Deploying renewable energy infrastructure at former oil and gas extraction sites: potential and sustainability implications

by Charles Chase

Advisor: Dalia Patino-Echeverri

April 30, 2021

Nicholas School of the Environment

Master's Project

Abstract:

The demand for energy in the United States is ever-increasing and energy production in all forms requires changes to land use. This case study asks: *Is it possible to utilize disturbed areas from oil and gas development for renewable energy production*? It considers federal lands managed by the Bureau of Land Management (BLM) in southeastern New Mexico. It determines the availability of sites and the solar power generating capacity at former oil and gas sites based on quantitative analysis of spatial data. It sheds light on the feasibility of a transition from oil and gas to renewable power under existing National Environmental Policy Act (NEPA) provisions applicable to the study area based on a literature review and interviews with BLM employees. Finally, it presents a rough estimate of the solar energy potential from former oil and gas sites based on the geospatial analysis and parameters as discussed in the literature.

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Executive Summary

Land-use changes are among the most contentious impacts of energy infrastructure. Generating energy implies an impact to land, air, water, and biodiversity resources. This is the same for renewable and non-renewable energy resources. There is always a spatial footprint associated with energy production, a non-negligible environmental impact. Moreover, the location of these impacts is determined by the resource availability, which constrains decisions for sitting infrastructure for extraction, transformation, transmission, and distribution of energy. As the United States transitions away from fossil fuel based energy production to renewable energy production the disturbance on the landscape must be considered. This case study considers the potential of developing renewable energy generation sites at former fossil fuel extraction sites, specifically abandoned oil and gas sites. In the United States the Environmental Protection Agency estimates there are two to three million plugged and abandoned oil and natural gas well sites. With a typical spatial footprint of one to five acres, there may be an untapped resource for renewable energy development, particularly photovoltaic (PV) solar development. This case study poses the question: *Is it possible to utilize disturbed areas from oil and gas development for renewable energy production*?

In order to answer this question qualitative and quantitative methods were employed. A study area was selected to focus on an area with a uniform regulatory structure, abundant solar resources as well as plugged and abandoned well sites. Based on these criteria the study area was based in southeastern New Mexico, an area with high solar energy potential, active and historic oil and gas development, and a large area of land managed by the Bureau of Land Management (BLM) under a common resource management plan. After selecting a study area spatial analyses were conducted to determine the number of available sites and their associated footprint. These data were then combined with energy modeling to determine the solar generating potential from these sites. Interviews with BLM employees were conducted to understand the intricacies of site conversion and potential policy and regulatory challenges associated with this particular transition. A literature review was conducted in order to understand additional challenges and environmental concerns associated with both plugged and abandoned well sites and solar energy development.

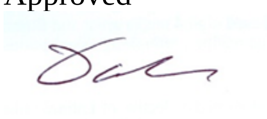
The number of potential sites and solar generating potential in the study area is significant. The study area's limited number of sites could potentially meet greater than eighty percent of New Mexico's residential demand based on kilowatt hour consumption. The actual transition from oil and gas to solar development is not a simple measure. Oil and gas and PV ultimately generate energy, however under current policy, the land uses must be analyzed as separate activities given the different impacts on the landscape. The abandoned well sites in the study area may help solve environmental problems through the generation of electricity to remediate legacy oil and gas impacts, and to create a unique microclimate on the landscape to aid in revegetation.

The oil and gas industry is looking for multiple ways to reduce its overall carbon footprint. Certain companies are even pursuing production of a carbon neutral barrel of crude oil. Renewable energy generated adjacent to exiting oil and can help offset this and should be studied. Policy changes that could streamline the process of transitioning from one method of generating energy to another should be considered and even incentivized, as there is not a current structure to easily do this.

Key points

- A growing demand for renewable energy will mean that additional land will be occupied for energy development
- Plugged and abandoned well sites occupy area that could be used for renewable energy development, particularly in southeast New Mexico
- High solar potential and a number of sites could meet energy demand for a large portion of the local population
- There is no regulatory mechanism to smoothly transition from oil and gas to renewables

Approved



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Dr. Dalia Patiño Echeverri

_______04-28-2021________________

Date

1. Introduction

Energy and land-use are interrelated, and this interrelation must be recognized. Generating energy implies a sacrifice of land, air, water and soil quality, and biodiversity. This is the same for renewable and non-renewable energy resources. There is always a spatial footprint associated with energy production, a non-negligible environmental impact. Moreover, the location of these impacts is determined by the resource availability, which constrains decisions for siting infrastructure for extraction, transformation, transmission, and distribution of energy. In non-renewable resource extraction, equipment and facilities must be sited where the resource exists; this is a function of geology. An oil well or coal mine cannot be placed where it makes the most sense from a land-use planning standpoint, as the resource is not likely collocated in that area, or if the area does contain resources, they may be scarce, and their extraction not economical. In much the same way, efficient siting of renewable energy requires sustained high wind speeds and abundant solar irradiance. Nevertheless, there is a difference in the long-term footprint on the landscape of renewables and non-renewables. Renewable energy infrastructure likely will remain as a fixture on the landscape for 25-40 years[i]. The scope and scale of these disturbances is determined by the resource and its economic viability.

The transition away from fossil fuels to renewable development will occupy a significant amount of land. Estimates range as high as an area the size of the entirety of the state of West Virginia needed for solar production to meet US energy demand[ii]. This is a significant amount of new disturbance to surface lands in the U.S.

The productive life of an oil or natural gas well can range from 15-30 years[iii]. As the wells become uneconomical, they are eventually plugged, and the affected area restored back to match the undisturbed adjacent area or re-purposed by the landowner for their own benefit[iv]. For a site to reach full closure and be absolved of environmental obligations, all potential environmental liabilities must be resolved. In most regulatory environments this final closure of the site is referred to as a final abandonment notice (FAN) [ii]. Abandonment in this instance should not be seen as a dereliction of responsibility, but rather a fulfillment of necessary obligations and a release of liability. Approval of the FAN ultimately results in the release of the bond associated with the initial drilling of the well [ii]. Once the bond has been released on an oil and gas site, the physical location can now be considered reclaimed or fully restored, unless additional environmental concerns are discovered later.

When discussing oil and gas exploration and production, it is important to note two distinct components of the landscape' impact. There is first the physical wellbore or well, which has a minimal footprint. A natural gas well can exist and operate in an area as small as 10 feet by 10 feet[v]. The associated infrastructure however is referred to as the well pad and production facility. Well pads, necessary to place the drilling rig for installing the well, and production facilities necessary to conduct the primary stages of oil and gas processing, vary greatly in size. The well pads and production facilities can be commingled on the same disturbance, or entirely separated. In instances where a well pad is separate from the production facility and interconnected via a pipeline, the original well pad disturbance may shrink to a 10'x10' area[vi]. If a site has commingled wells and production facilities, the long-term disturbance can be from 1-10 acres depending on the number of wells produced from the well pad, the processes necessary to produce the oil and natural gas from the well, and the regulatory requirements for the well operator to conduct interim reclamation[vii].

It is currently estimated by the United States Environmental Protection Agency (EPA) that there are nearly three million abandoned well sites in the US[viii]. Depending on the current land-use, wishes of the landowner, and regulatory policy of the states and federal government, this land could potentially be used for renewable energy. In an oversimplified calculation at 1 acre per abandoned well site, there could be 2.4-3 million acres of land with the potential to be converted to small-scale photovoltaic solar generation. These sites under ideal circumstances could generate 357 megawatt hours/year/acre or 856,800 gigawatt hours/year. This translates to roughly twenty percent of U.S. electricity consumption[ix]. These numbers are under idealized circumstances where every landowner wishes to have solar energy generating capacity installed on their property, every former well site/production facility has the appropriate slope, topography, and amount of insolation, and a way to connect to the grid or be useful to support an area microgrid.

The concept of reutilizing former industrial sites or brownfield sites as generation sites for renewable energy is nothing new. There are existing projects in Germany and Turkey that have taken former mining and manufacturing sites and converted them to PV generation sites[x].

Siting renewable energy generation sources requires careful consideration, much like the siting decision of any other major energy generation source. Given their long-term disturbance on the landscape, careful planning and explorations of alternatives is a must. The loss of natural resources for energy generation is troubling and renewable sources should not be exempt from scrutiny in siting. Erosion, loss of vegetation, disruption of wildlife migration corridors, invasive species and vegetation management are all items that must be considered at all energy projects[xi],[xii],[xiii]. For many existing oil and gas sites, this analysis has been conducted in some manner. State regulatory agencies in certain states require a pre-disturbance site assessment and federal projects will require NEPA analysis. Additionally, when working with private landowners during the initial siting of oil and gas facilities, negotiations take place between the leasing company and landowner to site the facility in the most appropriate spot from the landowner's point of view. Often these facilities are sited at the edge of a field, or on a non-productive piece of property with little agricultural value. By continuing to utilize these areas there isn't a net loss of land, as this land was previously occupied.

With the ever-increasing demand for clean energy and the non-negligible impacts of renewable energy on land-use, it is expected that power generation will always have an associated footprint. However, the conversion of previously disturbed land from oil and gas extraction to sites for wind and solar energy development may offer a reduction of these impacts. This case study will focus on the following question: *Is it possible to utilize disturbed areas from oil and gas development for renewable energy production?*

2. Background and Relevancy

2.1 Geography and Oil and Gas

The Permian Basin of Texas and New Mexico is one of the most prolific oil and gas producing basins in the world. This producing area has significant spatial dimensions, nearly 225,000 square kilometers, or roughly the size of the State of Utah in the United States[xiv]. This area is also sparsely populated, with a population of around two million people between both New Mexico and Texas[xv]. Key population centers in the area include the cities of Midland, TX and Odessa, TX.

Development of oil and gas resources in this basin has occurred since 1920 and continues to this day. Cumulative oil production in the basin has approached nearly thirty billion barrels during the past one hundred years[xvi]. In 2019 the Permian Basin became the largest producing oil field in the world with output of 4 million barrels of oil per day[xvii]. With the many iterations of hydrocarbon development in the area, there is a significant disturbance footprint left behind on the landscape. This disturbance comes from the well sites, gathering, transportation, and processing facilities. The development of these resources requires stripping the land of vegetation and constructing facilities for oil and gas production. Over the producing life of a well, reclamation efforts are made to help stabilize sites, but a significant footprint is still required for day-to-day operations. A quick review of aerial imagery of south eastern New Mexico or western Texas shows the extent of this disturbance.

Cattle grazing and limited agriculture occurs in areas where vegetation can support cattle and there is recreational use of the land for different activities including hunting, recreational shooting, and off-road exploration. In many instances, land-use is heavily focused on energy extraction. Although the overall landscape is contiguous between New Mexico and Texas, there are a couple of distinct differences based on which side of the border a project is sited. In Texas, the vast majority of the land is under private ownership with many different landowners. In the New Mexico portion of the basin, the United States Department of the Interior-Bureau of Land Management (BLM) manages over two million surface acres[xviii]. Both states and the BLM have different management standards for oil and gas development activity, which leads to different long-term goals for production and final abandonment. In Texas, final abandonment goals are between the landowner and the oil and gas producer with limited oversite from state regulatory agencies, whereas in New Mexico, final abandonment standards are set and established via the BLM on sites with federal ownership[xix]. The federal standards are uniform based on the specific field office jurisdiction and existing NEPA documents. Even with the remarkable, long lived fossil fuel resources available in the Permian Basin the geographic area has significant potential for renewable energy development.

2.2 Renewable Potential

The recent advances in renewable energy technology and additional focus on transitioning away from fossil fuels has sparked a significant interest in the siting and pursuit of large and small-scale utility projects. The best indicator of the renewable potential of a geographic region is the number of industry players that are attempting to make a profitable project. Clearly there are drivers for both wind and photovoltaic solar projects in the area. This is evidenced by current large-scale wind and solar projects that have been recently installed. A cursory search provides numerous links to projects happening throughout the Permian Basin. Most recently the Recurrent Energy Maplewood I and Maplewood II solar project was completed near Ft. Stockton, TX at the southeastern corner of the Permian Basin[xx]. The combined output of these projects is nearly 400-megawatt peak (MWp), with a number of buyers for the electricity including manufacturing, oil and gas, and residential utility use[xxi]. Xcel energy currently operates three significant wind projects in the Permian Basin. The Sagamore Project in New Mexico and Bonita and Hale projects in Texas combine for an output of 1600 MWh[xxii].

Oil and gas operators are starting to adapt their business to utilize renewable energy to help power their operations. The petroleum industry is a significant consumer of electricity in the area. Electricity is utilized to run pumps, automation equipment, and drive motors to move product and to lift product from the geologic producing reservoirs[xxiii]. Most recently, Occidental Petroleum Corporation (Oxy) installed a 16MW facility outside of Goldsmith, TX in order to provide electrical generation capacity to their equipment and facilities[xxiv]. The Maplewood II solar project referenced above will generate electricity exclusively for Energy Transfer, a company focused on transporting crude oil, natural gas, and natural gas liquids[xxv]. Oxy is also currently pursuing a long-term goal of a carbon net-neutral barrel of oil by utilizing more renewable power, but also developing direct air carbon capture technologies in order to capture and sequester carbon dioxide from the atmosphere[xxvi]. These activities will require significant electricity inputs and renewable energy will be in high demand as companies look to reduce their overall greenhouse gas emissions.

An emerging area of study in the oil and gas industry is the potential of reclaiming minerals from oil and gas waste materials[xxvii]. The recent development of oil and gas activities and exploitation of the Wolfcamp and Spraberry formations has shown that these prolific hydrocarbon producing zones also produce significant amounts of formation water with the oil, referred to as produced water. It is currently estimated that for every barrel of oil (42 US gallons or 159 liters) produced in the Permian basin that there is between four and ten barrels of produced water associated with that oil[xxviii]. The vast majority of this produced water is transported either via truck or pipeline to facilities that then re-inject the water into non-oil producing formations with capacity to store the water[xxix]. The re-injection of produced water into the subsurface has a number of issues associated with it, most alarmingly induced seismicity where the injected water acts as a lubricant along fault lines, causing small scale seismic episodes[xxx]. Knowing that induced seismicity and ever decreasing injection capacity are growing issues and significant risks for ongoing production, oil and gas producers are studying other uses for produced water. A number of studies have looked at the potential of recovering rare earth elements, lithium (Li) in particular from these waters[xxxi]. Additional uses for produced water also include the potential for surface discharge to be used for agricultural purposes or for drinking water. Significant energy would need to be consumed to treat water to a surface discharge or drinking water standard given the chemical makeup of the produced water. The removal of hydrocarbons is a relatively simple process and can be conducted through settling or filtration[xxxii]. The removal of dissolved solids is a significant undertaking requiring reverse osmosis or distillation[xxxiii]. Both are energy intensive processes that could be an outlet for new electricity generation from renewables.

Direct air capture (DAC) is an emerging technology that is being developed to remove carbon dioxide (CO2) from the atmosphere[xxxiv]. Oxy has committed to utilizing DAC to capture and then sequester CO2 in subsurface geologic formations or use CO2 as a tertiary oil recovery method known in the industry as CO2 flooding for enhanced oil recovery[xxxv]. DAC is still in the development phase, but the process of running giant fans to push air through membranes that strip CO2 out of the atmosphere will undoubtedly require significant amounts of electricity. As oil and gas companies continue to tout this as a way to produce a net-zero carbon barrel of oil, it will only make sense that they procure energy from renewable generation sites. Having renewable energy co-located with existing oil and gas fields may prove to be an economic driver. Abundant, locally sourced energy generated without direct site emissions could potentially help companies meet goals while providing a solution to combating climate change.

3. Objectives

1. ***To explore the array of issues determining the feasibility of converting oil and gas sites to solar energy generation sites.***

In order to understand the feasibility of a project like this analysis needs to be conducted to better understand the number of available sites on public land that could be utilized. Given that nearly thirty-five percent of New Mexico’s surface area is managed by the federal government additional focus will need to occur to find a suitable project area. The siting of solar sites is significantly different than that of siting a well site and these characteristics may ultimately prove that some oil and gas sites may need to be eliminated as potential transition candidates.

2. ***To conduct a case study to better understand the regulatory and technical constraints associated with oil and gas production and renewable energy production at former oil and gas sites.***

Given that both solar and oil and gas are ongoing energy concerns an understanding in the differences and similarities in the overall regulatory structure will be necessary. The technical aspects of oil and gas development are not necessarily something a solar developer would need to consider; however, the land use and surface disturbance aspects of physically siting projects should be better understood. Additionally, the rules regarding site stabilization, reclamation, and prevention of degradation away from the project area will need to be considered and compared. Limiting factors may include topography and aspect of the former oil and gas sites. As previously discussed, an end user for the newly generated electricity will need to be considered. From a policy perspective this case study aims to clarify the differences in the NEPA process for solar and oil and gas and understand if there is a mechanism to convert sites over from use to another.

3. ***To utilize lessons learned from the case study to assess scalability within the United States in association with the ongoing transition to renewable energy.***

Lastly the project will consider different potential benefits for both the general public and for industry and government within the boundaries of solar energy development at former oil and gas sites and if the concept is scalable. Given the large footprint of oil and gas extraction the scalability of a project like this needs to be assessed. With sustainable energy goals in the United States at the forefront of energy discussions, assessment of any additional renewable capacity should be considered.

4. Methods and Data

To-assess the overall feasibility there are two components that need to be discussed and better understood: policy issues and the overall renewable energy capacity of the study area. These approaches for addressing the problem require two distinct methods of research and include both qualitative methods and quantitative methods.

4.1 Site Selection

In order to maintain a limited scope of study site selection was focused on a number of components. Of particular importance in framing the study area are the following characteristics:

- Number of oil and gas sites
- Number of abandoned oil and gas sites
- Existing rules and regulations related to solar
- Existing rules and regulations related to oil and gas
- Access and proximity of sites to electrical transmission lines
- Consistency in regulation

This analysis focuses, for reasons explained below, on public lands under the jurisdiction of New Mexico's Pecos District Bureau of Land Management Carlsbad Field Office (BLM), an area with abundant oil and gas production. This is an area with a topography favorable to solar PV development and rich solar potential, so the analysis concentrates on the feasibility of developing and expanding this renewable resource. Uniform regulatory jurisdiction allows for analysis across a large scale of land and eliminates the variables of dealing with multiple landowners. The timeframe and effort to contact multiple landowners across a large landscape level area like this is not in the scope of this study. Appendix B details the overall project area.

4.2 Qualitative Methods

The qualitative analysis is informed by interviews with experts and stakeholders. These interviews were conducted during digital meetings utilizing the Zoom platform, enabling video and audio to be utilized. Zoom allows for the recording of conversations and meetings in order preserve the conversation for additional review. Interview participants were also given the option to respond to a series of questions through email if an interview was not feasible. The interview protocol is provided on Appendix A. Given the significant policy concerns associated with long term planning on public lands and the vast energy development currently occurring on public lands, this study focused on public lands.

Focusing on public lands allowed for consistent interpretation of rules and regulations as well as various policy concerns. Attempting to study and gain information on whether private landowners would be amenable would require a much more in-depth study and significantly more field work. The complications of leasing property and the terms associated with those leases are not in the public record. Private landowners also can be difficult to contact and do not have to disclose important details of leasing, such as long-term lease payments, royalty and access rates, and other improvements a developer may need to provide as compensation to the landowner as conditions of approval for the project. Information like this is well guarded and oftentimes proprietary between landowners and industry operators. Given the multitude of variables, public lands as administered by the Department of the Interior, Bureau of Land Management (BLM) were selected as the focus of this study.

Interviewees from the BLM consisted of staff from multiple disciplines as selected by local BLM management from the Pecos District-Carlsbad Field Office (CFO). Interviewees disciplines included NEPA policy, existing resource management plans, renewable energy development, surface reclamation, and realty specialists focused on the administrative focus of leasing and development of public lands. A multi-disciplinary review from staff at the CFO is not unlike the actual permitting process that a major energy project would undergo prior to approval.

4.3 Literature Review

Peer reviewed scientific journal articles were sought out to understand existing research that has been conducted regarding PV solar development. Literature was specifically selected based on environmental considerations including the effects of PV development on wildlife and vegetation. Journal articles were also considered related to academic research associated with oil and gas activities to understand potential waste challenges that oil and gas operators potentially could use abundant electricity. Periodical publications from the geographic study area were reviewed to understand existing and proposed renewable projects to understand feasibility and renewable potential, as well as collect data on the overall scope, scale, and participators in these large-scale renewable projects.

Lastly, NEPA documents from the CFO were studied to understand the overarching goals of the BLM field office. The CFO is currently undergoing a Resource Management Plan (RMP). The RMP is the overarching guidance document for the CFO and establishes expectations for all activities and actions that occur on CFO administered lands. This document is still in “Draft” status. The CFO has established alternatives for solar activities and Solar Alternative A, the most restrictive alternative for industry was selected for the analysis[xxxvi]. Using the most restrictive alternative for the analysis will provide the most structure around the analysis.

4.4 Quantitative methods and data

This study conducts a geospatial analysis of the land under BLM's jurisdiction, which provides relevant information on multiple public data sets discussed below.

Although a thorough exploration of alternatives to reduce renewable energy's footprint, requires, besides the assessment of development feasibility in previously disturbed lands, the quantification of land availability and corresponding power generation capacity, this project is limited to a case study of the Permian/Delaware basin of South Eastern New Mexico. The detailed examination of this particular location provides valuable insight on the possibilities of repurposing oil and gas fields for solar and wind energy in the rest of the country and the nature of the barriers and obstacles that must be sorted.

This analysis focuses, for reasons explained below, on a stretch of public land under the jurisdiction of New Mexico's Pecos District Carlsbad Field Office Bureau of Land Management (BLM), and area with abundant plugged and abandoned wells. Also, this is an area with a topography favorable to solar PV development and rich solar potential, so the analysis concentrates on the feasibility of this renewable resource.

It is important to note the relationship between the qualitative data and quantitative data associated with this study. Consideration needs to be given to existing and proposed regulation in order to help parse out which potential sites meet the requirements for both solar energy production and oil and gas production.

4.5 Spatial Data

Spatial data was collected from a variety of sources utilizing publicly available data sets showing the physical location of oil and gas wells, topography, and multiple data sets from the BLM. Figure 1 details the data set and source of the data used. Rudimentary analyses were conducted on these data to understand what abandoned sites were available based on attributes within the data set. Only well sites with an "ABANDONED" well status were considered for the scope of this study and narrow the data set. A status of "ABANDONED" designates that the wellbore is no longer active, and oil and gas activities at the site are complete. Additional review of the project area was undertaken to understand the proximity to producing wells. With the advent of directional and horizontal drilling, operators have utilized technology to drill new wells from existing disturbance areas. It is important to consider that additional minimization of footprint and utilizing existing disturbance is for new drilling has been in use for a number of years and that information could potentially eliminate well sites for the purpose of this study. In order to better understand this potential conflict, a buffer analysis was able to eliminate multiple wells that had a status of “PRODUCING” or “INJECTING” within 25 meters of the abandoned wellbore. 25 meters was selected as typical wellbore spacing on the surface ranges for directional or horizontal drilling is significantly smaller, usually two to three meters apart. This is done for ease of drilling multiple wellbores and avoid significant cost and time to move the drilling rig multiple times.

Upon determining sites, a review of aerial imagery helped to determine the overall footprint of disturbance associated with abandoned wells. Each well site is different in the overall footprint it occupies for a number of reasons. Site topography, drilling and completions technology used, wildlife proximity, and natural features all determine the surface siting concerns for a well site. Buffers were established around the sites utilizing a handful of different sizes spreading from a 25m buffer to a 100m buffer to a 500m buffer. Utilizing the Minimum Bounding Geometry and Feature Envelope tools in ArcGIS a consistent square polygon was generated using the former well bore location as the center of the site. After generating these square polygons which are uniform in size, square meters can be calculated and applied to the number of wells. This is a quick way to establish uniform polygons and reduce the input and manual manipulation of data and hand digitization of features. These polygons were then measured utilizing the ArcGIS measurement tool to calculate the hectare footprint of disturbance associated with oil and gas activities. With the uniform size of the site established, the number of sites can be multiplied by the measured size. The total area of the abandoned wellsite can then be used to assess the maximum size of the PV facility that can be installed at the site and its overall electric power generating capacity. Potential output from PV cells was calculated using the National Renewable Energy Laboratory System Advisor Model.

Given the multiple land uses in the CFO, a significant amount of study has been conducted to show what land uses are compatible with specific geographic areas. GIS data from the CFO Resource Management Plan scoping documents is available and provides oversite on which areas are suitable for a number of different development activities. The NEPA process requires a number of alternatives to be considered for all development activities. There are typically three alternatives of varying intensity of development and a no action alternative. For the purposes of this study all scenarios were assessed using Alternative A, which is the most restrictive alternative when considering development activities.

Once the well sites had been selected the "Clip" function was utilized in ArcGIS to extract well sites that were in areas that were suitable under Alternative A. The Clip feature utilizes the boundary of a polygon to extract other features that fall within the polygon[xxxvii]. Data from the US Department of Homeland Security was obtained to visualize what interconnections and transmission lines are located in the area. The Clip function was once again utilized after creating multiple buffers around the transmission lines and substations to extract well sites that were one, three, seven, and fifteen miles away from transmission lines. Distance from the sites to transmission lines was measured to understand if there were economic limitations to connecting sites to the electrical grid. Distribution line information was not readily available and therefore not considered in this case study.

Spatial Dataset	Data Provider	Utilization
Wells Data Set[xxxviii]	IHS Markit Well Database	Number of wells Status of wells Location of wells
Carlsbad Field Office RMP Planning[xxxix]	United States Department of the Interior Bureau of Land Management	RMP Solar Alternatives Topography Slope/Aspect
Transmission Lines[xl]	United States Department of Homeland Security	Location of regulated transmission lines in the study area
Electrical Substations[xli]	United States Department of Homeland Security	Location of regulated electrical substations in the study area
Aerial imagery base map[xlii]	Bing Hybrid Aerial	Ground truthing location and disturbance. Establishing site footprint to build buffers

Figure 1: Spatial data sources and their utilization in this analysis

4.6 The NREL System Advisor Model (SAM)

The NREL-SAM is a multivariable spatial data set that estimates electricity production from solar PV facilities, accounting for azimuth, slope, and the size of the PV installation[xliii]. The tool utilizes data based on weather and climate records to account for direct beam, global horizontal, and diffuse horizontal insolation. Weather information is important to understand how many days of direct sunlight, ambient temperature, as well as understanding limiting factors like snow cover[xliv]. SAM also provides estimates on construction and operation costs.

4.7 Calculations

Utilizing these variables simple calculations can be conducted to understand the potential generation capacity for the sites. The following basic equations were used to better understand potential generating capacity.

$$A \times O = E$$

$$E \times N = TE$$

$$\frac{A \times O \times N}{C} = H$$

Where:

E = Daily electricity generating capacity of a PV system of average size A, in kilowatt-hours/day

A = Average surface area of a site in study area, in square meters

N = Number of available sites in study area

$O = \text{Average electricity generation from a PV system in kWh per } m^2 \text{ per day}$

TE = Total Potential daily electricity generating capacity of study area, in kWh per day

C = Average residential electricity consumption in study area, in kWh per housing unit per day

H = Number of housing units that could be served by generated power from PV installation in study area

5. Results

5.1 Quantitative Results

Estimating the total power generation capacity of this oil and gas production area requires determining the number of well-sites. Based on the spatial analyses, there are 179 total P&A well-sites in the CFO; of these sites there are 149 suitable sites. The suitable sites for solar PV generation are located in areas that have been classified under the CFO RMP as suitable under Alternative A. There are a total of 30 P&A sites disqualified from the total number due to them being located in an area not suitable for solar development under Alternative A.

Further spatial analysis reveals typical P&A sites have a typical footprint of 1.41 hectares. By overlaying the generated square buffer on the point representing the location of the well bore, the buffer lines up around the overall footprint of the site. Figure 3 shows this alignment of spatial buffer and site footprint at a typical well site. It should be noted that this figure depicts a site with active oil and gas infrastructure. This is due to the lag time of the aerial imagery versus the current well status. The characteristics of P&A sites are summarized in Figure 1 and information on the sites distance to electrical infrastructure is presented in Figure 2.

SAM data yields an estimate of average site generating potential of 6.93kWh/m^2/day based on weather and climate data and localized irradiance at the sites. Given the potential for solar generation, assuming the entire 14,100 square meters or site area can be used to install PV panels, an estimate of the overall daily electricity generation capacity of an average site is:

$$\left((14{,}100 \times 6.93)\right) = 97{,}713\ kWh\ per\ site\ per\ day$$

The power generation potential per site can then be combined with the estimated number of sites available in the study area to calculate the total potential electricity generation in the study area of 97,713 kWh/site-day x 149 sites = 14,559,237 kWh-day. This potential can be compared with electricity consumption to provide context for the magnitude of this solar resource. According to the EIA, in 2019, NM residential customers consumed an average of 640 kWh/month[xlv]. This renders an average daily consumption of 21.3 kWh/day, which indicates that the total electricity generating potential of all the P&A well sites in the study region is about 682,464 times the average electricity consumption of a New Mexico's household. The U.S. Census Bureau reported in 2019 780,249 households in New Mexico[xlvi]. The established numbers here represent 86% of the total electricity residential consumption of NM could be offset with PV generation from the P&A sites in the study region.

Given the average residential electricity consumption in the U.S., at 887/kWh-month or 29.57 kWh-day. is higher than New Mexico's, covering the available well-sites of the study region with PV panels would generate the same electricity as the total consumed by almost half a million U.S. households (calculated as 492,420 households)

SAM data also provides a brief summary of the economic factors associated with a typical site in this study area. A typical site would require an initial capital expense of $860,000 for construction and would have a 13-year return on capital investment before the individual site becomes profitable. Figure 5 shows a tabular summary generated using SAM detailing rough economic considerations for a project like this.

Site Categorization	Number of Sites	Total Hectares (1.41 ha/site)	Solar Potential Generating Capacity (kWh)*
P&A suitable with Solar Alt A	149	210	14,559,237 kWh
CFO P&A sites	179	N/A	N/A
Major transmission lines	161	N/A	N/A
Substations	128	N/A	N/A

Figure 2: Summary of statistics for CFO P&A well sites and electrical infrastructure

	Distance to Infrastructure <1 mi	**Distance to Infrastructure <3 mi**	**Distance to Infrastructure >7 mi**
P&A Sites	**2%**	**2%**	**50%**

Figure 3: Distance to electrical infrastructure

Figure 4: The Burton 6 Federal P&A site shows the approximation of the generated spatial buffer in relation to a plugged and abandoned well site. It should be noted that the imagery is from 2015 while the plug and abandonment activity occurred in 2019.

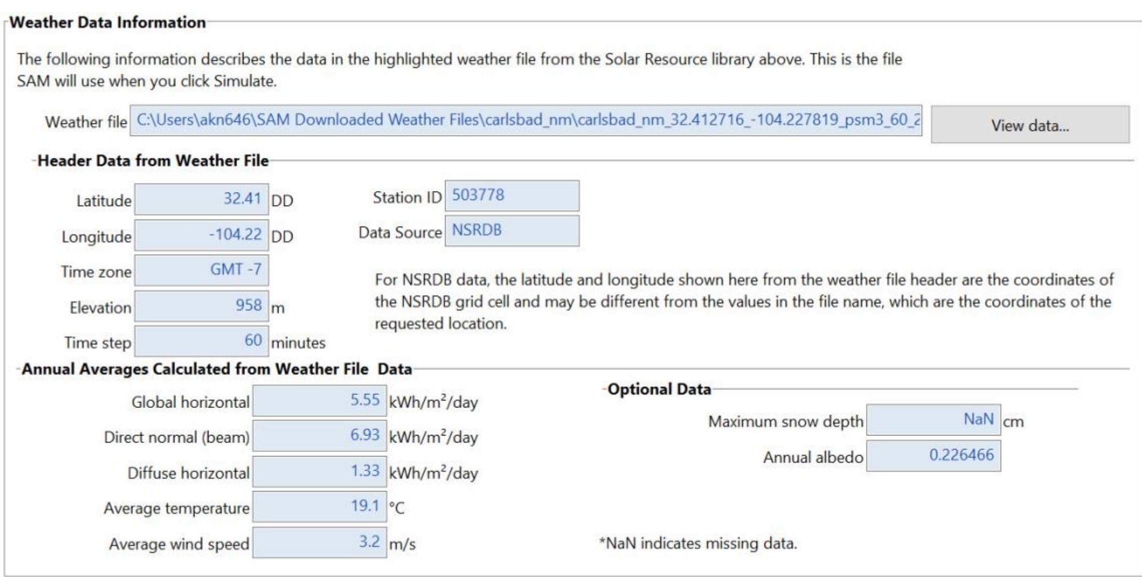


Figure 5: PV Solar Generation Potential as Generated by SAM

Metric	Value
Annual energy (year 1)	887,476 kWh
Capacity factor (year 1)	20.3%
Energy yield (year 1)	1,780 kWh/kW
Performance ratio (year 1)	0.79
Levelized COE (nominal)	3.23 ¢/kWh
Levelized COE (real)	2.58 ¢/kWh
Electricity bill without system (year 1)	$104,614
Electricity bill with system (year 1)	$52,196
Net savings with system (year 1)	$52,418
Net present value	$189,259
Simple payback period	13.3 years
Discounted payback period	NaN
Net capital cost	$860,881
Equity	$0
Debt	$860,881

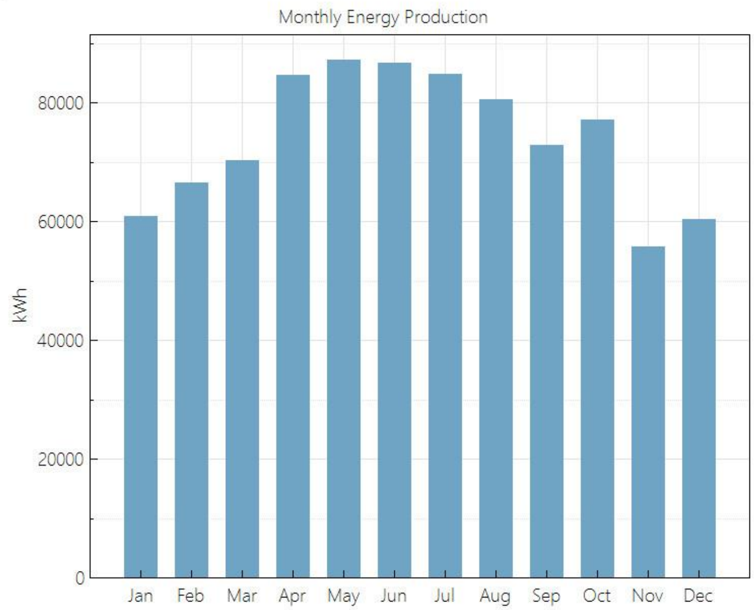


Figure 6: Economic considerations as generated by SAM

5.2 Qualitative Results-Interview Data

Based on conversations with BLM staff members there were a couple of key findings specifically related to how solar energy interacts with existing disturbances and oil and gas leases. The disturbance bonding mechanism, often referred to as the reclamation bond for the site, cannot be transferred from an oil and gas operator to a renewable energy project. However, the right of way and lease for the site could be transferred from one operator to another. Operators often divest and acquire other producing wells when oil and gas wells no longer become economic for a large operator but may be well within the profit margins for a smaller operator. Given the different type of activity a solar project would have, when compared to an oil and gas project, a different bond would be required, or the site would need to be re-bonded. A title and right of way change could occur to swap the access to the site from the oil and gas operator to the solar operator but would require different permitting to follow through with an actual project. The process of moving a right of way is more of an administrative task related to real estate as opposed to a new renewable project. A new project would require new permitting. With the acquisition of these sites, great care would need to be taken to ensure an operator is not taking on environmental liabilities associated with the former oil and gas site. Hydrocarbon impacts to soil and groundwater are commonly found while going through the P&A and site decommissioning process. The transfer of title and right of way can be conducted without those impacts being remediated, leaving the new operator as the entity responsible for meeting cleanup standards. In speaking with BLM staff Petroleum Engineering Technician and Environmental Specialist Jim Amos offered the following wisdom: "The devil is truly in the details when it comes to any sort of site conversion, especially when it comes to former oil and gas sites."

Beyond the challenges associated with a site conversion and the potential impacts and liabilities of past oil and gas operations, another large component of the discussion must be focused around the NEPA policy and where a project fits within the larger objectives of the regulatory structure. Individual oil and gas projects and solar projects can fall under different Environmental Analysis (EA) or Environmental Impact Statements (EIS) within the same large scale Resource Management Plant (RMP). The current Carlsbad District Office RMP is currently being revised and updated, with the last major revision happening in 2008. The revision of an RMP is a significant undertaking for any BLM office, as the RMP is the all-encompassing document that other activities (EA, EIS) must reference back to. The BLM noted that solar specifically can create additional conflicts on the land between different stakeholders. Cattle and sheep grazing can have conflicts with the footprint, particularly if the construction of solar panels is not tall enough for livestock to graze under. Surface mining activities are also seen as a potential conflict, in that the entirety of the footprint of the disturbance now will have surface equipment. In theory mining activities can occur directly adjacent to oil and gas activities so long as the well bore and production facilities aren't compromised by encroaching mining activities. Further study is necessary to understand the impacts to wildlife that are created when establishing a new solar project.

Given all the above-mentioned conflicts and differences in land use, a solar project on existing oil and gas disturbance would require new permitting. Although the land use ultimately can be distilled down to energy generation, the activities are simply too different to be compatible under the current NEPA documents in the Carlsbad Field office. Current Acting Field Manager (AFM) Ty Bryson offered a fitting summary of the proposed idea, "The current revisions happening in the RMP are mostly related to ongoing oil and gas development and don't necessarily consider renewables in this manner, as revisions began in earnest to make sure oil and gas impacts were evaluated. A scenario (where oil and gas sites would be converted to renewable sites) would need to be permitted as a new action, because there isn't currently a mechanism to do this. The analysis is different for a renewable project and an oil and gas project, as they have different impacts on the landscape."

5.3 Qualitative Results-Literature Review

5.3.1 NEPA Documents

Given the land-use goals of the BLM for all projects, this data was then compared to proposed focus areas for the Carlsbad District Field Office's land-use goals as described under the proposed alternatives in the resource management plan. Understanding the long-term land-use goals and future plans for the area helps to determine siting, or if there are better areas for siting.

It is important to remember that land utilized for energy extraction, both renewable and non-renewable, can still allow other productive uses or provide ecosystem services. New Mexico and the BLM both require reclamation activities associated with oil and gas disturbances as well as renewable energy disturbance. Conservation of topsoil and establishing diverse, self-sustaining vegetation is of particular importance for any development. It helps to enhance water quality by eliminating sedimentation in waterways. This is of particular importance in an arid region like southeastern New Mexico.

5.3.2 Current New Mexico Legislation

Recent legislation has been proposed in New Mexico that strictly limits what industrial activities fresh water can be used for as the state is continuing to see upcoming challenges and additional effects of climate change. The legislation introduced by Senators Antoinette Sedillo Lopez and Elizabeth "Liz" Stefanics in Senate Bill 086 in the 2021 Regular session of the New Mexico state legislature specifically prohibits using freshwater for drilling of oil and gas activities[xlvii]. This legislation was given a "Do Pass with amendments" recommendation and is currently being studied by the New Mexico Senate Judiciary Committee. Given the proposed limitations on fresh water use for oil and gas, renewable energy could potentially be a way to treat produced waters for recycling for further industrial use. It is clear that there is growing momentum in the New Mexico legislature to reform oil and gas development and additional adoption of renewable energy by industry will benefit all parties involved.

5.3.4 Vegetation

Establishing vegetation through reclamation processes is a requirement of any surface disturbing activity on BLM surface. Although the areas unused directly by energy development are revegetated, the change in land-use is important to acknowledge. Sites will go through phases of succession after such a drastic disturbance and it's important to maintain oversight and management of these sites to prevent encroachment of invasive or undesirable species. The BLM also requires a reclamation plan as a part of every application for a permit to drill[xlviii].

The addition of PV solar to P&A well sites may also aid in the reclamation of the abandoned site. With the growth of PV in many areas, research is being conducted to better understand the abiotic and biotic effects of large-scale PV on soils and vegetation[xlix]. The arid desert of SE New Mexico has a number of challenges from a vegetation reclamation standpoint. Typically speaking the area averages less than 35cm of precipitation per year[l]. Arid climates like this typically do not respond rapidly to disturbance and great care must be taken to set the conditions for reclamation success[li]. The microclimate at the site and shielding of the site from heat, direct sunlight, evaporation loss of soil moisture, and other factors have all been researched with various results. Important factors that were observed in a handful of studies have included lower soil temperatures and increased humidity, which are both factors that can contribute to reclamation success[lii]. This is a relatively new area of study and much research must still be conducted to understand all of the implications and the longer-term effects of the creation of this microclimate.

5.3.5 Orphaned Well Sites

There are currently seven hundred eight (708) wells in New Mexico that are considered to have orphan status[liii]. An "orphaned" well is one where there is no longer a solvent operator to handle the outstanding liabilities associated with the well[xlviii]. These wells become the responsibility of the regulatory agencies that oversee oil and gas production activities[xlviii]. Costs associated with these wells will ultimately be borne by the public and environmental concerns will be paid for through tax dollars[xlviii]. Given the liabilities associated with orphaned well sites, a potential revenue generating option would be to convert these sites to solar energy generation spots, assuming of course proximity to transmission infrastructure exists. Revenue could be generated via the sale of electricity to help offset the costs of the plugging and abandonment of the well and any additional outstanding environmental liabilities that could be at the site.

5.3.6 Public Perception

All activities on public lands must go through a public comment process as part of the NEPA analysis. Typically projects that receive significant public comment come from many different stakeholders, tribal and indigenous peoples, recreational land users, grazers, hunters, energy and mineral developers, non-governmental organizations and individual citizens all have a vested interest in any and all projects associated with public lands. These diverse interests create significant discussion around projects and have the ability to push projects forward if there's consensus or to significantly stall projects if there is controversy. Although there are mechanisms available to the BLM to expedite projects, like categorical exclusions (CX or CE), an existing larger scale NEPA document must be in place[liv]. Based on the literature review a number of issues can arise from a solar project which aren't entirely different from an oil and gas project[lv]. Surface disturbance and the removal of vegetation for construction activities, erosion and topsoil loss, impacts to wildlife migration corridors, the loss of historic viewsheds and encroachment on other sensitive areas are all pressing items.

6. Discussion

It is evident based simply on the number of sites that the area has significant potential for solar energy development and production, along with an abundance of land to set up operations. Although as discussed by BLM staff, the two different methods for extracting energy are very different activities and require different sets of analyses. That being said, the idea is still very much in the structuring and consideration phase. The novelty of this idea was apparent in discussion with staff from BLM as the thought had not been considered nor had they been approached with a concept like this.

Oil and gas operators are looking at improving their environmental stewardship and reducing their environmental footprint. Environmental, sustainability, and governance (ESG) report scores from the investment community is becoming a more important focus for oil and gas operators. Companies are recognizing that reserves and production numbers do not move the needle as much as being a sustainable operator that scores well in ESG. In recognizing this, major operators including Shell and British Petroleum, for example, have developed renewable energy operations within their corporate structure[lvi]. In many ways, the ability to generate solar energy at former well sites could lead to an additional revenue stream based on existing capital expenditures.

The regulatory mechanisms for an idea like this to happen do not exist and do not appear to be in consideration in the immediate future. Even with the reworking of the existing CFO RMP, the focus will be limited to existing land uses. Currently there are no proposed solar activities in this particular field office which is a contributing factor to not considering an idea as proposed in this research. It is important to remember that under the scope of the NEPA permitting renewable energy production and oil and gas extraction are considered separate, un-related activities and must be analyzed differently.

An idea like this will need to be analyzed from an overall economic standpoint. Clearly a project like this has the potential to generate revenue from an electricity sales standpoint. Discussions should be had around site bonding, final reclamation costs, and the costs associated with having outstanding liabilities and environmental obligations for a site that is no longer productive and generates no revenue. As oil and gas companies and other extractive industries begin to focus on their overall ESG performance as it relates to access to capital the economics of a venture into renewable energy production at legacy sites may become appealing. A regulatory mechanism would be necessary for the idea to gain traction and could potentially be used to incentivize the action. The ability to generate revenue through electricity sales while receiving tax incentives could certainly be a mutually beneficial situation for industry, government, and the public. The generation of clean energy and creating new generation sites will only help to satisfy the United States increasing demand not only for energy, but specifically for clean, renewable sources of energy. Sites that are disturbed will remain disturbed longer, however they are still productive even if in a different manner. Building on top of existing disturbance prevents new disturbance, or further encroachment into undisturbed areas. Future policy and the long-term economics of an idea like this need to be further discussed and are outside of the scope of this research.

7. Conclusions

Former oil and gas producing sites have the capacity to generate renewable energy in the form of photovoltaic solar generation. The current inventory of plugged and abandoned well sites under ideal circumstances could generate electricity equivalent to the consumption of nearly half a million typical homes in the United States or the consumption of more than 80% of the households in New Mexico. Distance from well sites to electrical infrastructure could be a limiting factor, yet the oil and gas industry continues to electrify their operations, which yields a potential output from the site to the local grid. At this time there is no regulatory mechanism to move a site from a former oil and gas site to a newly developed renewable energy producing site without additional NEPA analysis and permitting. The concept is a new one, but as renewable energy is further explored and expanded in the United States as a crucial component to supply electrical demand additional disturbance on the landscape will be necessary. Further study of this topic is necessary, particularly around the economic concerns and constraints associated with further expansion. Additional policy considerations around NEPA analysis should be considered to understand a transition from extractive energy to renewable energy given that both require an impact to the landscape. There will always be a relic of previous resource management plans and what was allowed under previous guidance documents that may not meet standards based on new information, as evidenced by plugged and abandoned well sites in areas that under proposed alternatives are not suitable for solar development. The impact of the existing disturbances on the landscape should not be discredited, but rather used as a fundamental point of understanding and determination that a site has suitable characteristics for generating energy. As oil and gas sites begin their inevitable decline from a producing asset to something that is no longer economic, more and more plugged abandoned well sites will be on the landscape. Solar generation has the ability to help maintain a productive use of the landscape and can provide additional stabilization of the site. This mutual benefit towards the land and society as a whole is worth further study and consideration.

Appendix A: Interview Questions

Interview Questions

The 9 questions below represent an overall framework to stimulate conversations regarding the potential of transitioning former oil and gas sites to renewable power generation. The goal of these questions is to understand and look for any potential gaps that would make the idea unfeasible. Additionally, the hope from these questions would be to address a general sense of applicability with existing energy and land use policies.

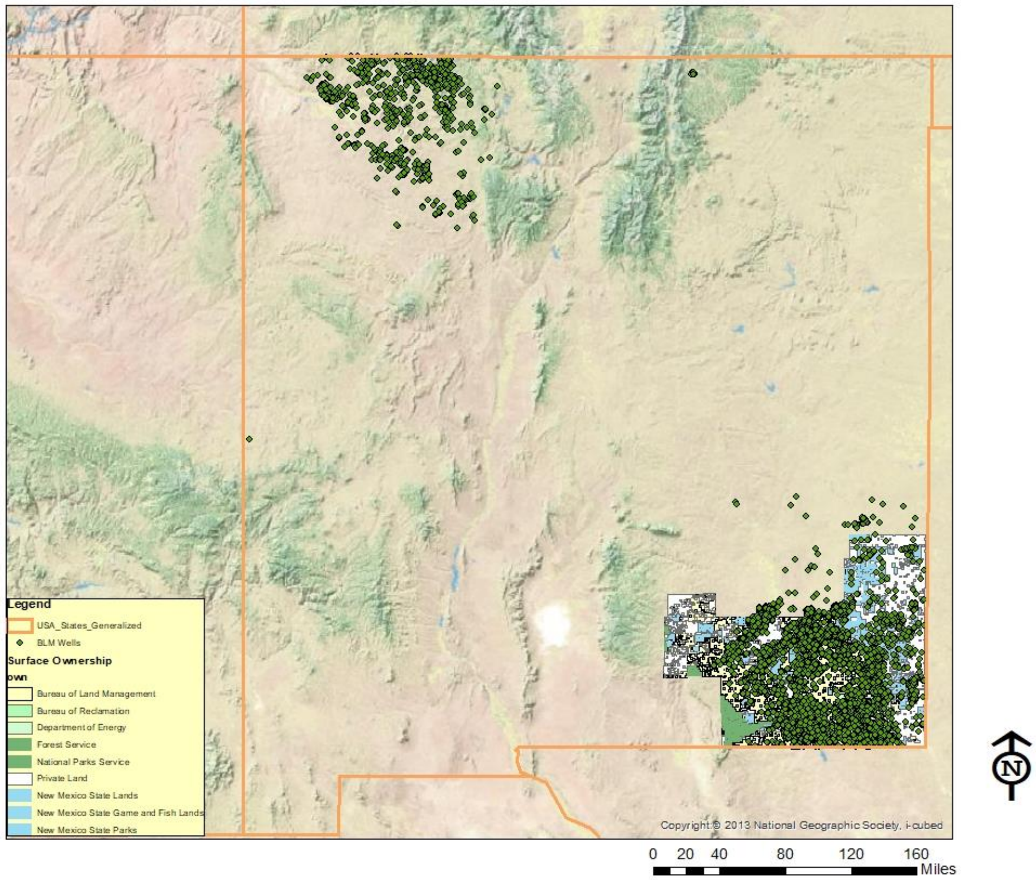
Describe role and background with energy/reclamation/etc. Ask to record interview for note taking to complement notes.

1. What are the plans for lands that have been disturbed by O&G?
   1.b. Do you view the long-term disturbance associated with fossil fuel development as a potential opportunity for renewable energy generation?
2. What do the land use goals look like in your area?
   2.b. Potential follow ups? Main concern economic development? Remediation/reclamation? Natural areas? Agency goals, community goals, stakeholder goals?
3. Would large scale disturbance associated with renewable generation fit into these land use goals?
4. What do you think are the downsides of renewable generation?
   4b. Do you see land use associated with energy development (renewable or extractive) as an overall "loss" for other land use activities? Why?
   a. Thermal solar? PV? Etc.

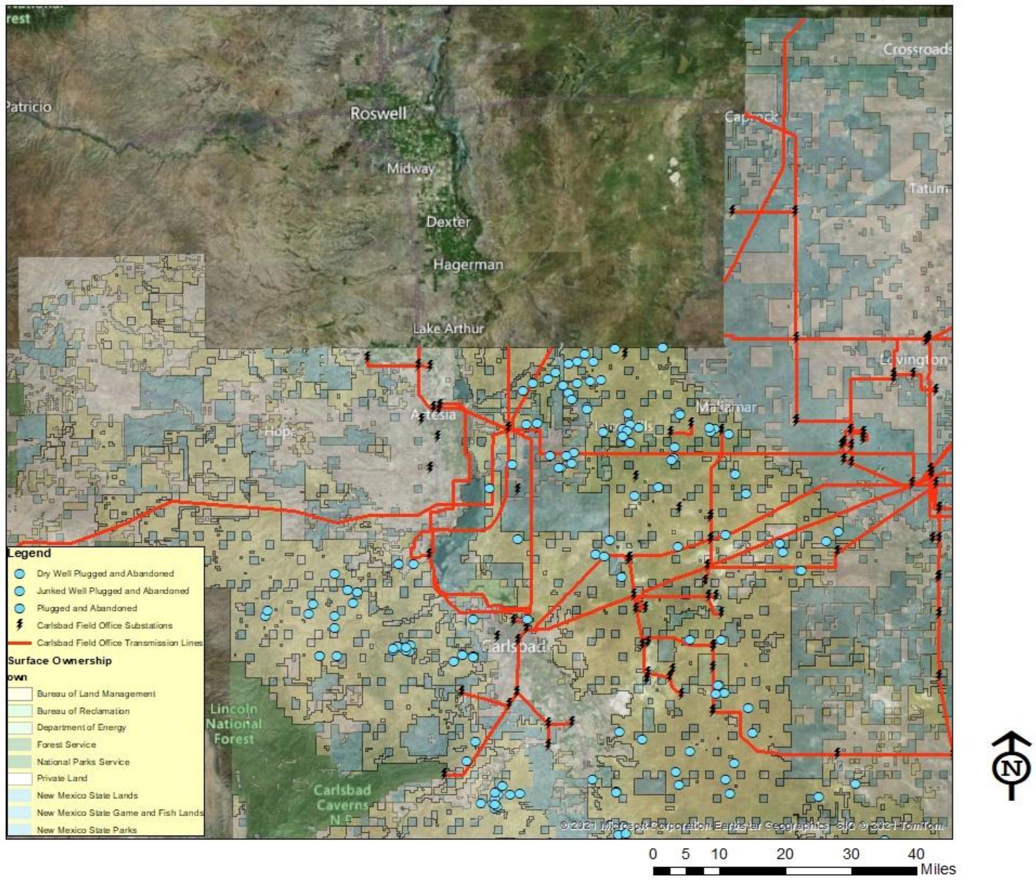
5. Is there opportunity for industry and government to collaborate to help meet New Mexico's renewable energy goals?
6. Could pairing renewable energy production with reclamation of former wells sites and production facilities lead to incentives for oil and gas producers? Such as bond release or transfer of required bonding for surface disturbance to the renewable energy generator?
7. Given the volume of produced water from development of oil and gas resources, if operators were to utilize solar for produced water treatment and the ultimate beneficial reuse of produced water for agricultural purposes, could there be other opportunities for incentives either from BLM or the State of New Mexico?
8. Are there any differences in requirements for renewable energy to proceed through the NEPA process?

If an EA/EIS and ROD, etc. already exists for an extractive energy project, could a renewable project move in on top of that same footprint without any additional permitting?

Appendix B: Area Maps



Map 1: Overview of Oil and Gas Wells on Bureau of Land Management Lands in New Mexico



Map 2: Case Study Focus Area

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