Optimizing Land Use for Ecosystem Services and Solar Power in Michigan:

Final Report

Project Team: E. Healy, L. Kralik, C. Spieske, A. Starobinskiy, & Y. Wei
Advisor: S. Mills & B. O'Neill
Client: Consumers Energy – D. Detterman & G. Bruner

Masters of Science Program
School for Environment and Sustainability
University of Michigan
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Abstract

Consumers Energy has set a goal of net zero carbon emissions by 2040, including the deployment of nearly 8,000 megawatts of solar energy, which requires significant land use for ground-mounted photovoltaic (PV) arrays. This project aims to explore sustainable ways to optimize solar farm land for both energy and ecosystem services. Specifically, the project objective is to develop a framework to analyze the costs and benefits of integrating dual-use land in Consumers Energy's ground-mounted PV installations. This has been done by focusing on potential solar energy and ecosystem synergies and creating frameworks to evaluate these and future strategies that are of interest to Consumers Energy. In addition to evaluating dual-use land opportunities for a specific Consumers Energy solar farm, we extend this analysis for use in future sites. We generally find competing incentives when analyzing ecosystem services, policy, land area use, cost, and community implications of these dual-use land strategies, and suggest multi-criteria decision analysis with user-designated prioritization of decision criteria as a future pathway for co-optimization.

Introduction

Consumers Energy has set a goal of net zero carbon emissions by 2040, including the deployment of nearly 8,000 megawatts of solar energy, which requires significant land use for ground-mounted solar arrays. Depending on the type of photovoltaic panel, Consumers Energy could need roughly 23,000 to 33,000 acres for solar arrays alone (Table 1). Although Consumers Energy is Michigan's largest utility, for the state to reach its renewable energy targets, Michigan's other electric utilities will also need land to site solar. Clearly, this is a substantial land requirement, and the question arises as to where this land will come from. In Michigan as in other states nationwide, farmland is attractive for utility scale solar due to large size parcels and less conflicts with neighboring properties.[1] Data from the InSPIRE Agri Voltaics Map shows that since 2009, there have been more than 500 solar projects across the United States that are used for energy production and other activities such as crop production, habitat (pollinators, native grasses), grazing, and greenhouses.[2] Figure 1 below shows the number of these projects by year and system size.

Table 1: Land occupied for installing 8,00 MW solar; Power density data is sourced from M Bolinger, G Bolinger.[3]

Panel type	Power projected (MW)	Power density (MWdc/acre)	Land use (acre)
Fixed-tilt	8,000	0.35	22,857
Tracking	8,000	0.24	33,333

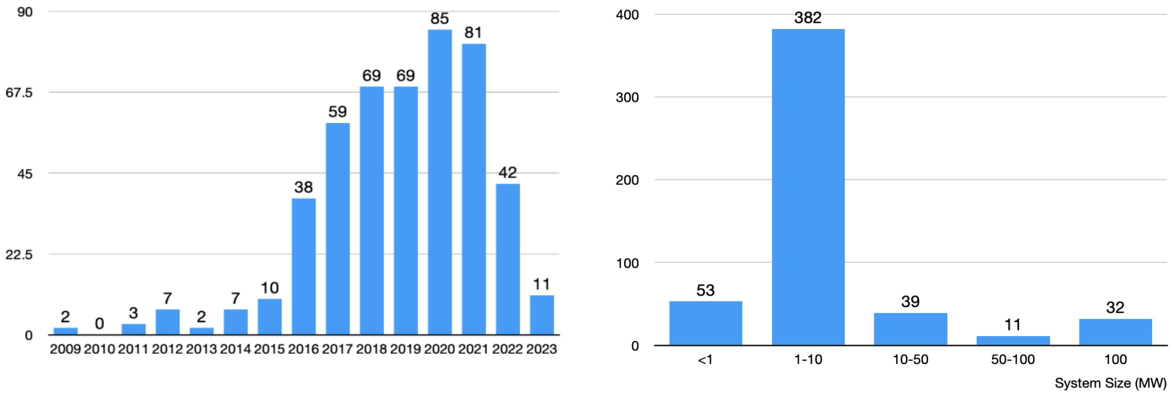

Figure 1: The number of agrivoltaic projects (y-axis) by year 2009- 2023 (left panel) and system size in megawatts (right panel); Source from InSPIRE Agri Voltaics Map.[4]

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[1] Daniels, Tom, and Hannah Wagner. 2022. "Regulating Utility-Scale Solar Projects on Agricultural Land." Kleinman Center for Energy Policy. https://kleinmanenergy.upenn.edu/wp-content/uploads/2022/08/KCEP-Regulating-Utility-Scale-Solar-Projects.pdf.

[2] InSPIRE. 2024. "InSPIRE Agri Voltaics Map." Accessed: 15/4/2024. openei.org/wiki/InSPIRE/Agrivoltaics_Map.

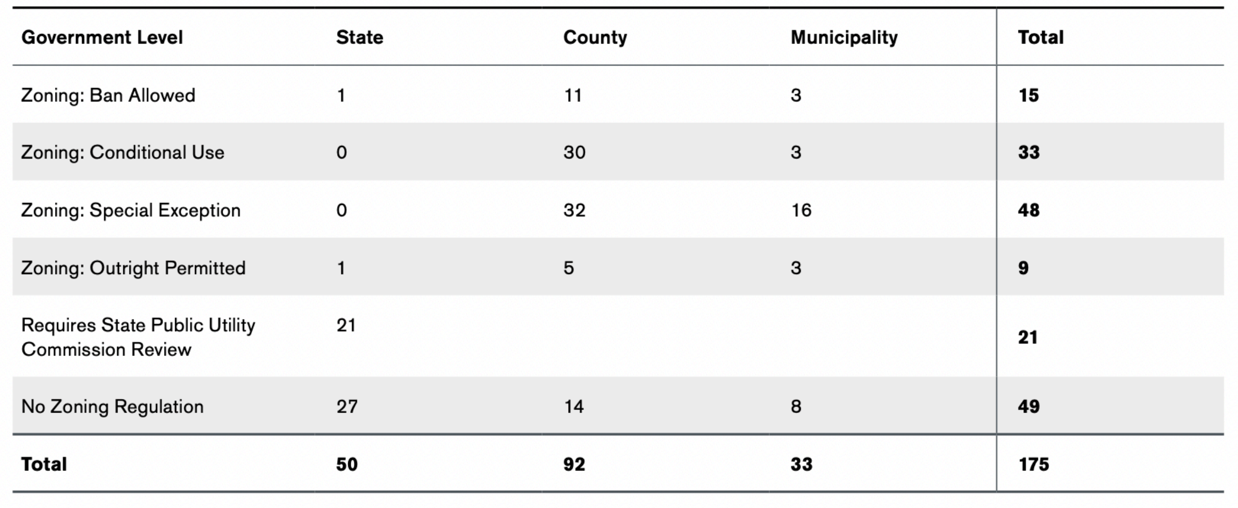
[3] Bolinger, Mark, and Greta Bolinger. "Land requirements for utility-scale PV: an empirical update on power and energy density." *IEEE Journal of Photovoltaics* 12.2 (2022): 589-594.

[4] InSPIRE. 2024. "InSPIRE Agri Voltaics Map." Accessed: 15/4/2024. openei.org/wiki/InSPIRE/Agrivoltaics_Map.

Although the installation of utility scale solar furthers grid decarbonization, it also faces sustainability challenges. A key issue is land-use change. As with any project that has a large footprint, there are trade-offs when deciding to change the land use of an area into a solar farm for example if the land is used for agriculture or supplies other ecosystem services from the native habitat. It therefore matters what type of land is being changed into a solar farm. Placing panels on top of a landfill that is not otherwise being used has different land-use impacts than turning viable farmland into a solar farm. As solar installations are sited, it is essential to consider how that land-use change impacts the surrounding ecosystem–including the plant, animal, and human communities.

Another key barrier to large scale solar is the project siting opposition and the challenge it poses to energy democracy – both the capacity for local communities to have access to sustainable energy and have a say in where it is located. Communities deserve to have local control over decisions regarding their energy generation and many municipalities have enacted solar ordinances that restrict utility scale solar due to local priorities. A report from Columbia Law School's Sabin Center for Climate Change Law identified that local opposition to renewable energy facilities is prevalent and growing. At least 228 local laws, ordinances and policies across 35 states, restrict the siting of renewable energy projects. Michigan is one of these states. In a one year period from March 2022, 13 new local restrictions were adopted in Michigan.[5] Regarding solar projects, an NREL study found 839 U.S. ordinances that could impact utility-scale solar.[6] In particular, the fear of land loss and negative impacts on environment, scenic views, food production and the agricultural industry triggers local resistance on solar projects building on farmland. As seen in the figure below, regulating utility-scale solar on farmland is common throughout the country at the state, county, and municipal levels[7].

Table 2: Summary of regulation of utility scale solar on farmland by state or county or municipality.[8]



Government Level	State	County	Municipality	Total
Zoning: Ban Allowed	1	11	3	**15**
Zoning: Conditional Use	0	30	3	**33**
Zoning: Special Exception	0	32	16	**48**
Zoning: Outright Permitted	1	5	3	**9**
Requires State Public Utility Commission Review	21			**21**
No Zoning Regulation	27	14	8	**49**
Total	**50**	**92**	**33**	**175**

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[5] Matthew Eisenson, Opposition to Renewable Energy Facilities in the United States (Sabin Center for Climate Change Law May 2023 ed.). Available at: https://scholarship.law.columbia.edu/sabin_climate_change/200/

[6] Lopez, Anthony, et al. "Impact of citing ordinances on land availability for wind and solar development." *Nature Energy* 8.9 (2023): 1034-1043.

[7] Daniels, Tom, and Hannah Wagner. 2022. "Regulating Utility-Scale Solar Projects on Agricultural Land." Kleinman Center for Energy Policy. https://kleinmanenergy.upenn.edu/wp-content/uploads/2022/08/KCEP-Regulating-Utility-Scale-Solar-Projects.pdf.

[8] Daniels, T. L., & Wagner, H. (n.d.). *Regulating Utility-Scale Solar Projects on Agricultural Land.*

In response to the rising tension between decarbonization goals and land-intensive solar farms, there has been a new global trend for solar installations to achieve the highest energy production and best use the limited land resource.[9] One novel approach for doing so is to use the solar farm land for dual-purposes, creating both solar energy generation and ecosystem services. In the United States, dual land use solar farm research and pilot programs exist already. The feasibility of agrivoltaics, or the use of land for both agriculture and solar energy production, is an active area of research. An NREL report, for example, emphasizes how site climate, configuration, crop selection, compatibility, and collaboration are important factors for a successful agri voltaic project.[10] The Nature Conservancy in Michigan has outlined guidelines for solar array owners to simultaneously provide habitat for native wildlife,[11] and Ohio State University has provided suggestions for seed mixes that would allow utility scale solar to also grow forage.[12] If the land area of a solar farm could be optimized for both energy generation and ecosystem services, the overall land use change impacts would likely be positive. If the land area of a solar farm could also be optimized to include ecosystem priorities of local community members, opposition to solar farms may decrease.

Consumers Energy has recognized this potential for the land of a solar farm to be simultaneously used for other environmental and community benefits and are exploring sustainable ways to optimize dual land use for solar power and ecosystem services. The SEAS Masters Project team was tasked with evaluating potential dual-use land strategies. The team's focus was on Spring Creek, a future Consumers Energy solar farm site that is currently active farmland, and our goal was to provide opportunities and analysis frameworks for co-optimization of ecosystem services and solar power. This includes land use directly under panels, in alleys between arrays, and in buffer zones or offsets between arrays and field edges. Through different analysis methods, we examined how ecosystem services, policy, land area use, cost, and community impacts could be affected through dual-use land strategies, and provided an outline for evaluating the optimal Spring Creek strategy. A schematic of the approach is below. Although the analysis is based on Spring Creek specifics, it also presents a guideline that can be used for any future Consumers solar farm sites. Ultimately, there are generally competing incentives when analyzing the techno-ecological implications of dual-use land strategies. Multi-criteria decision analysis with user-designated prioritization of decision criteria is a potential future pathway for optimizing dual-use land as it aims to account for stakeholder preferences.

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[9] Adeh, E.H., Good, S.P., Calaf, M. et al. Solar PV Power Potential is Greatest Over Croplands. Sci Rep 9, 11442 (2019). https://doi.org/10.1038/s41598-019-47803-3

[10] Macknick, J. et al. (2022). The 5 Cs of Agrivoltaic Success Factors in the United States: Lessons From the InSPIRE Research Study. Golden, CO: *National Renewable Energy Laboratory.* NREL/TP-6A20-83566. https://www.nrel.gov/docs/fy22osti/83566.pdf

[11] Steinberger, K.J. (2021). Native Plant Installation and Maintenance for Solar Sites. *The Nature Conservancy in Michigan.*

[12] Gelley, C. et. al. (2021). Forage as Vegetation Cover for Utility-Scale Solar. *Ohioline.* https://ohioline.osu.edu/factsheet/cdfs-4106

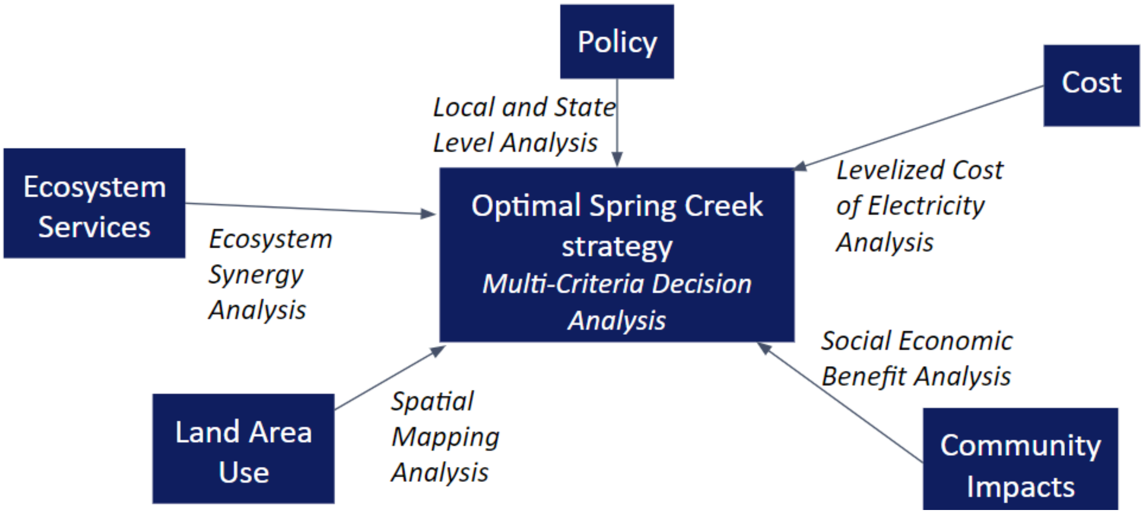

Figure 2: A visual outline of the research approach in this report focused on solar development at Spring Creek. Analysis methods are italicized, while the areas of research are represented by the navy blue boxes.

Ecosystem Services and Synergies

Pasture for Forage or Hay

Optimizing the conversion of crop land to solar energy production presents opportunities for improvement over the business as usual, which for solar farms is often a mix of turf grasses, maintained by regular mowing. One such opportunity is creating pasture for grazing animals that develops a synergy between solar energy production and an agricultural product which in this case would be grazing pasture for animals.

Literature reviews showed that the transition from cropland to perennial grassland offers numerous benefits. Transitioning to perennial grassland helps to mitigate soil erosion and improve soil health. Grassland ecosystems promote well-aggregated soil, high water infiltration rates, and deep root growth, thereby enhancing soil fertility and structure. Research comparing perennial grasslands to annual croplands demonstrates higher levels of soil fertility, microbial activity, and water-stable aggregates in grassland soils. Moreover, perennial grass cover protects against erosion and contributes to the formation and maintenance of healthy soil. Economic considerations also favor the conversion to perennial grassland, albeit with a detailed financial analysis required. While establishing new pastures can be initially costly and time-consuming, the long-term benefits include reduced or eliminated mowing costs for solar energy production and a reduced cost to feed the foraging animals. Grazing systems utilizing perennial grasses offer resilience and profitability, as demonstrated by successful farm operations such as the Shepherd farm in Missouri and the La Brisa Ranch in Texas. These sites underscore the potential for alternative agriculture to capture niche markets and restore productivity to marginal cropland. Ultimately, transitioning from cropland to perennial grassland requires careful planning, proper plant selection, and effective management practices to maximize the ecological and economic benefits of the conversion.[13,14]

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[13] P. Sullivan, “Converting Cropland to Perennial Grassland”.

[14] “Converting Cropland Back to Grass Pastures,” UNL Beef. Accessed: Apr. 09, 2024. [Online]. Available: https://beef.unl.edu/converting-cropland-back-to-grass-pastures

The Spring Creek project spans over two thousand acres with many fields having previously been planted to forage (i.e. corn and alfalfa) for the on-site dairy. The site is optimized for dual use of solar energy and pasture. The following section details important considerations for managing vegetation at Spring Creek, both under panels and within alleys, and in buffer zones and set-backs. Given the management history of the site was for forage production, selecting pasture plant species suitable under and around arrays may be an ideal option. Below we detail plant mixtures which suit these conditions, and considerations for establishment and management. Forage grazing (i.e. cows and sheep) is discussed generally as an option for large ground-mounted solar installation, recognizing that at Spring Creek, this approach may be limited or used for testing future installations. Ideally the forage recommendations detailed below could be used for a portion of the site as a valuable source of hay for the adjacent dairy. Finally, given that the arrays for this development are spread over numerous agricultural fields, of varying dimensions, sizes and designs, vegetation selections may be suitable for some areas (i.e. larger offset areas or buffer zones) and not others.

The reviewed literature emphasizes the importance of selecting appropriate forage species tailored to environmental conditions. Perennial legumes and grasses are indicated as foundational components of forage production, the increasing availability of annual species with forage value is also noted. Based on the factors offered in the literature the complete list of factors that were considered for the selection of recommended forage species include plant functional type, life cycle, adaptation to environmental conditions, seeding rates, and suitability for various applications like hay, pasture, or cover crops. The forage species are also segregated into functional groups based on physiology and morphology (cool-season grasses, warm-season grasses, legumes, and forbs) and further categorized by life cycles (annuals, biennials, and perennials).[15]

In addition to optimizing forage options for the site, Consumers Energy has put the highest priority on decreasing operating costs which - an additional consideration for the best forage mix at Spring Creek. To satisfy successful forage growth with reduced management cost, the chosen plants must thrive under reduced sunlight, persist over the long term without the need for frequent replanting, maintain a low height to avoid interfering with solar panel operation, and require minimal upkeep to reduce resource inputs and operational costs. The following factors were prioritized during the forage selection process:

- Shade Tolerance: One of the primary considerations for forage selection in Michigan solar farms is shade tolerance. Solar panels cast shadows that create shaded areas on the ground, limiting sunlight penetration and affecting plant growth. Therefore, selecting shade-tolerant forage species is essential to ensure adequate ground cover and ecosystem productivity. It is worth noting that shade tolerance is not a key to success of the selected plants but rather allows them to thrive in a range of light conditions from full sun to shaded.
- Perenniality: Perennial forage species offer several advantages for solar farm applications. Unlike annuals, perennials do not require frequent replanting, reducing labor associated with maintenance. Additionally, perennial plants establish deeper root systems, improving soil stability and erosion control, which is important in settings where soil disturbance should be minimized.
- Interference with Solar Panel Operation: The mature height of forage species is a critical consideration to prevent interference with solar panel operation and maintenance activities.

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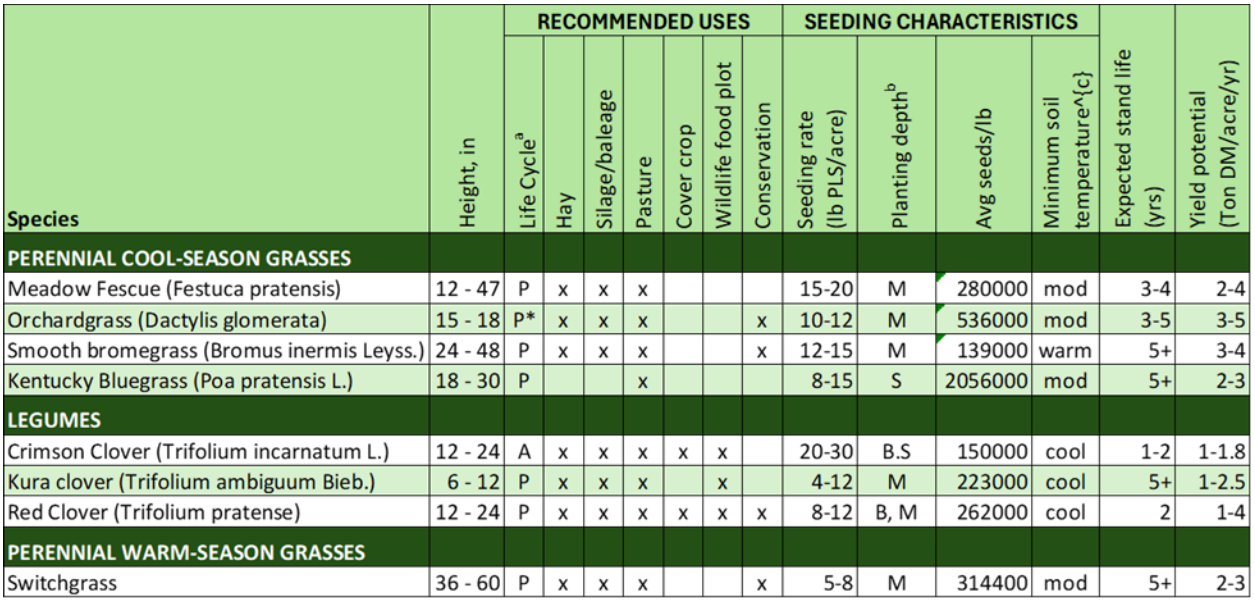
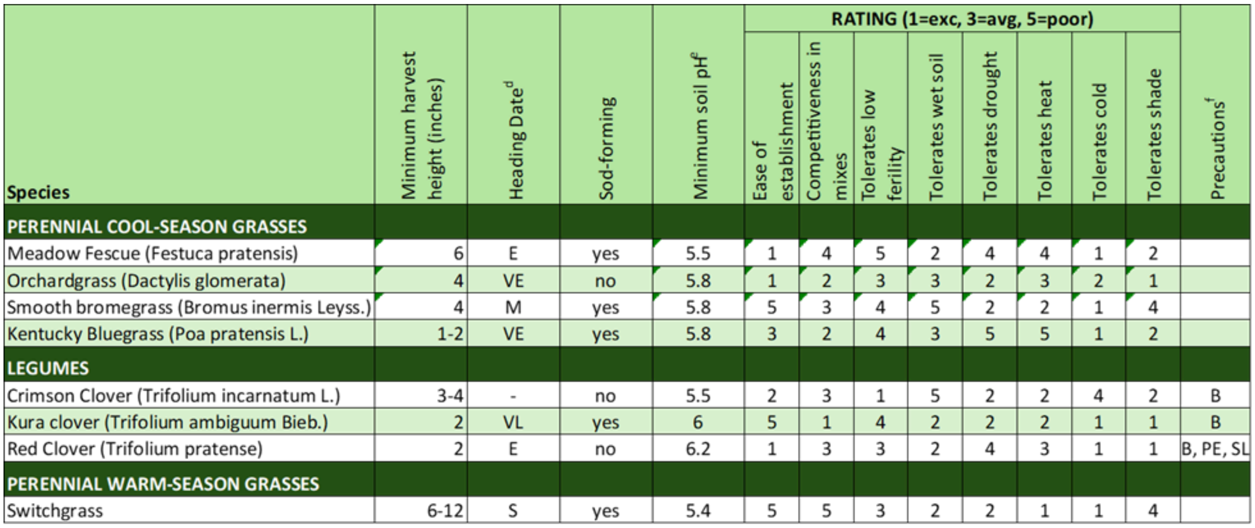
[15] K. Cassida and P. Kaatz, "Recommended Hay and Pasture Forages for Michigan," *Tall Fescue*.

Tall or invasive species can obstruct sunlight exposure to solar panels and impede access for maintenance personnel. Therefore, selecting forage species with a low mature height is essential to ensure unobstructed solar energy capture and ease of maintenance.

Table 3: Plant species for optimal forage at Spring Creek based on key factors, uses and characteristics.[16]



Species	Height, in	RECOMMENDED USES Life Cycle[a]	Hay	Silage/baleage	Pasture	Cover crop	Wildlife food plot	Conservation	SEEDING CHARACTERISTICS Seeding rate (lb PLS/acre)	Planting depth[b]	Avg seeds/lb	Minimum soil temperature^{c}	Expected stand life (yrs)	Yield potential (Ton DM/acre/yr)
PERENNIAL COOL-SEASON GRASSES														
Meadow Fescue (Festuca pratensis)	12 - 47	P	x	x	x				15-20	M	280000	mod	3-4	2-4
Orchardgrass (Dactylis glomerata)	15 - 18	P*	x	x	x			x	10-12	M	536000	mod	3-5	3-5
Smooth bromegrass (Bromus inermis Leyss.)	24 - 48	P	x	x	x			x	12-15	M	139000	warm	5+	3-4
Kentucky Bluegrass (Poa pratensis L.)	18 - 30	P			x				8-15	S	2056000	mod	5+	2-3
LEGUMES														
Crimson Clover (Trifolium incarnatum L.)	12 - 24	A	x	x	x	x	x		20-30	B.S	150000	cool	1-2	1-1.8
Kura clover (Trifolium ambiguum Bieb.)	6 - 12	P	x	x	x		x		4-12	M	223000	cool	5+	1-2.5
Red Clover (Trifolium pratense)	12 - 24	P	x	x	x	x	x	x	8-12	B, M	262000	cool	2	1-4
PERENNIAL WARM-SEASON GRASSES														
Switchgrass	36 - 60	P	x	x	x			x	5-8	M	314400	mod	5+	2-3



Species	Minimum harvest height (inches)	Heading Date[d]	Sod-forming	Minimum soil pH[e]	RATING (1=exc, 3=avg, 5=poor) Ease of establishment	Competitiveness in mixes	Tolerates low ferility	Tolerates wet soil	Tolerates drought	Tolerates heat	Tolerates cold	Tolerates shade	Precautions[f]
PERENNIAL COOL-SEASON GRASSES													
Meadow Fescue (Festuca pratensis)	6	E	yes	5.5	1	4	5	2	4	4	1	2	
Orchardgrass (Dactylis glomerata)	4	VE	no	5.8	1	2	3	3	2	3	2	1	
Smooth bromegrass (Bromus inermis Leyss.)	4	M	yes	5.8	5	3	4	5	2	2	1	4	
Kentucky Bluegrass (Poa pratensis L.)	1-2	VE	yes	5.8	3	2	4	3	5	5	1	2	
LEGUMES													
Crimson Clover (Trifolium incarnatum L.)	3-4	-	no	5.5	2	3	1	5	2	2	4	2	B
Kura clover (Trifolium ambiguum Bieb.)	2	VL	yes	6	5	1	4	2	2	2	1	1	B
Red Clover (Trifolium pratense)	2	E	no	6.2	1	3	3	2	4	3	1	1	B, PE, SL
PERENNIAL WARM-SEASON GRASSES													
Switchgrass	6-12	S	yes	5.4	5	5	3	2	2	1	1	4	

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[16] K. Cassida and P. Kaatz, "Recommended Hay and Pasture Forages for Michigan," *Tall Fescue.*

[a] Life Cycle Key: A=annual, WA=winter annual, B=biennial, P=perennial.
[b] Planting depth key: B=broadcast, S=0.12-0.25 inch, M=0.25-0.50 inch, D=>0.50 inch
[c] Soil germination temperature key: cold (34-40 F), cool (40-49 F), moderate (50-59 F), warm (60-69 F).
[d] Heading date key: VE-very early spring, E=early spring, L=late spring, VL=very late spring, S=summer.
[e] The minimum required soil pH should not be considered preferable to optimum soil pH which is 6.0 to 7.0 for most species.
[f] Issues key: A=alkaloids, B=bloat, GSN=glucosynolates, NP=nitrate poisoning, PA=prussic acid, PE=phytoestrogens, PEM=polioencephalomalacia, PS=photosensitization, SARA=subacute ruminal acidosis, SL=slobbers, W=weediness

By choosing species that thrive in shaded environments, establish deep root systems, require minimal maintenance, and maintain a low profile, solar farm operators can create sustainable ecosystems that support biodiversity and maximize solar energy production. The final selection of forage plants for Spring Creek can be seen in Table 3.

By combining different species a diverse seed mix will optimize yield potential. The grasses are high-yielding and ensure a plentiful food supply for grazers throughout the season. They are also sod forming which helps prevent soil erosion. The inclusion of legumes contributes to increased yield by fixing nitrogen, improving soil fertility, and promoting overall pasture productivity. Incorporating species with varying growth habits and plant traits allows for adaptation to different soil conditions, the pasture becomes more resilient to adverse weather conditions and pest pressure. This resilience ensures consistent forage availability, even in adverse weather conditions and under pest pressure.[17]

The seed mix proportions were crafted to create a one size fits most seed mix that would cater to the specific needs of forage in a solar farm setting, where adaptability to varying light conditions and a shorter stature are crucial to prevent interference with solar panel operations. Based on the provided seed options and their respective characteristics, growth habits, and shade tolerance, a suggested seed mix for a solar farm forage would be:

- Meadow Fescue (Festuca pratensis): 20%
- Orchardgrass (Dactylis glomerata): 15%
- Kentucky Bluegrass (Poa pratensis): 15%
- Crimson Clover (Trifolium incarnatum): 10%
- Red Clover (Trifolium pratense): 10%
- Kura Clover (Trifolium ambiguum): 5%
- Switchgrass (Panicum virgatum): 10%
- Smooth Brome Grass (Bromus inermis): 15%

Grasses like Kentucky bluegrass improve palatability, which increases feed intake, ensuring that cattle consume an adequate amount of nutrients for optimal growth and performance. Enhanced palatability also reduces the risk of selective grazing, leading to more uniform utilization of the

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[17] K. Cassida and P. Kaatz, "Recommended Hay and Pasture Forages for Michigan," *Tall Fescue.*

pasture. Grasses with rhizomatous growth habits, such as smooth bromegrass and Kentucky bluegrass, form dense sods that improve pasture stability and longevity. Legumes like clover contribute to stand persistence by fixing nitrogen and enhancing soil health. An additional benefit of legumes is tannins, which inhibit the formation of foam in the rumen, reducing the likelihood of bloat. By carefully managing legume proportions in the seed mix, cattle can graze safely without the risk of bloat-related health issues.[18]

An additional benefit that this seed mix provides is pollinator habitat. Clover species (comprising 25 percent of the recommended pasture mix) are ideal for attracting pollinators such as bees. Orchardgrass produces small, inconspicuous flowers which are not as attractive to pollinators but along with other grasses, can provide habitat for small insects and other invertebrates, which in turn may contribute to pollination.[19,20,21,22,23,24,25]

The following procedure was used to calculate the proportions of the seed in the seed mix.

Step 1: Match species to use based on conditions in the Spring Creek installation and the characteristics of each species listed in the species tables.

Step 2: Select a starting point for seeding density for each species based on a target percentage of the monoculture seeding density (number of seeds planted per square foot). An equal proportion seeding density is a reasonable starting point.

Step 3: Adjust the target seeding density for yield potential in the harvested mix. Smaller plants yield less than larger plants when seeded at the same density, so unequal seeding proportion is also a factor of desired yield. .

Step 4: Adjust the target seeding density for ease of establishment and competitiveness in mixtures. Reduce the proportion in the mix for highly competitive species that are easy to establish and increase it up to the full monoculture rate for poor competitors that are hard to establish.

Step 5: Multiply the target seeding density by the monoculture seeding rate and divide by 100 to get the mix seeding rate in pounds per live seed (PLS) per acre for each component to determine the supply of seed needed for each species in a mix.

Step 6: If mixing your own seed, divide the mix seeding rate in pounds PLS per acre by the PLS (percentage germination x percentage purity / 100) from your seed tag and multiply by 100 to get the mix seeding rate in pounds seed per acre.

Step 7: Add the weights of each component from step 6 to get the total seeding rate per acre of the seed after mixing.

Step 8: To calculate the proportion of each seed type, divide the weight (pounds seed per acre) of

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[18] P. Sullivan, “Converting Cropland to Perennial Grassland”.
[19] K. Albrecht, “SPECIES • COOL-SEASON PERENNIAL LEGUMES,” *Nat. Resour. Conserv. Serv.*.
[20] “Kura (Caucasian) Clover,” Forage Information System. Accessed: Apr. 14, 2024. [Online]. Available: https://forages.oregonstate.edu/forages/kura-caucasian-clover
[21] J. S. Peterson, “KENTUCKY BLUEGRASS”.
[22] R. H. Mohlenbrock, “Caution: This plant may become invasive.”.
[23] L. Allain, “Caution: This plant may become invasive. Please consult a specialist in your area.”.
[24] “RED CLOVER Trifolium pratense.pdf.”
[25] “SWITCHGRASS Panicum virgatum.pdf.”

each component by the total seeding weight per acre and multiply by 100 to get the percentage of seed by weight in the planting mix.

Table 4:Result of the calculations for grass seed mix.[26]

	Monoculture seeding rate (lb PLS/ac)	Desired seeding density, %	Mix seeding rate (lb PLS/ac)	PLS, % (from seed tag: germination x % purity / 100)	Mix seeding rate (lb seed/acre)	Mix seed proportion by weight, %
PERENNIAL COOL-SEASON GRASSES						
Meadow Fescue (Festuca pratensis)	20	20%	**4.00**	90%	**444.44**	**25%**
Orchardgrass (Dactylis glomerata)	12	15%	**1.80**	95%	**189.47**	**11%**
Smooth bromegrass (Bromus inermis Leyss.)	15	10%	**1.50**	92%	**163.04**	**9%**
Kentucky Bluegrass (Poa pratensis L.)	15	5%	**0.75**	85%	**88.24**	**5%**
LEGUMES						
Crimson Clover (Trifolium incarnatum L.)	30	10%	**3.00**	90%	**333.33**	**19%**
Kura clover (Trifolium ambiguum Bieb.)	23	5%	**1.15**	80%	**143.75**	**8%**
Red Clover (Trifolium pratense)	23	5%	**1.15**	95%	**121.05**	**7%**
PERENNIAL WARM-SEASON GRASSES						
Switchgrass	8	30%	**2.40**	85%	**282.35**	**16%**

The next step to converting agricultural land to be used for pasture is the seed bed preparation and seeding. Seed mix establishment plays a critical role in the development and maintenance of diverse grassland ecosystems. Achieving optimal seedbed conditions is fundamental for ensuring successful germination, root development, and subsequent plant growth, including the following factors:

- Good seed-to-soil contact for adequate moisture and proper germination. Mulch from existing plant residues helps retain moisture, control erosion, and inhibit weed growth, Moldboard plowing may be necessary for sites with dense,existing perennial cover, followed by disking or multiple passes for weed control or mulching.[27]

- Soil fertility parameters include soil with a pH between 5.5 and 8.0, adequate phosphorus for rapid root development during grass establishment and should be incorporated into the soil before seeding or placed with the seed at seeding time if necessary. Nitrogen application should be avoided at seeding, except in severely deficient soils, as it can stimulate weed growth and hinder grass establishment.

- Seeding depth is crucial for successful grass establishment, with depths ranging from 1/8 to 1/2 inch in fine textured soils and 1/2 to 1 inch in sandy soils. Grassland drills designed specifically for seeding grasses are ideal, equipped with features like agitators to prevent seed bridging and a positive feed mechanism for uniform seed distribution. Double disk openers with depth bands create furrows for seed placement, while packer wheels firm the soil around the seed. A roller can be used behind the drill to prevent excessive seed covering. For smooth, residue-free fields with ample moisture, cultipacker seeders are effective, compacting soil around the seed for good contact. Broadcast seeding is not recommended because of the increased margin of error, but rolling after seeding can improve seed-soil contact, partially offsetting the drawbacks of broadcast seeding.

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[26] K. Cassida and P. Kaatz, "Recommended Hay and Pasture Forages for Michigan," *Tall Fescue.*

[27]

- Warm-season grasses should be seeded between April 1 and May 15 to promote faster establishment. In areas where severe weed problems are anticipated, herbicides can be used to control weeds before seeding around May 15. Cool-season grasses are best seeded between Aug. 1 and Sept. 15, relying on late summer and fall rains for establishment. Spring seedings are successful between March 1 and April 30 but may face competition from annual weeds. The recommended seed mixture for Spring Creek includes both warm and cool season grasses and legumes to simplify the seeding process; the proposed window for planting the selected seed mix is between April 1st and April 30th.

While dryland pastures or hay typically include one or two species for easier management, mixtures containing four or more species of either cool-season or warm-season grasses often provide more stable and consistent productivity. While mixtures of both warm- and cool-season grasses can be challenging to manage, most seedings should include at least five species to ensure adaptability and persistence in diverse and harsh environments. Which is achievable with the seed mix developed for the Spring Creek site.[28]

Effective weed control is also important for the successful establishment of grass seedlings, as competition from weeds is a common cause of seeding failure. Late summer seeding for cool-season grasses can help avoid summer annual weed issues, while early spring seeding minimizes competition from weeds. Taller weeds pose a significant risk to new seedlings by shading them from light. Mowing can help reduce competition from grassy weeds, but it should be done carefully to avoid smothering young seedlings with clippings. Herbicides like Plateau can be effective for controlling weeds in warm-season grasses, while 2,4-D ester is commonly used for broadleaf weed control in grass seedlings. Special herbicides permitted for use in Conservation Reserve Program (CRP) acres are also available for weed control. Whichever type of weed control if any is to be used should be ascertained by monitoring the condition of the pasture.[29] Where stands of warm-season grass are slow to establish or weeds are not controlled well the first season, two or three years may be necessary to establish a vigorous stand. Dormant seeds that did not germinate the first year may germinate during year two to help thicken stands.

Soil Characteristics at Spring Creek

In the fall of 2023, soils at numerous fields at Spring Creek were sampled for fertility and basic soil health. Prior to sampling, the Natural Resources Conservation Service Web Soil Survey tool was used to identify the dominant soil types for each field. Multiple soil cores were taken, to a depth of 20 centimeters, from the representative soil type on each field and were then composited and homogenized before a sub-sample was taken for analysis. In total 13 distinct agricultural fields were sampled. In additional soils from three natural areas on the site which were in some stage of forest regeneration, were sampled to compare to fields under long term management.

Table 5: Soil samples tested at Spring Creek, including Field ID (see map in figure II-5 for

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[28] "extensionpubs.unl.edu/publication/g1705/html/view#target9." Accessed: Apr. 18, 2024. [Online]. Available: https://extensionpubs.unl.edu/publication/g1705/html/view#target9

[29] "extensionpubs.unl.edu/publication/g1705/html/view#target9." Accessed: Apr. 18, 2024. [Online]. Available: https://extensionpubs.unl.edu/publication/g1705/html/view#target9

locations). Testing parameters are soil pH, percent organic matter (%OM), and concentration of phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca) in parts per million, as well as cation exchange capacity (CEC) in milli-equivalents of charge per 100 grams of soil. Values represent mean values where more than one sample was taken from the same field. Fields shaded blue are non-agricultural, reference fields.

Field ID	Soil pH	% OM	P	K	Mg	Ca	CEC
1	6.9	2.05	53.5	111	160	1200	7.75
2	6.95	1.8	51	172.5	195	1050	7.45
3	6.55	1.45	14	78	162.5	950	6.9
4	7.2	1.65	68.5	92	145	1075	6.8
5	6.95	1.9	15.5	85	145	800	5.45
6	6.4	1.7	16	61	110	500	4.8
7	7.3	1.95	99.5	93	125	1125	6.9
8	7.3	2	27	100	140	1100	6.9
9	5.2	3.1	5	90	80	450	5.5
10	7	1.1	32	55	135	650	4.5
11	7.3	1.5	17	87	225	950	6.8
12	7	1.8	42	131	160	850	5.9
13	7.4	1.7	23	76	120	1050	6.4
14	7.1	2.3	25	79	160	950	6.3
15	7.3	2	291	76	135	1650	9.6
16	7.1	1.7	214	180	155	1100	7.3

The soils types across all agricultural fields at Spring Creek are dominated by loams (from the Kalamazoo soil series) and sandy loams (from the Oshtemo soil series) – both of which are generally highly fertile, well-drained soils, suitable for crop production. Soil testing results support that these soils have high fertility and soil health potential. This includes the mean percent organic matter of cultivated soils or 1.78 %. The mean organic matter on adjacent soils is higher at 2.18% - this result is driven by field 9, but indicates that these soils at Spring Creek have the capacity to sequester significantly more carbon with less intensive agricultural management. The soil pH of the cultivated soils is generally neutral (mean 7.01), and the phosphorus content is relatively high, indicating that the fields have been limed to optimize plant growth, and application of manure has increased nutrients on some fields. Values for potassium, magnesium, calcium and cation exchange capacity suggest more than adequate fertility status.

Field surveys of soil compaction, using a soil penetrometer, found relatively high sub-surface compaction across most agricultural fields, possibly due to the large equipment (i.e manure spreaders) and frequent traffic on these fields. This compaction may influence drainage on some fields, increasing run-off potential. The high fertility of the soil is ideal for pasture plant species. Deep-rooting, diverse mixtures of grasses are more likely to reduce compaction, improve drainage and increase soil carbon accumulation at depth.

Grazing

After receiving several options for grazing the type of grazing that would be the most synergistic with solar energy production is rotational grazing. Rotational grazing involves deliberately moving livestock between at least two enclosed areas of pasture, known as paddocks, with alternating periods of grazing and rest. Some researchers define rotational grazing based on a minimum number of paddocks and a maximum grazing period duration. The intensity of rotational grazing can vary, with producers adjusting the duration of grazing periods and the frequency of movements between paddocks. For example, in a simple four-paddock system, livestock would graze one paddock while the others rest. The length of the grazing period and the number of rotations over the grazing season can vary depending on the specific management practices employed.[30]

Rotational grazing has been promoted as a method to improve productivity, profitability, and environmental outcomes in farming, including in solar farms. While practitioner testimonies and region-specific articles often advocate for rotational grazing, experimental research on grazing systems provides mixed support for these claims. Studies suggest that rotational grazing, compared to continuous grazing, may increase soil organic carbon, contributing to better soil health and potential carbon sequestration. However, the economic benefits of rotational grazing are less conclusive, and require further research.[31]

Regionally, adopters of rotational grazing perceive benefits related to forage health, environmental resilience, and livestock productivity. The potential environmental benefits of rotational grazing include improvements in vegetative outcomes, soil health, erosion reduction, and weed control. Government conservation programs often incentivize the adoption of rotational grazing through financial assistance and technical support. Overall, while rotational grazing holds promise for improving environmental outcomes, its economic viability varies depending on farm-specific factors and regional conditions, especially if this includes economic viability on solar sites like Spring Creek.[32]

There are several ways rotational grazing would complement solar energy production. First, the highly flexible rotation schedule allows for easy accommodation of maintenance activities related to solar energy infrastructure. By strategically planned grazing rotations, livestock can be moved away from areas where maintenance work is being conducted, ensuring the safety of both animals and workers. Additionally, rotational grazing can optimize land use efficiency, allowing for the integration of solar panels within grazing areas without compromising productivity. It also creates economic opportunities by reducing or completely eliminating mowing costs for the Spring Creek facility and providing a reduced cost of secondary product by providing free forage for the grazing livestock.

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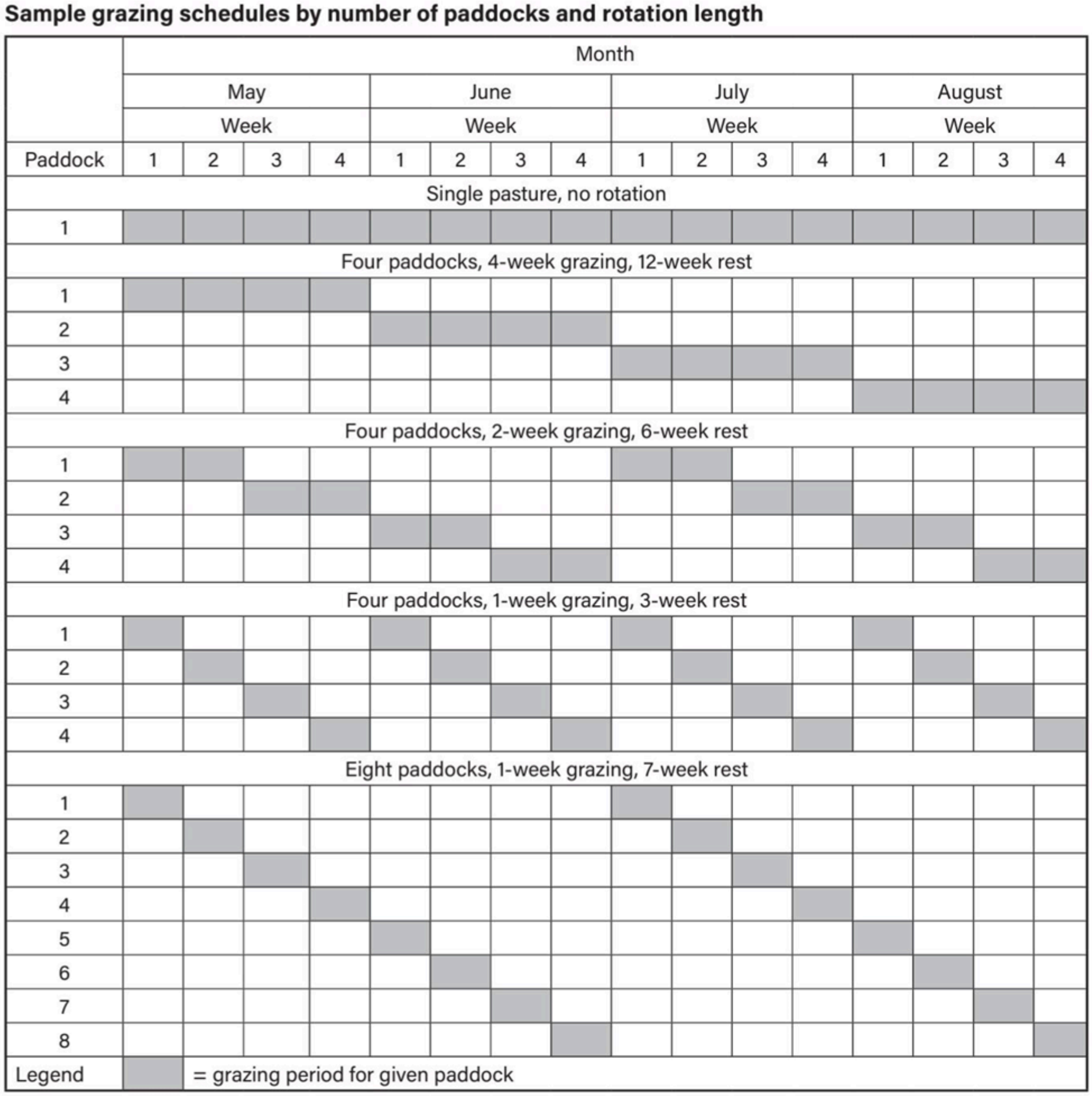
[30] C. Whitt, "Rotational Grazing Adoption by Cow-Calf Operations".

[31] C. Whitt, "Rotational Grazing Adoption by Cow-Calf Operations".

[32] C. Whitt, "Rotational Grazing Adoption by Cow-Calf Operations".

Table 6: A sample grazing schedule for prime months of forage growth and rotation among paddocks.[33]



Sample grazing schedules by number of paddocks and rotation length

	Month															
	May				June				July				August			
	Week				Week				Week				Week			
Paddock	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Single pasture, no rotation																
1	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Four paddocks, 4-week grazing, 12-week rest																
1	▨	▨	▨	▨												
2					▨	▨	▨	▨								
3									▨	▨	▨	▨				
4													▨	▨	▨	▨
Four paddocks, 2-week grazing, 6-week rest																
1	▨	▨							▨	▨						
2			▨	▨							▨	▨				
3					▨	▨							▨	▨		
4							▨	▨							▨	▨
Four paddocks, 1-week grazing, 3-week rest																
1	▨				▨				▨				▨			
2		▨				▨				▨				▨		
3			▨				▨				▨				▨	
4				▨				▨				▨				▨
Eight paddocks, 1-week grazing, 7-week rest																
1	▨								▨							
2		▨								▨						
3			▨								▨					
4				▨								▨				
5					▨								▨			
6						▨								▨		
7							▨								▨	
8								▨								▨
Legend	▨	= grazing period for given paddock														

The grazing systems depicted in Figure 7 range from least intensive to most intensive, with intensity measured by the duration of grazing periods and resting periods, as well as the number of rotations over time. Less intensive systems have longer grazing periods and resting periods, while more intensive systems involve shorter grazing periods and resting periods, often achieved by dividing the pasture into more, smaller paddocks. Intensity is measured by the number of livestock per acre at a given time. While Figure 7 shows grazing periods of equal length to illustrate tradeoffs, in practice, grazing periods and rotations vary based on plant recovery and growth rates. Methods to distinguish between basic rotational grazing (BRG) and intensive rotational grazing (IRG) include the number

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[33] C. Whitt, "Rotational Grazing Adoption by Cow-Calf Operations".

of paddocks, rotation frequency, length of grazing period, and vegetative condition. IRG is defined here as systems with an average grazing period of 14 or fewer days per paddock.[34]

The fields around Spring Creek have been managed for forage for the adjacent dairy. The animals at the dairy are currently not rotated onto pasture. Were this the case, the traffic and nutrients of the animals would have to be considered as part of future management. The manure from the dairy, however, has been routinely spread across these fields, which has likely maintained the current soil organic matter status and contributed to the higher fertility of these intensively cropped fields. In the future, the manure which has previously been returned to fields will enter a digester system on the farm to generate biogas.

Forage crops which required more inputs, such as alfalfa and corn will no longer have manure nutrient inputs. A pasture of perennial forage species fits both the high quality of the soil and the reduced inputs which can maintain quality forage. The options for the Spring Creek include adapting the recommended pasture mix within panel arrays themselves, adjacent to arrays or in buffer strips, all of which may vary based on the specific field within the site. Given the proximity of the dairy, this should be the obvious grazer for this location, however without this option grazing could include beef cattle or sheep. In the absence of grazing, high quality pasture could be used to produce hay multiple times per season, which could be used on the dairy or marketed offsite.

Buffer Region Vegetation

Buffer zone vegetation plays a critical role in mitigating the environmental impacts of various developments, serving as a transitional space between human activities and natural habitats. In the context of solar farm projects, buffer zones refer to designated areas around the facility where specific offsets must be maintained to minimize ecological disturbance and visual impacts.[35] Traditionally, these buffer zones have been left vacant, serving primarily as a visual barrier. However, in a departure from conventional approaches, the proposal for the Spring Creek solar farm project seeks to reimagine buffer zone vegetation as multifunctional spaces that integrate ecological, aesthetic, and practical considerations.

Instead of maintaining vacant land, the proposed approach for this solar farm project involves utilizing buffer zones for elements such as pasture, orchards, and tall grasses into the buffer zone vegetation. These options provide avenues to address concerns such as reducing maintenance costs, visual impact and land use efficiency.

Grazing within the buffer zone is limited in scale compared to grazing on the entire solar farm, or in larger buffer zones. The buffer zone pasture will provide the same benefits as grazing or producing hay across the entire array but on a smaller scale. The main consideration to implementing buffer zone pasture is that it would require less effort to implement and reduced interference with the solar farm operations.

Because the buffer zones do not require the consideration of shade created by the solar farm equipment, if desired, the quality of the forage can be improved by adjusting the seed mix to include species that require full sun. Most commercially available forage mixes would be suitable. This provides an opportunity for increased forage quality and quantity.

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[34] C. Whitt, "Rotational Grazing Adoption by Cow-Calf Operations".

[35] I. E. Palmer, R. J. Gehl, T. G. Ranney, D. Touchell, and N. George, "Biomass yield, nitrogen response, and nutrient uptake of perennial bioenergy grasses in North Carolina," *Biomass Bioenergy*, vol. 63, pp. 218–228, Apr. 2014, doi: 10.1016/j.biombioe.2014.02.016.

In addition to the reduced site maintenance costs and the ecological benefits offered by the seed mix, grazing within the buffer zone provides an opportunity to minimize visual impacts on the solar farm. Utilizing the foraging animals on the perimeter of the solar farm should introduce some of the rural aesthetic back to the site.

To further preserve scenic views a more robust privacy screen is necessary. Utilizing tall grass species may be an ideal option. Unfortunately, non-invasive grasses do not offer the required height. Research from producing biofuel crops (for lignocellulosic bioenergy production) may indicate species suitable for both screening or even biomass production if desired for forage, livestock bedding or bioenergy (such as inclusion in manure digesters). Biomass produced by these grasses is significant. As an example, in a study performed in a coastal region of North Carolina dry matter yields for three tall grasses: the giant reed, giant miscanthus, ravenna grass which yielded 27.4, 20.8, 14.3 Mg per hectare per year, respectively.[36] Further research would be required to determine the exact yield that can be produced in the buffer zones at Spring Creek site, but it stands to reason that an energy company looking to diversify its portfolio would be interested in this opportunity.

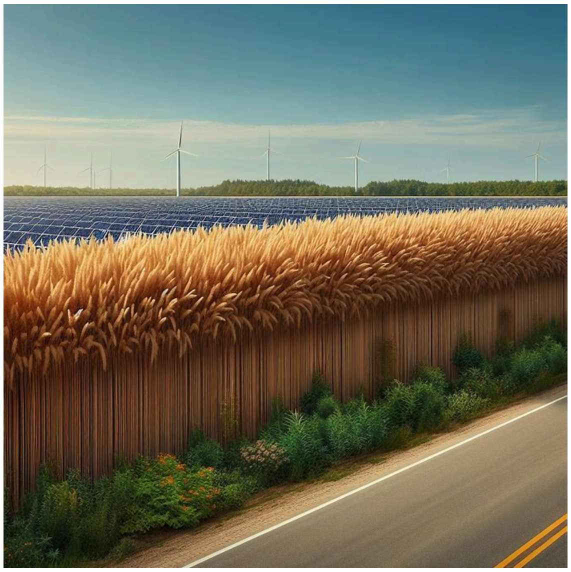

Figure 3: Example of a tall grass privacy screen.

Unlike the grasses in the forage mix these grasses propagate by rhizomes and require a different approach to planting. They also require a higher level of control to make sure that the invasive species does not damage the local ecosystem. The planting procedure for all 3 grasses is the same.

To prepare the soil for planting, begin by conducting a soil test to assess key parameters such as pH, nutrient levels, and texture. Utilize this information to determine necessary soil amendments for optimal plant growth. Adjust the soil pH to the ideal range of 5.5 to 7.5 using agricultural lime for acidity or elemental sulfur for alkalinity, based on the test results. Incorporate organic matter like compost or well-aged manure to enhance soil structure and fertility. Till the soil to a depth of 6 to 8 inches using suitable equipment like a plow or disk harrow to loosen compacted soil, improve drainage, and create an ideal seedbed. Control weeds mechanically through methods like plowing, disking, or hand-weeding, and consider applying non-selective herbicides if needed to prevent weed competition during establishment. Ensure adequate soil moisture levels before planting by irrigating if necessary.[37]

Plant rhizomes or root cuttings at a depth of 2 to 4 inches and spaced approximately 3 feet apart in rows, row spacing should be 3 feet this will minimize the number of rhizomes per acre. Ensuring proper spacing between rows allows for proper airflow and sunlight penetration. The spacing can

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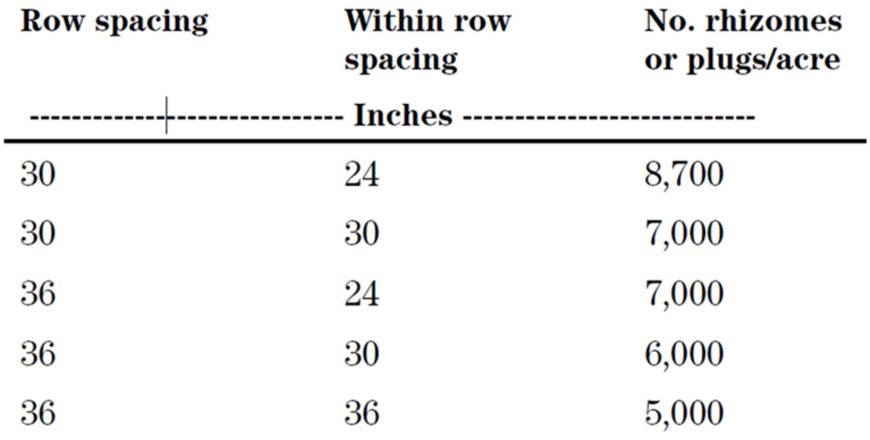
[36] I. E. Palmer, R. J. Gehl, T. G. Ranney, D. Touchell, and N. George, "Biomass yield, nitrogen response, and nutrient uptake of perennial bioenergy grasses in North Carolina," *Biomass Bioenergy*, vol. 63, pp. 218–228, Apr. 2014, doi: 10.1016/j.biombioe.2014.02.016.

[37] "Planting and Managing Giant Miscanthus as a Biomass Energy Crop," no. 4, 2011.

also be adjusted for a mode dense cover.[38]

Table 7: An example of how the spacing of the rhizomes will affect the number of rhizomes required per acre.



Row spacing	Within row spacing	No. rhizomes or plugs/acre
----------	---------- Inches ----------	----------
30	24	8,700
30	30	7,000
36	24	7,000
36	30	6,000
36	36	5,000

Apply organic mulch around newly planted rhizomes to conserve moisture, suppress weeds, and provide insulation. Depending on soil nutrient levels and plant requirements, apply balanced fertilizer as recommended by soil test results or crop nutrient requirements, avoiding over-fertilization to prevent environmental pollution and maintain plant health. By following these soil preparation guidelines, you can create an optimal growing environment for tall grasses, ensuring healthy establishment and robust growth of these versatile perennial species.[39]

Since the depth of rhizome offshoots can vary in different types of soil it is hard to say exactly how deep the root barrier needs to be. The image on the right shows an example of how the root barrier works.

The depth of the root barrier required to effectively contain rhizomatous grass species depends on several factors, including the specific characteristics of the grass species, soil conditions, and the desired level of containment. In general, root barriers are typically installed to a depth of at least 24 to 36 inches below the soil surface, an example seen in the image on the left. This depth is sufficient to intercept and prevent the lateral spread of rhizomes, as most grass species' rhizomes tend to grow within the top few feet of soil. However, in areas where soil conditions are favorable for deeper root penetration or where there is a need for enhanced containment, root barriers may be installed to greater depths, up to 48 inches or more. Additionally, the root barrier should extend slightly above the soil surface to prevent rhizomes from growing over the top of the barrier. Proper installation and maintenance of the root barrier are essential to ensure its effectiveness in containing rhizomatous grasses and preventing unwanted spread.[40]

To reduce the amount of land that has to be taken out of productions for the purpose of the privacy screen the proposed privacy screen width should be adjusted to 16 feet. This will allow for an 8-foot-wide flail mower to mow the grass on half of the strip if necessary while the remaining 8-foot stand of grass will provide the necessary privacy cover. This width allows for efficient mowing operations while ensuring adequate coverage and density of the planted grasses minimizing the time

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[38] "Planting and Managing Giant Miscanthus as a Biomass Energy Crop," no. 4, 2011.

[39] "Planting and Managing Giant Miscanthus as a Biomass Energy Crop," no. 4, 2011.

[40] "Planting and Managing Giant Miscanthus as a Biomass Energy Crop," no. 4, 2011.

and effort required for maintenance.

If the optimization of biomass production is desired, the 16-foot wide privacy screen can be easily integrated into border-to-border planting. This entails planting grasses from one edge of the buffer zone to the other, ensuring complete coverage and uniformity throughout the area. By implementing a border-to-border planting strategy, the buffer zone can effectively harness the full potential of the planted grasses to provide the highest volume of biomass production while maintaining privacy screening, erosion control, and other environmental benefits. Moreover, this approach promotes efficient land use and enhances the aesthetic appeal of the buffer zone, creating a cohesive and visually appealing landscape around the solar farm.

The second option is to create a privacy screen made of fruiting plants. Both American Hazelnut and PawPaw are suitable for this purpose. While they have their differences both naturally grow in colonies and form thickets. Which makes them suitable to be used as a privacy screen.

The American Hazelnut, can act as a privacy screen and offers multiple ecological benefits. The nuts produced by American Hazelnut are a valuable food source for various wildlife species, including squirrels, foxes, deer, northern bobwhite, ruffed grouse, turkey, woodpeckers, and pheasants.. Additionally, the leaves, twigs, and catkins of the American Hazelnut plant are browsed by rabbits, and deer further enriching their habitat. The dense, low growth habit of the American hazelnut shrub provides cover and nesting sites for many wildlife species, enhancing biodiversity within the ecosystem.[41]

The nuts produced by American Hazelnut have a higher nutritional value and can be eaten raw or ground into flour. Extracts from American hazelnut, primarily glycerides of the fatty acids, are used for emollients in skin care products. Finally, American Hazelnut has long been valued as an ornamental plant, adding beauty to landscapes and naturalized settings. Overall, American Hazelnut provides a range of options for ecological benefits by supporting biodiversity and ecosystem functions demonstrates its importance in both natural and cultivated environments.[42]

To prepare the soil for planting American hazelnut shrubs, first conduct a soil test to evaluate pH, nutrient levels, and texture. Based on the results, adjust the pH to suit the preferences of American hazelnuts, which generally prefer moist to dry woods and thickets with rich, well-drained soil. Till the soil to loosen it and improve drainage, especially if it's compacted. Clear the planting area of weeds and debris. American hazelnuts thrive in sun or partial shade, so select a suitable location. Plant the shrubs at a spacing of 3-10 feet apart to allow for their colonial growth habit. Mulch around the base of the shrubs to retain moisture and suppress weeds. Water the newly planted shrubs regularly, especially during dry periods, to promote establishment. Additionally, consider the Sun Harvest Germplasm cultivar, which was selected for its improved canopy symmetry, plant height, nut production, and resistance to pests and diseases. Following these steps will create an optimal environment for American hazelnut shrubs, ensuring their healthy growth and productivity.[43]

The PawPaw also has a range of benefits as a potential screen with ecosystem benefits. .The fruits of the pawpaw tree serve as an essential food source for various wildlife species.. Additionally, the larvae of the Zebra Swallowtail butterfly feed exclusively on the leaves of the pawpaw tree,

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[41] G. Nesom, "AMERICAN HAZELNUT," *USDA NRCS Natl. Plant Data Cent. Biota N. Am. Program.*

[42] G. Nesom, "AMERICAN HAZELNUT," *USDA NRCS Natl. Plant Data Cent. Biota N. Am. Program.*

[43] G. Nesom, "AMERICAN HAZELNUT," *USDA NRCS Natl. Plant Data Cent. Biota N. Am. Program.*

highlighting its significance in supporting insect populations. The dense foliage and fruit production of pawpaw trees create conducive habitats in forested areas or natural landscapes, promoting biodiversity and ecological balance.[44]

Like American Hazelnuts, Pawpaw also offers several benefits to humans. Firstly, the fruit of the pawpaw tree serves as a nutritious food source. Historically, Native American tribes cultivated and consumed pawpaw fruit, which is known for its high amino acid content. The fruit, described as the largest edible fruit native to America, provides a source of essential nutrients and can be eaten fresh or processed into various culinary products. Pawpaw grow in thickets and can be planted directly in soil or in stands with trees 10-15 feet apart.[45]

Creating a proper orchard of either Paw Paw or American Hazelnut requires a significant amount of planning and goes outside the scope of this project. One option would be to involve local farmers and have them prepare and operate the orchards. Figure3 Shows an example of how a buffer zone orchard would look If they are set up to operate like a commercial orchard. But if so, desired a small scale experimental orchard could be set up following the basic soil preparation instructions.

Table 8: Quick reference to the chosen privacy screen vegetation and the criteria used for selecting them.

	Care and Cultivation					Utilization as a Privacy Fence			
Species	**USDA Hardiness Zones**	**Soil**	**Sunlight**	**Watering**	**Maintenance**	**Planting Density**	**Height and Spacing**	**Wildlife Benefits**	**Environmental Considerations**
Woody									
American Hazelnut (Corylus americana)	4 - 9	Well-drained, tolerant to sandy & clayey	Full sun to partial shade	Drought-tolerant	Root barriers Pruning	Forms thickets	6-12 ft tall, 4-6 ft apart	Edible Fruit Polinator Friendly Food for Wildlife	Native, non-invasive
Pawpaw (Asimina triloba)	5 - 9	Well-draining, slightly acidic	Full sun to partial shade	Consistent watering	Pruning Fertilizer in spring	Forms thickets	15-30 ft tall, 10-15 ft apart	Edible Fruit Polinator Friendly Food for Wildlife	Native, non-invasive
GRASSES									
Giant Reed Grass (Arundo donax)	6a - 9b	Well-draining Adaptable	Full sun to partial shade	Drought-tolerant	Spread controll Root barriers	Dense stands	16-20 ft tall 3-5 ft apart		Invasive species Root Barrier
Elephant Grass (Miscanthus giganteus)	5-9	Well-draining Adaptable	Full sun to partial shade	Drought-tolerant	Spread controll Root barriers	Dense stands	10-15 ft tall 3-5 ft apart	Attracts birds	Invasive species Root Barrier
Ravenna Grass (Saccharum ravennae)	6-10	Well-draining Adaptable	Full sun, partial shade	Drought-tolerant	Spread controll Root barriers	Dense stands	10-15 ft tall 3-5 ft apart		Invasive species Root Barrier

There are a multitude of opportunities that ecosystem science can utilize to optimize the synergies between solar energy production and agricultural production. By integrating solar energy production into agricultural landscapes, we can maximize land productivity and resource utilization while simultaneously generating renewable energy and agricultural products. Pastures can serve as grazing areas for livestock, promoting sustainable agriculture practices and enhancing soil health. Orchards planted within buffer zones would provide screening for solar panels but also produce valuable crops, diversifying income streams for landowners. Additionally, the ecosystem services provided by posture grasses and fruit bearing plants will provide habitat for wildlife, promote biodiversity, and provide other benefits not discussed in this report. These synergistic approaches offer a win-win solution for both energy production and agricultural production, highlighting the importance of integrated planning and collaboration across sectors to achieve a more resilient and environmentally friendly future.

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[44] "PAWPAW Asimina triloba (L.) Dunal.pdf."

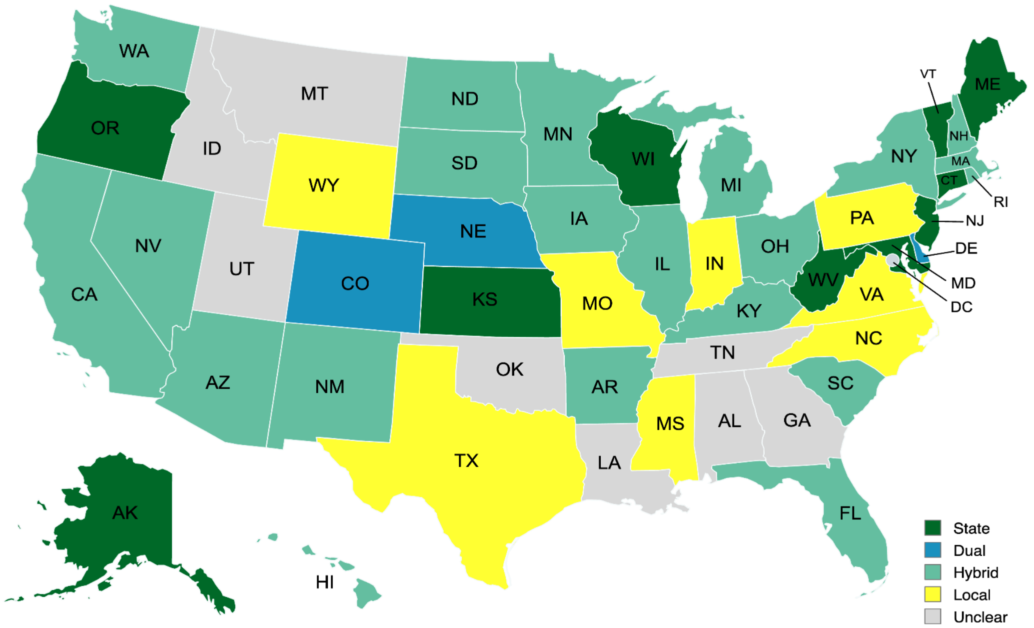
[45] "PAWPAW Asimina triloba (L.) Dunal.pdf."

Local and State Level Policy Implications

Background

Before construction, a renewable energy project developer must carefully select a proper site for the project, and consider the regulatory framework for obtaining all required permits at the local, state and federal levels. These permits may require complying with local zoning ordinances, state-level regulatory processes, and federal environmental laws[46].

The siting/permitting process is often identified as one of the key obstacles to accelerate solar and wind deployment. The average timeframe for building a utility-scale solar or wind facility project including permitting, siting and construction, spans four years[47]. Specifically, the siting and permitting process alone can take up to three to five years to complete[48]. In this process, state and local governments are critical actors. Currently, permitting/siting regimes for renewable energy projects on private lands differ across states. As the figure 4 shows, some state governments have final authority over the siting of a utility scale renewable energy facility (AK, CT, KS, others), or on the siting of the project over a certain capacity (CA, FL, IL, others)[49]. Conversely, in states such as Indiana and Texas, land use approvals are all done at the local level.



Created with mapchart.net

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[46] "Solar Siting | ACP." n.d. American Clean Power Association. Accessed April 7, 2024. https://cleanpower.org/policy/solar-siting/.

[47] Bird, Lori, and Katrina McLaughlin. 2023. "Reforming Clean Energy Permitting in the US." World Resources Institute. https://www.wri.org/insights/clean-energy-permitting-reform-us.

[48] "Land Use & Solar Development | SEIA." n.d. Solar Energy Industries Association. Accessed April 8, 2024. https://www.seia.org/initiatives/land-use-solar-development.

[49] Davis, Jon. 2024. "Wind, Solar and Siting: A Look at Recent Laws and Legislative Trends in the Midwest - CSG Midwest." CSG Midwest. https://csgmidwest.org/2024/02/29/wind-solar-and-siting/.

Figure 4: Solar siting authority by state. Source: Solar Siting Authority Across the United States from UM[50] with recent regulation updates in Michigan, Illinois[51].
Note: Solar projects with capacity of over 30 MW must obtain a permit from the state Industrial Siting Council in Wyoming[52]; Solar projects over 50 MW have the option to undergo the state siting process in Michigan from 11/29/2024.

Starting November 29, 2024, Michigan will end its history of local-level decision-making for the siting of renewable energy projects, with the implementation of PA 233 of 2023 (hereinafter PA 233). This law, which passed in Fall 2023, provides an alternative siting process for large-scale renewables projects to instead seek land use approval at the Michigan Public Service Commission (MPSC).A solar developer with a project with a capacity of or over 50 MW has two options for permitting: continuing to seek zoning approval at the local level or instead following the state process under PA 233. Local governments have a way to ensure developers must first work with them by adopting a Compatible Renewable Energy Ordinance (CREO) which is defined as being no more restrictive than the provisions in section 226(8) of the Act[53], including setback, fencing, height, noise, lighting, and other more stringent and necessary requirements adopted by the Commission later. However, according to a 2019 study of solar ordinances done by the Michigan Office of Climate and Energy, “fewer than 20% of Michigan communities have zoning regulations in place to address all scales of SES (solar energy systems)[54]”. Among available local ordinance, 50 of 252 ordinances match setbacks/height/noise requirements, with extra limitations on location, landscaping, etc[55]. To be sure, developers can still choose to seek permits with a local government that does not have a CREO, but PA 233 allows them a new option if they find the local process unworkable.

In conclusion, navigating the complex regulatory landscape for renewable energy project siting and permitting requires a thorough understanding of both state and local regulations. Developers must carefully evaluate the pros and cons of each permitting process and select the optimal approach based on project-specific considerations and regulatory requirements.

This report will provide a case study of how a utility-scale solar project on farmland in Michigan might determine whether to seek local or state permitting approval by studying and comparing state and local regulations with following steps,

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[50] Essa, Elena, Kristina Curtiss, and Claire Dodinval. 2021. “Solar Siting Authority Across the United States | Center for Local, State, and Urban Policy.” CLOSUP. https://closup.umich.edu/research/working-papers/solar-siting-authority-across-united-states.

[51] Ryan C. Granholm, Amy Antoniolli, and Jane E. Montgomery. 2023. “Illinois Standardizes Permit Laws For Solar and Wind Energy Facil.” The National Law Review. https://natlawreview.com/article/illinois-enacts-new-law-to-standardize-local-permitting-renewable-energy-facilities.

[52] “Wyo. Stat. § 35-12-102.” n.d. casetext. Accessed April 7, 2024. https://casetext.com/statute/wyoming-statutes/title-35-public-health-and-safety/chapter-12-industrial-development-and-siting/section-35-12-102-definitions.

[53] Sec. 221 (f)

[54] Beyea, Wayne, Harmony Fierke-Gmazel, M. C. Gould, Bradley Neumann, Mary Reilly, and Sarah Mills. 2021. “Planning & Zoning for Solar Energy Systems: A Guide for Michigan Local Governments - Planning.” MSU College of Agriculture and Natural Resources. https://www.canr.msu.edu/resources/planning-zoning-for-solar-energy-systems-a-guide-for-michigan-local-governments.

[55] Mills, Sarah, Judy Allen, and Catherine Kaufman. 2024. “MPSC Renewable Energy and Energy Storage Facility Siting Meeting.” State of Michigan. https://www.michigan.gov/mpsc/-/media/Project/Websites/mpsc/workgroups/2023-Energy-Legislation/Renewable-Energy-and-Energy-Storage-Siting/Siting-Presentation-3-7-24.pdf?rev=6d3cd63f96fa4bfb90276e15e4f06f4d&hash=F65A48FED040992A2F64122248455EAF.

1. Identify current available permitting regulations
2. Compare differences between state and local regulations
3. Assess the pros and cons of each process
4. Recommend the optimal permitting plan

Finally, a decision-making framework for future renewable energy projects to apply will be generated based on the case study.

Regulation Analysis

Spring Creek project is a solar farm of estimated capacity of 100 MW building on 2,053.3 acres of farmland with 56.2% of total land used for agriculture (466.7 hectares). The site is located in two local units of government: 1617.7 acres in Johnstown Township, Barry County for 78.8% of the total acreage, and 435.5 acres in Bedford Township, Calhoun County for 21.2% of the total acreage (See Appendix). Currently, Johnstown Township and Barry County lack local ordinances for solar energy facilities and have no solar energy project online as of 2023[56]. As Table 9 shows, while Calhoun County has three solar energy projects online, none of these projects are in Bedford. All of these three projects were approved by corresponding townships through conditional/special land use permits[57][58][59]. Bedford Township has a Solar Energy Systems Ordinance that became effective on August 17, 2023, which amended its zoning ordinance regarding application, requirements and standards for solar energy system approval[60].

Table 9: Utility scale solar projects that are online by 2023 in Calhoun County; Source from Clean Grid Alliance[61].

Location	Utility/Owner	Plant	Power Capacity	Year Online
Marshall Township, Calhoun, Michigan	Pine Gate Renewables	13 Mile Solar	2 MW	2,020
Convis Township & Pennfield Township, Calhoun, Michigan	Invenergy	Calhoun Solar Energy Center	200 MW	2,023

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[56] *Solar Energy Projects – Michigan*. n.d. N.p.: Clean Grid Alliance. Accessed 4 7, 2024. https://cleangridalliance.org/focus-areas/projects?gp=michigan&tp=Solar&gad_source=1&gclid=CjwKCAiAxaCvBhBaEiwAvsLmWETKMArGg0Z3o_wU8yC7LZwc9p97DtXljfReJOPVPwgt_LC0dkZFJBoCmiAQAvD_BwE.

[57] LaNoue, Mike. 2020. "13 Mile Solar project brings renewable energy to Marshall." J-Ad Graphics. https://www.advisor-chronicle.com/13-mile-solar-project-brings-renewable-energy-to-marshall.

[58] Invenergy. 2020. "Calhoun Solar Energy Center Development Plan." Revize. https://webgen1files.revize.com/pennfieldctmi//Document%20Center/How%20Do%20I/Find%20Learn%20About/Calhoun%20Solar%20Energy%20Plan/Calhoun-County-Solar-Energy-Project.pdf.

[59] "Cereal City Solar Energy Center." n.d. NextEra Energy Resources. Accessed April 6, 2024. https://www.nexteraenergyresources.com/cereal-city-solar/project-overview.html.

[60] CHARTER TOWNSHIP OF BEDFORD CALHOUN COUNTY STATE OF MICHIGAN. 2023. "Solar Energy Systems Ordinance." https://webgen1files.revize.com/bedfordctmi/Solar%20Ordinance.pdf.

[61] *Solar Energy Projects – Michigan*. n.d. N.p.: Clean Grid Alliance. Accessed 4 7, 2024. https://cleangridalliance.org/focus-areas/projects?gp=michigan&tp=Solar&gad_source=1&gclid=CjwKCAiAxaCvBhBaEiwAvsLmWETKMArGg0Z3o_wU8yC7LZwc9p97DtXljfReJOPVPwgt_LC0dkZFJBoCmiAQAvD_BwE.

Marshall Township, Calhoun, Michigan	NextEra Energy Inc.	Cereal City Solar	100 MW	2,023

Therefore, we will study PA 233 of 2023 and Bedford's SES Ordinance for the permitting of the Spring Creek project.

Zoning & Approval Process

Both the state and Bedford allow large solar projects on farmland with specific requirements as shown in Table 10. In PA 233, "The proposed energy facility will not unreasonably diminish farmland, including, but not limited to, prime farmland and, to the extent that evidence of such farmland is available in the evidentiary record, farmland dedicated to the cultivation of specialty crops [62]", but it is unclear how the state will define prime farmland, and what situation is defined as 'not unreasonably diminish farmland'. In Bedford, solar farms, defined as utility-scale commercial facilities for the primary purpose of wholesale or retail sales, are only allowed in the AG (agricultural) zoning district and require a conditional land use permit, site plan review and approval, and are also subject to the requirements of SES Ordinance.

Another difference lies in the review time and duration of the approval. An application submitted to the local unit with CREO will be approved or denied within 120 days, much shorter than the current local process time (since there is no limit), while an application submitted to the Commission may be under review for up to 1 year. Projects approved at the MPSC will expire if construction is not able to begin within 5 years after the granted date of the permit. Additionally, there is no specified application review time in Bedford's Zoning Ordinance[63] and SES Ordinance, which means they will be determined case by case. According to PA 234 of 2023 which became effective on February 13, 2024, any renewable energy projects that received special land use approval at the local level, never expire if the developer spends an expenditure equal to 10% of the project construction costs or $10,000.00, whichever is less[64].

Table 10: PA 233 and Bedford SES ordinance is different in the scope, zoning, and approval process.

	PA 233 of 2023	Bedford SES ordinance
Scope	Any solar energy facility with a nameplate capacity of 50 megawatts or more.	Solar farm for the primary purpose of wholesale or retail sales of generated electric power off-site

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[62] Sec. 226 (7)f

[63] "THE CHARTER TOWNSHIP OF BEDFORD ZONING ORDINANCE." 2014. https://webgen1files.revize.com/bedfordctmi/Document_Center/Document%20Center/Ordinances/zoning-ordinances-amendments.pdf.

[64] "MCL - Section 125.3205 - Michigan Legislature." n.d. Michigan Legislature. Accessed April 15, 2024. https://legislature.mi.gov/Laws/MCL?objectName=MCL-125-3205.

Zoning	All, but extra requirements if proposed energy facility is on farmland or brownfield	AG
Approval Method	NA	Special Land Use
Review Time	CREO: 120 days for local unit Commission: 1 year	NA
Public Hearing	Yes	Yes
Duration of Approval	5 years	Never expire if $10,000 worth of expenditure made

Cost and fees

Permitting cost only accounts for a small proportion of total cost of a solar project[65], but some requirements would raise the cost significantly. As Table 11 shows, in the state process, an applicant must pay an intervenor compensation fund with $75,000 per affected local unit but not more than $150,000 in total, and $2k/MW as host community benefits to each affected local unit. Here, each affected local unit includes townships, countries, villages, or cities where a project is located, not just those with zoning authority. In the Spring Creek project case, the developer would pay $2k/MW to both townships and counties, amounting to $2k/MW * 2 units * 100MW = 400k. Both the $150k fund and $400k community payment are not required in local ordinance. But local units still have the opportunity to get community benefits by applying for a Renewable Ready Communities Award (RRCA). This award granted by the state will provide up to $5k per renewable energy megawatt permitted locally on or after October 1, 2023, higher than that in PA 233, serving as incentives to communities and developers, who go through local permitting.

The labor requirements are another source of rising costs. PA 233 mandates apprenticeship programs during the installation and construction phases of the project, prevailing local wage standards for construction workers, and construction entities to operate under a project labor agreement or collective bargaining agreement. These requirements, which are not included in local ordinances, raise construction costs and pose challenges for out-of-state developers that do not have existing relationships with local labor organizations.

However, these advantages in local permitting can be offset by extra financial guarantees, a General Maintenance Bond and Liability Insurance. The bond is noted in Bedford SES ordinance and does not appear at all in PA 233, and is required to equal the contractor bid for construction of all fencing, landscaping and drainage improvements. The liability insurance found in Bedford's ordinance is also not standard in PA 233 requirements. To comply with it, the solar farm owner and

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[65] Solar Energy Technologies Office. n.d. "Solar Soft Costs Basics." Department of Energy. Accessed April 8, 2024. https://www.energy.gov/eere/solar/solar-soft-costs-basics.

operator would need to acquire insurance covering $2M/per occurrence/per participating lot * XX lots * XX occurrence.

In both the local and state processes, financial guarantees for decommissioning are required. In Bedford, an applicant would pay the amount of 125% of demolition costs updated every 2 years at the rate of 1.5 times CPI for each year. By contrast, the state permitting requires financial assurance of estimated cost of decommissioning minus salvage values, which may be posted in increments starting with at least 25% by the start of full commercial operation.

Table11: The cost and fees required by the PA 233 and Bedford SES ordinance

	PA 233 of 2023	Bedford SES ordinance
Application fee	Yes	Yes
Compensation fund	$75,000 per affected local unit but not more than $150,000 in total	NA
Community Benefits	$2k/MW per affected local unit	NA (a Renewables Ready Communities Award of up to $5k/MW may apply)
Labor	Apprenticeship programs; prevailing wage standard; Labor agreement/a collective bargaining agreement	NA
Financial guarantee for decommissioning	Cost of decommissioning minus salvage value, posted in increments starting with 25% of the cost	125% of demolition estimate
General maintenance Bond	NA	Bond for all fencing, landscaping, and drainage improvements
Liability Insurance	NA	$2,000,000 per occurrence, per participating lot

Application requirements
An application should provide required information and documentations to the Commission or township for a certificate. Here, Table 12 shows application documents specified in PA 233 and Bedford SES ordinance.

Ten documents are required both by the state and Bedford, including basic information of the applicant, construction timeline, site plan, etc. Bedford requires 14 specific documentations that are not included in PA 233, some of which need a lot of work, such as the scaled drawings depicting all components, complaints resolution plan. While the state process requires 8 specific documents, such as community related materials, description of expected use and public benefits of the project.

In conclusion, the state process requires less documentation overall. However, both state and Bedford could request more information or documentation as needed. This means the amount of information and paperwork required may vary depending on the specific case.

Table 12: Application information and documentation requirements in the PA 233 and Bedford SES ordinance.

State specific	Required by both	Local specific
8	10	14
Community description of site area	Basic information	Scaled drawings depicting all components
A description of expected use of the energy facility	Construction timeline	A map and narrative description of the land uses of all non-participating parcels
Expected public benefits	Site plan	A list of all parcels included in the project area
Anticipated public health and safety effects	Environmental and natural resources impacts and mitigation plan	Operations agreement
A summary of the community outreach and education efforts	Erosion management and sediment control plan	Current photographs of the subject property
Consultation with applicable state and federal agencies prior submission	Copy of environmental permits	A graphical demonstration
Feasible site alternatives	Interconnection information	Drain tile maintenance plan
Fire and emergency response plan	Electromagnetic impacts and mitigation plan	Escrow payment

	Stormwater assessment and drainage mitigation plan	Financial security
	Decommissioning & Reclamation plan	Complaints resolution plan
		Hazardous waste plan
		Transportation plan
		Manufacturer's installation instructions
		Copy of the manufacturer's safety manual for each component

Land use

Land use requirements primarily consist of setback and landscaping, which affect the amount of land used for solar energy generation and ecosystem services. An NREL research based on 839 ordinances for solar estimated that solar resources would be reduced if adding setback requirements through the country in resource assessment, highlighting that setback would result in less land used for solar energy development[66].

As seen in Table 13, both state and Bedford require 50 feet setback distance from non-participating parcels, while state requires additional setback of 300 feet from occupied community buildings and dwellings on non-participating properties. However, the setbacks of 300 feet from public roads in Bedford SES ordinance is much more restrictive than PA 233's requirement of 50 feet from public roads. Furthermore, Bedford requires a 50 foot setback from participating parcels, meaning that where two adjoining participating parcels are about, there would need to be at least a 100 foot gap between solar arrays–50 feet on each side of the property line. The local ordinance also requires accessory setbacks for inverters and battery storage buildings, which would force these infrastructure to the interior of the project. We are unable to calculate the exact amount of land affected by setbacks, due to data and map availability, but the general comparison between the two regulations demonstrate that Bedford standard is way more restrictive than state standard.

Regarding the landscaping, PA 233 does not specify buffering/screening, posing a challenge for communities, as it helps reduce sound and visual impacts, which are one of the concerns creating opposition to large scale solar energy in Michigan[67]. But complying with buffering in Bedford solar ordinance is significantly expensive. Trees must be at least 12 feet high at planting with maximum

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[66] Lopez, A., Cole, W., Sergi, B. *et al.* Impact of siting ordinances on land availability for wind and solar development. *Nat Energy* 8, 1034–1043 (2023). https://doi.org/10.1038/s41560-023-01319-3

[67] Crawford, Jessica, Douglas Bessette, and Sarah B. Mills. "Rallying the anti-crowd: Organized opposition, democratic deficit, and a potential social gap in large-scale solar energy." *Energy Research & Social Science* 90 (2022): 102597.

separation of 10 feet on center, as well as one row planted on a 4-foot berm. Typically, evergreen trees are at least 6 feet in height at planting with larger space in local ordinance, such as the ordinance of Convis Township where a 200 MW solar project is located[68]. This will create a huge cost for developers because the price of a 12-feet evergreen tree can be 3 times of a 6-feet one if it's an eastern white pine[69].

Table 13: Setback and landscaping requirements in the PA 233 and Bedford SES ordinance

		PA 233 of 2023	**Bedford SES ordinance**
Setback	Occupied community buildings and dwellings on nonparticipating properties	300 feet	NA
	Public road right of way	50 feet	300 feet
	Non-participating parties	50 feet	50 feet
	Wetland	NA	200 feet
	Participating parcel	NA	50 feet
	Additional setbacks for inverters and battery storage buildings		
	non-participating lot	NA	1000 feet
	participating lot	NA	200 feet
Landscaping	Minimum height of planting	NA	12 feet
	Maximum spaced	NA	10 feet
	Minimum berm height	NA	4-foot
	Existing trees and woodlands	NA	Preserved
	vegetative ground cover	Pollinator as a condition	Native grasses, grazing grasses, pollinator habitat

Infrastructure

There are lots of differences in infrastructure as shown in Table 14. Bedford has more stringent regulation on fencing and sound than PA 233. The requirement of a 6 foot high fence with a self-locking gate is acceptable, but the additional requirement that evergreen landscaping to buffer any mechanical equipment is not included in PA 233.

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[68] "Convis Township Zoning Ordinance." n.d. Accessed April 10, 2024. http://www.convistownship.org/Portals/1013/Convis%20Twp%20Draft%20Zoning%20Ordinance%20-%20March%202021.pdf?ver=opszJysTfIoMPRSEP4VbUw%3d%3d.

[69] "Eastern White Pine." n.d. Bower & Branch. Accessed April 10, 2024. https://bowerandbranch.com/products/eastern-white-pine?variant=44364918718618.

Bedford also has more restrictive sound regulation. The maximum sound of a solar energy facility in the state standard is 55 average hourly dB(A) measured at the outer wall of dwelling on an adjacent non-participating property, which, because of the required setbacks, is at least 300 feet from the fence of the solar project. By contrast, the noise requirement in Bedford SES ordinance is 40 dB(A) Leq 1 second or 50 dB(C) Leq 1 second, as measured at the property line of adjacent non-participating parcels. Not only are the numbers lower, but the descriptor (Leq 1 second) effectively is more challenging to achieve than PA 233's "hourly average." Furthermore, this measurement in Bedford to the property line rather than the dwelling makes it a much stricter ordinance. Additionally, Bedford solar ordinance considers noise levels surrounding all inverters, with an extra mandate that a double row of evergreen trees with minimum 8 feet height and maximum separation of 10 feet must be within 20 feet of inverters. This requirement is not in PA 233, nor in Convis Township.

Other requirements such as lighting, signage and wiring also vary, but not as much as the above factors.

Table 14: Infrastructure requirements in the PA 233 and Bedford SES ordinance

	PA 233 of 2023	Bedford SES ordinance
Maximum solar panel height	25 feet	15 feet
Fencing	NEC	6 foot high fence with evergreen landscaping to buffer view
Maximum sound	55 average hourly decibels (A)	40 dB(A) Leq 1 second or 50 dB(C) Leq 1 second
Measured from non-participating parcel	Outer wall of dwelling	The property line
Additional Sound Buffer	NA	Double row of 8 feet evergreen trees within 20 feet of the inverters
Lighting	Dark sky-friendly lighting solutions	15 feet lighting rods with possibility of being higher
Signage	NA	One sign per lot, with at least two to six square feet in area
Wiring	NEC	Whichever depth is greater, minimum 6 feet and deeper than drain tile, or NEC

Summary

Overall, Bedford SES ordinance makes it expensive to build solar panels due to the significantly stringent requirements in financial security, landscaping, setbacks, and other requirements, showcasing a strong stance against utility solar projects in this region.

The state-level process is generally favorable for developers, with more relaxed standards of setback, sound, and fencing, though the labor and wage requirements would add expense. However, the biggest challenge is timescale. The law will be effective on 11/29/2024, so the first permit certificate is estimated to be issued no earlier than 2026 Q2. Furthermore, the ambiguity and gray area under state path would pose risks for applicants.

Recommendation

In summary, the Spring Creek project can go through either the state process or the local level ordinance. Local level ordinances include CREO defined in the PA233, and non-CREO local ordinances.

Table 15 compares these options in terms of time, cost and community acceptability. Time refers to the review time of an applicant. Normal cost includes the cost for permitting such as application fee, and cost caused by setbacks, landscaping, noise control, which are common both in state and local regulations. State specific cost is the cost only required in PA 233, including intervenor compensation funds, community benefits payments, and extra labor cost. Community acceptance is assessed by the level of community engagement in the process and how friendly the regulation is to developers.

Table 15: A comparison of approaches to get permitting approval

Factor	Time	Cost		Community Acceptance
		Normal Cost	State Specific Cost	
CREO	Fastest/ 120 days	The lowest	0	Accepted
State	1 year	The lowest	The highest	Least accepted
Bedford	Unknown	The highest	0	Most accepted
Barry	Unknown	Unknown	0	Unknown
Abandon	0	0	0	Most accepted

The CREO process appears to be the most advantageous for developers. A developer can comply with the same regulation as the state, get a permit just within 120 days after application, and does not have to pay state specific costs. The core challenge is the availability. 80% of current local solar ordinances are more restrictive than PA 233[70], and it will take some time for local governments to adopt CREOs. Further, it is unclear that a well-matched local ordinance including additional standards that are common at local but are not required in PA 233, would qualify as CREOs, and so local governments may not be inclined to develop a CREO.

If a CREO is not available, developers must choose between the state process and the local process. As noted in the "Summary" section, the state process is better than the Bedford SES ordinance because compliance with the Bedford SES ordinance is costly, and may be costly even when accounting for the state-specific cost. Barry County, which is responsible for planning and zoning for Johnstown, has no solar ordinance and no prior experience with siting. It is possible that it will adopt an ordinance that is less costly to comply with than Bedford Township's, but it will take the County time to do so. And as a result, it's not clear whether working with Barry County will be cheaper or faster than the state-level process.

Community acceptance, however, may reverse the outcome of the comparison. The state process, led by the Commission, a state agency, is a more centralized approach with high-level decision making. While local governments and immediately adjacent neighbors are allowed to participate as interveners, other community members are allowed to participate in the contested cases only if they are approved as intervenors with a direct interest in the case. This one-size-fits-all approach has sparked wide local opposition. The Township Association, representing 1,240 local units of governments that govern more than 96% of Michigan land area, and serve for more than half of Michigan citizens, strongly oppose PA 233[71]. While local ordinance tailors to the needs and preferences of local communities, and enables developers to directly engage with local stakeholders early, which is seen as a way to minimize local opposition originating from personal interests[72]. Therefore, for a Michigan-based developer who prioritizes community acceptance over other considerations and values its reputation of maintaining long-term relationships with local communities, we do recommend avoiding the state process, which is the least acceptable option for community engagement.

Then, the optimal permitting approach returns to the local process. Apart from CREO and existing local ordinances, community and planning experts propose a new concept: a "workable" ordinance[73]. This kind of local ordinance does not satisfy the definition of a CREO, but enables developers to build viable projects. Developers can use PA 233 as a reference point to negotiate with local governments for adopting a "workable" ordinance though there is time associated with the negotiation process.

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[70] Mills, Sarah, Judy Allen, and Catherine Kaufman. 2024. "MPSC Renewable Energy and Energy Storage Facility Siting Meeting." State of Michigan. https://www.michigan.gov/mpsc/-/media/Project/Websites/mpsc/workgroups/2023-Energy-Legislation/Renewable-Energy-and-Energy-Storage-Siting/Siting-Presentation-3-7-24.pdf?rev=6d3cd63f96fa4bfb90276e15e4f06f4d&hash=F65A48FED040992A2F64122248455EAF.

[71] "Renewable energy siting and permitting – Michigan Townships Association." n.d. Michigan Townships Association. Accessed April 10, 2024. https://michigantownships.org/renewable-energy-siting-and-permitting/.

[72] Susskind, Lawrence, et al. "Sources of opposition to renewable energy projects in the United States." *Energy Policy* 165 (2022): 112922.

[73] Mills, Sarah, and Madeleine Krol. 2024. "What Local Governments Should Know about Michigan's New Renewable Energy Siting Policies." https://graham.umich.edu/media/files/FAQ-How-HB5120-Works.pdf.

The Spring Creek project is located across counties, thus we propose different permitting strategies in the two locations respectively. For Bedford, developers should first assess how costly it is and decide:

a) If it is financially feasible to build solar under the current zoning;
b) How much time they are willing to spend to negotiate with the Township to find a "workable" ordinance, making changes to the most infeasible parts of the zoning.
c) Whether they are willing to undergo the state process with the risk of public backlash;
d) Whether they have to abandon that part of the project for energy generation, and instead use the acreage in this township to preserve farmland and provide ecosystem services.

For the part in Barry County, developers have the following options, in order of priority:

a) Negotiate with the county to see if a CREO is feasible;
b) Assist with the county to adopt a "workable" ordinance that developers are willing to provide compensation beyond the state standard, such as additional setback distances, building buffering and landscaping, and adding additional community benefits;
c) They can go through the state process.

Land Use Area Analysis Through Spatial Mapping

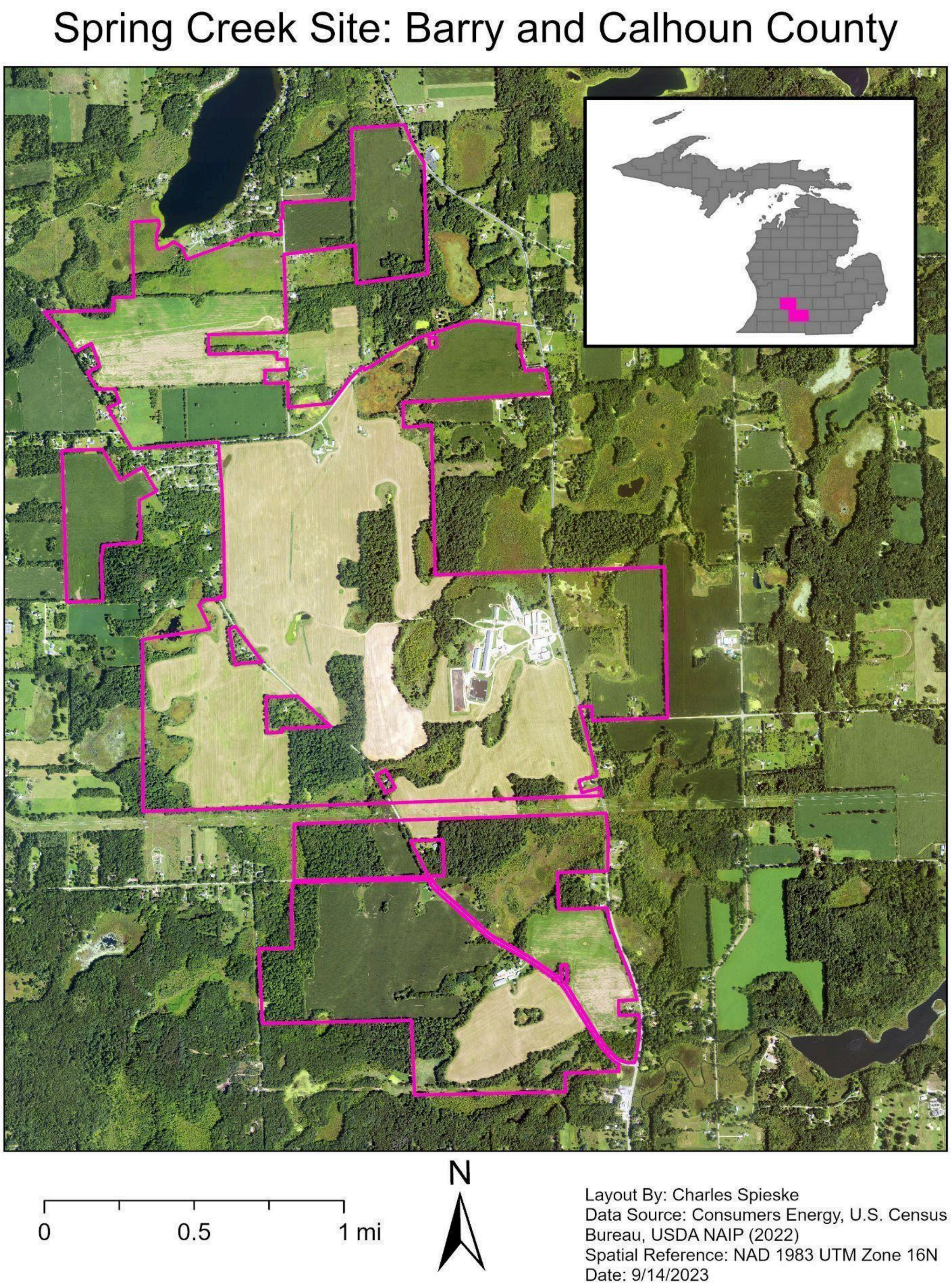
Spatial analysis is a useful tool that can be used to gauge site statistics and properties alongside or in lieu of in-situ work. Most analysis stemmed from base, remotely sensed data that further analyses can build off of – in this case, aerial photography of the site and site boundary shapefiles provided by Consumers Energy represented the initial building blocks. This base was further supplemented by work in geographic information system (GIS) software, namely ArcGIS Pro. GIS is a powerful tool that streamlines the implementation of simpler processes, such as mapping in-situ sampling locations, while also being capable of more intense computations such as image classification and raster calculations. In general, spatial mapping was used to generate and display information about the land that the Spring Creek site encompasses, and to tie this information together in a final suitability analysis. The outputs from this section can be used in tandem with other sections in this report to guide the installation of PV panels on dual-use land and to help visualize the impacts of buffering and local/state policy on the site landscape. The final suitability analysis output acts as a final recommendation for locations at the Spring Creek site that could be best utilized for the implementation of photovoltaics on dual-use land. That recommendation is based on the following categories outlined within this section.

Acquisition of Aerial Imagery and Site Statistics

Aerial Imagery of the Spring Creek site was acquired from the USGS Earth Explorer web tool. The imagery was taken by the USGS National Aerial Imagery Program (NAIP) with a repeat coverage time of no less than 3 years and a 60 centimeter resolution. Aerial imagery in the contiguous United States has numerous benefits over publicly available satellite imagery from programs such as Landsat (U.S.) or Sentinel (EU). Resolution is significantly higher and images are cloud free as the use of planes for imaging allows a choice of weather conditions and flight below the cloud base. Aerial photography often has a limited spectral resolution, especially when compared to hyperspectral programs such as Hyperion, but this is a non-factor for the purposes of this project. Property boundary shapefiles were provided by Consumers Energy. Site Statistics were calculated using ArcGIS Pro as well as web surveys from the USDA National Resources Conservation Service (NRCS). Site maps were created using the NAIP imagery and boundary files (Figure 5) to serve as a reference and for use with later sampling. The Spring Creek site is divided across two counties, with 1,618 acres lying within Barry County (Johnstown Twp) and 435 acres lying within Calhoun County (Bedford Twp).

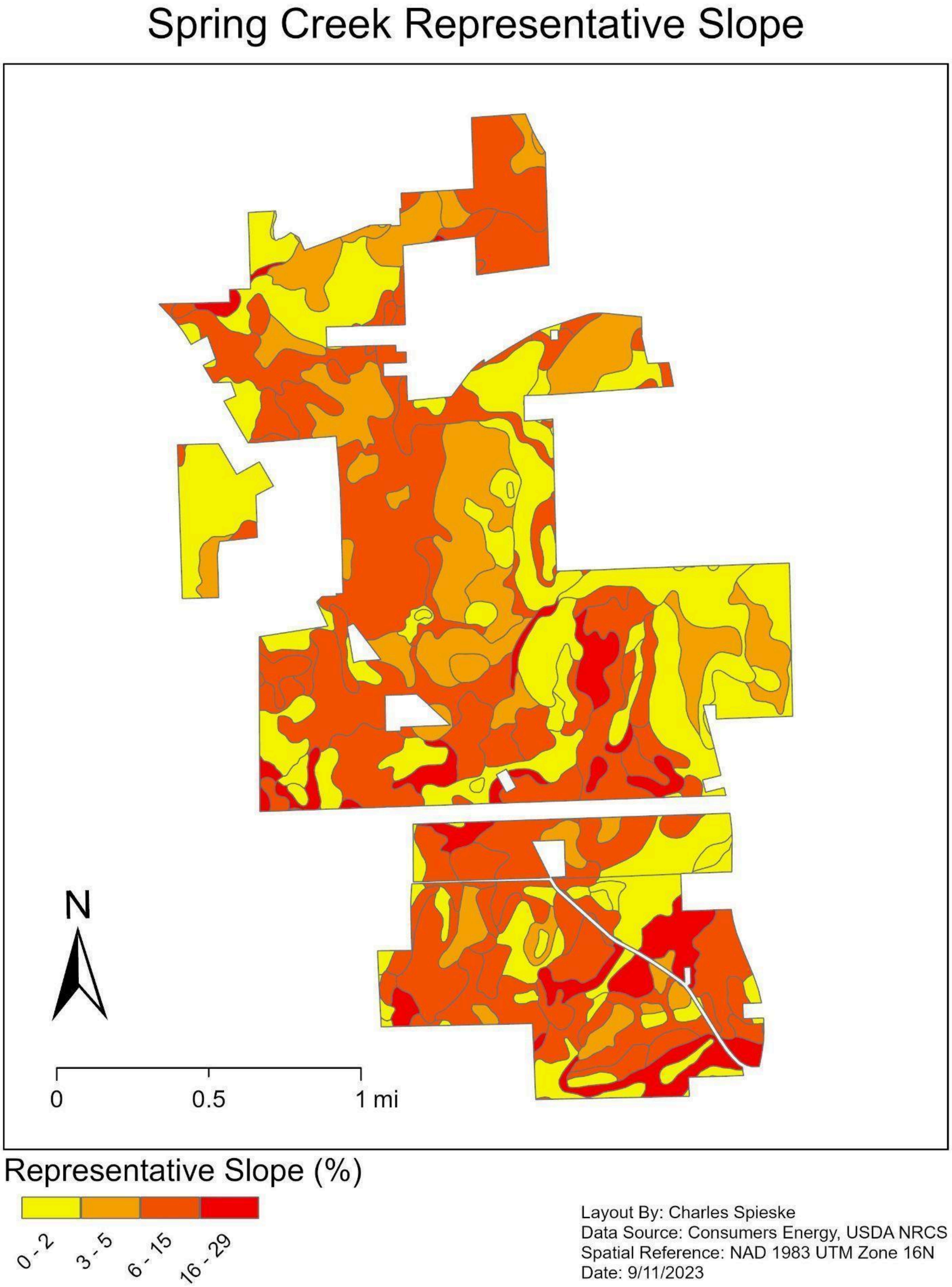
Representative Slope

The site boundary shapefile was put into the USDA NRCS Web Soil Survey (WSS) in order to generate data about land slope. The tabular data from the WSS was then brought into ArcGIS Pro to be converted into spatial data and visualized on a map of the site (Figure 6). Representative slope is expressed as the differential in height between two points in relation to the linear distance between them. A color ramp gradient was used to aid in the visualization of the spatial variability across the site. Slope is an important consideration wherever solar panels are concerned as it can often be a key variable in determining site suitability. Consumers Energy indicated that a 10% slope is the cutoff for areas where photovoltaic panels will be installed.


Spring Creek Site: Barry and Calhoun County

Layout By: Charles Spieske
Data Source: Consumers Energy, U.S. Census Bureau, USDA NAIP (2022)
Spatial Reference: NAD 1983 UTM Zone 16N
Date: 9/14/2023

Figure 5: Map showing NAIP Imagery of Spring Creek site with property boundary in pink.



Layout By: Charles Spieske
Data Source: Consumers Energy, USDA NRCS
Spatial Reference: NAD 1983 UTM Zone 16N
Date: 9/11/2023

Figure 6: Map showing representative slope values across Spring Creek site.

LC/LU Supervised Classification

Four images were combined using the “Mosaic to New Raster” tool in ArcGIS Pro in order to create a complete picture of the Spring Creek site and to prepare for analysis. A supervised land cover / land use classification was performed in ArcGIS Pro in order to determine variation in land surface across the site (Figure 7). Four general National Land Cover Database (NLCD - 2011) classes were chosen for the analysis: 20 - Developed, 40 - Forest, 80 - Planted/Cultivated, 90 - Wetlands. 77 training samples containing known land cover classes were created to be used in the classification. These polygons were evenly distributed across the site in an attempt to capture within-class variations. After running the classification, 500 accuracy assessment points were created using the ground-truth data and randomly placed across the site. These points were then updated with the classified data in order to create a confusion matrix for accuracy assessment (Figure 8). The confusion matrix was created in ArcGIS Pro and plots the accuracy of the ground truth data (columns) vs the accuracy of the classified data (rows). A “kappa” statistic is also computed that indicates the overall accuracy of the classification. Once the accuracy of the classification is checked, the data was used to generate statistical information about the percentage of each land cover and its spatial variability. The total area of the Spring Creek site was found to be 831 hectares, broken down into 21 hectares of developed land (2.6% of total area), 213 hectares of forested land (25.7% of total area), 467 hectares of planted/cultivated land (56.2% of total area), and 130 hectares of wetland (15.5% of total area). This information is synthesized in Figure 11.

In-Situ Sampling and Georeferencing

Soil samples were collected across the Spring Creek site to gather information about soil characteristics (Figure 9). A total of 22 soil cores were collected from the top 6 inches of topsoil (tillage depth). Samples were collected using a punch and then individually bagged for testing. At each sampling location, coordinates were taken to be used for later georeferencing of samples. Most samples were collected on agricultural fields, but three reference samples were taken in forested areas. Once collected, samples were sieved and air dried. Soils were measured for organic matter, strong bray phosphorus, total available phosphorus, exchangeable potassium, magnesium, calcium, cation exchange capacity (CEC), and percent base saturation of cation elements.

Carbon Sequestration Rates

A survey of recent literature was conducted to determine carbon sequestration rates for different types of land cover (Figure 10). Conventional tillage agriculture (practiced at Spring Creek) was found to have no carbon sequestration in the soil and often results in carbon being lost due to tillage [74]. Forested lands were found to have a carbon sequestration potential of 1.94 ton C ha^{-1} $year^{-1}$ [75]. Wetlands had 1.12 ton C ha^{-1} $year^{-1}$ [76]. Conversion of degraded cropland to grassland showed an average carbon sequestration rate of about 0.4 ton C ha^{-1} $year^{-1}$ for a 30 year period [77]. Several other studies show similar rates for conversion of arable land to either perennial grassland or forest: 0.53

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[74] West, T.O ; Marland, G. “Net Carbon Flux from Agricultural Ecosystems: Methodology for Full Carbon Cycle Analyses.” *Environmental Pollution (1987)*, vol. 116, no. 3, Oxford: Elsevier Ltd, 2002, pp. 439–44, doi:10.1016/S0269-7491(01)00221-4.

[75] Ma, Wu ; Domke, Grant M. ; Woodall, Christopher W. ; D’Amato, Anthony W. (2020). Contemporary forest carbon dynamics in the northern U.S. associated with land cover changes. *Ecological indicators*. Elsevier Ltd.

[76] Pendea, I. F. ; Kanavillil, N. ; Kurissery, S. ; Chmura, G. L. (2023). Carbon Stocks and Recent Rates of Carbon Sequestration in Nutrient‐Rich Freshwater Wetlands From Lake Simcoe Watershed (Southern Canada). *Journal of geophysical research. Biogeosciences*. Washington: Blackwell Publishing Ltd.

[77] Preger, A. C. ; Koesters, Raimund ; Du Preez, C. C. ; Brodowski, S. ; Amelung, W. (2010). Carbon sequestration in secondary pasture soils; a chronosequence study in the South African Highveld. *European journal of soil science*. Oxford, UK: Wiley-Blackwell on behalf of the British Society of Soil Science, and the National Societies of Soil Science in Europe.

ton C ha^{-1} $year^{-1}$ average for 120 years, 0.37 ton C ha^{-1} $year^{-1}$ average for 118 years [78], 0.51 ton C ha^{-1} $year^{-1}$ average for 35 years [79].

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[78] POULTON, P. R. ; PYE, E. ; HARGREAVES, P. R. ; JENKINSON, D. S. (2003). Accumulation of carbon and nitrogen by old arable land reverting to woodland. *Global change biology*. Oxford, UK:

[79] Goulding, K.W.T. & Poulton, P.R. 2005. The missing link.Geoscientist,15, 4–7.

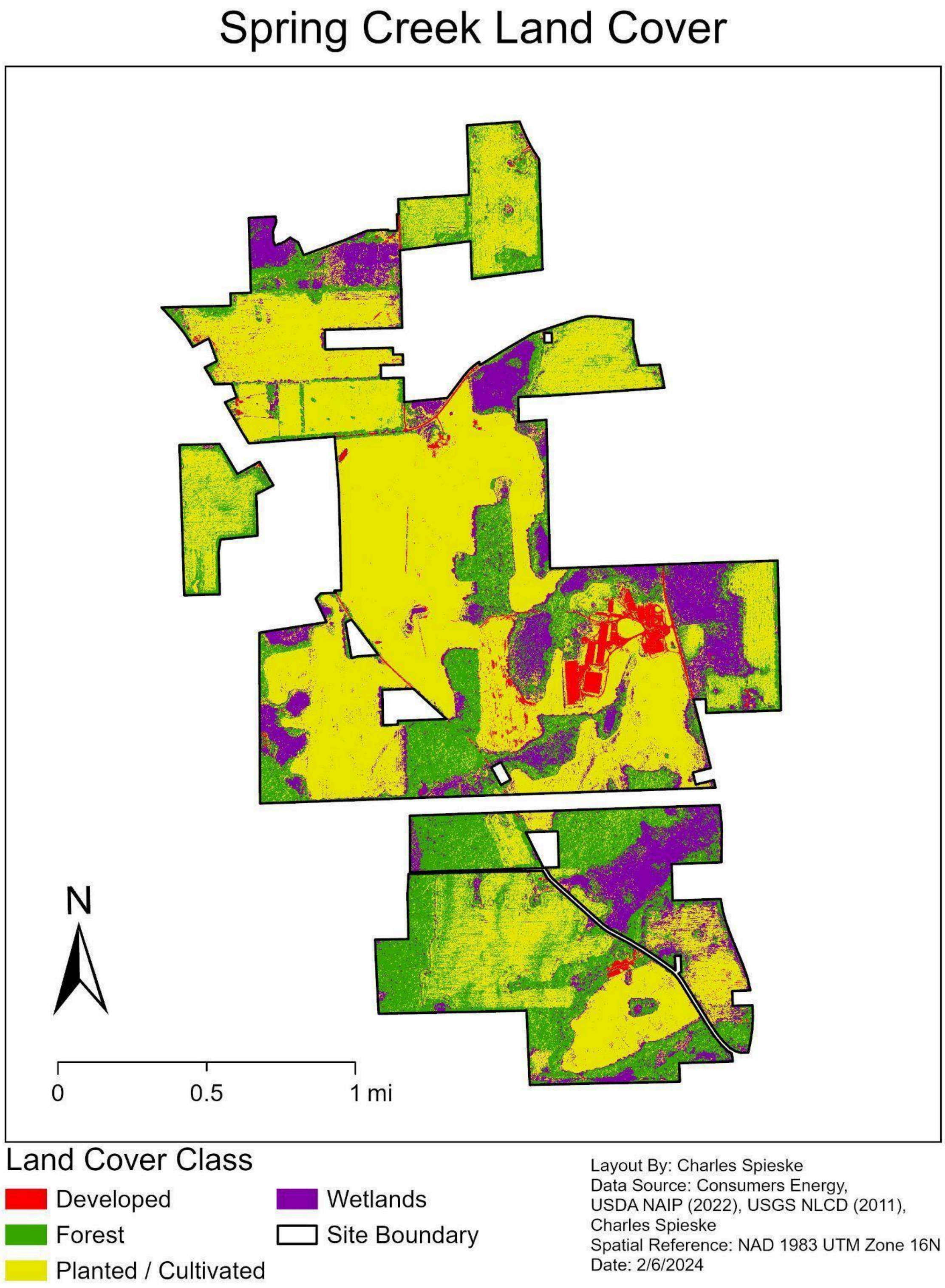
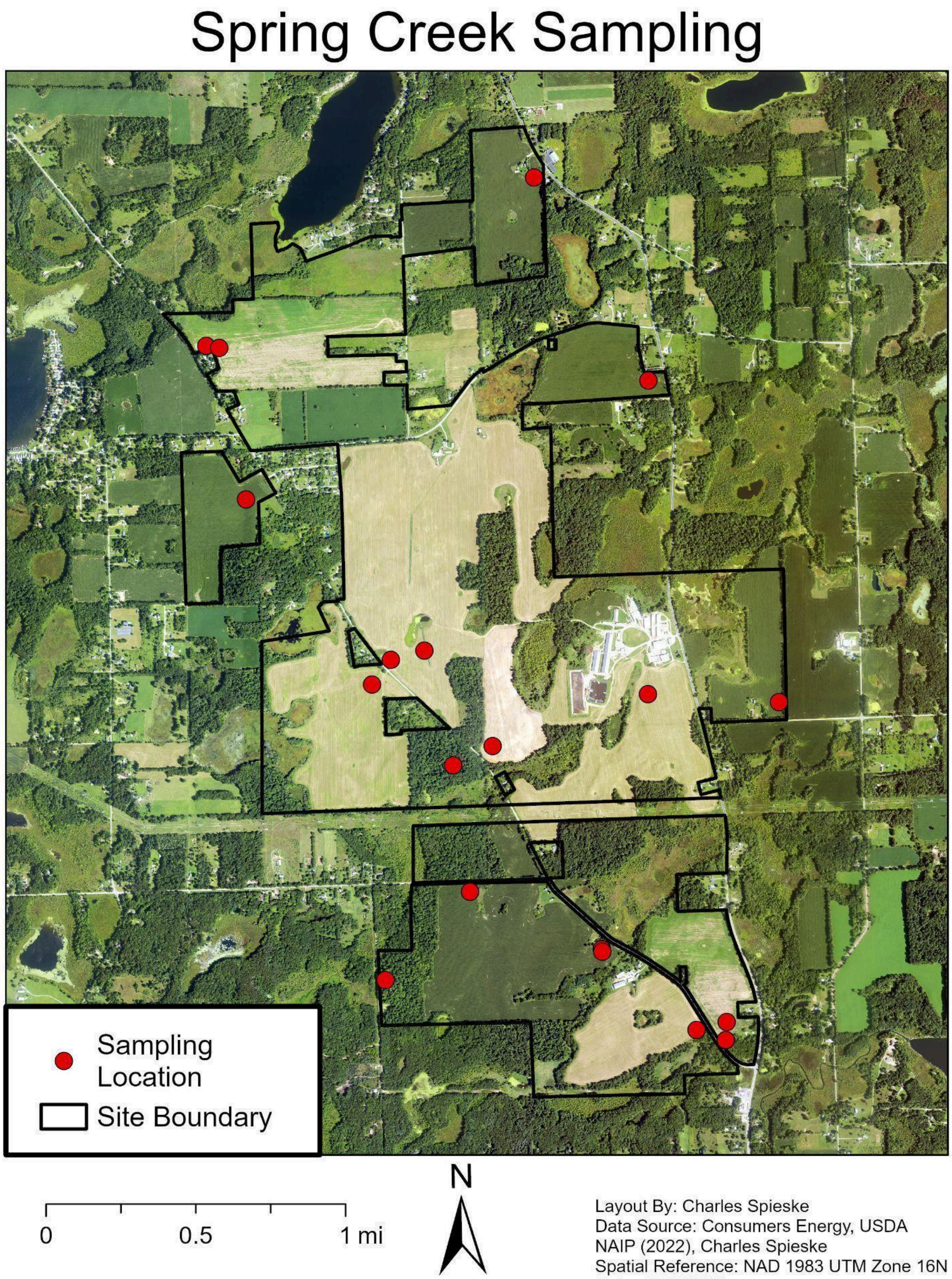


Figure 7: Map showing supervised land cover classification of Spring Creek site.

ClassValue	C_20	C_40	C_80	C_90	Total	U_Accuracy	Kappa
C_20 - Developed	10	0	3	0	13	0.77	0
C_40 - Forest	0	70	28	0	98	0.71	0
C_80 - Planted / Cultivated	0	10	340	1	351	0.97	0
C_90 - Wetlands	0	3	12	26	41	0.63	0
Total	10	83	383	27	503	0	0
P_Accuracy	1	0.84	0.89	0.96	0	0.89	0
Kappa	0	0	0	0	0	0	0.74

Figure 8: Confusion Matrix showing accuracy of land use classifications and kappa value of 0.74 (74%).



Layout By: Charles Spieske
Data Source: Consumers Energy, USDA NAIP (2022), Charles Spieske
Spatial Reference: NAD 1983 UTM Zone 16N
Date: 11/12/2023

Figure 9: Map showing soil sampling locations in red at Spring Creek site.

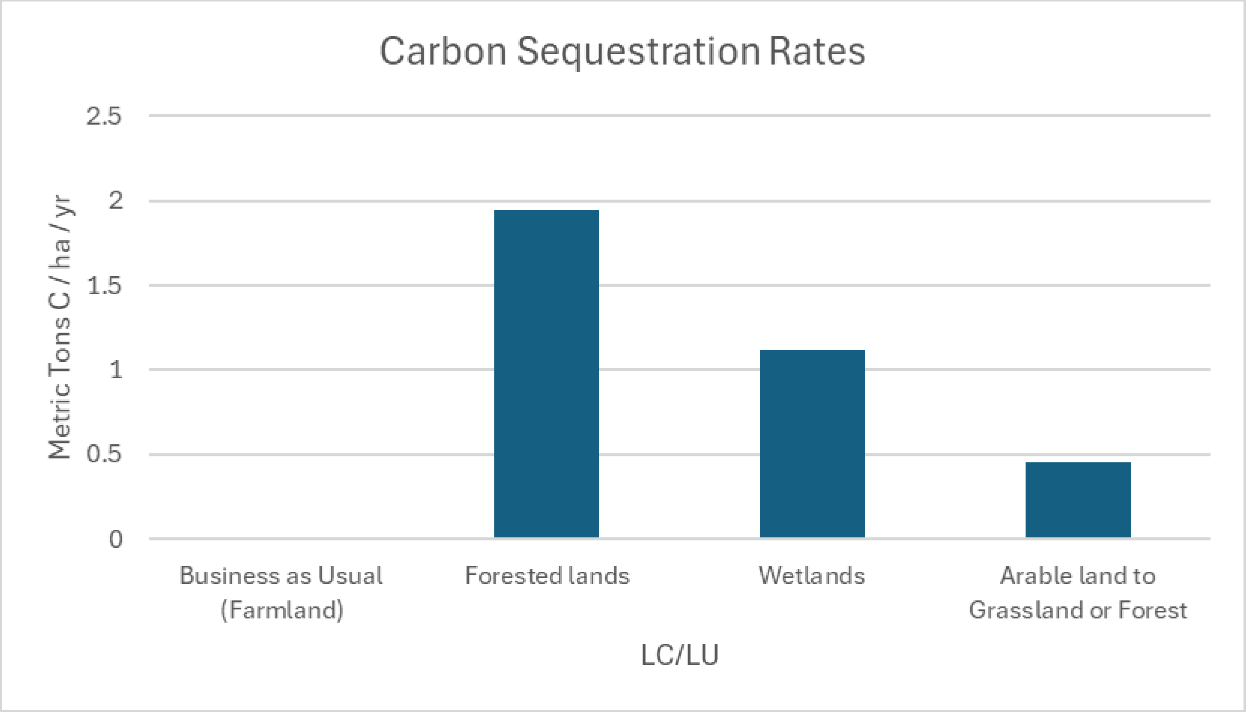


Figure 10: Graph of literature-derived C-seq rates by land cover or land use.

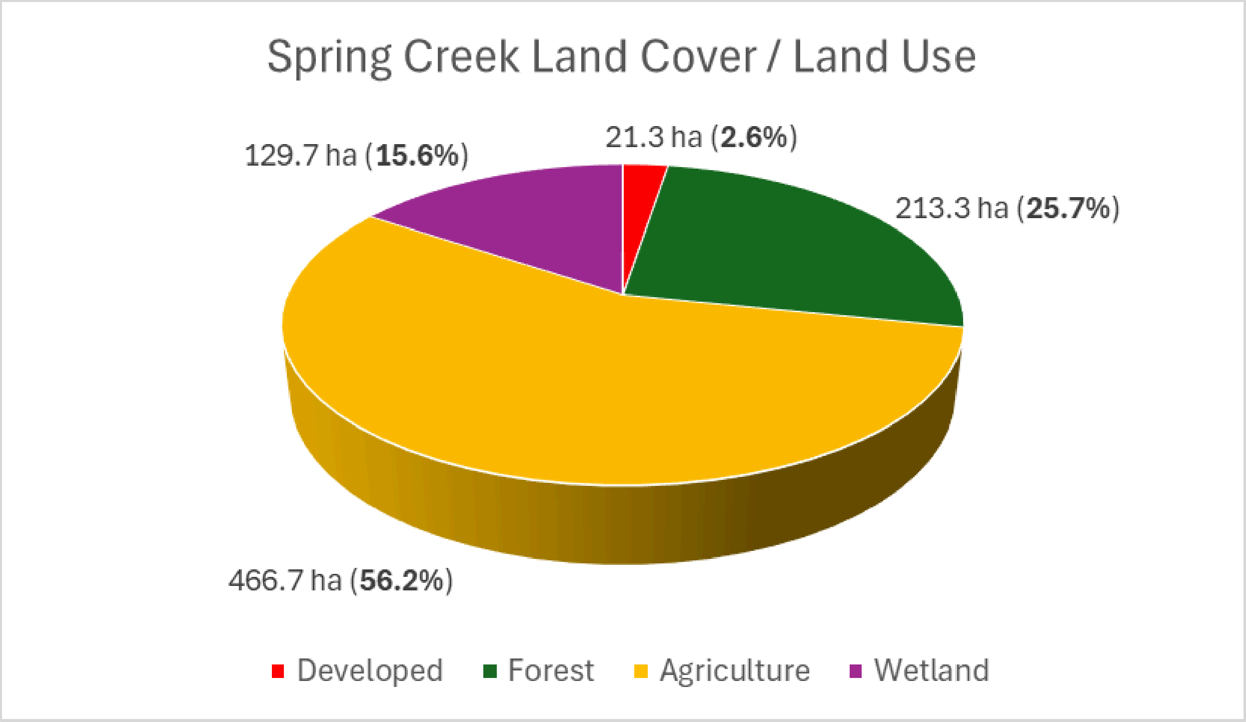


Figure 11: Pie chart of land cover / land use at Spring Creek from supervised classification.

Buffer Zone Calculations

Due to the uncertain climate surrounding regulations for solar installations and differences between these regulations at the state and local levels it is difficult to pin down the exact amount of buffering needed at the Spring Creek site. Instead, it could be helpful to calculate a multiplier value that can be used to estimate the amount of carbon sequestration in potential buffer space per unit length of buffer. Values were calculated for a 50 foot wide buffer as described in Michigan state legislature (MI_HB5120), and a 300 foot wide buffer as described in Bedford Township's solar ordinance (Figure 12). The carbon sequestration rates for changing arable land to planted perennials (trees or grasses) from the previous section were averaged to create a single value for calculation (0.45 ton C ha^{-1} $year^{-1}$). The multiplier for the 300 foot wide buffer was calculated to be 1.3E-3 ton C $year^{-1}$ for every foot of buffer length. The multiplier for the 50 foot wide buffer was calculated to be 2.1E-4 ton C $year^{-1}$ for every foot of buffer length.

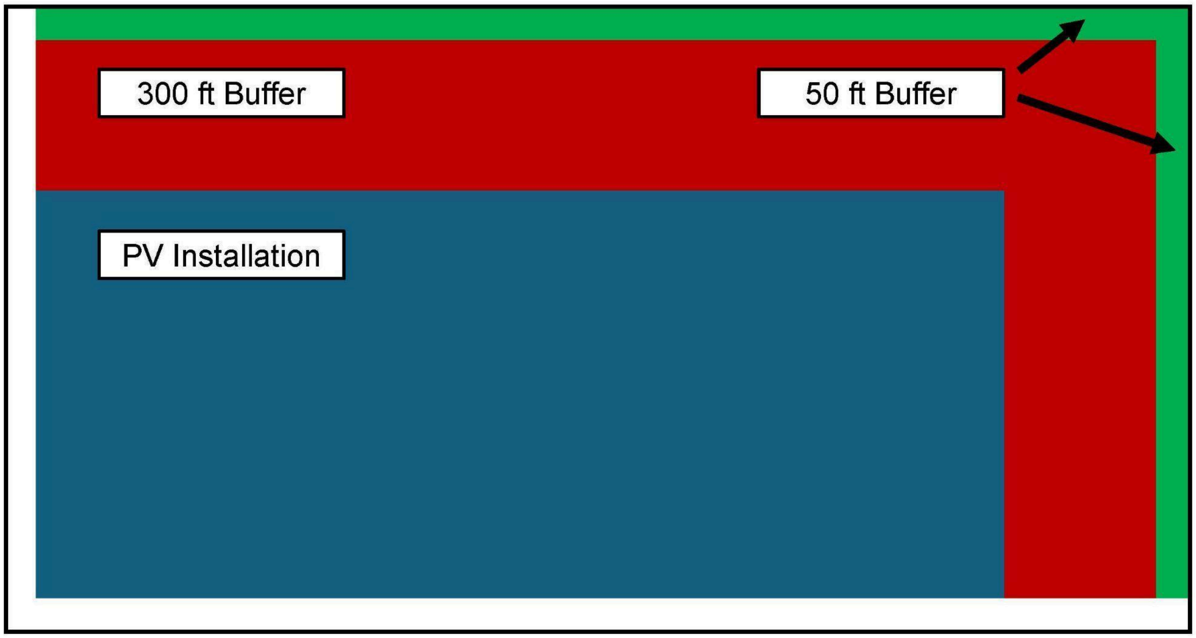


Figure 12: Simple graphic showing one example of a site layout at Spring Creek.

Final Suitability Analysis

A final suitability analysis for the Spring Creek site was conducted, combining recommendations from the representative slope calculations, soil sampling, and supervised land use classification. Soil slope polygons retrieved from the USDA NRCS data were converted into a raster for input into the suitability calculations. All slope raster cells were subtracted from the maximum slope value to represent the inverse slope. This ensured that higher slope values would negatively affect the final calculation - replicating the need for relatively flat land in solar development. From the soil sampling results, soil pH [80] and cation exchange capacity (CEC) [81] were determined to be good indicators of

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[80] Smith, Jeffrey L ; Doran, John W. (1997). Measurement and Use of pH and Electrical Conductivity for Soil Quality Analysis. Madison, WI, USA: Soil Science Society of America.

[81] Kaufman, Martin M. ; Steffen, Jacob M. ; Yates, Katie L. (2020). Sustainability of soil organic matter at organic mixed vegetable farms in Michigan, USA. *Organic agriculture*. Dordrecht: Springer Netherlands.

soil health and used as inputs. All data from soil sampling were originally collected as points, and the data was interpolated to rasters using inverse distance weighted interpolation (IDW) with a power value of 2. This is known as inverse distance squared weighted interpolation. Two soil health rasters were created with IDW, one representing CEC and another to represent soil pH. The soil pH raster was inverted using the same process as most plants prefer a slightly-acidic to acidic soil pH. Areas of planted or cultivated land use as determined by the supervised classification were used as the final input into the suitability analysis, assumptions were made that PV panels would only be installed on previously disturbed, agricultural land. All four rasters were stretched to a range of values from 0 to 100 so that they had the same relative scale. The four factors (Slope, CEC, pH, Land use) were used in a calculation to create an index with the following weighting:

$$0.3 * \text{“Slope \%”} + 0.3 * \text{“Land Use”} + 0.2 * \text{“CEC”} + 0.2 * \text{“pH”}$$

Slope and land use were given higher weights due to those being main commercial determinants for PV installation, while CEC and pH are ancillary benefits associated with dual land-use. The created average weighted index gives a score from 0-100 across the Spring Creek site (Figure 13**)**. Higher values indicate a greater level of suitability for land use focusing on both solar power and ecosystem services.

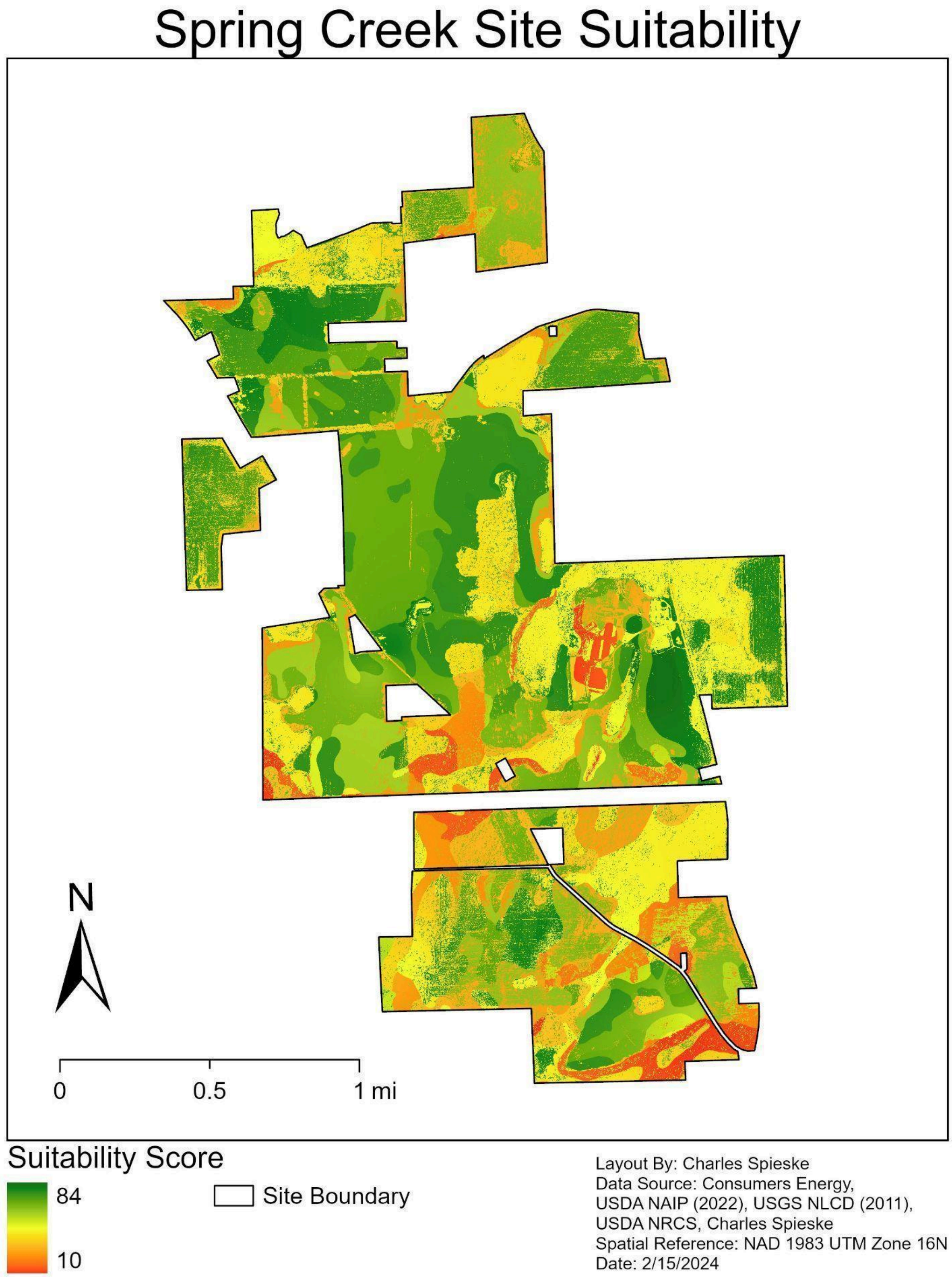

Figure 13: Final site suitability map output for dual-use solar installations at Spring Creek.

Levelized Cost of Electricity

An important metric for evaluating the economic impact of any dual-use land synergy is the levelized cost of electricity (LCOE) which calculates the cost of electricity per unit, such as $/MWh. LCOE takes into account the overall costs of an energy generation facility, including both capital and operating costs, and the expected generation output of the facility over its lifetime. A simplified version of an LCOE equation is shown below.[82]

$$\text{LCOE} = \frac{\text{Total life cycle cost}}{\text{Total lifetime energy production}}$$

At a high level, the equation shows that strategies that will either increase the energy generation of a facility or decrease the costs associated with the project, whether that be capital investment or operation and maintenance (O&M), will decrease the overall LCOE of the electricity generated by the facility. Consequently, modeling the LCOE is an important step in analyzing the potential of a dual land use strategy.

The ultimate LCOE calculation for a solar farm will be significantly more complicated than the equation above, and will have to incorporate additional factors such as the PV panel degradation rate, site permitting costs, operational and installation labor costs, and internal staffing expenses, among others. However, to understand how cost would be affected by different land use strategies at Spring Creek, and more broadly how LCOE analysis can be used at any future solar farm site, we looked at two case studies: reducing mowing O&M costs and increasing ground reflectance.

Case Study: O&M costs for dual-land use scenarios

To demonstrate the potential of LCOE analysis for evaluating dual-land use scenarios, a streamlined approach was taken to consider just one aspect of the LCOE equation, fixed O&M costs. Of these costs, Consumers Energy ranked mowing costs as a high priority area for reduction. Therefore, determining how a land use strategy impacts mowing costs can offer insight into how the LCOE would change. As detailed in the Appendix, the yearly mowing costs per acre of solar farm are dependent on the labor cost of mowing an acre of land, the variable costs of fuel and consumables of mowing an acre of land, and the number of times an acre of land needs to be mowed each year. Some of the land-use strategies described above will affect these parameters. To evaluate this, the mowing LCOE costs for the business as usual scenario over a 25 year lifetime was first calculated, and was found to cost $2.31/MWh. It is clear how there is potential synergy with ecosystem services here–if Consumers Energy were to plant ground cover that improved ecosystem health and also reduced mowing costs, it could benefit project costs and ecosystem health. One such strategy would be to plant a pollinator mix underneath and between the panels. These mixes generally only need to be mowed about once every three years, and therefore significantly reduced the LCOE mowing costs to $0.19/MWh. We can also imagine removing the need for mowing entirely by implementing pasture underneath and between all panels. In this case, livestock would do all the labor or mowing and there would be no mowing LCOE lifetime costs. Of course, the acquisition costs and other capital or O&M expenses as a result of each of these strategies would also need to be taken into

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[82] Philbin, S. P., & Hsueh-Ming Wang, S. (2019). Perspectives on The Techno-Economic Analysis of Carbon Capture and Storage. *Journal of Technology Management & Innovation*, *14*(3), 3–17

account for a final evaluation. For example, the cost of acquiring the livestock for grazing means that the overall LCOE of a pasture strategy will be greater than zero, though it may be very small depending on whether the cost of maintaining pasture is offset by the benefit of raising animals on the forage. Ultimately, once final details for Spring Creek are decided, LCOE provides a framework for evaluating the net impacts of a land-use strategy, both at Spring Creek and for any future solar farm site.

Table 16: Evaluation of LCOE Implications for Panel Land-Use Strategies

Panel Land Use Scenario	Mowing cost for 25 year lifetime ($/MWh)
Ditch Mix (BAU)	2.3114
Pollinator Mix	0.1926
Pasture	0

Evaluation of how land-use strategies for the site buffer regions would impact LCOE are less straightforward. Because LCOE is dependent on the amount of energy produced over the plant's lifetime, the costs of buffer region strategies depend on the overall site layout's generation potential. This is convoluted with the buffer zone size; as buffer region width decreases there is more space for solar panels, though that in turn would increase capital costs for the purchase of the panels. Ultimately, it will depend on Consumers Energy's site preference and company priorities. Qualitatively, we can expect that choosing vegetation that reduces the overall area needed for the buffer regions would also decrease the yearly mowing costs. This could justify an increased purchase price of the buffer vegetation. There is also the potential for a synergy with ecosystem benefits because any extra buffer region width could also be used for pasture. Finally, any forest or wetland regions will not need to be mowed and would not increase the mowing LCOE costs. These regions can sequester carbon, as described in the section above, and so could reduce LCOE if certifiable carbon credits are produced on this land.

Case Study: Energy generation implications from intentional albedo modification

A second way to reduce LCOE by ecosystem services is through albedo modification. Planting crops around the solar panels that reflect more of the sun's radiation would increase the radiation reaching the photovoltaic (PV) panels. In other words, the reflected radiation as detailed in the figure below can be seasonally tuned based on the type of crop planted.

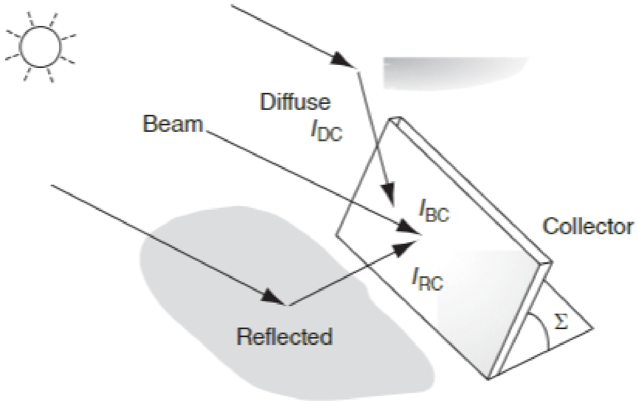

Figure 14: The three types of radiation (beam, diffuse, and reflected) for photovoltaic energy production. Although the bulk of energy comes from beam radiation, increasing reflected radiation through crop albedo could increase energy generation for a solar farm site. Figure from[83]

The idea of increasing energy generation through the increase of albedo is not novel. Multiple studies have shown the gain in energy due to albedo, which is particularly important for bifacial panels. As seen in Figure 15, not only does a bifacial panel produce a higher amount of energy at a given albedo, but as albedo increases, the bifacial gain also increases. Because bifacial panels are becoming the industry standard for utility-scale solar,[84] investments in improving ground reflectance could have an outsized impact on PV energy generation. Consumers Energy also plans to use bifacial panels for Spring Creek and other future sites.

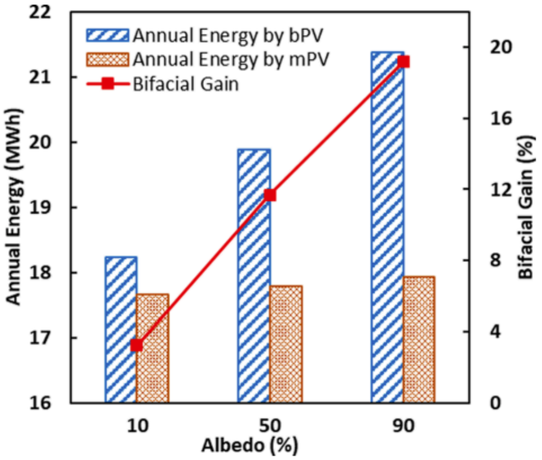

Figure 15: Albedo can be especially impactful for bifacial PV panels, which are growingly used in utility-scale solar. This figure shows how for varying values of albedo, the annual energy generation for a bifacial PV panel (bPV) and a monofacial PV panel (mPV) increases. As shown by the right axis, the bifacial gain, or the increase in generation due to the additional side of a bifacial panel, increases with a larger albedo. This figure was taken from an analysis for panels manufactured by Trina Solar.[85]

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[83] Masters, Gilbert M.. Renewable and Efficient Electric Power Systems, John Wiley & Sons, Incorporated, 2013. ProQuest Ebook Central, http://ebookcentral.proquest.com/lib/umichigan/detail.action?docID=1207615

[84] https://www.trinasolar.com/us/resources/blog/why-bifacial-modules-are-rise-utility-scale-solar-installations

[85] C. Ghenai et al. Solar Energy 223 (2021) 44–53.

Similarly, research has been conducted to understand the albedo of different surface materials. Gul et al recorded the albedo of different materials, including grass, sand, and white pebbles, to understand how it would affect solar energy generation.[86] In particular, they emphasized how this can have an impact on days with clouds, which is especially relevant to Michigan and points to the potential for surface albedo modification to have significant impact for utility-scale solar for Consumers Energy in Michigan. While this study did not focus on different crops for their albedo measurements, Kala et al assessed crop albedo enhancement's ability to reduce temperatures during heat waves.[87] They demonstrated that crops can have significant large-scale impacts on albedo. Genesio et al studied the reflectance of crops with less chlorophyll content.[88] They argue that planting crops with less chlorophyll could be a method of solar radiation management. In their earlier work, they show that the Minnegold soybean variety, which has much lighter leaves than the commercial Eiko soybean variety, displays higher surface reflectance.[89] Consumers Energy has the opportunity to tie together these findings: if albedo impacts energy generation, crops have been shown to impact land albedo, and certain crops can be tailored to increase albedo, there is a clear potential for synergistic crop planting in solar farms to improve solar generation on bifacial PV panels.

To evaluate the potential for albedo modification for a Consumers Energy solar farm, a sensitivity analysis of albedo on energy generation was conducted. NREL's PVWatts tool was used to model an acre of solar farm with bifacial, single-axis tracking panels at Spring Creek with varying values for albedo. The monthly energy generation with no albedo modification (the albedo values provided by the National Solar Resource Database (NSRDB)) was calculated and is represented by the bars in Figure 16 below. As expected, the summer months produce the most amount of energy. The albedo values were then varied to represent a range of ground treatments available in the literature: 0.75 for aluminum foil, 0.56 for white pebbles, 0.37 for sand, and 0.19 for grass.[90] As a simplification, alternative albedo values to those provided by the NSRDB were taken to be constant throughout the year. Additional details on model parameters can be found in Appendix A. The percent increase in monthly generation due to each albedo are plotted as lines in Figure 16. As seen in the figure, artificially modifying the albedo decreases, rather than increases, energy generation in the winter months. This is likely due to the snow in the winter, which has a high albedo. The modified albedo otherwise increases energy generation in the spring, summer, and fall. This trend aligns well with the growing season of a crop; it is opportune that the greatest potential for impact from albedo modification is during the months in which a crop could be present. Although these ground treatments are not those evaluated for ecosystem benefits, this nevertheless demonstrates the potential for purposeful albedo modification through intentional crop choice to increase solar energy generation.

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[86] Gul, M., Kotak, Y., Muneer, T., & Ivanova, S. (2018). Enhancement of Albedo for Solar Energy Gain with Particular Emphasis on Overcast Skies. *Energies*, *11*(11), 2881. https://doi.org/10.3390/en11112881

[87] Kala, J., Hirsch, A. L., Ziehn, T., Perkins-Kirkpatrick, S. E., De Kauwe, M. G., & Pitman, A. (2022). Assessing the potential for crop albedo enhancement in reducing heatwave frequency, duration, and intensity under future climate change. *Weather and Climate Extremes*, *35*, 100415. https://doi.org/10.1016/j.wace.2022.100415

[88] Genesio, L., Bassi, R., & Miglietta, F. (2021). Plants with less chlorophyll: A global change perspective. *Global Change Biology*, *27*(5), 959–967. https://doi.org/10.1111/gcb.15470

[89] Genesio, L., Bright, R. M., Alberti, G., Peressotti, A., Delle Vedove, G., Incerti, G., Toscano, P., Rinaldi, M., Muller, O., & Miglietta, F. (2020). A chlorophyll-deficient, highly reflective soybean mutant: Radiative forcing and yield gaps. *Environmental Research Letters*, *15*(7), 074014. https://doi.org/10.1088/1748-9326/ab865e

[90] Gul, M., Kotak, Y., Muneer, T., & Ivanova, S. (2018). Enhancement of Albedo for Solar Energy Gain with Particular Emphasis on Overcast Skies. *Energies*, *11*(11), 2881. https://doi.org/10.3390/en11112881

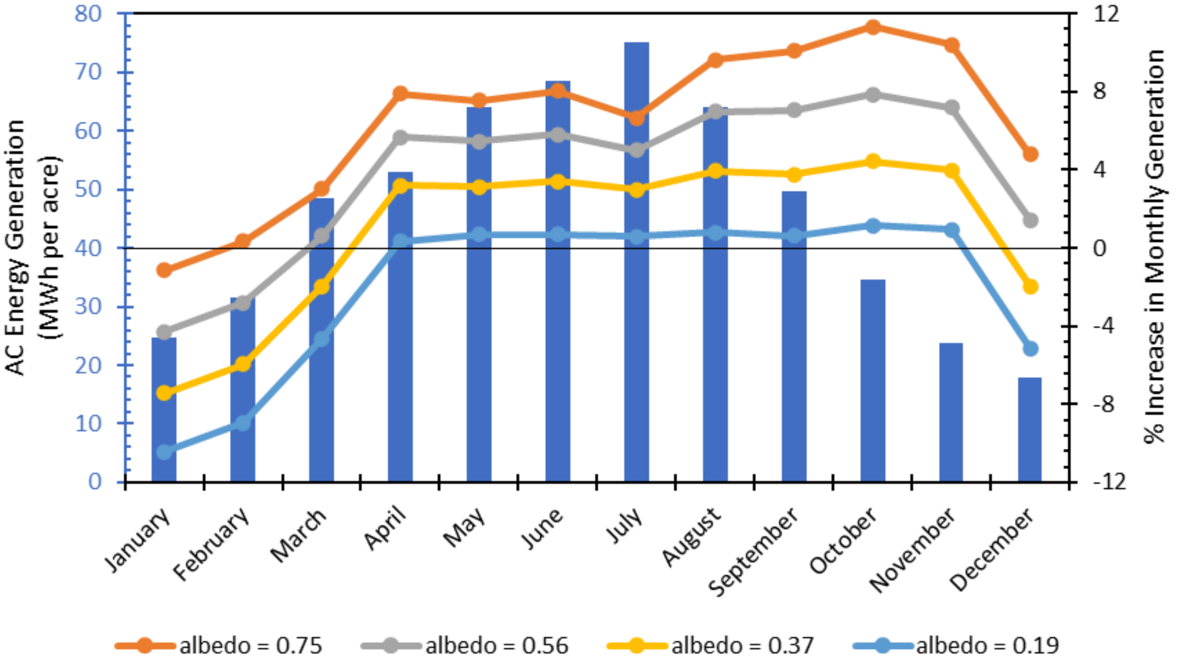

Figure 16: The percent increase in energy generation due to albedo modification aligns with the typical growing season of a crop, suggesting intentional crop choice can increase annual energy generation. Albedo values represent aluminum foil (0.75), white pebbles (0.56), sand (0.37), and grass (0.19).

It is clear that albedo modification through intentional ground cover choice can increase energy generation at Spring Creek and therefore has the potential to lower the site's LCOE. However, the ultimate impact of albedo modification on LCOE will depend on other site characteristics. The height of the panels, for instance, is important. If the height of a crop that would increase albedo is greater than the desired panel height, Consumers Energy would have to increase the panel height which would incur additional capital costs. Additionally, as illustrated in the above example, O&M costs have an impact on LCOE. Planting a low-chlorophyll soybean variety, for example, may increase energy generation but significantly increase maintenance costs, and therefore may not be a viable option. The net outcome of either of these scenarios, as well as future scenarios, can be determined by an LCOE analysis, once the site layout and other details of Spring Creek are determined.

Performing sensitivity analysis of LCOE for different land-use strategies can be an essential analysis tool when determining which dual-land use method to pursue. It is important to note that LCOE focuses solely on quantifiable operational and capital costs and does not factor positive or negative externalities into overall cost. The following analysis method demonstrates alternative ways to take into account societal impacts of any potential dual-use land strategies.

Social Economic Cost-Benefit Analysis (SCBA)

SCBA Introduction

A SCBA is a systematic framework used to evaluate the social impacts and welfare implications of projects, policies, or programs. While a SCBA may be used in various sectors and disciplines, for the purposes of this paper, the impact of a large-scale solar installation on prior farmland in the Midwest and Northeastern United States growing regions 5-6 will be analyzed. This involves assessing the social costs and benefits associated with various categories and the relevant factors considered in each category. Then, these are compared to determine the overall desirability and feasibility of a particular course of action.

Some of the influential concepts of SCBA date back to 1920 when British economist Arthur Cecil Pigou wrote "*The Economics of Welfare*."[91] Though this book focused on economic welfare and market externalities, the ideas were foundational. Later, economists such as Harold Hotelling, Paul Samuelson, and Kenneth Arrow made instrumental contributions to the theory of welfare economics and Cost-Benefit Analysis (CBA), laying the groundwork for the consideration of social impacts in decision-making.[92][93][94] It wasn't until 1969 when a Yale University seminar emphasized the need for economic investors to evaluate the ethical obligation to society when developing large scale projects, thereby precipitating the lawful duty of government on Social Impact Assessment (SIA), a close link to SCBA. The National Environmental Policy Act (NEPA) exponentially increased the use of SIA, and while companies began to assess the financial impact, the SCBA commensurately increased.[95]

SCBA offers several advantages to decision-makers. It provides a holistic and comprehensive assessment of economic, social, and environmental impacts in multi-directional relationships. By aligning values of the project stakeholders and society, it allows for informed determination from differing alternatives to be quantified and evaluated for a potential return on money invested from areas often under-evaluated or overlooked. Evaluation of all areas could mitigate or lessen project risk for current investments and increase future long-term viability and project success. Identifying projects that yield the highest net benefits to society efficiently allocates resources efficiently, maximizes social welfare, and gives potential investors confidence that social justices are being considered. Lastly, it promotes transparency and accountability by making explicit comparisons of stakeholders and historical approaches.

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[91] Pigou, A. C., "The economics of welfare." Macmillan and Co., Limited, London, 1938.

[92] Franco, Marco P.V. ; Gaspard, Marion ; Mueller, Thomas, "Time discounting in Harold Hotelling's approach to natural resource economics: The unsolved ethical question," *Ecological economics*, vol. 163. Elsevier B.V, pp. 52–60, 2019.

[93] Puttaswamaiah, K. (2002). Paul Samuelson and the Foundations of Modern Economics (1st ed.). Routledge. https://doi-org.proxy.lib.umich.edu/10.4324/9781351324809

[94] "Handbook of Mathematical Economics. Vol. 3." North Holland Imprint, [Place of publication not identified], 1986.

[95] [104] J. B. Jacquet, "A Short History of Social Impact Assessment," Headwaters Economics, Nov. 2014. DOI: 10.13140/RG.2.1.1470.5686

SCBA Scope

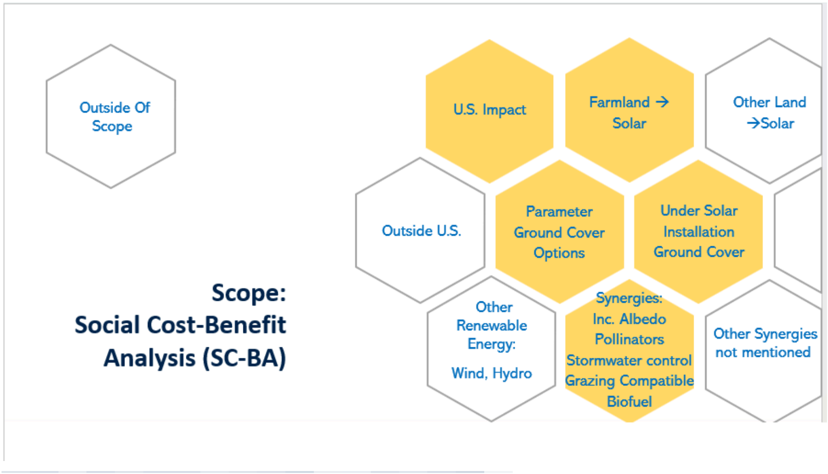

Figure 17 SCBA Scope

The topic of solar installation can be quite complex and multivariate; therefore, a well-defined scope of the analysis is imperative. Determining how to define scope of solar installation, though, requires deliberation because the installation of solar has potentially global impact. Accordingly, it would be remiss not to mention the potential negative global externalities involved in the mining of metallurgical-grade silicon (MGS) and necessary materials for solar installations, which occur mostly outside the United States.[96] Many humanitarian rights activists have shown specific concern for parts of Xinjiang, China's role in mining, though investigations have not been conducted by the International Criminal Court (ICC) to confirm these allegations and China's ambassadors deny all accusations.[97][98][99] Indeed, solar installations also have the potential to impact positive externalities globally such as economic markets of trade. However, the scope of this project will focus on the United States of America and specifically those communities closest to the solar installations.

As stated previously, only solar installations on prior farmland are considered, as this paper focuses on synergic opportunities ecosystem services provide on solar farms. Refining this category in more detail are specifics of the solar farm into sub-categories evaluated.

The first sub-category evaluated is screening options for the outside perimeter of the solar farm. This topic has been of high interest due to some community opposition to solar in certain geographic regions due to perceived aesthetic appeal. From this perspective, aesthetic impact of a solar installation can be related to a visual disturbance due to the large size, incongruous man-made industrial structure taking up the space of nature, blockade to distant scenic beauty beyond the land

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[96] Nick Holdstock. China's Forgotten People : Xinjiang, Terror, and the Chinese State. I.B. Tauris, 2015. EBSCOhost, search.ebscohost.com/login.aspx?direct=true&db=e000xna&AN=1056406&site=ehost-live&scope=site. China's Forgotten People : Xinjiang, Terror and the Chinese State (umich.edu)

[97] Hoffs, Charlie. (2022, Oct 19). "Mining Raw Materials for Solar Panels: Problems and Solutions" Source. [Online]. Available: https://blog.ucsusa.org/author/charlie-hoffs/. Accessed: April 22, 2024.Mining Raw Materials for Solar Panels: Problems and Solutions - Union of Concerned Scientists (ucsusa.org)

[98] Gunter, Joel. (2021, June 10). "China has created a dystopian hellscape in Xinjiang, Amnesty report says." Source. [Online]. Available: https://www.bbc.com/news/world-asia-china-57386625. Accessed: April 22, 2024.China has created a dystopian hellscape in Xinjiang, Amnesty report says (bbc.com)

[99] (2022, May 24). "Who are the Uyghurs and why is China being accused of genocide?" Source. [Online]. Available: https://www.bbc.com/news/world-asia-china-22278037. Accessed: April 22, 2024.Who are the Uyghurs and why is China being accused of genocide? - BBC News

of the installation, and glare.[100] One approach utilities have tried to gain community acceptance is to place evergreens or perceived aesthetically pleasing plants and trees on the outside perimeter of the installation, blocking neighbors and passers-by from view of the solar panels. In these cases, the attraction of both aesthetics and high-density rating are the key indicators social impact measure, therefore are weighted more heavily.

Other indicators for perimeter plantings, besides density, deserve attention. The height of the plant must be tall enough for community acceptance, but short enough to reduce shading on solar panels. Any shading could cause a negative effect of reducing power capacity. As with height, the plant spread diameter and cost were evaluated for dollars per linear foot covered.

Whether the plant had invasive capabilities, insect attraction, and affinity for disease where these would cause negative externalities needed to be determined to avoid high-risk assessment in these areas. Additional social benefits considered were ratings for aesthetically pleasing (see SCBA Guidelines, Methods, and Assumptions), bioenergy, nutrient improvement ability, and carbon sequestration.

Three grasses, and six tree options were evaluated and compared for solar screening around the perimeter. The grasses included Saccharum Ravennae, Giant Miscanthus, and Arundo Donax (giant reed). The traditional perimeter plant options were tested next to these options and included Arbor Vitae, White Spruce, Eastern Red Cedar (Juniperis Virginiana), and the Tulip Tree. Additional trees considered are American hazelnut and poplar.

The second subcategory analyzed was ground cover under a solar panel installation. Solar land-use uptake is another public concern. Even amongst environmentalists, the topic of solar land alteration or disruption provokes debate. This is why solar synergies residing on current farmland are of high interest. Finding ways to have multiple purposes on one piece of property can bring both aesthetic appeal and congruence to prior use, adding an advantage to solar farm management.

A good solar ground cover should increase albedo and maintain a minimum height to reduce shading, thereby minimizing the potential decrease in power capacity. Like screening options for the outer perimeter of the solar installation, native species are preferred for their ecosystem benefits. Additionally, factors such as aesthetic appeal, bioenergy potential, nutrient improvement, and carbon sequestration are included as indicators for determining a good ground cover. Other important considerations, although not always included in the perimeter, are the potential for providing animal feed, human food, and creating a pollinator-friendly habitat.

The options for ground cover evaluated were a chlorophyll-deficient soybean and three seed mixtures: a 'ditch mixture,' and 'eco-management custom mix,' and 'pollinator mixture.' The ditch mixture was chosen because this is a typical ground cover for solar arrays. Since this is the 'business-as-usual' case, it will be used as the standard to test against. The other three mixtures

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[100] Sánchez-Pantoja, Núria & Vidal, Rosario & Pastor, Mamen. (2018). Aesthetic impact of solar energy systems. Renewable and Sustainable Energy Reviews. 98. 227-238. 10.1016/j.rser.2018.09.021.

provide ecosystem synergies and were chosen to give an increase in social impact.

The analysis is not mutually exclusive in which multiple alternatives can be undertaken simultaneously or sequentially without affecting each other's feasibility or outcomes. This allows decision-makers to weigh other variables. To achieve the best combination for the multiple outputs that develop a positive net benefit, a multi-criteria decision analysis (MCDA) could be performed. This would give combinations of outcomes relative to weighted stakeholders interests.

SCBA Guidelines, Methods, and Assumptions

This SCBA will be conducted *ex-ante* to explore the available possibilities and recommendations provided by ecosystem services management advice. The guidelines will closely follow practices outlined by Boardman et al. in their work where appropriate, 'Cost-benefit analysis: Concepts and Practice.' [101] Only when best-practice judgment deviates or limitations exist will new criteria be implemented. Areas where there are deviances are asterisked and explained in this section. The steps are as follows:

1. Define the scope of the project.
2. Specify the options or set of alternatives under consideration.
3. Identify the impacts to be measured and select measurement indicators.
4. *Predict the impacts over the life of the proposed project, program, or policy.
5. Monetize all impacts (US $ dollars).
6. Discount future costs and benefits to obtain present values.
7. Compute the net present value (NPV) of each project.
8. Perform a sensitivity analysis.
9. Reach a conclusion.

*The predictions for this paper were conducted on an average per year basis. The costs are spread over the lifetime and then averaged on a per year basis. For comparison purposes, this paper uses one hundred square acres and assumes all one hundred acres are usable for solar power. It assumes that the ground cover will go under the entire solar installation and the perimeter planting will go around the entire perimeter of the acreage. A fifty-foot set-back is calculated.

When a standard or historical option exists, the suggested new option will be compared to the standard. This will be compared using indicators where an indicator encompasses any item within the scope of the project that has a social impact, whether directly or indirectly associated. To perform a sensitivity analysis the low, medium, and high estimate of each indicator value will be input.

Social impacts are often qualitative, but a SCBA applies quantitative monetary terms for assessment. This SCBA will use literature review data, nursery prices and information, and US fish and wildlife records to assign a U.S. dollar ($) per unit in instances where only qualitative terms are provided.

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[101] Boardman, Anthony, David Greenberg, Aidan Vining, and David Weimer. 2005. Cost Benefit Analysis: Concepts and Practice

Dollar values will be rounded up or down to the whole value. This methodological eclecticism enables us to navigate the inherent uncertainties and complexities of social impact assessment and foster a nuanced understanding of the implications of large-scale solar installations on farmland. By triangulating diverse sources of evidence and perspectives, our SCBA framework seeks to engender robust and contextually grounded insights that inform project formulation and implementation.

While aesthetic appeal can be subjective, a rating system based on the data found will be applied. If the plant were found to be "ornamental," this would be considered an increase in aesthetic appeal. However, if a web-based source referred to the plant as "beautiful" or "pretty blossoms" for example, these would rank the aesthetics higher than an ornamental grass. If a plant is present for more seasons, then this would add to the aesthetic appeal ranking higher for each season it retains its seasonal palette or does not undergo senescence during a particular season.

The trees and plantings are assumed to be one single row and grasses are assumed to be one standard plant grouping. A plant grouping refers to a cluster of plants intended to be planted together in the same hole, all belonging to the same species. Where more than one row is considered, new calculations would have to be considered and the scope increased.

When perimeter linear foot is not given then acres are assumed to be a perfect square. However, two other options are given for unknown perimeter length. Machine learning programming utilized polygon evaluation for twenty-five polygons to obtain an average estimated change from perfect square. If the exact linear foot is not known but the acreage is shaped in a rectangle then an 85% accuracy is assumed and therefore 15% is added to the linear square foot assumption from perfect square. If a polygon with unusual shapes and many cut-outs and angles is chosen, then to account for the extra perimeter this increases linear foot. In this case, a 66% accuracy from perfect square is assumed and therefore, 34% is added to the perimeter measurement for a perfect square.

SimaPro software was used in calculating the carbon reduction in planting a native species. Attributes included water quantity savings, fertilizer reduction benefits, reduced soil preparation, transportation, and some ancillary impacts.[102] End-of-life (EOL) of the product or plant was not included in this section and was instead added to "post-use clean-up" if any associated costs were needed when the solar installation lifetime had ended.

Biomass was utilized for carbon sequestration capabilities and the $10 per ton CO_2 reduction was given for calculations. Though, the capability to sequester carbon does not mean this would be utilized throughout the lifetime of the plant. For some species, it would be necessary to do a cutting every year to obtain the numbers given. This may impact screening ability and reduce benefit impact in other areas.

While invasive species were typically avoided in this study, the need to provide an economical border and fast growth potential to screen allowed some mildly invasive species to be considered. The cost

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[102] SimaPro [Software]. Retrieved from http://css-simapro.adsroot.itcs.umich.edu/

to control an invasive species was estimated by the nature of the removal cost function. Obtaining reliable estimates of removal costs, however, is challenging because the effectiveness of invasive species control is often unobserved[103]. Accordingly, there are few estimates of invasive species removal costs in the literature. This study will incorporate knowledge of invader population dynamics and estimates of the damage and control cost functions. One study found that removal costs are linear, therefore estimates will be scaled linearly based on potential to invade native and neighboring grounds. Annual damage of all invasive species and the monetary value needed to remediate all species is levelized to a per acre value. An indicator of user-input changeable value is used as a weighting factor for invasiveness capability. The higher the weighting the more increased the cost of remediation was applied.

Where a plant is usable as a biofuel, GREET 2023 software analysis was performed to determine CO_2 equivalent avoided emissions for total greenhouse gas emissions from well-to-wheel. Well-to-wheel (WTW) refers to the comprehensive analysis of energy and emissions associated with the entire lifecycle of a vehicle, from the extraction or production of fuel to the consumption or use in the vehicle's engine or motor.[104] This analysis encompasses all stages of the fuel lifecycle, including extraction, refining, distribution, storage, and combustion. By considering the full lifecycle of a vehicle's fuel, the well-to-wheel approach provides a holistic understanding of the environmental impacts, energy efficiency, and sustainability of different transportation fuels and technologies.

Well-to-wheel analyses are commonly used to compare the environmental performance of different fuels and vehicle technologies. In our case greenhouse gas emission avoidance assumes a biofuel heavy duty rural transportation bus.

SCBA Excel Model for Future Analyses

The SCBA Excel Model was developed to facilitate the analysis of multiple items for social cost-benefit assessment across the same set of categories and sub-categories, linked to monetary terms. Given the need for repetitive analysis and comparison, the Excel model provided a systematic framework for conducting quick analyses while minimizing the risk of clerical errors.

By leveraging the capabilities of Excel, the model enabled a more robust comparison of distinct items, ensuring consistency and accuracy in the evaluation process. Its structured format allowed for easy input of data and parameters, streamlining the analysis workflow, and enhancing efficiency.

The development of this Excel model lays the framework for project analyses of similar scale and scope. Its adaptable structure and functionality make it a valuable tool that can be utilized for similar assessments. With proper documentation and validation, the Excel model has the potential to serve as a starting point for expanded scopes, as well. Careful caution would be required to accurately

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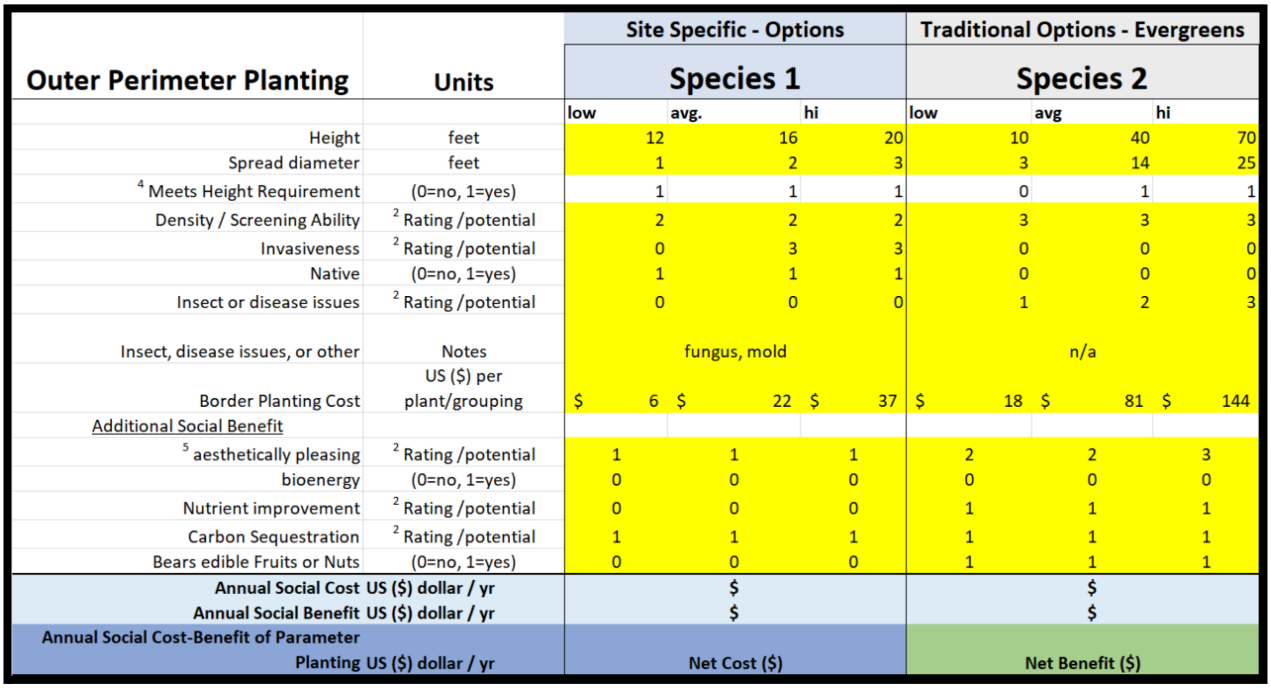
[103] S. L. Jardine and J. N. Sanchirico, "Estimating the cost of invasive species control," J. Environ. Econ. Manage., vol. 87, pp. 242-257, 2018. https://doi.org/10.1016/j.jeem.2017.07.004
[104] Argonne National Laboratory. (2023). GREET Excel Model [Software]. Retrieved from https://greet.anl.gov/greet_excel_model.models

calculate final net cost-benefits.

Table 17 is an example of the Excel model being utilized for Outer Perimeter Planting options given for one solar project. This shows the new site-specific option (light blue column) being compared against a more standard traditional option (light gray column). Indicator values (yellow) may be entered for both the site-specific option and the tradition option. Keeping in mind that the social-cost benefit final output will only be accurate with ethical purity of value entered for the indicators. Indicators help to assess usability and impact. For example, an indicator for parameter plantings is "Density/Screening Ability" where a rating system is applied by the user. The value may be any real number from zero to three, where three is the highest density opacity coverage and zero represents a transparency greater than 90%. A value added is cross-linked between the indicator and literature review where applicable. This is then given a US ($) dollar value based on values found for Willingness to Pay (WTP). Where WTP values are not found, some key assumptions are made and recorded. If a WTP value is found to be different from a default value, a user must enter the new WTP value in the default tab for that indicator. WTP is something that is hard to measure, in that it can be very subjective, and tends to increase with income and age.

*Table 17 SEQ Table * ARABIC 1Example of SCBA Excel Model Indicator inputs*



		Site Specific - Options			Traditional Options - Evergreens		
Outer Perimeter Planting	**Units**	**Species 1**			**Species 2**		
		low	avg.	hi	low	avg	hi
Height	feet	12	16	20	10	40	70
Spread diameter	feet	1	2	3	3	14	25
[4] Meets Height Requirement	(0=no, 1=yes)	1	1	1	0	1	1
Density / Screening Ability	[2] Rating /potential	2	2	2	3	3	3
Invasiveness	[2] Rating /potential	0	3	3	0	0	0
Native	(0=no, 1=yes)	1	1	1	0	0	0
Insect or disease issues	[2] Rating /potential	0	0	0	1	2	3
Insect, disease issues, or other	Notes	fungus, mold			n/a		
Border Planting Cost	US ($) per plant/grouping	$ 6	$ 22	$ 37	$ 18	$ 81	$ 144
Additional Social Benefit							
[5] aesthetically pleasing	[2] Rating /potential	1	1	1	2	2	3
bioenergy	(0=no, 1=yes)	0	0	0	0	0	0
Nutrient improvement	[2] Rating /potential	0	0	0	1	1	1
Carbon Sequestration	[2] Rating /potential	1	1	1	1	1	1
Bears edible Fruits or Nuts	(0=no, 1=yes)	0	0	0	1	1	1
Annual Social Cost	**US ($) dollar / yr**		**$**			**$**	
Annual Social Benefit	**US ($) dollar / yr**		**$**			**$**	
Annual Social Cost-Benefit of Parameter Planting	**US ($) dollar / yr**		**Net Cost ($)**			**Net Benefit ($)**	

The model allows for many indicators to be rated on its potential in a particular impact category. Where this is available, the following scale should be applied: none/very low =0, low =1, medium=2, high=3. Where high is the highest possible probability for that category.

Social costs are calculated assuming a set-back parameter entered for the community. One example is the cost impact for shading from trees or perimeter plants onto the solar panels. Unless a community set-back is given, the shading cover rating is scored according to a fifty-foot set-back. The taller the tree, the greater percentage of shading is calculated. In addition, where a plant height requirement is entered, the community requirement for set height must be entered and is given.

In the future analysis, any plant can be replaced by the site-specific ones, if the user enters the options in yellow. When a user chooses not to include one of the options or indicators, they simply leave the field blank and that item will not be summarized in the calculation.

SCBA Data

Options for the outer perimeter of the solar installation and the ground cover under the installation were compared against each other for an estimated social net benefit. All calculations we entered using the Excel Model. A low, medium, and high value were given for each option and reported in thousands of dollars per year. Of the traditional options, Eastern Red Cedar and the Tulip Tree were found to be the highest net benefits. Some salient benefits of these options were the width or stretch diameter of the foliage to give more linear foot per dollar of coverage, and the high aesthetic appeal value given based on nursery data. One note of caution for these options is their capability to provide shading onto the solar installation which would decrease power capacity. However, if they are managed to the proper height, with a fifty-foot set-back, shading could be reduced.

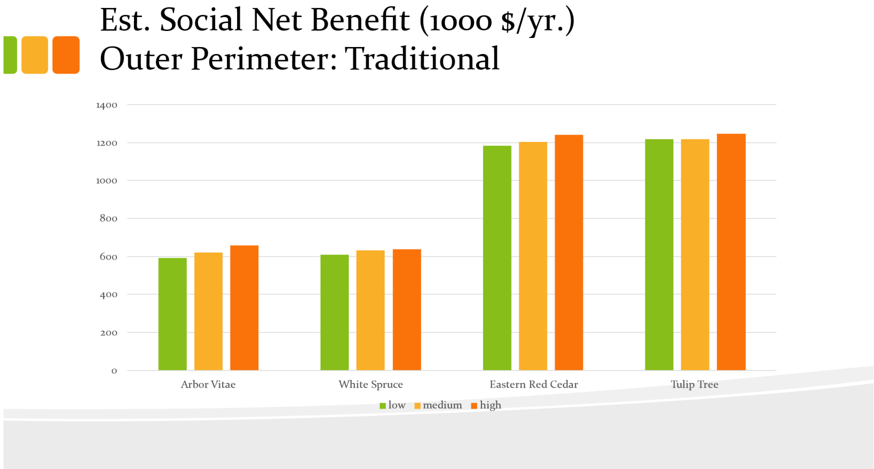


Figure 18 SCBA of Outer Perimeter Options: Traditional ($1000/yr)

The traditional options were compared to three tall grass options and the native Pawpaw tree. The grasses were selected because they have high screening ability and are fast growing. Though these options do provide good screening, two of the options were shown to be on invasive species lists. The ability to invade neighboring ecosystems was weighted heavily and therefore highly considered in the model which gave these grasses a net cost instead of a net benefit.

The Giant Miscanthus and the Native Pawpaw provided net benefits similar to the traditional perimeter options. Although, it is important to note that careful consideration must be made to assure the Giant Miscanthus species selected has a sterile hybrid so that it is non-invasive and only grows through the planting of rhizomes. It is also important to mention, the Giant Miscanthus performed well in the social benefit analysis due to its capability to be a biofuel. It would be necessary to harvest each season for the largest net benefit. This would allow for greenhouse gas reduction, as well as carbon sequestration which are both social benefit impact indicators. While this may be true, if screening is of high value, then harvesting the Giant Miscanthus would eliminate the screening ability during some seasons.

The options for ground cover under the installation were also evaluated using the Excel Model. The 'ditch mix' was considered the traditional option in which the other options were compared. The ditch mixture was chosen because this is a typical ground cover for solar arrays, therefore, its advantage is that most ground management companies are equipped to plant and manage it. While this is a common mixture, it provides very little if any synergic ecosystem services.

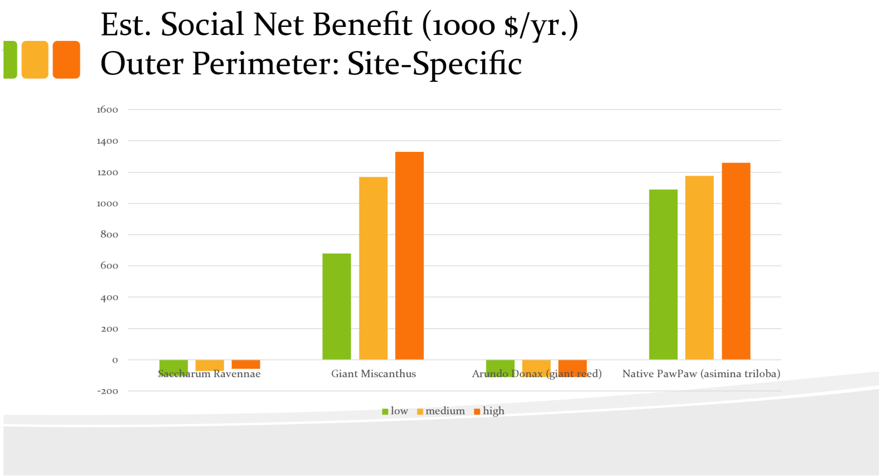


Figure 19 SCBA of Outer Perimeter Options: Site-Specific ($1000/yr)

The three options selected were the Chlorophyll-deficient soybean, and two seed mixtures.

The soybean species was selected for its multiple capabilities, including increasing albedo, and use as a biofuel source. Soybean is a primary source identified for bioenergy especially for use in biodiesel vehicles. These can provide a greenhouse gas reduction to transportation as an indirect benefit. One downfall to soybean is the labor harvesting requirements are intensive. In addition, the cost to purchase specifically chlorophyll-deficient soybean increased the seed price per acre much higher than the other options.

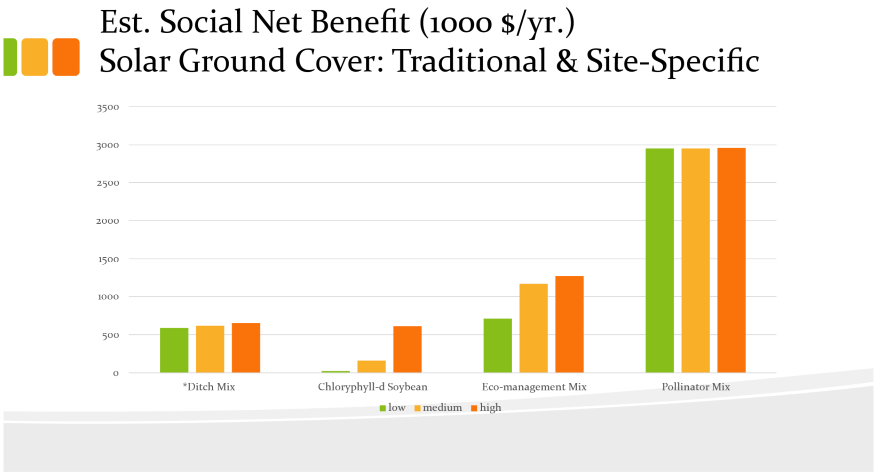


Figure 20 SCBA of Solar Ground Cover Options: Traditional Site-Specific ($1000/yr)

A pollinator seed mixture, consisting of a diverse mix of flowering plants that attract and support pollinators such as bees, butterflies, and other insects, offered several benefits. Pollinator seed mixtures provide essential forage and habitat for pollinators, helping to support their health and populations. By offering a diverse array of flowering plants with varying bloom times, the seed mixture ensures a continuous food source for pollinators throughout the growing season. In addition, they help increase biodiversity by creating habitats that support a wide range of pollinator species. The diverse mix of flowering plants attract pollinators that can provide increased harvest yields for neighboring farms, as well as provide a home for wildlife. The aesthetic appeal, stormwater management and soil erosion control all increase the pollinator mix to provide the largest net benefit.

SCBA results

The four highest net benefit options for the perimeter were very close in value and included the Red Eastern Cedar, the Tulip Tree, and the Giant Miscanthus, and the Native Pawpaw. These planting options, while close in benefit value, if the Giant Miscanthus were not harvested due to screening ability decrease, then standard deviation of the other three options were too close to make them distinguishable. If other indicators were found to be of higher salience, such as the environmental justice aspect of a Native Pawpaw's importance to Native Americans then this would provide a higher net benefit.

The highest net benefit for solar power ground cover for its many positive attributes, was the pollinator mixture. These are typically purchased wholesale by many seed suppliers that already provide a mixture specific to region, keeping the cost low. This in addition to its benefit to neighboring areas, gave the pollinator mixture a much higher and distinguishable benefit from the other options.

The sensitivity of the social net benefit was done using low, medium, and high extreme values of all inputs against the social impact indicators. The analysis showed that the social benefit was consistent and did not have a high variability when extremes of each value were chosen.

SCBA *Note of from the Authors

While this SCBA provides an estimate of net impact in US dollars per year (cost or benefit), it is important to recognize its limitations. The data should be utilized as a relative tool for comparing impacts and making informed decisions rather than as precise monetary values. Factors such as uncertainties, assumptions, and the complexity of real-world scenarios may affect the accuracy of the results. Therefore, it is crucial to exercise caution and consider other qualitative and quantitative factors when interpreting the findings. Furthermore, when utilizing the SCBA Excel Model, it is imperative that the user provide any indicator values entered with the utmost honesty and ethical judgment to ensure the most accurate comparison and results.

Applicability to Future Sites

The analysis presented above focuses on the solar farm site of Spring Creek. It should be noted, however, that these analytical frameworks can, and should, be used when evaluating any future solar farm site. Because dual-land use presents major opportunities for co-optimization, a broad set of methods are needed to evaluate benefits and drawbacks.

Despite the changing siting/permitting regulations in state and local levels, the steps to determine the optimal permitting approach for any future projects remain the same: identify current available permitting regulations, compare differences between existing regulations, assess the pros and cons of each process, and determine the optimal permitting plan. Two table tools can be used in the process. First, a comparison table (See Appendix) including key considerations of permitting can be used to compare the differences of existing regulations or help adopt a workable ordinance accordingly. Some considerations may change as ambiguity and gray area in the PA 233 will be clear with more interpretation and implementation released. Second, a permitting approaches review table (See Appendix) including key decision criteria of time, cost, and community acceptance can be used to assess the trade-offs among the options, which can also be the inputs for future MCDA analysis. Then, developers can weigh the importance of each criteria and determine the optimal process.

All of the spatial analysis techniques used for the Spring Creek site can easily be replicated for any site in the country. International sites could also be easily analyzed but the availability of remotely sensed imagery applies. The NAIP imagery used for the basis of analysis is readily available for free from the USDA across the contiguous United States. Soil sampling was based on the standardized technique of sampling at tillage depth (top 0-6 inches). The ArcGIS Pro software requires a license but is provided for free by most universities. The spatial methods applied using software as well as the in-situ soil sampling, all serve as a baseline and can be used to gauge progress as site development / use proceeds into the future. It should be noted that for Spring Creek in particular, the site plan is ever-changing and Consumers Energy is still making management and development decisions. Thus, spatial tools and their resulting outputs are flexible to account for these changes. This flexibility ensures the applicability of the methods in this document to practically any site in the future.

Generalizing to a future site, an LCOE analysis can be completed for any dual-land use strategy in consideration. The advantage of LCOE is that it puts the cost of projects on the same reference (such as MWh), and therefore the key takeaways from LCOE will occur when it is compared across different land-use strategies. Site layout determines total energy generation and therefore strongly influences LCOE. In future sites with a very large energy generation expectation, for example, a percentage increase in generation due to albedo modification may have a significant impact on LCOE. In another case where energy generation is limited by inverter and substation capacity, reducing O&M costs may be a more effective method to reduce site LCOE. Regardless, the LCOE metric can provide key insight when determining future site land-use decisions.

Multi-Criteria Decision Analysis (MCDA)

Future analysis could be done in combination with the social cost-benefit analysis, site-specific data, and stakeholders weighted scores. A MCDA could be utilized as an assessment tool for evaluating the complex decisions involved in accounting for options in the large scale solar power installations projects. It provides the capability to organize information and structure the process, supporting decision-makers in their sustainable choices. In this manner, non-mutually exclusive options could be weighted and utilized in the quantities determined by the pareto frontier. An optimal solution or set of solutions could be output.

Conclusions and Future Work

Due to the volatile nature of solar permitting in Michigan, along with the sheer amount of variability between sites, this report serves as a general recommendation not only for Spring Creek but also for any future solar projects looking to optimize their work for ecosystem services. Ideally, the concepts and practices mentioned above will provide enough information to cast a wide net on the landscape surrounding utility-scale solar and its interactions with the environment. It is often the case that cost-reducing measures are considered paramount especially when energy utilities are involved. If there is an opportunity to include the benefits from ecosystem services in these considerations, it should be explored to the fullest extent possible.

Future work should consist of continuing to monitor the site and note any changes in land use in the form of land clearing or new plantings. Soil samples should continue to be taken to account for any soil quality alterations or fluxes in nutrients. These samples also serve as checks to determine whether measures taken at the site are having any net benefits. We also think that further research into the possibility of orchards being utilized in the buffer zones and biofuel production integration would be valuable. Values in the MCDA, LCOE, and SCBA frameworks should continue to be updated as the site progresses. Continuous monitoring of state and local level policy is key to ensure that the site not only falls within regulations, but also to maximize benefit to be gained from any new regulations.

Appendix A: Methodology

Albedo Modification

The potential increase in energy generation due to albedo modification at a solar farm site was determined using NREL's open access tool, PVWatts.[105] PVWatts generates irradiance and albedo information from the National Solar Radiation Database based on the location inputted by the user. For this analysis, the zip code of a future Consumers Energy solar farm was used. PVWatts also allows the specification of additional system parameters. For this model, bifacial, single axis tracking panels were used with a 1.3 DC to AC size ratio, based on provided Consumers Energy parameters. The baseline system losses of 14.08% were inputted, as well as the default 96% inverter efficiency. The number of panels for an acre of land, using the ground cover ratio of 0.41 provided by Consumers Energy, was used to calculate the system size of 359 kW DC, which was used in PVWatts. Table A1 below shows the monthly percent increase from the baseline NSRDB data in AC energy generation with different albedos. As discussed in the main body of the report, the large increases in the summer and fall months matches well with a crop growing season.

Table A1: Percent Increase in Monthly Energy Generation (MWac) due to a constant albedo of 0.3, 0.5, and 0.7.

	albedo = 0.75	albedo = 0.56	albedo = 0.37	albedo = 0.19
January	-1.15	-4.29	-7.44	-10.42
February	0.36	-2.79	-5.95	-8.94
March	3.01	0.61	-1.96	-4.63
April	7.89	5.69	3.2	0.34
May	7.54	5.46	3.14	0.7
June	8.05	5.82	3.42	0.68
July	6.66	4.99	2.98	0.6
August	9.63	6.99	3.94	0.8
September	10.1	7.04	3.78	0.61
October	11.31	7.87	4.43	1.16
November	10.4	7.2	3.99	0.96
December	4.81	1.43	-1.95	-5.15

O&M Impact on LCOE

$$Yearly\ Mowing\ Costs/Acre \ = \ (average\ mowing\ rate\ [hr/acre]\ *\ labor\ rate\ [\$/hr]\ +$$

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[105] https://pvwatts.nrel.gov/index.php

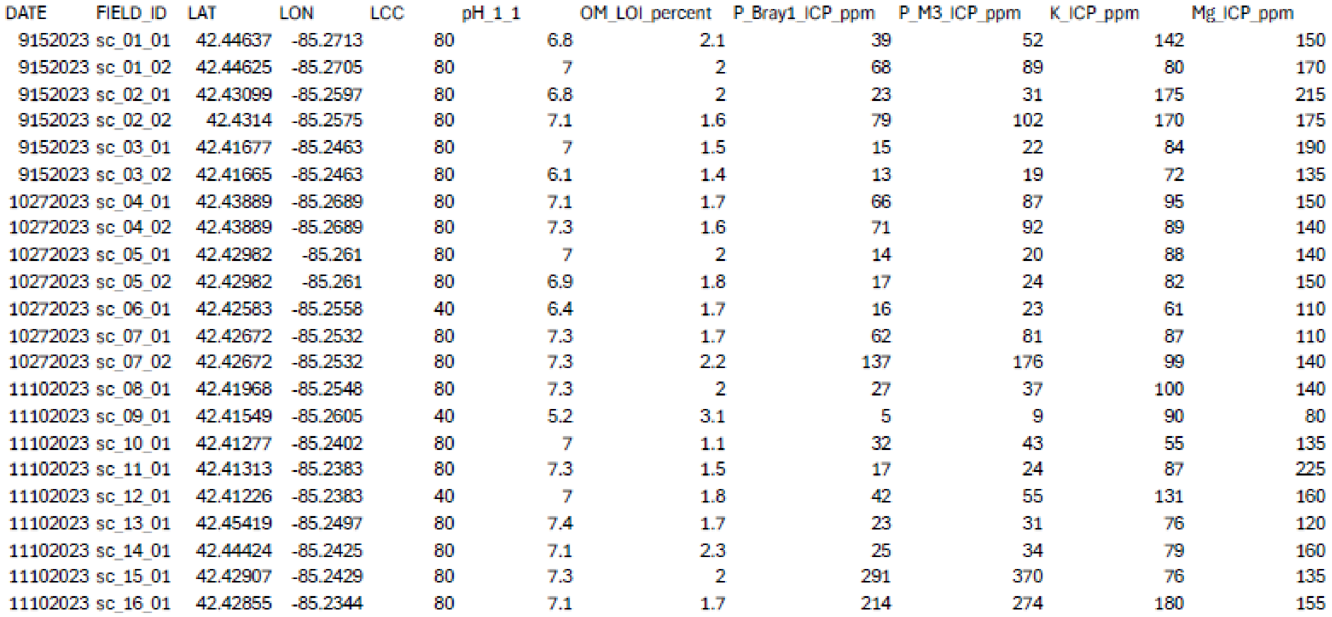
$$variable\ costs\ (fuel,\ consumables)\ [\$/acre])\ \ *\ \ number\ of\ times\ mowed\ per\ year\ [1/year]$$

$$Lifetime\ Mowing\ LCOE\ (\$/MWh)\ =\ 25\ *\ Yearly\ Mowing\ Costs/Acre\ *\ 1000/(359\ kW/acre)\ /\ 8760\ hr$$

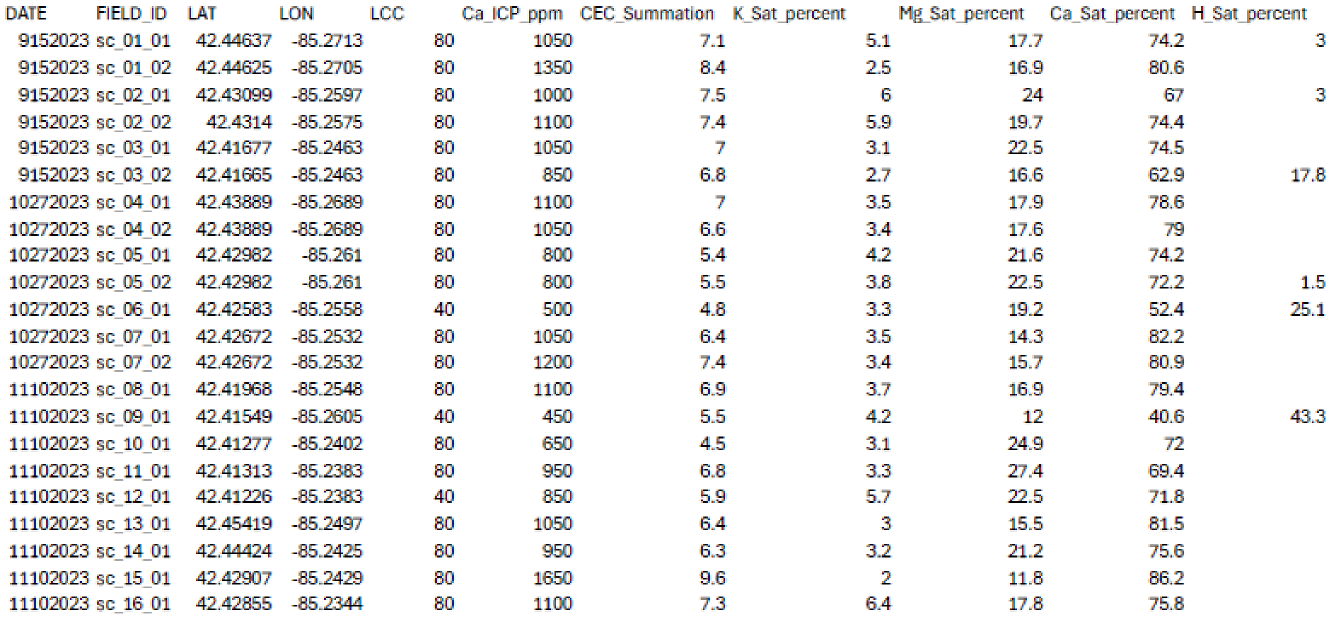
This assumes the equipment to mow has already been purchased and will be used for other projects, so is not considered in this calculation. For the different potential synergies, specifically the vegetation buffer zones and the grazing of livestock, the required area to be mowed will be reduced. Data for the average mowing rate, labor rate, and variable fuel costs were provided by Consumers Energy.

II: Spatial Mapping

In-Situ Sampling and Georeferencing



DATE	FIELD_ID	LAT	LON	LCC	pH_1_1	OM_LOI_percent	P_Bray1_ICP_ppm	P_M3_ICP_ppm	K_ICP_ppm	Mg_ICP_ppm
9152023	sc_01_01	42.44637	-85.2713	80	6.8	2.1	39	52	142	150
9152023	sc_01_02	42.44625	-85.2705	80	7	2	68	89	80	170
9152023	sc_02_01	42.43099	-85.2597	80	6.8	2	23	31	175	215
9152023	sc_02_02	42.4314	-85.2575	80	7.1	1.6	79	102	170	175
9152023	sc_03_01	42.41677	-85.2463	80	7	1.5	15	22	84	190
9152023	sc_03_02	42.41665	-85.2463	80	6.1	1.4	13	19	72	135
10272023	sc_04_01	42.43889	-85.2689	80	7.1	1.7	66	87	95	150
10272023	sc_04_02	42.43889	-85.2689	80	7.3	1.6	71	92	89	140
10272023	sc_05_01	42.42982	-85.261	80	7	2	14	20	88	140
10272023	sc_05_02	42.42982	-85.261	80	6.9	1.8	17	24	82	150
10272023	sc_06_01	42.42583	-85.2558	40	6.4	1.7	16	23	61	110
10272023	sc_07_01	42.42672	-85.2532	80	7.3	1.7	62	81	87	110
10272023	sc_07_02	42.42672	-85.2532	80	7.3	2.2	137	176	99	140
11102023	sc_08_01	42.41968	-85.2548	80	7.3	2	27	37	100	140
11102023	sc_09_01	42.41549	-85.2605	40	5.2	3.1	5	9	90	80
11102023	sc_10_01	42.41277	-85.2402	80	7	1.1	32	43	55	135
11102023	sc_11_01	42.41313	-85.2383	80	7.3	1.5	17	24	87	225
11102023	sc_12_01	42.41226	-85.2383	40	7	1.8	42	55	131	160
11102023	sc_13_01	42.45419	-85.2497	80	7.4	1.7	23	31	76	120
11102023	sc_14_01	42.44424	-85.2425	80	7.1	2.3	25	34	79	160
11102023	sc_15_01	42.42907	-85.2429	80	7.3	2	291	370	76	135
11102023	sc_16_01	42.42855	-85.2344	80	7.1	1.7	214	274	180	155



DATE	FIELD_ID	LAT	LON	LCC	Ca_ICP_ppm	CEC_Summation	K_Sat_percent	Mg_Sat_percent	Ca_Sat_percent	H_Sat_percent
9152023	sc_01_01	42.44637	-85.2713	80	1050	7.1	5.1	17.7	74.2	3
9152023	sc_01_02	42.44625	-85.2705	80	1350	8.4	2.5	16.9	80.6	
9152023	sc_02_01	42.43099	-85.2597	80	1000	7.5	6	24	67	3
9152023	sc_02_02	42.4314	-85.2575	80	1100	7.4	5.9	19.7	74.4	
9152023	sc_03_01	42.41677	-85.2463	80	1050	7	3.1	22.5	74.5	
9152023	sc_03_02	42.41665	-85.2463	80	850	6.8	2.7	16.6	62.9	17.8
10272023	sc_04_01	42.43889	-85.2689	80	1100	7	3.5	17.9	78.6	
10272023	sc_04_02	42.43889	-85.2689	80	1050	6.6	3.4	17.6	79	
10272023	sc_05_01	42.42982	-85.261	80	800	5.4	4.2	21.6	74.2	
10272023	sc_05_02	42.42982	-85.261	80	800	5.5	3.8	22.5	72.2	1.5
10272023	sc_06_01	42.42583	-85.2558	40	500	4.8	3.3	19.2	52.4	25.1
10272023	sc_07_01	42.42672	-85.2532	80	1050	6.4	3.5	14.3	82.2	
10272023	sc_07_02	42.42672	-85.2532	80	1200	7.4	3.4	15.7	80.9	
11102023	sc_08_01	42.41968	-85.2548	80	1100	6.9	3.7	16.9	79.4	
11102023	sc_09_01	42.41549	-85.2605	40	450	5.5	4.2	12	40.6	43.3
11102023	sc_10_01	42.41277	-85.2402	80	650	4.5	3.1	24.9	72	
11102023	sc_11_01	42.41313	-85.2383	80	950	6.8	3.3	27.4	69.4	
11102023	sc_12_01	42.41226	-85.2383	40	850	5.9	5.7	22.5	71.8	
11102023	sc_13_01	42.45419	-85.2497	80	1050	6.4	3	15.5	81.5	
11102023	sc_14_01	42.44424	-85.2425	80	950	6.3	3.2	21.2	75.6	
11102023	sc_15_01	42.42907	-85.2429	80	1650	9.6	2	11.8	86.2	
11102023	sc_16_01	42.42855	-85.2344	80	1100	7.3	6.4	17.8	75.8	

Policy comparison

Despite the changing renewable energy facility citing regulations, a comparison table including key considerations can be used for future projects to compare the differences of existing regulations or adopt a workable ordinance accordingly.

Table A2: Template for a Comparison Table of Permitting Regulations

Permitting regulation comparison table			
		PA 233 of 2023	**Local Ordinance**
	Scope	Any solar energy facility with a nameplate capacity of 50 megawatts or more.	
	Zoning	All, but extra requirements if proposed energy facility is on farmland or brownfield	
	Approval Method	NA	
	Review Time	CREO: 120 days for local unit Commission: 1 year	
	Public Hearing	Yes	
	Duration of Approval	5 years	
Cost	Application fee	Yes	
	Intervenor fund	$75,000 per affected local unit but not more than $150,000 in total	
	Community Benefits	$2k/MW per affected local unit	
	Labor	Apprenticeship programs; Prevailing wage standard; Labor agreement/a collective bargaining agreement	
	Financial guarantee	Cost of decommissioning	

	for decommissioning	minus salvage value, posted in increments starting with 25% of the cost	
	Additional cost	NA	
Application requirements	Basic information	Yes	
	Construction timeline	Yes	
	Site plan	Yes	
	community description of site area	Yes	
	Expected public benefits	Yes	
	Environmental and natural resources impacts and mitigation plan	Yes	
	Erosion management and sediment control plan	Yes	
	Anticipated public health and safety effects	Yes	
	A summary of the community outreach and education efforts	Yes	
	Consultation with applicable state and	Yes	

	federal agencies prior submission		
	Copy of environmental permits	Complies with 1994 PA451	
	Interconnection information	Yes	
	Feasible site alternatives	Yes	
	Electromagnetic impacts and mitigation plan	Yes	
	Stormwater assessment and drainage mitigation plan	Yes	
	Fire and emergency response plan	Yes	
	Decommissioning & Reclamation plan	Yes	
	Additional information/documentation	NA	
Setback	Occupied community buildings and dwellings on nonparticipating properties	300 feet	
	Public road right of way	50 feet	
	Non-participating	50 feet	

	parties		
	Wetland	NA	
	Participating parcel	NA	
	Additional setback	NA	
Landscaping	Minimum height of planting	NA	
	Maximum row distance between trees		
	Minimum berm height		
	Existing trees and woodlands		
	vegetative ground cover	Pollinator as a condition	
	Agriculture protection	not unreasonably diminish farmland	
Infrastructure	Height	25 feet	
	Fencing	NEC	
	Maximum sound	55 average hourly decibels (A)	
	Measured from non-participating parcel	Outer wall of dwelling	
	Lighting	dark sky-friendly lighting solutions	
	Signage	NA	
	Wiring	NEC	

Next, an option review table including key decision criteria of time, cost, and community acceptance can be used to assess the trade-offs among the options, which can also be the inputs for future

MCDA analysis. The blank cells are left for developers to fill in on a case by case basis. Then, developers can weigh the importance of each criteria and determine the optimal process.

Table A3: Template for a Comparison Table of Permitting Approaches

	Time	Cost		Community Acceptance
		Normal Cost	State specific cost	
non-CREO local ordinance				Most accepted
CREO	Fastest/ 120 days	The lowest	0	Accepted
State	1 year	The lowest	The highest	Least accepted
Abandon	0	0	0	Most accepted

Note:
Time is how long an applicant will be approved or denied after submission
Normal costs include permitting cost and cost resulting from setbacks, landscaping, infrastructure and other requirements.
State specific costs include an intervenor fund, community benefits payment and cost for labor requirements.