NCF-Envirothon 2024 New York

Current Issue Part A Study Resources

Key Topic #3: Renewable Energy and Natural Resources

12. Describe the impact renewable energy projects have on natural resources and the environment on both local and global scales.
13. Identify actions or innovative approaches to address negative impacts from renewable energy on natural resources and the environment.
14. Explain the benefits and limitations of concurrent use of renewable energy projects on agricultural lands.

Study Resources

Resource Title	Source	Located on
Agrivoltaics: Coming Soon to a Farm Near You?	*US Department of Agriculture Northeast Climate Hub, 2023*	Pages 111 - 113
Maine's Prime Farmland is Being Lost to Solar – Is 'Dual Use' the Answer?	*Kate Cough – The Maine Monitor, 2022*	Pages 114 - 119
Solar Farms Shine a Ray of Hope on Bees and Butterflies	*Jodi Helmer – Scientific American, 2019*	Pages 120 - 123
We can't ignore that offshore wind farms are part of marine ecosystems	*Becki Robins – Popular Science, 2023*	Pages 124 - 128
Farm with the Wind	*Matthew Wilde – Progressive Farmer, 2021*	Pages 129 - 134
Hydropower and the Environment	*US Energy Information Administration, 2022*	Page 135
Hydropower Dams Threaten Fish Habitats Worldwide	*Sarah Cafasso – Stanford Natural Capital Project, 2020*	Pages 136 - 137

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Agrivoltaics: Coming Soon to a Farm Near You?

US Department of Agriculture Northeast Climate Hub, 2023

In 2020, U.S. renewable energy production (and consumption) hit a record high. The increase was mainly driven by more solar and wind.

Despite this, renewable energy still only accounts for 12% of total U.S. energy consumption. Meeting the goal of "a net-zero emissions economy by 2050", will require much more. According to a recent U.S. Department of Energy report, Solar Futures Study, "it is now possible to envision—and chart a path toward—a future where solar provides 40% of the nation's electricity by 2035." In that future, farmers and farmland will play a key role. One issue with renewable power is that it requires far more land per unit of power produced than fossil fuels. While many may favor renewable energy in the U.S. – that sentiment often changes when projects are proposed close to home. An energy system built on renewables – like solar or wind – would mean locating sites and infrastructure a lot closer to where those resources are either abundant and/or easily distributed. And, in many cases, this would mean areas that have not yet seen energy production or infrastructure in their own community backyards before.

How much land is needed?

According to the Solar Futures Study, a lot of land will be needed. By 2050, ground-based solar could need about 0.5% of the land in the contiguous U.S. To put this into perspective, about 5% of land is already in urban areas and roads and another 0.1% in golf courses. Agriculture occupies about 43% of the lower forty-eight states surface area. The report points to prioritizing disturbed lands (8% of land) and dual-use land opportunities. Examples of disturbed lands include invasive species-impacted lands, non-vegetated lands such as quarries or gravel pits, and lands identified as contaminated but remediated for some forms of reuse. Agriculture will be an important dual-use case.

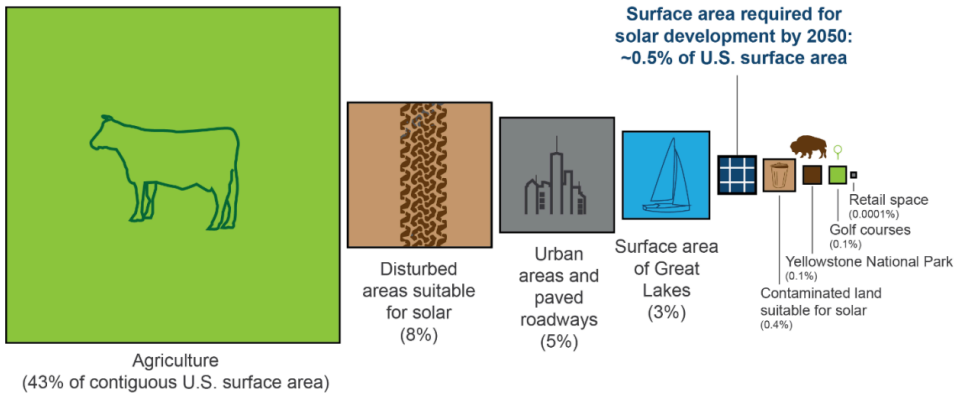

Figure 8 - 7. Maximum land use required for solar in 2050 in the *Solar Futures* scenarios compared with solar-suitable disturbed and contaminated areas and examples of other U.S. areas

Amounts of disturbed and contaminated lands depicted here represent the amounts suitable for solar energy development calculated in the *Solar Futures Study*. Sources: (EPA 2020; USDA 2014; LANDFIRE, n.d.).

The idea is called: Agrivoltaics

Agrivoltaics is the use of land for both agriculture and solar photovoltaic energy generation. It's also sometimes referred to as agrisolar, dual use solar, low impact solar. Solar grazing is a variation where livestock graze in and around solar panels. This system looks at agriculture and solar energy production as compliments to the other instead of as competitors. By allowing working lands to stay working, agrivoltaic systems could help farms diversify income. Other benefits include energy resilience, and a reduced carbon footprint.

A symbiotic 'cooling' relationship occurs when growing crops (or native grasses and forbs) under solar panels. Together, each helps keep the other cool. While all crops need sunlight to grow, too much can cause some to get stressed, especially cool season plants such as brassicas. Plants growing under the diffused shade of photovoltaic panels are buffered from the day's most intense rays. Shade reduces air temperature and the amount of water evaporating from soils; a win-win for both plants and farm workers on hot summer days. The plants in turn give off water vapor that helps to naturally cool the photovoltaic panels from below, which can increase panel efficiency.

Agrivoltaics in the Northeast

The largest agrivoltaics site in the U.S. is on a blueberry farm in Rockport, Maine. This new 10-acre, 4.2-megawatt project is the first of its kind in the state, and will offer critical insights and experience. Researchers from University of Maine Cooperative Extension are evaluating the impact of panel installation on the blueberry plants. They will also see how the crop fares over time under the solar array.

Another form of agrivoltaics seen across the Northeast integrates livestock and pastures. This concept is commonly referred to as 'solar grazing.' It has taken off in recent years as a win-win-win for farmers, solar companies, and the environment. Traditionally, the grasses that would grow up between solar panels need to be mowed to prevent the plants from shading the panels and reducing their efficiency. However, when sheep can be used, the high maintenance costs associated with mowing are eliminated for the solar company. At the same time, local shepherds can benefit from an added revenue stream to graze their sheep at these sites. Removing mowing operations not only keeps grassy areas safer for wildlife (i.e., nesting ground birds), but means less fuels and emissions too.

Researchers and farmers around the country are currently experimenting and collecting data on what crops, pollinator plants, and/or livestock situations work best with photovoltaic setups. Agrivoltaic systems can offer farmers many exciting opportunities. How agricultural systems perform, and how project economics shake out is still to be determined. Also to be seen is how states and communities will decide to address policy regulations and/or zoning laws based on this dual land use option.

Agrivoltaics Research

The U.S. Department of Energy is supporting solar development and agriculture with their InSPIRE program. This program is managed by the National Renewable Energy Laboratory

(NREL). It seeks to improve the mutual benefits of solar, agriculture, and native landscapes. Currently, there are 22 projects sites across the U.S. These bring together a wide array of researchers, farmers, and industry partners.

NREL research projects located in the Northeast:

- University of Massachusetts Amherst: Researchers are studying the effects of co-locating solar energy panels and agriculture operations at up to eight different farms across the state. This research will help farmers and communities make informed decisions about solar.
- Cornell University: Researchers are looking at the benefits of pollinator-friendly plantings on solar farms. One goal is to see if wildflower plantings on solar sites can increase pollinator populations. Another is to see if wildflower plantings on solar farms encourage pollinators to visit crop flowers. Other Cornell research is looking at how sheep grazing may influence pollinator habitat and sequestration of soil carbon.

Other regional agrivoltaic research projects of note:

- Rutgers University: In June 2021 the Dual-use Solar Act was passed in New Jersey. This act set up a pilot program "to enable a limited number of farmers to have agrivoltaic systems on their property while the technology is being tested, observed and refined." Funds also went to the New Jersey Agricultural Experiment Station to build and study agrivoltaic systems on their research farms.
- University of Vermont: This past fall, UVM Extension's Center for Sustainable Agriculture put on a workshop called, Solar Energy in Vermont's Working Landscape. The event brought together experts and stakeholders to address existing practices and barriers to solar grazing adoption as well as requirements for long-term success in the state. Before this, the Center's pasture program worked with Vermont Agency of Agriculture, Food & Markets and Two Rivers-Ottauquechee Regional Commission. They developed guides for how to "balance the needs of community and farm-scale energy needs with a shared commitment to protecting agricultural lands."

While a lot of research is underway, many questions about agrivoltaic systems persist. Various research and demonstration sites around the country are working to find answers to questions like: What are the long-term impacts of solar energy infrastructure on soil quality? What crops, in what regions, are best suited for photovoltaic systems? How can both crop and energy systems be optimized? How will livestock (and wildlife) interact with solar energy equipment? What types of business agreements will work best between a solar developer or company and agricultural producer or landowner?

Maine's prime farmland is being lost to solar. Is 'dual use' the answer?

By Kate Cough – The Maine Monitor – January 16, 2022

A report urges developers to build dual-use projects with elevated panels that permit farming and grazing beneath. Critics say the approach is not yet affordable.

Maine farmer Michael Dennett of Jefferson stands with his flock of sheep. Dennett has contracts to graze his sheep beneath solar panels, essentially providing a mowing service for developers. Photo by Garrick Hoffman.

On an overcast afternoon in early July, Michael Dennett drove to a paddock near midcoast Maine to check on his sheep. They'd been there for a couple of days, and it was almost time to move them to another section of pasture.

Dennett, who owns Crescent Run Farm in Jefferson with his wife, Ryan, has been a sheep farmer for years. But this pasture was different from where he'd grazed sheep in the past: It was a commercial-scale solar project, and Dennett's sheep were providing the mowing services.

"Ideally we get through a site within 30 days, particularly in the spring when grass is growing really fast," said Dennett. Per his contract with ReVision Energy, Dennett does two grazes annually on several sites not far from the couple's home.

Arrangements like Dennett's — grazing sheep, or growing blueberries under solar panels — are known as "dual-use." As Maine farmers lose prime land to solar developers who want it for panels, dual-use has emerged as a way to keep the land in production, yet also use it to generate energy from the sun.

Farmland, with its open fields, southern exposure and well-drained soils, is typically one of the easiest and cheapest places to put a solar project. But that type of land is also limited in Maine.

A lack of regulations around where solar can be sited has resulted in farms being converted to panels at a rapid clip, an analysis by The Maine Monitor found. Developers outcompete farmers for prime land, or offer working farmers attractive sums to take some land out of production.

In an effort to help stem the conversion, a report expected out this week from the Governor's Energy office stakeholder group encourages farmers considering solar on actively farmed land to prioritize dual-use, to keep as much of that land in production as possible.

Except those systems, solar developers say, are so costly to construct that they aren't viable in Maine on any grand scale.

"That's the technology that we can't afford in this state," Matt Kearns, chief development officer of Longroad Energy and member of the Agriculture Solar Stakeholder Group, told members at a meeting in December.

Sheep are able to graze under traditional ground-mounted systems, and the shade the panels provide is great for the animals, said Dennett. But other kinds of dual-use projects, such as those that allow for vegetable farming or cattle grazing, require elevating panels and spacing them farther apart.

As Maine farmers lose prime land to solar development, dual-use farming has emerged as a way to keep the land in production, yet also use it to generate energy. Photo by Michael Dennett.

That means more materials, like steel and aluminum, and less energy (and thus less revenue) per acre compared to traditional ground-mounted systems, where panels can be placed close together.

"It's very expensive, very hard to do," said Kearns. "If we're encouraging dual-use … that's basically just saying the farmer can't develop solar."

Farmers can't compete

Maine, the most heavily forested state in the U.S., has a finite amount of soil suitable for agriculture. About 10 percent of the state's nearly 22 million acres are considered "soils of statewide importance." Of those soils, 800,000 acres are considered "prime," or land that is "of major importance in meeting the nation's short- and long-range needs for food and fiber," according to the U.S. Department of Agriculture.

Only half of the land suitable for farming in Maine is being farmed, and increasing local food production is one of the goals of Maine Won't Wait, the state's climate action plan. State officials have said they want to triple the amount of food consumed in Maine from state food producers to 30% by 2030.

But amid the state's solar gold rush, much of that land has stopped growing food or fiber altogether. It now produces solar energy.

The state does not track how much farmland has been lost to solar projects, but a recent analysis by the Maine Audubon Society found that of 180 projects waiting to be reviewed by the Maine Department of Environmental Protection, 163 intersected with soils classified as prime or of statewide importance. That number is potentially much higher, since only projects on more than 20 acres go through full DEP review.

“The reality is we’re losing habitats. And the reality is we’re losing farmland,” said Sarah Haggerty, a conservation biologist with the Maine Audubon, in a presentation to the Agriculture Solar Stakeholder group.

The group, convened by the Department of Agriculture, Conservation and Forestry, and the Governor’s Energy Office, was tasked with seeking ways to protect important agricultural land while helping to reach solar generation goals.

While state and local officials have championed building those solar projects on capped landfills, brownfields and land that is otherwise unusable, that’s not where they’re ending up.

“We were pretty disappointed to find that 11 of the 180 projects intersect with gravel pits, and just six of them are uncapped landfills,” said Haggerty.

Solar is not the only threat to farmland, which is also being developed for housing and sold off as older farmers (the average age of a Maine farmer is 57) retire and there is no one to take their place. But what makes for good farmland — southern exposure, well-drained soils — also makes an excellent location for solar panels.

And once there are panels on that land, it’s highly unlikely it will ever be farmland again, at least not for many decades.

“I do not think we should expect large amounts of land to return to other uses from solar at the end of the first generation of life,” said Fortunat Mueller, a managing partner at ReVision Energy, during a recent stakeholder meeting.

Pressure from solar developers makes it more difficult for the roughly 25 percent of Maine farmers who lease their farmland to compete in the market. It also makes it harder for new farmers, many of whom lease land before they’re able to buy.

Younger farmers are “competing with developers who are offering $1,000 an acre on average, when we can maybe offer $200 an acre for row crop quality soil,” said Andy Smith, who participated in the committee and runs The Milkhouse, a dairy farm in Monmouth, with his partner, Caitlin Frame.

Farmers who lease hay fields, where they often pay $50 per acre or less for a lease, have been particularly hard hit by solar development, said Smith. “We’re at a massive disadvantage.”

The ‘wild east’ of solar

One reason Maine has seen such rampant solar development on farmland is that lawmakers have yet to enact rules around siting solar on those soils, or set regulations that would direct projects away from open space.

The state was flooded with proposals after the Legislature, in 2019, put in place incentives aimed at helping meet its renewable energy goals. With few regulations on where projects can be located, companies have typically looked to the cheapest, easiest options.

Other states and countries have grappled with the issue for years. Massachusetts, faced with rapid loss of farmland and open space to solar and housing development, set rules allowing solar development on agricultural land only if panels are raised at least 10 feet above ground and shading from the array covers no more than 50 percent of the field. It also pays companies with such projects more for the energy they produce.

Vermont, responding to a similar issue, enacted rules in 2017 that would pay companies more for putting panels on landfills, sandpits and brownfields, although many of those incentives are ending.

Building solar projects on landfills is 10% to 15% more expensive than siting them on undeveloped land. It requires altering construction practices to keep from compromising the landfill's protective cap, which can increase labor costs. The presence of the cap also means that posts typically can't be driven into the ground but must be stabilized with ballast or mounted on long concrete footings, an additional expense.

Landfills and brownfields, which often have remnants of industrial infrastructure and environmental hazards, may also require more in-depth review than putting posts and panels in an empty field. Landfill projects must be monitored to ensure they do not compromise the site's integrity in the long term. Size is also an issue; many brownfields and landfills aren't large enough for grid scale arrays.

Solar on commercial rooftops is possible, but companies often don't want panels there because they take away from a building's development possibility, Drew Pierson, head of sustainability at BlueWave Solar, told the stakeholder group.

That's why developers say financial incentives are essential for companies to build on those kinds of sites or to put up dual-use projects on farmland.

"This all feels good. It sounds good. But it's not going to get done without additional incentives," said Jeremy Payne, executive director of the Maine Renewable Energy Association, in a December meeting.

Anything that increases costs to ratepayers will be a non-starter politically, the stakeholder group agreed.

"Massachusetts, sure. Big, big economy, a lot of ratepayers. Maine has a million and a half ratepayers," said Kearns of Longroad Energy. "I don't think we can afford that here."

Solar can keep land in agricultural production

Solar can also provide an economic cushion for farmers, who often operate on thin and unpredictable margins. Many see it as a way to possibly return the land to farming in the future, even if it's taken out of agricultural production in the short term, or as a way to use marginal areas that aren't being actively farmed.

That's the case for Rick Dyer and his family, who run Clemedow Farms in Monmouth. Dyer decided to allow a developer to install ground-mounted panels (Dyer wasn't aware of dual-use at the time) on 45 of the 1,000 acres the family owns in order to help sustain the rest of the farm.

"It provides a buffer by which if all else were to end tomorrow," said Dyer, "the economic value that comes in will pay the taxes on the entire property for the next 20 to 40 years and maybe beyond."

The panels, he said, provide economic support that will help keep the rest of the land in open space and able to be farmed.

"Farming in Maine is difficult at best," Dyer added. "For dairy farmers right now, it's really trying. The same price of milk is getting paid to the dairy farmer today that was getting paid to my grandfather 60 years ago, and the cost of that tractor went from $15,000 to $150,000."

Once the contract on the Clemedow Farms solar project is up, there are decommissioning plans that could allow the land to be put back into agricultural production.

Dyer hopes that will be the case. Had a housing development been built on that 45 acres, it would be nearly impossible to return that land to agricultural use, he pointed out. Putting up panels on one section will keep that hope alive.

Farmers want more evidence about dual-use

Economics aside, several farmers said they want to see more data that dual-use systems can work in Maine before agreeing to put panels on productive land.

"There's a lot of talk about dual-use and working with farmers and all of this, but at the end of the day not much else is ever going to be able to happen under these arrays other than sheep grazing and bees foraging on clover or something," said Smith, of The Milkhouse. Providing pollinator habitat is often counted as dual-use.

"But that to me is kind of greenwashing to call that agriculture," he said. "Not that it's not important, but we're not producing a lot of calories off that land."

Smith and his partner, whose 250-acre farm has a substation in the center, were contacted by more than a dozen companies after the legislation passed in 2019. They have a rooftop array that offsets the farm's energy use and were interested in putting up a dual-use system for their sheep and cattle to graze under. A developer told them it didn't make "economic sense."

While there are examples of crops successfully growing elsewhere under dual-use conditions, including a 24-acre vegetable farm with 3,200 panels in Colorado, it's important to see examples of it working in Maine, said Smith.

Scientists are studying a dual-use array on a 10-acre patch of blueberry field in Rockport to see how many years it takes the berries to begin producing after the array is installed, and also to see how well they do in shade.

Pierson, of BlueWave Solar, told the stakeholder group that globally there are already many examples of this working.

But, he added: “It’s not all roses … (Farmers) are going to need to invest in new equipment, or even business models to figure out how this works.” That could mean learning new methods and departing from long-held philosophies on farming.

Certain pieces of equipment cannot fit between the poles, tractors may not be able to maneuver, and farmers have to be careful not to get chemicals on the panels themselves.

“There are low-impact methods that may not have been on farmers’ minds before that are now actually required because you don’t want to damage the solar project,” said Pierson.

Group recommends changes

The stakeholder group came up with several recommendations that it hopes will ease pressure on farmers while still allowing Maine to meet its renewable energy goals. A dual-use pilot program of at least 20 megawatts was suggested, along with the creation of a database with information on solar projects.

The report also suggests regulators consider streamlining the permitting process by making dual-use and/or co-location (in which panels are installed on a portion of farmland, as at Monmouth’s Clemedow Farms) eligible for permit-by-rule, which essentially allows companies to meet certain criteria and be exempt from full site law of development review.

“If we really are going to go big on clean energy, we want to be careful about, you know, just adding a ton of new restrictions,” said Kearns of Longroad Energy.

The report advocates for allowing farms to keep their agricultural use tax designation even if they put up solar panels, as long as farming remains on the land. Under current rules, farmers typically lose that designation on the portion of the land with panels, which can amount to many thousands of dollars each year.

In public comments, many urged for solar panels to be installed on farmland only as a last resort.

“I am an advocate for solar power, but I believe that panels should be on every rooftop and parking lot and brownfield before we cover farmland,” wrote David Asmussen, a commercial vegetable farmer.

Anything that slows solar implementation, argue developers and advocates, will hold Maine back from meeting its renewable energy goals. But farmers and others point out that a local food system and a biodiverse landscape are also some of the best ways to fight climate change, even if the benefit is harder to quantify financially.

“It’s really important that people understand that this is rapidly changing the landscape of Maine,” Smith added. “We’re talking about the development of tens of thousands of acres of land in the state, just to meet our initial (portion) of renewable energy goals.”

CONSERVATION

Solar Farms Shine a Ray of Hope on Bees and Butterflies

A trend of planting wildflowers on solar sites could maintain habitat for disappearing bees and butterflies

By Jodi Helmer on January 14, 2019 أعرض هذا باللغة العربية

NREL scientist Jordan Macknick and Jake Janski, from Minnesota Native Landscapes survey a pollinator test plot planted underneath the photovoltaic array at the Chisago Solar Site, part of the Aurora Solar Project in Minnesota. Credit: Dennis Schroeder National Renewable Energy Lab *Flickr* (CC BY-NC-ND 2.0)

The tidy rows of gleaming solar panels at Pine Gate Renewables facility in southwestern Oregon originally sat amid the squat grasses of a former cattle pasture. But in 2017 the company started sowing the 41-acre site with a colorful riot of native wildflowers. The shift was not merely aesthetic; similar projects at a growing number of solar farms around the country aim to help reverse the worrying declines in bees, butterflies and other key pollinating species observed in recent years.

Up to $577 billion in annual global food production relies on pollination by insects and other animals such as hummingbirds and bats, according to the United Nations. But more than half of native bee species (pdf) in the U.S. have seen their numbers drop sharply since 2005, with almost 25 percent now at risk of extinction. Meanwhile the North American monarch butterfly population has declined 68 percent over the past two decades, the nonprofit Center for Biological Diversity says. Suspected factors include climate change, pesticide use and parasites—along with shrinking habitat,

largely blamed on natural landscapes (such as scrublands or wetlands) being converted for agricultural use.

And as pollinator habitat wanes, solar installations are taking up ever more land. The U.S. is expected to convert six million acres of land to such facilities before 2050, according to the National Renewable Energy Laboratory (NREL). Some researchers see this as an opportunity to reclaim land for pollinating species by replacing the usual grass or gravel at these sites with wildflowers that need insects to pollinate them, and that produce the nectar those insects eat. “If we can create some habitat where there wasn’t habitat before, like on solar farms, we can likely have a positive impact,” says Scott McArt, an entomologist at Cornell University.

A monarch Butterfly feeds on flowers being grown for seed at Minnesota Native Landscapes in Foley, Minn. Credit: Dennis Schroeder National Renewable Energy Lab *Flickr* (CC BY-NC-ND 2.0)

MORE PLANTS = MORE POLLINATORS?

Minnesota-based Great River Energy (pdf) has also introduced pollinator-supporting plants—such as purple prairie clover and wild lupine—at several of its solar sites, as has SoCore Energy at some of its outfits in Wisconsin. In 2018 the NREL identified 1,350 square miles of land near existing and planned utility-scale solar energy facilities around the country that could be similarly converted. Although no national statistics are available, in Minnesota alone it is estimated that half of the 4,000 acres of commercial solar projects installed in 2016 and 2017 included pollinator habitat.

Designing such habitat is not a matter of simply scattering some wildflower seeds, though. The right mix of a broad range of native plants is needed to attract and support the hundreds of pollinator species, from bees to birds, that can be found in some areas. A number of them have adapted to specific plants—such as monarch butterflies that feed on milkweed—or are extremely imperiled, as is the case with native bumblebees, says Sarah Foltz Jordan, a senior pollinator conservation specialist for the nonprofit environmental organization Xerces Society for Invertebrate Conservation. “A common issue with pollinator habitat is that the seed mixes aren’t

very diverse," she says. "So they may look pretty, but when you don't have a highly diverse plant community, you don't support a highly diverse pollinator community."

There is some limited evidence (pdf) solar farms with mixed plant life can support a wider array of bee and butterfly communities than those with grass or gravel beds can, but researchers are still investigating just how much this can affect the insects' long-term survival. "We don't have the data to say whether meaningful changes occur at a broad scale just due to solar sites," McArt says. "We don't know if this is going to have a substantial impact." But he hopes to change that. In July, through a partnership between Cornell and North Carolina–based solar developer Cypress Creek Renewables, McArt launched a three-year study to determine whether—and how much—establishing habitat on solar sites benefits pollinator populations.

The team will compare the abundance and diversity of wild bee species at a solar site planted with native wildflowers with an installation that has turfgrass growing beneath its panels. Then the researchers will test which seed mixes are most effective at attracting wild bees over longer periods. "Maybe it's not the seed mix that looks fantastic and attracts a lot of bees in the first year," he notes. "Maybe the better seed mix is the one that takes longer to establish but is much more resilient over time."

Minnesota bee keeper, Jim Degiovanni, inspects "BareHoney" hives outside IMS Solar, a pollinator-friendly photovoltaic array site in St. Joseph, Minn. Credit: Dennis Schroeder National Renewable Energy Lab *Flickr* (CC BY-NC-ND 2.0)

BOOST TO FARMS AND BUSINESS

When solar developers consider planting pollinator habitat, they also look at the bottom line, notes Lee Walston, an ecologist at Argonne National Laboratory outside Chicago. Despite a higher upfront cost to purchase and plant seed mixes, Walston contends this can actually offer long-term savings. For example, a field of wildflowers requires less mowing and pesticides than conventional grass does. And gravel absorbs heat whereas plants can help keep panels cool, improving energy efficiency.

Moreover, Walston believes planting wildflowers can help garner support in rural communities that might be resistant to leasing productive farmland to solar developers. New research has found raising pollinator numbers can bring higher yields of crops such as fruits and nuts, offering an obvious boon to farmers.

But one problem with siting insect-friendly solar installations next to pesticide-using farms is the chemicals can drift onto the wildflowers. Pesticides have been shown to impair various pollinating insects' foraging ability, decrease their immune responses, interfere with their absorption of nutrients and shorten their life spans. Mandatory buffer zones could help protect habitat from pesticide drift, Foltz Jordan says. Ultimately, she adds, converting some farmland to solar sites could also reduce overall pesticide use.

Still, experts warn such projects are hardly a panacea. "Establishing pollinator habitat on solar facilities is not the answer to pollinator decline," says Argonne ecologist Ihor Hlohowskyj—but he believes it is still one valuable way to prop up imperiled species. "With the large surface areas that solar facilities occupy," he says, "they offer a pretty unique opportunity to plant and establish pollinator habitat that could help conserve pollinator diversity."

ABOUT THE AUTHOR(S)

We can’t ignore that offshore wind farms are part of marine ecosystems

Offshore wind farms can create their own local climates and may alter currents. How does that affect marine life around them?

BY BECKI ROBINS / UNDARK | PUBLISHED AUG 24, 2023 – POPULAR SCIENCE

Scientists have a lot more work to do before they can know the true effect of thousands of offshore wind turbines, as well as how and where they should be built. DEPOSITPHOTOS

Last year, the Biden administration announced an ambitious goal: enough offshore wind to power 10 million homes by 2030. The move would reduce carbon emissions, create jobs, and strengthen energy security. It would also help the United States—which was responsible for just 0.1 percent of the world’s offshore wind capacity last year—catch up with renewable energy leaders like China and Europe.

The plan is already well underway: Massive turbines are rising off the coast of Massachusetts, and more projects are planned up and down the U.S. coastlines. Advocates say these turbines, and other offshore projects around the world, are a crucial tool in minimizing the effects of climate change: The technology is touted as clean, renewable, and plentiful. And, since offshore wind farms aren’t located in anyone’s backyard, they are, at least in theory, less prone to the political pushback onshore wind power has faced.

It will take a lot of turbines to meet Biden’s 2030 goal, and while wind turbines don’t use fossil fuels or generate carbon emissions, they are enormous structures, with some reaching heights of more than 850 feet above the water’s surface. (The Statue of Liberty, in comparison, stands a little over 300 feet.) As such, they will likely have some effect on the ocean environment.

Scientists already know some of the local impacts of wind farms. For example, they can, somewhat counterintuitively, reduce local wind speed. They also create their own local climates, and cause disturbances in the water in the form of a downwind wake. But what those changes might mean for marine life or for industries that depend on ocean resources is something that scientists are still trying to figure out.

Meanwhile, in the U.S., offshore wind has become the subject of bitter political disagreement and fear, fueling lobbying and lawsuits aimed at halting projects before they even begin. As researchers work to model potential outcomes, they stress that they don't want to derail offshore wind, but rather seek to better understand it so that any negative effects can be minimized, and positive effects maximized.

Scientists have a lot more work to do before they can know the true effect of thousands of offshore wind turbines, as well as how and where they should be built. There may even be questions they haven't thought to ask yet, said Ute Daewel, a scientist who studies marine ecosystems at The Helmholtz-Zentrum Hereon in Germany.

"It's so complex," she said, "that I sometimes think we probably also miss a lot of things that might happen."

Advocates of offshore wind turbines can point to a range of benefits—starting with their proximity to the places most in need of clean energy. Around 40 percent of the world's population lives within 60 miles of the ocean. Energy demand in densely populated coastal regions tends to be high, so offshore wind farms will be located close to where they are most needed.

Evidence suggests offshore wind power could lower energy costs, especially during extreme events like cold snaps when energy demands are high and wholesale prices peak. Meanwhile, the Department of Energy says that, in addition to reducing carbon emissions, the technology would improve human health by cutting air pollution from fossil fuels.

But wind farms have also come under intense criticism from a diverse coalition of stakeholders, including conservation nonprofits worried about the impact on marine ecosystems, fishing industry groups concerned about access to traditional fishing grounds, coastal homeowners keen to maintain their views, and groups that appear to be funded by large oil companies hoping to stifle competition.

Some of those criticisms focus on the impact on animals. Like onshore wind, the turbines can kill birds, though some researchers studying large-bodied waterbirds like sea ducks and geese have found they tend to avoid the turbines, which may mean less bird mortality offshore. Recent criticism from Republican lawmakers also suggests that the noise from offshore wind turbines might kill whales, although the National Oceanic and Atmospheric Administration says there's no evidence to back up this concern.

Meanwhile, some research suggests wind farms might even help fish and other marine life. "A lot of people say, hey, this is going to be a habitat improvement because there's going to be rocks on the bottom, which make artificial reefs," said Daphne Munroe, a shellfish ecologist at Rutgers University. "And that's absolutely true. But it's a shift away from what was there."

Munroe studies pressures on marine ecosystems, including the effects of climate, pollution, and resource exploitation. She's also the lead author of a 2022 Bureau of Ocean Energy Management study on the impacts of offshore wind on surfclams—a type of clam commonly used to make chowders, soups, and stews. (The BOEM study was funded by the federal agency; Munroe has received funding from wind farm developers to conduct other projects.)

The fishing industry fears wind farms will affect their ability to yield a profitable catch — especially since the windy, shallow waters that support a rich diversity of sea life also tend to be ideal locations for turbines. Some scientists say these fears have been overblown—a 2022 study, for example, concluded that the Block Island Wind Farm located off the coast of Rhode Island does not appear to negatively impact bottom-dwelling fish. (Coastal regulators in the state of Rhode Island mandated the study be conducted and paid for by wind farm developers.) Others, like Munroe, say specific fisheries such as Atlantic surfclams will be significantly affected.

Surfclam fishing in wind farm areas, said Munroe, is logistically difficult, if not impossible, since vessels use dredges that drag though the sand to collect the clams. The presence of power cables on the ocean floor, she said, would make it too dangerous to use this kind of equipment around wind farms.

Installed boulders surrounding turbine foundations will also create obstacles, according to Munroe. “Each of the foundations is going to have what’s called scour protection,” she said. “So basically, big boulder fields that are going to be placed around the base of the turbine foundation in order to prevent the sand from scouring away.”

Currently, there are no legal restrictions on fishing in windfarm areas, Munroe said, just physical ones. “They could still get out there, but in order to fish efficiently and be able to get the catch they need and get back to the dock in a reasonable amount of time, it just wouldn’t be feasible,” she said. In her 2022 study, Munroe and her co-authors concluded that the presence of large offshore wind farms could cause fleet revenues to decline by up to 14 percent in some areas.

The industry has also been vocal about other consequences, such as habitat destruction and the possibility that the turbines’ sound might affect fish populations. In Maine, lobstermen worry that heavy mooring lines will drive their catch away. In Massachusetts, groups that represent fishing interests have filed lawsuits against the Bureau of Ocean Energy Management on the grounds that the agency failed to consider the fishing industry when it approved the 62-turbine Vineyard Wind project.

“The Bureau made limited efforts to review commercial fishing impacts,” wrote the plaintiffs in one of the Vineyard Wind lawsuits. “The limited effort that was made focused almost solely on impacts to the State of Massachusetts and on the scallop fishery, despite other fisheries being more active in the lease areas.”

Physical changes to the ecosystem, such as the placement of turbine foundations and scour protection, are some of the more obvious impacts of offshore wind turbines. But wind farms might elicit more subtle changes in local weather, affecting wind patterns and water currents, which models predict could reverberate through the food chain.

A 2023 study led by oceanographer Kaustubha Raghukumar, for example, found that turbine-driven alterations in wind speed could produce changes in ocean upwelling—a natural process where cold water from the deeper parts of the ocean rises to the surface—“outside the bounds of natural variability.” Those cold waters contain nutrients that support phytoplankton, the single-celled plants and other tiny organisms that form the basis of the oceanic food chain. Shifts in upwelling could have an impact on phytoplankton—although those impacts are still in question, particularly as climate change alters the equation.

Raghukumar and his colleagues at Integral, an environmental consulting company, based their predictions off historical data. But such an approach might not create an accurate picture of what will happen in the future as some scientists predict warmer global temperatures will produce stronger winds and increased upwelling, while others foresee localized decreases in upwelling. In their 2023 paper, which was funded by the California Energy Commission and the Ocean Protection Council, the authors noted that wind farms might reinforce—or even counteract—some of these climate change-driven changes in upwelling, but that all remains uncertain.

While Raghukumar's study didn't model how changes in upwelling might affect marine life, other scientists are closely studying possible changes to the ecosystem, though these are also likely to be complex and difficult to predict. A 2022 paper modeled the effect that planned wind farms might have in the North Sea, off the coasts of the U.K. and Norway, and concluded that they could influence phytoplankton, which could alter the food web.

Daewel, the study's lead author, stopped short of drawing conclusions about what these changes might mean for the ecosystem as a whole. "We cannot say if that's really a bad thing or a good thing because the ecosystem is very dynamic, especially in the North Sea," she said.

Changes to ocean processes could impact fish survival, but, again, no one is really sure how. "Young fish need to be in a specific area at a specific time to find the right types of prey," said Daewel. "So this redistribution of ecosystem parameters, that could mean that there might be a mismatch, or a better match also, for fishery life stages. But this is purely hypothetical."

With or without wind farms, climate change is already altering the timing of critical ecosystem processes, said Robert Dorrell, lead author of a 2022 paper that investigated the effects of offshore wind on seasonally stratified shelf seas—coastal regions where water separates during the spring into different layers, with warm water at the top and colder water at the bottom. Shelf seas only represent about 8 percent of the ocean, but the phytoplankton that bloom there generate an estimated 15 to 30 percent of the organic matter that forms the basis of the food web.

In seasonally stratified shelf seas, phytoplankton grow in the upper layers, using up nutrients but also creating a food source for a myriad of marine animals. When the bloom is over, ocean mixing, a natural process driven by wind and waves, helps bring oxygen to the bottom layers and nutrients to the top, ensuring that creatures at every level can thrive. But climate change is expected to increase ocean stratification, which interferes with natural ocean mixing.

"When you have cold water underneath, which is of a higher density, that density difference makes it harder in general to mix water vertically, upwards or downwards," said Dorrell.

Dorrell and his co-authors believe that wind farms could provide a partial solution to this problem by introducing artificial mixing of stratified shelf seas. This process, Dorrell said, is a little like stirring a cup of French coffee. "We have a nice coffee on the bottom and then you have foamy milk on the top. And if you would get a spoon and stir your French coffee you would mix the light milk up with the heavier coffee below."

In much the same way, the downwind wake generated by an offshore turbine could help mix the warm and cold layers of water, which might help offset some of the effects of climate change.

Fortunately, scientists like Dorrell say, there is time to figure out the more subtle nuances of offshore wind and its larger effects on the marine ecosystem. "I think what we have to remember

with offshore wind is that although there are plans underway at the moment, they are long-term plans," he said. "In the U.K., for example, there are targets for 2030 certainly, but there are targets all the way through to 2050 and beyond. And there's certainly time there for research to inform and support and maximize the best delivery of offshore wind for the benefit of everybody."

Daewel added that papers like hers, which might suggest potential problems, aren't an argument against wind farms. Instead, they are a call to closely monitor existing wind farms and those that will be built in the future. "I think that's kind of the rule here, to be cautious and make sure that you understand what's happening to your system while you're building," she said.

It's possible that the way wind farms are built and where they are placed might help reduce potential negative impacts on the ocean ecosystem, though that research has yet to be done. "I think it will be a really interesting optimization kind of study, to kind of place the turbines in different locations and different densities," said Raghukumar. The information gleaned from such a study, he said, could be used to balance the benefits of wind energy against any adverse consequences.

As research into the impacts of offshore wind energy continues, scientists say it's important to maintain a sense of perspective, since fossil fuels also affect the ocean by driving changes to the climate.

"It's not our intention to say this is a negative development. It's also not our intention to say wind parks destroy the ecosystem. That's not what our research shows," Daewel said. "I just want to stress the research shows that we need to expect changes, and it's better to learn that as soon as possible."

Becki Robins is a freelance writer who lives with her family in rural Northern California. She writes about science, nature, history, and travel; her favorite stories include a little of all four. Her work has appeared in Science News, Comstock's Magazine, Hakai Magazine, and others.

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Farm with the Wind

By Matthew Wilde, Progressive Farmer Crops Editor – Progressive Farmer – March 31, 2021

Corn pours into Kelly Nieuwenhuis' combine grain tank this past fall as 20-plus mph winds keep two MidAmerican Energy wind turbines spinning in his field. The northwest-Iowa row-crop farmer, in effect, is harvesting two revenue streams, but the latter is a stable source.

"For the last four years, the turbines were the most profitable part of my farm," Nieuwenhuis claims as he maneuvers his combine around the base of one of the 262-foot towers. "I wish I had 10 of them."

It's been a struggle to make a profit growing corn and soybeans the past five years, the Primghar farmer contends. The annual lease payment from MidAmerican of about $25,000 -- use of about 2 acres of land for two turbines and infrastructure -- that started in 2017 provides needed revenue to help offset fluctuating commodity markets.

When 40 acres of prime farmland came up for sale three years ago next to his field with the two turbines, Nieuwenhuis says the steady revenue the twin towers offer provided him with the confidence to purchase the property.

"I've been real happy with the wind turbines since they've been built," he continues.

OPPOSITION

Despite Nieuwenhuis' favorable experience, there's plenty of opposition to wind energy. This includes farmers and non-farmers alike.

Opponents have banded together to stop wind farms under development and encourage governing bodies to pass or consider passing zoning ordinances that would effectively prevent future wind development. In some cases, the conflict results in litigation.

Critics generally believe wind turbines are noisy eyesores that reduce property values. They claim audible and inaudible noise (infrasound), and shadow flicker (caused when rotating turbine blades pass between the sun and a home) from turning turbine blades can cause sleep deprivation and other health issues such as headache, fatigue, nausea, dizziness, ear pressure or pain and vertigo.

"It all comes down to quality of life," says Matt Amos, a Reno County, Kansas, resident who opposes the Pretty Prairie Wind Farm project proposed in the county.

Florida-based NextEra Energy Resources signed leases several years ago with 69 Kansas landowners for the 82-turbine wind farm that covers about 45,000 acres. The project was put on hold in 2019 after Reno County Citizens for Quality of Life, of which Amos is a member, submitted a protest petition against the project to county leaders. As a result, the county's three commissioners had to vote unanimously to approve the project's conditional-use permit. One commissioner voted no, so the permit was denied. NextEra is challenging the validity of the petition in court.

"We understand landowners want to make money. Payments can help during lean years with crops," Amos says. "I admire farmers ... but we want our health and [property] rights protected, too."

Nieuwenhuis says commercial wind turbines operate in every direction from his house, with the closest being 1,200 feet away. He reports no ill health effects, such as dizziness or headaches, as a result.

"Some people say [commercial wind turbine] noise is an issue, but I don't even notice it," he adds.

WINDFALL

Nieuwenhuis, like many landowners who have wind turbines on their land, sees opportunity in wind energy. The industry paid $1.6 billion in taxes and land-lease payments in 2020, according to American Clean Power (ACP), formerly the American Wind Energy Association.

Texas is the No. 1 wind energy generator. The state's landowners and taxing bodies annually receive $192 million and $285 million, respectively, in revenue.

"Wind energy provides farmers the chance to enhance revenue given the uncertainty of farming, and it generates taxes to help pay for essential services," says Jeff Danielson, ACP central states director. "That is the reason farm states have embraced it."

Property taxes from wind projects provide revenue for local schools, fire departments, law enforcement and more.

Bruce Dunahoo grows corn and soybeans on 440 acres near Zearing, Iowa. He has one wind turbine on his property, which is part of the 100-turbine Story County 1 Wind Farm, owned by NextEra. Dunahoo has earned more than $20,000 in six years since the lone turbine on his property has been operational.

"The pay is pretty good, but I see it as doing my part to help the environment," he says. "In the future, we will be relying on more green, safe energy."

The wind turbine on Dunahoo's land is located about 1,200 feet from his house. He reports no health issues from the turbine. Occasionally, Dunahoo notices shadow flicker in his house. But, he doesn't consider it a problem that window blinds can't address.

DIVISION

Wind energy has divided some rural communities. It pits supporters against residents who don't want to see turbines or hear the whooshing sound of rotating turbine blades -- some which are about 200 feet long. "It has created animosity, which is bad," Amos admits.

The small business owner and U.S. Marine Corps veteran built a house on 20 acres in southeast Reno County to get away from city noise and lights. Amos lost parts of both legs in a roadside bomb attack in Afghanistan and suffered two traumatic brain injuries.

Amos is concerned the flashing red safety lights on top of the nacelle (the gearbox on top of the tower) of turbines, shadow flicker and turbine noise would be detrimental to his health and property value. The closest turbine, if built, to Amos' house would be about a half-mile away.

Other members of the Reno citizens group, he says, share his concerns.

When the Pretty Prairie project was in the development phase, Amos says the citizens' group asked NextEra to do several things to alleviate concerns. Requests included turbines no closer than 3,000 feet or six times the turbine height from property lines of landowners not participating in the project and high-tech safety lights that only turn on when airplanes are near. NextEra proposed a setback distance of 2,000 feet from homes and wouldn't commit to the more expensive lights, Amos says.

"We live here, and we have something they want. I would think they would want to work with us," he continues.

NextEra spokesperson Conlan Kennedy says the company strives to work with lawmakers and residents in Reno County. He says it sites all of its wind projects to ensure the protection of public health. All local and state guidelines are followed.

He declined to comment about the future of the Pretty Prairie project because of pending litigation.

"I can't speculate on peoples' motives for opposing an industry that has brought great benefits to rural communities across the country," Kennedy says. "Based on our experience in many communities, wind energy still enjoys widespread support in Kansas and throughout the country."

WIND RESTRICTIONS

A fierce battle rages in Madison County, Iowa, about the Arbor Hill Wind Farm, proposed by MidAmerican Energy. If built, it would consist of 52 turbines.

The Madison County Board of Supervisors, in a 2-1 vote, passed in December what some say is the most restrictive commercial wind energy ordinance in the nation. The county is known worldwide for its covered bridges made famous by Robert Waller's best-selling novel "The Bridges of Madison County" and movie of the same name starring Clint Eastwood and Meryl Streep.

Madison County's new ordinance caps the number of turbines in the county at 51 (the current number). It also requires that any new turbine erected must be 1.5 miles from a non-participating landowner's property line.

"To put it bluntly, it's an effective ban on wind energy," says Adam Jablonski, MidAmerican Energy vice president of resource development.

The company filed a lawsuit in January challenging the ordinance. MidAmerican argues it could build the Arbor Hill project because it received previous county approval, which withstood legal challenges from an opposition group.

Jablonski says MidAmerican is "evaluating" the project as the latest court battle continues. County supervisor Diane Fitch says board members can't comment due to ongoing litigation.

Mary and Roy Jobst, of rural Earlham, Iowa, hope the Arbor Hill project remains on the shelf. Even though they signed a development easement with MidAmerican in 2017, which means two turbines could be built on their property, the couple no longer wants to participate. They've asked MidAmerican to terminate the contract to no avail.

The Jobsts, who farm 360 acres, say they agreed to the easement without researching the negative health effects of wind turbines and considering neighbor dissension.

"It's the worst decision we ever made," Mary says. "We should have done our homework and sought legal advice. The money is not worth having [bad] neighbor relations."

She cites a Council of Canadian Academies report that says there's sufficient evidence that exposure to wind turbine noise causes annoyance among some people. The report also says there's limited evidence to establish a causal relationship between exposure to wind turbine noise and sleep disturbance.

However, the report also states the evidence is inadequate to come to any conclusion that exposure to wind turbine noise causes health issues such as fatigue, nausea and cardiovascular disease.

"It's misleading [for proponents] to make assertions that scientific studies have 'proven' that industrial wind turbines don't pose risks to human health," Mary says.

A joint statement from the Environmental Health Sciences Research Center at the University of Iowa College of Public Health, the Common Good Iowa and the Iowa Environmental Council says "there is little evidence that sound from wind turbines represents a risk to human health."

ACP's Danielson continues, "There's no evidence wind turbines cause negative health effects beyond simple annoyance, or they result in a loss of property values."

FUTURE OF WIND ENERGY

Green energy is a priority of President Joe Biden's administration. Goals include a 100% clean-energy economy with zero-net carbon emissions by 2050 and decarbonizing the U.S. power sector by 2035.

To meet these goals, Danielson projects the U.S. will need about 120,000 wind turbines, which is double the current number.

The National Renewable Energy Laboratory says it costs, on average, $991,000 per megawatt (MW) to build a commercial wind turbine. Most commercial units exceed 2 MW.

"The wind is at our back ... the sky's the limit," Danielson asserts. "But, clean energy has to be a partnership between the local, state and federal level."

Local governments passing commercial wind energy ordinances that restrict development concerns the Iowa Conservative Energy Forum (ICEF). The group believes landowners have the right to utilize their property and profit from it as they see fit.

"We want folks to be able to look at the pluses and minuses of wind energy, and make decisions that best work for them," says Ray Gaesser, a farmer and ICEF chairman.

Judy and Steve Neal, of Madison County, filled out MidAmerican Energy's landowner interest form years ago with hopes of financially benefiting from wind turbines on family land. The extra income would come in handy, the retirees say. It would allow them to visit family in California more and help pay for grandkids' college educations.

The Neals fear both county leaders and the fierce opposition have dashed their hopes of a more financially secure future.

"Apparently, we only have the right to pay property taxes," Steve quips.

Judy adds, "I feel [county leaders] are dictating what we can and cannot do on our farm."

Wind Energy Contracts 101:

Experts familiar with commercial wind energy contracts recommend landowners consult with an attorney before they sign on the dotted line to allow wind turbines on their property. Wind energy companies may foot all or part of the legal fees, explains Mary Ludwig, an agricultural attorney and partner at Johnson and Taylor, in Pontiac, Illinois.

Ludwig has reviewed about 80 wind energy contracts for clients. Some agreements can be lengthy, up to 60 pages, and provide companies access to land for decades, she says. It's in the landowner's best interest to understand all provisions within a contract to protect their rights and property.

"Wind companies write contacts in their favor to protect their multimillion-dollar projects. That's why a landowner needs to have their own attorney review it," Ludwig explains. "A farmer may get paid for the use of their land, but they need to know how wind turbines could affect farm operations."

Here are eight points landowners should consider before signing a wind energy contract:

- It's important to understand the basic concepts of all lease and easement provisions and associated time periods. A contract typically includes an option agreement, operating option and option to extend. Lease agreements typically last 20 to 30 years but could be extended for decades more. If the land is sold, the new owner assumes the contract. Wind farm decommissioning provisions are also usually part of the contract, spelling out how the wind provider will remove turbines and infrastructure.
- Payment terms. Contracts could include options such as fixed payments, royalty or revenue-based payments, or a combination of both.
- Wind turbine and infrastructure placement. It's unlikely a company can pinpoint where construction will take place, if at all, when a landowner agrees to participate since siting studies and landowner participation are usually not complete, Ludwig says. However, she recommends farmers keep in contact with the land agent to get a "good feel" of the location, because it can affect farm operations.
- Detail how agricultural drainage tile and fencing will be repaired or replaced if damaged during construction. A landowner may want their own contractor to make repairs or

supervise the wind company's contractor. Farmers may want GPS coordinates of tile repairs.

- Crop and soil-compaction damage. Both could occur during construction, and the latter could cause yield losses for years to come. Farmers may want to include provisions on how yield loss is calculated, time frames and what price is used to determine loss payments.
- Farming obstacles. Farmers can request electric transmission lines be buried and other structures associated with the wind farm be removed or placed in areas that don't impede farming activities.
- Existing infrastructure. Landowners can request the wind energy company keep existing roads, fences, culverts driveways, vegetation, etc., in good condition.
- Property taxes. A wind energy company often will pay the increase in property taxes for wind turbines, but landowners will want to make sure they are not stuck with the bill.

"Generally, I would say most of my clients are happy after entering into agreements with wind energy companies, but a few declined because they heard about bad experiences or could foresee possible issues with neighbors or other things," Ludwig says.

Hydropower Explained: Hydropower and the Environment

US Energy Information Administration, 2022

Hydropower generators produce clean electricity, but hydropower does affect the environment

Most dams in the United States were built mainly for flood control, municipal water supply, and irrigation water. Although many of these dams have hydroelectric generators, only a small number of dams were built specifically for hydropower generation. Hydropower generators do not directly emit air pollutants. However, dams, reservoirs, and the operation of hydroelectric generators can affect the environment.

A dam that creates a reservoir (or a dam that diverts water to a run-of-river hydropower plant) may obstruct fish migration. A dam and reservoir can also change natural water temperatures, water chemistry, river flow characteristics, and silt loads. All of these changes can affect the ecology and the physical characteristics of the river. These changes may have negative effects on native plants and on animals in and around the river. Reservoirs may cover important natural areas, agricultural land, or archeological sites. A reservoir and the operation of the dam may also result in the relocation of people. The physical impacts of a dam and reservoir, the operation of the dam, and the use of the water can change the environment over a much larger area than the area a reservoir covers.

Manufacturing the concrete and steel in hydropower dams requires equipment that may produce emissions. If fossil fuels are the energy sources for making these materials, then the emissions from the equipment could be associated with the electricity that hydropower facilities generate. However, given the long operating lifetime of a hydropower plant (50 years to 100 years) these emissions are offset by the emissions-free hydroelectricity.

Greenhouse gases (GHG) such as carbon dioxide and methane form in natural aquatic systems and in human-made water storage reservoirs as a result of the aerobic and anaerobic decomposition of biomass in the water. The exact amounts of GHG that form in and are emitted from hydropower reservoirs is uncertain and depend on many site specific and regional factors.

Fish ladders help salmon reach their spawning grounds

Hydropower turbines kill and injure some of the fish that pass through the turbine. The U.S. Department of Energy has sponsored the research and development of turbines that could reduce fish deaths to lower than 2%, in comparison with fish kills of 5% to 10% for the best existing turbines.

Many species of fish, such as salmon and shad, swim up rivers and streams from the sea to reproduce in their spawning grounds in the beds of rivers and streams. Dams can block their way. Different approaches to fixing this problem include the construction of fish ladders and elevators that help fish move around or over dams to the spawning grounds upstream.

The Safe Harbor Dam on the Susquehanna River in Pennsylvania has elevators that lift migrating shad from the base of the dam to the top of the reservoir.

Hydropower dams threaten fish habitats worldwide

New research maps impacts of hydropower dams on species critical to human livelihoods.

BY SARAH CAFASSO, STANFORD NATURAL CAPITAL PROJECT – February 3, 2020

Rivers and other ecosystems that provide essential habitats to freshwater fish are under increasing pressure from global hydropower development. While dams can provide flood protection, energy supply, and water security, they also pose a significant threat to freshwater species. Dams block fish from moving along their natural pathways between feeding and spawning grounds, causing interruptions in their life cycles that limit their abilities to reproduce. As hydropower development continues along river basins around the world, scientists are concerned about the unknown impacts to the diverse species found in freshwater habitats – many of which are critical sources of food and livelihood for humans.

"Because fisheries based on migratory species support tens of millions of people, understanding where hydropower development could negatively impact river basin connectivity – and therefore fish – is an important step in identifying solutions that deliver needed electricity while minimizing the loss of essential natural resources," said Jeff Opperman, Global Lead Freshwater Scientist for World Wildlife Fund.

Without detailed information about where exactly freshwater species feed and spawn, it has been difficult for planners to make more sustainable decisions around hydropower and river basin development. Now, researchers from the Stanford Natural Capital Project and Radboud University have mapped the impacts of past and future hydropower development on fish habitats worldwide. Their results were published Feb. 3 in Proceedings of the National Academy of Sciences.

"We've known that future development will impact fish species, but we didn't have the detailed information about some of the places with the highest development pressures – like the Amazon, the Mekong, and the Congo – until now." – RAFAEL SCHMITT, Postdoctoral Research Fellow, Natural Capital Project

Data-driven decision making

"We've known that future development will impact fish species, but we didn't have the detailed information about some of the places with the highest development pressures – like the Amazon, the Mekong, and the Congo – until now," said Rafael Schmitt, researcher at the Natural Capital Project and second author on the study. "This dataset will help decision-makers better understand impacts of land and infrastructure development on aquatic biodiversity, so they can make choices that protect it."

The researchers used detailed spatial data for 10,000 fish species to measure impacts of dams on their habitats. They evaluated around 40,000 existing and 3,700 planned hydropower dams to create high resolution global maps. "These dams pose a real danger to the survival of species and associated human livelihoods," said Schmitt. "Salmonids in North America were mostly wiped out by dams, and with them the livelihoods of people depending on their annual migration. Now,

similar impacts become evident in other geographies. Recently, we've seen how dams on the Yangtze contributed to the extinction of the Chinese paddlefish, a source of food and cultural reverence for communities along the river. If we aren't more strategic about where and how we develop future hydropower, we can expect to see more and more examples like this one."

Opportunity for strategic hydropower planning

The study shows the highest numbers of fragmented habitats from current hydropower are found in the United States, Europe, South Africa, India and China. In developing countries, though, the impacts of planned hydropower development are disproportionally high. "For example, we see that the completion of only one dam close to the outlet of Purari River in Papua New Guinea will decrease habitat connectivity by about 80 percent on average for freshwater fish in the region," said Valerio Barbarossa, environmental researcher at Radboud University and lead author on the study.

"With these maps, we have a global picture of where fish species are already impacted by dams and where local conservation efforts should be fostered," said Barbarossa.

The researchers hope that their results will help guide strategic decision-making around hydropower planning. "Evaluating impacts of dams is only the first step," said Schmitt. "These data can be used to highlight the additional benefits of thoughtful, strategic river basin development to drive conservation and restoration efforts in local areas and at global scales."

Rafael Schmitt is a postdoctoral fellow at the Natural Capital Project and the Stanford Woods Institute for the Environment.