Respect Big Bend

Development by Design in West Texas:

Mitigating Energy Sprawl Through Cooperative Landscape Planning

Technical Report • May 2021

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Foreword

The Cynthia and George Mitchell Foundation (CGMF) is a philanthropic organization focused on fundamental change in complex systems critical to achieving a sustainable society. The foundation's programs promote clean energy, land protection, water conservation and shale sustainability. These interrelated resource issues pose challenging inconsistencies and demand trade-offs in a rigorous analysis of optimal energy systems. Is the relatively poor energy density (the unit of land needed to produce a unit of energy) of renewables worth the carbon savings from displacing coal or natural gas? Are the water savings from wind and solar development worth the loss of land and soil resources? How do you balance the jobs created today by the shale industry with the threat of climate change tomorrow? These questions are a good reminder that there are no impact-free energy resources.

I believe there is a better way for energy development to happen – in West Texas and beyond. It can be done in a way that engages and protects communities and natural resources.

The hypothesis we investigated in this project has its origins in a CGMF collaboration with the the Aspen Institute's Energy and Environment Program. Together we convened subject matter experts to develop recommendations to improve the regulatory context for managing risk in the governance of oil and gas development from shale resources, particularly through enhanced stakeholder engagement practices. Over the course of the Aspen Institute collaboration, growing renewables and shale development in the Big Bend region afforded us a real world opportunity to test the new governance approach.

Besides growing up in the Permian Basin, the Big Bend holds profound personal meaning for me. I grew concerned about the impacts of development on the habitat and beauty of the area while reading news articles about major new renewables projects and shale discoveries slated for development. Understanding the potential impact on landowners, scarce water resources and small communities, we set out on a project to engage stakeholders and empower local communities to conserve what matters most to them, whatever that might be.

This is how Respect Big Bend came to be. The goals are simple: protect, mitigate, restore and set a precedent, creating a model for energy development that transcends the status quo.

- Where energy development is minimal, before many leases have been signed, we would work to establish a process that gives landowners and community members a voice in protecting their communities, land and water resources.
- Where leases have already been signed, we would work with landowners and the energy industry to mitigate the impact of energy development on the communities, land and water of the region.
- Where energy development has already taken hold, we would work with landowners and the energy industry – both fossil and renewables developers – to establish high

standards for the restoration and enhancement of communities and land impacted by energy development.
- Last, and maybe most important for the future of Texas and other undeveloped areas, we would document our effort, both achievements and setbacks, so that others will benefit from what we learn in the greater Big Bend region.

The major outputs from the Respect Big Bend program include novel ecological asset mapping techniques and energy forecasts, values-based recommendations from local stakeholders and a framework for encouraging low-impact energy development. Together these outputs clarify and improve the chances for responsible energy development that protects regional ecosystem and cultural values today and in the future.

I am both personally and, as a representative of the Cynthia and George Mitchell Foundation, professionally delighted to have supported the Respect Big Bend project and resulting report. Taken together, these endeavors provide useful insights to those interested in continuing to improve the performance of energy development of any type anywhere, especially regarding habitat and community protection.

I thank all those involved for their valuable input throughout this process and look forward to utilizing this report as a valuable resource.

Marilu Hastings

Chief Innovation Officer, The Cynthia and George Mitchell Foundation

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1. INTRODUCTION

This project is about harnessing a regional stakeholder planning process to advance low-impact energy development that mitigates potential impacts to locally significant ecological and social-cultural assets. We forecast the growing energy demand and identify the places where that demand is likely to be met – in the form of traditional and renewable energy: oil and gas, solar and wind. This information is mapped against areas representing the ecological and social-cultural values that define the character of the Big Bend Region. When considered together, we can improve the likelihood of finding a new energy roadmap that accommodates development while ensuring the persistence of those regional values considered most evocative of the landscape that generations have called home.

Why is this necessary?

By 2050, there will be between two and three billion more people on our planet than there are today. They will all need food, housing and access to energy [1, 2]. These growing demands pose significant challenges for the natural resources needed to accommodate the expected growth in energy production. In a world seeking to decarbonize energy production, this demand would be met by increasing renewable energy sources such as solar, wind and hydropower [3–6]. Avoiding climate projections most accepted by many scientific experts will require achieving net-zero greenhouse gas emissions by mid-century, which in turn necessarily involves a transition to renewable energy.

But renewables, even with their environmental appeal, are not without their own impacts to wildlife and biodiversity [7]. Solar panels are land-intensive [8]; turbine blades from windmills strike birds and bats; hydropower development interferes with fish migration and distorts natural flood regimes; and transmission lines linking utility-scale renewable energy into our power grid fragment habitats and become conduits for the spread of non-native species [9]. Renewable installations sited without careful consideration can adversely impact significant social and cultural values, wildlife habitats and critical ecosystem services in a place.

Texas is not immune to these same development pressures. In many ways Texas is a microcosm for how these trends will play out on the global stage. Today, Texas' population is approaching 29 million people [10]. That number is predicted to surge to nearly 55 million by 2050, with most people clustered in already-dense urban centers. The attendant increase in demand for energy, food and water resources will need to be met by ecosystems that are already under stress from extended droughts, record-breaking heat waves and devastating floods [11].

Nowhere is this concern more acute than in West Texas, one of the most energy-intensive places in one of the most biologically diverse desert systems in the United States [12]. The nation's top producer of crude oil and natural gas and the leading generator of wind-powered energy in 2019, Texas is also the largest energy-consuming state in the United States. [13]. Finding solutions that balance energy development with the resident biodiversity and within expanses of unbroken open space valued by the rural and ranching communities and recreationalists alike is a challenge.

In Texas, this challenge is compounded by the fact that 95 percent of the land is privately-owned. That means that most of the energy development in the state – oil and gas, as well as renewables – also occurs on private land. Currently, decisions about where to site new facilities are made by energy companies and private landowners, with little input from other stakeholders. This process makes it extremely difficult to plan energy development that avoids negative landscape-level impacts while meeting growing energy demands.

Moreover, in Texas, there are few regulatory requirements related to siting new energy facilities on private lands. As described in ***Section 5***, oil and gas operators must obtain a drilling permit from the Railroad Commission of Texas before drilling a new well, but the permit review does not include consideration of the spatial impacts of development. No state permit is required prior to construction of a new wind farm or solar facility. As is the case for oil and gas, provisions designed to reduce the land impact of renewable energy development are included in agreements between the private landowner and the operator, either in the lease agreement or, in some cases, a surface use agreement. But those instruments are not especially relevant to impacts at the broad, landscape scale.

So, what then are the options?

One option is to reduce demand – to decouple human well-being from cheap energy. This would be done through increased efficiency and improved technologies for energy storage and transmission, which would lower pressures for massive new energy development [14]. But even the most optimistic projections of social change and energy innovation cannot slow the short-term need for still ambitious energy developments that are already part of national and regional development plans [5].

A second approach would be to object to new, specific energy projects that potentially conflict with the characteristics of those places people value. But a strategy focused on curtailing energy impacts one project at a time is costly; risks social and political resentment; and does little to resolve the energy supply gap [15].

A third course of action would be to co-design the development and delivery of energy in such a way to maintain biodiversity and other values, such as recreational opportunities or viewsheds. This is the approach proposed here. Data and modeling can be used to identify “areas of lower conservation value” for energy development and “areas of high conservation values” as zones for continued conservation, restoration, protection and preservation [16–18]. The hypothesis underlying this approach is that, by identifying low-impact places where energy development might go, one also gains leverage to secure high conservation value and “no-go” areas.

This path tackles three big and connected problems together:

1. Low-cost energy access for everyone;
2. habitat and wildlife protection in the context of new pressures for land conversion from expanding energy development; and
3. climate change projections that drive the urgent push for a more rapid transition to a decarbonized economy.

Moreover, managing each of these three problems alone, much less all together, will require engaging a diverse group of stakeholders, scientists and land use decision-makers at the same table, at the same time, in a collaborative manner.

Proactive landscape-level planning that accounts for land use constraints, supports private landowner rights and effectively manages the health of conservation values in the siting of energy infrastructure is needed to meet growing demands for energy in a low-impact, low-conflict manner. Instead, oftentimes traditional energy development planning is ad-hoc, project-by-project, and can fail to consider cumulative impacts at meaningful scales. It narrowly focuses on site-level impacts of a particular project rather than how it contributes to the cumulative negative impacts of multiple development projects taken together within a broader landscape [19]. As a result, money spent on mitigation efforts to avoid, minimize, restore or offset potential impacts often flounders in efforts to make lasting positive gains for conservation [20]. With the work presented here, **we seek to move away from piece-meal, reactive development planning and to move toward planning at early stages that proactively identifies likely impacts, minimizes avoidable conflicts and improves mitigation, restoration and conservation action.**

Developers or conservation practitioners seek to reduce development impacts through application of the mitigation hierarchy: avoid, minimize, restore and offset. To **avoid** impacts on conservation values, measures are taken to prevent impacts from the outset, such as through careful spatial or temporal placement of development footprints or impacts. To **minimize**, measures are taken to reduce the duration, intensity and/or extent of impacts that cannot be completely avoided. With **restoration**, measures are taken to rehabilitate degraded ecosystems after impacts that cannot be completely avoided and/or minimized have occurred. Finally, to **offset** impacts, measures are taken to compensate for any residual adverse impacts that cannot be avoided, minimized and/or restored. These actions typically occur away from where the development footprint/impacts have occurred. Offsets can take the form of positive management interventions such as restoration of degraded habitat or protecting areas where loss of conservation values is imminent. Attempts to meet conservation goals through the application of the mitigation hierarchy have gained wide traction with increased development of public policy, lending standards and corporate policy.

To advance this process in West Texas, the Respect Big Bend team together with the Stakeholder Advisory Group drew on decades of conservation planning experience with a history of achieving on-the-ground conservation results that also benefit people. Following The Nature Conservancy's Development by Design framework, our team embarked on this effort to help decision-makers avoid and mitigate potential conflicts between development objectives and conservation priorities. The following steps help to achieve better outcomes for people and nature:

1. **Develop a landscape conservation vision** that asks: what are the values people want to maintain and thus where are the highest priority areas for conservation action in the landscape?
2. **Project future potential energy development**. Where is future oil and gas, solar and wind development likely to expand into?
3. **Clarify the impacts and tradeoffs**. How might conservation values (i.e., biodiversity, social, cultural values) be impacted by potential future energy development?
4. What **mitigation actions** can be deployed to efficiently and effectively mitigate potential impacts?
5. What **policy, legal and educational tools and resources** are available to mitigate potential impacts? What can be learned from government agencies that lease public land for energy development?

Who We Are

The Respect Big Bend Coalition includes Big Bend organizations and landowners, organizations and companies with projects and operations in West Texas and scientific experts. We share a commitment to the future of far West Texas. Our mission is to inspire and empower all stakeholders to conserve the unique resources and protect the iconic communities of the Big Bend Region of Texas while developing energy responsibly.

We are dedicated to collaborating with communities and landowners to maximize the benefits of responsible energy development while sustaining the communities, land, water, and wildlife of the Big Bend region.

The coalition was established by the Cynthia and George Mitchell Foundation, a Texas foundation that supports projects at the nexus of environmental protection, social equity, and economic vibrancy.

To learn more about the Respect Big Bend Coalition visit RespectBigBend.org.

2. THE RESPECT BIG BEND PROJECT & STUDY AREA

The 18-county region of the Respect Big Bend project's study area in west Texas spans 28 million acres (113,190 km^2) of nearly continuous Chihuahuan Desert scrub and grasslands. These desert types climb into the foothills of the Guadalupe, Davis and Chisos mountains, the United States and Texas portions of which are delineated by the Rio Grande along its western and southern borders.

The region comprises an area larger than the state of Virginia and is one of the least densely populated regions in Texas, averaging less than 1 person per acre. Several of Texas' largest parcels of public lands in the state can be found in the project area – among them Big Bend Ranch State Park (311,040 acres) and Big Bend National Park (801,280 acres).

Emblems of a quintessentially western American landscape - cowboys, ranchers, and explorers – still loom large here and belie the region's central role on the global energy stage. It is within this layered story that the Respect Big Bend Coalition finds itself.

The focus of this report is on the Tri-County Region of Jeff Davis, Brewster and Presidio counties. The report describes the natural resources and potential energy trajectories of the 18-county Respect Big Bend (RBB) study area (**Figure 1**). Additionally, this report explores the ecology of the landscape, perspectives about future energy development and those valued landscape assets, identified by a Big Bend Region Stakeholder Advisory Group, with which the still-unfolding energy narrative will need reconciliation.

The Respect Big Bend Study Area

The bulk of the study area lies within the Chihuahuan Desert ecoregion. It reaches to parts of the southern High Plains ecoregion in the northeastern counties and the Edwards Plateau ecoregion to the southeast. The physiography of the region is extremely diverse. Elevations above mean sea level range from 900 feet at the confluence of the Pecos River and Rio Grande rivers to over 8,750 feet at Guadalupe Peak, the highest point in Texas. Topography varies from rugged peaks and sky islands to rolling hills to flat grasslands and desert shrublands. The region's climate is typically semi-arid with annual precipitation averaging approximately 12 inches. The substantial differences in elevation and topography within the region contribute to high local variability of rainfall, fluctuating from an average of 9 to 27 inches annually. The entire region is prone to frequent and intense drought.

Significant variation in topography and rainfall across the 18-county study area also translates to diverse vegetation communities. Dominant plant communities shift from creosote bush and mesquite in the desert shrublands at lower elevations to mid-elevation grasslands and conifer woodlands at the highest elevations. Cottonwoods, desert willow and hackberry typically populate the riparian buffers.

From desert grasslands to cienegas to ponderosa pine forests, this region of deep West Texas supports more than 2,000 plant species, 500 bird species, 170 reptile and amphibian species and 120 mammal species. The native wildlife includes iconic grassland species such as pronghorn, kit fox and black-tailed prairie dog, kangaroo rats, burrowing owl and diverse birds-of-prey and several grassland bird species of known continental decline. Bat diversity in this study area is one of the highest in the state rivaling other places in the southwestern United States with as many as 18 recorded species. Arid-land reptile diversity is extraordinary, mostly among snakes and lizards, while also including rare aquatic turtles. Where permanent water occurs at springs, creeks and rivers, native fish species are numerous, often at risk, and several occur nowhere else. Regional bird diversity is rich in this mixing zone of two continental migratory flyways, and large native mammals like black bears, mule deer and desert bighorn sheep live in isolated sky island mountain ranges and cross lowlands and foothills while moving between mountain ranges.

Perceptions of Energy Development in the Big Bend Region

In the fall of 2017, the Cynthia and George Mitchell Foundation commissioned public opinion research on statewide and local perspectives about energy development in the Respect Big Bend region. This was done in 2 phases with focus groups and telephone surveys (for additional details and results, see supplement *S1. Public Opinion Research Findings*).

Attitudes about energy development and how it plays out in a landscape were consistent across the groups. These attitudes included:

1. A majority of Texans think energy development is good for the state, but, like Far West Texas residents, they do not want it to take place just anywhere. When asked to choose, most Texans prioritized protecting communities and land and water resources for future generations over energy development.
2. People are skeptical that energy can be produced without harming communities and natural resources.
3. Eighty-one percent of Texans believe that cities and towns should have greater input when energy development is likely to have an impact on their own communities and quality of life.

Avoiding the worst impacts from energy development on their communities will require better planning that includes meaningful and substantive participation directly from community members. However, there is a general feeling that communities are brought in too late in the process, when important decisions have already been made.

In addition to having a greater say in what happens in their communities, residents favor a wide variety of proposals to manage potential impacts. Among these proposals are increased reporting requirements on water contamination and stronger mitigation standards that anticipate and prevent negative impacts, while also requiring restoration of impacted lands to their original state.

The Development by Design approach is meant to address these core concerns by bringing together the right mix of people, or actors – from the energy industry, elected officials, land managers, conservationists, scientists and community members – to take into account the needs and priorities of all stakeholders at the earliest stages of land use and development decision-making.

The Stakeholder Advisory Group

RBB convened experts and stakeholders from the tri-county Big Bend region (i.e., Brewster, Jeff Davis, and Presidio counties) to serve on a Stakeholder Advisory Group (SAG) to identify priorities in the region. Members of the SAG include local landowners, energy industry and service providers, community members, government officials, and conservation partners. This group had deep knowledge of the study area, available data, local laws and policies, and the feasibility of various strategies to implement the group's recommendations. For a full list of SAG members, please see supplement section

S2. Stakeholder Engagement Process..

Over the course of two years starting in 2019, the SAG met 13 times and identified seven values that are the foundation of a shared conservation vision for the Tri-County Region. They provided valuable guidance to efforts to map these values, review energy projections and delineate solutions to encourage development that would avoid or minimize impacts to conservation values.

The SAG focused on values that were important for their local counties. Although we mapped these values across the larger 18-county study area to put these values in context, we acknowledge that a comprehensive list of focal values for this larger region would require additional outreach with stakeholders outside of the Tri-County Region. These seven Tri-County-centered values are:

1. Ranching heritage and private property rights
2. Sky islands, water resources and grasslands
3. Wildlife and migratory corridors
4. Tourism and hunting
5. Viewsheds and vistas, dark skies, remoteness and quietude
6. Community, safety and quality of life
7. Culture, music and the arts

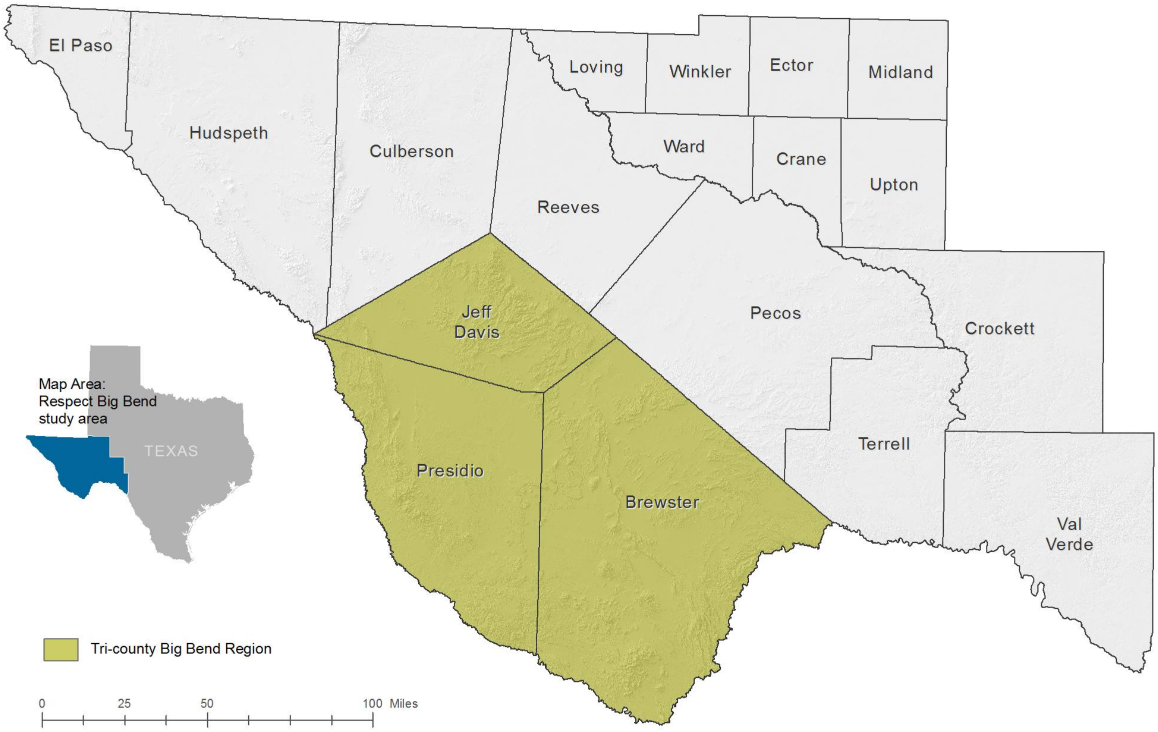


Figure 1. *18-county study area & the Tri-County Region.*

3. A CONSERVATION VISION IN THE CONTEXT OF FUTURE ENERGY DEVELOPMENT

Identifying and mapping important landscape values is a critical first step to understanding and managing the possible impacts of future energy development [19, 21]. These values are intended to capture what makes the Tri-County Region unique and important to those who live there, to the state of Texas and to those who visit. Taken together, these values articulate **a conservation vision** to inform and assess potential impact from future development. The goal is to maintain these values even as the landscape; the communities and economies that exist within it; and the policies that govern them shift and evolve.

Ultimately, long-term conservation success will be inextricably tied to coordinated action among a diverse community of stakeholders. A shared conservation vision and its potential overlap with modeled future energy projections is vital to proactively consider possible conflicts, clarify tradeoffs and strategize how to work in concert to guide an emerging story of development toward a more low-impact future in this rugged and remote West Texas country. Here, RBB presents an overview of methods (for detailed methods, please see supplement sections *S3*-*S5*).

Methods: Develop a Landscape Conservation Vision

RBB developed this project's conservation vision by translating the ecological and social values identified by the SAG into spatial data proxies (**Table 1**,

Figure 2. Tri-County values mapped across the 18-county study area (1-13).) and convening a science subcommittee of the SAG to review the representations of the biological values. The team adopted a coarse-filter/fine-filter approach to manage the complex organization of biological systems present and the practical limits of existing data representing those systems. The rationale behind the approach is that a first-step focus on terrestrial ecosystems (the coarse-filter) will also conserve the majority of individual species and intact habitats that can support processes needed for the long-term persistence of those species [22]. As a second step, a subset of species was targeted (the fine-filter) that would not be well-represented when attending to a coarse-filter systems approach alone. Candidates may include species that are rare, those with highly specific habitat requirements and/or changing habitat needs over their life cycle, or species that are migratory over long distances [22]. Three species were selected – pronghorn, bighorn sheep and mountain lion – to serve as indicators of important habitat (grasslands and montane forests of the sky islands) and functional connectivity between habitat patches.

All input values were equally weighted and summed together into a single metric representing a surface of cumulative values across the entire landscape. To derive this layer, each input was re-scaled from 0 to 1 to make disparate values comparable. The focal mean value was calculated for each pixel within a 0.6 mile (1 km) radius for each 30 meter grid cell across the study area. This essentially turned every layer into a measure of density. Focal means were not calculated for values already measured as a continuous metric (e.g., irradiance values for nighttime lights). All inputs were resampled to 30m rasters.

For ease in reporting and summarizing, the continuous nature of the cumulative values map were grouped into 5 equal-interval classes. These classes were titled: very high, high, moderate, low and very low.

Methods: Project Future Potential for Energy Development

The goal in estimating future energy development patterns is to determine the likelihood (probability) that oil and gas, solar and/or wind development may occur at a particular location over the next 30 years, circa 2050. To the extent possible, a similar approach was tailored for each energy system by following these key steps:

1. Map existing infrastructure and evaluate landscape alteration patterns;
2. Exclude anthropogenic areas restricted from development (e.g., airports, roads, cities, already-developed areas, etc.);
3. Evaluate resource potential (e.g., reservoir quality, solar radiance, wind speed);
4. Project amount of energy production (i.e., barrel of oil equivalent (BOE) and megawatts (MW)) under different development scenarios, defined in relation to the expected landscape impact as low, medium, or high;
5. Evaluate probability for infrastructure placement at a particular location, based on several criteria, including distance to existing roads, pipelines, transmission lines, and other operating facilities;
6. And estimate locations of new production facilities using projected energy production and placement probabilities.

To cover the range of uncertainty that accompanies any forecast, three impact scenarios were identified for oil and gas, solar and wind energy. “Impact” refers to the construction of well pads, pipeline right-of-ways (ROWs), photovoltaic solar installations, etc., all of which facilitate energy production.

For oil and gas development, it is assumed that the trends in landscape change and energy production seen in the last decade will continue into the future unchanged. This represents the medium impact scenario, what RBB is calling the “business as usual” (BAU) case. To help develop the low and high impact scenarios, the number of wells built on each drilling pad was used as a proxy. In the medium scenario, three wells would be built per pad on average, an assumption consistent with observations today, reports found in the literature and in discussion with operators [12, 23, 24]. For the high impact scenario, only one well would be developed on each drilling pad following historical practices (closer to 1.15 wells per pad) [25]. The high impact scenario requires more new pads to be built on the landscape for the same number of wells. The low impact scenario assumed a combination of reduced well-drilling activity given low oil and gas prices, an increased number of wells per pad as a result of technological advances and/or some other economic incentives. Operationally, the low impact scenario would triple the number of wells per pad (compared to the BAU) to nine wells per pad (hence, 1/3 the number of well pads would be needed).

Specific placement of new well pads for oil and gas development used the results reported by Pierre et al. (2020) [12].

For solar and wind energy production, future development was estimated together in a single Capacity Expansion Model known as "Switch" [26] to take advantage of differences in peak performance between day (solar) and evening (wind) time periods. Switch matches electricity demand anticipated by the Electric Reliability Council of Texas (ERCOT) over the next 30 years, with future generation capacity for low, medium (i.e., BAU) and high supply scenarios. The Switch model included facilities across the entire ERCOT service area of Texas, which reduces uncertainty that would be introduced by modeling the Trans-Pecos Region in isolation (electricity moves across transmission lines into and out of West Texas, but not across state lines). The outcome of this model provided future estimates of both solar and wind generation measured in gigawatts (GW) for each ERCOT region and ultimately for each county in Texas.

Similar to how Pierre et al. (2020) projected oil and gas well pads, a probability raster using expert-driven knowledge of placement criteria was created; however, considering the vast area of land suitable for both wind and solar energy development, we have not placed new facilities on the landscape. Ongoing work will focus on identifying factors important for mapping where new infrastructure is likely to be placed. These factors will be similar to those used for placing hypothetical oil and gas facilities. However, additional factors may be considered when locating electricity generation facilities on the landscape. For example, developers may want to avoid clustering of facilities [12, 27, 28] to limit the potential for transmission line congestion that occurs when too many facilities are built close to one another, leading to curtailment of electricity production. We used the Switch model results to estimate how much new solar and wind electricity production is needed to support projected future electricity demand and then estimated the footprint of future renewable facilities using the median capacity and the median footprint of existing facilities within the ERCOT region.

Results

Cumulative Values Map

Within the 18-county study region, there are ~11 million acres (44,000 km^2) in the high or very high cumulative classes, 40 percent (or, 4.4 million acres/17,800 km^2) of which is in the Big Bend Region. This is in part because Brewster and Presidio Counties are among the largest counties in the study area (**Figure 3**). Brewster, Presidio and Jeff Davis Counties are home to some of the largest and most intact occurrences of these high value areas found in the study region. The majority of intact grassland landscapes and movement corridors for our focal species in the highest value classes are found in the Tri-County Region. All told, 81 percent of the Tri-County Region is in the High and Very High cumulative value classes.

Other counties in the study region with large areas in the High and Very High cumulative classes include Hudspeth (1.6 million acres/6,629 km^2), Culberson (1.4 million acres/5,701 km^2) and Pecos (752,994 acres/3,047 km^2). Counties without areas included in the High and Very High classes include Crane, Ector, Loving, Midland, Ward and Winkler (coincidentally, counties with the highest concentrations of energy development). (**Figure 4**).

Individual Input Values & Irreplaceability

Most of the individual mapped values are well-represented in the High and Very High cumulative value areas (**Figure 6**). However, special attention needs to continue to be paid to several individual values with outsized importance. Among them are riparian, wetland and spring areas, which are especially critical and irreplaceable for maintaining healthy ecosystems and the species dependent on them in this arid region. These features are not apparent in the cumulative values map, because they are typically mapped as small areas (e.g., springs) or narrow linear features (e.g., riparian areas) and their distribution is limited across the region.

This approach emphasizes areas of high aggregations of individual values. Areas of low cumulative values may still include the presence of otherwise irreplaceable or other valuable elements in good condition. Attention should continue to be paid to understand the individual values present in any area of interest.

Energy projections

- **Oil and gas:** Currently, there are an estimated 122,433 well pads in the study area, constituting a total direct footprint of 187,410 acres (758 km^2). Our forecasts suggest that an additional 24,925 to 180,849 new well pads could be built by 2050, resulting in an estimated 258,758 to 900,062 acres (1,156-3,642 km^2) of cumulative direct impact (*Error! Reference source not found.**Figure 5 A1-A3***). The bulk of these impacts will be concentrated in Midland, Pecos, Reeves, and to a lesser extent, Culberson counties.
- **Solar:** To date, ~8,896 acres (36 km^2) of landscape alteration have occurred from utility-scale solar development in the 18-county study area. We mapped a total of 12 million acres (49,349 km^2) of suitable lands with sufficient resource potential for siting future solar facilities (***Figure 5B***). The "Switch" model calls for an additional 13 to 16.5 GW of capacity from utility-scale solar facilities to be built in ERCOT Region 2 across the different scenarios over the next 30 years. Considering the median capacity (78MW) and size (642 acres/2.6 km^2) of facilities in Region 2, an additional 170 to 213 new facilities could be built, resulting in a cumulative direct footprint of between 116,896-144,396 acres (473-584 km^2). In all three scenarios, we found that the Tri-County Region could expect to host new solar facilities.
- **Wind:** To date, 118,611 acres (480 km^2) of land have been altered from wind energy development in the 18-county study area. We mapped a total of 13 million acres (54,238 km^2) of suitable lands with sufficient resource potential for siting future wind facilities (***Figure 5C***). The median capacity of existing facilities is ~145 MW, requiring a median land area of ~6,672 acres (27 km2), or a footprint of ~46 acres/MW. When looking to the future, the "Switch" model calls for a capacity increase of 1,628 MW from utility-scale wind farm facilities. Depending on the energy demand scenario (low, medium, high), this would lead to between 23 and

233 new facilities, resulting in a cumulative land alteration ranging between 389,191 and 2.9 million acres (1,575–11,573 km^2). See **Table 2** for a summation of expected alteration from all energy sources, broken down by energy type (columns) and by scenario (rows).

Using current trends and accounting for the transition of the Texas electricity grid toward renewable energy, it is anticipated that both oil and gas and renewable infrastructure will continue to be installed in West Texas although the Tri-County Region does not appear to be a top priority for any energy type. The likelihood of intensive oil and gas development in the Tri-County Region is low, although future technologies may change the ability to recover hydrocarbons from geologic units in these counties, just as hydraulic fracturing technology unlocked oil and gas reserves elsewhere in West Texas and elsewhere. Solar irradiance levels in the RBB area of West Texas are very high (increasing westward), and wind energy potential is higher eastward and northward; thus, the area is favorable for solar and/or wind energy development, increasing the potential for broader-scale investment, construction, and land alteration.

Impacts and Tradeoffs to the Landscape Conservation Vision from Future Potential Energy Development

Potential conflicts with oil and gas: Oil and gas resources are highest in Pecos, Culberson and Midland counties, but potential overlap with High and Very High value classes are relatively low in Midland County – mostly because Midland is already highly impacted and has fewer areas in these two classes. Depending on the development scenario, ~2,980-23,000 acres (12-94 km^2) of High and Very High value areas in Culberson, ~2,040-14,171 acres (8-57 km^2) in Pecos and ~1.798-13.125 acres (7.3-53 km^2) in Reeves counties remain vulnerable to conversion (**Table 3**, **Figure 7**).

At every development class, most projected potential impacts are confined to areas overlapping the Low and Very Low conservation value classes; but 25 percent of the forecasted development footprint in every scenario reaches into areas in the upper half of the conservation values range. It is anticipated that development is unlikely to be restricted exclusively to the lowest conservation value classes, because the siting of oil and gas well pads is more tightly tied to the location of the hydrocarbon-bearing resource: the oil and gas or shale formation from which the resource can be extracted.

Potential conflicts with renewables*:* In contrast to the projections for oil and gas development, siting *potential* for renewable development was evaluated across the entire 18-county study area and the overlap of all potentially suitable sites with conservation values was also evaluated. This overlap significantly overestimates the potential for conflict because of the very low probability that all the areas suitable for renewables will be developed. For example, we estimate ~270,580-2,741,136 acres (1,095-11,093 km^2) of potential impact from wind energy development across the RBB study area, all of which could be sited within the 8-83 percent of the 3.3 million acres (13,398 km^2) of land area classified with Very Low cumulative value that also has adequate wind resources. Similarly, for solar development, it is projected that the ~84,510-105,500 acres (342-426 km^2) of new potential impacts could be sited within 2-3 percent of the 3.9 million acres (16,061 km^2) of Very Low cumulative conservation value areas that also are suitable for solar facility siting.

The High and Very High cumulative conservation value classes potentially at risk from renewable energy development are concentrated in Culberson, Brewster, Hudspeth, Jeff Davis and Pecos counties and to a lesser extent, Reeves and Terrell counties (**Table 4**, **Figure 8**). The Very High cumulative value areas in Presidio County are especially at risk (solar: 131,200 acres, wind: 87,680 acres). Culberson and Pecos counties are also of particular concern because they could also be under high pressure from forecasted oil and gas development.

SUMMARY

The Tri-County Region is home to most of the pristine, intact landscape values in the 18-county study area.

Using data about the region's geology, topography, weather patterns and projections about Texas' future energy demands and the ongoing transition toward more renewable sources of energy, RBB anticipates that both oil and gas and renewable infrastructure development will continue in West Texas.

- **Oil and Gas:** It is expected that development will be highest in Pecos, Culberson and Midland counties. Potential conflicts with areas of Very High and High cumulative value classes are most salient in Culberson, Pecos and Reeves counties.
- **Renewables:** Resource potential for solar facility siting is highest in Pecos, Reeves, Hudspeth, Culberson and Winkler counties. Potential conflicts with areas of Very High and High cumulative values classes are notable in Hudspeth, Culberson, Presidio and Brewster counties. Resource potential for wind energy facilities is highest in Pecos, Culberson, Crockett, Val Verde, Terrell and Winkler counties. Potential conflicts with areas of Very High and High cumulative values classes are focused in Culberson, Pecos, Hudspeth and Presidio counties.

The ability to manage siting impacts will vary by energy type: Though this analysis does not include all of the potential impacts associated with oil and gas development (for example, water and air pollution are not discussed), the spatial impacts of forecasted solar and wind development are projected to exceed the land footprint of future oil and gas development [29, 30].

Moreover, the distinct ways that oil and gas, solar and wind energy resources are distributed within the 18-county study region have implications for siting decisions. Specifically, oil and gas production activity is more constrained within the study area, whereas solar and wind resources for electricity generation are broadly located. The larger land area with suitable solar and wind resources across the 18-county study region when compared with oil and gas resources, lends some greater flexibility to siting renewable energy facilities away from the most important areas on the landscape (i.e., areas of High or Very High aggregations of conservation values) to areas with fewer conflicts. This potential siting flexibility at broader scales is less obviously available to oil and gas operators. Prospects for easy tradeoffs diminish further in those counties where future oil and gas development is expected and where areas of High or Very High aggregated values are located.

Table 1. *Landscape values identified by the Stakeholder Advisory Group and the associated spatial proxies mapped.*

Values		Spatial Proxy	
(1)	Ranching heritage	(1)	Intact landscapes
	Private property rights		
(2)	Grasslands	(2)	Grasslands
	Water resources	(3)	Riparian areas & wetlands
		(4)	Springs
(3)	Sky islands, wildlife & migratory corridors	(5)	Bighorn sheep model
		(6)	Pronghorn model
		(7)	Mountain lion model
(4)	Tourism & hunting	(8)	Pronghorn herd units
		(9)	Mule deer herd units
		(10)	Recreational routes & trails
		(11)	Managed areas
(5)	Viewsheds	(12)	Viewsheds
	Dark skies	(13)	Dark skies
	Remoteness		
(6)	Community, safety & quality of life*		
(7)	Culture, music & arts*		

** values were not mapped*

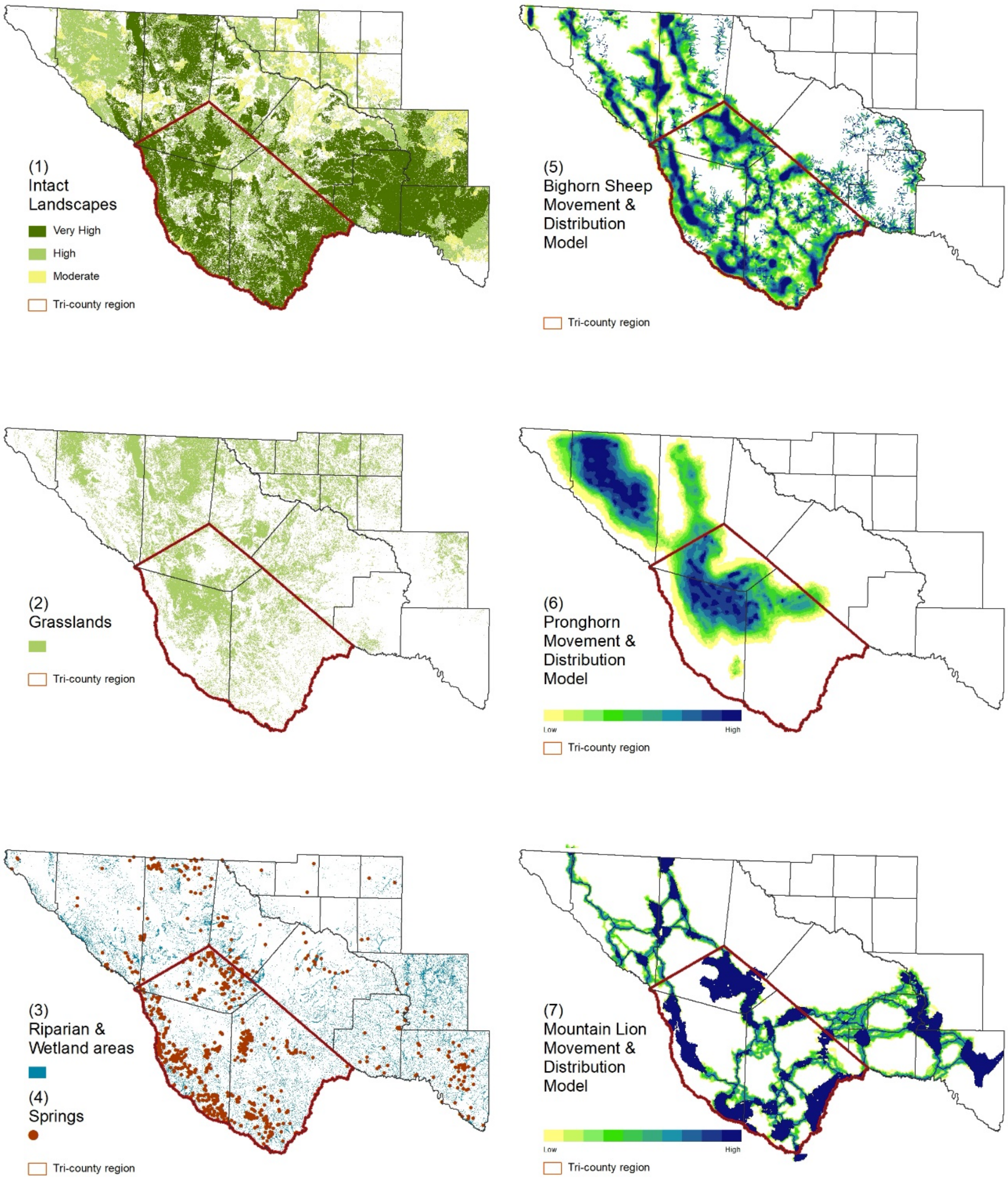
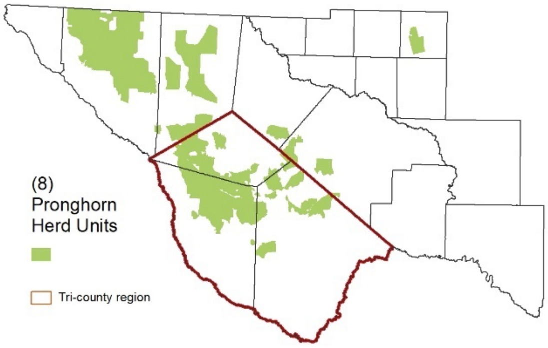
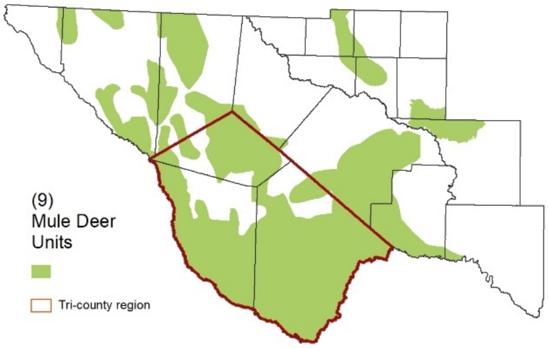
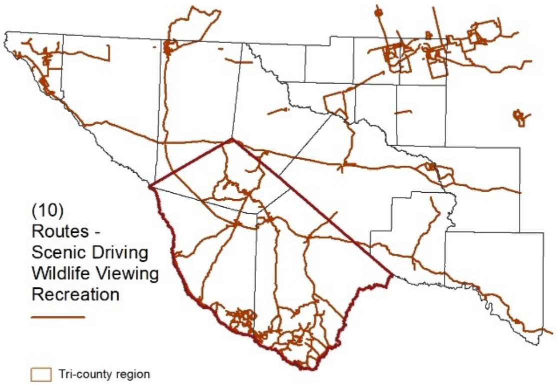
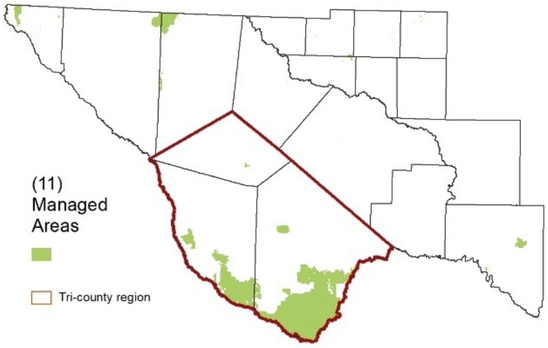


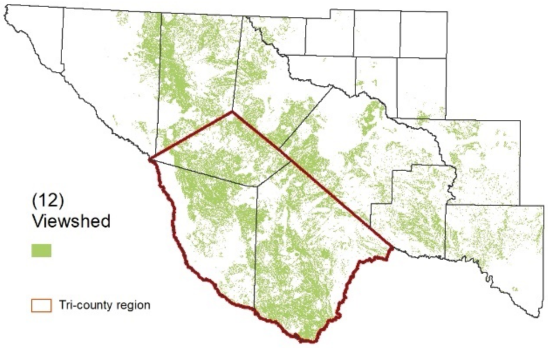
Figure 2. *Tri-County values mapped across the 18-county study area (1-13).*

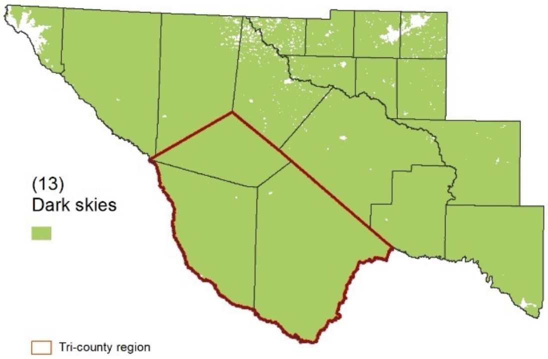

(8)
Pronghorn Herd Units
🟩
☐ Tri-county region


(9)
Mule Deer Units
🟩
☐ Tri-county region


(10)
Routes -
Scenic Driving
Wildlife Viewing
Recreation
☐ Tri-county region


(11)
Managed Areas
🟩
☐ Tri-county region


(12)
Viewshed
🟩
☐ Tri-county region


(13)
Dark skies
🟩
☐ Tri-county region

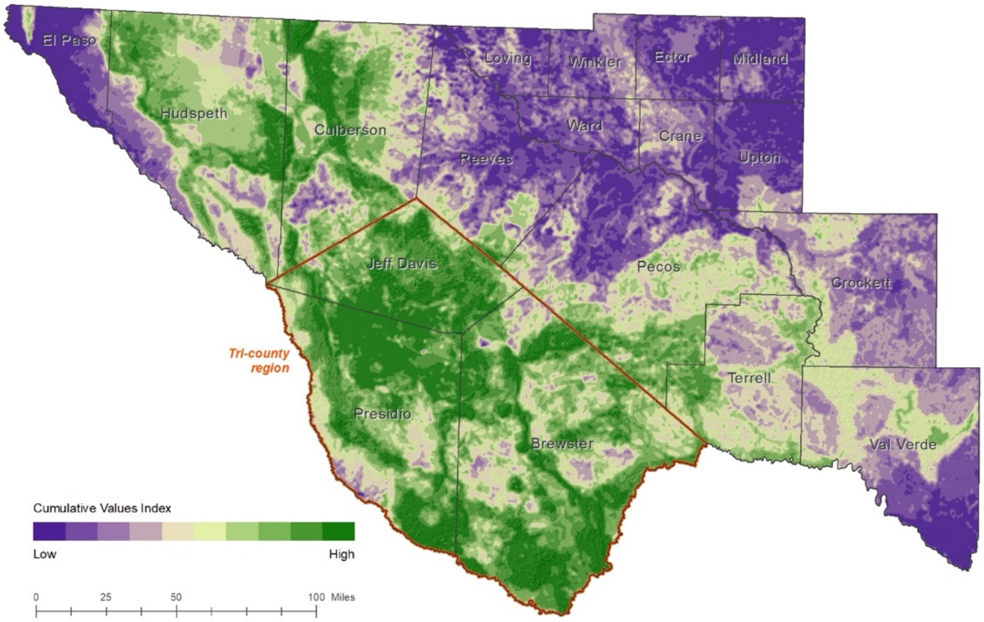
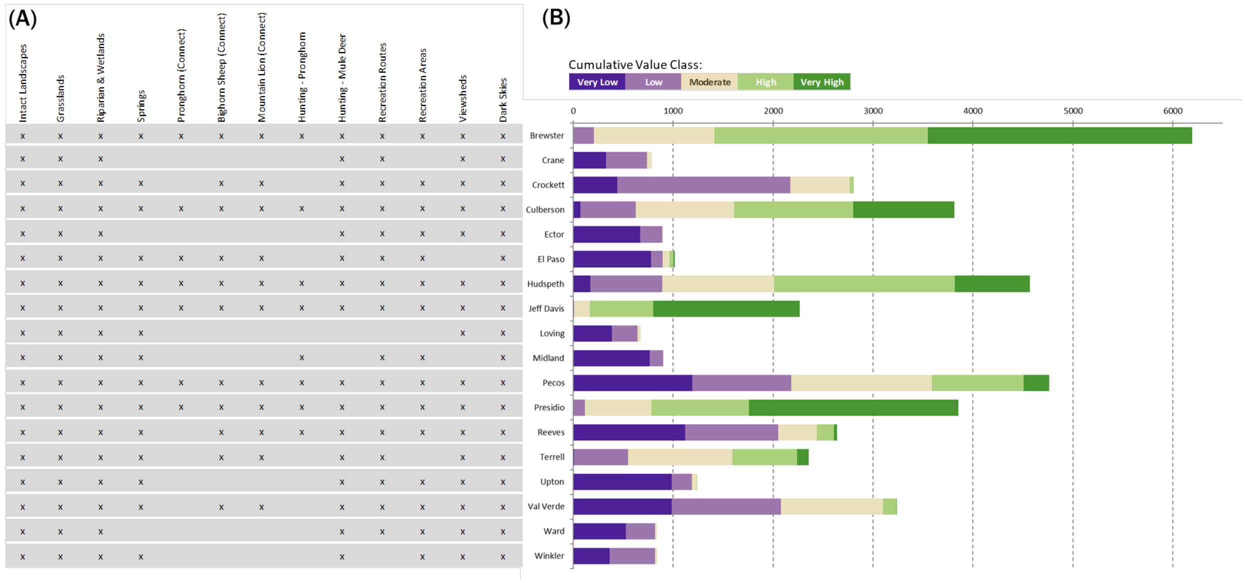


Figure 3. Cumulative Values map based on Stakeholder Advisory Group recommendations. This map represents aggregations across the larger 18-county study area of values identified primarily for the Tri-County Region



	Intact Landscapes	Grasslands	Riparian & Wetlands	Springs	Pronghorn (Connect)	Bighorn Sheep (Connect)	Mountain Lion (Connect)	Hunting - Pronghorn	Hunting - Mule Deer	Recreation Routes	Recreation Areas	Viewsheds	Dark Skies
Brewster	x	x	x	x	x	x	x	x	x	x	x	x	x
Crane	x	x	x						x	x		x	x
Crockett	x	x	x	x		x	x		x	x	x	x	x
Culberson	x	x	x	x	x	x	x	x	x	x	x	x	x
Ector	x	x	x						x	x	x	x	x
El Paso	x	x	x	x	x	x	x		x	x	x		x
Hudspeth	x	x	x	x	x	x	x	x	x	x	x	x	x
Jeff Davis	x	x	x	x	x	x	x	x	x	x	x	x	x
Loving	x	x	x	x								x	x
Midland	x	x	x	x				x		x	x		x
Pecos	x	x	x	x	x	x	x	x	x	x	x	x	x
Presidio	x	x	x	x	x	x	x	x	x	x	x	x	x
Reeves	x	x	x	x		x	x	x	x	x	x	x	x
Terrell	x	x	x	x		x	x		x	x		x	x
Upton	x	x	x	x					x	x	x	x	x
Val Verde	x	x	x	x		x	x		x	x	x	x	x
Ward	x	x	x						x	x	x	x	x
Winkler	x	x	x	x					x		x	x	x

Figure 4. Distribution of individual values by county (A) and distribution (in cares) of cumulative value classes by county (B).

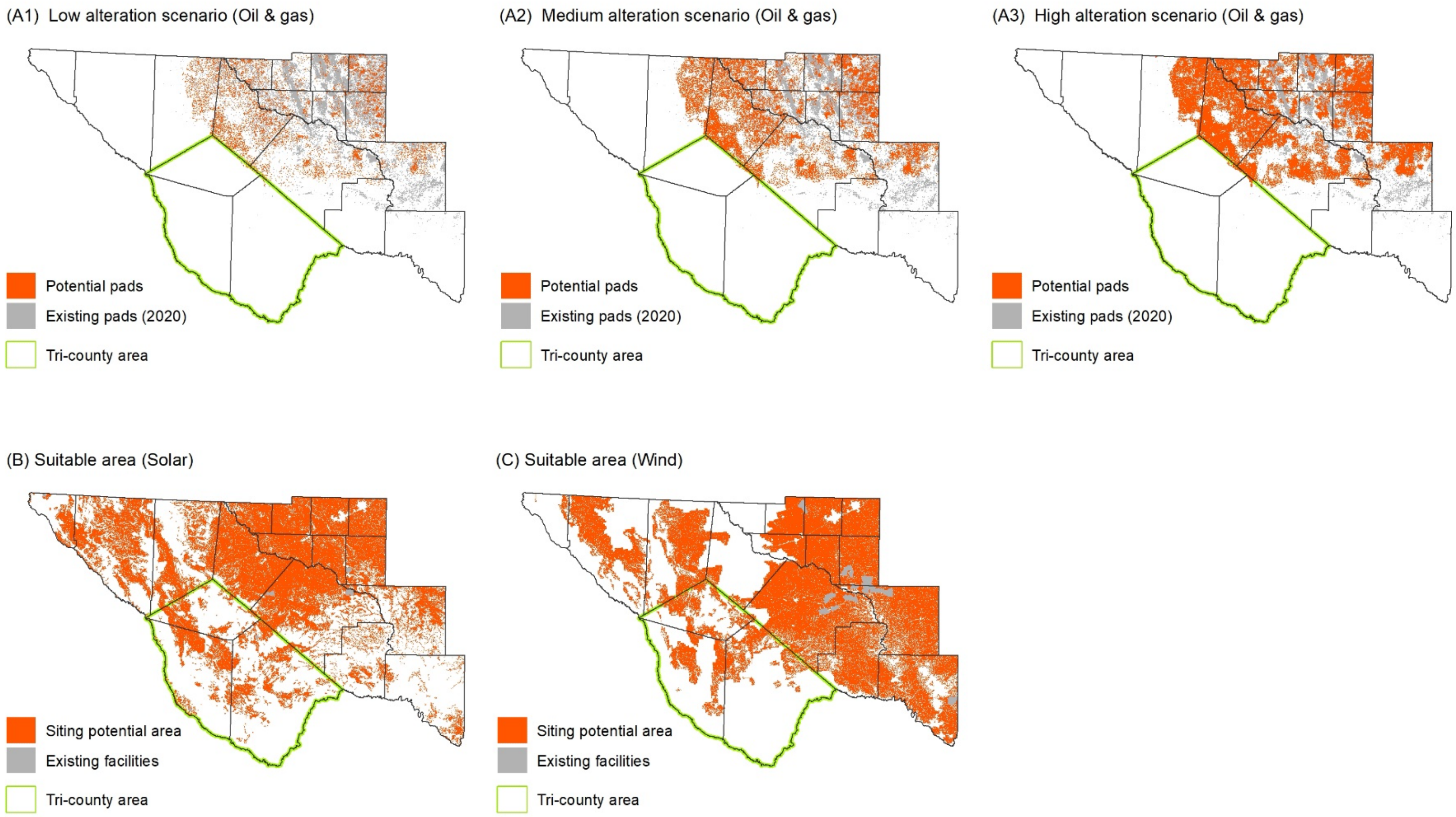


Figure 5. *Low, Medium and High land alteration scenarios for oil and gas development (A1-A3) and suitable lands for potential siting of solar (B) and wind (C) development.*

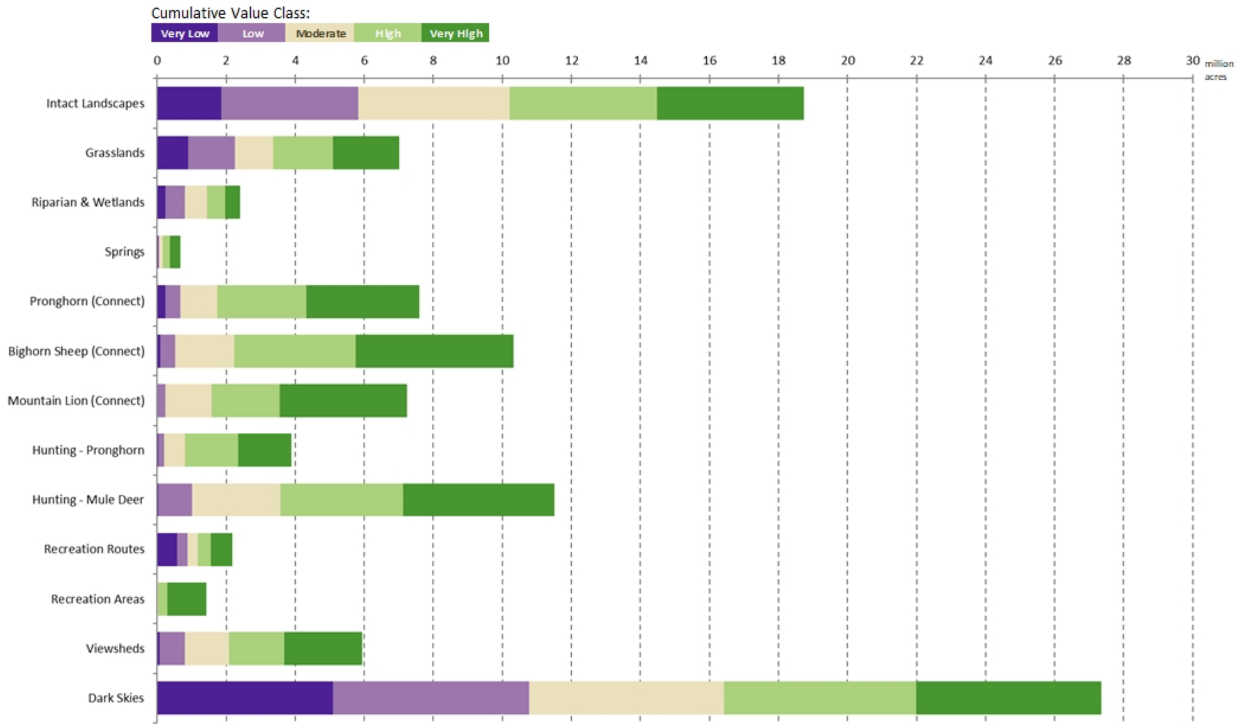


Figure 6. *Distribution of individual values in each cumulative value class (in million acres).*

Table 2. *Current, projected potential future direct land alteration (in acres, km^2), and cumulative footprints (current + future) by energy type for entire 18-county RBB areas.*

					Cumulative Footprints (Current + Future)		
Scenario:		Oil & Gas	Solar	Wind	Oil & Gas	Solar	Wind
Current	acres	187,410	8,896	118,611			
	(km^2)	(758.4)	(36.0)	(480.0)			
Future Scenarios (possible additional footprint):							
Low	acres	98,348	75,614	270,580	285,758	84,510	389,191
	(km^2)	(398.0)	(306.0)	(1,095.0)	(1,156.4)	(342.0)	(1,575.0)
Medium	acres	291,584	78,579	1,600,005	478,994	87,475	1,718,616
	(km^2)	(1,180.0)	(318.0)	(6,475.0)	(1,938.4)	(354.0)	(6,955.0)
High	acres	712,652	96,371	2,741,136	900,062	105,267	2,859,747
	(km^2)	(2,884.0)	(390.0)	(11,093.0)	(3,642.4)	(426.0)	(11,573.0)

Table 3. *Total potential oil and gas footprint by development scenario and overlap with cumulative value classes by county (in acres and km^2).*

County		Total Potential O&G Footprint			Cumulative Value Class X Low Development Scenario					Cumulative Value Class X Medium Development Scenario					Cumulative Value Class X High Development Scenario				
		Low	Med	High	Very Low	Low	Moderate	High	Very High	Very Low	Low	Moderate	High	Very High	Very Low	Low	Moderate	High	Very High
Brewster	**(acres)**	**247**	**494**	**1,236**	**0**	**40**	**67**	**52**	**0**	**0**	**128**	**237**	**140**	**0**	**0**	**318**	**616**	**364**	**0**
	(km^2)	***(1.0)***	***(2.0)***	***(5.0)***	***(0.0)***	***(0.2)***	***(0.3)***	***(0.2)***	***(0.0)***	***(0.0)***	***(0.5)***	***(1.0)***	***(0.6)***	***(0.0)***	***(0.0)***	***(1.3)***	***(2.5)***	***(1.5)***	***(0.0)***
Crane	(acres)	1,977	5,436	13,344	908	952	52	0	0	2,634	2,818	62	0	0	6,108	7,055	222	0	0
	(km^2)	*(8.0)*	*(22.0)*	*(54.0)*	*(3.7)*	*(3.9)*	*(0.2)*	*(0.0)*	*(0.0)*	*(10.7)*	*(11.4)*	*(0.3)*	*(0.0)*	*(0.0)*	*(24.7)*	*(28.6)*	*(0.9)*	*(0.0)*	*(0.0)*
Crockett	(acres)	7,660	22,487	54,610	1,714	4,548	1,404	20	0	5,092	13,570	3,819	87	0	12,441	32,371	9,469	210	0
	(km^2)	*(31.0)*	*(91.0)*	*(221.0)*	*(6.9)*	*(18.4)*	*(5.7)*	*(0.1)*	*(0.0)*	*(20.6)*	*(54.9)*	*(15.5)*	*(0.4)*	*(0.0)*	*(50.3)*	*(131.0)*	*(38.3)*	*(0.9)*	*(0.0)*
Culberson	(acres)	10,131	30,147	77,344	220	2,702	4,204	2,482	498	789	8,070	12,340	7,418	1,434	2,005	20,268	31,896	19,554	3,774
	(km^2)	*(41.0)*	*(122.0)*	*(313.0)*	*(0.9)*	*(10.9)*	*(17.0)*	*(10.0)*	*(2.0)*	*(3.2)*	*(32.7)*	*(49.9)*	*(30.0)*	*(5.8)*	*(8.1)*	*(82.0)*	*(129.1)*	*(79.1)*	*(15.3)*
Ector	(acres)	2,965	8,649	21,251	2,285	697	0	0	0	6,762	2,008	1	0	0	16,177	5,128	13	0	0
	(km^2)	*(12.0)*	*(35.0)*	*(86.0)*	*(9.2)*	*(2.8)*	*(0.0)*	*(0.0)*	*(0.0)*	*(27.4)*	*(8.1)*	*(0.0)*	*(0.0)*	*(0.0)*	*(65.5)*	*(20.8)*	*(0.1)*	*(0.0)*	*(0.0)*
El Paso	(acres)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	(km^2)	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*
Hudspeth	(acres)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	(km^2)	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*
Jeff Davis	**(acres)**	**494**	**1,730**	**3,459**	**0**	**36**	**168**	**240**	**110**	**0**	**99**	**537**	**719**	**312**	**0**	**281**	**1,043**	**1,562**	**526**
	(km^2)	***(2.0)***	***(7.0)***	***(14.0)***	***(0.0)***	***(0.1)***	***(0.7)***	***(1.0)***	***(0.4)***	***(0.0)***	***(0.4)***	***(2.2)***	***(2.9)***	***(1.3)***	***(0.0)***	***(1.1)***	***(4.2)***	***(6.3)***	***(2.1)***
Loving	(acres)	5,931	18,039	44,973	3,639	2,008	284	0	0	10,970	6,216	861	0	0	26,604	16,210	2,233	0	0
	(km^2)	*(24.0)*	*(73.0)*	*(182.0)*	*(14.7)*	*(8.1)*	*(1.1)*	*(0.0)*	*(0.0)*	*(44.4)*	*(25.2)*	*(3.5)*	*(0.0)*	*(0.0)*	*(107.7)*	*(65.6)*	*(9.0)*	*(0.0)*	*(0.0)*
Midland	(acres)	9,637	28,911	65,483	8,751	974	4	0	0	26,093	2,870	4	0	0	58,150	7,224	19	0	0
	(km^2)	*(39.0)*	*(117.0)*	*(265.0)*	*(35.4)*	*(3.9)*	*(0.0)*	*(0.0)*	*(0.0)*	*(105.6)*	*(11.6)*	*(0.0)*	*(0.0)*	*(0.0)*	*(235.3)*	*(29.2)*	*(0.1)*	*(0.0)*	*(0.0)*
Pecos	(acres)	15,815	46,456	113,668	4,110	3,663	6,092	2,034	6	12,478	10,728	17,527	5,833	13	31,882	26,364	41,279	14,149	22
	(km^2)	*(64.0)*	*(188.0)*	*(460.0)*	*(16.6)*	*(14.8)*	*(24.7)*	*(8.2)*	*(0.0)*	*(50.5)*	*(43.4)*	*(70.9)*	*(23.6)*	*(0.1)*	*(129.0)*	*(106.7)*	*(167.0)*	*(57.3)*	*(0.1)*
Presidio	**(acres)**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	(km^2)	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***	***(0.0)***
Reeves	(acres)	25,205	74,873	186,564	10,301	9,025	4,074	1,514	284	30,883	26,546	12,198	4,483	799	77,660	66,957	28,668	11,288	1,837
	(km^2)	*(102.0)*	*(303.0)*	*(755.0)*	*(41.7)*	*(36.5)*	*(16.5)*	*(6.1)*	*(1.1)*	*(125.0)*	*(107.4)*	*(49.4)*	*(18.1)*	*(3.2)*	*(314.3)*	*(271.0)*	*(116.0)*	*(45.7)*	*(7.4)*
Terrell	(acres)	494	1,483	3,459	0	109	300	52	0	1	293	874	179	0	0	818	2,139	375	0
	(km^2)	*(2.0)*	*(6.0)*	*(14.0)*	*(0.0)*	*(0.4)*	*(1.2)*	*(0.2)*	*(0.0)*	*(0.0)*	*(1.2)*	*(3.5)*	*(0.7)*	*(0.0)*	*(0.0)*	*(3.3)*	*(8.7)*	*(1.5)*	*(0.0)*
Upton	(acres)	8,154	24,711	57,328	7,014	1,035	118	0	0	21,303	3,142	292	15	0	49,471	7,161	737	32	0
	(km^2)	*(33.0)*	*(100.0)*	*(232.0)*	*(28.4)*	*(4.2)*	*(0.5)*	*(0.0)*	*(0.0)*	*(86.2)*	*(12.7)*	*(1.2)*	*(0.1)*	*(0.0)*	*(200.2)*	*(29.0)*	*(3.0)*	*(0.1)*	*(0.0)*
Val Verde	(acres)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	(km^2)	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*	*(0.0)*
Ward	(acres)	3,954	11,367	28,170	2,423	1,404	4	0	0	7,240	4,127	38	0	0	17,370	10,678	109	0	0
	(km^2)	*(16.0)*	*(46.0)*	*(114.0)*	*(9.8)*	*(5.7)*	*(0.0)*	*(0.0)*	*(0.0)*	*(29.3)*	*(16.7)*	*(0.2)*	*(0.0)*	*(0.0)*	*(70.3)*	*(43.2)*	*(0.4)*	*(0.0)*	*(0.0)*
Winkler	(acres)	2,718	8,154	20,510	1,457	1,295	33	0	0	4,190	3,884	66	0	0	10,286	9,956	212	0	0
	(km^2)	*(11.0)*	*(33.0)*	*(83.0)*	*(5.9)*	*(5.2)*	*(0.1)*	*(0.0)*	*(0.0)*	*(17.0)*	*(15.7)*	*(0.3)*	*(0.0)*	*(0.0)*	*(41.6)*	*(40.3)*	*(0.9)*	*(0.0)*	*(0.0)*
Total	(acres)	98,348	291,584	712,652	45,107	29,184	16,802	6,394	898	135,198	86,508	48,857	18,873	2,558	324,331	215,915	118,667	47,534	6,160
	(km^2)	*(398.0)*	*(1,180.0)*	*(2,884.0)*	*(182.5)*	*(118.1)*	*(68.0)*	*(25.9)*	*(3.6)*	*(547.1)*	*(350.1)*	*(197.7)*	*(76.4)*	*(10.4)*	*(1,312.5)*	*(873.8)*	*(480.2)*	*(192.4)*	*(24.9)*

Table 4. Estimated total renewable projected footprint and overlap of cumulative value classes by siting potential by county (in acres and km^2).

County		Total Siting Potential		Cumulative Value Class X Solar Siting Potential					Cumulative Value Class X Wind Siting Potential				
		Solar	Wind	Very Low	Low	Moderate	High	Very High	Very Low	Low	Moderate	High	Very High
Brewster	**(acres)**	**796,528**	**597,555**	**24**	**83,089**	**323,019**	**300,651**	**89,745**	**25**	**32,222**	**114,927**	**208,887**	**241,494**
	(km^2)	***(3,223.4)***	***(2,418.2)***	***(0.1)***	***(336.2)***	***(1,307.2)***	***(1,216.7)***	***(363.2)***	***(0.1)***	***(130.4)***	***(465.1)***	***(845.3)***	***(977.3)***
Crane	(acres)	437,145	475,936	176,939	231,107	29,099	0	0	192,894	251,249	31,794	0	0
	(km^2)	*(1,769.1)*	*(1,926.0)*	*(716.0)*	*(935.3)*	*(117.8)*	*(0.0)*	*(0.0)*	*(780.6)*	*(1,016.8)*	*(128.7)*	*(0.0)*	*(0.0)*
Crockett	(acres)	673,942	1,403,771	114,403	453,120	96,195	10,223	0	233,653	914,831	237,965	17,322	0
	(km^2)	*(2,727.3)*	*(5,680.9)*	*(463.0)*	*(1,833.7)*	*(389.3)*	*(41.4)*	*(0.0)*	*(945.6)*	*(3,702.2)*	*(963.0)*	*(70.1)*	*(0.0)*
Culberson	(acres)	1,005,692	1,165,870	35,149	239,987	336,175	336,492	57,888	6,257	104,717	317,814	474,432	262,650
	(km^2)	*(4,069.9)*	*(4,718.1)*	*(142.2)*	*(971.2)*	*(1,360.5)*	*(1,361.7)*	*(234.3)*	*(25.3)*	*(423.8)*	*(1,286.2)*	*(1,920.0)*	*(1,062.9)*
Ector	(acres)	481,890	498,615	349,568	127,435	4,887	0	0	356,024	134,669	7,922	0	0
	(km^2)	*(1,950.1)*	*(2,017.8)*	*(1,414.7)*	*(515.7)*	*(19.8)*	*(0.0)*	*(0.0)*	*(1,440.8)*	*(545.0)*	*(32.1)*	*(0.0)*	*(0.0)*
El Paso	(acres)	225,545	48,726	165,098	46,683	11,883	1,876	5	5,334	15,743	16,504	9,933	1,213
	(km^2)	*(912.8)*	*(197.2)*	*(668.1)*	*(188.9)*	*(48.1)*	*(7.6)*	*(0.0)*	*(21.6)*	*(63.7)*	*(66.8)*	*(40.2)*	*(4.9)*
Hudspeth	(acres)	1,417,238	1,092,318	56,303	308,776	410,821	555,242	86,096	0	27,631	157,333	631,635	275,719
	(km^2)	*(5,735.4)*	*(4,420.5)*	*(227.9)*	*(1,249.6)*	*(1,662.5)*	*(2,247.0)*	*(348.4)*	*(0.0)*	*(111.8)*	*(636.7)*	*(2,556.1)*	*(1,115.8)*
Jeff Davis	**(acres)**	**392,138**	**527,027**	**0**	**4,643**	**40,459**	**163,775**	**183,262**	**0**	**1,410**	**54,763**	**203,568**	**267,285**
	(km^2)	***(1,586.9)***	***(2,132.8)***	***(0.0)***	***(18.8)***	***(163.7)***	***(662.8)***	***(741.6)***	***(0.0)***	***(5.7)***	***(221.6)***	***(823.8)***	***(1,081.7)***
Loving	(acres)	367,232	1,144	208,268	140,075	18,890	0	0	167	977	0	0	0
	(km^2)	*(1,486.1)*	*(4.6)*	*(842.8)*	*(566.9)*	*(76.4)*	*(0.0)*	*(0.0)*	*(0.7)*	*(4.0)*	*(0.0)*	*(0.0)*	*(0.0)*
Midland	(acres)	479,464	504,276	399,291	79,869	304	0	0	419,795	84,168	312	0	0
	(km^2)	*(1,940.3)*	*(2,040.7)*	*(1,615.9)*	*(323.2)*	*(1.2)*	*(0.0)*	*(0.0)*	*(1,698.9)*	*(340.6)*	*(1.3)*	*(0.0)*	*(0.0)*
Pecos	(acres)	1,742,786	2,460,472	666,198	484,512	413,017	157,933	21,127	698,936	544,135	715,276	412,010	90,115
	(km^2)	*(7,052.8)*	*(9,957.2)*	*(2,696.0)*	*(1,960.8)*	*(1,671.4)*	*(639.1)*	*(85.5)*	*(2,828.5)*	*(2,202.0)*	*(2,894.6)*	*(1,667.3)*	*(364.7)*
Presidio	**(acres)**	**653,235**	**583,826**	**1,145**	**39,715**	**86,136**	**110,349**	**415,890**	**0**	**704**	**26,330**	**178,927**	**377,864**
	(km^2)	***(2,643.6)***	***(2,362.7)***	***(4.6)***	***(160.7)***	***(348.6)***	***(446.6)***	***(1,683.0)***	***(0.0)***	***(2.9)***	***(106.6)***	***(724.1)***	***(1,529.2)***
Reeves	(acres)	1,402,820	281,365	629,425	517,259	175,752	77,733	2,651	76,118	95,853	67,062	30,330	12,001
	(km^2)	*(5,677.0)*	*(1,138.6)*	*(2,547.2)*	*(2,093.3)*	*(711.2)*	*(314.6)*	*(10.7)*	*(308.0)*	*(387.9)*	*(271.4)*	*(122.7)*	*(48.6)*
Terrell	(acres)	306,061	1,045,636	2,287	104,116	153,098	43,733	2,828	4,112	301,009	509,084	205,396	26,036
	(km^2)	*(1,238.6)*	*(4,231.5)*	*(9.3)*	*(421.3)*	*(619.6)*	*(177.0)*	*(11.4)*	*(16.6)*	*(1,218.1)*	*(2,060.2)*	*(831.2)*	*(105.4)*
Upton	(acres)	621,657	696,224	522,273	80,695	16,163	2,527	0	569,284	101,181	23,102	2,657	0
	(km^2)	*(2,515.8)*	*(2,817.5)*	*(2,113.6)*	*(326.6)*	*(65.4)*	*(10.2)*	*(0.0)*	*(2,303.8)*	*(409.5)*	*(93.5)*	*(10.8)*	*(0.0)*
Val Verde	(acres)	231,830	1,298,116	132,513	68,827	26,990	3,501	0	426,991	544,454	305,704	20,967	0
	(km^2)	*(938.2)*	*(5,253.3)*	*(536.3)*	*(278.5)*	*(109.2)*	*(14.2)*	*(0.0)*	*(1,728.0)*	*(2,203.3)*	*(1,237.1)*	*(84.9)*	*(0.0)*
Ward	(acres)	471,152	327,406	296,528	168,879	5,746	0	0	182,947	136,650	7,808	0	0
	(km^2)	*(1,906.7)*	*(1,325.0)*	*(1,200.0)*	*(683.4)*	*(23.3)*	*(0.0)*	*(0.0)*	*(740.4)*	*(553.0)*	*(31.6)*	*(0.0)*	*(0.0)*
Winkler	(acres)	488,057	394,090	213,480	262,846	11,732	0	0	138,054	242,324	13,711	0	0
	(km^2)	*(1,975.1)*	*(1,594.8)*	*(863.9)*	*(1,063.7)*	*(47.5)*	*(0.0)*	*(0.0)*	*(558.7)*	*(980.7)*	*(55.5)*	*(0.0)*	*(0.0)*
Total	(acres)	12,194,416	13,402,374	3,968,893	3,441,632	2,160,363	1,764,036	859,492	3,310,593	3,533,926	2,607,413	2,396,065	1,554,376
	(km^2)	*(49,349.1)*	*(54,237.5)*	*(16,061.6)*	*(13,927.8)*	*(8,742.7)*	*(7,138.8)*	*(3,478.2)*	*(13,397.5)*	*(14,301.3)*	*(10,551.8)*	*(9,696.5)*	*(6,290.3)*

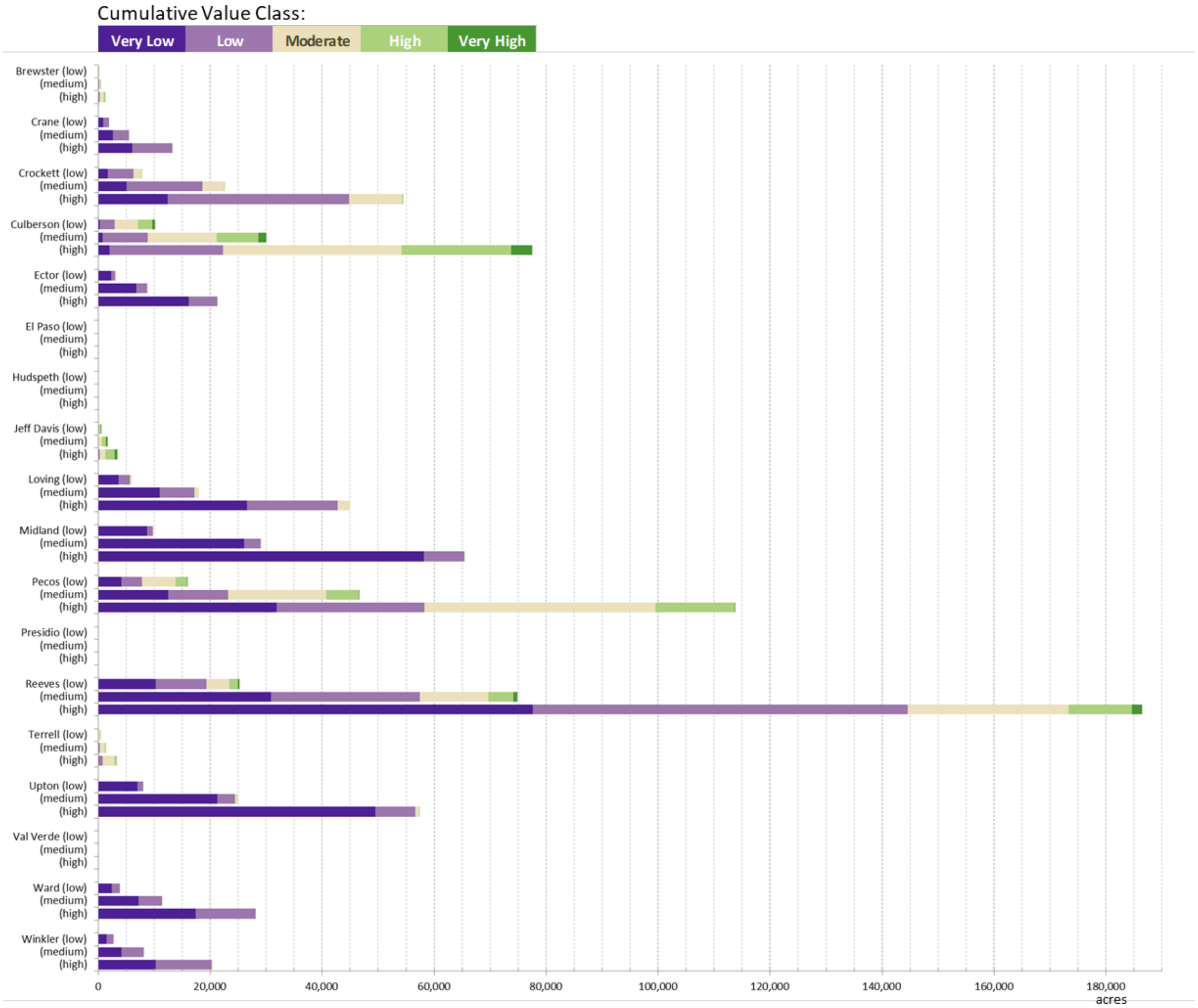


Figure 7. *Overlap of Cumulative Value classes and potential oil and gas footprint by county and by development scenario (low, medium, high) (in acres^2).*

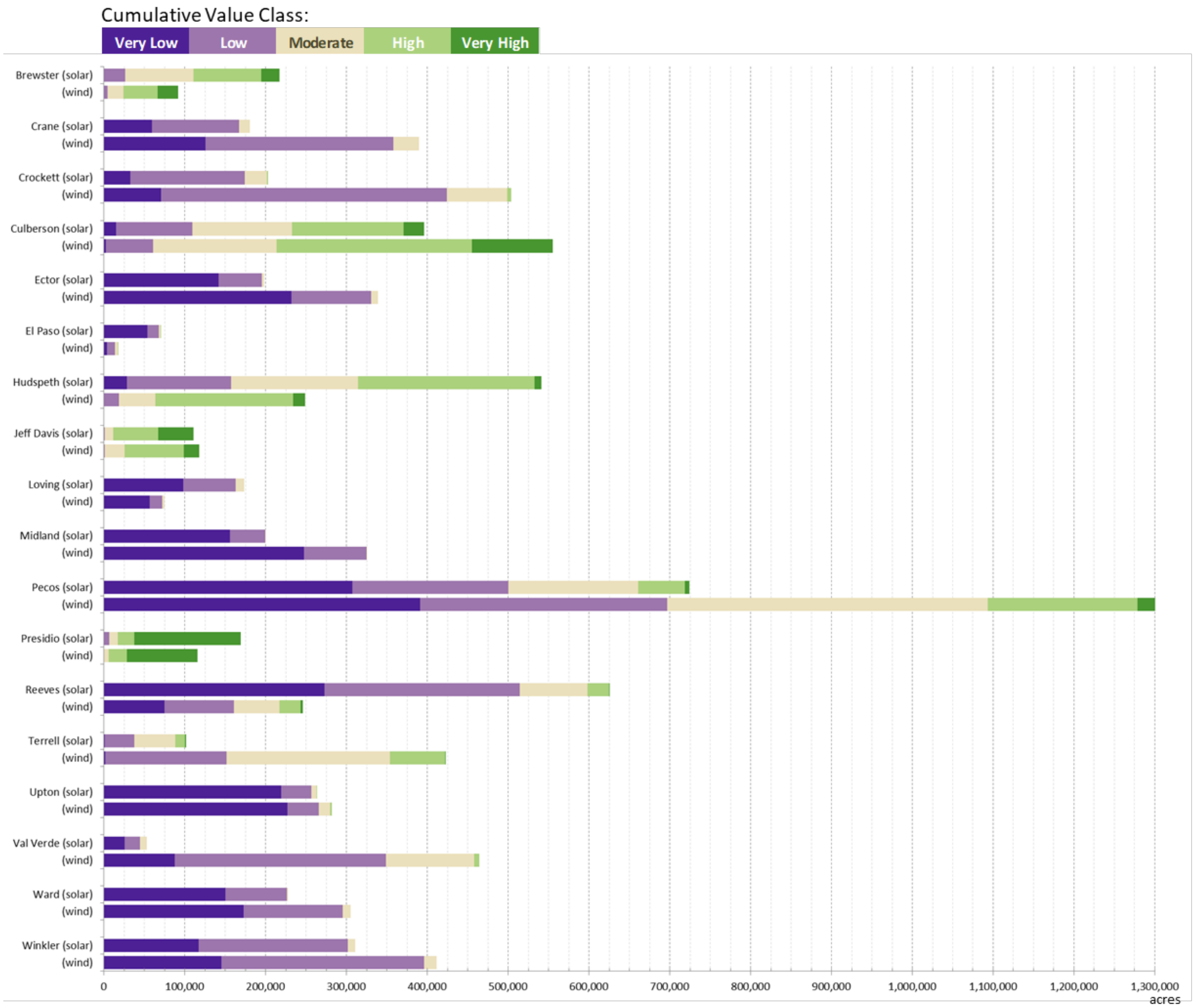


Figure 8. *Overlap of Cumulative Value classes and renewable resource (solar and wind) potential by county (in acres and km²).*

4. HOW TO USE THESE DATA

In the 18-county study area, an evolving transition to a low-carbon energy future is taking place. These developments point to low-emission pathways to meet coming energy demands while minimizing the associated problems of climate change. Although, this story is not without its caveats, renewables have a larger terrestrial footprint per unit energy produced compared to oil and gas production [14] and all forms of energy development will necessarily lead to habitat loss and fragmentation, which in turn is linked to ecosystem degradation, population declines of sensitive species and potential impacts to social values such as recreation and viewsheds. Sub-optimal siting will only intensify these challenges, but how these footprints ultimately play out within this landscape is still undetermined.

The Development by Design approach provides information to manage this challenge of multi-objective land-use decision-making. It harnesses the power of systematic conservation planning to bring a regional context to how the parts of a landscape contribute to the whole – to make conservation values spatially explicit and to understand the potential cumulative impacts of development across time, space, and sectors to those values. The results of our analysis can be used from the landscape to site-level scale (see **Figure 9**) to guide the application of the mitigation hierarchy to better resolve competing goals between development and the conservation of natural resources. That is, to maintain the valued characteristics of a landscape by avoiding and minimizing unnecessary and costly impacts to more sensitive or irreplaceable values, restoring those values where possible and compensating through mechanisms such as offsets for impacts that cannot be entirely avoided or fully restored.

This report outlines some of the ways in which these data can be used to steer land-use decision-making at different scales. Additionally, this report includes best management practices (BMPs) of some of the different ways decision-making can be implemented at the landscape scale to avoid and minimize impacts at the site-level (**Table 5**).

Avoid Impacts

Early planning and mapping of values and projected development enables increased flexibility in decision-making before major investments of resources are already committed. This is especially true for the first step of the mitigation hierarchy – **avoidance**. As a starting point, impacts to High and Very High conservation value areas should be avoided when possible. Alternatively, development should be steered to lower value areas to avert conflicts or costly restoration efforts that would be required after impacts and disturbances occur.

In the 18-county study area, it is projected that 98,348-712,652 acres (398-2,884 km^2) of new well pads, 75,614- 96,371 acres (306-390 km^2) of new solar development, and 270,580-2.7 million acres (1,095-11,093 km^2) of new wind development may be developed. Avoidance is an important strategy for high intensity impacts from energy development that entails complete conversion, as in oil and gas and solar. But there is a wide gap in the flexibility to exercise that first step. For example, in the case of solar and wind development, there are respectively 47 times and 12 times the amount of area within the Very Low cumulative conservation value class with suitable resource potential and facility siting criteria in the lowest development scenario.

Taking the landscape perspective when siting development therefore allows early detection of potential conflicts. Land managers and decision-makers can consider alternatives to steer development away from areas where values are concentrated. This strategy would not obviate the need to further examine the features that may be potentially impacted, since low cumulative value areas are not necessarily low conservation value areas. There may be occurrences of highly sensitive and important values, such as a spring or riparian area, critical animal movement linkages or viewsheds. Additional measures may be needed to avoid impacts.

This regional perspective also aids in understanding the cumulative impacts of multiple potential energy projects within and across sectors on the health of the landscape values, thereby informing efforts to improve siting of associated infrastructure (e.g., roads, pipelines). This can extend to road network design, co-location of infrastructure, and to avoid especially sensitive or irreplaceable values (see **Table 5** for and ***Case Study #1*** for a hypothetical siting of a transmission line).

Minimize Impacts

In the case of projected oil and gas development, at every scenario level, a quarter of the potential new well pads overlap with the upper half of the cumulative values index. With oil and gas resources being narrowly distributed, there are constraints to pursuing a strategy of siting in low cumulative value areas alone. Oil and gas production represents a high intensity and high-density disturbance on the land, but there is still much that can be done to minimize these potential impacts. For example, in areas with high cumulative values, increased efforts can be made to co-locate infrastructure or to increase the number of wells per well pad to reduce overall surface disturbance.

Wind energy facilities represent a lower density form of development that is often compatible with other land uses, such as agriculture. Efforts to minimize potential disturbances from wind development may include targeting already disturbed lands for wind development (e.g., co-locating turbines with agricultural fields). Given turbine spacing needs, wind farms typically use only 2-4 percent of an area, making these facilities compatible with agricultural production. Moreover, compensation associated with development increases profitability of lands that balance agriculture and wind development. While land in row crops yield profits of less than $1,000 per hectare, farmers may receive $4,000-6,000 per year per turbine [16].

For all forms of energy production where development is likely to proceed, there are numerous BMPs that can be adopted to support goals to minimize potential impacts from creating riparian buffers, improving road location, design and construction and restoration activities to reclaim disturbed areas [31](see **Table 5** and ***Case Study #2*** for an example of how the data can be used in the siting of a proposed solar facility to minimize impacts to high cumulative value areas).

Restore

The results of the landscape analysis can also be used to target areas for restoration activities to maximize regional ecological outcomes or to prioritize values under heavy threat of disturbance for restoration focus. For example, land managers may want to focus restoration actions to buffer around high conservation value areas that in turn can preserve ecological functions or address degradation of critical pinch points in migratory corridors (see **Table 5**). However, there are limits to what can be adequately restored and uncertainties that restoration actions will succeed. As such, restoration actions should only be considered after efforts have been made to avoid or to minimize potential disturbance to an area of value.

Offset Impacts

Voluntary offsets to compensate for impacts from development, that cannot be reasonably avoided or minimized, is the last step in the mitigation hierarchy. There is broad guidance available on offset accounting to quantify offsets required to balance current or projected development disturbances against future gains to those elements impacted facilitating no net loss or net gain goals. Although a straight calculation of area directly or indirectly disturbed is the first and foremost factor considered, other criterion can include the functional quality of the value impacted (i.e., impact), the background rates of loss (i.e., the degree of threat), the duration and permanence of impact, and the time lag and probability of success in achieving equivalent habitat gains. The data created in this landscape analysis can be used to help establish a baseline of indicators from which to determine appropriate mitigation and offsets for unavoidable impacts.

Offsets can compensate for direct and indirect impacts to landscape values by preserving existing high-value areas currently under threat from non-compatible land uses or by improving habitat conditions through restoration activity. Offsets can be an especially useful mechanism to fund conservation action in a landscape dominated by private landownership. Specifically, offsets can be used to fund a Payment for Ecosystem Services (PES) program to compensate private landowners who forgo development and its associated economic gains and who instead manage their lands to maintain these community-identified values, such as providing enhanced habitat for wildlife, maintaining water quality or flows and preserving scenic views, for example.

The conservation vision is a useful starting point in identifying potential candidates for offset actions. For example, as seen in ***Case Study #3***, the attributes of different areas or parcels for conservation easement funding are compared. Alternatively, rare and sensitive systems, degraded habitat for declining species, or important pinch points for migratory corridors can be targeted for compensation to improve and restore natural cover and linkages that maintain animal movement and long-term population health in the landscape.

The future of energy production and persistence of those landscape assets that characterize the Trans-Pecos and the Tri-County Region will work itself out through a series of decisions about what goes where and what gets preserved. How likely the multiple objectives and needs of the region, the communities within it and the biodiversity elements and the people who call this place home are met, can only be improved by forward planning that incorporates landscape values alongside energy development. Overall, this report and analysis highlights that there is much to agree on about the important attributes of the region, that there is space and time available to provide for energy needs in a way that minimizes adverse impacts and that options exist of places to allocate resources to manage and conserve the attributes that make the place unique.

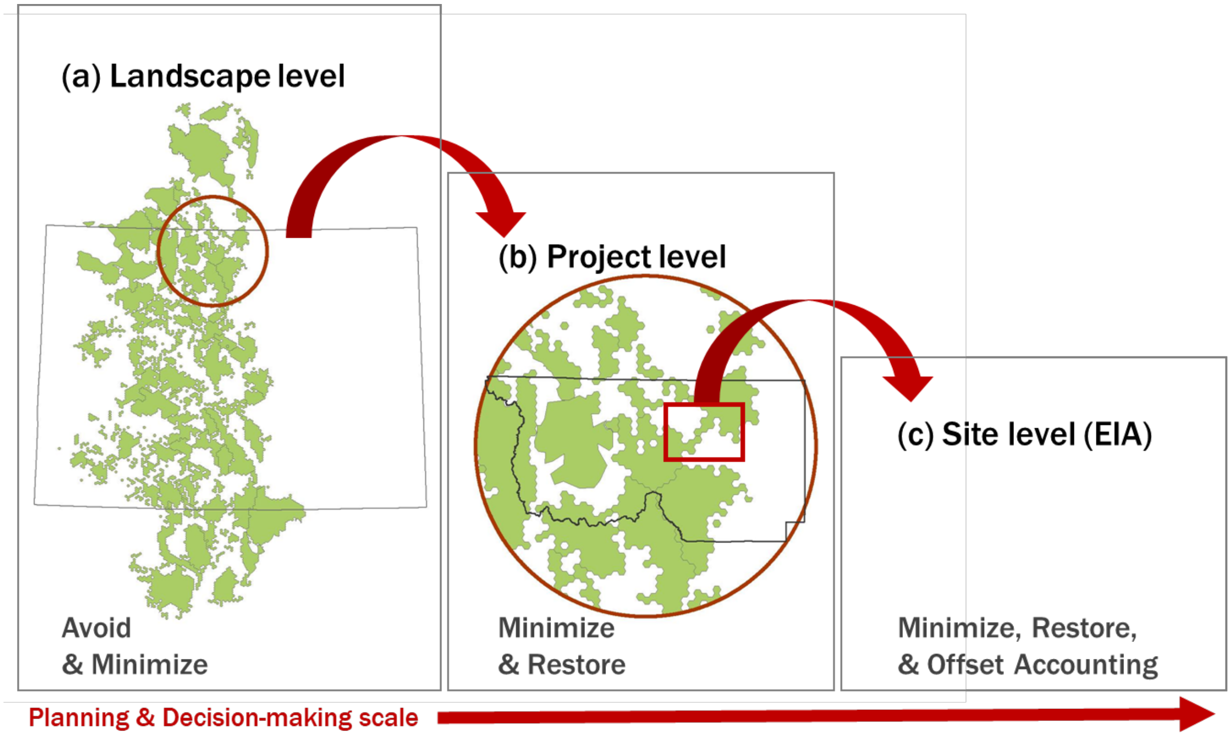


Figure 9. Landscape-level planning and decision-making framework.

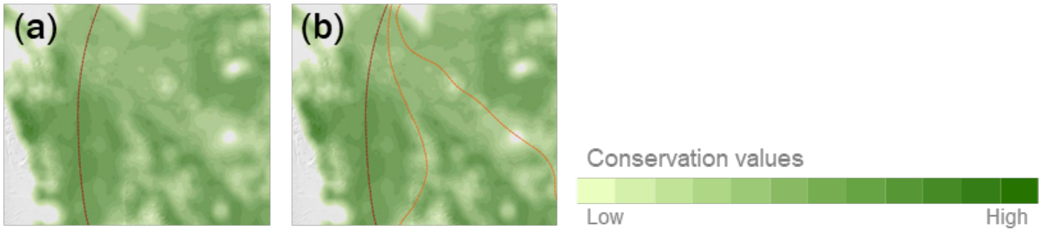
Table 5. Best management practices (BMPs) with general descriptions to mitigate potential impacts from oil and gas development. Table is reproduced and refers to Bearer et al 2012 [31] for an assessment on effectiveness of different BMP options.

BMP Category	**BMP subcategory**	**General description**
Comprehensive planning	Landscape-development planning	Plan and coordinate early at the landscape level and promote shared infrastructure. Well pad sites and infrastructure should be co-located with existing infrastructure (roads, pipelines, water sources) to minimize surface impacts.
Constraints mapping	Avoid forested areas	Generally, forested areas should be avoided in favor of open lands to reduce forest fragmentation, changes in storm runoff, protection of stream buffers, and preservation of existing water quality in streams.
	Avoid aquatic/riparian habitats	Operations should avoid riparian areas, floodplains, lakeshores, wetlands, and areas subject to severe erosion and mass soil movement.
	Avoid erosion-prone areas	Construction on steep slopes (over 15 percent or 30 percent) or highly erodible soils should be avoided. Level areas are preferred for site selection. If these areas cannot be avoided, the access road should be located in a manner that would minimize cuts and fills.
Erosion control	Buffer strips	A buffer strip of vegetation, width determined on a case-by-case basis, shall be left between areas of surface disturbance and riparian vegetation.
	Storm-water-control structures	It is strongly recommended to design storm-water-control structures and practices based on a 10-year/24-hour storm, not a 2-year/24-hour storm. This will provide better protection from the effects of larger storms on erosion, sedimentation, and stream stability.
	Road-construction limitations	Construct roads along the contour of the hillside. Avoid going directly up the lope or exceeding slopes of 15 percent. Properly space and install waterbars and/or culverts to prevent erosion problems.
	Erosion control products	Surface roads within 50 feet of waterways with erosion-resistant materials. Immediately stabilize cut banks and fill by using vegetation, rock, erosion blankets, or other suitable material. Install silt-fence barriers at outlets of drainage structures.
	Sediment barriers	Use hay, stray bales, or silt fences for sediment barriers in areas where excessive soil loss or sediment loads to a watercourse.
Infrastructure development	Road location and design	Access roads should be kept out of lowland bottoms, drainages, wet areas, and special status and threatened and endangered species habitat.
	Road-construction guidelines	Provide proper road drainage and erosion control for all road (e.g., use the Pennsylvania Dirt & Gravel Road guidelines for construction of permanent nonpaved roads). Ensure the maximum volume, weight, and speed of vehicles on surface roads are marked and enforced.

BMP Category	BMP subcategory	General description
	Stream-crossing guidelines	Design road crossings of streams to allow fish passage at all flows and to minimize the generation of sediment
	Dust suppression	Avoid dust-suppression activities within 300 feet of the ordinary high-water mark of any reservoie, lake, wetland, or natural perennial or seasonally flowing stream or river.
	Stream-crossing guidelines	Locate and construct all structures crossing intermittent and perennial streams such that they do not decrease channel stability or increase water velocity.
	Road location and design	Avoid crossings of wetland and riparian areas by linear features. Avoid road placements that bisect movement pathways. If a new road must cross a stream, it should be done at a 90° angle.
Lighting	Minimize and contain lighting	Direct site lighting downward and internally to the xtent possible and avoid uplights and wall washes, as well as lighting where the bulb is visible from the fixture.
Noise control	Minimize noise	Reduce noise from industrial development or traffic by using effective sound-dampening devices and techniques or by collocating infrastructure, especially in breeding and brooding-rearing habitats.
Restoration	Reclaim roads	Design for retirement (minimum compaction). Retire roads not used for regular well access as soon as possible.
Timing of operation	Seasonal restrictions	Enact seasonal restrictions on drilling and developing in areas with sensitive species (e.g., migration, breeding, or dispersal of sensitive species) or during critical nesting and mating seasons.
	Seasonal restrictions	Operations should avoid wet seasons and wet periods.
Vegetation management	Vegetation removal	Cutting by hand is the preferred method for removing/clearing vegetation. Use of mulchers and all-terrain vehicles should be avoided because they have significant potential to remove threatened and endangered species and introduce/spread invasives.
	Riparian vegetation	Do not remove native riparian canopy or streambank vegetation where possible. It is preferable to crush or shear streamside woody vegetation rather than completely remove it.
Wildlife	Bat roost sites	Void surface disturbance activities within 0.25 miles of all bat roost sites.
	Raptor nest-side buffer	Well pads, access roads, and other aboveground facilities will not be located within 825 ft of an active raptor nest, within 1000 ft of an active threatened species hawk nest, or within 2640 ft of any bald eagle nest.

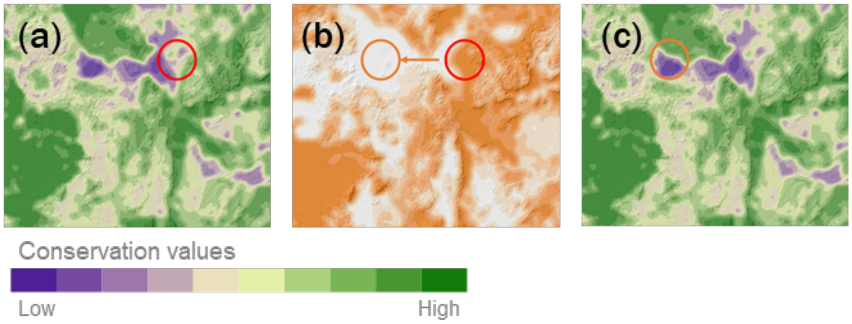
BMP Category	BMP subcategory	General description
	Breeding-habitat buffer	Although adequate buffer distances are unknown, because of the tendency for brooding females and nesting yearling females to avoid gas-field infrastructures, areas designated as suitable breeding habitats need to be buffered from gas-field development.
	Road closures	Road closures may be implemented during crucial periods (e.g., wildlife winter periods, spring runoff, and calving and fawning season).
	Seasonal restrictions	Schedule necessary construction in stream courses to avoid critical spawning times.
	Wildlife crossing	Manage pipelines for shrub cover rather than grass and create forested linkages at intervals across rights-of-ways to facilitate wildlife crossings.

Example 1. Avoid: Finding alternative routes for proposed transmission line



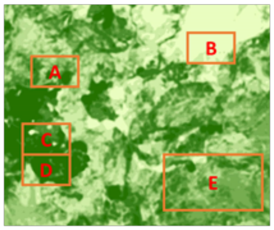
In this example, a proposed transmission line is examined (a). Overlaid on the conservation values map, it can be see that it cuts across high cumulative value areas and further of the underlying inputs shows that the transmission line would fragment one of the largest examples of intact grasslands in this county. Decision-makers might consider alternative routes (b) that follow lower cumulative value areas putting fewer important conservation values at risk of disturbance.

Example 2. Minimize: Relocating proposed wind turbine installation



In this example, potential impacts of a proposed wind turbine siting are especially concerning (a) to viewsheds in this important recreational area. The proposed site is overlayed on the data modeling viewshed areas (b) and alternative sites are considered where the proposed turbine does not impact the viewshed. It is confirmed with a second review of the cumulative values layer (c) that this new location is also unlikely to impact other values.

Example 3. Offset: Considering conservation easement acquisition among parcels



PARCEL	Acres	Cumulative Score (% in 3 categories)	Grassland	Riparian/ Welands	Bighorn	...
A	2200	25	700	100	100	
B	2000	0	100	100	1500	
C	1700	90	900	100	100	
D	2000	75	1500	100	50	
E	5000	35	3000	250	500	

In this example, a land trust is interested in acquiring a conservation easement to protect and restore critical grasslands areas. The land trust might consider prioritizing opportunities by using the conservation values map to take in to account the co-benefits to important species and systems of interest that occur on parcels under review. Additionally, landowners can see what values overlap with their parcels of land and connect with organizations and agencies that may be interested in partnering for restoration or conservation action.

5. LEGAL & POLICY ISSUES RELATED TO ENERGY DEVELOPMENT IN TEXAS

Approximately 95 percent of the land in Texas is privately-owned [32]. That means that most of the energy development in Texas – oil and gas, as well as wind and solar – occurs on private lands, and the terms and conditions under which the development is carried out are determined through negotiations between private landowners and energy companies. While the majority of energy development occurs on private lands, the General Land Office (GLO) leases approximately 13 million acres of state-owned land for oil and gas and renewables development and the University of Texas/Texas A&M Investment Management Company (UTIMCO) leases about 2.1 million acres on behalf of the Permanent University Fund. This section of the report discusses policies relevant to energy development on private and public lands in Texas.[1]

The land impacts of energy development, which are associated with land clearing and infrastructure development, including roads, pipelines, equipment, well pad construction, and the installation of solar panels or wind turbines, are experienced at the individual property owner-level and across the landscape. Effects of these types of development can include soil erosion and contamination, landscape fragmentation and habitat loss, light pollution, destruction of native vegetation, water use and contamination and more. The spatial area cleared for pipelines, transmission lines and other infrastructure often far exceeds that of the well pads and solar panels [33]. The extent and severity of land impacts resulting from development vary, depending on the intensity of the drilling operation or the size of the renewables project.

In addition to environmental impacts, energy development may affect neighboring landowners by reducing the aesthetic value of their property or affect property values. Energy development has been known to impact nearby communities. In boom times of intense development, communities benefit from increased sales tax revenue, well-paying jobs and increased investment into the community. Unfortunately, there are negative impacts too. Increased traffic, dust, air and water pollution, light pollution, inflation, over-crowded schools and noise were among the negative impacts of energy development identified by residents of West Texas communities when they were surveyed in 2017.[2]

With energy development occurring primarily on private land in Texas, this section discusses the legal and policy tools and resources available to private landowners to manage the terms of energy development on their property, helping to reduce the negative impacts that could occur. This section principally focuses on issues relevant to siting decisions, in order to reduce the impacts of development on the land. The various regulatory requirements that address water, air pollution and waste, or specific best management practices for oil and gas, wind, and solar development are not described.[3]

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[1] There is a very small amount of federal public land in Texas leased for energy development. This chapter does not discuss leasing practices on federal lands.

[2] The results of the survey are discussed in detail in Chapter 2 and further in Supplement section 1.

[3] Examples of Best Management Practices that have been developed by the energy sector are included in Section 4.

Where relevant, aspects of the GLO's and UTIMCO's leasing programs are discussed, noting that those agencies control the terms of energy development on their lands.

In Texas, there are few legal requirements that apply to the siting of oil and gas wells and utility-scale solar facilities and wind farms. The following is a brief description of the requirements that do exist, which is intended to provide context for the tools and resources that are presented in this section.

Oil and Gas

The Railroad Commission of Texas (RRC) has jurisdiction over most aspects of oil and gas development. RRC regulations require that oil and gas operators file and maintain an approved Organization Report that serves as a license to operate in Texas, and the Organization Report must be renewed every year (See 16 TAC §3.1(a)- (h)). To be in good standing, an operator must provide financial security and keep accurate records of its operations, including the amount of oil and gas produced by each well and the amount of oil on hand at the end of the year.

Prior to drilling a new oil or gas well, an operator must obtain a drilling permit from the RRC (16 TAC § 3.5). The permit application requires information about the location of the well and the depth of the producing formation, among other things. The operator must comply with the RRC's well spacing requirements (16 TAC § 3.38). The statewide spacing rule provides that no well for oil, gas, or geothermal resource may be drilled closer than 1,200 feet to any well completed in or drilling to the same horizon on the same tract. In addition, no well may be drilled nearer than 467 feet to any property line, lease line, or subdivision line (16 TAC § 3.37).[4] The spacing rules are designed to prevent waste and protect the property interests of the mineral rights holders, not to address the land impacts of energy development that are the focus of this project.

Under state law, an oil and gas operation is subject to the exclusive jurisdiction of the state of Texas; municipalities and counties have only limited authority to enact measures that regulate oil and gas operations within their boundaries (TEX. NAT. RES. CODE §81.0523). Municipalities are allowed to regulate only aboveground activity related to an oil and gas operation, including measures that govern fire and emergency response, traffic, lights, or noise. They are also permitted to enact "reasonable setback requirements"(TEX. NAT. RES. CODE §81.0523) from schools, hospitals, subdivisions, and the like. Municipalities may not enact bans or limits on oil and gas operations that would effectively ban the operations.

While the vast majority of oil and gas development occurs on private lands, a substantial amount takes place on Texas state lands (13 million acres) and lands managed by UTIMCO (2.1 million acres). The GLO manages energy development on state-owned lands, including submerged land along the coast, and university-owned lands are managed by UTIMCO. Revenues generated from GLO leases support public schools in Texas through the Permanent School Fund and revenues generated from the Permanent University Fund

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[4] The RRC may grant exceptions to these requirements if necessary to protect waste or private property interests.

lands support the University of Texas and Texas A&M University systems. GLO and UTIMCO have developed standard leases that are used in their transactions with energy operators.

Wind and Solar

Decisions about where to site new wind and solar facilities are driven by economics (for example, proximity to potential customers and transmission lines, and landowners' interest in leasing their property to a developer) and the potential of the site to generate electricity (how sunny or windy it is, for example, and factors like the slope of the land). In Texas, there is no formal process for public or agency review of siting decisions and there are few regulatory hurdles for renewable energy developers who plan a new facility. Indeed, the lack of regulations is cited frequently as one of the principal reasons that Texas has substantially more wind generation currently (over 24,000 MW) than any other state [34].

Over the years, the Texas Legislature has considered a handful of bills that would have created some degree of regulatory review of renewable energy facilities. In 2007, the legislature considered a bill that would have required the Texas Commission on Environmental Quality (TCEQ) to certify new wind farms, but the bill did not make it out of subcommittee (H.B. 2794, 80th Leg. Reg. Sess. (Tex 2007)). In 2019, a bill was introduced in the Texas Legislature that would have given the Texas Parks and Wildlife Department (TPWD) authority to weigh in on wind farms proposed for development near the Devil's River, but the bill did not pass.[5] The 2019 Legislature did pass HB 2845, which requires new wind leases to include specific provisions related to the removal and decommissioning of equipment after a facility ceases operations. The bill applies to wind leases signed after September 1, 2019. In 2017, the legislature passed the only bill that can be characterized as a siting bill: S.B. 277 denies wind farms located within 25 nautical miles of a military base the advantage of a tax abatement agreement with a county under the Texas Tax Code.

Local governments have limited authority over siting renewable facilities in Texas. Municipalities have zoning authority pursuant to the Local Government Code, including the power to regulate the height of structures, the location, setback, and percentage of a lot that may be occupied (TX Local Government Code Sec. 211.003). Approximately 24 local ordinances have been enacted in Texas that affect mostly small wind facilities (less than 100 MW), focusing primarily on height restrictions and setback requirements. For facilities constructed outside of a municipal jurisdiction, there are no siting regulations. Counties have the authority to withhold property tax abatement benefits that the renewable energy facilities could apply for as a way to discourage development, but otherwise, counties have no power to prohibit a new facility or regulate the issues associated with siting.

The few regulatory approvals required for new commercial scale wind farms and solar facilities are handled by the Electricity Reliability Council of Texas (ERCOT). ERCOT requires new electric generators of any type over 10 MW to complete a registration process

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[5] HB 4554 was intended to address the concerns of a number of private property owners near the Devil's River who were concerned about the impact of wind development on wildlife and scenic vistas. The bill received a hearing, but not a vote.

before selling electricity through the Texas electricity grid [35]. ERCOT also requires that new facilities enter into an interconnection agreement with a transmission service provider prior to connecting to a transmission line. The ERCOT registration process and interconnection agreement requirements do not address siting issues.

Policy Tools to Minimize Damage to Land from Energy Development

With almost no regulatory tools available in Texas to influence decisions about siting energy developments, private landowners, GLO and UTIMCO rely on contracts – surface use agreements, leases, and, sometimes, easements – to protect land resources. There are no regulatory mechanisms through which members of the public other than landowners have a say in the terms or location of energy development. There is no public notice requirement prior to development of an oil and gas field or renewable energy facility.

Surface Use Agreements

A surface use agreement is a voluntary agreement between the surface owner and the mineral owner/lessee (usually an oil and gas company) that describes the terms under which the property will be developed, the company's right to use water resources, roads, buildings, and other attributes of the surface, and the restoration that the company will carry out after the site is developed. Some states, including New Mexico and Oklahoma, require operators to enter into surface agreements with surface owners. In Texas, such agreements are not required by statute.

There are two distinct property rights with respect to land: the mineral estate and the surface estate. Mineral rights are severable, meaning they can be sold or conveyed to a third party separate from the surface rights. Once severed, the mineral interest holder has an implied easement to use the surface of the land for oil and gas exploration and development (Sun Oil v. Whitaker, 483 S.W. 2d 808 (Tex. 1982) (reh. Den'd)). The holder of the mineral rights may use as much of the surface of the land as "reasonably necessary" to access the minerals underneath, with few limits.[6] One scholar has described this right to use the surface as including "the legal privilege to use the surface in a way that interferes with the surface owner's use of the land and that significantly damages the surface, without the legal obligation to make any compensation whatsoever." [36].

Because the mineral rights are superior to, or *dominant* with respect to, the surface rights, in situations in which all of the mineral rights have been severed from the surface and conveyed to a third party the surface owner has very limited leverage to force the mineral owner to minimize damage to the surface during development, or to otherwise influence decisions about the development of the surface. Some oil and gas operators voluntarily negotiate with surface owners, however, in order to minimize disagreements and friction.

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[6] The mineral owner has the right to use as much of the surface as is "reasonably necessary" to access the minerals. Courts have been reticent to find that mineral owners exceeded that standard in particular cases. "Reasonably necessary" has been held to include a variety of activities related to oil and gas development, including drilling wells, building roads, pipelines, storage and processing facilities, and the use of water.

In cases where the surface owner retains even a fraction of the mineral interest, the surface owner has leverage to negotiate.

A surface use agreement is an increasingly popular tool used by landowners to protect their property. The agreements can be used to specify activities associated with development, including (1) the location and size of infrastructure and roads; (2) remediation that will be required of the surface post-development; (3) the use of surface and groundwater resources; (4) specific development practices to minimize the disturbance of ranching and farming on the property; and (5) monetary damages that will be paid to the surface owner, under appropriate circumstances [37].

A surface use agreement can be an effective tool for reducing the land impacts of energy development. Examples of terms that could be used to protect the values that are the focus of this report include (1) requiring the operator to drill multiple horizontal wells from the same drilling pad, in order to reduce fragmentation caused by roads, pipelines and other infrastructure between wells; (2) requiring the operator to construct fencing or other visual screens where the drilling operation interferes with open space or views; (3) requiring the operator to reduce the size of the drilling pad after the well is completed or plugged as a dry hole. In addition, some surface use agreements require payment by the operator per acre of land impacted. This provision encourages operators to consolidate their drilling locations and minimize their spatial footprint [36].

Surface use agreements for oil and gas operations are often appended to the lease. The same type of provisions described for oil and gas could be included in the leases for wind and utility-scale solar facilities. Lease provisions are described below.

Leases for Renewable Energy Facilities

Establishing a wind farm or utility scale solar facility on private land requires a contractual agreement – usually a lease – with one or more private landowners, allowing the developer to develop the surface of the property. In cases where the mineral rights have been severed from the surface, the developer will want to secure the agreement of the mineral owner, as well, and possibly negotiate the location and scale of future oil and gas development up front. Otherwise, there is a risk that later the mineral owner could demand access to the oil and gas resources on the property, which could disrupt the wind or solar facility's operations. Keeping in mind that the mineral estate is dominant to the surface estate.[7]

A lease for renewable energy development generally provides that the lessee (the energy developer) will have access to the surface as "necessary, helpful, appropriate or convenient" to construct and maintain the energy facility. In addition to the wind turbines and solar panels, this includes transmission and gathering lines, roads, storage facilities, pipelines, and maintenance yards, among other things. The lease generally has a lengthy

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[7] This chapter does not describe the specific measures that can be adopted to minimize conflict between mineral rights holders and renewable energy developers. For a detailed discussion of that topic, *see* E. Smith, J. Lederle, W. Berg, "Everything Under the Sun: A Guide to Siting Solar in the Lone Star State," TEX Oil Gas and Energy Law Journal, Vo. 12 (2017) [38].

term – for wind farms, the term can be 30-50 years or more – sometimes after a shorter initial term, during the which the developer assesses the viability of the site.

The landowner's interests in the surface can be protected through provisions that ensure that ranching and agricultural activities can continue and recreational activities, including hunting, are allowed, usually under specific conditions (the lease would specify details such as access to the property, location of the turbines or solar panels, protection of existing structures, and the like). For surface owners who also own the minerals under their land, the lease should include provisions that would ensure appropriate access to the oil and gas on the property. The lease should also include a provision to compensate the landowner if damages occur during the construction or operation phase of the facility.

During the negotiating process with the energy company, landowners have considerable leverage to negotiate for provisions to protect the important values on the property, such as scenic views, dark skies, and wildlife habitat. It is important that the landowner have competent legal representation during the negotiation phase to protect her interests.

University Lands' Lease for Oil and Gas Development

University Lands uses a standard lease with operators who drill on lands managed by UTIMCO. The lease contains a number of provisions that are designed to protect the surface of the land and minimize the environmental harm associated with drilling, including (1) a requirement that operators take measures to reduce waste generated; (2) avoid flaring and venting and other sources of air emissions, (3) undertake adequate plugging of abandoned wells; (4) maintain at least a 300-foot setback from any residence, barn, or other facility; and (5) restore the surface, as close as possible to the condition it was in before any operations or activities were commenced under the lease [39]. Under the lease, UTIMCO retains control over access to the surface, rights-of-way, access to water, and other resources.

The lease also contains a stringent surface damage provision. It reads:

> SURFACE DAMAGES. Lessee must repair, restore, and pay for all damages resulting from Lessee's, its representatives', agents', subcontractors', designees', assigns', and successors' activities under this Lease, including without limitation damages to real and personal property, water wells, improvements, livestock, and crops on the Leased Premises or adjacent lands owned or controlled by Lessor, regardless of the cause of such damage, pursuant to the then-current Rate and Damage Schedule. Lessee acknowledges that the cost of such repairs or damages contemplated by this Section or any other provision of this Lease requiring restoration or repair may exceed the fair market value of the property damaged, and the cost of such damages and repairs will not be limited by fair market value. By executing this Lease, Lessee agrees to promptly complete all required repairs, and no release, forfeiture, or termination of this Lease will relieve Lessee from its obligations under this Lease or pursuant to applicable law, including the obligation to plug all wells and clean and restore the Leased Premises (16 TAC § 3.38).

The University Lands lease is a model that should be used as much as possible by private landowners across Texas when negotiating with oil and gas companies.

University Lands has also developed standard lease agreements for use with wind and solar developers. There are currently four solar leases and three wind leases on University Lands. Like the oil and gas lease, the wind and solar leases protect the rights of the surface owner (UL) by ensuring that the developer must (1) obtain permission from University Lands prior to constructing roads and other infrastructure; (2) remove all equipment when the facility is decommissioned; and (3) restore the surface to its pre-development condition.[8] There are also provisions to ensure that other uses of the property may continue after development, including ranching, hunting, and oil and gas development. Like the University Lands lease for oil and gas, the wind and solar leases are excellent models for private landowners to use when negotiating with a renewable energy company.

General Land Office Lease for Development of State-Owned Oil and Gas

Like University Lands, the GLO uses a standard lease form when leasing mineral rights to an oil and gas company.[9] Though it is not as detailed and explicit as the University Lands standard lease, it also includes provisions to ensure that the surface owner is compensated when the operator damages the surface. The lease contains provisions related to the protection of the land, but does not reserve as much authority to the surface owner to approve development decisions as the UL lease does. The GLO also negotiates leases for utility scale solar facilities and wind farms on its land.

Conservation Easements

Another important tool for protecting the values associated with land – for example, scenic vistas, wildlife habitat, and water recharge – is the conservation easement. A conservation easement is a voluntary, binding legal agreement that restricts the otherwise permissible uses of the land in order to protect the land's conservation values. Usually, a conservation easement is a permanent restriction; that is, the easement becomes incorporated into the title of the land and binds both current and future landowners to its terms. Occasionally, temporary, or "term," easements are negotiated between landowners and government agencies or nongovernmental organizations, to provide shorter-term protection of the property.

Easements can take myriad forms and be crafted to address the unique circumstances of individual landowners. For example, some conservation easements provide that certain existing land uses, such as grazing and hunting, can continue on the property, but prohibit the construction of structures greater than a specified size. Others might cover only a portion of a landowner's property but have no effect on the remainder.

Easements provide tax benefits for the landowner. If the easement is donated to a non-governmental organization or a government agency, the landowner receives a federal tax deduction up to the landowner's adjusted gross income. Once the easement is in place, the

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[8] *See, e.g.,* University Lands Wind Lease (2017) *available at* http://www.utlands.utsystem.edu/Content/Documents/Operations/Wind_Lease.pdf.

[9] The lease is available at https://www.glo.texas.gov/energy-business/oil-gas/mineral-leasing/leasing/forms/Form_Relinquishment_Act_Lease.pdf.

appraised value of the property is usually lower than the fair market value prior to the easement, so the property tax rate will be less.

Easements are an effective tool for managing the surface uses of property, including protecting scenic vistas, because they govern the uses that will be allowed on the surface. It is important to note that a conservation easement that covers the surface does not necessarily prevent the development of the mineral resource by the mineral rights owner. The mineral rights owner has the right to use the surface to develop the mineral resource, even if there is a conservation easement in place.

Conclusion

There are few legal tools available in Texas to control energy sprawl. Oil and gas leases are negotiated by individual land (or mineral) owners and energy companies. There is no requirement that the public be notified prior to leasing and no requirement that the companies notify other landowners about the terms they have offered to their neighbors. It is up to each individual landowner to negotiate the most favorable terms possible, to minimize the potential for damage to the surface and protect the most important resources on the property. The model lease developed by University Lands is a useful template for individual landowners to use as they negotiate with energy companies themselves.

Renewable energy facilities require no state permits. Regulation is left to local governments and only a handful of cities in Texas have enacted ordinances that address setbacks and height restrictions. There are no applicable requirements for siting facilities outside city limits. Like for oil and gas, it is up to individual landowners to negotiate the most favorable terms possible to minimize the negative impacts on their property associated with development.

Texas has no state law that requires operators to negotiate surface use agreements prior to drilling like New Mexico, Oklahoma, and other states. It also has no surface damage act to ensure that surface owners are compensated when energy development damages the surface. In fact, Texas is the only major oil producing state without a surface damage act. To date, efforts to introduce a surface damage act in the legislature have failed.

To control energy sprawl on the landscape, it is important for property owners, interested community members, and energy companies to communicate as openly as possible and discuss options for minimizing negative impacts of development. The Respect Big Bend spatial tool provides extensive data about the location of key values that community members in the Big Bend Region identified as most important. The tool can be used to assess siting options that would avoid or minimize impacts on those places and ensure that individual properties are protected as much as possible.

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SUPPLEMENT

S1. Public Opinion Research Findings

In the fall of 2017, the Cynthia and George Mitchell Foundation commissioned Hudson Pacific to conduct public opinion research on how energy development in the Greater Big Bend region is perceived by Texans statewide, with a particular focus on area residents' opinions.

What we learned is meant to inform an approach to energy development in the region that better aligns the interests of residents, landowners, and their communities with energy developers and mineral rights holders.

We set out to answer two basic questions:

1. How much do Texans know about energy development taking place in the Trans-Pecos?
2. What do Texans think about it? Do they see it as an economic opportunity for their communities? Do they have concerns about impacts to their short- and long-term way of life?

Hudson Pacific explored these primary questions in two phases:

1. **Phase One:** residents in the region, who are the focus of this work; and
2. **Phase Two:** Texans statewide.

In the first phase, Hudson Pacific conducted a series of six focus groups with a diverse mix of residents from the communities of Alpine, Fort Davis, and Balmorhea/Pecos. In phase two, Hudson Pacific conducted a telephone survey (50 percent landline phones; 50 percent mobile phone), resulting in 1000 interviews with Texans statewide and an additional 200 interviews with Trans-Pecos residents.

Results – Phase One

The Alpine Community: When it comes to awareness of energy development in the Trans-Pecos, proximity matters. The people of Alpine, who are removed from energy development in the Permian Basin, focused on the solar installations on the outskirts of town and the pipeline that was built in their community recently.

The Fort Davis Community: Fort Davis residents were somewhat more aware of actions related to the Alpine High discovery, although their attention was focused more on the oil and gas development to their northeast in the Midland-Odessa region.

The Balmorhea and Pecos Communities: The residents of Balmorhea and Pecos shared how they are experiencing the impacts of energy development right now. But even among those who are closest to it, awareness of the biggest find in the region, the Alpine High, continues to be non-existent more than two years later.

> *"You may not know Alpine High, but a lot of people know about the fracking that's going on up in Balmorhea. There is a lot of talk about that, at least in the circles that I move in…."*

Trans-Pecos General Comments

Generally, we found that residents of the Trans-Pecos are resigned to energy development in their area. As one participant put it, "you know you live in Texas, right?" They express frustration at a lack of reliable sources of information—they lament the loss of reliable local news sources—as well as not having a voice in the process, either directly or through their elected representatives.

We heard that energy companies had convened meetings in their towns to explain what was happening; however, they felt that key decisions had already been made. Leaders were neither listening nor asking for input on how development can coexist with communities. Instead, they were simply outlining what was already a "done deal." And, while residents expect local leaders and elected officials to advocate for them and help coordinate development activities to limit impact on communities, they see most efforts as ineffective or having significant conflicts of interest.

> *"That's definitely our city council and city managers. They're not doing their job."*
>
> *"Now here's the guy who said he's leery of government getting involved, but I think the city fathers ought to be involved and ought to be speaking for us, and they ought to be listening to us when we talk to them about what—they're our employees."*
>
> *"I think there's so many conflicts of interest you can't get anywhere. That's what the problem has been from the beginning."*

Trans-Pecos Residents' Perceptions

In terms of the perceived downsides, we heard the most concern about traffic. Although this may seem surprising, on average, one person is killed daily on the roads congested with heaviest energy-related traffic. For those in the Balmorhea/Pecos area, they say they experience the impacts in real time, whether it's noise, structural damage to their homes, energy industry truck traffic on their roads, or shortages of and inflation in the price of every day goods such as gasoline and groceries.

People also express concern about development's impact on natural resources—the water supply, Balmorhea pool, and the potential for water contamination. Environmental impacts also could deter tourism, which residents see as a critical part of their respective local economies.

> *"When I decided to move here…. One of the attractions and one of the things that I looked at was what's the water source, 'Oh, aquifer.' There's a college, 'oh good.' There's a little emergency room/hospital, 'oh good.' What's the population, and how long has the population been 6,000? A long time, and that's a big attraction to me."*
>
> *"This is a tourist community, and guess what? Tourists aren't going to want to come if they have to dodge trucks and pull over and wait…and it's ugly…because it's beautiful now. They come here because it's beautiful and there's stuff to do."*

> *"I gave the impression that I want to see growth, [but] I'm not saying, 'Oh, let's be our own Fort Stockton.' No, not at all, but the town needs an income, and the income isn't ranching anymore. It's absolutely tourism. That is what's going on here. Now, you start putting oil fracking and that kind of thing, that changes the whole flavor of Alpine."*

Residents of the Trans-Pecos are an independent bunch. They live there for a reason and, even in the face of potential impacts from energy development, they are loath to see government play a larger role in the area. That said, they have a pretty clear idea of what they would like to see.

Residents would like to see more thoughtful short- and long-term planning, and they would like to have a bigger, meaningful say in that planning—which begins with improved information about what is happening in the region.

> *"Yeah, it's the city council. You can go to the meetings, but the city council, they really don't listen, I don't think."*
>
> *"Don't just give people a voice to hear what they have to say; act on what they say and develop empathy for the local people and not just your bottom line because you're a public corporation."*

Residents also said that planning should include making sure the area's infrastructure is sufficient to meet the scale and scope of the planned development.

> *"The infrastructure is not holding up to what's going on. You don't have the civic leaders in place that you should that are one step ahead of the game."*
>
> *"It's hypothetical and speculative, of course, but I think that if the people in the right place had been doing their due diligence then, hopefully, you would have had a less tremendous type of effect on the area."*

Residents also would like to see a standard implemented, "mitigation plus"—anticipating and preventing negative impacts and restoring lands to their original state.

> *"Maybe they could leave the place better than they found it. How about that idea?"*
>
> *"I think they should at least restore what they damage and be absolutely culpable for it, for instance, roads or other things that they might on the way."*

Area residents are acutely aware that energy development is in motion, and they are resigned to fight it. However, they expect it to happen in a way that makes sense for the long-term health and benefit of their communities and their own quality of life.

In the focus groups we conducted in the first phase of our public opinion research we asked area residents if they knew what other Texans thought about the Trans-Pecos area of the greater Big Bend region of West Texas. Do Texans think about it at all? Do they care about it?

Most participants didn't have an answer.

Results – Phase Two

To complement the Trans-Pecos focus groups, and to answer those and other questions, we conducted a statewide survey of 1,000 Texas registered voters plus two hundred interviews with people living in the Trans-Pecos region. We found that Texas voters think energy development is good for the state's economy, but they have concerns about where and how it takes place.

Majorities think energy development is good for the state

More than three-quarters of those who participated in the research said that energy development is good for Texas (***Figure S1***). Support for renewable energy development was especially high—more than 6 in 10 said wind and solar development would be "very good" for Texas. Another quarter said it would be "somewhat good."

While not surprising, there are significant partisan differences in the type of energy development Texans support. Republicans are somewhat more likely to favor oil and gas development, while Democrats overwhelmingly prefer wind and solar energy development. When asked why they thought development is good for the state, nearly all survey participants, regardless of party, pointed to job creation or support for the Texas economy.

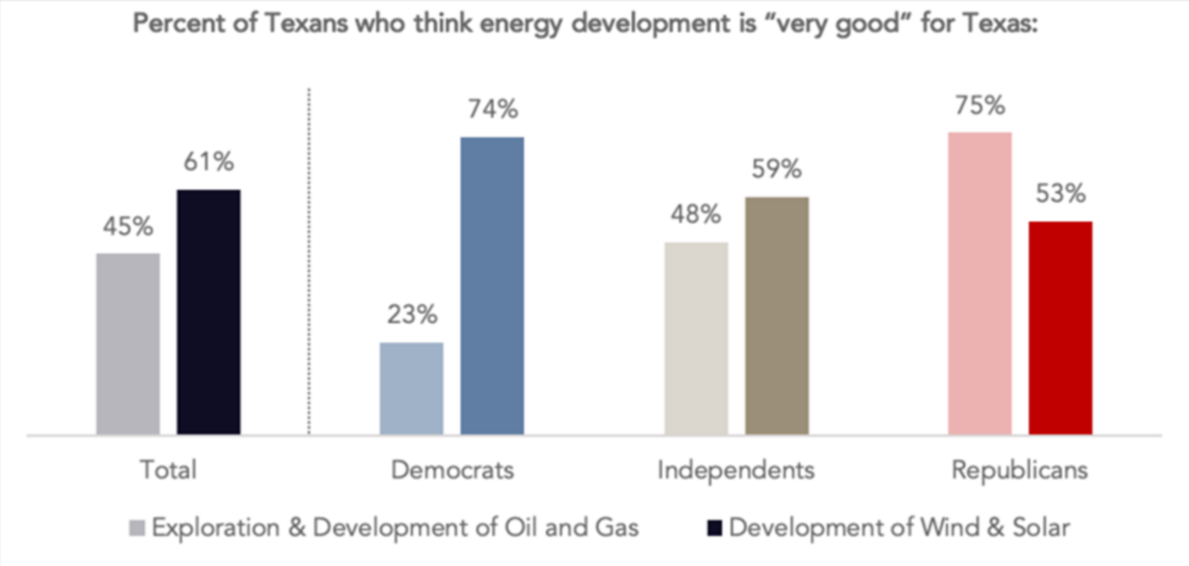

Figure S1. Percent of Texans who think energy development is 'very good' for Texas.

But even though Texans support energy development, they don't want it to take place just anywhere

When asked to choose, most Texans prioritized protecting communities and land and water resources for future generations (56 percent) over energy development (***Figure S2***). Less than a third (30 percent) said they think the benefits of energy development outweigh those protections.

Reflecting this view, more than half (52 percent) of those who participated in the survey opposed oil and gas exploration and production in their own local communities. Even more opposed development in some of the unique sites in the Trans-Pecos region, such as Big Bend National Park (70 percent were opposed), the Davis Mountains and the McDonald Observatory (63 percent) and the San Solomon springs at Balmorhea (54 percent).

As we discussed earlier, this is an area where energy development is starting to evolve.

Even most Republicans, who tend to be more supportive of energy development, agreed we should "protect communities and land and water resources in Far West Texas even if it means limiting energy production there."

Note that survey respondents weren't opposed to energy development everywhere. They were supportive of it happening in places such as the Gulf of Mexico (57 percent) and the Texas Coastline (50 percent).

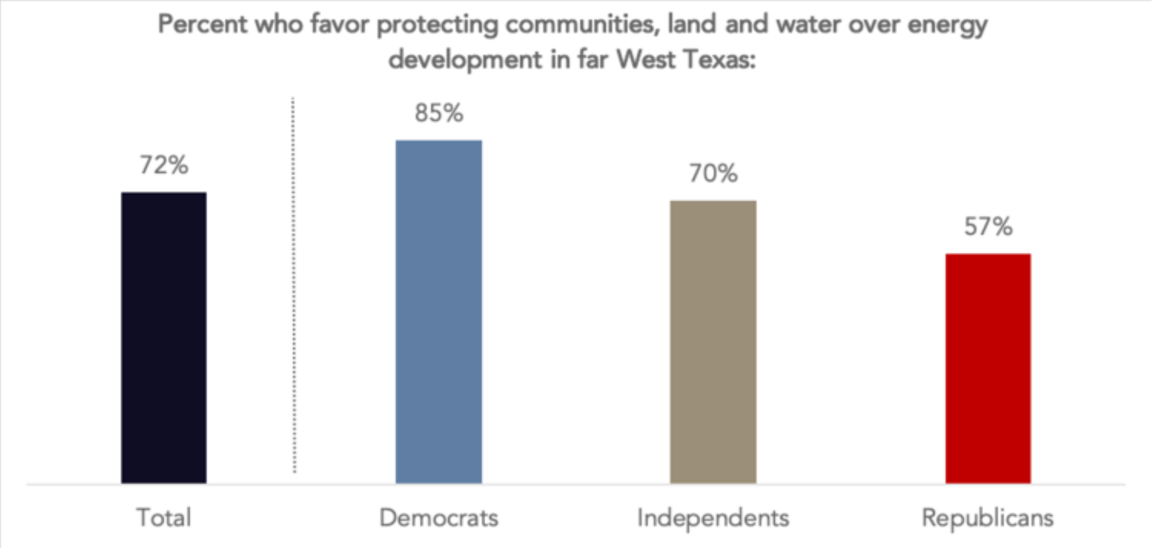

Figure S2. Percent who favor protecting communities, land, and water over energy development in far West Texas.

There is some skepticism that oil and gas can be produced without harming communities and resources

Some of the concern about protecting "special" places may be due to the fact that few Texans have complete confidence that oil and natural gas can be developed with minimal impact (***Figure S3***). The energy companies who would be doing the work are not seen as especially credible either.

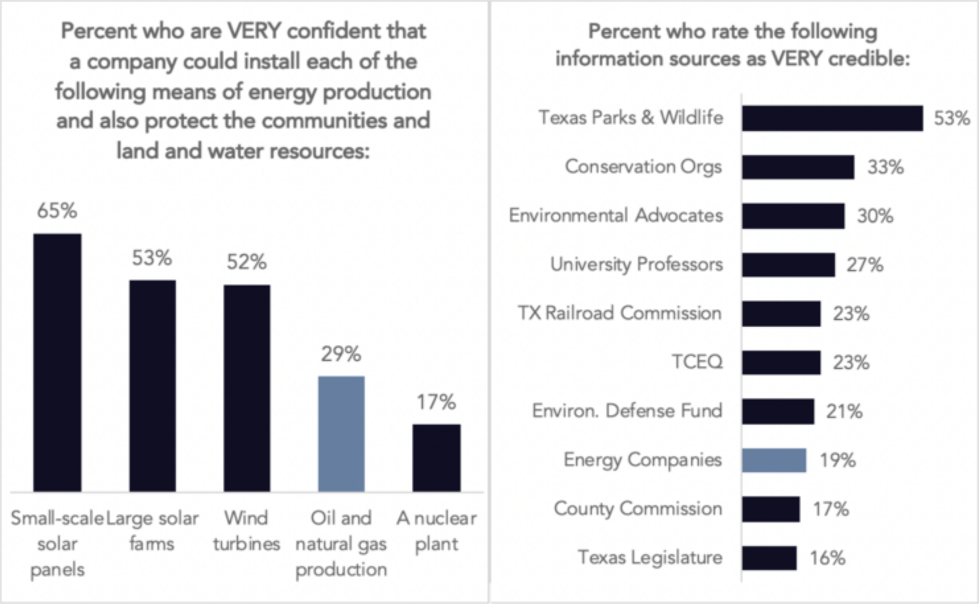

Figure S3. Questions on whether oil and gas can be produced without harming communities and resources.

What do Texans want when it comes to energy development?
Regardless of the issue we're talking about, there is no doubt that people want their voices to be heard. The data showed that Texans overwhelmingly think their fellow residents should have a greater say about what happens in their communities (***Figure S4***).

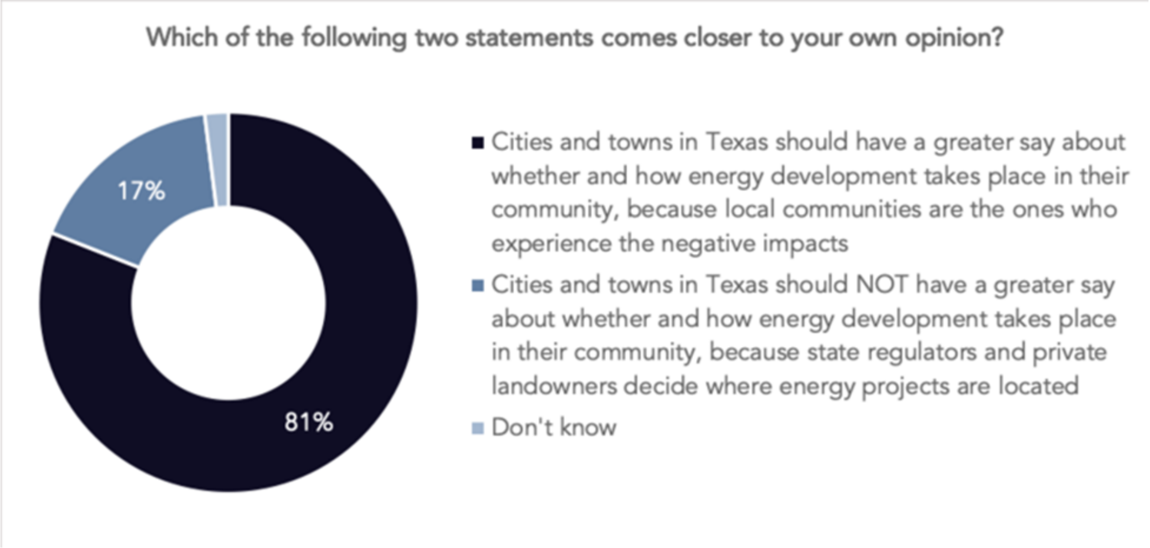

Figure S4. What Texans want when it comes to energy development.

When it comes to specific policy changes, Texans favored a wide variety of proposals. They weren't always as convinced that the ideas would be effective at making sure energy development reflects the needs and priorities of local communities, but a couple of items stood out as both popular and effective:

1. Increasing reporting requirements when it comes to water contamination. This reflects the concerns about water issues that arose spontaneously in our focus groups.
2. Restoring land to its original state.

S2. Stakeholder Engagement Process

The Respect Big Bend Coalition launched a community-driven process in the Tri-County Region to inform and guide future development and conservation decision-making. This effort included two parallel workstreams.

1. Convening a Stakeholder Advisory Group (SAG)
The SAG is made up of 14 people who have a stake in the Tri-County Region. The group includes land and mineral rights owners, local government officials, energy industry representatives, conservationists and community members – all have deep knowledge of the area, local laws and policies and a view on the feasibility of different conservation and restoration strategies. The Respect Big Bend Coalition and SAG also received input from oil and gas and renewable energy representatives, Texan by Nature and conservation organizations.

Using the Development by Design framework, these stakeholders articulated their values and developed a shared vision for the future of the Tri-County Region. Then, based on projections of future energy development prepared by RBB Coalition researchers, the SAG developed recommendations intended to mitigate potential impacts of development on the land and natural resources.

The SAG met bi-monthly over the course of two years to review findings, discuss and shape their conservation vision for the Tri-County Region.

Stakeholder Advisory Group Members

Terry Bishop	Farmer/Rancher, Presidio County
Eleazar Cano	Judge, Brewster County
Craig Carter	Rancher, Brewster County
Krysta Demere	West Texas Diversity Biologist, Texas Parks and Wildlife Department,
Leo Dominguez	VP University & Student Services, Sul Ross State University
Michael Janis	Wildlife District Leader, Texas Parks and Wildlife
Rainer Judd	President, Judd Foundation
John Karges	Associate Director of Field Science, The Nature Conservancy – Texas (Retired)
Michael Logan	Community Member, Fort Davis
Albert Miller	Rancher, Jeff Davis and Presidio Counties
Mo Morrow	Rancher, Brewster County
Robert Potts	President and CEO, Dixon Water Foundation
Janna Stubbs	Rancher, Brewster County
Jan Woodward	Community Member, Alpine

SAG Advisors	
Castlen Kennedy, Fay Walker	Apache Corporation
Jesse Wood	ConocoPhillips
Colin Meehan	First Solar
Gina Eddy, Emily Jolly, Kristian Koellner	Lower Colorado River Authority
Jamie Gentile	NextEra Energy Resources
Constance Wyman, Rebecca Zerwas, David Smithson, Therese Harris	Public Utility Commission/Electric Reliability Council of Texas
Representative	Rio Grande Joint Venture
Charlie Hemmeline	Texas Solar Power Association
Matt Gilhousen	Wind Energy Consultant

2. Engaging the community

The Respect Big Bend Coalition also led outreach efforts to inform and engage community members and interested parties across the state. The RBB Coalition brought these outside perspectives back to the Stakeholder Advisory Group for their consideration.

In-person work in the Tri-County region consisted of a community seminar series, an elected officials' luncheon, conservation partner brown-bag lunches and dozens of presentations to local community groups. These groups included:

- Brewster County Commissioners – Study Butte
- Rio Grande Council of Governments
- Presidio County Commissioners Court
- Fort Davis Chamber of Commerce
- Big Bend Chamber of Commerce
- Alpine Lions Club
- Marfa Rotary and Lions Clubs
- Terlingua Ranch Board Meeting
- Alpine Chamber of Commerce
- El Paso/Trans-Pecos Audubon Society
- Rio Grande Joint Venture
- Borderlands Research Institute Advisory Board

- Texas Parks and Wildlife Division (TPWD) Bighorn Sheep Advisory Committee
- Davis Mountains Heritage Association
- Texas Agricultural Land Trust (TALT) Advisory Board
- NRCS Wildlife subcommittee
- Chihuahuan Desert Research Institute
- Texas Parks and Wildlife Division (TPWD) Trans-Pecos WMA staff
- Big Bend National Park

A full list of meetings and seminars convened in the Tri-County region is available in the "*Respect Big Bend Stakeholder Engagement Progress Report – 2019*."

Online, the Coalition cultivated a community of nearly 33,000 social media followers and 1,100 email newsletter subscribers. These platforms were used to share news and research about the Big Bend Region and capture people's feedback.

RBB Coalition members also shared details about the project with elected officials in Austin, as well as energy companies and trade associations across the state.

S3. Detailed Methods: Mapping A Conservation Vision

All data sources used to map the individual components of the Cumulative Conservation Values map can be found online: *Table S1. Data sources for conservation values mapping*.

Ecological Values

We took a coarse-filter/fine-filter approach to manage the complex organization of biological systems and the practical limits of existing data and knowledge [40]. The practical advantage of this approach is that it makes the best use of available data to represent the full range of representative biodiversity with a reasonable number of biodiversity elements. Our knowledge regarding species ranges and habitat needs will always be incomplete; species data are limited and dependent on survey effort, and therefore, prone to vary in geographic coverage. Conversely, spatial data on coarse filter features such as ecosystem types are typically easy to access, updated semi-regularly and usually employ classification schemes that are consistent across geographies. The coarse-filter/fine-filter approach is designed to overcome the common challenges of uneven (in extent and quality) data coverage to yet create a conservation vision that credibly captures the range of ecological actors in a landscape and the intricate ways in which they organize and sort themselves.

We used the Ecological Mapping Systems of Texas [41] produced by the Texas Parks & Wildlife as the base for the coarse-filter, habitat-centric approach. We aggregated the ecological mapping systems into NatureServe habitat classes (i.e., forests & woodland savannas, grassland & herbaceous vegetation, herbaceous wetlands, shrublands, sparsely vegetated areas, woody wetlands & riparian areas) to represent the coarse-filter habitats (for full crosswalk, see online *Table S2. Crosswalk of the Ecological Mapping Systems of Texas and NatureServe classes*). We also updated three landcover classes (riparian areas, cliffs/crevices and converted lands) on the recommendation of the science subcommittee, because the current mapping of the classes were considered incomplete. We added in surface waters as mapped by the Texas Natural Resource Information System (TNRIS)[42] for the norther portion of Presidio county where they were missing. We also added in areas with slopes greater than 24 degrees in the counties of Crockett, Terrell and Val Verde to represent cliff areas in the Devils and Pecos River watersheds. Finally, we used the National Land Cover Database 2016 Developed Imperviousness (CONUS) [43–45] to update areas converted to impervious surfaces (i.e., roads, energy development, settled areas).

We then inventoried species (n = 516, for full list of species, see online *Table S3. Fine-filter species and habitat associations* and *Table S4. Summary of distribution of fine-filter species by taxonomic group, Texas SGCN status, global ranks, state protection status and habitat association*) with economic, iconic and conservation value in the region [46–48]. We selected three wide-ranging species (pronghorn, bighorn sheep and mountain lion) for further attention and produced habitat suitability and connectivity models as part of the fine-filter focus. We describe our methods in general details below.

Intact Landscapes:

Intact landscapes represent large, unfragmented patches of different habitat types with low levels of modification from human pressures. Expanses of unfragmented natural habitat, such as grasslands and shrublands, tap into the sense of the remote and "wide-open" landscapes that stakeholders identified as a central characteristic of the region.

Intact landscapes are ecologically important as well. Intact ecosystems are better positioned to support the long-term persistence of a full range of species who have their own individual minimum home area size requirements and needs for connected habitat. Fragmentation and habitat loss can lead to concerning population declines of iconic biodiversity residents of a place. Moreover, the habitat degradation that often follows significant fragmentation and loss can weaken an ecosystem's ability to withstand and recover from most natural disturbances (e.g., drought, erosion, fire).

To identify instances of intact landscapes off similar landcover types, we grouped 116 vegetation types from the Ecological Mapping Systems of Texas to five broad NatureServe systems classes:

- Forests and woodland savannas
- Herbaceous vegetation/grasslands
- Herbaceous wetlands
- Chihuahuan desert shrublands
- Woody wetlands and riparian

We applied size thresholds and a measure of condition for each patch to identify the set of best examples of each system [41, 47–49]. Size thresholds aim to estimate the minimum area required for an ecosystem type to be considered functionally able to sustain itself and the biota it supports over the long term.

We used a cumulative measure of human modification of terrestrial lands as an indirect measure of the condition of a patch. Human modification is represented as an integrated index of the physical extent and intensity of 10 anthropogenic pressures on the land. These stressors include: residential development, urban/commercial development, crop and pastureland, oil and gas wells, mines, concentrated/PV solar, wind farms, road footprint, railways and above-ground powerlines [50, 51]. Areas with multiple stressors are considered more degraded than areas with single stressors. We set ecologically-informed thresholds to delineate areas of low, moderate and high degrees of human modification [50, 51].

In the final step, intact landscapes are those ecosystem patches that are above a minimum moderate threshold size and are in the best condition as measured by the cumulative human modification index (***Table S5***). Because riparian and wetland resources were considered so essential in this arid landscape, we swept in all patches regardless of size, although we prioritized those in good condition over those which scored a heavily impacted by human activities per the human modification index.

Degree of Human Modification:	Patch Intactness		
Low (0-0.1)	LOW	**HIGH**	**VERY HIGH**
Moderate (0.1-0.4)	LOW	**MODERATE**	**HIGH**
High (0.4-0.7)	LOW	LOW	LOW
Very High (0.7-1.0)	LOW	LOW	LOW

Patch Size Thresholds:	Low	Moderate	High	
Ecosystem Class:				
(a) Forests & Woodlands (b) Shrublands	0 - 124	125 -12,355	>= 12,355	**acres**
(c) Grasslands	0 - 4,942	4,942 -24,711	>=24,711	**acres**
(d) Herbaceous Wetlands & Riparian areas (e) Sparsely Vegetated	** No size restrictions; all considered in "High patch size"			

Table S5. Human modification and patch size thresholds applied to categorize patches by intactness measures.

Grasslands & Riparian & Wetland Areas, Springs

The Stakeholder Advisory Group singled out three systems as having outsized importance in the Big Bend region. These are grasslands and systems such as riparian and wetlands and springs. These systems are especially vital in arid landscapes where they serve as refuges with high biodiversity, promote healthy hydrological function, slow erosion and improve system resiliency in the face of shifting climates. We include all grassland patches and riparian and wetland patches as mapped above regardless of size or condition separately again in the final values layer to emphasize this critical role in the landscape. We also include springs from the Spring Stewardship Institute database (2019).

Pronghorn, Bighorn Sheep and Mountain Lion Habitat Suitability and Connectivity

We selected three species – pronghorn, bighorn sheep and mountain lion – for further focus as part of the fine-filter approach. They are quintessential symbols of the West Texas landscape and are indicators of important habitats (i.e., grasslands and montane forests of the sky islands) and functional connectivity between these habitat patches. See the following Section S4 for detailed methods on these models.

Pronghorn were selected as the indicator species representing the habitat and connectivity needs of a suite of grassland species across the Trans-Pecos grasslands. Pronghorn are an iconic species and have been the focus of restoration efforts throughout the grasslands of the Big Bend region. There is also extensive data and research available from the Borderlands Research Institute on their presence and movement. The pronghorn data includes over 7 years of location data from 379 GPS-collared animals. Using this data, we modeled habitat suitability and connectivity for pronghorn across the Trans-Pecos grasslands.

Sky islands are the upper elevation of mountains in the Trans-Pecos and are surrounded by large expanses of lowlands. We used bighorn sheep and mountain lions as umbrella species for these habitats. Bighorn sheep represent the drier and less vegetated sky islands and are an important species economically. The Borderlands Research Institute has been involved with efforts to restore bighorns to the region and have over 5 years of data from 172 translocated animals. We used this data to model habitat suitability and connectivity for these drier sky islands.

Mountain lions use a broader range of habitats and sky islands, including forested higher elevation mountain ranges not inhabited by bighorns but which are also important to many species such as black bears. Researchers at Borderlands Research Institute have been studying mountain lions for the past decade and have a dataset of over 25,000 locations from GPS-collared animals. This data was used to model habitat suitability and connectivity for mountain lions and all species that inhabit and move between sky islands. The wider-ranging and broader habitat use by mountain lions allowed us to map important corridors that connect the large sky island archipelago in the Big Bend region.

Social Values

Hunting

We used the Texas Parks and Wildlife Department's Mule Deer Monitoring Units and Pronghorn Herd Units as a proxy for hunting in the Big Bend region. Monitoring and herd units are surveyed to determine animal density, distribution and abundance. Collected data is used to establish seasons, harvest recommendations, permit numbers and to advise hunters of the status of game populations in a region. We weighted units with higher densities above those units with lower densities.

Recreation

To represent recreation opportunities, we mapped or digitized scenic and wildlife-viewing routes, bicycle routes, publicly accessible hiking trails, running trails and managed areas such as national, state, county and city parks (e.g., Big Bend National Park). We then calculated the density of trails within a 1 km window.

Viewsheds

To capture the sweeping vistas of this remote landscape, we modeled viewsheds. Viewsheds identify areas that are visible from observer locations. To model viewsheds, we established observer locations from 2 sources: from major roads and photo point locations from FLICKR, an image sharing site. Major roads included interstate, U.S. and state highways (TIGER 2018). We also downloaded photo point locations from FLICKR. Because we were tapping into the aesthetics of the landscape, we excluded photos point within incorporated areas. We generated viewsheds using a digital surface model [52] that takes into account vegetation and other features that might restrict visibility. We modeled the viewshed using a 60 km radius and 1.5 m observer height offset. As a final step we masked out areas with high human modification.

Dark Skies

Nighttime lights from the Earth's surface have been used to track new urban settlements, economic productivity and even disease spread [53]. In West Texas, home to the famed

McDonald Observatory (a world class research institution and magnet for amateur star gazers of all ages), it is the absence of nighttime lights that is a valued commodity. The seven surrounding counties of McDonald Observatory have adopted outdoor lighting ordinances and the Observatory continues to collaborate with local communities to promote better nighttime lighting that minimizes impacts to dark skies for the Observatory.

We used the VIIRS (Visible Infrared Imaging Radiometer Suite) Night-time Lights 2016 composite of irradiance, or "brightness," values as a measure of the extent of areas of dark skies. These maps show the presence of electric lighting, mainly from human settlement areas, present on Earth's surface and visible from space [54]. We note that the composite data has been cleaned to exclude other potential sources of light such as fires and flares. We set the upper threshold for irradiance at 5 nWcm-2 sr-1 to identify settlements in rural areas and then took the inverse values where 1 = total darkness and 0 = 5 nWcm-2 sr-1.

Cumulative Values Layer

As a final step, we integrate all the inputs together into a single index as a continuous gradient of values (***Figure 3***). That is, we sum together all the individual values and arrive at a final surface scaled from 0 (= no values present) to a potential upper end of 14 (= all values present).

To derive this layer, we first re-scaled each input 0-1 to make disparate values comparable (see online *Table S1* for re-scaled values). Then we ran a focal window across the entire region, assigning the mean value of all pixels within a 1 km radius to the center of that window. In practice, this creates a gradient of values wherein places close to the edges of where values occur (e.g., pronghorn herd units) have lower value than places that are in the core. For line features (i.e., recreation routes) and point features (i.e., springs), this essentially turns them into a measure of the density of occurrence. For values already scored along as a continuous metric (e.g., irradiance values of night-time lights), we did not run a focal window to calculate means. Finally, we summed all these inputs together to create a continuous metric of stacked values across the entire region.

S4. Detailed Methods: Species Habitat Suitability and Connectivity Models

Authors: Justin French, Dana Karelus, Carlos Gonzalez, Louis Harveson and Patricia Moody Harveson

Pronghorn Habitat Suitability and Connectivity Models

Base Data Collection

Models were generated using collar data from 379 translocated pronghorn, released in the Trans-Pecos in six translocation events over seven years. The data represent pronghorn movement over eight years. The collars were set at different fix intervals, depending on translocation event. The longest interval was three hours between fixes. The data set was subset to three-hour intervals across all collars, yielding a data set of 556,465 locations used in the model.

Habitat Suitability Model

Habitat selection and movement parameters were estimated using integrated step selection functions [55], which separate and quantify habitat selection and movement behaviors from GPS data. This results in unbiased estimates of each from a single data set.

Selection was modeled as a function of absolute elevation, slope, terrain roughness, herbaceous vegetation cover and shrub cover. Since pronghorn occupy grasslands, and grasslands occur at mid-elevations in this region, we included a quadratic effect of elevation. This allows the model to seek an optimum, where the rate at which probability "falls off" is an estimated parameter. Edaphic variables were derived from a 30m digital elevation model (available via API through Amazon AWS https://registry.opendata.aws/terrain-tiles/). Vegetation variables were obtained from Multi-Resolution Land Characteristics Consortium, 2016 data (https://www.mrlc.gov/data). Variables were selected using AIC scores and model weights [56], which overwhelmingly supported the top model.

The resulting habitat kernel was projected across the Trans-Pecos at 30m resolution. This map represents a probability distribution of pronghorn selecting a given region of space, independent of any movement constraints.

Connectivity Model

We derived connectivity maps by simulating pronghorn movements across the habitat landscape, represented by the habitat kernel. We used the R package SiMRiV to simulate correlated random walks [57, 58], based on observed movement parameters of pronghorn. This package weights the step distribution against a map of movement costs to determine each step a simulated individual takes. We used a negative linear transformation of the habitat kernel ((1–*habitat*)/*max*(1–*habitat*)) to transform it to a cost surface. We generated 2,000, evenly spaced locations across the Trans-Pecos and retained only those with a cost less than 0.8 as starting locations for each simulation. This was done to ensure even representation of suitable habitat throughout the region and resulted in 115-120 simulated individuals per simulation. Each simulated individual took 2,000 steps from its origin, yielding a trajectory of expected pronghorn movement. We fit a Brownian Bridge utilization distribution to each simulated individual [59] and averaged the resulting surfaces across individuals within each simulation. This yielded a surface representing the probability a pronghorn passed through each pixel for each simulation. This process was repeated 100 times and averaged over simulations to produce the expected space use of pronghorn across the Trans-Pecos.

Bighorn Habitat Suitability and Connectivity Models

Base Data Collection

Models were generated using collar data from 172 translocated bighorn, released in the Trans-Pecos in four translocation events over five years. The collars were set at different fix intervals and durations, depending on translocation event, and ultimately represent bighorn movement over six years. The longest interval was five hours between fixes. The data set was subset to five-hour intervals across all collars for animals tracked for >30 days yielding a data set of 26,364 locations used in the model.

Habitat Suitability Model

We estimated a resource selection function (RSF) using the maxlike estimator for presence only data [60]. This estimates the absolute probability a bighorn would use a pixel, given it encountered it, without subjective delineation of the availability of locations to the bighorn. Principal component analysis (PCA) was used to evaluate differences within environmental variables used in a maximum likelihood test. This facilitated a selection of characteristics that explained the majority of variability within the environmental variables. This method allows for the reduction of strongly correlated data groups and only utilizes the factors that explain the most variance and are not related to each other [61]. Selection was modeled as a function of absolute elevation, slope, terrain roughness and woody vegetation cover. The resulting RSF was projected across the Trans-Pecos at 30m resolution.

Connectivity Model

We derived connectivity maps by simulating bighorn movements across the habitat landscape, represented by the projected RSF. We used the R package SiMRiV to simulate correlated random walks [57, 58], based on observed movement parameters of bighorn. This package weights the step distribution against a map of movement costs to determine each step a simulated individual takes. We used a negative linear transformation of the habitat kernel ((1 – *habitat*)/*max*(1 – *habitat*)) to transform it to a cost surface. We generated 120 starting locations for each simulation by sampling probabilistically across the RSF surface. This was done to ensured even representation of the highly fragmented areas of suitable habitat throughout the region. Each simulated individual took 2,000 steps from its origin, yielding a trajectory of expected bighorn movement. We fit a kernel density estimate of each simulated bighorns' utilization distribution [62], and averaged the resulting surfaces across individuals within each simulation. This yielded a surface representing the probability a bighorn passed through each pixel for each simulation. This process was repeated 100 times and averaged over simulations to produce the expected space use of bighorn across the Trans-Pecos.

Mountain Lion Habitat Suitability and Connectivity Models

Base Data Collection

We used GPS location data from 21 mountain lions previously caught and collared by the Borderlands Research Institute from 2011-2018. All individuals were tracked for at least one month and had suitable data for analyses. Four individuals were from Big Bend National Park (two females, two males; all adults) and 17 were from the Davis Mountains (12 females, five males; seven subadults, 10 adults). Fix schedules on collars varied among lions. In the Davis Mountains, two females had collars that obtained fixes every three hours and all others had collars that obtained six locations per day. In Big Bend National Park, all collars obtained six locations per day except on Wednesdays and Saturdays when collars collected fixes hourly. On average, there were 1408 ± 328 locations (± SE) per individual, ranging between 373 locations and 6629 locations. Individuals were tracked over an average (± SE) of 275 ± 58 days, ranging between 87 days and 1090 days.

Habitat Suitability Modeling

We estimated habitat suitability using resource selection functions (RSF; [63, 64]). For each individual, we fit generalized linear models with a binomial response of used/available (1/0), an additive effect of landform and HLI and assigned a large weight to available locations to reduce bias (used = 1, available = 5,000)[65].

To determine availability, we randomly selected five “available points” for each used point by an individual from within their respective 100 percent minimum convex polygon (MCP; [66]) plus a surrounding 5 km buffer. We extracted the values of our environmental covariates at the used and available locations. Our environmental covariates included a categorical raster of landforms and a categorical raster of heat load index (HLI); both layers were obtained from https://adaptwest.databasin.org/pages/adaptwest-landfacets with 100 x 100 m grid cells. The Landform raster originally included nine categories based on topographic position index (TPI), slope and elevation [67]; however, due to low available/used locations in two of the categories, we collapsed these down to seven categories (valleys, hilltop in valley/local ridge in plain, headwaters, ridges and peaks, plains/gentle slopes, local valley in plain and steep slopes). The HLI raster included three categories based on aspect and slope: cool, neutral and warm.

We estimated the population level covariates from the individual models using bootstrapping by sampling estimates from eight individuals at a time, calculating the mean, replicating the process 1,000 times, then calculating the overall mean and lower and upper confidence intervals from the replicates. Using the population level beta estimates, we predicted the RSF across the Trans-Pecos. We scaled the values of the resulting raster to range between 0 (poor habitat suitability) and 1 (high habitat suitability). Habitat suitability modeling was performed in R statistical software [68] using base functions and the packages raster [69] and sf [70] for raster processing operations and the package adehabitatHR [71] for creating the MCPs.

Connectivity Model

Connectivity modeling was performed using ArcGIS 10.7 and Linkage Mapper 2.0 toolbox [72]. We used circuit theory and least-cost path analysis to identify corridors connecting core habitat patches for mountain lions in West Texas [73–75]. Core habitat patches were generated based on the RSF using Gnarly Landscape Utilities 0.1 toolbox [76]. The RSF was aggregated to 1km^2 to improve processing time and core patches were created using the following settings: moving window radius = 6723m (equivalent to half the average home range size of an adult female mountain lion); minimum average habitat value = 0.4; minimum habitat value per pixel = 0.1; minimum core area size = 25km.

Corridors were generated using the least-cost path between adjacent core patches. A resistance surface was created from the predicted habitat suitability values (RSF) using a C2 transformation [77] and then rescaled to 1km^2:

$$100 - 99 \times \frac{1 - e^{-c \times h}}{1 - e^{-c}}$$

Where h is the predicted scaled habitat suitability value and c is a constant, here equal to 2, that allows for a negative exponential transformation from habitat suitability to resistance surface. In this way, we allowed for animals to have a greater probability to move through habitat that was not highly suitable, which is often the case for highly mobile animals that are dispersing [77, 78].

Corridors were truncated to a cost-weighted threshold of 200,000 with zero representing the highest connectivity. The corridor map was then overlaid with the core habitat patches (value = 0) to create a final map representing core habitat and linkages throughout West Texas."

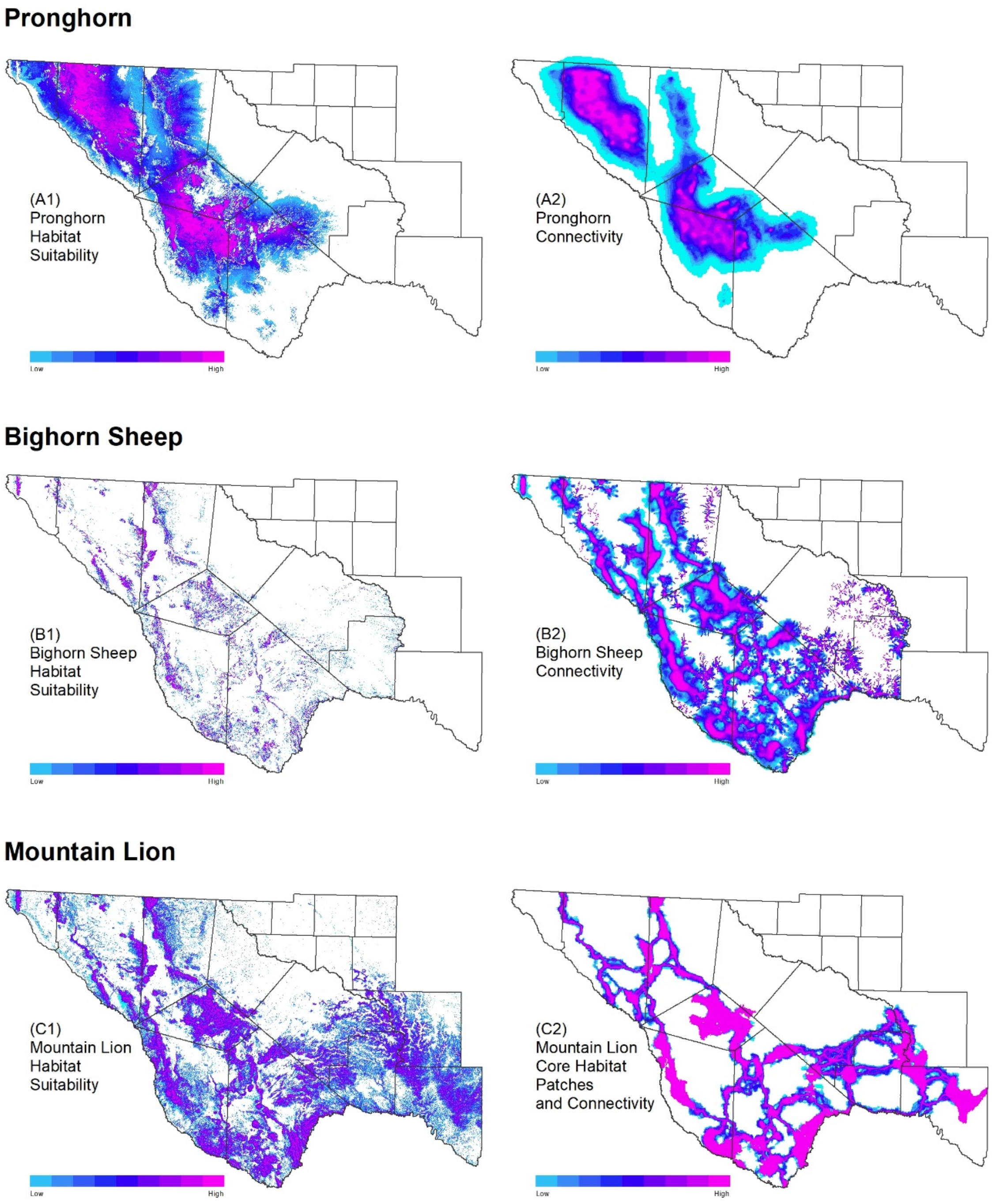

Figure S5. Species habitat suitability and connectivity models for pronghorn (A1, A2), bighorn sheep (B1, B2) and mountain lion (C1, C2).

S5. Detailed Methods: Future Energy Projections

Research conducted to understand and project energy development from oil and gas (O&G) exploration and production in the RBB study area included the broader west Texas region and the greater Permian Basin (PB) of Texas and New Mexico, which is the largest oil and gas production region in the United States [79]. We also conducted research into solar and wind electricity production in the RBB area that included the ERCOT regions of Texas but with a finer focus on Far West Texas and the potential for development in the 18-county study area. Historically, O&G development in West Texas has experienced boom and bust cycles. Today, however, at the same time O&G activity is ongoing, new renewable energy infrastructure is being installed, sometimes colocated. Solar and wind energy infrastructure across West Texas is being built to offset the retirement of coal-fired power plants, the increased electricity demand from population centers along the I-35 corridor and the increased demand from oil field operations.

If we assume that energy development in this region continues into the future, then land alteration will also continue, regardless of the energy type. Forecasts of these alterations can be used to determine potential impacts to habitat and to aid in conservation planning, reducing long-term effects [80, 81]. Different types of energy development alter landscapes in different ways, but all of them lead to increased landscape fragmentation, which is generally defined as the loss and the breaking apart of habitat at the landscape scale [82]. Given the wide variety of landscapes and land uses in West Texas, potential impacts from land alteration need to be considered individually [83] and as a whole.

In this section, we describe the steps taken to estimate future energy development across study area. To the extent possible, we tailored a similar approach for each energy system by following a few key steps. These steps are:

1. Map existing infrastructure and evaluate landscape alteration patterns
2. Exclude anthropogenic areas restricted from development (i.e., airports, roads, cities, already developed areas)
3. Evaluate resource potential (i.e., reservoir quality, solar insolation, wind class)
4. Project amount of increased production (i.e., BOE and MW) under low, medium, and high scenarios.

Here we present detail steps for each energy system and describe differences in approaches for different energy systems, when appropriate.

1. **Map existing infrastructure and evaluate landscape alteration patterns**
   We used the dataset published by Pierre et al (2020) [84] to map existing oil and gas infrastructure.

   For solar energy, we combined and mapped data for utility-scale solar facilities from the Solar Energy Industry Association and the United State Energy Information Administration (EIA Form 860 & 860M, SEIA 2019, personal communication).

   In the case of wind energy installations, we used the US Wind Turbine Database [86] (https://eerscmap.usgs.gov/uswtdb/), which is operated by the U.S. Geological Survey, the Lawrence Berkeley National Laboratory and the America Wind Energy Association.

The database provides specific information on each facility, including turbine height and nameplate capacity. We assumed that all land between the turbines were part of the facility, as done by Kiesecker et al. (2019) [87], but we recognize that these interspaces often remain in use for various activities, like grazing and irrigated agriculture. We varied from the methods of Kiesecker et al. (2019) [87] and used a concave hull to circumscribe the perimeter boundaries of existing wind farms (string or multiple strings of turbines), and then calculated the median area of these polygons to represent the amount of land that would be impacted from future wind farm development.

2. **Exclude anthropogenic areas restricted from development (i.e., airports, roads, cities, already developed areas)**
   For all energy types, we followed the same process described by Pierre et al. (2020)[84], who compiled information from 18 datasets (*Table S5*), including those showing cemeteries, waterbodies (including all stream orders, rivers, lakes, etc.), protected areas, roads, national and state parks, etc. For each energy type, existing facilities were excluded as possible locations for future infrastructure, though we did allow for future colocation of different energy types.

3. **Evaluate resource potential (i.e., reservoir quality, solar insolation, wind class)**
   In the case of O&G development, we projected future energy development by determining the trends of individual well pad development [84] and well-by-well energy production, attributed to each well pad, over the last 10 years, aggregated at the 1 km^2 scale. If the number of well pads increased with time and if energy production from existing or new wells increased with time, these would indicate that operators were accessing productive rock and that future well pads would be needed to support future drilling (given favorable economics). In these cases, we extrapolated the number of expected new pads forward in time by 33 years (from 2017 to 2050), and assigned these pads to specific 1 km^2 areas, except where excluded by existing infrastructure or other features (see [84]).

   In the case of solar development, we tailored the guidelines set forth by Wu et al. (2015 [88], see Table S2) to data available for Texas. This included mapping of available (not excluded) contiguous regions at least 1 km^2 or greater, with a global horizontal irradiance (GHI) of at least 5 kWh/m^2/day or more, and with a slope of 3 percent or less. The GHI data were obtained from the National Renewable Energy Laboratory (NREL, 2020, which cited [89]).

   In the case of wind development, we also tailored the guidance set forth by Wu et al. (2015) [88]. This included identifying contiguous regions at least 8 km^2 in area with a slope of 20 percent or less. However, due to wind data limitations, we followed NREL recommendations and used wind speeds 6.5 m/s or greater [90]. Using these criteria for solar and wind, we could identify lands we considered "suitable" for future utility-scale development.

4. **Project amount of increased production (i.e., BOE and MW) under low, medium and high scenarios**
   To cover the range of uncertainty that accompanies any forecast, we identified three landscape impact scenarios for O&G, solar and wind energy. Impact in this report refers to the construction of well pads, pipeline right-of-ways (ROWs), photovoltaic solar installations, etc., all of which accommodate energy production. The approach used for

the different energy systems was made as consistent as possible between energy sources. In each case, we selected a medium impact scenario, which we assumed was the business as usual (BAU) case, essentially following along existing trends. We then bracketed the BAU case with low and high landscape impact scenarios. Specific differences between the three energy systems are described:

For O&G development, we assumed that three wells per pad (on average) was a reasonable expectation for the future ([91, 92] and multiple discussions with various operators), and thus we considered this our medium landscape impact (BAU) scenario. Additional justification for three wells per pad can be found in Pierre et al. (2020) [84], where we note that historical well densities are closer to 1.15 wells per pad across the Permian Basin [12]. Thus, if future development follows the same, low well density practices, then more pads will be needed to accommodate the new wells, hence leading to a high landscape impact scenario. To develop a low landscape impact scenario where fewer well pads will be needed, we assumed either reduced well-drilling activity given low O&G prices, or an increased number of wells per pad as a result of technological advances or other economic incentives, or both. Operationally, this would triple the number of wells per pad (compared to the BAU case) to nine wells per pad (hence, 1/3 the number of well pads would be needed).

To match electricity demand anticipated by ERCOT for the next 30 years, with future generation capacity, RBB contracted with IdeaSmiths, LLC, an Austin-based company (https://www.ideasmiths.net/) that conducted modeling to assess future capacity needs. IdeaSmiths took into account factors that would influence renewable energy needs (e.g., retirement of coal plants, increases in population, economics of natural gas) and possible locations for the infrastructure based on the above-mentioned wind and solar resource maps available from NREL. The outcome of their modeling provided future estimates of both solar and wind generation, in megawatts (MW), for each county in Texas.

For solar and wind energy production, future development was estimated together in a single model to take advantage of differences in peak performance between day (solar) and evening (wind) time periods. The model included facilities across the entire state of Texas, which reduces uncertainty of modeling the west Texas region in isolation (electrons move into and out of west Texas but not across state lines). The Capacity Expansion Model, known as “Switch,”[26] was used for this project, using the following input values that separated medium (BAU), low and high impact scenarios.

Business as Usual (BAU):

Electric Vehicle Demand = ERCOT LTSA Forecast (ERCOT 2018)
Distributed Solar Capacity = ERCOT LTSA Forecast (ERCOT 2018)
Wind/Solar/Battery Capital Cost = NREL ATB 2019, Low (NREL 2019)
Natural Gas Combined Cycle Capital Cost = NREL ATB 2019 (NREL 2019)
Coal/Gas Prices = EIA AEO 2020 Prices (USIEA 2020)
Transmission Capital Cost = CREZ Project Data (Deetjen et al. 2018)

Low Renewables Development:

Electric Vehicle Demand = BAU X 0.5
Distributed Solar Capacity = BAU X 1.5
Wind/Solar/Battery Capital Cost = NREL ATB 2019, Mid (NREL 2019)
Natural Gas Combined Cycle Capital Cost = BAU
Coal/Gas Prices = BAU X 0.75
Transmission Capital Cost = BAU X 1.25

High Renewables Development:

Electric Vehicle Demand = BAU X 1.5
Distributed Solar Capacity = BAU X 0.5
Wind/Solar/Battery Capital Cost = BAU X 0.75
Natural Gas Combined Cycle Capital Cost = BAU X 1.25
Coal/Gas Prices = BAU X 1.25
Transmission Capital Cost = BAU X 0.75

Table S5. Spatial layers used to delineate areas excluded from future development.

Exclusion Layer	Download Date	Source
New Mexico National Cemeteries	1/10/2018	United States Department of Veterans Affairs National Cemetery Administration (2015) New Mexico National Cemeteries. https://rgis-data.unm.edu/rgisportal/
Waterbodies (rivers, streams, lakes, etc.)	9/4/2020	U.S. Geological Survey, 2007-2014, National Hydrography Dataset available on the World Wide Web. https://nhd.usgs.gov
New Mexico BLM Closed to Future Leasing	9/1/2018	U.S. Department of the Interior, Bureau of Land Management, Carlsbad Field Office, Pecos District, New Mexico (2018) Draft Resource Management Plan and Environmental Impact Statement. https://eplanning.blm.gov/epl-front-office/eplanning/planAndProjectSite.do?methodName=dispatchToPatternPage&currentPageId=90928
New Mexico Airports Points	4/4/2018	Federal Aviation Administration (FAA) and the Research and Innovative Technology Administration's Bureau of Transportation Statistics (RITA/BTS) National Transportation Atlas Databases (NTAD) (2006). New Mexico Airport Points. https://rgis-data.unm.edu/rgisportal/
New Mexico Airport Runways	4/4/2018	Federal Aviation Administration (FAA) and the Research and Innovative Technology Administration's Bureau of Transportation Statistics (RITA/BTS) National Transportation Atlas Databases (NTAD) (2006). New Mexico Airport Runways. https://rgis-data.unm.edu/rgisportal/
Urban Areas, railways, roadways, protected areas and military installations of the United States	9/4/2020	U.S. Department of Commerce, U.S. Census Bureau, Geography Division (2019) TIGER/Line Shapefiles. https://www.census.gov/cgi-bin/geo/shapefiles/index.php

Exclusion Layer	Download Date	Source
Protected areas of Texas	4/3/2018	Texas Parks & Wildlife Department. "Texas Parks & Wildlife Managed Lands." By Chris Beckcom, Nancy West and Joelynn Barclay. Land and Water Resources Conservation and Recreation Plan Statewide Inventory, 2002, revised. TPWD Managed Lands extracted from LWRCRP Statewide Inventory, 2010.
Texas airports and runways	4/20/2018	Texas Department of Transportation, Transportation Planning & Programming Division (2008). Texas Airports and Runways. https://tnris.org/data-catalog/entry/txdot-public-airports/
Texas Cemeteries	4/3/2018	Pavon, Miguel A., (2005) Texas Historical Commission Cemeteries (shapefile), 1:24,000. Austin, Tx USA. Texas Historical Commission, 2005. https://gis-txdot.opendata.arcgis.com/datasets/46892b74d36141949d932fc661caf3f9_0
Texas Railways	8/23/2018	Texas Department of Transportation (2016). Texas Railways. https://tnris.org/data-catalog/entry/txdot-railroads/
New Mexico Conservation Easements	4/4/2018	USDA/NRCS, (2017) National Geospatial Center of Excellence. New Mexico Conservation easements. https://www.arcgis.com/home/webmap/viewer.html?featurecollection=https percent3A percent2F percent2Fnrcsgeoservices.sc.egov.usda.gov percent2Farcgis percent2Frest percent2Fservices percent2Feasements percent3Ff percent3Djson percent26option percent3Dfootprints&supportsProjection=true&supportsJSONP=true
Urban Areas of Texas	1/19/2017	Texas Natural Resources Information System (2016) Urbanized areas in Texas. https://tnris.org/data-catalog/entry/urban-areas/
Texas 2014 roads buffered by ROW	3/31/2016	TXDOT (Texas Department of Transportation) (2015) TXDOT Roadways 2014. http://www.txdot.gov/inside-txdot/division/transportation-planning/roadway-inventory.html
Texas 2015 roads	3/31/2016	TXDOT (Texas Department of Transportation) (2016) TXDOT Roadways 2015. https://tnris.org/data-download/#!/statewide