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Local Environmental Benefits of SOLAR FARMING IN WISCONSIN

CLEAN WISCONSIN
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Strobus Solar Project in Black River Falls, Wisconsin. Image courtesy of OneEnergy Renewables

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Executive Summary

Integrating Solar into Our Agricultural Landscapes

In Wisconsin, using agricultural land to produce energy is nothing new. We devote 1.5 million acres of farmland in our state to grow corn for ethanol, and we produce about 25 million gallons a year of biodiesel from soybeans, accounting for another 700,000 acres. But growing these crops can come with significant environmental costs. Conventionally-grown corn and soybeans used for fuel production are produced in annual, monocropping systems—an intensive practice of cultivating a single crop year after year on large tracts of land, which requires substantial applications of fertilizers and pesticides to maximize production. These practices can lead to nutrient-depleted soils, erosion, and pollution of nearby waterways and drinking water supplies.

Today, we are seeing a new kind of energy production taking root on Wisconsin's agricultural land—solar farms. In Wisconsin and across the Midwest, solar farms are almost exclusively integrated into agricultural landscapes, which are relatively flat and already cleared of natural vegetation. Not only does integrating solar into farmland provide a steady source of income for family farms, it reduces the negative environmental impacts from conventional crop production and minimizes the conflicts with wildlife habitat that occur when solar is built in undeveloped, natural areas.

To reach net-zero carbon emissions by 2050 in Wisconsin, less than 1.5% of Wisconsin's 14 million acres of agricultural land will be needed for solar farms. From an environmental perspective, the positive impacts of this integration of solar into farmland are wide-ranging. Our report explores how solar farms are an important part of the carbon-free energy transition in Wisconsin and how, if appropriately sited, designed, and maintained, they can provide a range of public health and environmental benefits that go well beyond energy production.

KEY TAKEAWAYS

Energy Production Efficiency

- Solar farms produce 100 times more net energy per acre than corn grown for ethanol and are a far more efficient use of land.
- Wisconsin currently uses nearly 40% of its corn harvest—accounting for about 1.5 million acres—for ethanol production. In contrast, Wisconsin needs approximately 150,000–200,000 acres of solar farms to reach net-zero carbon emissions by 2050. That's only 10–15% of the land currently devoted to ethanol production.
- While rooftop solar is an important source of clean energy and remains an important element of the clean energy transition, alone, it is not expected to be implemented fast enough to meet Wisconsin's carbon-free energy goals in time to mitigate the impacts of climate change. Thus, solar farms are also needed to rapidly meet Wisconsin's carbon-free electricity goals. Large-scale solar farms are substantially more efficient than rooftop solar, both in terms of generation and cost. For the same installed capacity, utility-scale solar can generate 50% more electricity at less than half the cost of rooftop solar.

Water Quality

- Solar farms that replace conventionally farmed row crops like corn and soybeans reduce sediment and phosphorus pollution runoff into nearby lakes, rivers and streams by 75–95%.
- Nitrate pollution from conventional agriculture is the most widespread groundwater contaminant in Wisconsin but solar farms do not require nitrogen inputs once cover vegetation is established. This will reduce contamination of groundwater, which is the source of drinking water for two-thirds of Wisconsinites.

Soil Health

- The lack of disturbance and perennial, deep-rooted vegetative cover planted among solar panels reduces soil erosion, increases soil carbon sequestration by 65%, and improves overall soil health. The improved soil health would make the land more productive should it return to agricultural production after the solar project lifetime.

Wildlife Habitat

- Perennial native vegetation planted under and around solar panels and lack of frequent disturbance improves habitat compared to existing cropland for many species, including a 300% improvement in habitat quality for pollinators, which are in steep declines around Wisconsin and the world.

Measurable Health Benefits

- Climate change is a public health threat and experts have identified accelerating the transition to clean, renewable energy as the most important action we can take in Wisconsin to mitigate the health harms of climate change.
- Public health benefits from improved air quality due to solar electricity generation are estimated to be 5–10 cents per kWh, which exceed the cost of generating the electricity itself (3–4 cents per kWh).

Appropriate siting, coupled with environmentally friendly design and maintenance is key to maximizing these potential co-benefits.

- We provide recommendations for the siting, design, and maintenance of solar facilities to help ensure that the transition to clean, renewable energy production in Wisconsin is as sustainable and environmentally beneficial as possible including:
  - Avoiding areas of high biodiversity significance and prioritizing already-disturbed land
  - Prioritizing agricultural land disproportionately contributing to nitrogen and phosphorus losses
  - Avoiding grading, topsoil removal, and soil compaction during construction
  - Establish native, deep rooted perennial grassland vegetation under and around the panels rather than turfgrass.
  - Seed areas with pollinator-friendly flower mixes to establish new habitat for pollinators.
  - Use wildlife-permeable fencing to allow smaller animals to pass through perimeter fencing and established unfenced corridors to allow larger animals to pass through the landscape unimpeded.
  - Incorporate wildlife-friendly mowing practices to protect any grassland species nesting or raising young in the project area.

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Introduction

Purpose

Utility-scale solar development in Wisconsin is rapidly expanding. In 2020 there was only 150 megawatts (MW) of utility-scale solar capacity in the state, but by the end of 2024, the Wisconsin Public Service Commission anticipates there will be 650 MW of capacity online in the state. Furthermore, in 2023, the PSC approved six projects, totaling another 1,125 MW of capacity. Ensuring that utility-scale solar is sited, designed, and maintained in ways that maximize environmental co-benefits and minimize adverse environmental impacts is important.

These projects are critical pieces of the state's effort to clean up its electricity sector, as Wisconsin's electricity grid is the ninth-most carbon intensive in the country, ahead of all neighboring states (USEPA 2024a). Solar facilities emit no air pollution while they are generating electricity, and displacing fossil fuel electricity generation (i.e., coal and gas), and their associated climate-warming and harmful air pollution is the most obvious environmental benefit of utility-scale solar farms. When appropriately located, designed, and maintained, solar farms can also provide additional local environmental benefits, including reduced water contamination, increased habitat for pollinators and wildlife, and improved soil health.

In this report, we describe the need for utility-scale solar facilities in Wisconsin, summarize the current understanding of both positive and negative environmental and public health impacts of solar development, and discuss how to minimize potential adverse environmental impacts while maximizing the potential localized co-benefits of solar development in the state.

Utility-Scale Solar is an Important Part of **Wisconsin's Climate Solution**

Transition to Renewable Energy

Emissions from fossil fuel combustion are leading contributors to climate change and air pollution (IPCC 2021). To avoid the worst impacts of climate change, there is an urgent need to rapidly reduce carbon emissions. Currently, 73% of Wisconsin's electricity generation comes from fossil fuels (US EIA 2023a), and electricity generation is Wisconsin's largest sector of greenhouse gas emissions, contributing about one-third of the state's 145 million tons of annual greenhouse gas emissions (WDNR 2021). If Wisconsin is going to meet its carbon-free goals (Wisconsin Office of the Governor 2019), there is going to need to be a large-scale increase in energy efficiency and transition to renewable energy sources, including utility-scale solar photovoltaics.

To help contextualize this buildout, prior analyses indicate that 20–30 gigawatts (GW) of solar capacity may be needed for Wisconsin to reach carbon-free targets (Evolved Energy Research 2022; Wisconsin Office of Sustainability and Clean Energy 2022), and as of November 2024, Wisconsin has approximately 2.5 GW of solar capacity (Solar Energy Industries Association 2024; US EIA 2024). This suggests that Wisconsin will need to add an average of approximately 1 GW solar capacity every year between now and 2050. This corresponds to roughly three to four typical solar farms coming online every year[1].

Increased energy efficiency and distributed generation will minimize the need to develop utility-scale solar facilities. However, given the limits of these strategies and the significantly increased electric load due to shifts from fossil fuels (e.g., electrification of buildings and vehicles, new demands from energy-intensive industries like data centers), utility-scale solar will continue to be built in Wisconsin and is an important component of meeting carbon reduction goals quickly.

The Need for Utility-Scale Solar Power Facilities

Utility-scale solar projects are geographically centralized projects typically sized at least 1 MW but are often more than 100 MW. Utility-scale solar plants can face community pushback, largely due to concerns about aesthetics, changing the rural character of the area, and taking good farmland out of production, but also environmental and health concerns (Uebelhor et al. 2021). Because of this, some question the need for utility-scale solar to meet clean energy goals, or if distributed rooftop solar is adequate to meet the goal. This question can be addressed in three ways: the technical potential of rooftop solar (i.e., how much roof space is available that can accommodate solar), the potential for rooftop solar to integrate into the electric grid and provide adequately reliable electricity, and the feasibility of adopting enough rooftop solar to meet renewable energy goals.

The technical potential of rooftop solar depends on the amount of rooftop space that can reasonably accommodate solar energy systems. A 2016 National Renewable Energy Laboratory study took into account shading, the orientation and tilt of the roof plane, the azimuth for each square meter of roof area, and the amount of contiguous roof area when calculating the maximum amount of electricity sales that could theoretically be derived from rooftop solar alone (Gagnon et al. 2016). This study estimated that in Wisconsin, 40% of total 2013 electricity sales could potentially come from rooftop solar across all building types. Considering only small buildings (mostly residences, which is likely a better indicator for distributed-generation systems), about 27.6% of total electricity sales can be reached through rooftop solar in Wisconsin. This study only considers how much roof space is available for solar but does not consider how much of that rooftop potential can be connected to the grid.

[1] Solar farms in Wisconsin are currently about 250–300 megawatts (MW).

In 2021, the Public Service Commission of Wisconsin (PSCW) issued a study projecting maximum theoretical technical capacity of Wisconsin for rooftop solar deployment in 2026 and 2034 (Eckstein et al. 2021). This analysis concluded that distributed solar has the technical potential to cover up to 74% of Wisconsin's 2019 overall electricity generation (Eckstein et al. 2021).

However, the question of whether distributed-generation systems can meet electricity needs across the state also depends on the level of adoption at the customer level. Indeed, the PSCW's 2021 solar potential report found only 1.6% of that overall technical capacity is simulated to be adopted by 2034 under baseline economic conditions, and thus only accounting for 1.2% of Wisconsin's 2019 electricity generation (Eckstein et al. 2021). Utility-scale systems can be hampered by a lack of community support, but utilities have been increasingly building solar plants because the price of solar is decreasing and greater efficiencies are gained at greater scales of electrical generation. For customers, adoption of distributed-generation systems can be more complicated. As of 2019, there were 6,646 systems across Wisconsin owned by customers that provide a combined capacity of about 100 MW (Hubbuch et al. 2021). In contrast, there are currently 7,565 MW of utility-scale solar in the MISO queue in Wisconsin, indicating developer interest in utility-scale solar in the state (MISO 2024). Even if not all of these are built, the queue indicates market activity.

Additionally, we need to consider the urgency and challenge of decarbonizing as quickly as possible to avoid the worst impacts of climate change. As mentioned earlier, Wisconsin needs to average approximately 1 GW of new solar capacity every year to reach carbon-free targets by 2050. Utility-scale facilities more efficiently generate electricity than rooftop solar due to optimized panel placement, solar tracking and bifacial panels made possible at utility-scale facilities. Rooftop solar has a capacity factor of 13–14% (Eckstein et al. 2021), while utility-scale solar capacity factors in Wisconsin are 20–25%[2]. This means that for the same installed capacity, utility-scale solar generates 50% more electricity over the course of the year. There is some electricity loss from transmission from utility-scale facilities that rooftop solar does not experience, which is not accounted for in these comparisons. However, this loss is approximately 5% in Wisconsin (US EIA 2023b) and not enough to close the generation efficiency gaps between utility-scale and rooftop solar.

This increased production efficiency, coupled with economies of scale associated with installation and operation and maintenance costs, makes utility-scale solar significantly more cost-effective than rooftop solar. The latest (Q1 2023) benchmarks for installed solar from the National Renewable Energy Laboratory reports $0.96–1.17 per watt for utility-scale systems and $2.34–2.68 per watt for rooftop solar (National Renewable Energy Laboratory 2023).

Finally, implementing both utility-scale solar and distributed solar can create a more efficient grid than just one or the other. While utility-scale solar would provide the bulk of power due to its large scale and lower cost per unit of energy generated, distributed solar can account for fluctuations in the grid on a localized level to keep electricity stable for end users. Widespread adoption of both utility-scale and distributed solar requires improvements to and restructuring of the electric grid to increase flexibility. This is necessary when both distributed and utility-scale solar are used in conjunction with each other (and with battery storage) as is recommended (Trabish 2018; Merchant 2020).

Distributed generation (e.g., rooftop solar)—along with aggressive strategies to reduce demand (e.g., energy efficiency)—are critical components of the pathway to a carbon-free Wisconsin and will help to reduce the need for utility-scale facilities. However, to meet the scale of the transition needed, coupled with the urgency to decarbonize as quickly as possible and avoid the worst impacts of climate change, all options—including utility-scale facilities—are needed. Thus, siting, designing, and maintaining utility-scale solar in ways that maximize environmental co-benefits and minimize environmental harms will make the transition to renewable energy in Wisconsin as sustainable as possible.

[2] Calculated from capacity and annual production reported in CPCN Applications submitted to the PSC in 2021 and 2022: Silver Maple Solar (9813-CE-100), High Noon Solar (9814-CE-100), Northern Prairie Solar (9815-CE-100), Saratoga Solar (9816-CE-100), Langdon Mills Solar (9818-CE-100), Elk Creek (9819-CE-100).

Environmental Concerns with **Utility-Scale Solar**

Land Footprint

Perhaps the biggest environmental issue surrounding the implementation and adoption of utility-scale solar is its land footprint. Generally, solar in Wisconsin needs 5–7 acres per MW capacity (Ong et al. 2013; Macknick et al. 2013; Bolinger and Bolinger 2022). Utility-scale solar needs significant space to generate the equivalent amount of energy from fossil fuel plants. For example, fossil gas facilities have a lifecycle land footprint of around 1 square meter per megawatt-hour (MWh) while ground-mounted solar PV has a land footprint of 8 to 14 square meters per MWh (United Nations Economic Comission for Europe 2022), meaning that solar requires 8–14 times more land than fossil-fuel based electricity production. This can lead to concerns about habitat loss and fragmentation when sited on natural landscapes or concerns about land access when taking prime farmland out of production when sited in intensively cropped areas.

Deliberate siting decisions can minimize these potential impacts. Frameworks exist that include considerations for low impact solar siting, biodiversity conservation designs (TNC 2019) and productive agricultural land preservation (American Farmland Trust 2024).

Ideally, utility-scale solar projects would take place on already disturbed or sensitive sites with little other societal value such as capped landfills, contaminated sites like brownfields, or large-scale parking lots (Hoffacker et al. 2017). While these areas should be promoted for development of smaller-scale solar facilities, in Wisconsin there are not enough of these sites in a contiguous area to provide enough land to site larger (>100 MW) facilities[3].

For larger utility-scale installations in Wisconsin, agricultural land is perhaps the best siting option from an environmental perspective since converting the land use from agricultural production to solar installations can provide net environmental benefits. Agricultural land is already disturbed, and agricultural expansion and intensification are leading causes of biodiversity loss (Foley et al. 2005), so habitat loss and fragmentation issues are inherently minimized when solar production is sited on these lands. Conventional row crop agriculture is also a leading source of nonpoint pollution of nitrate, phosphorus, pesticides and sedimentation that impair surface waters and contaminate drinking water (Wisconsin Groundwater Coordinating Council 2024; WDNR 2024a; WDATCP 2024). Thus, conversion of agricultural land to utility-scale solar can result in local environmental improvement, as discussed below.

[3] See for example, the United States Environmental Protection Agency's RE-Powering Mapper. Available at: https://www.epa.gov/re-powering/re-powering-mapper

Agricultural land accounts for 40% of all the land area in Wisconsin[4] with approximately 14 million acres of farmland, including 8.8 million acres of harvested cropland. Of this cropland, 93% is used for corn (44%), soybean (25%), and livestock forage (e.g., hay, silage; 24%). The majority of these crops are produced for livestock feed, including all of the forage production and 60% of all corn production (Wisconsin Corn Growers Association 2024). Another 37% of the corn harvested in the state goes to ethanol production, leaving 3% of corn production going to export, human food products, and commercial and industrial products (Wisconsin Corn Growers Association 2024).

Clearly, placing solar on agricultural land would not be acceptable if it meant taking too much land out of food production. However, using existing estimates for the amount of utility-scale solar needed to reach state carbon-free targets shows that less than 2% of Wisconsin's current agricultural land would need to be converted into solar farms. The Wisconsin Clean Energy Plan estimates Wisconsin needs approximately 35 million MWh of utility-scale solar PV generation by 2050 to meet its carbon free target (Wisconsin Office of Sustainability and Clean Energy 2022). Using a conservative solar capacity factor of 16.5% for Wisconsin[5], meeting that goal that would require 24.2 GW of utility-scale solar capacity. Similarly, an Evolved Energy Research report estimated Wisconsin would need 28.5 GW of utility-scale solar capacity to achieve 100% clean energy in the state (Evolved Energy Research 2022).

Conservatively assuming 7 acres are needed per MW of utility-scale solar[6], between 170,000 and 200,000 acres of land for utility-scale solar facilities is needed to meet Wisconsin's carbon-free targets, based on the two prior estimates of 24.2 GW and 28.5 GW capacity. This represents 1.2–1.5% of all farmland in Wisconsin and 1.9–2.3% of all harvested cropland in the state[7].

Importantly, this land requirement is only a small fraction of the 2.1 million acres of agricultural land in Wisconsin already used to produce energy in the form of corn grown for ethanol or soybeans used for biodiesel. Wisconsin uses 1.5 million acres to grow corn for ethanol[8]. The state produces 25 million gallons of soy biodiesel each year (Wisconsin Soybean Marketing Board 2024), which requires about 700,000 acres of soybeans[9]. Thus, Wisconsin could achieve renewable energy goals by converting just 10% of the land currently used to produce corn ethanol or soy biodiesel to solar PV. Furthermore, solar PV is a far more efficient use of land for energy production than corn-based ethanol[10]. On a per-acre basis, solar PV can power 80 times more vehicle miles than corn-based ethanol and produce over 100 times more net energy.

There are also opportunities to co-locate solar arrays and agricultural activity, known as agrivoltaics, to maximize efficient use of agricultural land (Macknick et al. 2022). The potential of agrivoltaics in Wisconsin is not well understood, but a new research project by University of Wisconsin-Madison is aimed at improving this understanding (University of Wisconsin Madison

[4] The State Cartographer's Office lists Wisconsin's total land area at 35 million acres (sco.wisc.edu/wisconsin/geography/) and the 2022 Agricultural Census lists 14 million acres of farmland (nass.usda.gov/Publications/AgCensus/2022/Full_Report/Volume_1,_Chapter_1_State_Level/Wisconsin/)

[5] US EPA Documentation for Power Sector Modeling Platform v6. Table 4-44: epa.gov/power-sector-modeling/documentation-epas-power-sector-modeling-platform-v6; as discussed in section 1.2 above recent utility-scale solar applications in Wisconsin indicate anticipated capacity factors of 20-25%

[6] Internal analysis of existing and planned solar developments as of August 2023 finding ~6.5 acres per MW in Wisconsin; Ong et al. 2013; Bolinger and Bolinger. 2022.

[7] Based on the USDA's 2022 Census of Agriculture reporting 13,784,678 acres of farmland and 8,759,841 acres of harvested cropland in Wisconsin in 2022. Available at: nass.usda.gov/Publications/AgCensus/2022/Full_Report/Volume_1,_Chapter_2_US_State_Level/

[8] As noted earlier, 37% of Wisconsin's 4 million acres of corn harvest goes to ethanol production.

[9] Assuming 1.5 bushels of soybeans to produce 1 gallon of biodiesel (farm-energy.extension.org/soybeans-for-biodiesel-production/) and 54 bushels of soybeans per acre in Wisconsin (United States Department of Agriculture. 2023. Wisconsin 2022 State Agriculture Overview. Available at: nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=WISCONSIN).

[10] See **Appendix A** for full analysis

Image courtesy of Gretchen Casper

Office of Sustainability 2024). In dry environments solar panels can create cooler and more humid microclimates that are more favorable for crop production (e.g., Adeh et al. 2018). However, this is likely of limited value in Wisconsin given our cool, humid agroecological zone.

Although there are limited opportunities for agrivoltaics at scale under the current dominant paradigm of intensive machine-harvested row crops, it is possible to raise panels high enough to accommodate large machinery, although this comes with increased cost (Battersby 2023). Perhaps more feasible in Wisconsin is the practice of solar grazing, where sheep are introduced to the panel-array area as the main form of vegetation management, while providing sheep grazing operations access to high quality forage. This practice is already underway at several large-scale solar sites. Beyond improving land use efficiency and reducing vegetation management costs for the utility, agrivoltaics can decrease the carbon footprint of raising sheep by 25% through the avoided corn and soybean meal that otherwise would dominate the sheep diet (Handler and Pearce 2022). Another potentially valuable co-location of solar and livestock is with pastured dairy cows, where elevated solar panels could provide shade and reduce heat stress in cows, improving cow well-being and overall health (Sharpe et al. 2021).

Bird Mortality

There is concern that utility-scale solar can cause bird mortality through collisions with the solar panels and other facility infrastructure (e.g., Conkling et al. 2022 and citations therein). One often-cited mechanism for this mortality is the phenomenon known as the "lake effect", whereby birds mistake a solar project for a waterbody and collide with panels when trying to land. Prior analyses of mortality data from utility-scale solar PV facilities in the southwest United States report mortality rates of 1.8–11.6 birds per MW per year (Walston et al. 2016; Kosciuch et al. 2020; Smallwood et al. 2022). This translates to 48,600–313,200 avian deaths annually for the approximately 27 GW of solar capacity needed to meet carbon-free goals in Wisconsin. However, it is important to note that the current published research evaluating this issue has almost exclusively been conducted in arid or semi-arid environments (e.g., southwestern United States). As of this report, the science remains unclear how well mortality rates can be extrapolated to different environments like the humid Upper Midwest where natural lakes and ponds for landing sites are plentiful.

Limited post-construction bird mortality monitoring reports from two utility-scale solar facilities (Badger Hollow and Two Creeks) in Wisconsin have recently been submitted to the Wisconsin Public Service Commission and provide mortality rates within the panel arrays (i.e., does not include generation tie-lines)

(Rodriguez et al. 2023a,b). The mortality rates in these reports translate to 1.65–3.85 birds per MW per year. Thus, this initial data suggests Wisconsin avian mortality rates are on the lower end of previously reported rates from the Southwest. Furthermore, neither report found any water-obligate species mortalities, providing initial evidence that the "lake effect" may have limited impact in Wisconsin.

For context, fossil fuel facilities in the United States are estimated to cause 14.5 million avian deaths per year (inclusive of both direct mortalities and indirect mortalities related to climate change) (Sovacool 2009). The estimated annual bird mortality from other sources in the United States include two billion deaths from cats, 600 million from building collisions, and 200 million from vehicle collisions (Loss et al. 2015). Pesticide use on agricultural land is also correlated with declining bird populations on agricultural land in the United States (Minau & Whiteside 2013). While total bird mortality from agricultural pesticide exposure is difficult to quantify, one study estimated that pesticides cause 67 million bird deaths annually in the United States. Since pesticide use is significantly reduced, if not eliminated, on solar sites, this land use change alone could result in reduced impacts to avian populations when compared to agricultural land uses. Assuming that 28.5 GW of utility-scale solar is responsible for 150,000 bird mortalities per year in Wisconsin, this would amount to 1% of birds killed nationally by fossil fuel combustion, and less than one tenth of one percent of deaths from each of the other major sources of mortality: outdoor cats (<0.01%), building collisions (<0.03%), and vehicle collisions (<0.08%).

Furthermore, habitat loss (particularly for grassland species) and climate change are identified as major causes of avian species decline (e.g., Rosenberg et al. 2019; Bateman et al. 2020; Wu et al. 2022). Solar farms can increase grassland habitat around the panels in place of the former agricultural fields. Additionally, solar farms help mitigate climate change effects by displacing electricity production from fossil fuel power plants, which are major emitters of pollutants that directly contribute to climate change, while also providing habitat potentially suitable to grassland birds. Indeed, given the threat climate change poses to birds, bird conservation groups like the Audubon Society support appropriately sited and designed solar projects that mitigate climate change and have a net positive impact on birds (Audubon Society 2024).

Finally, while there has been considerable negative speculation, it is important to note that very little information exists about how the implementation of utility-scale solar facilities will affect bird populations in Wisconsin. As noted above, the available published research has been conducted in arid and semi-arid environments. Systematic monitoring of avian mortality at utility-scale solar facilities in Wisconsin would improve our scientific understanding of solar impacts on birds in the state. The United States Geological Survey has developed standardized monitoring protocols that can generate high-quality data and facilitate cross-facility comparisons of avian mortality impacts from solar installations across different regions of the United States and should be implemented by project developers more routinely to provide accurate data on this potential concern (Huso et al. 2016).

Public Health and Environmental Benefits

Public Health Benefits

Air quality benefits of displacing fossil-fuel combustion

One of the key public health benefits of solar energy is its ability to replace electricity generated from fossil fuel sources like coal and fossil gas. Air pollution from fossil fuel combustion places a significant burden on human health. Pollutants generated from the combustion of fossil fuels such as fine particulate matter ($PM_{2.5}$) and nitrogen dioxide (NO_2) pose risks to cardiovascular and respiratory health. Hazardous air pollutants associated with fossil fuel combustion, such as formaldehyde and toluene, also pose health risks for those living nearby. Those particularly at risk for bearing these burdens include older adults, people with pre-existing respiratory and cardiovascular conditions, children, low-income communities, BIPOC communities, and those who are active outdoors due to exercise or work (USEPA 2003; USEPA 2009; American Lung Association 2023).

Fine particulate matter exposure is the largest environmental risk factor for public health (Global Burden of Disease 2020). The most recent United States Environmental Protection Agency assessment determined a causal link between $PM_{2.5}$ exposure and premature death (USEPA 2019). Exposure is also associated with cardiovascular problems (e.g., heart disease, COPD, chronic bronchitis, lower respiratory infection), cancer, and nervous system damage.

While differing approaches to quantifying the health burden associated with $PM_{2.5}$ exposure led to mixed results, available estimates suggest $PM_{2.5}$ from fossil fuel combustion is attributable to hundreds or thousands of premature deaths in Wisconsin each year. For example, Vohra et al. (2021) found that 9,842 premature deaths in Wisconsin were attributable to $PM_{2.5}$ from all sources of fossil fuel combustion. Looking at only $PM_{2.5}$ pollution coming from fossil fuel energy generation, Thind et al. (2019) report 162 deaths annually in Wisconsin.

Fossil fuel combustion is the largest source of NO_2 pollution in the United States (USEPA 2022; Annenberg et al. 2022). NO_2 exposure harms respiratory health by aggravating existing cases of asthma and causing the onset of new cases. Khreis et al. (2021) report 2,154 cases of pediatric asthma in Wisconsin related to nitrogen dioxide pollution between 2006 and 2010.

Fossil fuel combustion also produces nitrogen oxides (NO_X), which are precursors to ground-level ozone, an air pollutant of concern in Wisconsin. Ground-level ozone levels are higher during warmer months, creating concern as temperatures warm with climate change. Currently, seven counties in Wisconsin do not meet the EPA's standards for ozone concentrations (WDNR 2022). The short-term health effects of ozone include the exacerbation of COPD, respiratory infections, and increased respiratory symptoms. Long-term effects include the onset of new asthma cases, worsened symptoms in children and adults with asthma and emphysema, and premature death (USEPA 2020). Decreasing ozone pollution has the potential to create substantial health benefits. Cromar et al. (2022) found that decreasing ozone levels to 60 ppb (70 ppb is the EPA standard) in Wisconsin could decrease ozone-related premature deaths by 102 cases per year and the number of adversely impacted school or workdays by 181,166 days each year.

To provide specific examples of air quality impacts from new fossil gas plants, we can examine three proposed fossil gas energy projects currently being proposed in Wisconsin: Wheaton, Nemadji, and Weston. New fossil gas plants threaten to increase particulate matter levels across Wisconsin. Both the Nemadji and Weston projects would increase their respective county's annual $PM_{2.5}$ concentration substantially. The Nemadji project would increase its county's $PM_{2.5}$ concentration by 10% to 10.3 µg/m3 (Burns & McDonnell 2019) while the Weston project would increase its county's $PM_{2.5}$ level by 53% to 11.2 µg/m3 (Wisconsin Electric Power Company 2021). The Wheaton application did not report $PM_{2.5}$ modeling results, but the proposed project would increase its county's course particulate matter (PM_{10}) levels by 89% to 50.9 µg/m3 (XCEL Energy 2023).

These predicted particulate matter concentrations are within the health-based standard of 12 µg/m3 at the time of the applications. However, in response to research showing that long- and short-term exposure to particulate matter below the current standard is associated with adverse health impacts (USEPA 2019), the EPA recently lowered the annual $PM_{2.5}$ standard level to 9.0 µg/m3. Both the proposed Nemadji and Weston projects are modeled to result in annual $PM_{2.5}$ levels in excess of the new standard.

Hazardous air pollutants are also emitted from fossil fuel electricity generation plants. All three proposed fossil fuel energy projects would emit numerous hazardous air pollutants, including formaldehyde and toluene in the highest quantities. Formaldehyde is a known carcinogen and causes respiratory problems, such as coughing, wheezing, and bronchitis USEPA 2016) while toluene, one of many neurotoxins released by fossil fuel combustion, is associated with nervous system dysfunction, narcosis, and decreased resistance to respiratory infections (USEPA 2012). Children are especially susceptible to air neurotoxins because of their rapidly developing brains (Grineski & Collins 2018).

The Weston project would emit 157 tons per year of formaldehyde (Wisconsin Electric Power Company 2021) while the Wheaton and Nemadji projects would emit six and three tons per year, respectively (Burns & McDonnell 2019; XCEL Energy 2023). The Nemadji project would emit two tons per year of toluene, while Wheaton and Weston would emit 0.7 and one ton per year, respectively. Toxins such as acrolein and cadmium, among others, would also be emitted from the projects.

The measurable negative health impacts caused by air pollution emitted from fossil fuel energy generation far outweigh the potential negative health effects of utility-scale solar energy. A study from North Carolina State investigated common concerns with utility-scale solar, including toxins found in panels, electromagnetic field (EMF) concerns, and fire concerns (North Carolina Clean Energy Technology Center 2017). This is the only study we are aware of that evaluates safety concerns from solar, and it concluded that public health risks are "extremely small" and safety concerns are negligible compared to the positive health impacts of reducing fossil fuel use and the hazardous pollution associated with fossil fuel power generation.

Any toxic components in solar panels are sealed and do not pose a risk during operation. Environmental exposure is possible during panel disposal in landfills, but efforts to increase recycling of retired panels and eliminate toxic leaching address this concern. In fact, since about 75% of the solar panels can be recycled (USEPA 2024b), the likelihood that decommissioning procedures would ignore these cost-saving benefits in favor of disposal in landfills further reduces the possibility of toxic leaching.

Crystalline silicon and cadmium telluride panels comprise the vast majority of solar panels, and there's no evidence that they contain arsenic, gallium, germanium, hexavalent chromium or PFAS, despite claims and concerns of exposure to such toxic compounds from solar panels (Mirletz et al. 2023). The cadmium telluride compound in cadmium telluride panels (currently 3% of panel market share) is highly stable and thus does not pose the same risk as elemental cadmium (Mirletz et al. 2023). The only potential toxic compound of health concern in commercially produced solar panels is the trace amount of lead contained in some solder, but this risk is reduced as manufacturers are looking to transition to lead-free solder (Mirletz et al. 2023).

The North Carolina study also found EMF concerns from solar arrays were negligible, as EMF levels drop below typical everyday exposure levels (North Carolina Clean Energy Technology Center 2017). Even within a few feet of a utility-scale inverter, which fenced off to prevent close access to, EMF levels are well below exposure limits (see also Tell et al. 2015). Similarly, EMF levels at the edge of facilities are well below the levels that medical devices like pacemakers are tested for regarding EMF interference.

Finally, fire concerns were found to be minimal, since only a small amount of solar panel materials are flammable, and thus would pose no additional risk if safety protocols are followed. The study concluded that the greatest health concerns with utility-scale solar were from the increased traffic during project construction and dangers to trespassers from the high voltage equipment, which should be avoided with proper signage.

In contrast, many studies have found significant health benefits from increased solar electricity generation displacing fossil fuel electricity generation. Milstein et al. (2017) found in 2015 the Upper Midwest received over 5 cents per kWh in air quality benefits from solar, which generated 1% of electricity in the region that year. Wiser et al. 2016 report health benefits of 9.2 cents per kWh in the Upper Midwest if solar contributed 14% of electricity generation by 2030. Similarly, Buonocore et al. (2019) found the Upper Midwest would see 5–7.5 cents in health benefits per kWh from deploying 100 to 3,000 MW of utility-scale solar; the second greatest health benefits from deploying utility-scale solar among US regions. These studies indicate air quality benefits from solar exceed the cost to generate the electricity itself, which is currently 3–4 cents per kWh for utility-scale solar photovoltaic systems (Lazard 2021).

Public health impacts of climate change

Fossil fuel combustion is the leading source of greenhouse gas emissions driving global warming (WDNR 2021). Over 200 of the world's leading medical journals published an editorial identifying global warming as the "greatest threat to global public health" (Atwoli et al. 2021). Similarly, over 70 medical and public health organizations in the United States—representing every major medical and health group—called climate change "the greatest public health challenge of the 21st century" and that a priority action is a rapid transition away from the use of coal, oil and natural gas (Climate Health Action 2019).

Climate change harms Wisconsinites public health in several ways, as documented in a report examining these impacts in Wisconsin (Patz et al. 2020). Extreme heat causes heat stroke, dehydration, and worsens chronic illnesses; leading to more emergency room and hospital visits. Young children and older adults over 65 are highly susceptible due to decreased temperature regulation. Older adults are also more likely to have chronic medical conditions that affect body temperature regulation. Those living in areas susceptible to the urban heat island effect are also at higher risk.

Flooding can result in drowning, electrocution, water-borne illness outbreaks from drinking water contamination, increased vector-borne diseases from more standing water, and mold growth increasing respiratory health risk. Harmful algal blooms produce toxins that can damage the nervous system, liver, cells, and irritate the skin. Ingesting water contaminated by algal toxins can cause vomiting, diarrhea and respiratory failure, while skin contact can cause rashes and hives. Ticks and mosquitoes can transmit various pathogens when biting someone. Such diseases include Lyme disease, anaplasmosis, West Nile virus, and La Crosse encephalitis. Milder winters lead to greater numbers of ticks and mosquitoes, expanded ranges, and increased exposure seasons, all leading to increased risk of disease transmission.

Indeed, the report on climate change health impacts in Wisconsin states: "The sooner we take action, the more harm we can prevent, and the more we can protect the health of all Wisconsinites. The most important action we can take to protect our health is to greatly accelerate our transition to clean renewable energy in Wisconsin" (Patz et al. 2020; emphasis added).

Local Environmental Co-Benefits of Replacing Row Crop Agriculture With Solar Facilities

Reduced water contamination

Locating solar installations on agricultural land can reduce water quality impacts created by traditional crop production practices. By its nature, agricultural production causes nutrient losses to surface and ground water and soil eroded from farm fields often makes its way into our lakes and streams further causing water quality impairments. Nitrate is Wisconsin's most widespread groundwater pollutant and can cause blue baby syndrome, birth defects, thyroid issues, and increased risk for certain cancers (Ward et al. 2018; WDHS 2024). In Wisconsin, approximately 90% of groundwater nitrate contamination comes from agriculture, largely from the use of nitrogen fertilizers (Wisconsin Groundwater Coordinating Council 2023). Similarly, phosphorus accounts for 49% of all surface water impairments in Wisconsin, making it the most common pollutant of surface water and it is largely caused by runoff from agricultural application of fertilizer and manure (WDNR 2024a).

Nutrient pollution in lakes, rivers, streams and wetlands can lead to excessive plant and algal growth. Algal blooms limit light penetration to aquatic plants, and when the blooms die, bacterial decomposition reduces the levels of dissolved oxygen in the water. In extreme situations, this can result in "dead zones" where there is too little dissolved oxygen to support aquatic life including fish and other beneficial biota. Algal blooms also interfere with recreation on affected waterbodies and blooms of toxin-producing cyanobacteria can be hazardous to humans, pets, and wildlife.

Sediment is also often transported from farm fields to bodies of water through runoff and affects water quality largely by reducing a water body's suitability as habitat for aquatic life. Too much sediment prevents sunlight from reaching aquatic plants, clogs fish gills, or smothers larvae and eggs of fish or other aquatic life. Sediment runoff, which also carries pollutants, is increased by soil tillage and when soil is left bare, both of which regularly occur in conventional row crop agriculture systems.

Plans to improve water quality and reduce non-point pollution sources often highlight the need to reduce chemical inputs, nutrient and erosion from agricultural lands[11]. Converting land used for row crop agriculture to utility-scale solar helps reduce water quality impacts in several ways. First, fertilizer, herbicide, and insecticide use is eliminated or greatly reduced compared to levels used in agricultural production. Second, covering the soil beneath solar panels with permanent vegetation reduces the erosive forces of rainfall and holds the soil in place through the network of plant roots, both of which significantly reduce the amount of erosion and

[11] See, for example, county Land and Water Resource Management Plans, available at: datcp.wi.gov/Pages/Programs_Services/LWCPlanning.aspx

runoff within solar fields (EPRI 2020). Lastly, soil is also disturbed less frequently when used for solar panels compared to routine tillage that often takes place within traditional row crop agriculture.

Our analyses indicate that a solar facility with perennial grassland maintained under and around the panels can reduce phosphorus loading to nearby surface waters by 75–95%, compared to previous row cropping land use[12]. Similarly, another study estimates that utility-scale solar facilities reduce sediment export by 90–98% compared to traditional row crop agriculture in the Midwest (Walston et al. 2021).

Finally, significant declines in nitrate contamination of drinking water have been reported within a decade of agricultural land conversion (Rayne et al. 2019), illustrating how cessation of agricultural inputs can improve drinking water quality within the timescale of a typical solar lease. Indeed, a project in Minnesota is exploring how solar farms can be used to protect drinking water wellhead protection areas vulnerable to nitrate contamination (Minnesota Department of Health nd).

Improved wildlife habitat

Native pollinator populations, especially bees and butterflies, have been declining in Wisconsin (WDNR nd). Some species are even considered endangered, such as the rusty patched bumblebee (WDNR nd) and the monarch butterfly (IUCN 2022). Pollinators are critical for plant growth, including that of some agricultural crops. Even if crops do not heavily depend on pollinators, their presence boosts crop yield (Locke et al. 2016). Conventional row crop agriculture contributes to pollinator decline due to lack of crop diversity, lower numbers and varieties of flowers, pesticides loss, and conversion of natural habitat and food sources (Hamilton 2021).

Planting deep-rooted perennial prairie plants along edges of farms creates pollinator habitat in addition to reducing erosion, increasing nutrient retention, and doubling as wildlife habitat or forage for grazing animals (Locke et al. 2016). These same pollinator benefits are realized on a larger scale through planting native plants beneath and around utility-scale solar arrays. Planting native plants (and other pollinator-friendly plants) beneath and around utility-scale solar arrays helps support native pollinators populations (TNC 2019; Armstrong et al. 2021; Blaydes 2021; Blaydes et al. 2022; Walston et al. 2024). Studies of pollinator activity around solar facilities found that pollinators visited all areas (full sun, partial sun, and full shade) indiscriminately and were not deterred by the presence of panels, illustrating the scope of potential habitat expansion (Graham et al. 2021).

Another study found solar facilities in the Midwest that were vegetated with native grassland increased

[12] See **Appendix B1** and **B2** for full analyses

pollinator habitat quality 300% more than land used for row crop agriculture (Walston et al. 2021). Pollinator habitat under solar panels can increase biodiversity as well as crop yield for nearby farmland (Katkar et al. 2021). Most relevant to Wisconsin, soybean and cranberries, two significant crops in the state, benefit in quality and quantity from increased pollinator activity (Walston et al. 2018). This increased activity can come from nearby (up to about 1 mile away) utility-scale solar arrays planted with pollinator-friendly flowers (Walston et al. 2024). An analysis found that increased soybean yields from pollinator-friendly solar development in Minnesota result in a benefit of $250 per acre per year (Siegner et al. 2019).

More generally, conventional row crop agriculture is a major driver of biodiversity loss (e.g., Foley et al. 2005), and thus the reduced disturbance and increased vegetation diversity on cropland converted to solar facilities can increase habitat for other species beyond pollinators. For example, a study in the United Kingdom found significantly greater total plant diversity and bee, butterfly, and bird abundance on solar plots compared to nearby agricultural land (Montag et al. 2016). Another study in Central Europe found greater bird diversity in solar farms compared to surrounding agricultural land (Jarčuška et al. 2024).

Carbon sequestration and improved soil health

There is an urgent need to reduce atmospheric carbon levels to avoid the worst impacts of climate change. Carbon can be sequestered into soil and plant biomass, thus taking it out of the atmosphere. Forests, grasslands, and other undeveloped landscapes sequester more carbon than developed or agricultural land due to a higher density of biomass and a lower level of soil disturbance. Research from Wisconsin and elsewhere indicates that in an agricultural setting, perennial vegetation such as pastures are far more effective at maintaining, or even storing, soil carbon than techniques used in annual cropping systems like cover crops or no-till (Grandy & Robertson 2007).

The conversion of native prairies and grasslands to agriculture over the past couple of centuries has substantially reduced soil carbon as the soil is tilled and otherwise disturbed (McLauchlan et al. 2006; Hernández et al. 2013). The large losses of carbon from converted agricultural land suggest there is great potential to sequester carbon by restoring native vegetation on previously farmed land. Several studies found restoring prairies and grassland on former agricultural land in the Midwestern United States increased soil carbon storage (McLauchlan et al. 2006; Hernández et al. 2013; Jelinksi & Kucharik 2009; Yang et al. 2019). This storage takes over a decade

for increases to be meaningful, and thus a project like utility-scale solar facilities, with timeframes of 30–50 years, would be long enough to realize increased soil carbon sequestration.

Planting perennial, deep-rooted native grasses and forbs under and around utility-scale solar arrays can help land previously used for row crop agriculture to sequester more carbon than it would under its prior use. A study found that a solar siting scenario in the Midwest with solar and native grassland has a carbon storage capacity 65% greater than traditional row crop agriculture (Walston et al. 2021).

Similarly, other studies report soil carbon sequestration rates when converting annual row cropping to grassland or pasture ranging from 1.2–13.2 (median: 3.1) tons CO_2 per hectare per year (Franzluebbers et al. 2014; Conant et al. 2017; Stanley et al. 2018; Becker et al. 2022). Although it would require validation, it is reasonable to assume that perennial, deep-rooted vegetative cover established at a utility-scale solar facility could accumulate soil carbon at a similar rate as grassland or pasture.

Applying these figures to a hypothetical 300 MW utility-scale solar project on 2,000 acres of former cropland, the conversion to solar has the potential to store 2,500 (range: 1,000–10,600) tons of CO_2 per year. Over a 40-year operational period, this amounts to 100,000 (range: 39,000–425,000) tons of CO_2 stored in the soil by the facility. According to the EPA's Greenhouse Gas Equivalencies calculator, this would be the equivalent of taking 23,800 (range: 9,300–101,200 passenger cars off the road or offsetting the greenhouse gas emissions of 13,000 (range: 5,100–55,400) homes' energy use.

This same benefit would not be realized by converting undeveloped or unfarmed landscapes to solar, since undisturbed landscapes already sequester more carbon than previously-converted sites. When disturbed during the construction process, forests or grassland release more carbon than disturbed agricultural land. Once converted to solar arrays, even with vegetation management, undeveloped landscapes are unlikely to sequester the same capacity of carbon they had before development. Therefore, carbon sequestration benefits are highest when development targets previously disturbed land like agriculture. Putting solar arrays on previously developed land instead of forests and grassland ensures the latter can continue providing their robust carbon sequestration function (TNC 2019).

While soil carbon sequestration is a potential co-benefit associated with utility-scale solar, we note that carbon storage is very site-specific and depends on prior soil management, soil characteristics, moisture regimes, and other environmental factors. Thus, restorations coupled with solar development may not always promote soil carbon sequestration. Furthermore, this benefit can be reversed if the land is returned to annual crop agriculture.

Planting properly managed mixed grasses can increase organic matter in soil and restore degraded land (Makhijani 2021). The favorable microclimates created beneath PV—lower temperatures, greater soil moisture—can improve native grass performance, and subsequently increase biomass and carbon sequestration (Walston et al. 2021). It also promotes larger root systems, which contribute to greater soil stabilization and reduced runoff. Walston et al. (2021) found the solar and native grassland scenario reduced soil export in the Midwest by 95% from row crop agriculture. The study also found the solar and native grassland scenario increased water retention by 19% from row crop agriculture. Healthier soil holds more water, which can contribute to increased water use efficiency on the land (Hernández et al. 2019; Nordberg et al. 2021). Wisconsin's general regulatory requirements for construction projects provide a baseline level of environmental protection from negative environmental impacts (WDNR nd). All solar projects must complete an endangered resources review to ensure that they avoid harming state- and federally-listed species. Impacts to surface waters and wetlands need to be minimized and authorized by the Wisconsin Department of Natural Resources. Stormwater permits are also required, meaning that stormwater management performance standards must be met during construction and post-construction to minimize runoff and prevent erosion while the land is disturbed and once the panels are in place. Compliance with and oversight of these existing regulatory standards, especially the Erosion Control and Storm Water Management Plans, are particularly important during the construction period, when problems like runoff and erosion are most likely to occur.

While these general construction regulatory requirements establish a baseline prevention of harm, the following recommendations go above and beyond this baseline to encourage solar development in Wisconsin that does not harm the environment but also provides local environmental benefits to maximize the sustainability of solar development in Wisconsin.

Solar Development in Wisconsin

Site Selection

A solar project's environmental benefits are enhanced beyond the climate and air quality benefits of displacing fossil fuel generation when the facility is sited where its physical footprint will enhance local environmental quality rather than displacing important undeveloped habitat. Solar should be sited on already disturbed or degraded land rather than clearing natural vegetation in order to minimize habitat loss and fragmentation. In particular, development should be avoided in ecologically sensitive or high biodiversity areas identified by The Nature Conservancy's Site Renewables Right mapping tool[13].

Given the potential environmental co-benefits of utility-scale solar on current agricultural land discussed in this report, when agricultural landscapes are being considered for project siting, it is advantageous to locate developments in areas of Wisconsin where these benefits are maximized.

Siting solar on agricultural fields disproportionately contributing to phosphorus loading of nearby surface water should be prioritized to maximize the benefit of reduced sediment and phosphorus runoff from land use conversion to solar (Fig. 1). Similarly, solar siting on fields in areas where groundwater is vulnerable to contamination and that are currently receiving high levels of nitrogen fertilizer input (Fig. 2) maximizes the benefit of reduced nitrogen leaching into vulnerable aquifers. For example, county wellhead protection plans identify the source area for each municipal drinking water well in the county and can include land use considerations and restrictions to protect the municipal water supplies to protect public health. Wellhead protection plans are required by state law (Wis. Admin. Code. s. NR 811.129(6)) and developers should consider consulting with county and local governments to identify wellhead protection zones and prioritize solar field siting in these areas to provide groundwater quality protection.

The pollination benefit of pollinator-friendly solar development can be maximized by siting solar projects near fields growing pollinator-dependent crops (Fig. 3). Co-locating solar fields near or adjacent to agricultural operations like grazing sheep can simplify and maximize agrivoltaic like grazing opportunities, although we note that sheep can also be trucked in from farther away as part of a rotational grazing plan so proximity is not as critical for this benefit.

In addition to deliberately siting to maximize potential co-benefits, solar development should be minimized

[13] The Nature Conservancy: Site Renewables Right. Available at: nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/site-wind-right/?vu=siterenewablesright

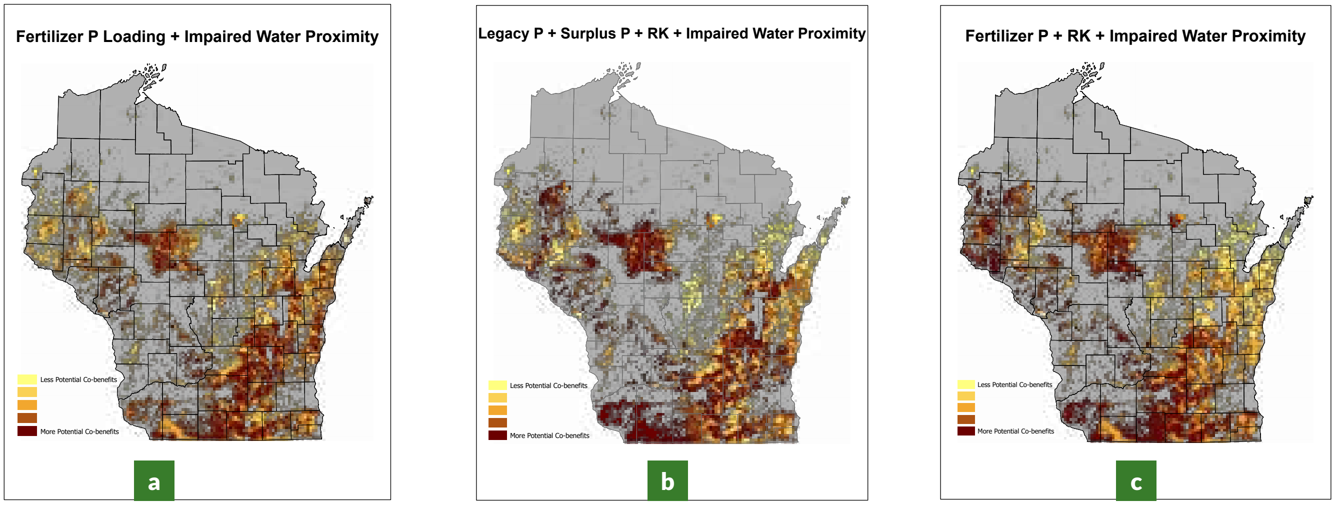

FIGURE 1. Relative potential for solar development to reduce phosphorus (P) export from cropland to impaired waters in Wisconsin, accounting for fertilizer P applications, soil erosion potential (as measured by the RUSLE RK factor), and proximity to a waterbody impaired for by excess phosphorus. Darker colors indicate a greater potential for solar development to provide this environmental co-benefit. We used three different sources of phosphorus export potential: the USGS SPARROW model (a); Sabo et al. (b), and NuGIS (c). Note that the SPARROW model already incorporates erodibility in its P loading estimate. See Appendix C for full details.

on fields that will create additional environmental issues. Specifically, care should be taken to avoid areas where there is a high demand for land for proper manure spreading . Siting in these areas could result in overapplication of manure on adjacent and nearby fields or the placement of manure on fields more vulnerable to runoff or groundwater contamination, both of which could inadvertently increase manure pollution to surface and groundwater. To the extent possible, marginal farmland should be prioritized for solar development to keep the most productive land in active farming. This also helps avoid the potential shifting of agricultural production to less productive farmland, which could require additional fertilizer or pesticide inputs and increase nutrient and sediment runoff.

Construction

Site preparation should occur with minimal or no grading. Not only does grading increase construction time and costs, grading can remove topsoil from the land, making it more difficult to establish desired vegetative cover that is critical to many co-benefits (as discussed below). Grading ultimately lowers the value of ecosystem services within the development site and the state at large. Disturbing the land through grading can also facilitate the spread of invasive species, which reduces local biodiversity and can cause invasive spread into farming areas abutting the solar site. Where topsoil removal is necessary for grading, it should be appropriately stockpiled separately from other subsoils and replaced during reclamation or otherwise reapplied within the project area.

Avoiding compaction and addressing compaction that does occur is an important component of achieving these environmental benefits and avoiding negative impacts. Soil compaction negatively impacts stormwater management by increasing runoff, making it more difficult for vegetation to establish, and making it more difficult to return the land to productive agriculture following the project's decommissioning. Indeed, a recent analysis by the National Renewable Energy Laboratory and Great Plains Institute found that soil compaction is the most significant factor affecting stormwater management at solar facilities (Great Plains Institute 2023a). Recommended measures from Yavari et al. (2022) and Great Plains Institute (2023b) to minimize compaction, and adequately address compaction that does occur, include:

- Limit construction activity during wet and rainy conditions
- Limit use of compaction-inducing heavy equipment to designated work areas
- Use low ground pressure equipment, particularly in areas where soils are prone to compaction
- Take soil bulk density measurements in representative areas pre-construction to establish bulk density benchmarks that can be used to 1) identify areas post-construction that have been significantly compacted and 2) establish a target for decompaction success.

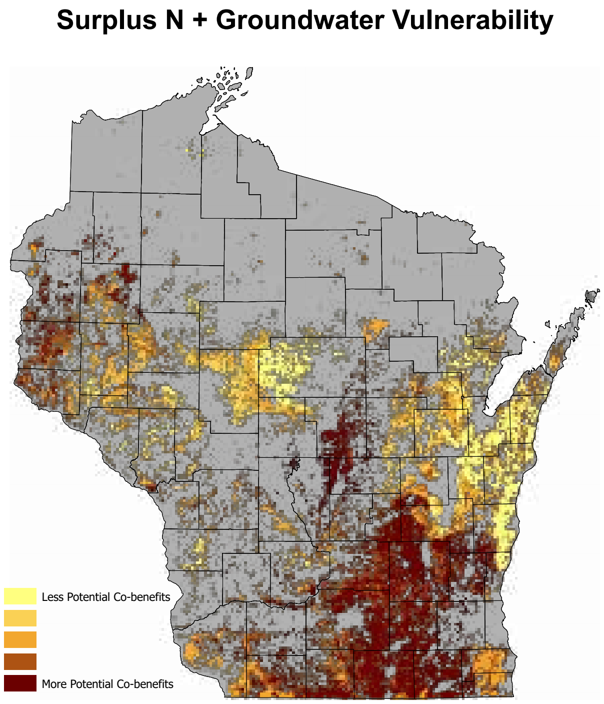

FIGURE 2. Relative potential for solar development to reduce nitrogen leaching from cropland and improve groundwater quality in Wisconsin, accounting for surplus nitrogen applications and the vulnerability of the groundwater to surface contamination. Darker colors indicate a greater potential for solar development to provide this environmental co-benefit. See Appendix C for full details.

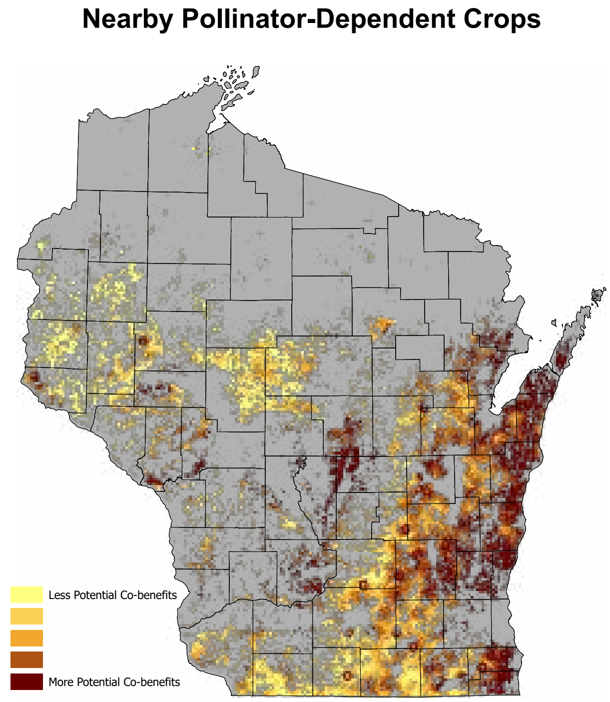

FIGURE 3. Relative potential for pollinator-friendly solar development to benefit nearby crops highly dependent on pollinators like orchards and cranberry bogs. Soybean, found throughout the agricultural regions of the state, are also moderately dependent on pollinators as discussed in the report but are not included here to focus on the most highly-dependent crops. Darker colors indicate a greater potential for solar development to provide this environmental co-benefit. See Appendix C for full details.

Design and Maintenance

Establish deep-rooted perennial vegetation

Appropriate vegetation management is critical to obtaining all the co-benefits discussed here. Establishing and maintaining perennial vegetative cover under and around the development site is necessary to prevent soil erosion, minimize stormwater runoff, sequester carbon and improve soil health. Establishing and maintaining flowering plants is necessary to provide pollinator habitat and can also provide resources for other wildlife like birds (Fisher & Davis 2010; Garfinkel et al. 2022). Beyond these environmental benefits, carefully selected, low growing, native vegetative cover can limit the amount of regular maintenance needed, reducing cost (TNC 2021).

Vegetation under and around panels should be native, deep-rooted grasses instead of turfgrass. Turfgrass cannot effectively contribute to water quality like deep-rooted perennial plants can, since turfgrass roots extend only several inches into the soil whereas deep-rooted perennials can exceed several feet depending on the plant (Fig. 4). Extensive, deep root networks hold soil in place better to prevent erosion and improves soil structure and hydraulic properties, allowing for greater carbon sequestration, greater total water uptake, and improved evapotranspiration below the panels (Asbjornsen et al. 2014). Runoff from turfgrass surrounding panels increases stormwater runoff by 38% compared to deep-rooted perennials (Great Plains Institute 2023a). Finally, long-term maintenance of turfgrass is more expensive than that of deep-rooted perennials because of costs related to mowing, reseeding, and herbicide application (Janke et al. 2021).

Establish pollinator-friendly habitat

Pollinator species have seen dramatic declines in recent years, with a major factor being habitat loss including the conversion to row crop agriculture. Solar farms present an opportunity to provide new habitat through the establishment of pollinator-friendly vegetation in and around the panel arrays. Entomologists in Wisconsin and other states have developed pollinator-

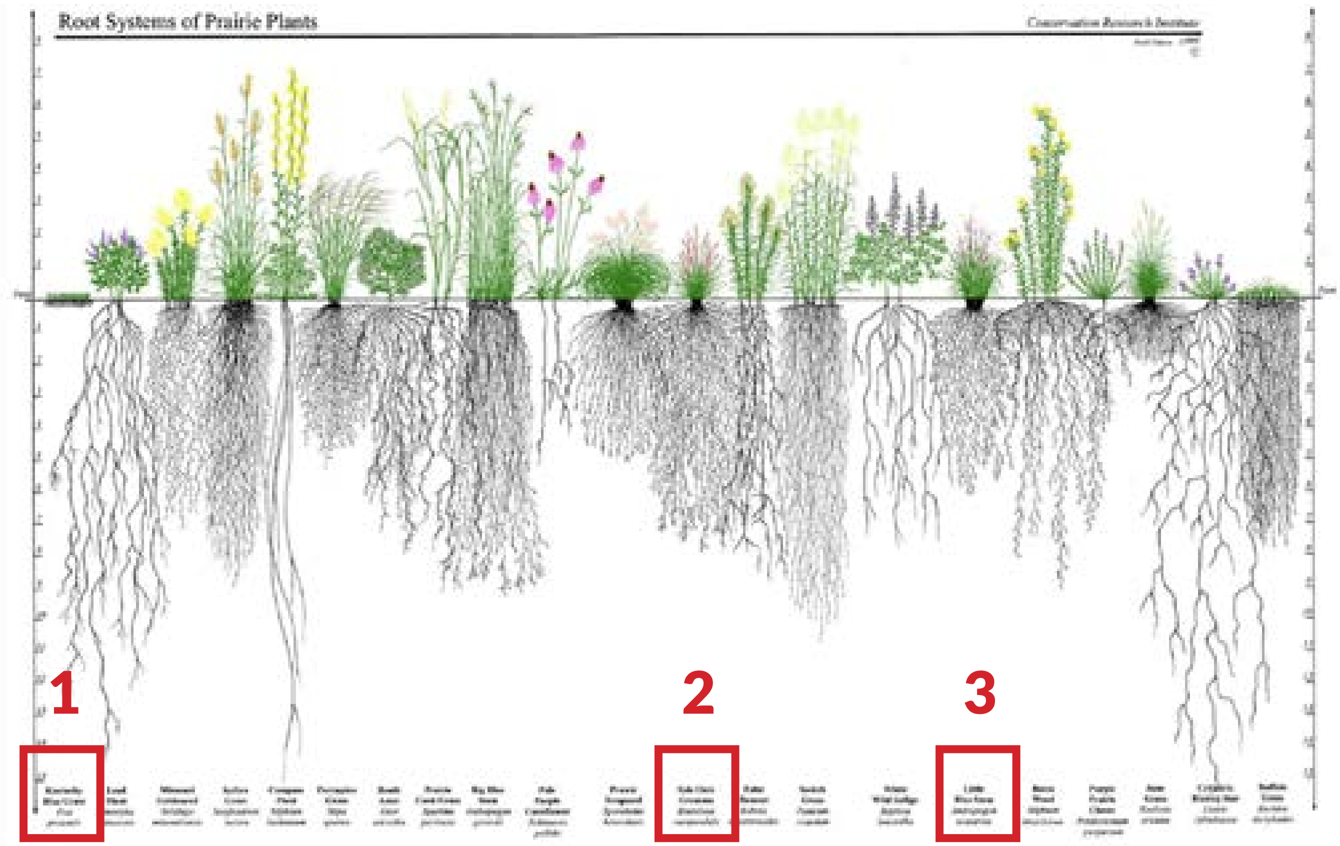

FIGURE 4. Illustration of typical turfgrass root depth (1) and native prairie grasses, including side oats gramma (2) and little blue stem (3), two deep-rooted grasses that can be used at solar farms. Underlying image credit: Heidi Nature, Conservation Research Institute, 1997.

friendly guidelines for solar projects (Minnesota Department of Natural Resources 2020; UMass Clean Energy Extension nd; Wisconsin Solar-Pollinator Program nd). A consistent, guiding theme is that to create high quality pollinator habitat, it is important to have several flowering species blooming at each point throughout the growing season to ensure a steady food source for pollinators. Seed mixes should contain at least three species blooming in each of the early (late March–May), middle (June–August), and late (September–October) bloom periods.

Pollinator habitat scorecards developed by entomologists provide objective criteria against which to evaluate pollinator habitat quality[14]. Facilities should evaluate their vegetation management plan against such criteria. If the management plan does not meet these objective pollinator-friendly standards, developers should make necessary adjustments to improve habitat quality or refrain from claiming to provide quality pollinator habitat.

Despite some critiques of pollinator scorecards (EPRI 2021), there is value in using them to enhance solar projects. Uncertainty as to how effective practices encouraged by scorecards translate into improved pollinator habitat exist, especially in the absence of a standardized interstate third-party certification process. However, scorecard criteria—regardless of how different elements are weighed across scorecards—reflect general best management practices for vegetation management to improve pollinator habitat and are developed by entomological experts. Thus, they provide an independent, expert-informed benchmark against which to evaluate a proposed vegetation management plan and developer claims of pollinator-friendly co-benefits.

[14] Wisconsin (drive.google.com/file/d/1BEB8Zd36dpbaUXgMPnk78-D0Kc_t5dCQ/view); Ohio (fresh-energy.org/wp-content/uploads/2019/12/Ohio-Solar-Site-Pollinator-Habitat-Planning-and-Assessment-Form-v.9.pdf); Indiana (ag.purdue.edu/climate/indiana-solar-site-pollinator-habitat-planning-scorecard/); Michigan (canr.msu.edu/home_gardening/uploads/files/MSU_Solar_Pollinators_Scorecard_2018_October.pdf); Minnesota (bwsr.state.mn.us/sites/default/files/2019-02/Project%20Planning%20Assessment%20Form.pdf)

Utilizing pollinator scorecards can benefit solar development projects in two ways. First, scorecards identify feasible practices or adjustments not previously considered by the developer that lead to onsite and offsite co-benefits. Second, comparing the vegetation management plan to independent, expert established benchmarks can validate a developer's claims that the project will establish pollinator-friendly habitat which can build trust between developers and a skeptical local community who may perceive developer-stated pollinator co-benefits as corporate "greenwashing".

Regardless of whether pollinator-friendly habitat is being intentionally created at the site, developers should source seeds that are not pretreated with neonicotinoid pesticides, which are harmful to pollinators and other beneficial insects, as well as other resident wildlife, birds and aquatic organisms.

Wildlife-friendly design

To allow wildlife to travel through utility-scale solar arrays while reducing habitat fragmentation and funneling of wildlife movement to roadways, which may increase vehicle collision risk, permeable fencing and wildlife corridors should be included in project design. Permeable fencing has larger gaps along the bottom which allows small-to-medium–sized animals (such as turtles, birds, and raccoons) to pass through (TNC 2019). Wildlife corridors are unfenced areas between arrays, rather than continuous fencing, to allow larger animals (such as deer, coyotes, and bear) to continue moving through the larger landscape unimpeded by the solar facility (TNC 2019).

Native grassland vegetation beneath solar arrays, recommended here for its environmental benefits, also enhances wildlife benefits by providing cover, habitat, and foraging space for animals that are not excluded from the array area (TNC 2019). Solar developers can also provide supplemental habitat in the form of vegetation buffers around the solar array or boxes for bees, birds, and bats within the array (TNC 2019).

As discussed in Section 3.2 of this report, avian mortality at utility-scale solar facilities is poorly understood, particularly in the upper Midwest. This creates a lack of science-based recommendations as to how to reduce mortality via site design. For more on the need for additional research to understand the impact of solar development on wildlife see Chock et al. (2021). An avian mortality monitoring program as discussed would yield insight into design considerations that could minimize bird mortality impacts. In the meantime, the most important consideration is likely to site solar facilities on already disturbed land rather than converting currently undeveloped land that will cause additional habitat loss and fragmentation.

Wildlife-friendly mowing practices are encouraged to protect ground nesting birds or other wildlife that may utilize native vegetation cover in the array areas during especially important times of the year, such as mating and nesting seasons. Delaying mowing as late into the summer as possible allows many grassland birds to complete at least one nesting cycle. For example, a recent analysis of the effect of mowing on grassland birds in Iowa recommends delaying mowing until after July 31 (McMullen & Harms 2020). Using flushing bars on mowing equipment allows wildlife extra time to escape death or injury.

Finally, burying collector and generation tie lines while incorporating avian safe designs into any new overhead power lines will help reduce avian collisions (Bateman et la. 2023).

Maintain Appropriate Panel Spacing to Manage Stormwater Runoff

Solar panels create large areas of impervious surface that have the potential to create stormwater runoff concerns. While understanding how solar farms change the hydrology and runoff volume in fields is still an active area of research, early indications are that runoff concerns can largely be addressed by adequate vegetation establishment under and around the panels (as discussed above) and by maintaining appropriate spacing between panels (Cook & McCuen 2013; Gulotta et al. 2023; Bajehbaj et al. 2024; Nair et al. 2024). This spacing is referred to as "disconnection" and allows runoff from panel driplines to be absorbed and filtered rather than allowing the runoff from the panels to become too concentrated and cause excessive erosion. For example, research from the National Renewable Energy Laboratory and Great Plains Institute found a 14% increase in runoff when reducing panel spacing from 35 feet to 15 feet (Great Plains Institute 2023a). Panel arrays located on poorly draining soils or steeper slopes may need larger interpanel distances or, in extreme situations, installation of stormwater management structures like infiltration basins to collect increased runoff from the addition of panels to the landscape (Bajehbaj et al. 2024). The Wisconsin Department of Natural Resources has developed some recommended spacing based on soil, vegetation and slope properties of the array area (WDNR 2024b).

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Appendices

Appendix A:
Corn Ethanol vs Solar Land Use Comparison
cleanwisconsin.org/wp-content/uploads/2025/02/Corn-Ethanol-vs-Solar-Land-Use-Comparison.pdf

Appendix B1:
Analysis of Phosphorus Runoff Reduction at the Onion River Solar Farm
cleanwisconsin.org/wp-content/uploads/2025/02/Analysis-of-Phosphorus-Runoff-Reduction-at-the-Onion-River-Solar-Farm.pdf

Appendix B2:
Analysis of Phosphorus Runoff Reduction at the Koshkonong Solar Farm
cleanwisconsin.org/wp-content/uploads/2025/02/Analysis-of-Phosphorus-Runoff-Reduction-at-the-Koshkonong-Solar-Farm.pdf

Appendix C:
Mapping Potential Environmental Co-benefits from Solar Development
cleanwisconsin.org/wp-content/uploads/2025/02/Mapping-Potential-Environmental-Co-benefits-from-Solar-Development.pdf

Strobus Solar Project in Black River Falls, Wisconsin. Image courtesy of OneEnergy Renewables

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