

Maximizing Land Use Benefits From Utility-Scale Solar

A Cost-Benefit Analysis of Pollinator-Friendly Solar in Minnesota



Photo courtesy of Rob Davis, Fresh Energy

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Executive Summary

As utility-scale solar development expands throughout the United States, with an expected land footprint of 3 million acres by 2030,¹ there is growing interest across various stakeholder groups in adopting land use best practices for new projects. Pollinator-friendly solar, which incorporates native grasses and wildflowers throughout a solar installation, is one approach to cultivating additional land use benefits from solar projects. The practice is increasingly common, especially in Minnesota, the first state to adopt a voluntary pollinator-friendly solar standard. However, research has yet to produce a comprehensive cost-benefit analysis that assesses both private and social returns from pollinator-friendly solar, as compared to conventional solar or pre-existing agricultural land uses.

To conduct a cost-benefit analysis of these three land uses in Minnesota, we developed a solar project finance model alongside a farm cash flow model. The model incorporates environmental externalities — including carbon emissions, soil erosion, and groundwater recharge — associated with land devoted to conventional solar, pollinator-friendly solar, and farming.

Our analysis reveals that pollinator-friendly solar may generate private benefits to solar developers that justify its adoption without policy intervention. These benefits largely flow from higher energy output, from panel efficiency gains attributed to the cooler microclimate created by perennial plantings. A small added benefit accrues from the lower operations and maintenance (O&M) costs over the project lifetime thanks to the reduced frequency of mowings for native plants as compared to turfgrass. However, we hypothesize that information and behavioral failures are currently preventing developers from adopting the practice. Thus, there may be a role for policy to spur the incorporation of pollinator-friendly practices in future solar development.

That role becomes clearer when we evaluate the social benefits associated with these projects. As with conventional solar, a large social benefit of pollinator-friendly solar stems from the carbon emissions that solar energy production avoids. Pollinator-friendly solar also results in more groundwater recharge and a greater reduction in soil erosion than either conventional solar or farming — two additional ecosystem benefits. Lastly, pollinator-friendly solar contributes another sizable social benefit in the form of increased crop yields when projects are sited near pollinator-dependent farmland. In our model, improved crop yields result from projects co-located with farmland producing soy, but not corn, which is not pollinator-dependent. That benefit could be even greater if the adjacent crop were highly pollinator-dependent, as is the case for most specialty crops.

¹ Jordan Macknick, Brenda Beatty, and Graham Hill, “Overview of Opportunities for Co-Location of Solar Energy Technologies and Vegetation,” U.S. Department of Energy National Renewable Energy Laboratory, December 2013, <https://www.nrel.gov/docs/fy14osti/60240.pdf>.

The added social benefits that pollinator-friendly solar contribute relative to conventional solar and farming warrant policy intervention. Governmental research and development funding could help support studies that are underway with a goal of providing more detail on the localized impacts of this practice. Research is needed to better understand the panel efficiency gains and potential private benefits, as well as the social benefits flowing from the ecosystem services that pollinator-friendly solar projects provide. Additionally, site-specific policies, which would drive maximal benefit from increased crop yields and ecosystem services, merit consideration. These policies could be targeted at either a solar developer or a farmer: states could provide extra incentive for developers to site their pollinator-friendly projects near specialty crop farms, or they could educate farmers and incentivize them to grow specialty crops if their land abuts a pollinator-friendly solar site.

As Minnesota pursues its renewable portfolio standard target of 10% of energy produced from solar by 2030, there is large potential for pollinator-friendly solar development to deliver ecosystem and agricultural benefits for the state, in addition to the zero-carbon electricity generation that a solar project already provides. Our research shows that pollinator-friendly solar yields benefits for a range of stakeholders, from developers to farmers to surrounding communities. In the near term, there are opportunities for research and education to generate a more robust understanding of the practice, and in the long-term, the environmental and social externalities could be monetized and captured by astute policymakers.

Introduction | 06

The Model: Inputs, Assumptions and Methodology | 09

MODEL DESCRIPTION | 09

MODEL INPUTS AND ASSUMPTIONS | 10

MODEL METHODOLOGY | 10

Results | 12

FARM MODEL | 12

COMPARING FARMLAND TO CONVENTIONAL SOLAR | 13

COMPARING FARMLAND TO POLLINATOR-FRIENDLY SOLAR | 15

COMPARING POLLINATOR-FRIENDLY TO CONVENTIONAL SOLAR | 16

COMPARING PRIVATE AND SOCIAL BENEFITS ACROSS ALL THREE LAND USES | 18

EXTRAPOLATING SOCIAL BENEFITS ACROSS MINNESOTA | 19

Sensitivity Analysis | 20

Policy Implications | 21

PRIVATE BENEFITS | 22

SOCIAL AND ENVIRONMENTAL BENEFITS | 23

LOCATION-SPECIFIC BENEFITS | 23

Future Research Applications | 24

Conclusion | 25

Introduction

Utility-scale solar development has expanded rapidly across the U.S. in recent years, driven by declining costs and improving technology. The most recent Lazard levelized cost of energy (LCOE) analysis shows utility-scale solar now equivalent to or below the cost of conventional generation, with a price range of \$36-44 per megawatt-hour (MWh).² Thirty-two gigawatts (GW) of utility-scale solar have been installed in the United States to date, and another 50 GW are planned or in development. By 2030, the Department of Energy SunShot program estimates that solar development will encompass between 1 to 3 million acres of land.³ As the geographic footprint of solar increases beyond the arid southwestern United States, so too has interest in the land use under the panels.

In these new geographies, including the Midwest and Northeast, solar is often sited on agricultural land. The ideal tract of land for solar development is flat, dry, unshaded, and close to transmission and load. All of these characteristics are associated with farmland, raising possible tensions between solar and farming as competing land uses.⁴ For the most part, solar developers plant shallow-rooted turfgrass or spread gravel under panels, rendering that land unproductive aside from the generation of electricity. However, the co-location of solar projects and innovative vegetation management plans offers the potential to ameliorate this potential land use conflict. Improving the “landscape compatibility” of utility-scale solar has become a topic of great interest in the energy, land use and agricultural research communities.⁵ Examples of co-location include growing crops underneath solar trackers; grazing cattle or sheep among elevated solar panels that also provide shade for the livestock; and installing solar in the non-irrigated corners of center-pivot irrigation plots.⁶ These approaches can be grouped under the recently coined umbrella term “agrivoltaics.”⁷

Co-location can also refer to measures that restore habitat and improve ecosystem functions. This is the idea behind the development of pollinator-friendly solar sites: the planting, throughout a solar project

2 Douglas Ray, “Lazard’s Levelized Cost of Energy Analysis—Version 11.0,” Lazard, November, 2018, <https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf>.

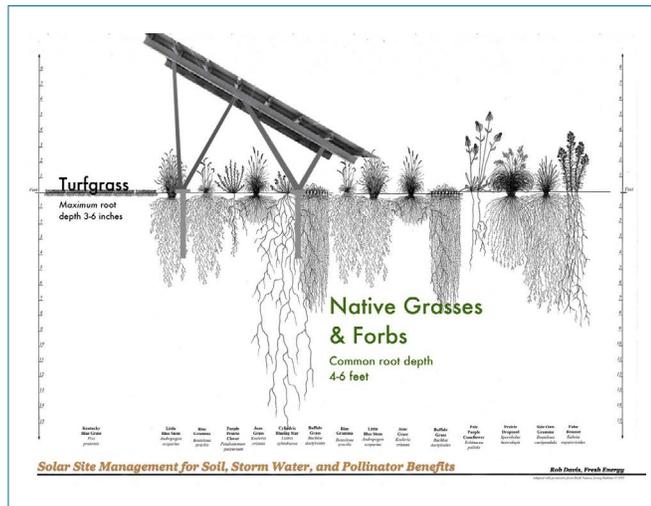
3 Macknick, “Overview of Opportunities.”

4 Travis Grout and Jennifer Ifft, “Approaches to Balancing Solar Expansion and Farmland Preservation: A Comparison across Selected States,” *Cornell University, Dyson School of Applied Economics and Management*, May, 2018, <https://dyson.cornell.edu/wp-content/uploads/sites/5/2019/02/Cornell-Dyson-eb1804.pdf>.

5 Leroy J. Walston, Shruti K. Mishra, Heidi M. Hartmann, Ihor Hlohowskyj, James McCall, and Jordan Macknick, “Examining the Potential for Agricultural Benefits from Pollinator Habitat at Solar Facilities in the United States,” *Environmental Science & Technology* 52, no. 13 (May 2018): 7566—76, <https://pubs.acs.org/doi/pdf/10.1021/acs.est.8b00020>.

6 Macknick, “Overview of Opportunities.”

7 Dinesh Harshavardhan and Joshua M. Pearce, “The Potential of Agrivoltaic Systems,” *Renewable and Sustainable Energy Reviews*, 54 (February 2016): 299-308, <http://www.sciencedirect.com/science/article/pii/S136403211501103X>.



footprint, of native grasses and wildflowers that are beneficial to insect pollinators. This practice offers both ecological and economic benefits. From an ecosystem services perspective, pollinator-friendly solar can provide habitat to threatened species such as honeybees — thereby preserving biodiversity and increasing pollination of nearby crops. The deep-rooted native plants also improve soil quality and carbon sequestration, reduce erosion, boost groundwater recharge, reduce runoff and improve water quality

thanks to avoided fertilizer application. From an economic perspective, private benefits accrue to nearby farmers if they are growing pollinator-dependent crops that would benefit from the increased pollination services. Crops that are pollinator dependent include soy, cotton and beans on the low end, and specialty crops such as almonds, cranberries, apples and melons on the highly-dependent end.⁸ Solar developers can also benefit: preliminary research shows that native vegetation creates a cooler microclimate around solar panels, boosting panel efficiency and translating to additional revenue gains.⁹ Additionally, pollinator-friendly plantings require less mowing and improve the aesthetic appeal of the project, leading to reduced operations and maintenance costs over the lifetime of the project and the potential for a smoother permitting process due to reduced community opposition.¹⁰

Despite the growing interest in pollinator-friendly solar, a comprehensive cost-benefit analysis of the practice has yet to be completed. As Macknick et al. note, “additional research could help quantify potential benefits and costs associated with different levels and types of co-location”¹¹; this would help solar developers and policymakers more fully account for the range of private and social impacts of these projects. Our research question attempts to fill this literature gap: what are the relative costs and benefits of pollinator-friendly solar as compared to conventional solar as well as status quo land uses such as corn and soy farming in Minnesota? The goal is to shed light on land use decisions between agriculture and solar in Minnesota, and to explore whether or how pollinator-friendly projects might add value.

We chose to focus on Minnesota for several reasons. As with many of its Midwestern neighbors, farming comprises a large share of the state economy: agriculture is the second largest economic sector in the

⁸ Walston et al., “Examining the Potential.”

⁹ Elnaz Hassanpour Adeh, John S. Selker, and Chad W. Higgins, “Remarkable Agrivoltaic Influence on Soil Moisture, Micrometeorology and Water-Use Efficiency,” *PLOS ONE* 13, no. 11 (November 2018), <https://doi.org/10.1371/journal.pone.0203256>.

¹⁰ Rob Davis (director, Center for Pollinators in Energy, Fresh Energy), interview with the authors.

¹¹ Macknick, “Overview of Opportunities.”

state, and farmland encompasses 26.9 million acres — 54% of Minnesota’s total land area.¹² Thus, the state offers a fitting case study to examine the pitfalls and benefits that pollinator-friendly solar presents as contrasted to farmland. Solar development in the state is also growing rapidly. Minnesota had 1.2 GW installed as of Q2 2019¹³, and the state renewable portfolio standard (RPS) includes a 10% solar target by 2030, which represents approximately 6 GW of installed capacity. With solar’s land footprint estimated at 7 acres per MW, this new solar development would only encompass a small fraction of the state’s farmland acreage; however, solar siting remains a topic of concern in the agricultural community.¹⁴ Thus, solar advocates in the state began to examine the potential for novel siting practices that could assuage farmers’ concerns.

In 2016, Minnesota passed, HF 3353, the first voluntary pollinator-friendly solar standard. Developers choosing to certify their project as “pollinator-friendly” are required to complete a “Habitat Assessment Scorecard” that rates their vegetation management plan according to several criteria, including species diversity and percent of site planted with native grasses and wildflowers. If the project meets the relevant standard, the project owner is able to claim their project is pollinator-friendly, which advocates expect would boost public approval and facilitate project permitting. Ongoing research aims to highlight additional benefits these projects might generate, yet a full accounting of the private and social benefits has yet to be modeled. Nevertheless, developers have already expressed interest, and in some cases, have incorporated pollinator-friendly practices into their projects. For example, Enel Green Power North America worked with the Minnesota’s Department of Natural Resources and Department of Agriculture to shape the Minnesota standard, and has since implemented one of the first pollinator-friendly projects in the state. Similarly, Cypress Creek Renewables has committed to pollinator-friendly solar projects for a portion of its portfolio.

Since the implementation of Minnesota’s voluntary standard, roughly 50% of the new solar acreage in the state has been developed as pollinator-friendly projects¹⁵; additionally, Xcel Energy recently announced they will be requiring vegetation management plans for all future solar requests-for-proposals, with an eye towards prioritizing pollinator-friendly projects.¹⁶

12 “Minnesota Agriculture: The Foundation of Minnesota’s Economy,” Minnesota Department of Agriculture, 2007, <https://www.leg.state.mn.us/docs/2008/other/o80928.pdf>.

13 “Minnesota Solar,” Minnesota Solar Energy Industries Association, 2019, <https://www.seia.org/state-solar-policy/minnesota-solar>.

14 Davis, interview.

15 Frank Jossi, “Putting the ‘Farm’ Back in Solar Farms: Study to Test Ag Potential at PV Sites,” Midwest Energy News, January 22, 2018, <https://energynews.us/2018/01/22/midwest/putting-the-farm-back-in-solar-farms-study-to-test-crop-potential-at-pv-sites/>.

16 Catherine Morehouse, “In Bid to Help Bees, Xcel to Require Vegetation Disclosure in Solar RFPs,” Utility Dive, October 12, 2018, <https://www.utilitydive.com/news/in-bid-to-help-bees-xcel-to-require-vegetation-disclosure-in-solar-rfps/539521/>.

Other states are also following suit: Maryland, New York, Vermont and Illinois have all passed voluntary standards similar to Minnesota's, indicating that they also recognize the land use and goodwill benefits associated with encouraging the practice. These policies are light-touch, business-friendly interventions; if pollinator-friendly solar indeed provides additional quantifiable private and/or social benefits, more robust policy measures may be warranted. Future policy development should be informed by the monetized private and social/environmental costs and benefits — as well as an understanding of the various actors who stand to benefit. Thus, we developed a model that quantifies costs and benefits of land used for corn and soy farming, conventional solar, and pollinator-friendly solar in Minnesota. The remainder of this paper proceeds as follows: first, discussion of our methodology, assumptions and model; next, presentation of results, sensitivity analyses and sources of uncertainty; and finally, the policy implications of our findings.

The Model: Inputs, Assumptions and Methodology

Model Description

We developed an Excel-based modelling tool to understand the tradeoffs, costs and benefits between maintaining land as conventional farmland or converting a portion of it to either a conventional solar facility or a pollinator-friendly solar facility. The model accounts for spatial, economic and environmental differences across three counties in South-central Minnesota: Fillmore, Hennepin and Rock. The model is designed as a cash-flow project finance model that incorporates monetized environmental and social costs and benefits. As project finance is the predominant method for financing solar projects in the United States, and a large proportion of a project's financial return is delivered through preferred tax status and tax credits, we modeled both pre- and post-tax cash flows from the solar projects.¹⁷ Our model also includes a cash-flow operating model for a conventional soy or corn farm. For all land uses, the model incorporates the monetized value of environmental externalities, including carbon emissions, soil erosion and groundwater recharge. Not all externalities and ecosystem services were modeled, due to data limitations and difficulties in quantifying benefits such as habitat creation and biodiversity. We created multiple scenarios within the model to analyze differences in private and social value streams across counties, crop type, and a range of upside and downside inputs.

The model outputs are a series of cost-benefit analyses comparing the three main land uses — pollinator-friendly solar, conventional solar, and farming. The financial return of each use varies by crop type, location and upside/downside scenarios.

¹⁷ Chris Groobey, John Pierce, Michael Faber, and Greg Broome, "Project Finance Primer for Renewable Energy and Clean Tech Projects," Wilson Sonsini Goodrich & Rosati, 2010, https://www.wsgr.com/PDFSearch/ctp_guide.pdf.

Model Inputs and Assumptions

KEY MODEL ASSUMPTIONS	
	<p>Conventional Solar Assumptions</p> <ul style="list-style-type: none"> • 10 MW solar project, full investment tax credit • National average install costs (SEIA) • Solar land footprint: 7 acre/MW
	<p>Pollinator-Friendly Solar Assumptions</p> <ul style="list-style-type: none"> • 5% installation cost premium • 0.4% efficiency gain (microclimate) • O&M cost savings (less)
	<p>Conventional Farming Assumptions</p> <ul style="list-style-type: none"> • Soy is pollinator dependent, corn is not • Pollinator range 1.5km • 50% surrounding land area actively farmed
	<p>Other Model and Analysis Assumptions</p> <ul style="list-style-type: none"> • \$10/ton social cost of carbon • Constant grid emission factor • 1.5–2% revenue cost escalation

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Model Methodology

The base of the operating model is a solar project cash flow and finance structure, modeled from hypothetical but realistic inputs. Annual electricity generation is calculated based on technology specifications from a Sunpower Model E series 320-Watt solar panel, county-level irradiance data, and assumed system losses.¹⁸ The system revenue is derived from an assumed power purchase agreement (PPA) at a per-kilowatt-hour rate equal to the average PPA rate for Xcel in Minnesota.¹⁹ Annual costs are derived from the 2017 Lazard Levelized Cost of Electricity Study.²⁰ We assume the hypothetical project was leveraged with a maximum loan term of 18 years assuming a 1.4x debt service coverage ratio and a 6% fixed interest rate.

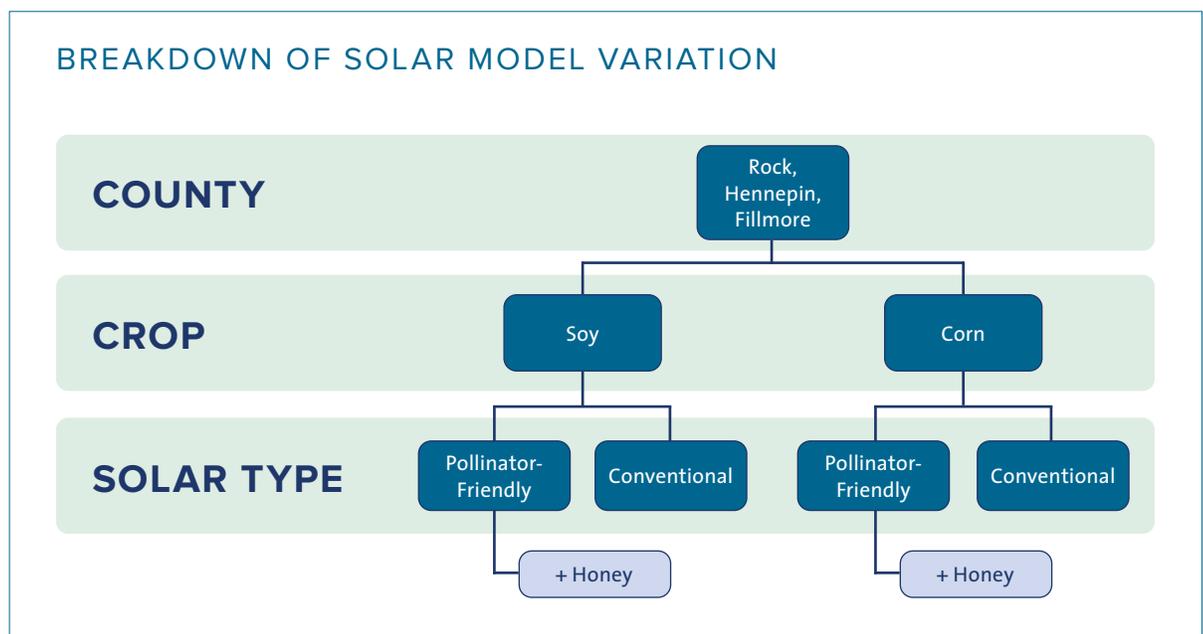
An after-tax internal rate of return (IRR) is calculated as a basis for comparing each of the potential solar project scenarios. The tax model assumes full monetization of the federal Investment Tax Credit (ITC) at the commercial operations date (COD), and all depreciation and tax benefits are captured.

¹⁸ “Sunpower E-Series Solar Panels,” Sunpower, December 2016, <https://us.sunpower.com/sites/default/files/media-library/data-sheets/ds-e20-series-327-residential-solar-panels.pdf>.

¹⁹ Letter from Aakash Chandarana, Regional Vice President, Rates and Regulatory Affairs, Xcel Energy, to Daniel P. Wolf, Executive Secretary, Minnesota Public Utilities Commission, Docket No. E-002/M-13-867, Re: Reply Comments, March 4, 2015, p. 10. 17 Minnesota Public Utilities Commission (n.d.).

²⁰ Ray, “Lazard’s Levelized Cost.”

There are seven major scenarios in the solar operating model: base case, upside, and downside cases for both the conventional solar project and pollinator-friendly solar project. The seventh case uses the same inputs as the pollinator-friendly base case but also incorporates additional revenue derived from operating an apiary on the solar site and selling the honey wholesale. The solar operating model also calculates environmental externalities as monetized benefits or costs. These externalities taken together are described as social benefits and include: carbon benefits from avoided grid emissions and soil carbon sequestration, groundwater recharge benefits, avoided soil erosion benefits, and increased crop yields resulting from the presence of native pollinators. These increased yields apply to the pollinator-friendly solar + soy farming scenarios only, as soy is moderately pollinator-dependent; in the absence of insect pollinators, soy producers use autopollination and high loads of pesticides to boost yields.²¹ To calculate the value of these externalities, we used a low-end estimate from the Minnesota Public Utility Commission’s social cost of carbon (SCC), which ranges from \$9-40/ton; Environmental Protection Agency (EPA) estimates for Minnesota groundwater recharge value; and topsoil costs that account for the impact of soil erosion.



The resulting solar project finance model is nested on top of a simple farming cash flow model we developed to compare land use practices. The farm model scenario manager assesses differences in crop types — corn and soy — and location — Fillmore, Hennepin and Rock counties. Farm input costs including seed, fertilizer, fuel, rent and machinery are modeled from U.S. Census and USDA data; these costs are specific to each county and crop type. The gross farm revenue is based on the average yield per

²¹ Marcelo de O. Milfont, Epifania M. Rocha, Afonso Odério N. Lima, and Breno M. Freitas. “Higher Soybean Production Using Honeybee and Wild Pollinators, a Sustainable Alternative to Pesticides and Autopollination,” *Environmental Chemistry Letters* 11, no 4 (April 2013): 335-41.

acre per county, multiplied by the average commodity price for each crop in Minnesota. Expenses are subtracted from revenue to calculate net income. A simple tax model calculates after tax cash-flow to the farmer and assumes the farm is fully incorporated and pays corporate income taxes (a simplifying assumption). Like the solar operating model, the farm model monetizes environmental externalities as benefits or costs.

The model calculates the private and social rents from each of the three land uses —pollinator-friendly solar, conventional solar and conventional farming — and discounts these to their net present value (NPV) for a 30-year project lifetime using a social discount rate of 3% for the base case. Lastly, total welfare gains and losses were calculated by comparing the net gain in private, social and tax benefits across all of the land uses, and in relation to the two major crop types: corn and soy. Results are discussed below, including an extrapolation to the entire state by applying per-acre and per-MW model outputs to the projected statewide solar capacity that would result from Minnesota’s 10% solar RPS carve-out. Additional sensitivity analysis tested key model inputs.

Results

Farm Model

To conduct our analysis, we started from a baseline of existing farmland. While private and social costs and benefits varied by county, we discuss results in terms of averages across the three counties. In our model, soy earns a higher price per bushel than corn, but realizes a lower net income per acre due to lower average yields. In fact, our model calculates net losses for soy, when averaged across the three counties. This is because the model does not factor in agricultural subsidies.

Our model additionally calculates the social costs and benefits associated with farmland, which encompasses carbon emissions, soil erosion, and groundwater recharge. Due to limitations in data granularity, our model assumes corn and soy farms have equivalent soil conditions and thus yield equal social costs in these categories.

Soil erosion and carbon emissions contribute \$239 and \$226, respectively, in social costs per acre. These costs stem from conventional tilling practices, common on most large-scale farms in Minnesota, as well as farming’s fertilizer and fuel inputs. Conventional tilling leaves less than 30% of crop residue as ground cover, and often involves the use of plows or chisels.²² These characteristics both cause high levels of

22 Brooke Rust and John D. Williams, “How Tillage Affects Soil Erosion and Runoff,” USDA/ARS Columbia Plateau Conservation Research Center, accessed December 18, 2018, <https://www.ars.usda.gov/ARSUserFiles/20740000/PublicResources/How%20Tillage%20Affects%20Soil%20Erosion%20and%20Runoff.pdf>.

soil erosion. On some Minnesota farms, an acre of farmland can lose more than five tons of topsoil per year due to wind erosion alone.²³ Despite soil compression and shallow root systems, row crop farming realizes small net benefits for groundwater recharge, albeit less than what would be expected on land uses or farm practices with more sustainable soil management. Conventional tilling practices additionally reduce soil's ability to sequester carbon, and row crop farming inputs such as fertilizer and fuel for machinery generate additional carbon emissions.

COSTS AND BENEFITS OF FARMING		
30-YEAR PROJECT LIFESPAN COSTS AND BENEFITS, 3% DISCOUNT RATE, \$2018		
	Corn	Soy
Private Benefits (Costs) Per Acre		
After-Tax Revenue	\$3,189.27	(\$103.68)
Net Private Benefits	\$3,189.27	(\$103.68)
Social Benefits (Costs) Per Acre		
Carbon Emissions	(\$225.73)	(\$225.73)
Cost of Soil Erosion	(\$239.49)	(\$239.49)
Value of Groundwater Recharge	\$28.84	\$28.84
Net Social Benefits	(\$436.38)	(\$436.38)
Net Benefits	\$2,752.90	(\$540.06)

Comparing Farmland to Conventional Solar

Our model's most interesting and insightful results come from comparison of costs and benefits associated with converting farmland to both conventional solar and pollinator-friendly solar. Similar to the farmland case, we generated outputs for private and social benefits and costs. We first compare farmland to conventional solar.

The private revenue per acre for conventional solar far outweighs its costs, resulting in additional net income of \$68,350 or \$71,643 per acre for a solar project (in NPV, over a 30-year project lifetime), relative to farmland used for corn and soy, respectively. Because corn has a higher per-acre value than soy, replacing corn farmland with conventional solar yields a slightly lower change in net income than the soy scenario. This difference is marginal compared to the far greater returns that accrue from solar

²³ "Reduce Wind Erosion for Long-Term Profitability," University of Minnesota Extension, accessed December 18, 2018, <https://extension.umn.edu/soil-management-and-health/reduce-wind-erosion-long-term-profitability#wind-erosion-in-minnesota-1392111>.

development compared to farming, however. Notably, despite solar’s status as a more lucrative land use, agricultural land uses are protected in many states in order to promote domestic food production.

The environmental benefits of conventional solar also surpass those of farming, primarily due to the carbon benefits of solar development. Carbon benefits account for displaced emissions from Minnesota’s grid, the relatively small life cycle emissions of the solar array compared to emissions from farming inputs, and negligible soil carbon sequestration from both land uses. Accordingly, the social benefits of conventional solar are largely driven by avoided emissions from solar as a zero-carbon generation source; this value is quantified based on Minnesota’s average grid emissions factor. The model reveals that conventional solar would yield \$14,526 per acre in carbon benefits over the 30-year lifetime.

Our model assumes that land use for conventional solar would yield a 50% reduction in soil erosion relative to land used for row crops, mostly due to the avoided tilling. As such, the \$226 in topsoil losses per acre in the farm model is added back as a \$114 social gain per acre for land used for conventional solar. To calculate a value for groundwater recharge, we assume conventional solar’s water use patterns are equivalent to that of developed open space (e.g. parks). This land use type has slightly improved groundwater recharge rates compared to farmland rates, which is why the value for this groundwater recharge is positive but minimal — only \$11 per acre.

The social benefits of converting farmland to conventional solar total \$14,651. Capturing these social benefits could increase value of conventional solar by more than 20%.

COSTS AND BENEFITS OF CONVENTIONAL SOLAR, RELATIVE TO FARMING		
30-YEAR PROJECT LIFESPAN COSTS AND BENEFITS, 3% DISCOUNT RATE, \$2018		
	Corn	Soy
Private Benefits (Costs) Per Acre		
Increase After-Tax Revenue	\$68,350	\$71,643
Net Private Benefits	\$68,350	\$71,643
Social Benefits (Costs) Per Acre		
Carbon Benefits (Avoided Emissions)	\$14,526	\$14,526
Savings from Reduced Soil Erosion	\$114	\$114
Value of Additional Groundwater Recharge	\$11	\$11
Increase in Crop Yield from Pollinators Present	\$0	\$0
Net Social Benefits	\$14,651	\$14,651
Net Benefits	\$83,001	\$86,294

Comparing Farmland to Pollinator-Friendly Solar

Similar to our conventional solar scenario, our model calculates positive private and social benefits by comparing pollinator-friendly solar with farmland. In terms of private benefits, pollinator-friendly projects increase net income beyond that of conventional solar. The primary assumption driving this result is that panels in a pollinator-friendly solar array will yield slightly higher electricity output compared to conventional solar due to the efficiency gains from the cooler microclimate conditions under the panel.

The pollinator-friendly solar scenario additionally results in lower lifetime project costs. While upfront costs are higher due to more expensive native seed mixes and additional maintenance required for prairie establishment, O&M costs decline after the first five years as native grasses and wildflowers require less ongoing maintenance and fewer mowings compared to turfgrass.²⁴ Thus, there is an incentive for developers to install pollinator-friendly projects purely from a private financial perspective.

Pollinator-friendly solar also yields greater social benefits than either farmland or conventional solar. Carbon benefits from displaced grid emissions remain the largest contributing factor within the carbon benefits category. However, in this case our model assumes a small but non-negligible amount of soil carbon sequestration thanks to the deep-rooted native plantings and the superior soil quality they foster, slightly increasing the carbon benefits from pollinator-friendly solar.

In terms of soil erosion, our model assumes that native grasses entirely eliminate the soil erosion that occurs in the farmland scenario. For groundwater, native grasslands in Minnesota have higher rates of recharge on average across soil types relative to both row crops and developed open space (the land use cover used in the conventional solar scenario).

Lastly, unlike the conventional solar scenario, pollinator-friendly solar has the potential to increase crop yields on surrounding farmland because of the increased pollinator presence. Prior research has established that a typical pollinator foraging area equates to a 1.5 kilometer radius around pollinator habitat.²⁵ While neither corn nor soy are exclusively pollinator-dependent crops, our research revealed that soy — a partially pollinator-dependent crop — exhibits higher crop yields in the presence of native pollinators, whereas corn — a wind-pollinated crop — does not. As such, our model assumes pollinator-friendly solar increases crop yields in surrounding soy farms by approximately 6.3%,²⁶ but no crop yield benefit for corn farms. The increased crop yields for soy farms can boost social benefits from pollinator-friendly solar by as much as \$7,457 per acre.

²⁴ Davis, interview.

²⁵ Walston, "Examining the Potential."

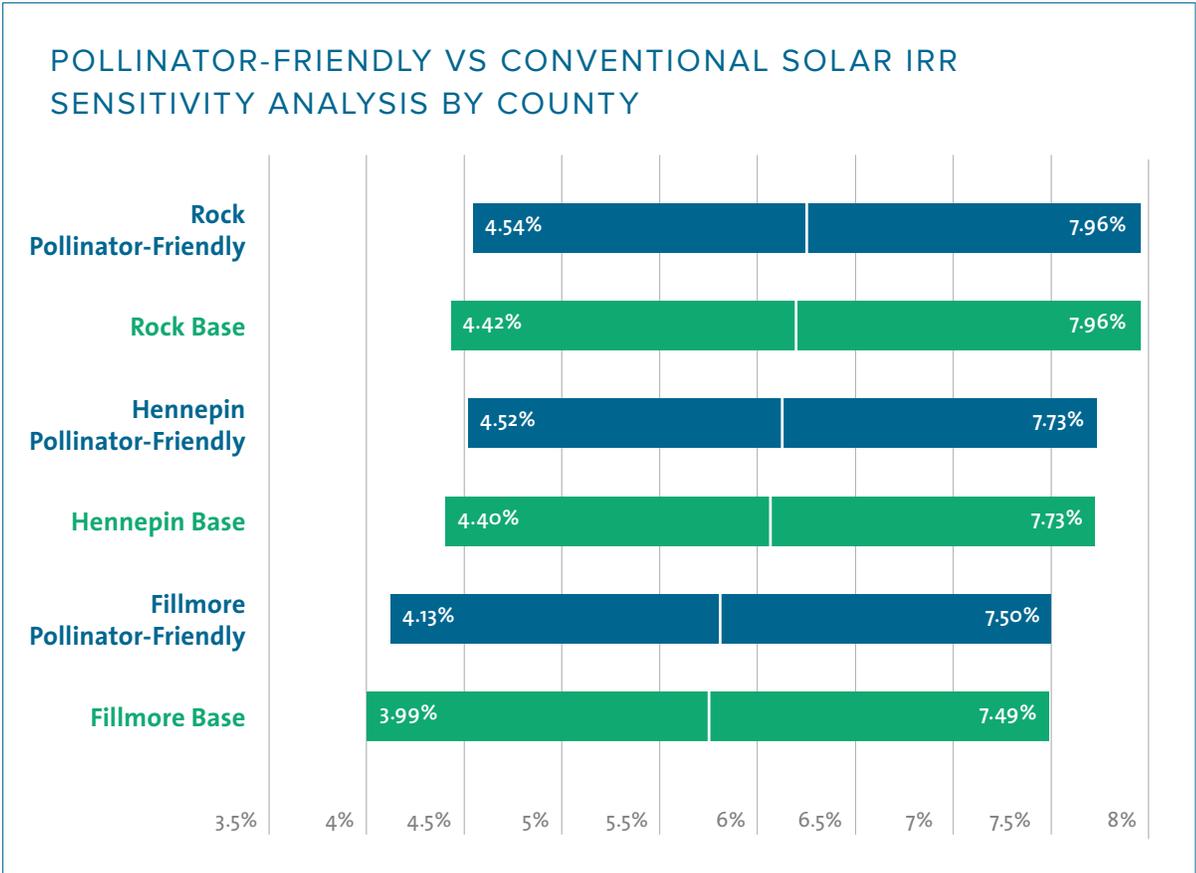
²⁶ De O. Milfont et al., "Higher Soybean Production."

Given that soy farmland currently operates as a loss in our model, the conversion of a portion of this land to pollinator-friendly solar can offer considerable additional value. Some of these values are currently monetized and can offer immediate economic gains, such as increased revenue from solar output generation, and increased crop yields for soy farmers. Overall, pollinator-friendly solar's private and social benefits relative to farming range from \$88,417 to \$99,166, a larger range than conventional solar because of the greater increase in soy's crop yield benefits.

COSTS AND BENEFITS OF POLLINATOR-FRIENDLY SOLAR, RELATIVE TO FARMING		
30-YEAR PROJECT LIFESPAN COSTS AND BENEFITS, 3% DISCOUNT RATE, \$2018		
	Corn	Soy
Private Benefits (Costs) Per Acre		
Increase After-Tax Revenue	\$73,278	\$76,571
Net Private Benefits	\$73,278	\$76,571
Social Benefits (Costs) Per Acre		
Carbon Benefits (Avoided Emissions)	\$14,894	\$14,894
Savings from Reduced Soil Erosion	\$228	\$228
Value of Additional Groundwater Recharge	\$17	\$17
Increase in Crop Yield from Pollinators Present	\$0	\$7,457
Net Social Benefits	\$15,139	\$22,596
Net Benefits	\$88,417	\$99,166

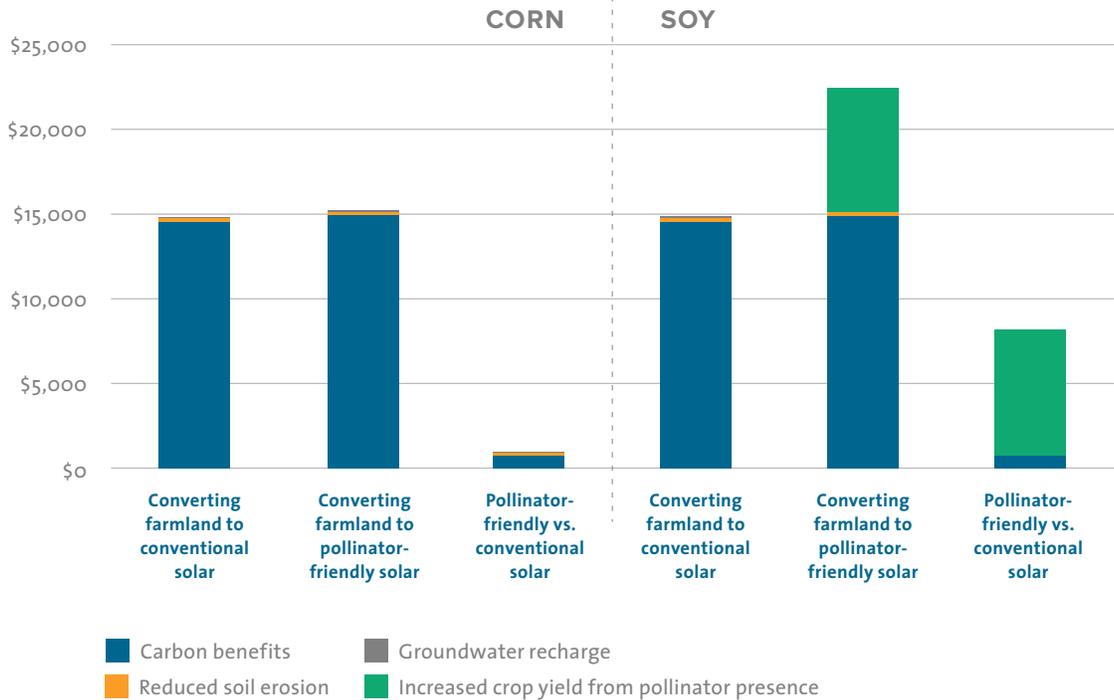
Comparing Pollinator-Friendly to Conventional Solar

Our results reveal that pollinator-friendly solar projects can achieve higher private and social benefits than conventional solar projects. For instance, an IRR sensitivity analysis for conventional and pollinator-friendly solar projects shows that, for each county, pollinator-friendly solar projects achieve a higher base case IRR. This means that pollinator-friendly solar has the potential to achieve higher earnings compared to conventional solar in every county. Additionally, while the sensitivity analysis shows an equal upside IRR for both types of solar projects, the downside IRR is higher for pollinator-friendly projects by 0.12-0.14% per year in all counties. Thus, pollinator-friendly solar projects offer developers the opportunity to increase revenue and mitigate the risk of lower returns in a downside scenario.



As previously shown, both types of solar projects yield greater social benefits than farming. Yet, compared to conventional solar, pollinator-friendly solar has the potential to produce significantly more benefit. For the lifetime of a project, the net social benefits per acre increase from \$14,651 for conventional projects to \$22,5976 for pollinator-friendly projects sited adjacent to soy farms. This is primarily due to the crop yield increase and the higher energy output of pollinator-friendly projects, which increases avoided carbon emissions as more clean electricity flows to the grid. Additionally, thanks to the deeper roots of native grasses and wildflowers compared to turfgrass, both avoided soil erosion and groundwater recharge are slightly higher for pollinator-friendly projects when compared to conventional projects.

SOCIAL BENEFITS OF CONVERTING FARMLAND TO POLLINATOR-FRIENDLY VERSUS CONVENTIONAL SOLAR (PER ACRE AND BY CROP TYPE)

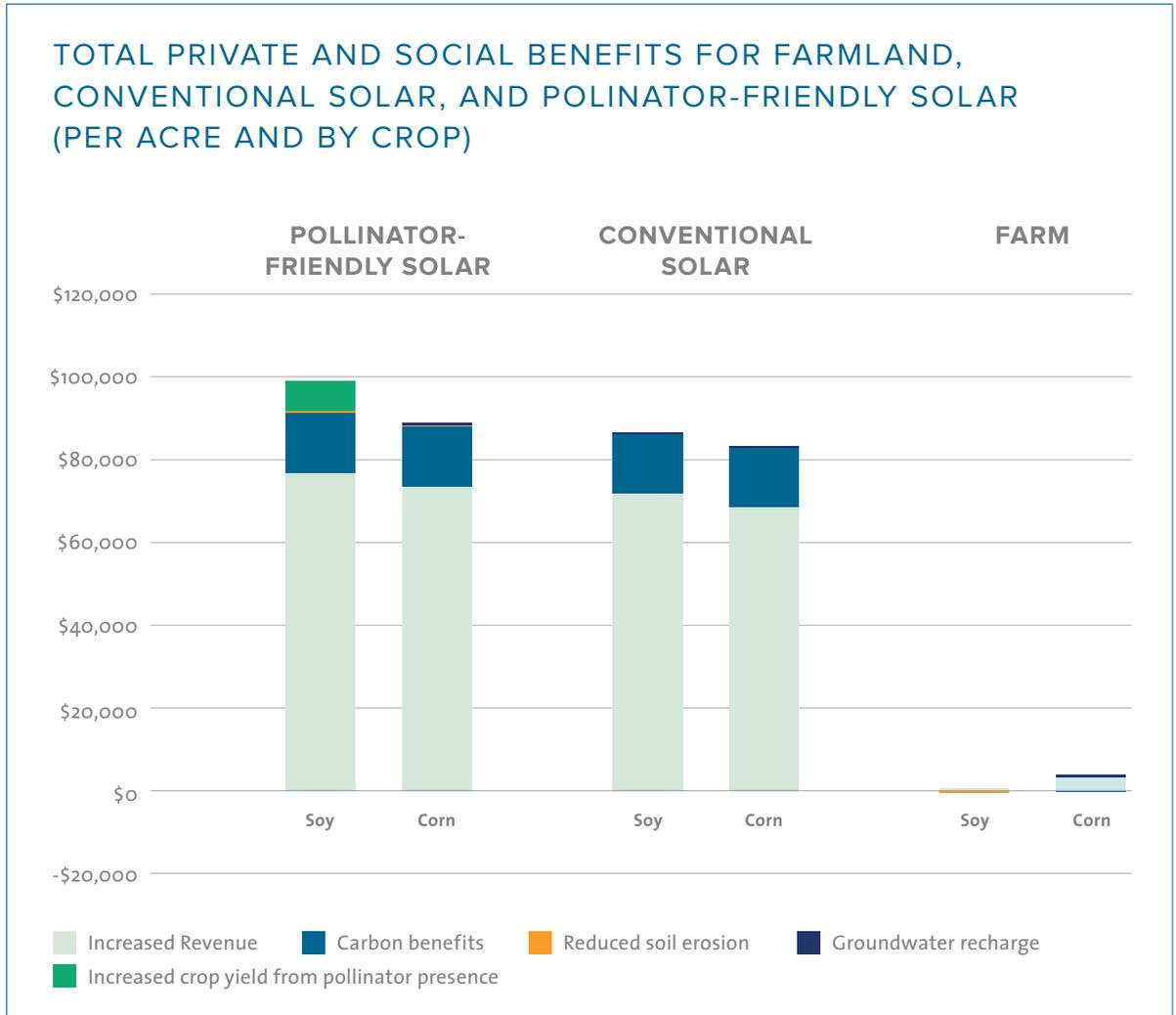


Comparing Private and Social Benefits Across All Three Land Uses

For pollinator-friendly and conventional solar, private benefits make up more than 75% of total benefits in all cases. The largest social benefit is avoided carbon emissions, which accounted for more than 15% of benefits in all cases. For pollinator-friendly solar, increased crop yield accounted for 7.5% of total benefits when projects are sited adjacent to soy farms.

Overall, solar energy production is a more lucrative land use than farming on our modeled sites. The monetary value of the private and social benefits for conventional solar is 30 times greater than that of a corn farm and 160 times greater than that of a soy farm. Similarly, the monetary value of the private and social benefits for a pollinator-friendly solar project is 32 times greater than that of a corn farm and 184 times greater than that of a soy farm. However, that is not to say that farmland should indiscriminately be converted to solar development. Such an extrapolation is neither socially beneficial nor warranted, particularly given solar's small land footprint relative to farming. These model results merely indicate that, where decisions between land uses are being made, solar development can yield

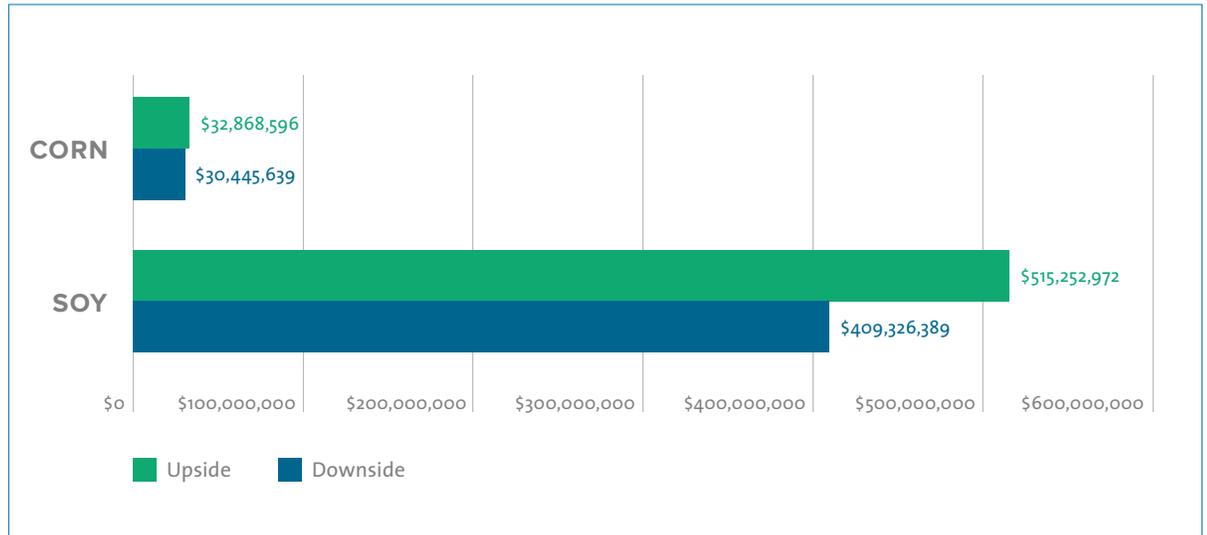
significant benefits — and even more so when it is developed according to land use best practices such as pollinator-friendly solar.



Extrapolating Social Benefits Across Minnesota

Minnesota has a statewide target of producing 10% of its energy from solar by 2030, which equates to roughly 6 GW of solar capacity. As of 2017, the state requires 5.3 GW of more new solar projects to achieve this goal. Assuming that 1 MW of solar production requires 7 acres of land, this new solar capacity would encompass 37,002 acres of land, only 0.13% of Minnesota’s 26.9 million acres of farmland.

If Minnesota were to meet the rest of its 2030 target exclusively with pollinator-friendly projects, the added private and social benefits would be quite significant. For example, assuming these projects were surrounded by soy farms, the total undiscounted benefit would be \$410-515 million dollars. If the projects were surrounded by corn farms, the benefits would be less, but still sizable at \$30-33 million dollars.



Sensitivity Analysis

In order to test the impact of changes in our assumptions on our model outputs, we conducted sensitivity analyses around several key inputs. These included the social cost of carbon (SCC), the discount rate for future revenue, the pollinator-friendly installation cost premium, and the panel efficiency gain in pollinator-friendly installations.

We used a \$10/ton SCC as our base case assumption, which is a conservative figure as it represents the low end of the \$10-40/ton SCC that the Minnesota Public Utility Commission uses in its regulations. In our sensitivity analysis, we tested the impact of different SCCs, ranging from \$5-250/ton, on the NPV of social benefits from conventional solar over a 30-year project lifetime. For simplicity, we just looked at values for one county at a time (in the case of the figure below, Hennepin). The resulting NPV spread ranged from \$501,414 to nearly \$25 million. A \$10/ton SCC yields a figure of nearly \$1 million.

NET PRESENT VALUE OF SOCIAL BENEFITS PER ACRE OF CONVENTIONAL SOLAR IN HENNEPIN COUNTY BY SOCIAL COST OF CARBON

		NPV of Social Benefits						
		Active County: Hennepin						
		Sensitivity to Social Discount Rate and SCC						
Social Cost of Carbon	Social Discount Rate							
	1.50%	2%	3%	4%	5%	6%	7%	
\$5	\$616,981	\$574,583	\$501,414	\$441,023	\$390,799	\$348,719	\$313,206	
\$10	\$1,225,526	\$1,141,338	\$996,044	\$876,117	\$776,378	\$692,809	\$622,277	
\$25	\$3,051,161	\$2,841,603	\$2,479,932	\$2,181,401	\$1,933,115	\$1,725,077	\$1,549,491	
\$50	\$6,093,886	\$5,675,377	\$4,953,080	\$4,356,874	\$3,861,010	\$3,445,524	\$3,094,848	
\$75	\$9,136,611	\$8,509,151	\$7,426,227	\$6,532,347	\$5,788,905	\$5,165,971	\$4,640,205	
\$100	\$12,179,336	\$11,342,925	\$9,899,375	\$8,707,820	\$7,716,800	\$6,886,418	\$6,185,561	
\$250	\$30,435,685	\$28,345,571	\$24,738,260	\$21,760,657	\$19,284,170	\$17,209,100	\$15,457,701	

Our discount rate of 3% was based on studies of social discount rates used in climate modeling. We conducted a sensitivity analysis for a discount rate range of 1.5-7%, which, at a \$10/ton SCC, produced a range of NPVs for conventional solar from \$622,277-1,225,526 over the project life.

Research indicates that pollinator-friendly solar sites require greater upfront costs due to more expensive seed mixes and additional maintenance to establish the plants, though we were unable to track down an exact figure to quantify this cost premium. We estimate a 5% premium above the installation costs of a conventional solar project, which produces a 6.26% IRR in Rock County. Given the uncertainty of this estimate, we also conducted a sensitivity analysis for this input. Sensitizing around a 0-10% cost premium gave us an IRR range of 6.48% if there is no cost premium, and 6.06% at a 10% premium.

The anticipated panel efficiency gain that would result from pollinator-friendly plantings was another area where we conducted a sensitivity analysis. In Rock County, our assumed 0.4% efficiency gain yields a project IRR of 6.21%. We analyzed the impact of a 0-1% range of efficiency gains, which produced an IRR range of 5.98-6.57%.

Policy Implications

Our results and analysis highlight three areas for policy improvement or implementation: facilitating the capture of private benefits that are being left on the table; creating incentives to reflect the social and environmental benefits of pollinator-friendly solar; and maximizing the location-specific benefits through solar or agricultural siting policies.

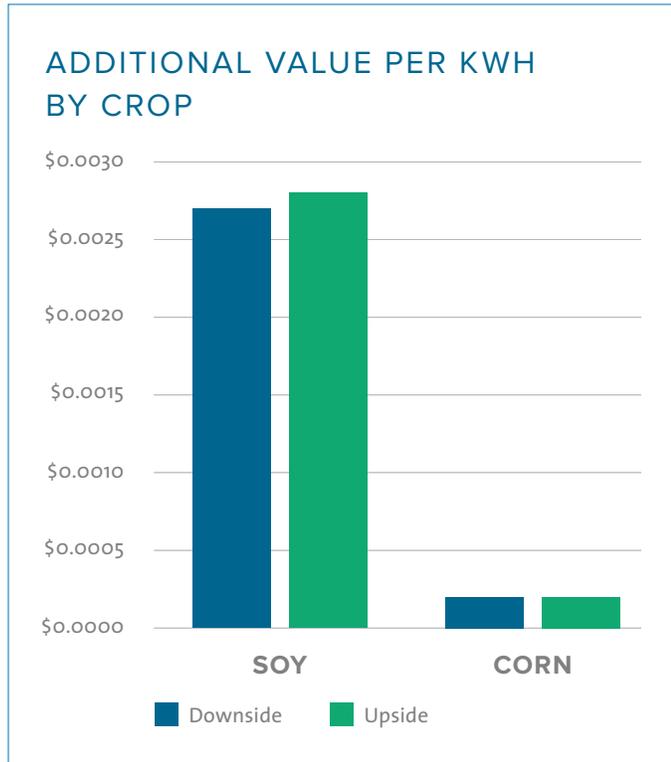
Private Benefits

Our model demonstrates that the private revenue streams from pollinator-friendly solar projects exceed those of conventional solar projects. As we've noted, the primary assumption driving this conclusion is a 0.4% efficiency gain for pollinator-friendly solar panels due to ambient microclimate conditions created by the native plantings. This efficiency gain assumption drives an IRR of 6.26% for base case pollinator-friendly solar projects, relative to a 6.22% IRR for the base case conventional solar scenario. Whether or not developers can expect higher returns from pollinator-friendly solar projects in the absence of subsidies or other policy support has important implications for future policy design.

First and foremost, to resolve uncertainty around these anticipated efficiency gains, policies that provide research and development funding could help to correct this information market failure and clarify the relationship between native plantings, microclimates and solar panel output. If ongoing research confirms these efficiency gain estimates from pollinator-friendly solar projects and investment in such projects does not pick up, that would indicate that there is a behavioral failure present as well. Thus, the first policy priority is funding research to clarify and communicate information about private returns from pollinator-friendly solar projects.

If the efficiency gain assumption proves to be correct or even underestimated, and still pollinator-friendly solar development does not occur at scale, then policies should be designed to address the market and behavioral failures that might continue to inhibit investment in the practice. Pollinator-friendly solar projects require interdisciplinary expertise, including novel collaboration between solar developers and native landscape experts. We hypothesize that the entrenched status quo of conventional solar development could be creating a path-dependent behavioral failure. Programs — such as webinars or local permitting requirements — that would familiarize developers with pollinator-friendly practices and local landscape companies could mitigate perceived barriers. Stakeholder engagement across potential collaborating organizations (local land trusts, entomologists, farm bureaus, etc.) will also be important to cultivate consensus and awareness in step with policy design.

Over time, we expect learning-by-doing will drive down the time and money required up front to coordinate pollinator-friendly solar projects. Such learning-by-doing gains could even increase the marginal returns for these projects relative to conventional solar, making them even more attractive to developers. Navigating permitting requirements, understanding native seed maintenance, and achieving habitat restoration standards are all areas where developers can expect costs to decrease as pollinator-friendly solar standards and practices mature throughout the industry. In the interim, public entities can play a role by facilitating partnerships, synthesizing and communicating learnings, and even subsidizing early project endeavors.



Social and Environmental Benefits

Independent of uncertainty around the private benefits, our model reveals clear social benefits to be gained from pollinator-friendly solar development relative to conventional solar. The externalities monetized in the model justify offering subsidies, incentives or mandates to realize the social benefits of pollinator-friendly solar projects. We believe our model generates a conservative estimate for social benefits, considering a number of potential ecosystem services are unmodeled and we used a low-end value for the SCC. Nevertheless, the model

indicates significant monetized benefits if Minnesota were to achieve its 10% solar target with 6 GW of pollinator-friendly solar projects. These benefits could be captured most efficiently by policies that provide developers with a PPA “adder” representing the per-kWh social benefits of pollinator-friendly solar. Second-best policy measures include a pollinator-friendly solar mandate (as opposed to the voluntary standards currently in favor among states), or tax credits to subsidize the practice.

Research and development funding would also help to improve ecosystem valuation and inform the appropriate incentive amount that would efficiently internalize the ecosystem and avoided carbon benefits. The National Renewable Energy Laboratory’s three-year Innovative Site Preparation and Impact Reductions on the Environment (InSPIRE) initiative is an example in progress of research seeking to understand the full potential of pollinator-friendly solar’s co-benefits. Additionally, there are a variety of grants and funding opportunities currently available through organizations like the Minnesota Department of Natural Resources for land and water conservation practices. Streamlining these opportunities or creating a carve-out program that earmarks grants for pollinator-friendly solar projects could make it simpler for developers to capitalize on existing funding sources.

Location-Specific Benefits

A final model takeaway with important policy implications is that project location impacts benefit calculations at a very granular level. Our analysis began with three counties in order to highlight

geographical differences associated with farming and solar production, but we soon learned that ecosystem valuation is even more contextually complicated than a county-level analysis could capture. For instance, values for soil carbon sequestration and groundwater recharge are highly dependent on topographies and soil types that could differ even between plots within a single farm. Additionally, while we did not include water quality improvements in our model, they are also very site-specific: nutrient loading from fertilizer runoff is dependent on a variety of watershed characteristics, such as upstream land uses and a plot's proximity to streams. Fertilizer reduction benefits from pollinator-friendly solar projects (which don't use fertilizers or pesticides) could accrue to a different county or state downstream, thus making it difficult for local decision-makers to value that benefit. Policies will need to be designed to direct and reward the siting of pollinator-friendly solar projects on lands where they will realize maximum social benefit. To take benefits from fertilizer reduction as an example, a policy could be designed to include payment schemes where downstream water users finance upstream water quality enhancements, such as pollinator-friendly solar sites.

Furthermore, our analysis shows that pollinator-friendly solar benefits depend greatly on surrounding crop type. Policies to support these projects should ensure they achieve increased crop yield benefits by encouraging project development near crops that are pollinator-dependent, such as soy — or better yet, specialty crops such as apples, cranberries, or squash. The reverse consideration could also apply: policies might encourage farmers to grow pollinator-dependent crops near pollinator-friendly solar projects. While our analysis modeled a 6.3% crop yield increase for a moderately pollinator-dependent crop (soy), the yield increase for specialty crops has the potential to be much greater.²⁷ Site-specific policy examples include property tax abatement and streamlined permitting processes, both of which could be used to channel pollinator-friendly solar development towards optimal land. Another policy option could be a tiered subsidy system where the subsidy for pollinator-friendly solar projects is scaled up or down based on the value of ecosystem benefits that a project helps realize in the area where it is developed.

Future Research Applications

As our results and policy discussion indicate, there is a strong need for additional research to inform the implementation of this relatively new solar development practice. Many of the inputs used in this model are estimates acquired from the limited data currently available; however, several new studies are now ongoing to collect and assess data from recently established pollinator-friendly solar projects. The National Renewable Energy Laboratory's InSPIRE Project, for example, is a three-year effort spanning more than 20 pollinator-friendly solar projects across the United States to collect data on soil quality, carbon sequestration, solar panel efficiency, crop yields and more.²⁸ This research will likely inform future study, implementation and policy intervention around pollinator-friendly solar.

²⁷ Davis, interview.

²⁸ "DOE InSPIRE Project Overview," OpenEI, U.S. Department of Energy National Renewable Energy Laboratory, August 2018, <https://openei.org/wiki/InSPIRE/Project>.

Once more detailed data is available, future models could incorporate some of the environmental benefits that we did not model, such as water quality improvements. Additionally, considering that soy is not a highly pollinator-dependent crop, further research should quantify the crop yield increase for crops that are more pollinator-dependent. The value stream from beehives and honey production on-site, and potential markets for that honey, would also be an interesting subject for future study. Lastly, assuming a carbon market is established in the future, new models could incorporate scenarios for various carbon pricing schemes and assess how that would alter the social benefit calculus.

Conclusion

Minnesota has a strong and growing solar industry supported through the state's RPS carve-out and popular community solar program. Solar development in Minnesota and across the Midwest is poised to continue on land traditionally devoted to conventional agriculture. Growing interest in low-impact solar development and co-location of solar projects with pollinator-friendly plants represents an opportunity to mitigate energy-versus-food tensions and provide additional benefits to agriculture, ecosystems, and private developers alike. The model presented in this paper takes an important step towards quantifying and monetizing the benefits of pollinator-friendly solar development as a land use option in Minnesota.

Understanding the full monetary value of pollinator-friendly solar is necessary to design policies that efficiently and effectively support its development in locations that optimize project value. As the practice continues to gain popularity, there is a pressing need for additional research that clarifies the value of ecosystem services created by this innovative land use. Improved understanding of the diverse social and private benefits of pollinator-friendly solar will allow for strategic deployment of these projects — and will maximize returns for all stakeholders.