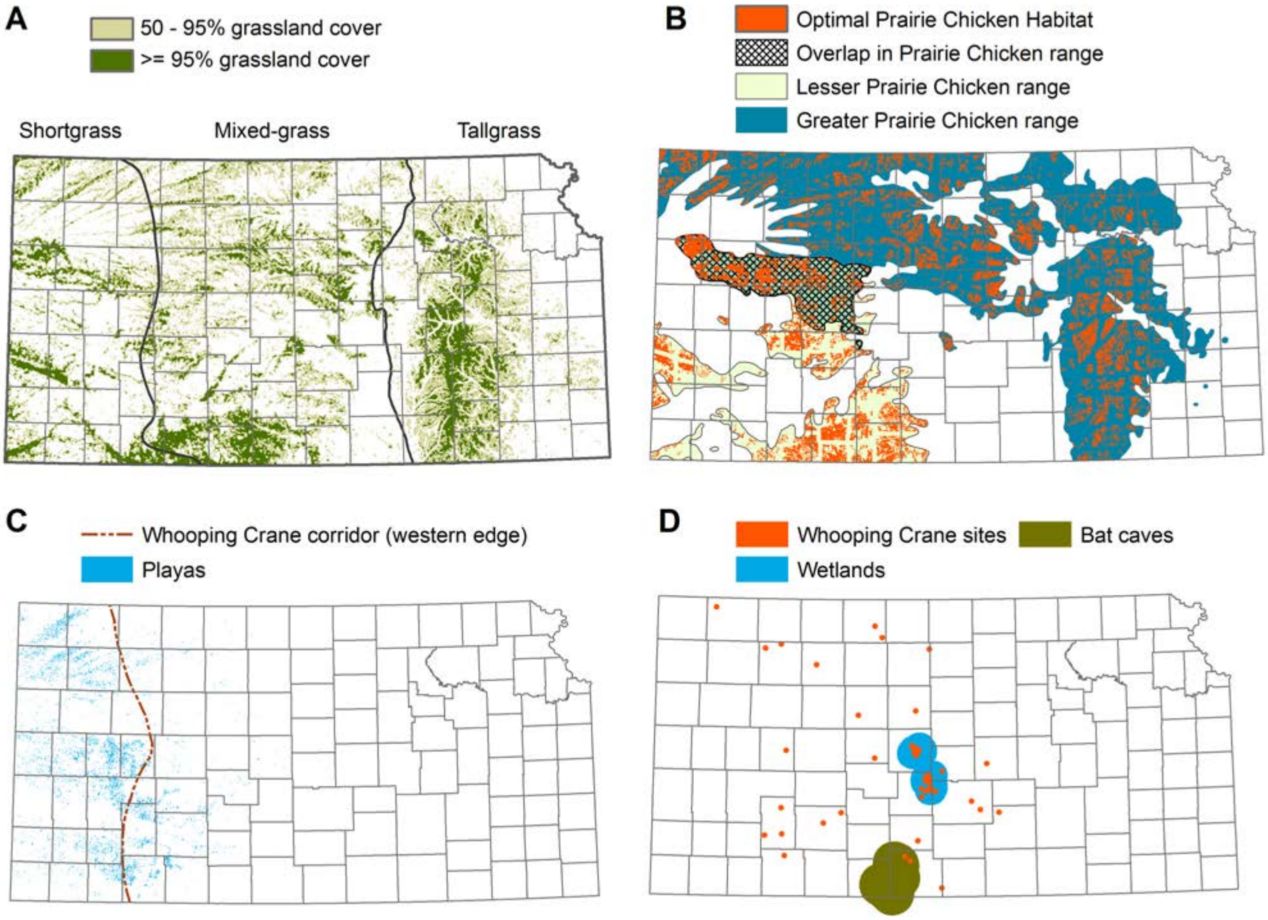


Figure 4. *Key habitats in Kansas. A) Intact grasslands. Light green for grasslands 50-95% intact, darker green for grasslands >95% intact. Blue lines show boundaries for shortgrass, mixed grass, tallgrass ecoregions. B) Prairie-chicken range and optimal habitat for greater and lesser prairie-chickens. C) Playas and the western edge of the whooping crane migration corridor. D) Repeated whooping crane stopover sites, Cheyenne Bottoms and Quivira National Wildlife Refuge with a 16 km buffer, and Red/Gypsum Hills bat roosts with a 24 km buffer.*

Tallgrass prairie is the continent's most diminished ecosystem in terms of area lost, with only 4 percent of the original tallgrass prairie area remaining (Noss et al. 1995, Samson and Knopf 1996, Steinauer and Collins 1996). Although less impacted than tallgrass prairies, short and mixed-grass prairies have also experienced significant reductions throughout the Great Plains. Estimated state and provincial declines of native mixed-grass prairie range from 30 to 99 percent, and 20 to 85 percent for shortgrass prairie (Samson and Knopf 1996). Consequently, large, intact native prairies are unique habitat types that cannot be replaced and are critical to sustaining population of several species, such as greater and lesser prairie-chicken. We recommend that areas with remaining grassland cover of greater than 95 percent intactness, as defined below, be avoided for wind energy development. Further, for the subset of these grasslands that are also considered optimal prairie-chicken habitat, we recommend that no turbines be placed within a 1.6 km surrounding buffer. This is based on 1) evidence that prairie-chicken avoid areas affected by habitat fragmentation, human activity, and the presence of vertical structures (Hagen et al. 2004, Robel et al. 2004, Pitman et al. 2005, Pruett et al. 2009a), 2) data showing reduced nest success and fecundity of prairie chickens in proximity (<2.2 km) of a wind facility (Robel 2011) , 3) other species of grouse's avoidance of wind turbines (Zeiler and Grunschachner-Berger 2009) and oil and gas development (Braun et al. 2002, Naugle et al. 2011), and 4) expert opinion (Robel 2002, Pruett et al. 2009b, Robel 2011).

To effectively delineate intact grasslands, we first identified grasslands using data layers for CRP lands and warm season grasses from the 2005 Kansas Land Cover Patterns dataset (Kansas Applied Remote Sensing 2009). We then applied a moving 800 m radius window to identify areas with remaining grassland cover exceeding 95 percent as "intact grasslands" (Figure 4A). We identified optimal prairie-chicken habitat (Multi-Entity Collaboration to Promote Lesser Prairie-Chicken Voluntary Habitat Conservation and Prioritized Management Actions 2010) by first delineating potential habitat. Native prairie and CRP grasslands (Kansas Applied Remote Sensing 2009) within the known prairie-chicken range with greater than 50 percent grassland cover were considered potential habitat. Potential habitat was then smoothed using a 90 m x 90 m moving window. The following areas (Multi-Entity Collaboration to Promote Lesser Prairie-Chicken Voluntary Habitat Conservation and Prioritized Management Actions 2010) were excluded from potential habitat due to existing impacts: 1) primary and secondary roads with a 2,377 m buffer; 2) wind turbines and urban areas with a 1,600 m buffer; 3) oil and gas wells with a 564 m buffer; 4) electric transmission lines greater than or equal to 345 kv with a 500 m buffer; and 5) woodlands and a 161 m buffer. We then removed patches smaller than 518 ha and the remaining land was considered optimal prairie-chicken habitat (Figure 4B). The subset of this optimal prairie chicken habitat that occurs on >95 percent intact grasslands should be avoided by wind development.

In addition to the state's intact grasslands, there are several important areas of wildlife concentration in Kansas. Cheyenne Bottoms, the largest marsh complex in the interior United States, and Quivira National Wildlife Refuge together comprise one of the most important shorebird migration stopover sites in the Western Hemisphere (Skagen and Knopf 1994, Western Hemisphere Shorebird Reserve Network 2009, Ramsar Convention on Wetlands 2011). Spring surveys indicate that up to 45 percent of the North American shorebird population may utilize these wetlands during northward migration in some years (Western Hemisphere Shorebird Reserve Network 2009, Ramsar Convention on Wetlands 2011). Because the legal boundaries for these sites do not include adjacent areas of ecological importance, we recommend a buffer of 16 km around Cheyenne Bottoms and Quivira National Wildlife Refuge (Figure 4D). This buffer also addresses the fact that these two large wetlands and closely associated uplands are frequently used by whooping cranes and other species of concern. Whooping cranes, a federally listed species with approximately 380 individuals remaining (Glick 2005, U.S. Fish and Wildlife Service 2011), depend on the Cheyenne Bottoms-Quivira wetland complex for survival during migration. Whooping cranes may be susceptible to collisions with turbines when landing, taking off, and travelling to foraging sites (U.S. Fish and Wildlife Service Regions 2 and 6 2009).

The U.S. Fish & Wildlife Service (FWS) has empirically defined a whooping crane migration corridor as the boundary within which 95 percent of all whooping crane stopover sightings have occurred. Areas with repeated whooping crane sightings represent the best empirically-based approach to predicting future use of sites by the species. Whooping cranes may be at risk of turbine collisions when ascending or descending from migration, or when making low flights from roost sites to foraging areas, which often extend for up to 3.2 km (U.S. Fish and Wildlife Service Regions 2 and 6 2009). To address this concern, we recommend that areas within 3.2 km of repeated whooping crane stopover sites be avoided by wind energy development (Figure 4D).

In central and western Kansas, migratory birds rely on seasonal, shallow, clay-lined lakes, referred to as playas (Playa Lakes Joint Venture 2011). Playas differ in size, connectivity, and their surrounding land cover (e.g., grassland versus cropland). A recent assessment of playas in Kansas suggests that relatively few of the 22,000 playas in Kansas likely function at a very high level and that these playas should be the top priority for conservation (M. McLachlan, PLJV, personal communication). We recommend that playas of “very high quality” within the whooping crane migration corridor be avoided for wind energy development within 800 m, because whooping cranes are likely to avoid playas within 800 m of a turbine (U.S. Fish and Wildlife Service Regions 2 and 6 2009). In general, playas provide important habitat for a wide range of birds in addition to whooping cranes (including migratory birds covered under the Migratory Bird Act). Therefore, we recommend that playas of very high quality outside of the whooping crane migration corridor be avoided within 400 m (Figure 4C) based on evidence that: 1) Anseriformes and Charadriiformes experience declines in abundance in proximity to wind facilities (Stewart et al. 2007); 2) European golden plovers and northern lapwings were displaced by as much as 600 m at a wind facility in Denmark (Pedersen and Poulsen 1991); and 3) Several European studies found up to a 95 percent reduction in birds up to 250-500 m away from wind turbines (Winkelman 1995).

Bats, especially migratory tree-roosting species, have exhibited high mortality rates associated with wind turbines (Arnett et al. 2008), perhaps because bats are attracted to wind turbines (Horn et al. 2008, Cryan and Barclay 2009) and bats can be killed by the pressure drop associated with wind turbines even without direct strikes from turbine blades (Baerwald et al. 2008). In general, little information is available regarding the geographic distribution of bat roosting, foraging, and migration areas. However, a cluster of caves in the Red/Gypsum Hills are known to provide important habitats for bats (Prendergast et al. 2010). Bats have been shown to forage out to 24 km from roosting sites (Hayward 1970, Kansas Biological Survey 2011). Pending additional research, we therefore recommend an avoidance buffer of 24 km surrounding known bat concentration sites in south-central Kansas (Figure 4D).

Finally, any area identified by the FWS or the Kansas Department of Wildlife and Parks as containing threatened and endangered species habitat or occurrences should be avoided for wind energy development. Each project area should be assessed in consultation with these agencies.

Quantifying Impacts that Need to be Offset

Among the sensitive habitats described above, development and corresponding compensatory mitigation would be allowed only for impacts to grasslands and prairie-chicken habitat that is 50–95 percent intact and for playas of less than very high quality (Table 2). Other sensitive habitats described previously (Cheyenne Bottoms/Quivira National Wildlife Refuge, Red/Gypsum Hills bat caves, and repeat whooping crane stopover sites) should be avoided entirely. Therefore, offsets need not be calculated for them.

We calculate the area impacted for each habitat type by estimating the ecological footprint of each turbine. The ecological footprint differs among species and habitat types, due to differences in species’ turbine avoidance behavior and direct mortality vulnerability. As discussed above, we use three distances from turbines to calculate ecological footprints. For impacts to intact grasslands and greater or lesser prairie-chicken habitat, the ecological footprint encompasses a 1.6 km radius from wind turbines (Braun et al. 2002, Robel 2002, Hagen et al.

2004, Robel et al. 2004, Pitman et al. 2005, Pruett et al. 2009a, Pruett et al. 2009b, Zeiler and Grunschachner-Berger 2009, Naugle et al. 2011, Robel 2011). For impacts to playas outside the whooping crane migration corridor, a 400 m radius from wind turbines represents the ecological footprint (Pedersen and Poulsen 1991, Winkelman 1995, Stewart et al. 2007). For impacts to playas within the whooping crane migration corridor, the ecological footprint includes an 800 m radius from turbines (U.S. Fish and Wildlife Service Regions 2 and 6 2009).

Methods for Quantifying the Amount of Offset Needed

Under existing policies, habitat impacts are commonly offset according to “replacement ratios” that specify how many habitat units must be replaced or protected for each unit impacted. However, replacement ratios are generally too inflexible to address the ecological context for impacts and offsets, and common alternatives are too subjective (McKenney and Kiesecker 2010). The accounting method we propose seeks a more repeatable and transparent approach.

An offset’s contribution to no-net-loss goals depends on: 1) additionality (defined as an offset’s new contribution to conservation, in addition to existing values); 2) the probability of success (defined as the likelihood that offset actions will deliver expected conservation benefits); and 3) time lag to conservation maturity (evaluated as the length of time required for offset actions to replace lost habitat values; e.g. time to maturity for ecological restoration). Note that our framework can be applied to both habitat protection and restoration efforts. When offsets restore degraded ecosystems, they provide new contributions to conservation over time as the offset reaches maturity. Habitat preservation also delivers added conservation value when, taking into account real-world conditions and threats, such preservation reduces an expected rate of loss. For example, protecting a 1,000-ha grassland that was experiencing conversion to cropland at an average rate of 1 percent per year would deliver a new contribution to conservation of 10 hectares per year (1 percent of 1,000 ha). Such “background” rates of loss can be estimated using a range of threat assessment approaches, e.g. (Pocewicz et al. 2008, Copeland et al. 2009, Doherty et al. 2011).

Intact Grasslands

In order to conserve intact grasslands, offset projects should provide benefits equivalent to the area of grassland impacted by the ecological footprint of the project, which extends 1.6 km from each turbine. Compensatory mitigation should target preservation of large, intact grasslands that have 95 percent or greater grass cover (Figure 4A). Offsets containing similar ecological values, i.e. “in-kind offsets,” should be given preference. For example, impacts to short-grass habitats should be offset in a short-grass ecosystem (Figure 4A).

The scarcity of large intact prairie means that preserving the remaining occurrences, which are still at risk of conversion, is generally the top priority for conservation of grassland species (Steuter et al. 2003). Generally, restoration of native prairie is more expensive and less likely to provide diverse native habitat than protecting existing at-risk prairie with conservation easements. Conservation easements are the primary tool for preventing conversion of intact prairie by restricting future development rights in perpetuity. Common prohibitions in conservation easements include residential and commercial development, energy development and extraction, surface mining, and soil disturbance such as plowing. The per-ha value of a conservation easement is established by standard appraisal.

Targeting conservation easements towards existing prairie that is at risk of conversion can increase the amount of habitat remaining over time, compared to a scenario in which habitat losses continues unabated. Quantifying the “additional” benefit of prairie protection requires calculating the background rate of loss that is expected to occur in the absence of protection. We identify the rates of conversion, and the areas at risk for conversion, for three types of development in Kansas: wind energy development, exurban development, and cultivation.

Wind Development: We examined 32 proposed wind energy projects in Kansas (Ventyx Corporation 2012) to characterize areas with significant wind development potential. Over 90 percent of proposed new generating capacity is located on lands with wind power class (WPC) of 3 or greater (measured by the NREL 50 meter wind power class data (National Renewable Energy Lab 2008)), with a MW-weighted average WPC of 4.1 for all proposed new generation. For these projects, the farthest distance to transmission lines of 115 kV or greater was 25.5 km. We therefore considered areas with a WPC 3 and higher that are located within 25.5 km of current and proposed transmission lines of 115 kv or greater to have significant potential for wind energy development. We then excluded areas protected from wind development (Conservation Biology Institute 2010a) and urban areas in which wind development is not feasible (Homer et al. 2007, Multi-Resolution Land Characteristics Consortium 2010) (Figure 5A). In the future, new transmission lines could increase this area, indicating the need to update estimates of background rates of loss as new information becomes available.

Figure 5. Ongoing development in Kansas. *A) Areas of potential wind development, B) Areas of potential exurban development, C) Areas of potential cropland conversion.*

The DOE's "20% wind energy by 2030" report offers a scenario in which the U.S. could generate 20 percent of its electricity from wind power by 2030 (Department of Energy 2008). Under this scenario, Kansas would have 7.16 GW of nameplate capacity (peak electrical output of all turbines running at capacity). Kansas currently has 1.03 GW of nameplate wind energy capacity, suggesting that between 2010 and 2030, Kansas could acquire approximately 6.13 GW of new wind energy capacity. This is the equivalent of developing 306.5 MW of capacity per year for 20 years. New wind energy development in Kansas can, therefore, be expected to require about 7,000 ha per year. Given that 14.5 million ha of Kansas has significant potential for wind energy development, we calculate that these areas have a probability of wind development of 0.05 percent per year.

Exurban Development: We used the Kansas Natural Resources Conservation Service (NRCS) map of areas susceptible to urban expansion (Natural Resources Conservation Service 2010b) and the National Land Cover Database (NLCD) 1992–2001 Land Cover Change Retrofit product (Fry et al. 2009, Multi-Resolution Land Characteristics Consortium 2010) to estimate the rate of residential development. The NRCS estimates that the following areas in Kansas are at risk of exurban development: 1) within 48 km of metropolitan areas greater than 19,000 people;

2) within 24 km of other metropolitan areas; and 3) within 8 km of federal reservoirs. After excluding areas already protected from development and those already converted to urban uses, we estimate that there are 6.7 million ha at risk of conversion to exurban development in Kansas (Figure 5B). The NLCD change product allows us to quantify the land area that changed from other land cover categories to the "developed" category between 1992 and 2001. Within the areas we identified to be at risk of exurban development, the NLCD change product estimates that 12,500 ha were urbanized between 1992 and 2001. This is a rate of 1,400 ha per year, or 0.02 percent of the susceptible area per year.

Cropland Conversion: We used USDA's land capability class (Natural Resources Conservation Service 2010d) to estimate the areas at risk of conversion to cropland. USDA categorizes land into eight capability classes, with classes 1-4 described as suitable for cropland, and classes 5-8 described as unsuitable for cropland. We identified class 1-4 lands in the state, excluding areas that have already been converted to cropland (based on 2006-2008 NASS data (National Agricultural Statistics Service 2010)), lands that are protected from conversion (Conservation Biology Institute 2010a), and lands that have been developed for residential and commercial uses (based on NLCD "developed" layers (Homer et al. 2007, Multi-Resolution Land Characteristics Consortium 2010)). Based on this analysis, there are 5.2 million ha of potential cropland in Kansas that have not yet been cropped (Figure 6C). We used the NASS 2009 cropland data (National Agricultural Statistics Service 2010) to calculate the amount of new land converted. Because some lands are left fallow each year, comprehensively identifying existing cropland requires data from multiple years. We considered land that was cropped in any of the years 2006-2008 as existing cropland and only additional land cropped in 2009 as new cropland. This analysis suggests that approximately 200,000 ha was newly converted to cropland in Kansas in 2009, equivalent to 4.2 percent of the susceptible area per year.

Impacts from these three threat categories are cumulative, such that the total risk of development can be estimated by adding the risk of conversion from each category. However, our estimates suggest that the threat of conversion to cropland is two orders of magnitude higher than the threat of conversion to wind energy production or exurban development. Therefore, mitigation funds for protection should be targeted toward grasslands that are greater than 95 percent intact and that fall within the areas identified to be at risk of conversion to cropland.

Prairie-chickens

We recommend that impacts to optimal prairie-chicken habitat be offset through habitat restoration activities on existing intact grasslands. The greater prairie-chicken occurs in the northern and eastern portions of Kansas, and the lesser prairie-chicken occurs in the southern and western portions of the state, with some overlap in their ranges (Figure 4B). Preference should be given to in-kind offsets, so that impacts to greater prairie-chicken habitat should be offset with restoration of greater prairie-chicken habitat and impacts to lesser prairie-chicken habitat should be offset with restoration of lesser prairie-chicken habitat. Because lesser prairie-chickens are of higher conservation concern, we recommend that impacts within the area where the two species overlap be offset with restoration of lesser prairie-chicken habitat.

Altered fire return intervals, invasive species, and woody encroachment are considered major detriments to habitat quality for prairie-chickens (Robbins et al. 2002). We propose using mitigation funding to abate these threats on otherwise suitable prairie-chicken habitat. Targeting these restoration efforts to lands protected with conservation easements would ensure that the restoration efforts are not undone by future conversion of the restored lands. We estimated grassland restoration costs based on costs for tree removal and fire management, although invasive species control, range improvement, and other restoration activities may also be desirable to consider.

The ideal fire return interval for prairie chickens varies across tallgrass, mixed grass and short grass prairies. Ideal fire management for prairie-chickens in tallgrass prairie consists of prescribed burning approximately once every 3 years (McKee et al. 1998). This fire regime is consistent with pre-settlement fire regimes and is favorable to many grassland-dependent birds (Powell 2008). In much of Kansas' tallgrass prairie, frequent burning adversely affects habitat structure resulting in reduced nesting success for greater prairie-chickens (Robbins et al. 2002, McNew jr. 2010); thus, incentives for landowners to reduce fire frequency to once every 3 years are needed in these areas. In much of the rest of the state, fires are too infrequent, allowing woody plants to degrade habitat, thus incentives are needed to increase fire frequency. In mixed-grass prairie, a fire-return-interval of approximately once every 5 years is recommended; in shortgrass prairie, the ideal fire management consists of prescribed burning approximately once every 7 years (S.D. Fuhlendorf, personal communication). Recommendations presented here are of a general nature and specific management practices that would maximize habitat benefits would need to be tailored to specific properties.

Playas

Playa conservation typically requires acquisition (fee title or perpetual conservation easements) of playas and restoration of immediately adjacent grasslands. Most remaining playas in Kansas are in tilled agricultural fields, such that playa conservation requires restoring grasses and forbs around playas to restore hydrological function, reduce sedimentation, and limit fertilizer and pesticide runoff (Rocky Mountain Bird Observatory 2008, Skagen et al. 2008). Grassland restoration ratios are commonly established at three ha of grassland for each surface ha of the playa, based on the amount of grassland thought to be necessary to restore playa hydrological and ecological functions. Thus, for every hectare of high quality playa impacted, 1 ha of playa plus 3 ha of surrounding land (4 ha total) would be permanently protected, and the 3 ha surrounding the playa would be planted to native grasses and forbs. Because native grass and forb plantings constitute restoration of that playa, we consider all hectares of restored playa to be "additional." Funds generated from impacted playa habitats should be used to protect playas that are of high or very high quality and are within playa complexes. Priority should be given to playas with documented whooping crane use.

Mitigation Costs for Existing Wind Development

We obtained data on the spatial location of 5,792 existing wind turbines in Kansas (Ventyx Corporation 2012). We determined whether each turbine is located in an area where we recommend avoiding wind development. For the turbines outside of avoidance areas, we identified clusters of turbines (i.e. turbines whose ecological footprints overlap) and calculated mitigation costs, if any, for each cluster.

Results

Within Kansas there are approximately 14.5 million ha suitable for wind energy development (based on wind power class, distance to current and proposed transmission, and excluding urban and protected areas). If all of these areas were developed for wind energy, they could support approximately 668 GW of electrical capacity (WPC 3: 6,622,300 ha, 285 GW; WPC 4: 6,787,900 ha, 326 GW; WPC 5: 1,103,200 ha, 57 GW). After removing the wildlife avoidance areas that we identified, approximately 10.3 million ha remain as suitable for wind energy development. This “open” area is capable of yielding approximately 478 GW of electrical capacity (WPC 3: 4,478,500 ha, 193 GW; WPC 4: 5,012,700 ha, 241 GW; WPC 5: 857,300 ha, 45 GW). Even after removing both the wildlife avoidance areas and all areas where mitigation payments would be required, there are approximately 2.7 million ha suitable for wind energy development where no mitigation payments would be required (13 percent of the state). This area would be capable of supporting approximately 125 GW of electrical capacity (WPC 3: 1,366,000 ha, 59 GW; WPC 4: 1,193,700 ha, 57 GW; WPC 5: 175,500 ha, 9 GW). Note that the DOE goal for wind energy in Kansas is 7.16 GW, so even if all wind development was restricted to lands where no mitigation payment is needed, the wind capacity on these lands is 1,648 percent higher than (over 17 times higher than) the DOE goal.

Identifying Areas Where Wind Energy Development Should Be Avoided

Avoiding Cheyenne Bottoms and Quivira National Wildlife Refuge and lands within a 16 km radius of each marsh removes 264,900 ha of economically viable wind from potential production. Avoiding all areas within 800 m of repeated whooping crane stopover sites removes 95,600 ha of economically viable wind from potential production. Avoiding very high quality playas within the whooping crane corridor by 800 m, removes 2,300 ha of economically viable wind from potential production. Avoiding very high quality playas outside the whooping crane migration corridor by 400 m removes another 5,000 ha of economically viable wind resource from potential production. Avoiding wind energy development within a 24 km radius of bat roosts and hibernacula in the Kansas Red/Gypsum Hills removes 216,300 ha of economically viable wind potential from production. Although this is a large area, only 50,963 ha of this area requires avoidance due to bats alone – the rest of it would need to be avoided due to intact grasslands or whooping crane stopover sites, regardless of bats. Avoiding grasslands that are 95 percent intact, plus a 1.6 km buffer around intact grasslands that overlap with optimal prairie chicken habitat, removes 3,821,000 ha of economically viable wind resource from potential production.

Quantifying Impacts that need to be Offset

We identified 7.6 million ha outside of avoidance areas where development could proceed but where sensitive resources requiring compensatory mitigation exist (Figure 7). These sensitive resources are: 1) areas with 50-95 percent intact grasslands, 2) optimal prairie-chicken habitat, and 3) playas of less than very high quality. There are 7,203,000 ha of economically viable wind resource on intact grasslands that would require mitigation payments. This includes 1,660,900 ha of economically viable wind resources that would also require compensatory mitigation for prairie-chickens. For impacts to playas outside of the whooping crane migration corridor, there are 540,600 ha of economically viable wind where development would require compensatory mitigation. For impacts to playas inside of the whooping crane migration corridor, there are 278,000 ha of economically viable wind resource where development would require compensatory mitigation.

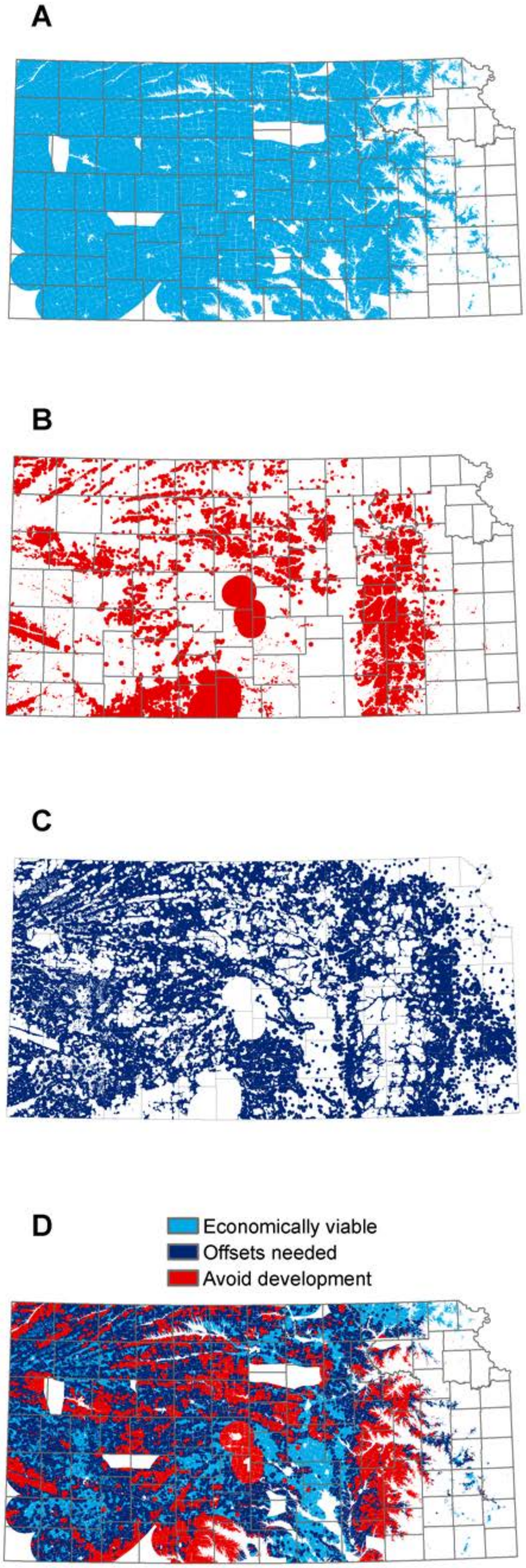


Figure 7. Avoidance and mitigation areas in Kansas. *A) areas of potential wind development, B) avoidance areas, C) areas requiring mitigation, and D) all three layers, with avoidance and mitigation areas superimposed over areas of potential wind development; remaining light blue areas indicate areas suitable for wind development where mitigation would not be required.*

Quantifying Compensatory Mitigation Costs

Intact Grasslands

Mitigation costs for impacts to shortgrass, mixed-grass and tallgrass habitats would be $825, $862, and $1,432 per ha of impact, respectively. We estimate that a successful offset program would protect lands that have, on average, an annual risk of conversion of 4.2 percent. Thus, protecting 100 ha of grassland under this program would result in 84 ha of avoided conversion after 20 years. Because development impacts begin immediately, whereas the benefits of avoided conversion accrue more slowly over time, we apply a temporal discounting factor of 3 percent per year to the benefits of avoided conversion. Based on this discounting and the annual risk of conversion, we calculate the benefit of protecting 100 ha to have a net present benefit equivalent to 60 ha. This means that no net habitat loss from wind energy projects requires protection of 1.67 ha for every hectare impacted. We calculate the price of land protection via perpetual easement at $494, $516, and $858 per ha for shortgrass, mixed-grass, and tallgrass habitats, respectively (Natural Resources Conservation Service 2010a). Because 1.67 ha need to be protected for every ha that is impacted, we multiply these easement prices by 1.67 to obtain the costs for each ha of impact. Conservation easements provide legal protection for land that is already good habitat, such that no discounting for the probability of success is required.

Prairie-chickens

For prairie chicken mitigation, we calculate the costs to: 1) restore and maintain natural fire return intervals, and 2) remove and prevent woody and other plant encroachments. Restoring fire return intervals to benefit prairie-chickens could be incentivized by paying to conduct prescribed burns. We estimate that prescribed burning costs $13 per ha ($5.25 per acre, based on WHIP NRCS rates for Kansas (Natural Resources Conservation Service 2010c)). Financial endowments sufficient to generate $13 per hectare every three, five, or seven years would require an initial investment of $82, 47, and $32 per hectare, respectively, assuming an average annual interest rate of 5 percent. Note that to receive payments landowners would be required to burn at the prescribed return interval, which may be more or less frequent than current practice. An additional one-time payment of $214 per ha for brush management (average of medium and low mechanical brush management treatment costs, based on WHIP NRCS rates for Kansas) (Natural Resources Conservation Service 2010c) should be added to the prescribed fire endowment to complete the mitigation offset.

Summing the costs of brush removal and the prescribed fire endowment, the total cost per ha is $296 for tallgrass prairie, $261 for mixed grass, and $246 for short grass. Habitat benefits from brush removal and prescribed fire occur consistently and rapidly after implementation, such that no temporal or probability of success discounting is required for these offset activities.

Playas

Offsets for impacts to playas will require restoring native grasses and forbs around existing playas and purchasing protection rights (via fee title or perpetual conservation easements) on both the playas and surrounding restored habitat. For each hectare of playa that is impacted by the wind energy development, 4 ha would be protected and 3 ha of these protected lands would be restored. Planting native grasses and forbs costs about $208 per ha, so that the 3 ha of required restoration for each ha of impact can be accomplished for $624. Average fee title prices in areas with high and very high quality playa lakes are $3,062 per ha ($1,239 per acre). Therefore, each hectare of high quality playa would require $12,872 of mitigation payments, including the restoration and protection of the grassland buffer. Based on their lower ecological function (i.e.

supporting fewer migratory birds on average across years), we assess that medium quality lakes require only 66 percent of the per-hectare mitigation costs for high quality lakes. For the same reasons, low quality playa lakes only require mitigation if they are a part of a multi-lake complex, and then only at 33 percent of the per-hectare mitigation cost. The benefits of replacing cropland with grassland are consistently realized quickly, such that no temporal or probability of success discounting is required.

Mitigation Costs for Existing Wind Development

For existing wind turbines, 15 percent are located in areas that we recommend be avoided and 19 percent are located in areas that would require no mitigation payments. Omitting turbines that are in avoidance areas, we found that the remaining turbines occurred in 128 clusters, where clusters contained turbines with overlapping ecological footprints. Of these, 21 clusters would not require any mitigation payments. For the remaining 107 clusters that did require offsets, the average per turbine cost of mitigation was $32 thousand dollars and the median cost was $23 thousand dollars. The cost of wind turbine development is roughly $4 million dollars per turbine, so the median cost of mitigation is roughly equal to 0.57 percent of development costs. Because the cost of mitigation varies greatly depending on project and turbine siting (Figure 8), developers can reduce mitigation costs by siting future development in areas with low mitigation costs.

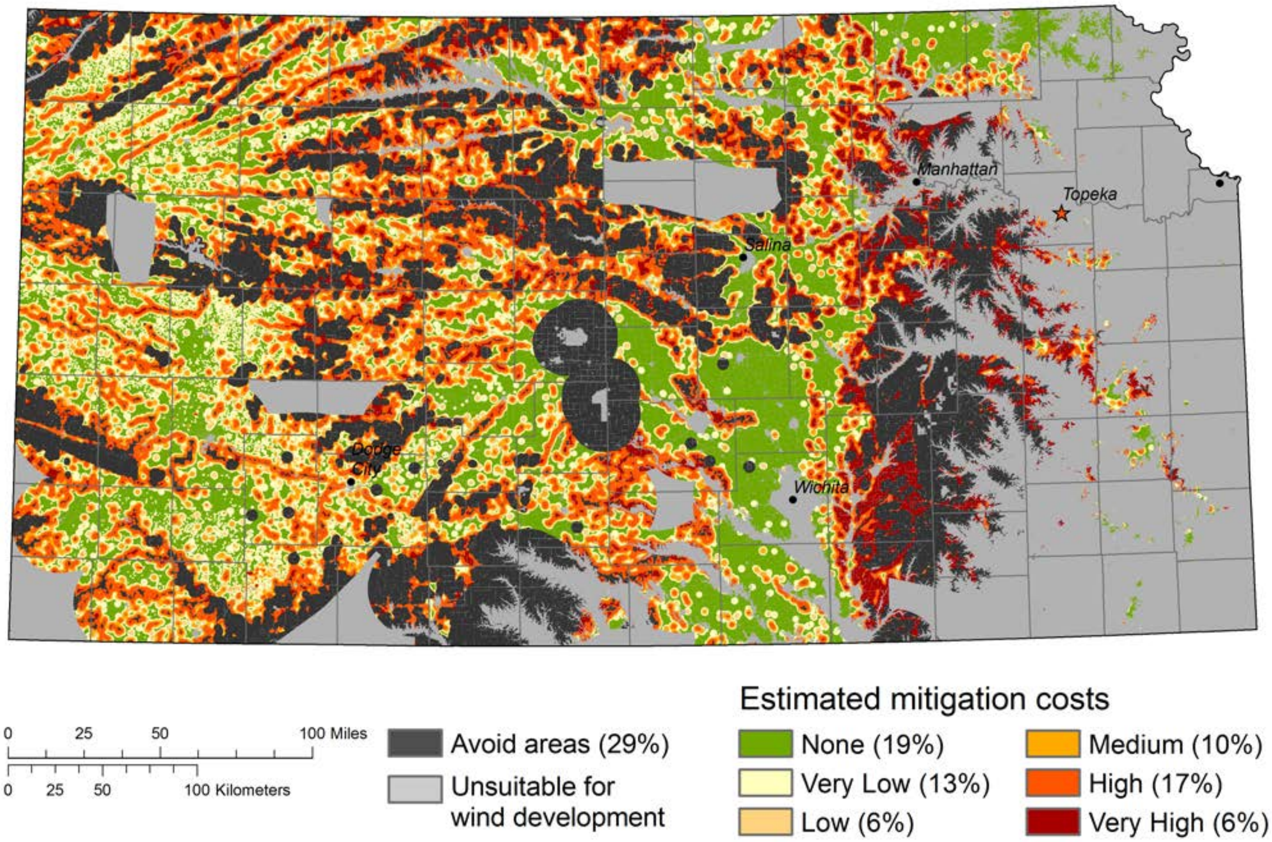


Figure 8. Relative mitigation cost surface for wind development in Kansas. *Relative mitigation costs were calculated only for areas suitable for wind outside of recommended avoidance areas. The percent of the total area suitable for wind is shown in parentheses for each category.*

Discussion

Our results are intended to facilitate ecologically appropriate siting of wind energy development, while ensuring that key ecological targets are conserved. The increase in wind energy production forecasted by DOE for Kansas may be compatible with wildlife needs, if commercial wind energy facilities are properly sited. For example, many of the tilled agricultural areas within the state represent low-quality habitats incapable of supporting populations of imperiled species or natural plant or animal communities. New wind energy development would likely have substantially less potential to impact wildlife if sited in these areas (Kiesecker et al. In Press).

Our analysis indicates that a network of land-based turbines has the potential to generate 478 GW of capacity on 10.3 million ha in Kansas, even after removing areas incompatible with conservation, areas with low wind speeds, and areas far away from transmission lines. This represents 6,674 percent of the DOE projection of 7.16 GW for Kansas needed to generate 20 percent electricity from wind by 2030. The fact that 85 percent of existing wind turbines are sited outside of areas incompatible with conservation further supports our argument that it is possible to develop wind energy without compromising conservation goals. Even after removal of all lands that would require compensatory mitigation for impact, there is still an ample land base of 2.7 million ha that can more than meet the DOE projections. Even if this land base were restricted to the highest WPC (i.e. WPC 5 in Kansas), this leaves 175,500 ha capable of siting 9 GW of wind, more than enough to meet the DOE goal.

Our approach describes ecologically important areas in Kansas where wind energy development impacts could not be offset. Our criteria for avoidance by wind energy development are based on the best available science regarding known high priority conservation targets in Kansas. Our analysis follows best practices for conservation planning (Margules and Pressey 2000), by considering multiple conservation targets designed to preserve both whole landscapes and particularly sensitive areas, including: key habitats (intact grasslands and playas); umbrella species (greater and lesser prairie-chickens); particularly imperiled species (whooping crane); and areas of wildlife congregation for taxa that may be particularly vulnerable to wind energy impacts (bat roosts and playas). We recognize that other approaches are possible and that better data would allow refinement of these avoidance areas, but we suggest that any comprehensive conservation planning approach would yield qualitatively similar conclusions about the location of the most sensitive habitats in Kansas.

Our approach to mitigation estimates the costs that would be required to offset the impacts of a particular project to achieve no net loss of habitats. In order to calculate these costs, we identified conservation strategies for application of mitigation dollars. Our strategies seek to provide high returns on investment, such as conservation easements and restoration practices that can be implemented by landowners with modest conservation payments. By pooling funds to achieve economies of scale and by facilitating strategic application of these funds, conservation outcomes are maximized, while mitigation costs for developers are reduced. The conservation practices and the spatial analyses used to select areas where practices would best be applied are intended to aid the strategic use of mitigation funds; they are not intended to constrain innovation or other opportunistic use of mitigation funds. Thus, our analyses describe minimum conservation benefits that can be achieved with the specified mitigation funds; strategic and innovative application of these funds could result in conservation benefits beyond those identified here.

Costs for mitigation actions described here could often be incorporated into the business costs of developing wind energy, given that the overall investment for a commercial wind energy facility is commonly hundreds of millions of dollars. We find that the median cost of mitigation is roughly half a percent of per turbine development costs. More importantly, wind energy developers can use the results of this analysis to proactively reduce the need for mitigation by siting projects in areas that would not warrant mitigation. This could substantially reduce the cost of mitigation across projects. For example, although we recognize that the costs per ha for playa impacts are noticeably higher than for impacts to intact grasslands and prairie-chickens, they are also easier to avoid because 1) the ecological footprints of wind turbines are smaller for playa impacts, 2) playas comprise a small percentage of the land area in Kansas (only 0.15 percent), and 3) playas are relatively small (median playa size is 0.67 ha), often allowing impacts to playas to be avoided through micro-siting of individual turbines.

In addition to avoiding and offsetting impacts, operational mitigation may be employed to reduce direct mortality impacts to some susceptible bats and birds. Ongoing research is evaluating the possibility of operational mitigation strategies to minimize mortality by feathering turbine blades (which stops the blades from spinning) at critical periods (Baerwald et al. 2009, Arnett et al. 2010). Bat fatalities occur during predictable times: at night, mostly during fall migration, and when wind speeds are below 6 meters per second (Arnett et al. 2008). Bat fatalities often coincide with particular weather conditions, e.g. when bats migrate with storm fronts. This suggests that radar and other remote sensing technology systems could be developed to detect bat or bird migrations in real time, allowing blades to be feathered as needed to minimize fatalities.

Our research illustrates that it is presently possible to implement a landscape-scale system that guides wind energy development to avoid, minimize, and offset ecological impacts. The approach outlined here, updated with new information as it becomes available, could be used to award "Green Certification" to projects that follow this protocol (Figure 9). Certification against the guidelines presented in this paper may help to expand and sustain the wind industry by facilitating the completion of individual projects sited to avoid sensitive areas and protecting the wind industry's reputation as an ecologically friendly source of electricity. Endorsement of a Green Certification process by electric utilities and financial backers would provide incentives for wind developers to seek certification for new facilities.

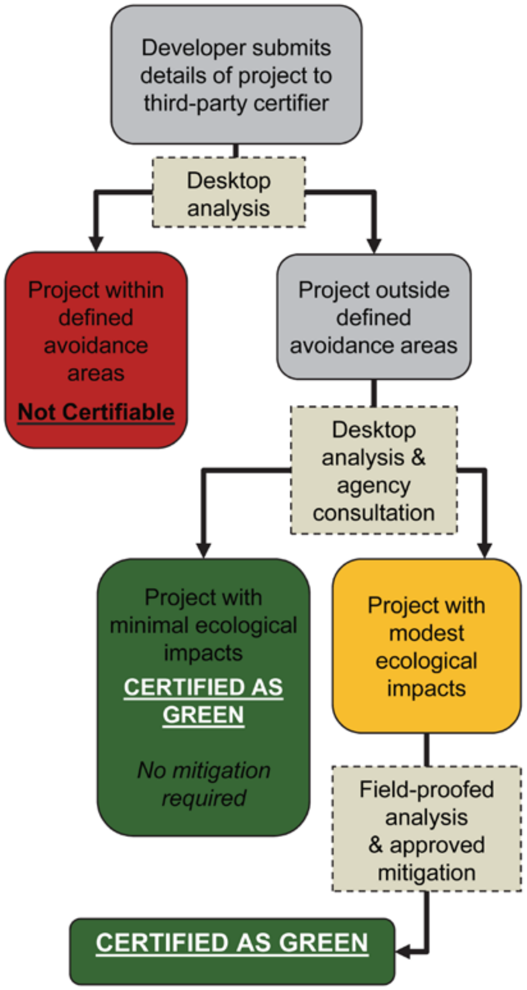


Figure 9. Schematic showing proposed steps of a Green Certification process for wind energy development.

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