Agrivoltaics in Energy Contracts with Landowners: Economics, Land Use, and Best Practices Considerations

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Executive Summary of Preliminary Findings

- Solar projects have relatively small footprints but occupy a much higher proportion of that footprint, with a sample of Oklahoma's existing solar projects occupying 39% of their footprint. Oklahoma's existing solar projects use approximately 7.28 acres of land per megawatt (MW) of capacity.
- At this ratio, building out the entire 3,877 MW of solar projects planned in Oklahoma in would require 28,236 acres of land - roughly 44 square miles. This is less than one tenth of one percent of Oklahoma's agricultural land in exchange for an estimated $11.2 billion in economic impact including $1.15 billion in landowner payments and $2.13 billion in ad valorem tax revenues.
- Assuming an approach where land used for solar development completely displaces agricultural production acre-for-acre, landowners would gain anywhere from $427 to $791 dollars per acre by leasing to solar projects. This increase in revenue is particularly critical in the present commodity price environment.
- An agrivoltaics approach of collocated solar and agricultural land uses requires careful coordination. Small ruminant grazing and some horticultural crops have demonstrated success in solar projects. Cattle grazing research has begun in earnest with the question being whether solar projects would need different structural elements to support cattle grazing.
- Supporting crop production with the current scale of agricultural equipment would require solar arrays to be significantly more spread out. However, future trends in both solar PV technologies and in agricultural equipment may reduce spacing needs and/or reduce the impacts of spacing on solar project efficiency.
- Pilot projects and research showing the efficacy of such uses, development of a set of best practices in the management of collocated uses, and creation of contract language managing those uses could facilitate developer and investor acceptance of the concept and create more opportunities for agricultural landowners.
- Best practices for collocated uses clear communication and coordination, indemnification and insurance agreements to protect against damages, agreements as to production practices that avoid impairing the counterparty's production systems, and the flexibility to adapt as more is learned about how the two systems interact with each other.

Issue Statement

Solar photovoltaic (PV) systems are currently among the cheapest forms of utility-scale electrical power generation, and in some cased are the cheapest form. This, coupled with decreases in battery electric storage system costs improving the economics of dispatchable solar power, have led to exponential growth in solar installations.

While solar installations have virtually no physical off-site impacts, some parties have expressed concerns regarding the loss of farmland to solar projects. At the same time, farmers and ranchers are exploring how to supplement income from agricultural operations with income from solar project leases. Thus, there is work to be done in evaluating how agricultural uses can be collocated with solar PV projects.

Analysis

Oklahoma's renewable energy industry began in earnest in the early 2000s with its first utility scale wind power projects coming online in late 2003. Wind energy projects provide a useful contrast in the land use characteristics of their solar brethren. While wind projects may extend in east-west lines for several miles and with those lines extending several miles north-south, the actual project equipment, faculties, and access roads occupy relatively little of that space. In the most densely packed area of wind turbines identified in a 2015 study of Oklahoma's wind industry, four turbines were located in one quarter section of land in Custer County northwest of Weatherford. Even with this density of equipment, the turbines and their access roads only occupied 2.46 percent of the quarter section. Thus, while wind projects may seem large, they are relatively sparse in their land use.

Conversely, solar projects tend to have smaller footprints compared to their wind energy counterparts, but they occupy a much larger proportion of that footprint. To compare this land use in Oklahoma, the project team evaluated five solar projects outside of metropolitan areas that had previously been used for agricultural purposes and that were surrounded by agricultural land. These projects were the Hinton, Covington, Pine Ridge, Cyril, and Tuttle projects. Google Earth imagery and data from the U.S. Photovoltaic Database (a project administered by the Lawrence Berkley National Laboratory and the U.S. Geological Survey) were used to individually trace the project fence lines, all project roads and equipment areas, and all PV arrays. The area of the PV arrays, roads, and equipment was then compared to the area encompassed by the fence line to determine how much green space remained.

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Table 1: Land use characteristics of sample of Oklahoma PV projects

Project	Year Online	Capacity (MW)	Average row spacing (ft)	Total fence line area (ac)	PV arrays (ac)	Roads (ac)	Total land occupied (ac)	Open area (ac)	Use ratio	Gross land use (ac/MW)
Hinton	2017	3.0	7.6	18.04	7.94	1.80	9.73	8.31	53.95%	6.01
Covington	2018	10.0	30.2	72.82	18.55	1.91	20.46	55.93	28.10%	7.28
Pine Ridge	2017	3.0	9.1	19.24	6.83	1.66	8.50	10.74	44.16%	6.41
Cyril	2017	5.0	7.5	41.16	11.18	2.31	13.49	27.67	32.77%	8.23
Tuttle	2017	4.0	7.8	33.90	9.88	1.83	11.71	22.18	34.56%	8.47
								Average	38.71%	7.28

The ratio of land used within the fence line of the projects ranged from 28.10 percent to 53.95 percent, with an average of 38.71 percent. Much of this variation can be explained by the amount of open space allocated by each project, with some projects having large open areas round the PV arrays and others keeping the fence line relatively close to the arrays. The implication of these figures is that, even within the fence line, projects had anywhere from approximately 46 to 72 percent of their area still open to potential agricultural applications from livestock grazing to crop production.

These measurements provide some important insights aiding one in understanding both potential land use tradeoffs and how agrivoltaics applications could work. First, the average land use per megawatt (MW) of capacity in this sample is 7.28 acres/MW. This is almost perfectly the average of the Solar Energy Industry Association (SEIA) estimated range of 5 acres/MW to 10 acres/MW. It is also estimated that as improvements to PV module efficiency continue, this ratio will trend toward the lower end of that spectrum.

Assuming this 7.28 acre/MW figure, how much land would be required to build out the planned solar capacity of Oklahoma? Currently, the independent system operator / regional transmission operator (ISO/RTO) for the electrical grid encompassing Oklahoma, the Southwest Power Pool (SPP) has 3,877 MW of solar projects in various stages of the application process to connect to the grid. If 7.28 acres of land is required for each megawatt, this would require a total of 28,236 acres, or 44.12 square miles. To help visualize this amount of land, picture a square 6.64 miles on a side, or a little more than a township (six miles by six miles). By land mass, this is almost exactly the area of the city of Shawnee. But to provide another perspective, USDA land use figures estimate Oklahoma's total area of farmland at 58,750 square miles. Thus, building out the entire planned solar capacity – and assuming every acre used was farmland – would require 0.08 percent (in other words, less than one tenth of one percent) of Oklahoma's farmland. This would seem to represent a *de minimis* loss of agricultural productivity for the state.

Research at Oklahoma State University to estimate the economic impact of future renewables development in the state found that the development of all 3,877 MW of solar capacity would have a total economic impact of $11.2 billion over the lifetime of the solar projects, including an estimated $1.15 billion in lifetime lease payments to landowners and an estimated $2.13 billion in ad valorem taxes with $1.46 billion of those taxes being paid into local school districts.

While these macroeconomic impacts are important considerations, the microeconomic impacts to landowners must also be evaluated. To estimate these impacts, the project team considered a “solar or agriculture” scenario in which a landowner approached by a solar developer to lease their land must forego all agricultural production within the project footprint. In such cases, partial budget analysis is the farm management tool used to understand the complete microeconomic impact of a change in operations. Partial budget analysis considers, on one side of its ledger, the revenues foregone and increased costs of a change, and on the other, the increased revenues and decreased costs. The project team conducted partial budget analyses on eight of Oklahoma’s most common production systems: (1) winter wheat used for both grain production and cow-calf pair grazing, (2) corn, (3) soybeans, (4) grain sorghum, (5) canola, (6) cotton, (7) Bermuda hay, and (8) alfalfa hay. OSU’s enterprise budgets were used to estimate costs and revenues for each of these enterprises, updated with current commodity prices and input prices as of August 28, 2025. A solar lease rate of $750 per acre was used for solar revenue. While there is no published source for solar lease rates, individual Extension consultations with a number of landowners found this to be a common lease rate, though rates ranging from $500 to $1,000 per acre were also found. As a result of this range, the project team conducted a sensitivity analysis examining the partial budget impacts of this range of leases.

The partial budget analysis revealed that entering into a solar lease resulted in a net increase in farm revenue per acre across all production systems and the entire sensitivity range of solar lease payments. The largest net increase in farm revenue was found for canola production ranging from a $592.41 per acre increase at the $500/acre solar lease rate to $1,092 at the $1,000/acre solar lease rate. The smallest increase was found with alfalfa hay production ranging from a $177 per acre increase at the $500/acre solar lease rate to $667 per acre increase at the $1,000 per acre solar lease rate. In case one wonders how the increase to per-acre revenues could be greater than then amount of the lease, such scenarios are possible where one considers the agricultural inputs that are no longer needed if solar production takes place on the land and that commodity prices might mean producers face a net loss from production.

Table 2: Net income impacts from solar leasing (per acre)

	Per-acre solar lease rate			
Crop	**Baseline (no payment)**	**$500.00**	**$750.00**	**$1,000.00**
Winter wheat/cow-calf	**($28.96)**	**$528.96**	**$778.96**	**$1,028.96**
Corn	**($12.78)**	**$512.78**	**$762.78**	**$1,012.78**
Soybeans	**$69.99**	**$430.01**	**$680.01**	**$930.01**
Grain sorghum	**($41.30)**	**$541.30**	**$791.30**	**$1,041.30**
Canola	**($92.41)**	**$592.41**	**$842.41**	**$1,092.41**
Cotton	**$58.70**	**$441.30**	**$961.30**	**$941.30**
Bermuda hay	**$109.56**	**$390.44**	**$640.44**	**$890.44**
Alfalfa hay	**$322.57**	**$177.43**	**$427.43**	**$667.43**

Table 3: Net income impacts from solar leasing (quarter-section [160 ac] scale)

	Per-acre solar lease rate			
Crop	**Baseline (no payment)**	**$500.00**	**$750.00**	**$1,000.00**
Winter wheat/cow-calf	**($4,633.60)**	**$84,633.60**	**$124,633.60**	**$164,633.60**
Corn	**($2,044.80)**	**$82,044.80**	**$122,044.80**	**$162,044.80**
Soybeans	**$11,198.40**	**$68,801.60**	**$108,801.60**	**$148,801.60**
Grain sorghum	**($6,608.00)**	**$86,608.00**	**$126,608.00**	**$166,608.00**
Canola	**($14,785.60)**	**$94,785.60**	**$134,785.60**	**$174,785.60**
Cotton	**$9,392.00**	**$70,608.00**	**$153,808.00**	**$150,608.00**
Bermuda hay	**$17,529.60**	**$62,470.40**	**$102,470.40**	**$142,470.40**
Alfalfa hay	**$51,611.20**	**$28,388.80**	**$68,388.80**	**$106,788.80**

The takeaway from these analyses is that if an agricultural producers sole consideration is maximization of farm profit, leasing land for solar production would be the preferred choice even if it meant foregoing all agricultural production on the leased land. This is particularly important when one considers the current agricultural commodity price environment. Were it not for historically high prices in the cattle market, many Oklahoma producers would find themselves in difficult financial times. Four commodities – wheat, corn, sorghum, and canola – revealed negative per-acre returns, meaning that producers would be unable to cover even their variable costs (not considering fixed costs) at current price levels. This underscores the importance of alternative revenue sources for these producers, particularly at this time.

However, what if instead of "either," the operative word was "and?" In other words, what if agricultural production were allowed in the 46 to 72 percent of the solar project fence line areas that remain open greenspace? Small ruminant grazing and some horticultural crops have demonstrated success in collocating with solar projects. Small ruminants such as sheep and goats can actually provide a service of vegetation management in the project footprint by keeping said vegetation from growing up and shading the PV arrays while also providing an additional return to the livestock owner (who may also be the landowner). Some horticultural crops may also benefit from the additional shading provided by the PV arrays and actually increase production as a result. While there is a small body of peer reviewed scientific research on these topics, much research work remains to be done to determine whether agronomic crops such as those that predominate Oklahoma's agriculture industry or cattle grazing might be mutually beneficial to solar project operators and Oklahoma agricultural producers.

One principal consideration is the scale of agricultural equipment and its ability to operate within the footprint of a solar project. Consider the example of the Covington solar project – the project with the widest spacing between PV arrays of any of the projects examined at approximately 30 feet. If one were to increase the spacing of those arrays to 60 feet to accommodate a modern commercial grain combine, the area of the project would expand from 72.82 acres to 124.6 acres, an increase of 1.72 times. This increased spacing would require increased costs to solar developers in terms of connecting infrastructure such as electrical lines and access roads, and would result in some small losses in efficiency in terms of line losses of power. Additionally, while combines might require 60 feet of spacing, many modern sprayers are 120 feet in width – at that width, the Covington project would expand to over a section of land (690.8 acres).

However, there are solar projects that are indeed experimenting with these kinds of collocated agricultural uses. Such projects include configurations that use bifacial PV panels spaced for modern agricultural equipment to pass through them while creating a favorable microclimate for agricultural crops. Other projects are examining whether cattle can indeed graze among normal solar project configurations without causing damage, or whether the PV arrays can be raised above the height of the animals in an economical way that also provides improved shade for the cattle. The next few years will hopefully provide much more empirical data to show how a variety of agricultural production systems can collocate with solar projects, further reducing concerns about land use tradeoffs.

In the meantime, the only way to generate this empirical evidence is to "learn by doing." This requires actual experience in collocated agricultural uses, and this in turn requires a willingness on the part of developers (and their investors) to allow agricultural uses within the fence lines of their projects. The nexus of these accommodations comes from the development agreement between the landowner and the solar developer. Allowing collocated agricultural uses requires agreement language that broadly commits both parties to use commercially reasonable efforts and open communication to coordinate the agricultural and solar operations without causing material inference to the other. To that end, best practices must be developed to coordinate these uses, and again, that will take some operational experience and perhaps a measure of grace extended to each party.

A useful starting point may be the use of language similar to this in the development agreement:

1. Lessor may use areas not occupied by Project Equipment ("Project Equipment" shall include, but is not limited to, photovoltaic panels, mounting racks and frames, electrical transmission lines, inverter systems, supervisory control and data acquisition systems, and access roads) for the grazing of livestock and/or the production of agronomic or horticultural crops ("agricultural activities") provided that such agricultural activities shall not materially interfere with the normal operations of the Project.
2. Lessor and Lessee will use commercially reasonable efforts to develop a mutually agreed set of operating procedures to coordinate the use of the Property for Agricultural Production and Project Operations with the intent to minimize the extent to which Agricultural Production and Project Operations interfere with each other.
3. Such operating procedures shall include requirements for:

a) Sufficient notice (not less than 24 hours except in the case of an emergency condition posing risk of physical harm and/or material economic damage to a party) to the other party of any activities that might interfere with the other party's operations and/or that might require corrective actions.
b) Consultation among the parties with respect to the application of any herbicides, pesticides, or other chemicals that might impair Agricultural Activities or that could materially reduce the production capacity of the Project Equipment.
c) Delineation and/or marking of any areas where Project Equipment located below grade is not buried below the depth that might be reached by agricultural production equipment.
d) Temporary removal of any livestock prior to any project operations that pose a material threat of injury to livestock or circumstances in which the presence of livestock could pose a risk of harm to project personnel.
e) Immediate notification to the other party of any damage to Project Equipment, livestock, and/or crops as soon as a party has actual knowledge of such damage.
f) Indemnification for material damage caused to the Project Equipment, livestock, or crops caused by the other party or by parties acting on behalf of Lessor or Lessee.

4. Both parties shall maintain a policy of commercial liability insurance with a coverage limit of $X and naming the other party as a named insured, the coverage of which shall include those forms of damage that party could reasonably foresee being caused by its operations to the counterparty.

Conclusions

As stewards of the land, Oklahoma farmers and ranchers are naturally concerned about how best to manage their lands for both environmental and economic sustainability. Even if a portion of their land is converted to solar production with no active agricultural production, such conversion can provide significant economic returns to their operation while potentially preserving the land for future agricultural use. These increased returns represent a stable source of additional income, and are particularly important in the current commodity price environment. However, this may not be an "either" choice between agricultural production and solar production but may rather be an "and" opportunity. As more experience is developed, projects and producers are learning how a variety of agricultural production systems may be maintained within the fence line of solar projects. Any support to research on these opportunities will help accelerate the development of agrivoltaics opportunities. A critical piece of this development will be the creation of best practices and example development agreement language that will help both parties maintain productive and profitable operations on the shared land.