Institute for Sustainability, Energy, and Environment (iSEE)

ENVS 492 RES Final Report

Armani Ubeid

Pierce Lynch

Fina Healy

Yousuf Mitchell

Executive Summary—

Our group worked alongside Resource Environmental Solutions (RES), an environmental restoration company focused on reincorporating native plant life to degraded areas and maintaining newly developed restoration sites. The focus of this project was in researching native pollinators, native short-stature grasses, and low-mow fescue seed mixes as well as adaptive management strategies for a 1600 acre solar farm in Kansas, IL. The goal is to increase site biodiversity, as well as minimize maintenance costs and provide RES with additional resources to apply to future restoration projects.

Table of Contents

Project Description, Objectives and Scope

The goal of this project is to present more cost effective methods of maintaining an ecological restoration over a 20 year period whilst exploring potential new plant species to be introduced on the 1600 acre Prairie Wolf solar farm. There are multiple opportunities for RES to reduce upfront and operating costs and create new revenue streams. If more efficient or effective mowing equipment is utilized, some variable costs, and labor hours can be significantly reduced for each required maintenance event. Identifying different plant species that improve biodiversity or can potentially provide a more cost effective solution in different environments than the current standard seed mixes. Livestock grazing could provide some benefits when compared to traditional mechanical maintenance methods. Lastly, there are opportunities for additional revenue through carbon credits. These findings can be applied to the current project and if successful, can provide a model for future projects to follow.

This research splits into four primary objectives within a projected 20 year long project scope: mowing maintenance, carbon sequestration, native plant species identification, and solar grazing.

For mowing maintenance, a technical review was done on alternative equipment for mowing and maintaining the site. By finding a move effective solution for mowing underneath the solar panels, the company will be able to tackle the issue they face of trying to quickly and cost-effectively maintain the sites. Potential solutions were then directly compared against each other using a 20 year present value cost analysis method to determine the best option based on the differences in upfront and labor costs.

For carbon sequestration, research was conducted on four certification carbon registry companies: Indigo AG, Verra, Climate Action Reserve, and B Carbon with Rice University. Each company was analyzed to determine which would better align with RES' goals and provide greater potential profits overtime.

For native species identification, native species of the Midwest were researched, specifically tallgrass prairie species. Only plant species that can bring an added benefit to biodiversity and are compatible with species in the current seed list were considered. This was all compiled into a list of potential additional plant species including costs to consider being introduced to the project.

For solar grazing, another 20 year present value cost analysis for the required costs associated with equipping the site for grazing and contracting sheep herders was completed. This number is important to understand if sheep grazing has any cost benefits when compared to more traditional maintenance methods.

Barriers and Scope Adjustment

For all sectors of the project, there were issues with having limited information as solar sites and restorations are a relatively new process. For the mowing research, assumptions were made for the cost analysis when there was not enough information provided. However, the overall scope was not adjusted. With sheep grazing, it was difficult to understand if the data was scalable to the 1600 acre requirement as most of the available literature is for small scale, community solar power facilities, therefore, assumptions were made when necessary. It was also desired to add information on potential damages done to solar panels from mowing and compare that with potential damages done from solar grazing, but that information could not be found. The scope remained the same except for the removal of costs associated with damage. For plant selection, the scope was consistent with little barriers. There were assumptions made on the cost of plants that may not be entirely accurate as this information would be best found internally with RES. Lastly, for carbon markets there was limited online information and difficulties contacting Indigo Ag and B Carbon Registry. This lack of information made it difficult to determine which registry would work best for RES and provide the most revenue, creating issues in choosing a specific recommendation. This changed the scope of the project to laying out both options as possibilities with guided information on how to work with either company and potential profits overtime.

Research Methods

Carbon Markets Methods

The research on carbon markets was predominantly literature reviews, interviews from professors on campus, and phone calls reaching out to the carbon registry companies. Most of the information was found directly from the B carbon, Indigo AG, Verra, and Climate Action Reserve websites. The literature review was conducted through databases and Google scholar. The search results were based on finding outside source information about entering a carbon market through a third-party.

Furthermore, to learn more about carbon sequestration and soil organic carbon, an email exchange was conducted with Dr. Michelle M Wander, who is a professor at the University of Illinois at Urbana Champaign that specializes in these research topics.

Lastly, phone calls were made to BCarbon with a representative named Jim Blackburn that responded to provide an additional resource on metrics and protocol for the company. Numerous calls were made to Indigo AG with no response, so this data was compiled through Google scholars and through using their website for information.

Plant Species Methods

Research factors of the native seed list were centered around a few focal points including regional diversity, weed or invasive potential, grazing potential, height, and soil quality or wetland status. Considering the vast and diverse amount of information that is available on plant species, not all information could be pulled from one source. However, much of the information was gathered from Swink & Wilhelm book on *Plants of the Chicago Region.*[26] Other sources included USDA approved plant databases, journals, and websites giving specific information on toxicity, invasive potential and other factors to consider in plant selection.

The information within *Plants of the Chicago Region* was immensely helpful in determining the cohesiveness of the plant species within the same environment. Detailed information was then compiled into an excel spreadsheet to compare the desired environmental factors that each species needs to thrive. This information was helpful in determining promising recommendations for plant species that could be supplemented into the plant mix.

Mowing Methods

The majority of the information concerning the CBA and the mower information was collected through online resources and dealer contacts. Details pertaining to the site itself and internal maintenance costs and information came directly via RES directly through Matt Borden. Additional information was gained from the dealer, Superb Horticulture regarding the specifications of the mowers and the prices for the products.

Beginning with simple Google searches for types of professional grade mowers and solar farm maintenance. Farm equipment dealer and hardware store websites, along with Youtube, were consulted in order to identify what mowing options were available that would be applicable for the specific requirements of mowing around solar panels.

Multiple virtual inquiries were made to learn more about some of the machinery options identified through the initial round of searches to various dealers including Blueline Manufacturing and OESCO Inc. These inquiries and potential vendor identifications led to Superb Horticulture, where sales manager Kieth Norman was connected with via both email and phone to learn more about the mower options. He provided critical information on the specific capabilities and individual machine costs.

The additional costs associated with the maintenance events were gathered through agricultural academic literature through Iowa State University and the University of Illinois. These pertained to machine depreciation rates, fuel economies, and specific maintenance costs. Governmental databases were consulted to determine fuel prices as well as average inflation rates.

Solar Grazing Methods

The research on solar grazing was conducted almost exclusively online. For the very beginning of the research very simple google searches were used. These searches included key words and phrases such as “sheep grazing on solar farms,” “solar grazing,” and “agro-voltaics.” Through these searches very basic information on the topic was found. It also led to plenty of news articles about different solar farms that had implemented solar grazing. Through these news articles the American Solar Grazing Association was discovered, a not for profit trade association founded for and managed by sheep farmers who have become solar graziers. Their website was a great help in finding more detailed information about solar grazing. It was especially helpful because on their website they have several academic studies on solar grazing and related topics. It was discovered that on this same website they have some recorded webinars that were useful in better understanding the subject. In addition to recorded webinars they also offer signups for their monthly webinars. One such webinar was attended live via Zoom for research purposes.

Other academic papers on the subject or relating to the subject of solar grazing were searched for on Google Scholar and Scopus.com using similar search phrases but with additional words and phrases. Some of these additional words and phrases are “costs” or “capital costs” added to the original phrases. This was done in order to find better information that could be used for the solar grazing CBA, as well as information on agricultural practices relating to animal husbandry. Only a few related academic papers were discovered this way.

In addition to internet research, emails were sent in order to reach out to experts in solar grazing. At least one email was sent to each of the following; Agrivoltaic Solutions LLC, Sun-Raised Farms, and the American Solar Grazing Association (ASGA). Responses were received from Sun-Raised Farms, and the American Solar Grazing Association, but the ASGA was the only organization willing to help us in our research. Lexie Hain, a member of the ASGA managing board, shared an agrovoltiac study she thought would be useful as well as offered her time for a phone call.

Two phone calls were also conducted for research purposes. One call was with Lexie Hain as stated in the previous paragraph. The reason for this phone call was because Hain was curious about the research we were doing and wanted to know more about our project. She also wanted to help in our research. The other phone call was an interview with Kiyoshi Mino, a former organic farmer who has experience with raising sheep. This interview was conducted to better understand the needs of sheep and the types of costs associated with grazing sheep.

Analysis of Research

Carbon Markets

The initial research for carbon markets started with a literature review of voluntary carbon markets (VCMs). These are not government enforced, allowing the landowner, RES, to have the sole choice of participating in this voluntary system. This creates a financial incentive to make changes in their farming practices to increase carbon credit yield. These changes can include conservation tilling and proper crop rotations. Carbon certifier organizations work with landowners to help increase yield over time based on their agriculture practices, land and crops.[2]

The breakdown of the VCMs process starts at the solar site in Kansas, Illinois with the Landowner/Seller (RES) contacting an assembler to calculate the quantity of carbon emissions for determining the size of carbon credits. This is done by measuring the soil organic carbon (SOC).The assembler can be any company chosen by RES. Then after assembling, they will contact a third party verifier organization to verify the measurement of the carbon offsets. There are numerous verification companies, but depending on the certification company they may not be accepted. Both the verifier and assembler will be used to apply to the certifier who authorizes the authenticity of carbon offers and allocated carbon credits. The four certifiers investigated in this research to best fit RES are: BCarbon, Climate Action Reserve, Verra, and Indigo Ag. This breakdown of VCMS can be seen in Figure 9. There is no clear clarification on how agriculturally focused these companies are and if they work with restoration sites for carbon sequestration. Assumptions were made based on the specific protocols for the company's certification process.

The first carbon certifier that was researched was the BCarbon Soil Carbon Credit Systems. This system requires a 10 year “rolling commitment” which can extend for decades. The known standard that should apply through this registry are cropland or grazing lands that sequester carbon. This sequestration is determined by a static baseline soil sample test of the initial SOC which must be re-verified every five years for BCarbon’s “true-up” test. This test entails measuring directly the belowground carbon amount and the soil bulk density at the start of the enrollment, and every 5 years afterwards. There is also a required yearly protocol based on literature or modeling studies to issue interim credit in between the 5 year re-testing. The sampling depth varies depending on the site and specific considerations, however, normally depths of 30 cm or 1m are used.[1] After determining the total amount of credits from the solar farm, 10% of the credits will go to the buffer pool in case there are subsurface soil disturbances or other contingencies during the 10 year contract. Additionally, BCarbon will work with the restoration site to recommend land management changes, soil bulk density, soil texture, soil series, etc. to help increase the total amount of carbon sequestration over time. There is no minimum or maximum acreage specified with BCarbon.[4] Lastly, carbon dioxide is the only greenhouse gas (GHG) that credits can be awarded for as no other emission factors are tested. BCarbon will also not award credit for emission reduction techniques such as livestock usage. A phone call was conducted with Jim Blackburn where he informed that they are working on incorporating other greenhouse gas emissions in addition to carbon dioxide, however this process will take several years to incorporate.[29]

The second carbon certifier investigated was Verra, as they are the world's most widely used VCM. The specific protocol that best matched RES was the "VM0042 Methodology for Improved Agricultural Land Management v 1.0". This protocol was chosen because they accept numerous types of projects outside of agricultural lands including croplands, grasslands, and rangelands. Their activities and recommendations to help improve carbon sequestration for RES' solar site include: fertilizer, soil amendments, water management, crop planting and cover crops, grazing practices, and emissions. They also award credits for GHGs other than carbon dioxide such as N_20 and CH_4. The minimum number of years for the longevity of a project enrolled with Verra is 30 years. Similar to BCarbon, soil samples of SOC and bulk density are required to be directly measured to determine the amount of carbon sequestered and are reevaluated every 10 years. Models are not required but can be used to determine measurement in between the 10 year sampling period. Lastly, for determining the verification company, Verra has a list of approved independent third parties on their website.[6]

Moreover, the Climate Action Reserve protocol, "Climate Action Reserve Soil Enrichment Protocol v 1.0," is a potential option for RES. This protocol is very similar to Verra as they accept projects for rangelands, croplands, and grasslands. However, this protocol requires that RES makes changes to at least one sector of the solar site to increase the overall carbon sequestration. These changes include fertilizer changes, soil amendments, water management adjustment, crop planting and cover crops rotations, and grazing practices and emissions additions.[3] SOC and bulk density are directly measured initially and must be re-measured every five years. Monitoring must be ongoing with the requirement of reporting back annually. There is a non-committal permanence requirement with a minimum registry of 20 years. However, the shorter the length of commitment, the fewer credits the company will receive as this is issued as a proportion of the 100-year permanence timeframe.[4]

The last carbon certifier that was researched was Indio Ag. Due to lack of response, there is no clarification on if they would work with RES as their main focus is for farmers. However, on their website they indicated that they work with farm field crops in Illinois that adopt or advance one new carbon farming practice. These practices include: adding cover crops, increasing cover crop diversity, reducing fertilizer and tillage usage, and diversifying crop rotation. Moreover, they work with companies to help increase carbon sequestration and reduce other GHG emissions. Similarly to other certifiers, Indigo Ag requires direct measurement of the soil to determine the SOC and bulk density to determine the amount of carbon credits generated. They are flexible with their enrollment periods and require only a five year commitment for projects. Indigo Ag offers a Carbon Credit Payment per year estimate based on location and crop type. By indicating that the farm is 1600 acres and in Kansas, Illinois mainly using cover crops, RES could earn up to $13,571 per year through this certifier (See Figure 10 below). However they note that actual payments vary based on the soil measurement results and the actual amount of carbon credits generated from the land. Additionally, there is a 20% buffer pool holdback of carbon credits generated in case of subsurface soil issues and other contingencies (Indigo Ag, 2021).[5]

Additionally, through the interview with Dr. Michelle Wander, SOC is determined by a number of factors such as soil carbon stocks, including plant inputs, land use and management activities, climate, and soil types. Moreover, carbon is transferred into the soil by the deep root system of native prairies, indicating that RES's 25% of land for diversification of plant species can potentially increase the amount of carbon sequestered, and therefore creating more carbon credit revenue for any of the four certifiers listed above.

Plant Species

The analysis of the potential plant species and comparison of their properties was critical in determining how well they would work together. The potential plant species are listed in Table 1 on the next page. Overall, they all have high levels of diversity and can adapt to several varieties of soil. This determination gives us enough information to conclude that together each of these plant species have a strong chance of survival. With these plants having high diversity levels, they still have preferred environments and specific wetland statuses. Therefore, it is important to thoroughly understand which species are most similar in this way and which are different.

The majority of the species within this list are often found in Upland status regions, meaning they are rarely ever found growing in or near water. This is an important element in plant selection when observing the region in which these plants will live. The region of central Illinois, more specifically Kansas, Illinois, is rural and contains many prairies. Therefore, these species are strong candidates that can be conveniently maintained in this environment. The next most common wetland found within this list are Facultative Wetlands and Facultative Uplands, with three species from each. Facultative Wetlands determine that the species is usually a hydrophyte, meaning it usually grows in or around water. While Facultative Uplands means the species is more likely to not be a hydrophyte. However, the Facultative status of these species is telling us that they have the ability to adapt to either environment as a hydrophyte or not. Therefore, adapting to a majority Upland environment should not be very difficult for these species, and the ecosystem should have a balanced level of biodiversity. There are also two species with a Facultative status meaning they commonly occur both as a hydrophyte and not as a hydrophyte. This quality of adaptability is key in creating a diverse ecosystem that allows all species within it to thrive. Lastly, there is one Obligate species which rarely appears in Uplands and is almost always a hydrophyte. This particular species is a juncus, and is recommended because it is somewhat invasive and can adapt to different soil qualities. However, the necessity of this species within the ecosystem is not strong and can be easily replaced or removed without disturbing the balance or biodiversity.

Considering the height of the solar panels and the necessary room needed to perform maintenance and other tasks on them, height was highly regarded within the selection. The majority of these plants are not expected to grow more than 4 feet, giving ample room for the panels to be maintained. Lolium multiflorum was the only species that had the potential of growing up to 8 feet, however this is uncommon, and can easily be avoided with regular maintenance. It however cannot be maintained through grazing as it is toxic to sheep and most other livestock.

Grazing potential was also researched for each plant and divided into separate lists of toxic and non-toxic plants which can be seen in Table 3. The outcome showed that most of the plants listed below are non-toxic to sheep, with some even being a preferred diet for livestock. However there were 6 species that showed levels of toxicity to sheep either in dangerously high amounts, or lower amounts that require a gradual introduction into the sheep's diet. Weed potential for each plant is determined to imply whether it will be a potentially harmful species to the ecosystem. Region diversity was based on the research of Swink and Wilhelm in their research on *Plants of the Chicago Region*.[28] By identifying how many areas within all 22 of the Chicagoland area these plants were found, their region diversity was given a rating between low and high. With low ranging from 1-7, medium ranging from 8-15, and high ranging from 16-22 sections of the entire region. Wetland status is one of the most valuable pieces of information on this table as it shows us the plants preferred environment. The most adaptable species will have a facultative (FAC) status, while Upland (UPL) and Obligate (OBL) status mean that species prefers a more specific environment. Many of the plants listed fall under a facultative wetland (FACW) or facultative upland (FACU) status. The Illinois region is considered to be more of a wetland, so having FAC status gives this ecosystem a better chance of survival, however, UPL status plants can still have certain levels of adaptability that will allow them to survive within this plot. High C-factors also show that a plant is more capable of adapting, however with certain grass or oat species a C-factor is not applicable.

Table 1. All Plant Species displaying Family, Weed Potential, Height, Region Diversity, & Wetland Status

Acronym	Botanical Name	Family	Weed Potential	Height	Region Diversity	C-Factor	Wetland Status
avesat	Avena sativa	Poaceae or Gramineae	YES	< 3 feet	High	N/A	UPL
lolmul	Lolium multiflorum	Poaceae or Gramineae	NO	6 inches - 8 feet	Low-mid	N/A	UPL
agrala	Agrostis alba (Agrostis Gigantae)	Poaceae	Yes	2 - 3.5 feet	High	N/A	FACW
agrsmi	Agropyron smithii	Poaceae	Potentially a very dangerous weed. Current studies have shown this may not be entirely true	3 - 8 inches	High	N/A	FACU
fesrub	Festuca rubra	Poaceae or Gramineae	Invasive species, but is not usually spontaneous or aggressive. Often used to create low turf.	2 - 20 cm	Low	N/A	FAC
boucur	Bouteloua curtipendula	Poaceae	Very adaptive, most likely not	8 - 14 cm	High	8	UPL
elyvir	Elymus virginicus	Poaceae or Gramineae	No, not known to be invasive	5 - 25 cm	High	4	FACW
cxscop	Carex species (Carex	Cyperaceae	Yes, but is adaptable and not invasive	< 24 inches	Mid	7	FACW

Acronym	Botanical Name	Family	Weed Potential	Height	Region Diversity	C-Factor	Wetland Status
	Scoparia is my recommendation for its C-value and typical environment)						
junten	Juncus species (Juncus candesis is my recommendation for its adaptability and C-value)	Juncaceae	Somewhat invasive	2 - 4 ft	High	7	OBL
schsco	Schizachyrium scoparium	Poaceae	Yes, has potential to become invasive and will compete with turf grass	1 - 3 ft	Medium	5	FACU
triinc	Trifolium incarnatum	Fabaceae or Leguminosae	Yes, considered to be somewhat invasive	12 - 18 inches	Low	N/A	UPL
chafas	Chamaecrista fasciculata	Fabaceae or Leguminosae	Yes, it can become invasive if it is not well maintained	< 3 feet	Mid-High	5	FACU
asctub	Asclepias tuberosa	Apocynaceae	No	1 - 3 feet	High	7	UPL
allcer	Allium cernuum	Liliaceae	No, likely not invasive	12 - 18 inches	High	7	FAC
penhir	Penstemon	Plantaginacea	No, likely not	1 - 1.5	Mid	9	UPL

Acronym	Botanical Name	Family	Weed Potential	Height	Region Diversity	C-Factor	Wetland Status
	hirsutus	e	invasive	feet			
solnem	Solidago nemoralis	Asteraceae	No, not invasive, but removing flower head before ripening can reduce seed dispersal	.5 - 2 feet	High	4	UPL

The following table, Table 2, represents the cost of each plant in dollars per ounce, as well as the amount of seeds planted in ounces per acre. Using these values a total cost was calculated under the assumption that all plant species will be used. The total cost per acre was calculated to be $395.49 per acre of land, and a grand total of $143,958.36 for the entire plot. The table following table 2 shows another total cost analysis utilizing only grazing-friendly species. This would be the recommended plant list for a grazing-centered maintenance plan, with the grand total coming out to $60,587.80.

Table 2. Cost Breakdown for All Plant Species

Acronym	Botanical Name	Cost/oz	oz / acre
avesat	Avena sativa	$0.06	640
lolmul	Lolium multiflorum	$0.08	120
agrala	Agrostis alba (Agrostis Gigantae)	$0.40	2
agrsmi	Agropyron smithii	$0.19	48
fesrub	Festuca rubra	$0.18	16
boucur	Bouteloua curtipendula	$0.95	64
elyvir	Elymus virginicus	$0.50	32
cxscop	Carex species (Carex Scoparia is my recommendation for its C-value and typical environment)	$18.00	4

junten	Juncus species (Juncus candesis is my recommendation for its adaptability and C-value)	$1.50	0.1
schsco	Schizachyrium scoparium	$0.32	32
triinc	Trifolium incarnatum	$3.00	16
chafas	Chamaecrista fasciculata	$25.00	4
asctub	Asclepias tuberosa	$20.00	0.5
allcer	Allium cernuum	$18.00	0.5
penhir	Penstemon hirsutus	$30.00	0.2
solnem	Solidago nemoralis	$10.00	0.25
Total Acres	**364**	**Cost/acre**	**$395.49**
Total Cost		**$143,958.36**	

Table 3. Table Displaying Grazing Friendly Species' Attributes and Cost

Botanical Name	Grazing Potential	Height	Region Diversity	Wetland Status	Cost/oz	oz / acre
Agrostis alba (Agrostis Gigantae)	Considered a desirable feed for sheep in spring and summer	2 - 3.5 feet	High	FACW	$0.40	2
Agropyron smithii	Consdiered hihgly patable to sheep	3 - 8 inches (potentially a foot with other variables considered.	High	FACU	$0.19	48
Festuca rubra	Considered the most preferred diet item for sheep	2 - 20 cm	Low (can still be planted in many	FAC	$0.18	16

Botanical Name	Grazing Potential	Height	Region Diversity	Wetland Status	Cost/oz	oz / acre
			regions)			
Elymus virginicus	Highly palatable to sheep and is sustained by grazing	5 - 25 cm	High	FACW	$0.50	32
Carex species (Carex Scoparia is my recommendation for its C-value and typical environment)	Can be grazed by sheep	< 24 inches	Mid	FACW	$18.00	4
Juncus species (Juncus candesis is my recommendation for its adaptability and C-value)	Can be grazed by sheep	2 - 4 ft	High	OBL	$1.50	0.1
Trifolium incarnatum	Can be grazed until the blooming season, this is so the mature seeds can be dropped and replanted	12 - 18 inches	Low	UPL	$3.00	16
Allium cernuum	Can be grazed by sheep, likely not in high amounts	12 - 18 inches	High	FAC	$18.00	0.5
Penstemon hirsutus	Is not poisonous but can be toxic in large amounts	1 - 1.5 feet	Mid	UPL	$30.00	0.2
Solidago nemoralis	Can be grazed by sheep, but this can affect its ability to grow and spread	.5 - 2 feet	High	UPL	$10.00	0.25

Botanical Name	Grazing Potential	Height	Region Diversity	Wetland Status	Cost/oz	oz / acre
					Total acres	364
					Cost/acre	$166.45
					Total Cost	$60,587.80

Mowing

The culmination of the research regarding new mowers for RES is the net present value cost analysis comparing three different models of Perfect Van Wamel brand mowers to the current mower in use. The designs for each of the mower types can be seen in Figure 3. The current mower is the RF-220 model with a cutting radius of 7' and the three models in question are the RF-325 with a larger cutting radius of 10'8", the Sunswing-325 with a cutting radius of 10'8", and lastly, an MD-355 with dual-sided cutting up to 11'8". The full CBA can be seen in Figures 4-7, as well as, in the attached spreadsheet.

The estimates for the values are based on a 20-year life time span. The costs for each of the options were divided into machine costs, maintenance costs, labor and housing costs, delivery and trucking costs, and lastly the fuel costs. In order to determine the values, estimates for time required to do a maintenance event were calculated based on the given number of 90 hours per event at the current time using the RF-220 and the required hours for the other machinery were scaled based on the difference in shape, size, and potential max speed.

There are multiple assumptions and general prices that are consistent throughout all three scenarios. Everything was calculated assuming three separate maintenance events per year and each of the events being exactly the same cost. The upfront machine costs consisted of two tractors and two mowers that would be purchased during year 0 in each scenario with the tractor being constant throughout all 4 estimates. The cost of the tractors was set at $65k each based on the current available maintenance data. The rate of depreciation for each of the tractors and mowers was taken into account with the rate for both the tractors and mowers based on a table provided by Iowa State University.[7] The cost of labor was split between the managers and the operators with two operators being utilized for each of the maintenance events. The hourly wage of the managers and operators is taken directly from the price that RES currently pays their employees with the managers receiving $55/hr and the operators $26/hr with their housing cost set at $160 per day required to do the work. The maintenance costs were taken at a constant rate for all four scenarios with the lubrication being equivalent to 15% of the fuel costs,[7] the service costs being dependent on the machine costs and the number of events per year, and repair costs being a consistent 40% percentage of machine cost every 10 years.[7] The fuel economies for the tractors was set at 4.7 gal/hr based on estimates by the University of Illinois [9] and mowers all being set equal at 1.38 gal/hr based on their status as rotary mowers.[8] The price of fuel was consistent at $3.550/gal based on the current average cost for Illinois gasoline.[10] The net present values were calculated with a discount rate of 5% with the belief that the future value of the money is significant due to the required 20-year length of the maintenance contract. Lastly, everything was scaled per year at an average inflation rate of 2% based on historical price data.[11]

Starting with the Sunswing-325, the total present value of the costs over a 20 year period was $894,006.80 based on the given estimates. The major advantage of the Sunswing mower is the greater durability as well as the greater max speed as compared to the other mowers. It is capable of moving at a maximum speed of 2 mph as opposed to 1 to 1.5 mph for the other types of mowers. The greater speed of the machine allows it to be more efficient than a mower from the RF series which has a similar one-sided mower design but is only capable of going 1.5 mph. The Sunswing is designed specifically for solar farm applications, but it does not have many extra unique features as compared to the RF or MD series. In order to price the Sunswing appropriately the estimated hourly requirement to do a maintenance event compared to the smaller and slower RF-220 was 63 hours. This was determined by dividing the original 90-hour requirement by approximately 1.35 assuming the Sunswing is between 30 and 40% more effective than the RF-220. This results in only needing about 7 days for a full maintenance event already beating out the current RF-220 that requires 10 full work days for a maintenance event. This helps to reduce the labor, housing, delivery, and fuel numbers, however, the initial cost of the mower is nearly 10k more than the current RF-220 model. This gives a net present value for cost over the 20-year life span that is larger than the current RF-220 model. However, this number is given based on the assumption that the Sunswing is only 30-40% more efficient and it also does not take into account that the Sunswing is supposedly a higher quality product that is designed specifically for solar farm applications and therefore could provide other advantages that were not considered. This could mean that the Sunswing may have a longer lifespan than the other mowers and in the long run become even more cost competitive.

Moving forward to the RF-325, the total present value of the costs over a 20 year period was $1,030,707 based on the given estimates. The advantage that the RF-325 offers over the RF-220 is very simply that it has a larger cutting radius of 10’8” and therefore does offer the advantage of covering more of the ground under and around the solar panels needing fewer overall passes during mowing. Due to this fact, the estimated hours required for a full maintenance event were set to 81 hours per event with a 10% reduction in required time from the 90 hours with the RF-220. This 81-hour requirement would reduce the required days for a maintenance event to 9 from 10 days affecting the housing costs and labor costs. The mowers would cost $15,920 which is slightly more than the RF-220 at a cost of $13,025. Due to the RF-325 being identical to the current RF-220 in all regards except the increased cutting radius, it does not offer much additional benefit which is seen in the net present values of the costs.

Lastly, the MD-355 has a total present value of costs over a 20 year period of $795,885.40 based on the given estimates. The major advantage of the MD series of mowers as compared to the current RF series and the Sunswing series is that it features a double-sided mower design with an even larger cutting radius of up to 11'8". This double-sided design would allow for roughly half the required passes when mowing and therefore the estimated hours for a maintenance event were measured at 54 hours being roughly 66% faster than the current required hours of 90 hours. This means that a maintenance event would only require six full working days as opposed to the ten days for the current machinery. The reduction in hours and therefore days for each maintenance event causes there to be considerably less cost for labor and fuel directly affecting the maintenance costs as well as delivery and housing costs. The upfront cost of the mower is greater than the options in the RF series at a cost of $19,780, but the reduction in hours more than makes up for the differential in price. The effect of this reduction compounds throughout the 20-year lifespan and results in the lowest estimated present value for the costs.

All these estimates were directly compared to an estimated 20-year present value for the RF-220 which is the product that is currently in use and thus provides a base level estimate to see if any of the other options provide any real advantage. The comparison of all four can be seen in Table 4. The number of hours was set at a base of 90 hours based on the information provided by Matt for a mock maintenance event seen in Figure 2 for a similarly sized solar farm and using the same rates for everything else provides a comparable value of $1,104,753 over the 20 year lifespan of the project.

Table 4. Present Value of Mower Costs Comparison

Machine	Present Value of Costs
RF-220 (Current Machinery)	$1,104,753
Sun Swing 325	$894,006.80
RF-325	$1,030,707
MD-355	$795,885.40

Additionally, on top of the mower considerations, some potential add-on products were investigated with the RockBlock and a Qspray drag along chemical sprayer. The RockBlock is an attachment that can be installed to the mower to help to prevent any sort of rocks from being thrown out behind the machine as seen in Figure 8. In the event of damage to the mower or to the solar panels due to debris being kicked up by the mowers this could potentially be a good investment with the sizing varying between 7' and 13," with prices ranging from $600 to $1200. There might be other options that serve a similar purpose, but the RockBlock has a universal fit that could be the best fit for any of the mowers. The Qspray chemical sprayer option seen in Figure 9, is a pull along sprayer type with an attached boom that can be pulled behind the mower to provide additional chemical treatment to the plants after a mowing pass to try and eliminate the need to have an additional operator treat the remaining plants by hand. They offer multiple different tank sizes with the example one shown having a 200 gallon capacity. There was not much research emphasis placed on the chemical attachments, but the products could provide a potential solution or a jumping off point for future research.

Solar Grazing

Solar grazing is one of many forms of agrisolar (also known as agrivoltaics), which is the integration of solar photovoltaic projects with agricultural activity.[12] The concept of agrisolar was first proposed in Germany in 1981,[13] and the concept has been growing ever since. One of the main purposes of agrisolar is to increase efficiency of land use. For solar grazing in particular, instead of having two plots of land, one for photovoltaic energy production and the other for sheep grazing, you can achieve both with only one plot of land. Solar grazing has been reported to produce slightly lower herbage yields than a conventional open pasture, but despite this it has not been reported to have a negative impact on sheep production.[14] It is theorized that land productivity can be increased by 35–73% globally if agrivolatic systems are implemented.[15] In the past couple decades agrisolar has become increasingly popular especially with solar grazing, but the research on the subject is still relatively limited yet ongoing.

The concept of solar grazing and agrivoltaics fit RES's values. At RES's heart the goal is to be stewards of nature and to help restore natural ecosystems. Agriculture demands much of our land use, and so does energy production. Agrivoltaics through solar grazing provides the opportunity to create clean, renewable energy while at the same time provides the space for agriculture. This efficient land use means that less land is needed for energy production and agriculture, leaving more room for natural ecosystems. It makes sense why RES would pursue solar grazing for a potential project.

When it comes to animal selection, there are many different types of animals that may be best suited depending on the project. Some examples of animals that have been documented in Agrivoltaic systems are cattle, sheep, goats, and even poultry. For solar grazing, the most prevalent choice by far are sheep, especially with ground mounted, non elevated photovoltaics. One of the reasons sheep are more common than goats is because they are far more docile and don't climb obstacles as goats tend to do.[16]

When it comes to knowing whether or not sheep are a fit for a solar project, one of the first things that should be considered is panel height. A very common height minimum that was found from the solar grazing research was 30 cm above ground level.[13]Given that the lowest point of the PV's on the Prairie Wolf site is taller than this, it would be appropriate to have sheep graze on this site or a site with similar equipment specifications. There are other measures that must be taken with on site equipment though. It is recommended that all cables should be secured on the PV modules, in order to prevent damages as well as prevent the animals from getting tangled in the wires.[13] Cables should also be protected as they enter the ground, but this is most likely already the case to protect from mowers as well.[17] The type of solar array might also seem to be of importance when considering solar grazing however, both single axis and double axis solar tracking arrays have been found to be extremely compatible with solar grazing .[13]If the solar array on site is a tracking system though, some farmers have implemented motor guards to prevent the sheep's wool from getting caught in the moving parts of the array and the motors that drive the array.[13]

Another important factor to consider for a solar site where solar grazing might be implemented is fencing. Solar farms usually have perimeter fencing without solar grazing, but in areas where predators like coyotes are present, such as the state of Illinois, predator proof fencing is a wise precaution.[17] Even though it may be wise, it might not be completely necessary. One study conducted in New York state for a year only had a chain link fence surrounding the perimeter and there were no recorded predator issue.[18] There are also examples of solar grazing sites that used guard animals such as dogs or even donkeys, but the majority of sites mentioned in studies did not have guard animals including the previously mentioned study which states that "no guard-animals were necessary."[18]

Grazing efficiency is optimized when the practice of cell grazing, subdividing the land using internal fencing to ensure control over livestock grazing, is used.[13] Internal fencing is usually mobile in order to have flexibility over paddock sizes and locations. The most common type of internal fencing seems to be a mobile electric fencing called Electronet. Kiyoshi Mino stated that at the very least there should be twice as much, if not more, Electronet on site as needed for one paddock.[19] This is to ensure that when moving the flock, the next paddock would be ready to contain the flock. Also needed in addition to the mobile electric fencing are energizers, to power the electric fencing, as well as posts and gates. Mino also stated that the electric fencing not only contains the sheep but also protects against predators because they will be deterred from the electric shock.[19] It is reasonable to believe that the internal electric fencing may be sufficient enough to protect against predators, and no additional precautions are needed.

Types of vegetation on site are very important to consider as well. If the vegetation available for the sheep to graze does not meet their nutritional needs, it will result in poor health of the sheep which will further result in a decrease in the production of the livestock. In addition to a variety of grasses, legumes such as, "alfalfa, white clover, red clover, birdsfoot trefoil, ladino clover, alsike clover, and kura clover"[20] should be present as they provide important nutritional value for livestock. The ASGA has created seed mixes specifically for solar grazing. The seeds chosen were selected by experts from the Cornell University Sheep Program. Their standard mix is made up of Lolium perenne Tetraploid, Dactylis glomerata, Festuca elatior, Poa pratensis, Trifolium hybridum, Trifolium pratense Medium, Chrysanthemum leucanthemum, Cichorium intybus, Lotus corniculatus, Coreopsis lanceolata, and Solidago juncea.[21] Although some of the seeds listed, or related seeds, are also listed in the Prairie Wolf seed list, such as Solidago juncea, it would be advised that the list be changed to better suit sheep grazing for future projects if solar grazing is ever seriously considered. It should also be said that toxicity levels to livestock should be considered when curating seed lists. More specific recommendations are given in the Plant Species section of this paper and seen in Table 3. Additionally, if solar grazing is ever considered for an already planted site, then a forage sample should first be completed in order to determine the nutritional value of the site vegetation.

A more obvious need for solar grazing is a water source. If a water source is not already available on site, then underground water lines should be installed, or a well.[17] The type of water source is highly dependent on the location and geography of the site itself. In addition to the water source, several storage tanks will be needed to store water in several locations around the area being grazed, as well as troughs for the livestock to drink out of.

In solar grazing there is no one particular breed of sheep that works better than the other. According to a survey of 14 solar grazers, many breeds of sheep were used but the most prevalent were Khatadin and Dorper breeds which are hair sheep and primarily sold for their meat.[18] When figuring out how many sheep is needed for a project site, there are two important numbers that need to be considered; stocking rate and stocking density. Stocking rate describes "the relationship between the number of animals and the size of forage resource on which they are placed".[22] According to the same survey mentioned earlier, the average stocking rate was around 3 sheep per acre.[18] Other studies such as the one conducted by Fletcher and Lewis[17] and an Australian study conducted by the Clean Energy Council[13] found that a stocking rate of 4 sheep per acre was also sustainable. If we were to meet these studies in the middle and use the number 3.5 sheep per acre on a site such as Prairie Wolf, which has 1,140 acres of grazable land, we would expect that a total of 3,990 sheep would be needed to maintain the site. Stocking density describes the amount of animals on subplots of the pasture for a certain period of time.[22] This number is dependent on grazing plans and how the site is split up for cell grazing. In Cornell's study, that number varied between three to seven sheep per acre.[18] A higher stocking density would mean the livestock would need to be transferred to a new paddock quicker than if there was a lower stocking density. It should also be noted that the number of sheep on site should be flexible to account for overgrazing or under grazing, and may need to be supplemented during periods of heavy rain, or reduced later in the grazing season.[13]

When considering solar grazing it is understandable to be concerned about potential damages. The literature suggests that solar grazing is very safe for the PV's and other equipment. In the Fletcher and Lewis study, 7 solar farms in England were looked at for the period of one year and none of the farms ever reported any damages caused by sheep.[17] Out of all of the research done for this paper, there was only one study that mentioned damages. In the research it states, "There have been a few damaged panels in the fixed-tilt array paddocks where a sheep may have pushed its way through the small gap between panel and ground, but any damage caused by the sheep has been minimal compared to the damage caused from mowing."[13] That was all the information given on the damages to that ~ 25 acre farm in Queensland, Australia. The same study says that the risk of damage to cables by sheep is very low and that, "there have been no observed incidents of sheep chewing cables to date on Australian solar farms."[13]

After looking at the research one alleged benefit of solar grazing, besides the increased land productivity, is a decrease in operating and maintenance costs. This seems to be unanimous among all the sources that were found. The main reason for this seems to be because there is less labor involved. In a study that analysed Cornell's 22 acre Musgrave solar site for one grazing season, they found that "utilizing sheep for site vegetation management required a total of 139 hours including travel time, resulting in 2.5 times fewer labor hours than traditional vegetation management (mowing and string trimming) on site."[18] This number was found by using conventional mowing maintenance data from a 10 acre solar site, and extrapolating that data to match the 22 acre Musgrave site. Solar grazing farms do involve more expensive start up costs than normal solar farms however. One cost benefit analysis conducted for a theoretical 500 kW DC system found that installed system costs for a solar grazing, single axis tracking system site costs 4.2% more than for a non solar grazing, single axis tracking system site.[23] There is also the alleged benefit of decreased damages to equipment, but no useful data on damages to solar equipment from conventional maintenance was found so that could not be factored into the analysis. Additionally, solar grazing reduces the use of herbicides and other chemical maintenance,[24] but this too was not taken into account for the analysis given the fact that use of chemical maintenance is too dependent on unknown variables.

For the cost analysis, costs such as the grazing contract, fencing, water infrastructure, and transportation and equipment were looked at and the net present cost for over the course of 20 years was found. The analysis can be referenced in Figure 13. For the grazing contract (cost per acre), it was originally planned to use the average price per acre that was found through research, however most of the research only shows average price per acre for small-scale solar. An average for the Eastern US found by the Cornell survey was $308 per acre.[18] The sample size they used for the survey was small though, less than 20 solar grazing operations and mostly from small-scale sites. The only number found on large-scale utility sized sites was a very broad range from Sheep Industry News. In one of their articles the author claims the price can be anywhere from $100-$200 per acre.[24] It should be noted that this number was in reference to installations of hundreds of acres or more, which is also a very vague statement. It seems very possible that with even higher acreage that the price could easily get below $100 an acre due to economies of scale. Since a standard price for a site this large could not be found, it was decided to instead find the price range in which solar grazing would be more cost effective than RES's current mowing strategies.

For the fencing costs, prices for Electronet fencing, the energizers used to power the fencing, and additional posts and gates were all calculated. The amount of fencing required for 4 sets of 10 acre paddocks was calculated, and then the amount of energizers to power those fences was calculated. The costs for additional posts and gates was a very rough estimate. For all three categories, a yearly replacement and repair cost of 5% the initial investment was used. Additionally a 2% inflation rate was used.

For water infrastructure the costs of the water source, water troughs, and water storage were all estimated. The water source can vary from site to site depending on different factors, but it was assumed that a water well would need to be made. When looking at prices for wells it was found that prices can range from $10,000[23] - $30,000[25]. For the sake of this analysis, the higher number was used. A yearly maintenance fee of 2% the initial cost was also estimated every year that also included a 2% inflation rate. For water troughs, it was estimated that at least 70, 170 gallon troughs were needed. This was based on the flock size calculated earlier and the average intake of water by sheep which can be up to 5 gallons a day. A replacement cost of 10% the initial investment was used for every year, with a 2% inflation rate. For water storage, it was estimated that 4, 275 gallon storage tanks would be needed to ensure the sheep farmer could refill all troughs if empty. Every five years it was estimated that these might need to be fully replaced, so a 100% replacement cost was added every 5 years with a 2% inflation rate.

For transportation and equipment the costs of a UTV, UTV utility trailer, livestock trailer, and handling system were all estimated. The UTV chosen had a cost of $7,000. Depreciation was calculated as 20% for the first year, then 5% every year thereafter. It was assumed that the lifespan of the UTV would be 10 years, and a full replacement would be needed at year 10. The UTV utility trailer chosen had a price of $969 with a flatline depreciation of 5% every year. The lifespan of this trailer was also assumed to be 10 years, with a full replacement cost at year 10. The livestock trailer chosen had a cost of $30,000 and the depreciation rate of 20% for the first year and 5% every year thereafter was again used. The lifespan of the trailer was also assumed to be 10 years, with a full replacement cost at year 10. The handling system chosen had a cost of $6,995 and the same depreciation of 20% the first year and 5% the following years was used again. The lifespan was also assumed to be 10 years, with a full replacement cost at year 10.

Total present costs over the 20 years were calculated, but also the present costs for just the grazing contract over 20 years was calculated, as well as the grazing contract plus the water well over 20 years. This is because RES wouldn't be paying for all of the costs associated with solar grazing. According to Lexie Hain, a member of the ASGA management board, the sheep grazier is responsible for the management of the solar site once the contract is signed, therefore they are also responsible for all the equipment needed to perform solar grazing.[26] It varies from contract to contract but most of the time all the costs listed in the analysis would be covered by the solar grazier. The most likely cost for RES, besides the grazing contract cost, which RES would be responsible for would be the water source. That is why the additional two present cost calculations are made in cell B24, and cell B27.

In order to find what price per acre for the grazing contract would be cost competitive to the current mowing practices used, Cell B27 was set equal to the 20 year present cost for the current machinery ($1,104,753) found in Figure 6. Using the goal seek function in excel, it was found that the grazing price would have to be $63.75/acre if the 20 year net costs for the grazing contract and the water source were to equal the current mowing cost for 20 years. That means that a contract price less than $63.75 would benefit from cost savings over the 20 year period.

In addition to the present costs, the profits of the sheep grazier for year 1 were estimated. These estimations can be found in Figures 14 and 15. If there was a flock of 1,343 sheep with a Ram to Ewe ratio of 1:100, which is common, then if the expected lamb crop is 200%, which is also common, 2,660 lambs would be birthed. This would bring the size of the flock to around 4,000 sheep, which is close to the number needed for maintenance based on a 3.5 stocking rate. If a 5% death rate of lambs is assumed, then at the end of the grazing season there should be 2,527 lambs available for market sale. The market price used was the market price from the week starting on 11/28/21.[30] Expenses were as calculated in Figure 13. Figure 14 is the estimated profit if there was a grazing contract of $63.75/acre, and Figure 15 is the estimated profit if there was a contract of $0/acre. Even with no revenue from the grazing contract, a flock this large could produce a sizable profit. This is also only the profit of year 1, and in following years profit should be much larger because the expenses wouldn't have included as large of capital costs for equipment. It should also be noted that the expenses do not include veterinary bills, additional feed costs, winter housing and feeding costs, and other expenses livestock owners are responsible for. According to these estimates though, even an extremely low grazing contract price could mean profit for the sheep grazier, so it is very possible that a sheep grazier would accept a low enough contract price to make the grazing of a solar site this size cost effective.

When looking at the Figures, it will probably be noted that the numbers differ from the numbers given during the presentation. That is because the old calculations calculated NPV in two year intervals, but they have been changed to find the NPV of each year separately to make the calculations more accurate. This has changed the final values for the Mowing analysis and Solar Grazing analysis.

Research Implications

For carbon markets, there were numerous benefits and associated costs with each of the certifiers. There were similarities in all four as they all mandated a direct soil test to measure SOC and bulk density. It is unclear if there will be varying results of the generated carbon credits based on soil samples, so other factors were used instead to determine which registry would best fit RES. All certifiers assist with information on using better farming practices to sequester more carbon in the soil over time; however, Climate Action Reserve and Indigo Ag mandate that one of those practices must be made in order to work with them. This requirement gives less flexibility to RES on working with their solar farms making Verra and BCarbon better choices in this matter. Moveover, Verra, Climate Action Reserve, and Indigo Ag are open to providing credits for emission factors and emission reduction techniques such as livestock grazing, whereas BCarbon only provides credits for carbon dioxide and does not incentivize reduction techniques. The most varying difference between all the certifiers was the enrollment time of the projects. BCarbon has a minimum 10 year requirement with an extending enrollment period every 10 years. Verra has a minimum of 30 year enrollment. Climate Action reserve has a minimum of 20 years but over a 100 year payment plan so credits are worth less the shorter RES is enrolled with them. Lastly, Indigo Ag was most flexible with a minimum of a 5 year requirement. This analysis is summarized in Figure 11 below.

With taking all of these factors into consideration, an analysis was determined based on the factors that work best with RES. The solar site farm in Kansas, Illinois is on a 20 year contract so any with a larger requirement should not be chosen. This indicates that Indigo AG and BCarbon would be better certifiers for this solar site. Although Indigo AG is more flexible, due to limited response after reaching out to them, it was hard to determine if they will work with RES as they work primarily with farmers. Because of this factor, BCarbon with Rice University appears to be the most tangible option for RES and is guaranteed to help with solar farm restoration sites. To register with BCarbon, RES must follow the VCM (Figure 9) which can be found on the BCarbon website.

The research done on plant species provided vital information for how to make the best selections among plant species. Through finding plant species that are suitable for solar sites such as Prairie Wolf, there was much information gathered and analyzed on the chicago region and which are the most suitable plant attributes for it. This research also showed what changes should be made to the seed list if solar grazing is ever implemented. These changes would be needed to protect the sheep, ensure their nutritional health, and still maintain a good level of biodiversity.

The culmination of the findings regarding the mowing solutions available for RES as a result of the CBA and the relevant research provide valuable insight into making a purchase decision for the company for maintaining Prairie Wolf and future sites. The present value costs for each mower can be seen in Table 4 as well as the direct price differentials below in Table 5.

Table 5. Cost Differences between Current and New Mowers

Machine	Difference between Present Value Costs of Current Machinery (RF-220) and Tested Machine
Sunswing-325	$210,746.20
RF-325	$74,046
MD-355	$311,867.60

The numbers show that a mower from the MD series from Perfect mowers specifically with the 11’8” cutting radius (MD-355) allows for the greatest reduction in cost over the 20 year life span on a project. The MD-355 provides an estimated more than $300k cost advantage over the current RF-220. The ability to cut on both sides of the aisle at once allows for much of the labor time to be cut down resulting in such a large cost savings. However, it will be noted that the Sunswing-325 also provides an estimated more than $200k cost savings due to its increased size and max speed capability. It must be noted though that many of the costs were set as flat and with a large number of assumptions made, the true cost savings would likely fluctuate from the estimated values. However, the data suggests that it is a smart decision to switch to a new machine as there is a significant reduction in required labor hours for a maintenance event and therefore a reduction in costs in multiple areas from labor costs to fuel costs.

The findings for solar grazing have shown that solar grazing on a site similar to Prairie Wolf is certainly feasible. If RES can negotiate a contract lower than $63.75/acre then it would also save RES money over the course of 20 years. In Table 6, shown below, the potential present value savings based on given grazing contract prices are shown. If the contract price can be negotiated to $40/acre, RES would see a 20 year savings of almost $400,000.

Table 6. Savings Over 20 years When Comparing Curren Mowing Methods With Different Solar Grazing Contracts

Price Pre Acre		Present Costs over 20 yrs		Savings
$63.75/acre		$1,104,753.00		$0.00
$60/acre		$1,042,088.71		$62,664.29
$50/acre		$874,903.13		$229,849.87
$40/acre		$707,717.55		$397,035.45

There are still many uncertainties in the cost analysis however. This analysis has a large margin of error, and the prices per acre shown above might now reflect the industry average for sites this large. Again, accurate information for utility sized solar sites this big could not be found. A grazing contract that is under $63.75 may or may not be common for projects such as this. The solar grazier profit estimates in Figure 15 shows that even without revenue from a grazing contract, the lambs produced could make a sizable profit. That does not mean that they would be willing to graze for free though. The research does not show that sheep graziers are willing to maintain solar sites without a contracted payment.

Recommendations

The objective of this study was to make recommendations on decisions RES can make to help reduce costs and increase revenue for their Prairie Wolf solar site in Kansas, IL and hopefully provide relevant insight for future project decisions. These recommendations are broken down into the four main objectives of the research being mowing maintenance, sheep grazing, additional plant species adoption, and carbon sequestration credit.

Concerning the mowing maintenance, when looking at the cost comparisons for the proposed new mowers with the current machinery it is clear that a purchase decision should be made. The RF-220 shows a considerably higher present cost when compared to the other mowers, even the similar RF-325. However, based on the numbers in Table 5, it is clear that the MD-355 should be considered as the mower of choice for maintenance. Over the 20 year period, the cost savings are equivalent to more than 15 times the initial cost of the machine. This would improve the profitability of the company greatly if applied to not only Prairie Wolf, but future sites as well. The Sunswing-325 also provides a large cost savings and could potentially have a longer lifespan due to the increased build quality, but as it stands based on the current estimates the MD-355 is the obvious choice for a new mower.

Additionally, if the data shows over that time that the debris being ejected by the mower damaging the solar panels is a significant cost for RES, the RockBlock could be a worthwhile investment to try and minimize as much debris kickback as possible could be a worthwhile investment as their costs are relatively low. The cost for a universal fit guard is between $600 and $1000 dollars, so if the damages exceed such then they should be purchased. Lastly, if a tow along chemical sprayer is desired and can be operated and reasonably attached to the back of the mower, then a Qspray 200 gallon weed trailer with a foldable boom offers a reasonably sized and electronically controlled option for which the grass can be treated at the same time as mowing and normal maintenance occurs.

In terms of plant species recommendations, one of the first is dependent on the introduction of sheep grazing within the farm. If sheep are introduced then all of the toxic plant species should be removed from the seed mix. The reason behind this is that the sheep are not able to differentiate between plants and will simply eat whatever foliage is in front of them. The other option is attempting to control the placement of the seeds to keep the toxic plants out of reach of any livestock. Considering the well-being of the sheep may include additional expenses, another option is to use machinery to maintain the height of the plants if they grow too high. The lack of sheep may make maintenance more straightforward and the mix of species can remain the same, upholding the biodiversity of the plant mixture.

Another minor recommendation would be removing the Juncus species, as its unique wetland status (Obligate) may cause issues in its growth process. Substituting this species with other facultative species may allow for more flexible biodiversity and make life for the plant species easier. Plant species that are toxic to livestock can also be supplemented with non-toxic species if the use of grazing is implemented to maintain the ecosystem. Again, choosing species with a facultative wetland status may be the most convenient option to promote a community of plants that share the soil.

In terms of earning carbon credits, BCarbon is the best option for RES. Considering the 20 year life span of the Prairie Wolf project and the nature of the site itself. Although BCarbon was chosen to be the best certifier for RES, Indigo Ag does have promising results and may be an option for RES. It is recommended to look into Indigo Ag and see if they work with solar panel restoration sites a well. Another important factor to note is that BCarbon currently only works with carbon dioxide so if RES wanted to implement livestock as an emission reduction technique they would not receive more carbon credits for that, whereas with the other three certifiers they would gain more for livestock and other GHG emissions. Moreover, this analysis was based on the Kansas, IL site. If RES works with another site that has a longer project period extended 30 years or more, then Verra and Climate Action reserve might serve as better options for that project.

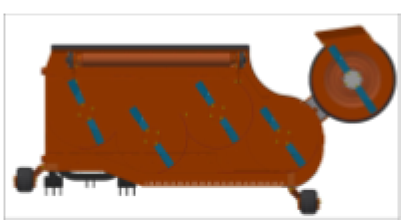
In terms of solar grazing, it is recommended that more research be done before solar grazing is considered as a potential maintenance option for a site similar to Prairie Wolf. If it is considered, then in order for it to be profitable, according to our estimates, there would have to be a contract price of less than $63.75/acre. However, it is still unknown if a price this low would be the norm for a large site similar to this one. It does seem feasible that a solar grazier would still profit off of a price lower than that though, and therefore might agree to that low of a price. Besides costs, the bigger challenge would be finding a large enough flock size close to the site. This is especially true for Illinois, and the Midwest in general. This part of the US is not a very large producer of sheep, and most flocks would not be nearly large enough to maintain this big of a site. There is the possibility that several sheep farmers might be willing to combine their flocks, but even then getting a large enough flock from farmers close to the solar site would still be extremely challenging.

If RES decides to continue their research into solar grazing, then I would recommend looking into implementing solar grazing on smaller solar sites. That of course is if RES is currently maintaining smaller sites or might possibly maintain them in the future. If not, and RES is still considering solar grazing, then I would recommend looking into a hybrid maintenance plan. Hybrid solar grazing and mowing maintenance plans came up during the research phase of this project, although not deeply looked into. It might be worth further investigating.

Appendices

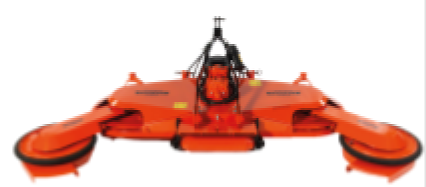
Activity	Resource Used	Quantity (hours)	Price	Inflation Adj. Price	Adjsuted Price	Total
Maintenance: Brush Hog	Operations Manager	40	$57.75	2.00	$60.06	$2,402.40
	Truck	4	$9.45	2.00	$9.83	$39.31
	Equipment Operator II	180	$57.75	2.00	$163.80	$10,810.80
	Tractor w/ Bush Hog (per day)	18	$157.50	2.00	$163.80	$2,948.40
	Truck	180	$9.45	2.00	$9.83	$1,769.04
	Equipment Operator II	180	$57.75	2.00	$60.06	$10,810.80
	Tractor w/ Bush Hog (per day)	18	$157.50	2.00	$163.80	$2,948.40
	Truck	180	$9.45	2.00	$9.83	$1,769.04
	Housing (per day)	40	$160.00	2.00	$166.40	$6,656.00

Figure 2. Mock Maintenance Event for 1625 Acre Project



Sunswing Series

RF Series



MD Series

Figure 3. Types of Perfect Mowers

http://www.superbhorticulture.com/products/1-10/Perfect

Time (Yrs)	0	1	2	3	4	5	6	7	8	9	10	11	12
Sunswing-325: 10'8" Cutting Radius	Requires 7 days at 9 hours/day for 2 opreators and 1 manager estimating 63 hours per machine per person and 126 labor hours												
Costs	213843.7	102713.9	48684.29	46844.56	45848.54	45339.53	46146.34	46969.29	46037.2	46893.39	68512.71	49128.99	49566.094
Machine Costs	177150	65289.5	10514.5	7914.5	6143	4843	4843	4843	3071.5	3071.5	3071.5	3543	3071.5
Tractor	130000	40300	9100	6500	5200	3900	3900	3900	2600	2600	2600	2600	2600
Mower	47150	24989.5	1414.5	1414.5	943	943	943	943	471.5	471.5	471.5	943	471.5
Maintenance incl Repair/Lubrication /Service Labour	1379.813	1404.289	1429.255	1454.72	1480.694	1507.188	1534.212	1561.776	1589.892	1618.57	22393.82	1677.657	1708.0905
Tractor	1102.04	1120.96	1140.259	1159.945	1180.024	1200.504	1221.394	1242.702	1264.436	1286.605	1309.217	1332.281	1355.8068
Mower	277.7733	283.3288	288.9953	294.7752	300.6708	306.6842	312.8179	319.0742	325.4557	331.9648	21084.6	345.3762	352.28371
Labour	20223	20627.46	21040.01	21460.81	21890.03	22327.83	22774.38	23229.87	23694.47	24168.36	24651.72	25144.76	25647.654
Manager	10395	10602.9	10814.96	11031.26	11251.88	11476.92	11706.46	11940.59	12179.4	12422.99	12671.45	12924.88	13183.373
Operator	9828	10024.56	10225.05	10429.55	10638.14	10850.91	11067.92	11289.28	11515.07	11745.37	11980.28	12219.88	12464.28
Housing	3360	3427.2	3495.744	3565.659	3636.972	3709.711	3783.906	3859.584	3936.776	4015.511	4095.821	4177.738	4261.2924
Delivery/Trucking	3572.1	3643.542	3716.413	3790.741	3866.556	3943.887	4022.765	4103.22	4185.284	4268.99	4354.37	4441.457	4530.2865
Fuel	8158.752	8321.927	8488.366	8658.133	8831.296	9007.921	9188.08	9371.841	9559.278	9750.464	9945.473	10144.38	10347.27
Tractor	6306.93	6433.069	6561.73	6692.965	6826.824	6963.36	7102.628	7244.68	7389.574	7537.365	7688.112	7841.875	7998.7122
Mower	1851.822	1888.858	1926.636	1965.168	2004.472	2044.561	2085.452	2127.161	2169.705	2213.099	2257.361	2302.508	2348.5581
Net Present Value	213843.7	97822.78	44158.08	40466.09	37719.71	35524.71	34435.11	33380.2	31159.79	30227.9	42060.86	28724.71	27600.256
Total Present Costs over 20 Years	894006.8												

Time (Yrs)	13	14	15	16	17	18	19	20
Sunswing-325: 10'8" Cutting Radius								
Costs	49192.865	50966.6728	51102.3862	53385.884	53089.052	54112.2826	54684.4783	76222.94786
Machine Costs	1771.5	2600	1771.5	3071.5	1771.5	1771.5	1300	1771.5
Tractor	1300	2600	1300	2600	1300	1300	1300	1300
Mower	471.5	0	471.5	471.5	471.5	471.5	0	471.5
Maintenance incl Repair/Lubrication /Service Labour	1739.1324	1770.795	1803.0909	1836.0327	1869.6334	1903.90604	1938.86416	21976.92144
Tractor	1379.803	1404.27903	1429.24461	1454.7095	1480.6837	1507.17737	1534.20091	1561.764932
Mower	359.32938	366.51597	373.84629	381.32322	388.94968	396.728673	404.663247	20415.15651
Labour	26160.607	26683.819	27217.4954	27761.845	28317.082	28883.4239	29461.0923	30050.31419
Manager	13447.041	13715.9817	13990.3014	14270.107	14555.51	14846.6197	15143.5521	15446.42318
Operator	12713.566	12967.8373	13227.194	13491.738	13761.573	14036.8041	14317.5402	14603.89101
Housing	4346.5183	4433.44864	4522.11762	4612.56	4704.8112	4798.90739	4894.88554	4992.78325
Delivery/Trucking	4620.8922	4713.31009	4807.57629	4903.7278	5001.8024	5101.83842	5203.87519	5307.952693
Fuel	10554.216	10765.3	10980.606	11200.218	11424.222	11652.7069	11885.7611	12123.47629
Tractor	8158.6865	8321.8602	8488.2974	8658.0633	8831.2246	9007.84911	9188.00609	9371.76621
Mower	2395.5292	2443.4398	2492.3086	2542.1548	2592.9979	2644.85782	2697.75498	2751.710079
Net Present Value	26088.027	25741.6331	24581.1215	24456.689	23162.577	22484.7711	21640.505	28727.6274
Total Present Costs over 20 Years								

Figure 4. Cost Analysis for Sunswing-325 Mower

Time (Yrs)	0	1	2	3	4	5	6	7	8	9	10	11	12
RF-325: 10'8" Cutting Radius	Requiring 9 days at 9 hours/day for 2 operators and 1 manager with 81 machine hours per person and 162 labour hours												
Costs	208973	105247.7	59086.07	57463.57	56842.21	56559.2	57596.53	58654.6	58115.44	59216.26	74348.7	61802.79	62652.592
Machine Costs	161840	57175.2	10055.2	7455.2	5836.8	4536.8	4536.8	4536.8	2918.4	2918.4	2918.4	3236.8	2918.4
Tractor	130000	40300	9100	6500	5200	3900	3900	3900	2600	2600	2600	2600	2600
Mower	31840	16875.2	955.2	955.2	636.8	636.8	636.8	636.8	318.4	318.4	318.4	636.8	318.4
Maintenance incl Repair/Lubrication /Service Labour	1729.474	1760.943	1793.042	1825.783	1859.178	1893.242	1927.987	1963.427	1999.575	2036.447	16083.66	2112.417	2151.545
Tractor	1372.337	1396.663	1421.476	1446.786	1472.602	1498.934	1525.792	1553.188	1581.132	1609.635	1638.707	1668.362	1698.6088
Mower	357.1371	364.2798	371.5654	378.9967	386.5767	394.3082	402.1944	410.2383	418.443	426.8119	14444.95	444.0551	452.9362
Labour	26001	26521.02	27051.44	27592.47	28144.32	28707.2	29281.35	29866.98	30464.32	31073.6	31695.07	32328.98	32975.555
Manager	13365	13632.3	13904.95	14183.04	14466.71	14756.04	15051.16	15352.18	15659.23	15972.41	16291.86	16617.7	16950.052
Operator	12636	12888.72	13146.49	13409.42	13677.61	13951.17	14230.19	14514.79	14805.09	15101.19	15403.21	15711.28	16025.503
Housing	4320	4406.4	4494.528	4584.419	4676.107	4769.629	4865.022	4962.322	5061.569	5162.8	5266.056	5371.377	5478.8046
Delivery/Trucking	4592.7	4684.554	4778.245	4873.81	4971.286	5070.712	5172.126	5275.569	5381.08	5488.702	5598.476	5710.445	5824.6541
Fuel	10489.82	10699.62	10913.61	11131.89	11354.52	11581.61	11813.25	12049.51	12290.5	12536.31	12787.04	13042.78	13303.633
Tractor	8108.91	8271.088	8436.51	8605.24	8777.345	8952.892	9131.95	9314.589	9500.88	9690.898	9884.716	10082.41	10284.059
Mower	2380.914	2428.532	2477.103	2526.645	2577.178	2628.721	2681.296	2734.922	2789.62	2845.413	2902.321	2960.367	3019.5746
Net Present Value	208973	100235.9	53592.81	49639.19	46764.23	44315.61	42979.42	41684.73	39334.82	38171.33	45643.65	36134.81	34887.307
Total Present Costs over 20 Years	1030707												

13	14	15	16	17	18	19	20
62544.156	64741.1507	64999.2537	67563.751	67553.538	68869.1205	69892.615	91582.14725
1618.4	2600	1618.4	2918.4	1618.4	1618.4	1300	1618.4
1300	2600	1300	2600	1300	1300	1300	1300
318.4	0	318.4	318.4	318.4	318.4	0	318.4
2191.4559	2232.165	2273.6883	2316.0421	2359.2429	2403.30776	2448.25392	22496.499
1729.461	1760.93018	1793.02878	1825.7694	1859.1647	1893.22804	1927.9726	1963.412055
461.99492	471.234819	480.659515	490.27271	500.07816	510.079723	520.281317	20533.08694
33635.066	34307.7673	34993.9227	35693.801	36407.677	37135.8307	37878.5473	38636.11824
17289.053	17634.8337	17987.5303	18347.281	18714.227	19088.5111	19470.2813	19859.68695
16346.013	16672.9337	17006.3923	17346.52	17693.451	18047.3196	18408.266	18776.4313
5588.3806	5700.14826	5814.15122	5930.4342	6049.0429	6170.02379	6293.42427	6419.292751
5941.1472	6059.97012	6181.16952	6304.7929	6430.8888	6559.50654	6690.69667	6824.510606
13569.706	13841.1	14117.922	14400.28	14688.286	14982.0518	15281.6928	15587.32666
10489.74	10699.5345	10913.5252	11131.796	11354.432	11581.5203	11813.1507	12049.4137
3079.9661	3141.56546	3204.39677	3268.4847	3333.8544	3400.53149	3468.54212	3537.912958
33168.501	32698.6805	31265.7524	30951.733	29473.385	28616.5421	27658.8811	34516.34812

Figure 5. Cost Analysis for RF-325 Mower

Time (Yrs)	0	1	2	3	4	5	6	7	8	9	10	11	12
MD-355: 11'8" Cutting Radius	Requiring 6 days at 9 hours/day for 2 operators and 1 manager with 54 machine hours per person and 108 labour hours												
Costs	201034	93367.16	43026.05	41077.71	40046.81	39424.8	40116.35	40821.74	39845.63	40579.51	58734.47	42487.19	42870.394
Machine Costs	169560	61266.8	10286.8	7686.8	5991.2	4691.2	4691.2	4691.2	2995.6	2995.6	2995.6	3391.2	2995.6
Tractor	130000	40300	9100	6500	5200	3900	3900	3900	2600	2600	2600	2600	2600
Mower	39560	20966.8	1186.8	1186.8	791.2	791.2	791.2	791.2	395.6	395.6	395.6	791.2	395.6
Maintenance incl Repair/Lubrication /Service Labour	1204.982	1225.962	1247.361	1269.189	1291.452	1314.161	1337.325	1360.951	1385.05	1409.631	18841.1	1460.278	1486.3633
Tractor	966.891	983.1088	999.651	1016.524	1033.734	1051.289	1069.195	1087.459	1106.088	1125.09	1144.472	1164.241	1184.4059
Mower	238.0914	242.8532	247.7103	252.6645	257.7178	262.8721	268.1296	273.4922	278.962	284.5413	17696.63	296.0367	301.95746
Labour	17334	17680.68	18034.29	18394.98	18762.88	19138.14	19520.9	19911.32	20309.54	20715.73	21130.05	21552.65	21983.703
Manager	8910	9088.2	9269.964	9455.363	9644.471	9837.36	10034.11	10234.79	10439.49	10648.27	10861.24	11078.47	11300.034
Operator	8424	8592.48	8764.33	8939.616	9118.409	9300.777	9486.792	9676.528	9870.059	10067.46	10268.81	10474.19	10683.669
Housing	2880	2937.6	2996.352	3056.279	3117.405	3179.753	3243.348	3308.215	3374.379	3441.867	3510.704	3580.918	3652.5364
Delivery/Trucking	3061.8	3123.036	3185.497	3249.207	3314.191	3380.475	3448.084	3517.046	3587.387	3659.134	3732.317	3806.963	3883.1027
Fuel	6993.216	7133.08	7275.742	7421.257	7569.682	7721.076	7875.497	8033.007	8193.667	8357.54	8524.691	8695.185	8869.0888
Tractor	5405.94	5514.059	5624.34	5736.827	5851.563	5968.595	6087.966	6209.726	6333.92	6460.599	6589.811	6721.607	6856.039
Mower	1587.276	1619.022	1651.402	1684.43	1718.119	1752.481	1787.531	1823.281	1859.747	1896.942	1934.881	1973.578	2013.0498
Net Present Value	201034	88921.1	39025.89	35484.47	32946.61	30890.36	29935.44	29011.25	26969.09	26157.91	36057.87	24841.38	23871.84
Total Present Costs over 20 Years	795885.4												

Time (Yrs)	13	14	15	16	17	18	19	20
MD-355: 11'8" Cutting Radius								
Costs	42364.77	44079.4338	44001.5025	46144.501	45704.359	46581.4137	47080.41	68390.89817
Machine Costs	1695.6	2600	1695.6	2995.6	1695.6	1695.6	1300	1695.6
Tractor	1300	2600	1300	2600	1300	1300	1300	1300
Mower	395.6	0	395.6	395.6	395.6	395.6	0	395.6
Maintenance incl Repair/Lubrication /Service Labour	1512.9706	1540.11	1567.7922	1596.028	1624.8286	1654.20518	1684.16928	21717.13267
Tractor	1204.974	1225.95345	1247.35252	1269.1796	1291.4432	1314.15203	1337.31507	1360.94137
Mower	307.99661	314.156546	320.439677	326.84847	333.38544	340.053149	346.854212	20356.1913
Labour	22423.377	22871.8449	23329.2818	23795.867	24271.785	24757.2205	25252.3649	25757.41216
Manager	11526.035	11756.5558	11991.6869	12231.521	12476.151	12725.6741	12980.1875	13239.7913
Operator	10897.342	11115.2891	11337.5949	11564.347	11795.634	12031.5464	12272.1773	12517.62086
Housing	3725.5871	3800.09884	3876.10081	3953.6228	4032.6953	4113.34919	4195.61618	4279.5285
Delivery/Trucking	3960.7648	4039.98008	4120.77968	4203.1953	4287.2592	4373.00436	4460.46445	4549.673737
Fuel	9046.4706	9227.4	9411.948	9600.187	9792.1907	9988.03451	10187.7952	10391.5511
Tractor	6993.1598	7133.02302	7275.68348	7421.1972	7569.6211	7721.01352	7875.43379	8032.942466
Mower	2053.3108	2094.37697	2136.26451	2178.9898	2222.5696	2267.02099	2312.36141	2358.608639
Net Present Value	22466.942	22263.1094	21165.475	21139.327	19940.66	19355.5395	18631.3169	25775.81024
Total Present Costs over 20 Years								

Figure 6. Cost Analysis for MD-355 Mower

Time (Yrs)	0	1	2	3	4	5	6	7	8	9	10	11	12
(Current Machinery Estimate)RF-220: 7' Cutting Radius	Requiring 10 days at 9 hours/day for 2 operators and 1 manager with 90 machine hours per person and 180 labour hours												
Costs	208402.7	107503.1	64748.21	62829.02	62646.55	62476.53	63629.12	64804.76	64308.31	65531.45	78241.04	68447.19	69349.591
Machine Costs	156050	54106.5	10286.8	7281.5	5991.2	4691.2	4691.2	4691.2	2995.6	2995.6	2995.6	3391.2	2995.6
Tractor	130000	40300	9100	6500	5200	3900	3900	3900	2600	2600	2600	2600	2600
Mower	26050	13806.5	1186.8	781.5	791.2	791.2	791.2	791.2	395.6	395.6	395.6	791.2	395.6
Maintenance incl Repair/Lubrication /Service Labour	1904.304	1939.27	1974.935	2011.314	2048.42	2086.269	2124.874	2164.252	2204.417	2245.385	13749.17	2329.796	2373.2722
Tractor	1507.485	1534.515	1562.085	1590.207	1618.891	1648.149	1677.992	1708.431	1739.48	1771.15	1803.453	1836.402	1870.0098
Mower	396.819	404.7554	412.8505	421.1075	429.5296	438.1202	446.8826	455.8203	464.9367	474.2354	11945.72	493.3945	503.26244
Labour	28890	29467.8	30057.16	30658.3	31271.47	31896.89	32534.83	33185.53	33849.24	34526.22	35216.75	35921.08	36639.505
Manager	14850	15147	15449.94	15758.94	16074.12	16395.6	16723.51	17057.98	17399.14	17747.12	18102.07	18464.11	18833.391
Operator	14040	14320.8	14607.22	14899.36	15197.35	15501.29	15811.32	16127.55	16450.1	16779.1	17114.68	17456.98	17806.115
Housing	4800	4896	4993.92	5093.798	5195.674	5299.588	5405.58	5513.691	5623.965	5736.444	5851.173	5968.197	6087.5606
Delivery/Trucking	5103	5205.06	5309.161	5415.344	5523.651	5634.124	5746.807	5861.743	5978.978	6098.557	6220.529	6344.939	6471.8379
Fuel	11655.36	11888.47	12126.24	12368.76	12616.14	12868.46	13125.83	13388.34	13656.11	13929.23	14207.82	14491.98	14781.815
Tractor	9009.9	9190.098	9373.9	9561.378	9752.606	9947.658	10146.61	10349.54	10556.53	10767.66	10983.02	11202.68	11426.732
Mower	2645.46	2698.369	2752.337	2807.383	2863.531	2920.802	2979.218	3038.802	3099.578	3161.57	3224.801	3289.297	3355.0829
Net Present Value	208402.7	102383.9	58728.53	54274.07	51539.47	48952	47481.03	46055.53	43526.4	42242.15	48033.21	40019.65	38616.447
Total Present Costs over 20 Years	1104753												

	13	14	15	16	17	18	19	20
	69373.551	71628.3897	72101.4374	74806.434	74939.531	76401.2895	77496.6833	99415.49695
	1695.6	2600	1695.6	2995.6	1695.6	1695.6	1300	1695.6
	1300	2600	1300	2600	1300	1300	1300	1300
	395.6	0	395.6	395.6	395.6	395.6	0	395.6
	2417.6176	2462.85	2508.987	2556.0467	2604.0477	2653.00863	2702.9488	22756.28778
	1904.29	1939.25576	1974.92087	2011.2993	2048.4053	2086.25338	2124.85845	2164.235616
	513.32769	523.594243	534.066128	544.74745	555.6424	566.755248	578.090353	20592.05216
	37372.296	38119.7415	38882.1363	39659.779	40452.975	41262.0341	42087.2748	42929.02027
	19210.058	19594.2596	19986.1448	20385.868	20793.585	21209.4568	21633.6459	22066.31883
	18162.237	18525.4818	18895.9915	19273.911	19659.39	20052.5773	20453.6289	20862.70144
	6209.3118	6333.49806	6460.16802	6589.3714	6721.1588	6855.58199	6992.69363	7132.547501
	6601.2746	6733.30013	6867.96613	7005.3255	7145.432	7288.3406	7434.10741	7582.789562
	15077.451	15379	15686.58	16000.312	16320.318	16646.7242	16979.6587	17319.25184
	11655.266	11888.3717	12126.1391	12368.662	12616.035	12868.3559	13125.723	13388.23744
	3422.1846	3490.62829	3560.44085	3631.6497	3704.2827	3778.36832	3853.93568	3931.014398
	36790.275	36177.2041	34682.0242	34269.689	32695.869	31746.3138	30668.0691	37468.65523

Figure 7. Cost Analysis for RF-220 Mower (Current Mower)

Figure 8. 10' Universal Rockblock™

https://shop.therockblock.net/

Figure 9. 200 Gallon Qspray Weed Trailer with Folding Boom

https://www.qspray.com/power-sprayers/power-spray-rigs-by-vehicle-type/trailer-tow-behind-sprayers/?sort=bestselling&page=1

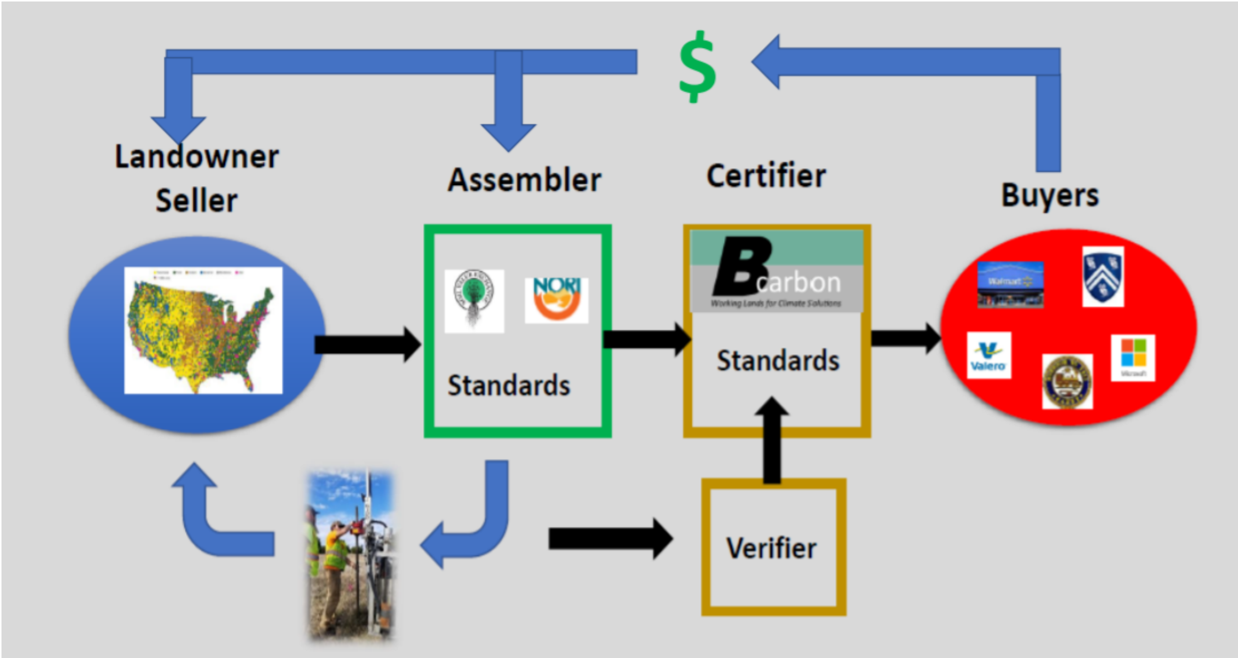


Figure 10. VCMs Structure Breakdown [Blackburn, J. (2021)]

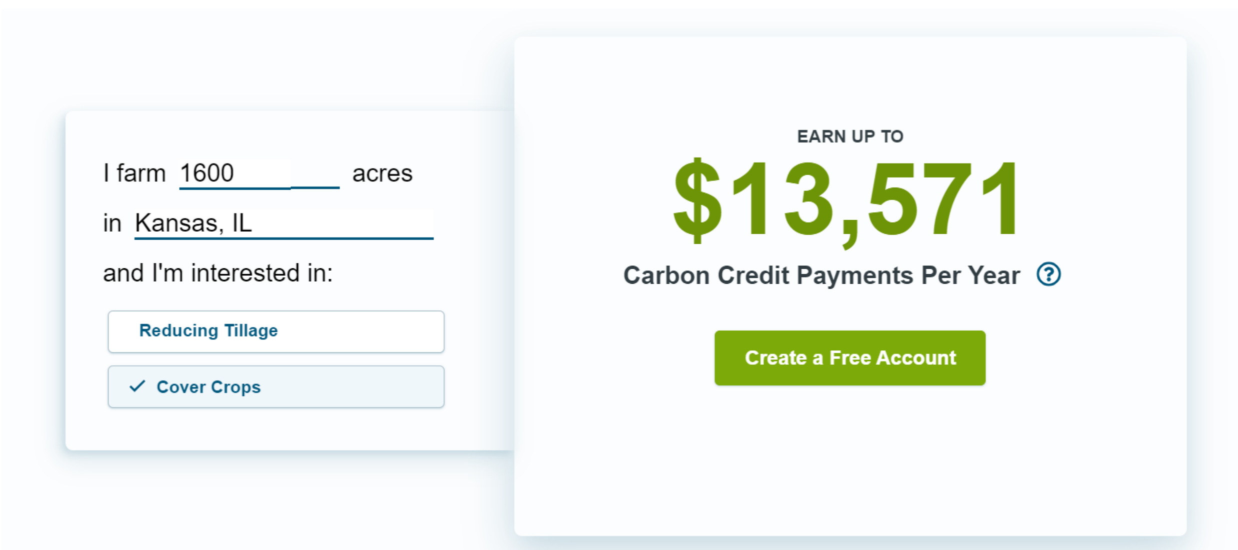


Figure 11. Cover Crop Indigo Ag Estimation for 1600 Acre Farm Land [Indigo Ag 2021]

	A	B	C	D	E
1	Organization/ Registry	Cropping System	Minimum Required Commitment	Requency of Monitoring	Emission Factors?
2	B Carbon Rice University	cropland or grazing lands that sequester carbon	10 year “rolling commitment”	every 5 years with annual updates	C02 Only
3	Indigo Ag	Adding cover crops, increasing cover crop diversity, and diversifying crop rotation	5 year mimimum	every 5 years with annual updates	Yes; Emissions factors are used in conjunction with project data in the protocol equations
4	Verra	cropland, grassland, and rangeland	30 years	10 years, need models to support between periods	C02, N20 and CH4
5	Climate Action Reserve	cropland, grassland, and rangeland	20 years minimum with 100-year permanence timeframe	every 5 years with annual updates	Yes; Emissions factors are used in conjunction with project data in the protocol equations

Figure 12. Certification Chart Summarization

Time (Yrs)	0	1	2	3	4	5	6	7	8	9
Solar Grazing										
Costs	$126,749.93	$85,446.23	$80,371.93	$81,927.38	$83,513.93	$87,031.20	$88,681.85	$88,466.54	$90,183.88	$91,935.56
Grazing Contract		$ 72,672.93	$ 74,126.39	$ 75,608.92	$ 77,121.10	$ 78,663.52	$ 80,236.79	$ 81,841.53	$ 83,478.36	$ 85,147.92
Grazing Price Per Acre	$ 63.75									
Grazable Acres	1,140									
Fencing	$ 35,016.67	$ 1,778.82	$ 1,807.37	$ 1,836.49	$ 1,866.19	$ 1,896.49	$ 1,927.39	$ 1,958.91	$ 1,991.06	$ 2,023.85
Electronet	$ 27,488.67	$ 1,401.92	$ 1,429.96	$ 1,458.56	$ 1,487.73	$ 1,517.49	$ 1,547.84	$ 1,578.79	$ 1,610.37	$ 1,642.58
Energizers	$ 7,028.00	$ 351.40	$ 351.40	$ 351.40	$ 351.40	$ 351.40	$ 351.40	$ 351.40	$ 351.40	$ 351.40
Posts and Gates	$ 500.00	$ 25.50	$ 26.01	$ 26.53	$ 27.06	$ 27.60	$ 28.15	$ 28.72	$ 29.29	$ 29.88
Water Infrastructure	$ 46,769.26	$ 2,147.03	$ 2,189.97	$ 2,233.77	$ 2,278.44	$ 4,222.99	$ 4,269.47	$ 2,417.90	$ 2,466.26	$ 2,515.59
Water Source (well)	$ 30,000.00	$ 612.00	$ 624.24	$ 636.72	$ 649.46	$ 662.45	$ 675.70	$ 689.21	$ 703.00	$ 717.06
Troughs	$ 15,049.30	$ 1,535.03	$ 1,565.73	$ 1,597.04	$ 1,628.98	$ 1,661.56	$ 1,694.80	$ 1,728.69	$ 1,763.27	$ 1,798.53
Water storage	$ 1,719.96	$ -	$ -	$ -	$ -	$ 1,898.97	$ -	$ -	$ -	$ -
Transport/Equipment	$ 44,964.00	$ 8,847.45	$ 2,248.20	$ 2,248.20	$ 2,248.20	$ 2,248.20	$ 2,248.20	$ 2,248.20	$ 2,248.20	$ 2,248.20
UTV	$ 7,000.00	$ 1,400.00	$ 350.00	$ 350.00	$ 350.00	$ 350.00	$ 350.00	$ 350.00	$ 350.00	$ 350.00
UTV utility trailer	$ 969.00	$ 48.45	$ 48.45	$ 48.45	$ 48.45	$ 48.45	$ 48.45	$ 48.45	$ 48.45	$ 48.45
Livestock trailer	$ 30,000.00	$ 6,000.00	$ 1,500.00	$ 1,500.00	$ 1,500.00	$ 1,500.00	$ 1,500.00	$ 1,500.00	$ 1,500.00	$ 1,500.00
Handling System	$ 6,995.00	$ 1,399.00	$ 349.75	$ 349.75	$ 349.75	$ 349.75	$ 349.75	$ 349.75	$ 349.75	$ 349.75
Net Present Value	$126,749.93	$81,377.37	$72,899.71	$70,771.95	$68,707.12	$68,191.22	$66,175.76	$62,871.52	$61,040.00	$59,262.48
Total Present Costs Over 20 yrs	$1,331,083.92									
Grazing Contract NPV	$0.00	$69,212.32	$67,234.82	$65,313.83	$63,447.72	$61,634.93	$59,873.93	$58,163.25	$56,501.44	$54,887.11
Total Present Costs for Grazing Contract Over 20 yrs	$1,065,777.77									
Grazing Contract + Water Source NPV	$30,000.00	$69,795.17	$67,801.03	$65,863.85	$63,982.03	$62,153.97	$60,378.14	$58,653.05	$56,977.25	$55,349.33
Total Present Costs for Grazing Contract + Water Source Over 20 yrs	$1,104,753.00									

10	11	12	13	14	15	16	17	18	19	20
$148,494.44	$104,540.49	$98,011.61	$99,907.69	$101,841.69	$106,129.21	$108,141.35	$107,878.89	$109,972.32	$112,107.61	$116,841.38
$ 86,850.88	$ 88,587.90	$ 90,359.66	$ 92,166.85	$ 94,010.19	$ 95,890.39	$ 97,808.20	$ 99,764.36	$101,759.65	$103,794.84	$105,870.74
$ 2,057.30	$ 2,091.42	$ 2,126.22	$ 2,161.72	$ 2,197.92	$ 2,234.85	$ 2,272.52	$ 2,310.94	$ 2,350.14	$ 2,390.11	$ 2,430.88
$ 1,675.43	$ 1,708.94	$ 1,743.11	$ 1,777.98	$ 1,813.54	$ 1,849.81	$ 1,886.80	$ 1,924.54	$ 1,963.03	$ 2,002.29	$ 2,042.34
$ 351.40	$ 351.40	$ 351.40	$ 351.40	$ 351.40	$ 351.40	$ 351.40	$ 351.40	$ 351.40	$ 351.40	$ 351.40
$ 30.47	$ 31.08	$ 31.71	$ 32.34	$ 32.99	$ 33.65	$ 34.32	$ 35.01	$ 35.71	$ 36.42	$ 37.15
$ 4,581.11	$ 2,617.22	$ 2,669.56	$ 2,722.95	$ 2,777.41	$ 5,147.80	$ 5,204.46	$ 2,947.41	$ 3,006.36	$ 3,066.49	$ 5,683.59
$ 731.40	$ 746.02	$ 760.95	$ 776.16	$ 791.69	$ 807.52	$ 823.67	$ 840.14	$ 856.95	$ 874.09	$ 891.57
$ 1,834.50	$ 1,871.19	$ 1,908.62	$ 1,946.79	$ 1,985.72	$ 2,025.44	$ 2,065.95	$ 2,107.27	$ 2,149.41	$ 2,192.40	$ 2,236.25
$ 2,015.21	$ -	$ -	$ -	$ -	$ 2,314.84	$ -	$ -	$ -	$ -	$ 2,555.77
$ 55,005.15	$ 11,243.95	$ 2,856.17	$ 2,856.17	$ 2,856.17	$ 2,856.17	$ 2,856.17	$ 2,856.17	$ 2,856.17	$ 2,856.17	$ 2,856.17
$ 8,703.62	$ 2,164.37	$ 541.09	$ 541.09	$ 541.09	$ 541.09	$ 541.09	$ 541.09	$ 541.09	$ 541.09	$ 541.09
$ 1,204.83	$ 60.24	$ 60.24	$ 60.24	$ 60.24	$ 60.24	$ 60.24	$ 60.24	$ 60.24	$ 60.24	$ 60.24
$ 36,569.83	$ 7,313.97	$ 1,828.49	$ 1,828.49	$ 1,828.49	$ 1,828.49	$ 1,828.49	$ 1,828.49	$ 1,828.49	$ 1,828.49	$ 1,828.49
$ 8,526.87	$ 1,705.37	$ 426.34	$ 426.34	$ 426.34	$ 426.34	$ 426.34	$ 426.34	$ 426.34	$ 426.34	$ 426.34
$91,162.70	$61,122.66	$54,576.53	$52,983.18	$51,436.97	$51,049.97	$49,540.80	$47,067.20	$45,695.77	$44,364.79	$44,036.29
$53,318.91	$51,795.51	$50,315.64	$48,878.05	$47,481.53	$46,124.92	$44,807.06	$43,526.86	$42,283.24	$41,075.14	$39,901.57
$53,767.92	$52,231.70	$50,739.36	$49,289.67	$47,881.39	$46,513.35	$45,184.40	$43,893.41	$42,639.32	$41,421.05	$40,237.59

Figure 13. Solar Grazing Cost Analysis

Ram to Ewe Ratio	0.01	Lamb crop	200%
Number of Ewes	1330	Lamb death rate	5%
Number of Rams	13	End of grazing season lamb crop	195%
Number of Lambs birthed	2660	Number of Lambs at end of season	2527
Total Livestock	4003		
Weighted average of Slaughter lamb prices $/cwt		$228.67	
Minimum cwt per Katahdin lamb @ 1 year		0.7	
cwt of lamb produced		1769	
Revenue from lamb sale		$404,494.36	
Grazing Contract Revenue		$ 72,675.00	
Expenses		$126,749.93	
	Profit:	$350,419.43	

Figure 14. Estimated Profit for Sheep Grazier at Grazing Contract Price of $63.75/acre

Ram to Ewe Ratio	0.01	Lamb crop	200%
Number of Ewes	1330	Lamb death rate	5%
Number of Rams	13	End of grazing season lamb crop	195%
Number of Lambs birthed	2660	Number of Lambs at end of season	2527
Total Livestock	4003		

Weighted average of Slaughter lamb prices $/cwt	$228.67
Minimum cwt per Katahdin lamb @ 1 year	0.7
cwt of lamb produced	1769
Revenue from lamb sale	$404,494.36
Grazing Contract Revenue	$ -
Expenses	$126,749.93
Profit:	$277,744.43

Figure 15. Estimated Profit of Sheep Grazier With No Grazing Contract

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