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EXPLORING FARMING AND SOLAR SYNERGIES

An Analysis Using Maryland Data

Arjun Makhijani, Ph.D.

February 2021

Cover photo source: North Carolina State University Extension
https://cals.ncsu.edu/news/got-sheep-want-a-solar-farm/
With Permission: Johnny Rogers, North Carolina State University Extension

I absolutely love the idea of dual use of land: solar + agriculture. Based on your figures and ideas, I think it has real potential to support/save mid-size family farms.

Susan Schoenian, Sheep and Goat Specialist
University of Maryland Extension

There is a lot of hope in joining solar and agriculture. Thank you for shining a beautiful light on a complex situation.

Ellen Polishuk
Plant to Profit

As a representative of the Maryland farming community, I'm glad to finally see an in depth assessment of a complicated issue. Siting solar facilities in Maryland is a major stumbling block to the progress of in-state solar energy generation. Finding some sort of common ground and possible solutions to this issue allows the state to process forward.

Colby Ferguson, Director of Government & Public Relations
Maryland Farm Bureau

We envision a clean, equitable energy system that directs control and benefits back to local communities. We're excited to see such benefits demonstrated in this report that shows how solar deployment and agricultural activities can flourish in the same space.

Corey Ramsden, Vice-President, Go Solar Programs
Solar United Neighbors

Here's a report that shows that whole farm profits can improve greatly with solar on a small fraction of a farm, graziers can be paid to graze instead of leasing land, and all five soil health principles can be fulfilled – all at the same time. Dual-use solar makes eminent economic and ecological sense; we look forward to its adoption across the country.

Lexie Hain, co-founder
American Solar Grazing Association

Abstract

This report explores the synergies between farming and solar photovoltaics with the premises that agricultural production on farmland should be maintained and farm profitability and soil health should be improved. Instead of focusing on solar siting, this report explores whether a strong case can be made from a public policy point of view for developing solar so that it helps to preserve and improve farmland and the ecosystem in which it is located, while enabling achievement of both energy system and food system goals. Three examples, using Maryland data, analyzed in the report illustrate the potential of this dual farming-plus-solar approach, with solar being on 10% or less of the farm operation: (i) solar on 100 acres leased from a 1,000 acre corn-soy commodity crop operation; (ii) solar owned by the farmer on 16 acres of a 300-acre dairy-grazing operation; (iii) solar on one-acre of a ten-acre horticultural farm. In each case profits increase substantially. Farm economic resilience is improved because solar revenues are independent of the vagaries of weather and crop markets. While the examples are Maryland-specific, the approach for analyzing dual-use solar is broadly applicable elsewhere in the United States.

The total land required for solar even in case of a well-designed, balanced 100% renewable electricity system would generally be a small fraction of agricultural land; in Maryland it would be on the order of 4%. It is recommended to limit the size of solar to 20% of a farm operation or 400 acres, whichever is smaller, in order to protect lessees and to spread out the benefits of solar-farming synergies to a large number of farmers. Exceptions should be allowed on a case-by-case basis. Pollinator-friendly grasses and managed grazing of sheep can improve soil quality and substantially reduce chemical inputs relative to conventional farming. Well-managed solar grazing satisfies all five soil health principles. Requiring agricultural activities when solar is put on farmland can also provide opportunities for young farmers, Black and Indigenous farmers, and other people of color to have secure access to land without having to buy or lease it.

Policy support will be required to systematically and substantially realize these benefits. That includes financial and tax incentives, support for grid-connection expenses when suitable land is too far from a suitable grid connection point, maintenance of net-metering incentives for farmers, investment in Agricultural Extension staff and services to enable them to provide technical support to farmers seeking to benefit from dual-use solar, low-interest loans to enable farm operations to own solar, and demonstration projects to greatly expand the types of agriculture that are compatible with solar without increasing the cost of solar electricity substantially.

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Preface and Acknowledgements

This report explores synergies between farming and solar, with the premises that *agricultural production on farmland should be maintained and farm profitability and soil health should be increased.* Therefore, instead of focusing on solar siting, this report explores whether a strong case can be made from a public policy point of view for developing solar so that helps to preserve and improve farmland and the ecosystem in which it is located, while enabling achievement of both energy system and food system goals.

Food security and food production capacity are imperatives that cannot be subsumed under a purely dollars-and-cents calculation. Therefore, this report explores whether the challenges of food security, protection of farmland, and improving soil health can be made compatible with improving farm operation profits and economic resilience with solar energy generation. In that framework, the ecological and environmental benefits, like less air pollution or reduced carbon dioxide emissions, would be collateral benefits consequent upon achievement of the farm economic and soil health objectives.

There is now considerable interest in the United States and in other countries in developing renewable energy and farming systems jointly. While the focus of the present report is on solar and farmland, the approach applies more widely, including specifically to wind power on farmland, which is already quite widespread in several states, like Iowa, Kansas, Minnesota, and Nebraska. The National Renewable Energy Laboratory, for instance, is exploring synergies between food and renewable energy systems.[1] Such developments indicate that the framework of this report is more broadly applicable, though the specific analysis is based on Maryland data.

Joining the farming and renewable energy systems could become much more important for the agricultural system in the coming years. Tens of millions of acres are currently used to grow corn as a feedstock for ethanol plants; the vast majority of this ethanol is used for automotive fuel, displacing about ten percent of gasoline. Battery prices are falling fast, leading to a correspondingly rapid increase in the adoption of electric vehicles. Could a *systematic* joining of the agricultural and renewable energy systems across the country create new opportunities to make family farms more economically robust while making soil and ecosystems healthier?

A number of terms are used to describe the dual use of land for solar installations and agriculture: agrivoltaics, agro-photovoltaics, agro-voltaics, and dual-use. This report uses the terms farming-centered, agrivoltaics, and dual-use. Quotations that are inset are in smaller font than the body of the text in order to distinguish them from the rest of the text. Quotations within paragraphs are in inverted commas.

A number of reviewers provided comments on drafts of this report (at different stages), including Michele Boyd, Kenny Braitman, Kevin Campbell, Emily Cole, Shannon Dill, Colby Ferguson, Mitch Hunter, Ellen Polishuk, Corey Ramsden, Terry Sankar, Drew Schiavone, Susan Schoenian, Greg Wilson, and several staff members of organizations in the Million Acre Challenge collaborative, including Amanda Cather, Erik Fisher, Lisa Garfield, and Alan Girard. I also want to thank Randy Ferguson of Ernst

[1] NREL 2019.

Conservation Seeds for permission to use the name of their trade-marked seed mix for grazing with pollinator friendly plants, Fuzz & Buzz™. One reviewer wished to remain anonymous. Amanda Cather gave a late draft of this report a thorough review; Morgan Johnson helped with some regulatory research. Christian Meyer of Next2Sun, a German solar company, provided photographs of and cost estimates for that company's vertical solar configuration. I am especially grateful to Lexie Hain who provided many insights into solar grazing as well as introductions to other experts. I am grateful to all the reviewers; their comments have helped improve this report. As the author, I take full responsibility for any errors, omissions, and problems that may remain and for the report's contents generally, including its conclusions and recommendations.

This report grew out of a background memorandum I prepared for a 2017 meeting between the Eastern Shore Land Conservancy and some Maryland solar industry leaders; it was arranged by Stuart Clarke, then Executive Director of the Town Creek Foundation. I did further work, in 2020, as part of the Million Acre Challenge, also funded by the Town Creek Foundation as one of its last grants before it closed its doors in December 2019. I am very grateful to the Foundation for its support, which enabled this report and much other work by the Institute for Energy and Environmental Research (IEER).

Arjun Makhijani
President, Institute for Energy and Environmental Research
February 2021

Executive Summary[2]

> Food and energy security need not be competing objectives. In fact, taking a holistic, integrated approach to food-energy-water decision making can increase resiliency of both food and energy systems.
>
> National Renewable Energy Laboratory (NREL) 2019

Maryland laws and policies have the promotion of in-state solar energy and healthy soils as important goals. The state has made significant investments in protecting prime farmland, incentivizing cover crops to promote soil health, and promoting solar energy.[3] In general, solar energy and healthy soils have been promoted on separate tracks. This has resulted in farm and food constituencies becoming wary of ground-mounted solar posing a risk to food and fiber production capacity. It has also resulted in major missed opportunities. As the quote above from the National Renewable Energy Laboratory indicates, the approach of seeing farming and energy in a holistic way could benefit both.

While climate change mitigation is a principal reason that solar energy is promoted in Maryland and worldwide, the present analysis of ground-mounted solar is not primarily from the perspective of energy system requirements. Rather, this report explores the possible synergies in Maryland mainly from the point of view of promoting farm profitability, farm economic resilience, and creating opportunities for improving soil health by incentivizing healthy soils when solar is sited on farmland.

The exploration in this report is approached at the level of farm operations (a corn-soybean operation, a dairy farm, and a small, intensive vegetable farm) and also from the overall point of view of possible solar development in light of Maryland's climate and energy goals. Two scenarios are examined – for the year 2030 (for which the state has a specific solar target: 14.5% of electricity sales) and for 2040, for which there is an aspirational goal of an emissions-free electricity sector. These goals for energy provide the context but not the imperatives for the assumptions about the use of agricultural land for solar. *The scenarios are oriented to estimating the extent to which farm profits can be supported by the development of solar while promoting dual use of that land for farming activities in ways that improve soil health. The assumption in the analyses in this report is that solar would be on a small fraction of the land of any farm operation; the findings are within that framework.*

A wide variety of farming activities are possible on farmland with solar; many have been demonstrated (Section IV.c.). However, the economic track record of dual use of land for farming and solar in the United States is mainly associated with (i) grazing sheep and (ii) apiaries sited on or adjacent to solar installations with pollinator friendly plants.

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[2] ***References and definitions are in the main body of the report except for those cases where a reference is needed for a quote or a specific statement that is only in this summary***.

[3] $184 million was spent on Solar Renewable Energy Credits between 2013 and 2018, a sum that was passed on to electricity ratepayers. PSC 2019, Table 5. In addition, the state provides rebates for solar energy; specific amounts have varied over the years. The current rebate for residential solar photovoltaics is $1,000 per project. MEA Incentives 2020. Expenditures on conservation easements have totaled $752 million; MALPF 2019, p. 1.

a. Findings

1. **A farm-centered approach to siting solar on farmland can result in significantly higher overall farm profitability and economic resilience, and simultaneously open up opportunities for promotion of healthy soils practices.** The goals of increasing farm profits, making them more resilient to the vicissitudes of climate and markets, and of encouraging widespread adoption of healthy soils practices can be achieved simultaneously. A variety of farming activities, including by third parties, on solar installation land can improve soil health, while increasing total farm operation profits, even when the solar is on a small fraction of the farm. For example, well-managed rotational sheep grazing on suitable pollinator friendly mixes meets all five soil health principles as enunciated by the Natural Resource Conservation Service: "soil armor, minimizing soil disturbance, plant diversity, continual live plant/root, and livestock integration."[4]
2. **A variety of farming activities are possible on solar installation land.** Almost all the land – on the order of 95% -- of a solar photovoltaic installation – remains available for some type of cultivation or farming, though, as a general matter, commodity crop cultivation (or equivalent crops) would not be feasible. Rotational sheep grazing, cultivating pollinator-friendly plants with or without apiaries, vegetable cultivation, berries, cattle grazing, mushroom production, and even saffron production (from crocus flowers) have all been done, although, as described below, crop production is regionally specific and influenced by climate and conditions. Only grazing sheep and pollinator-friendly seed mixes and, increasingly both, have been adopted at some scale so far (end of 2020). In some cases, for instance, when panels need to be raised for the specific crops being produced, a site-specific optimization of solar and farming costs and revenues needs to be done.
3. **Solar can reduce the pressure to convert farmland to urban and suburban development.** Between 2001 and 2016, a total of 102,800 acres of farmland were lost to dense urban development or low-density residential development, totaling about 4% of Maryland farmland, according to the State of the States survey by American Farmland Trust. Commodity crop gross revenues in Maryland are under $1,000 per acre, while the retail value of solar electricity in Maryland is $25,000 to $30,000 per acre. The value of solar electricity on just 4% of farmland would be more than double the value of all the crop production in Maryland and almost equal the value of all agricultural production, including poultry production. When land is under intense urban/suburban development pressure due to its location, solar on a modest fraction of that land could help keep it in agriculture. With suitable policies, thousands of farms could benefit.
4. **Solar on a small fraction of a farm operation can substantially increase overall farm profitability and economic resilience**. Reliable profits from solar on 2% to 10% of a farm operation can significantly and reliably improve farm finances. Profits per acre depend on whether the farm operation owns the solar or simply leases the land for solar. Lease revenues range from $500 to $2,000 per acre, depending mainly on farm location relative to a suitable substation. Ownership profits can be $5,000 per acre or more under Maryland's aggregate net metering law, which allows farmers to sell electricity at retail prices to other farmers, government institutions, schools, colleges, and non-profits. Figures S-1, S-2, and S-3 show the three cases examined in this report: (i) a corn-soybean operation with 900 acres of corn and soybeans and 100 acres of solar compared to 1,000

[4] NRCS Soil Health

acres without solar; (ii) a dairy farm with 16 acres in solar (with grazing sheep) and 284 in dairy compared to 300 acres in dairy only; and (iii) a one-acre solar installation on a 10-acre diversified vegetable farm. The calculations assume commercial rates for cost of capital. Farm-owned solar can yield even higher profits if low-interest loans were made available.

5. **Public support for enabling farm operations to own highly profitable aggregate net-metered solar could be used to incentivize healthy soils practices on the entire farm, notably for commodity crops and grazing operations.** Solar profits from ownership of aggregate net metered solar range can be on the order of $5,000 per acre; they could be much more if supported by low-interest loans to build the solar. In such cases, just 5 to 10% of a farm operation in dual-use solar can increase the net profits of a farm operation several fold. *Public support that increases farm profits could provide the occasion for requiring healthy soils practices throughout the farm operation*. The term public support includes a variety of public policies and financial incentives that would make it simpler, most cost effective and secure for farm operations to have solar on farmland with agricultural activities. They include low cost financing and direct investment of tax dollars or funds from electricity ratepayers for the public purposes served by the dual use of farmland.
6. **Solar can make farm operations more economically resilient**. Profits from commodity crop production, which accounts for most of Maryland's harvest cropland, are typically on the order of $100 or $200 per acre. They are of the same order of magnitude for grazing operations. Profits tend to be volatile, being subject to fluctuations in commodity crop prices, trade policies, climate extremes, and disruptive events such as the COVID-19 pandemic. Economic volatility causes loss of family farms and pressure to sell farmland for urban and suburban development. In contrast, revenues from solar electricity are steady and involve little risk, especially if policies for farm ownership of solar are designed to reduce the risk. When the land is leased for solar development, it generally carries little risk. As a result, solar revenues can make farms more economically resilient, helping them remain as sources for food, feed, and fiber production through the varying vicissitudes of agricultural production and marketing. Increased resiliency, combined with higher profits, also reduces pressures to sell agricultural land for urban and suburban development in difficult times. Figure S-4 shows whole-farm profits per acre for a corn-soy rotation with 10% of the land in solar as a function of lease revenue, which does not vary with farm-related parameters, compared to a farm with only a corn-soy rotation.
7. **Even a very ambitious program of ground-mounted solar in Maryland would require about 4% of farmland.** For the purposes of this evaluation, an "ambitious" program is defined in the context of a fully renewable electricity system in Maryland, with mostly electrified transportation and buildings; half of the electricity would be solar; half of the solar (25% of the total electricity) would be ground-mounted on farmland. Since the actual construction footprint of a solar installation is a small fraction of its area (2% or less), almost the entire farm would, with appropriate policies, still be used for farming activities. Cumulative land for solar in a 100% renewable electricity scenario for Maryland is shown in perspective of other land data in Figure S-5.
8. **Joint agricultural and solar sector development can result in large benefits for both and for rural communities more generally.** The renewable electricity sector scenario, with a significant farm-centered component, would create thousands of steady jobs in rural communities in Maryland, besides greatly strengthening the agricultural sector and making it more resilient.

9. **Dual use of solar installation land for farming activities could promote equity by allowing young, limited resource farmers and farmers from Black and Indigenous communities access to land**. The cost of land is a principal barrier for new entrants into farming, including for young farmers, and Black and Indigenous farmers who have also lost land or been deprived of it over the last century and more. To realize this possibility a number of other factors including access to capital, would need to be considered, as also the rights of landowners and lessees, who may want to take up the agricultural activities on the solar land. Solar developers who build on farmland lease the land in any case. Solar owners can reduce maintenance expenses if there are suitable farming activities on the site, while those who do the farming can earn a living on land they do not have to own or lease. Indeed, it is the practice, for instance, in grazing of sheep on solar land to pay the shepherds to graze their sheep. For the solar owners, such payments are offset by reduced maintenance expenses.

b. Recommendations

A farm-centered approach to siting solar on farmland can result in significantly higher farm operation profitability and economic resilience, and simultaneously in opportunities for widespread promotion of healthy soils practices. This section provides a set of recommendations for farm-centered solar development that are oriented to accomplishing those objectives simultaneously.

1. **Ensure, through policies and incentives, the dual use of farmland that has solar photovoltaics on it in a manner that supports soil and broader ecosystem health.** Farmland with solar should be required and incentivized to have farming activities on it. Since the construction footprint of solar photovoltaics is generally 2% or less, almost all the land can be put to dual use – solar plus agricultural activities like grazing sheep, growing mushrooms, growing a limited variety of shade crops, and a range of crops including vegetables. Given that dual use solar provides significant economic and ecological benefits to the community, a requirement for such use on as much of the land as technically feasible should be accompanied by an investment tax credit for expenses needed to accomplish dual use, such as watering facilities for sheep, restoring any top soil removed during construction, and reseeding with appropriate seed mixes. Other incentives could include public support for added payments needed to locate solar on land not close to a suitable grid-connection point, low interest loans when farmers want to own aggregate net-metered solar, and long-term contracts by government agencies to purchase the solar electricity from them. Solar installations of 2 acres or less on farmland can be exempted from the requirement of engaging in commercial dual-use agricultural activities. Permanent cover, including pollinator friendly plants, flowering perennials, etc., should be required to improve soil health while leaving any commercial activity – apiaries, grazing, vegetables or flowers – up to the farmers themselves to adopt, should it be feasible for them, or to lease it to third parties for such activities if that is practical. There may also be circumstances where solar on more than 2 acres may be feasible but not with agricultural activities, even if the land is still classified as agricultural. This may occur, for instance, due to salt water intrusion. An exemption may be granted under these if the solar developer can show, as part of process of obtaining the

necessary Certificate of Public Convenience and Necessity (CPCN), that dual use is not feasible. Public investment to remediate the land should be considered as part of the CPCN process.

2. **Develop guidelines and requirements for farming-centered solar on farmland:** Solar on farmland should be required to be dual-use, with agricultural activities on the land. At present, there are no such requirements, though guidelines for making the installation friendly to pollinators exist. This is insufficient to ensure agricultural activities when solar is located on farmland or to improve the soil there when it is. Ensuring dual-use solar installations necessitates the development of straightforward guidelines as well as a variety of options for solar developers and farmers to adopt, as well as the institutional infrastructure to enable easy adoption. For instance, managed grazing of sheep and an official pollinator-friendly designation with apiaries are both being done as part of a dual-use approach to solar. In fact, they are often being done simultaneously; this should be encouraged so as to improve food and/or fiber production.
3. **Fund the Agricultural Extension Service of the University of Maryland to provide technical support for joining solar with farming and soil health improvement, including the development of soil health guidelines, and to conduct research and development to widen the scope of joining solar with regenerative agriculture.** Joining solar with farming in a systematic way is a relatively new endeavor, especially if economic and soil health objectives are to be achieved simultaneously. Consistent funding to expand the capacity of Maryland's Extension programs is necessary to support these goals and to develop a large range of options for farmers to pursue farming-centered solar development. Expansion of the capacity of Extension to provide technical support is one of the keys to institutionalizing the agrivoltaic approach to solar. This is because, in many situations, solutions to farming activities on the solar installation land site-specific and/or region specific optimization of the economic and ecological benefits. There is so far significant experience in only two areas of joining agriculture with solar installations – solar grazing (sheep) and suitable pollinator friendly planting with apiaries. But the scope is far wider. Raising the panels increases sunlight, increasing the scope of farming, for instance, to include vegetables. But it also increases the cost of the solar installation. East-West facing bifacial vertically installed panels may allow vegetable and cultivation of other specialized crops as well as grazing cattle without significantly increasing the cost of the solar (Figures S-7 and S-8 below). Additional potential could be realized in relation to remediating land with high phosphorous loads, with solar providing the core profits. Research, pilot projects, and economic and ecological optimization are needed to find what combinations can best restore land while enabling farming in the variety of situations that occur in the state's agriculture.
4. **Provide public support for farm operations to own dual-use solar on a small fraction of their farms and sell surplus electricity based on the state's aggregate net metering rules**. Increasing farm profits significantly with medium and small dual-use solar (2 megawatts (MW)[5] or less) should be encouraged by

[5] A megawatt, abbreviated MW, is a unit of power; it the unit to describe the capacity of power plants – that, is the rate at which they generate electricity. One MW equals 1,000 kilowatts (kW). A 2 MW-ac (alternating current) single axis solar tracking installation will generate about 4,000 megawatt-hours of electricity in most of Maryland (in round numbers). That is enough to supply about 330 average Maryland households for one year. Solar panels generate direct current (DC) electricity; this is converted to alternating current (AC) to make it compatible with

a. Providing low interest loans for the solar system financed with tax-free bonds, something that is already done in the energy sector for public institutions;
b. Encouraging government institutions, including departments, schools, colleges and universities purchase solar electricity at a discount from farm-located aggregate net metered installations;
c. Providing an option of utility billing and collection (for an appropriate fee), as is done currently for corporations selling retail electricity in the deregulated electricity market; this would lift the burden of billing from the farm operation – a significant obstacle to farmer-owned aggregate net metering implementation at scale.

This public support can also be used to incentivize healthy soil practices on the entire farm operation, not just on the dual-use solar portion.

5. **Expand net metering to 3,000 MW**: The current net metering cap should be increased from the present limit of 1,500 MW to 3,000 MW. This will allow farmers and community solar subscribers to benefit while the more complex transition to a renewable electricity system is being worked out.
6. **Proposals for large solar plants on farmland (more than 2 MW) that adopt pre-approved agricultural activities under the inter-agency process should have a more streamlined approval process for getting a Certificate of Public Convenience and Necessity (CPCN)**. Electric power plants larger than 2 megawatts require a permit from the Public Service Commission called the Certificate of Public Convenience and Necessity (CPCN). Solar installations larger than 2 megawatts on farmland should only be permitted if there is a plan for dual use of the land. The Power Plant Research Program of the Department of Natural Resources coordinates the input of public agencies to the Public Service Commission, which issues Certificates of Public Convenience and Necessity for power plants larger than 2 megawatts. A list of acceptable dual-use options should be developed for ease of adoption and approval of dual-use in the CPCN process. Soil sampling every three to five years should be required of the solar owner and made part of the CPCN to ensure that soil health indicators such as soil organic matter and aggregate stability are improving.
7. **Restrict solar on farmland to a maximum of 400 acres or 20% of a farm operation, whichever is smaller**. Limiting the solar to a small fraction of any farm operation would ensure that most of the land on such farms could continue to be in traditional farming production; it would also protect lessee interest in continued farming. Limiting the maximum size will also enable much wider distribution of the benefits of solar. Landowners and lessees should be offered the right of first refusal to carry out suitable agricultural activities on solar installation land. Exemptions from size limitations may be granted under special circumstances, as for instance when solar might help remediate land with high nutrient loads while maintaining farm profits and food production. Another example would be when extra high voltage lines run through large farms making smaller size installations economically unfeasible but with larger ones offering the

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grid-supplied electricity. Prices of solar construction are usually cited in dollars per watt-dc; regulations regarding capacity, for instance about net metering, are generally set in terms of AC capacity. We follow this convention in this report. We have used a factor of 1.2 to relate the two: 1.2 watts-dc = 1 watt-ac. The terms "DC" and "AC" are capitalized when used by themselves and in lower case when used in conjunction with watt (W), kilowatt (kW), or megawatt (MW).

opportunity of economically stabilizing farming operations. However, there should be no exemption from the requirements of agricultural activities and soil health improvement in such situations.

8. **Require an escrow fund for complete decommissioning or similar third party bond or guaranty to ensure decommissioning:** Decommissioning solar on farmland after the end of generation (including any contract extensions) should be ensured so as to restore the land to a condition that allows unrestricted farming. This can take the form of an escrow fund or bond guaranties to the County where the solar is located to preclude abandonment without decommissioning at the end of the lease period (including any lease extensions). Decommissioning should include removal of all structures, footings, platforms, and foundations and restoration of those areas to a state where any type of farming previously possible could again be done.
9. **Invest in and incentivize infrastructural support to fully realize synergies between solar energy and farming:** Development of infrastructure, such as small local processing plants for sheep, storage, and farm to table marketing support, will be needed to fully realize the potential for solar energy and farming synergies to develop the rural areas of the state. Such infrastructure is also needed to improve food system resilience and shorten supply chains – both indicated by disruptions induced by the COVID-19 pandemic.
10. **Explore a variety of sources of revenue to support farm-centered solar development**: A number of sources of revenue could be used to support farm-centered solar, even considering the more strained fiscal circumstances created by the COVID-19 pandemic. A key basis for public investment is that the public at large would derive ecological benefits from dual-use solar, including achieving the objectives of preserving farmland for agricultural activities, increased farm economic resilience, and better soil health. The potential sources include putting added expenses of grid-connection into electricity rate base of utilities, increased general revenues from income or wealth taxes, a small gasoline tax – one cent a gallon would raise about $30 million a year.
11. **Establish a joint Agrivoltaics Committee of the Mitigation Working Group of the Maryland Commission on Climate Change and the Soil Health Advisory Committee to develop broad proposals for agrivoltaic development in Maryland.** The Mitigation Working Group of the Maryland Commission on Climate Change considers ways to reduce greenhouse gas emissions and to sequester carbon. The Soil Health Advisory Committee, staffed by the Maryland Department of Agriculture (MDA) considers issues related to improving soil health. MDA also has representatives on the Mitigation Working Group of the Climate Commission. A joint Agrivoltaics Committee of the Mitigation Working Group and the Soil Health Advisory Committee should be established to examine agrivoltaic development in the state and the policies and incentives needed to accomplish both renewable energy and healthy soils objectives. The charter of the Agrivoltaics Committee should include development of proposals that would provide increased land access to young farmers and Black and Indigenous farmers well as farmers from other under-represented communities.

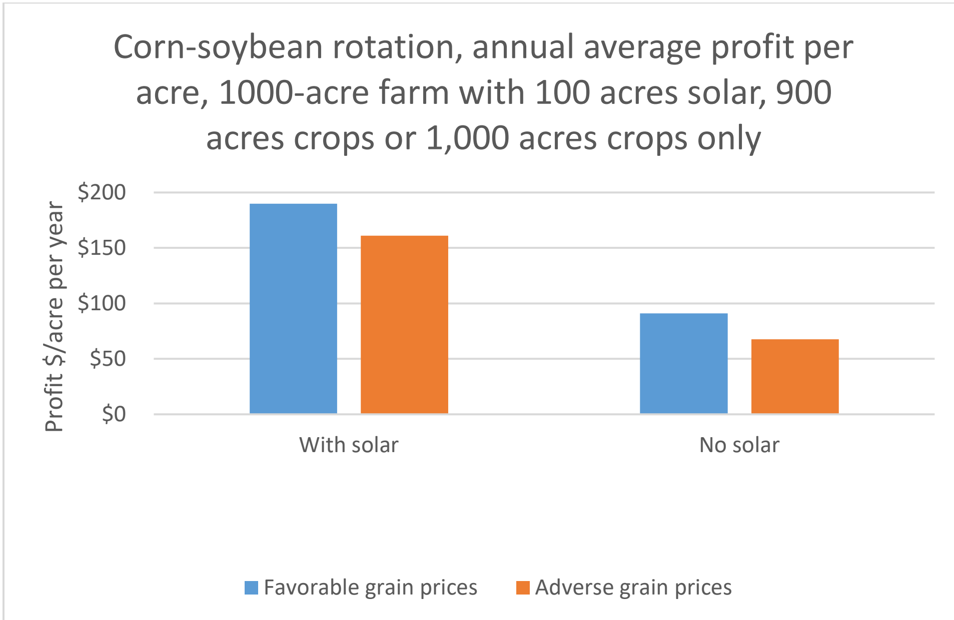

Figure S-1: A three-fold increase in farm profitability is indicated when 10% of a commodity crop farm is leased for solar and the rest maintained in commodity crops.

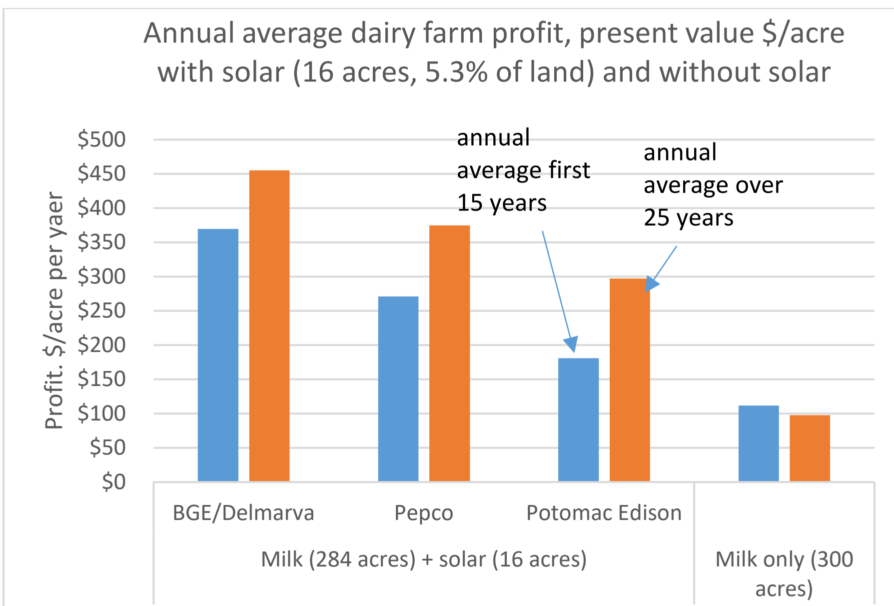

Figure S-2: A dairy farm with 300 acres of pasture, with and without 2 megawatts of aggregate net-metered solar owned by the farm operation. Annual average profitability for two time periods: over the **15-year loan term (blue)** and **25-year solar farm life (orange)**.

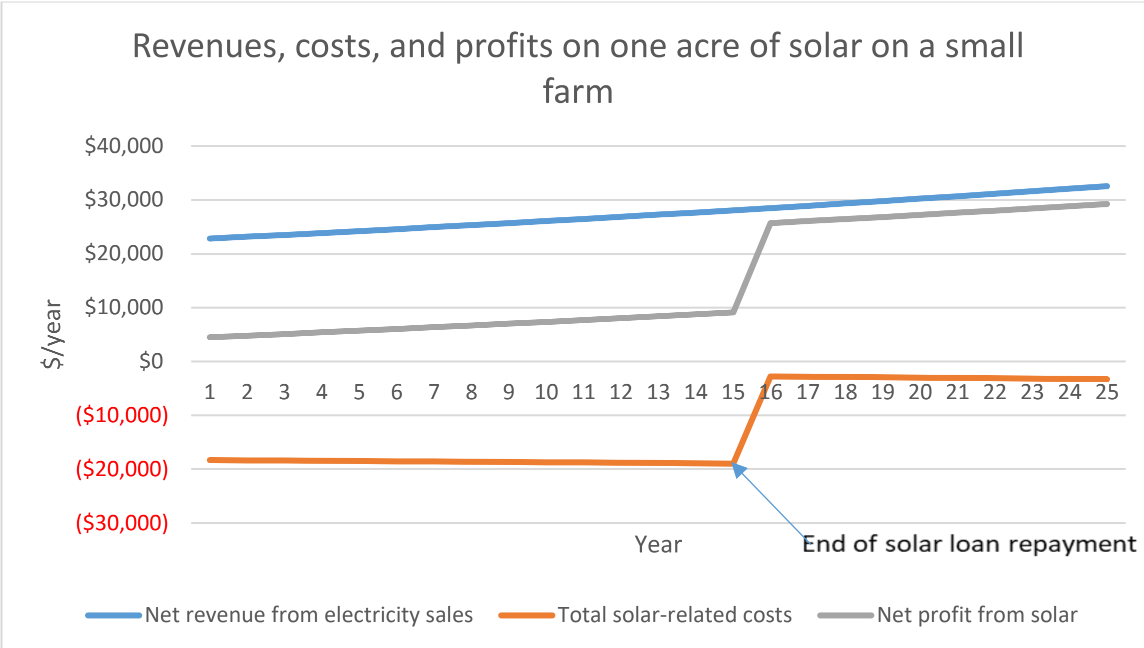

Figure S-3: Costs, revenues and net profits on one-acre of aggregate net-metered solar, 10% of a 10-acre farm. Revenues assume 2% inflation.

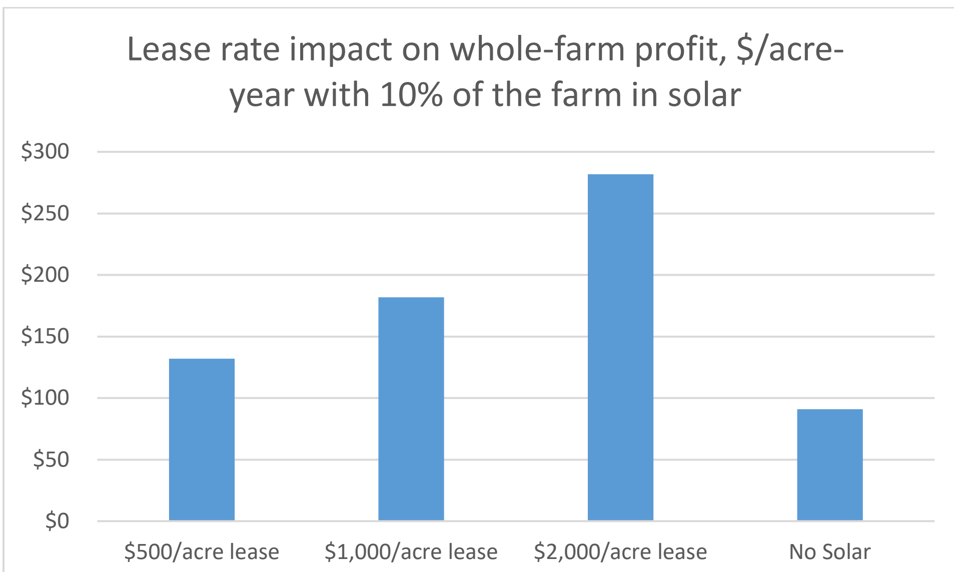

Figure S-4: Impact of solar lease rates on whole farm profit per acre, 10% of farm operation in solar and the rest in a commodity corn-soy rotation

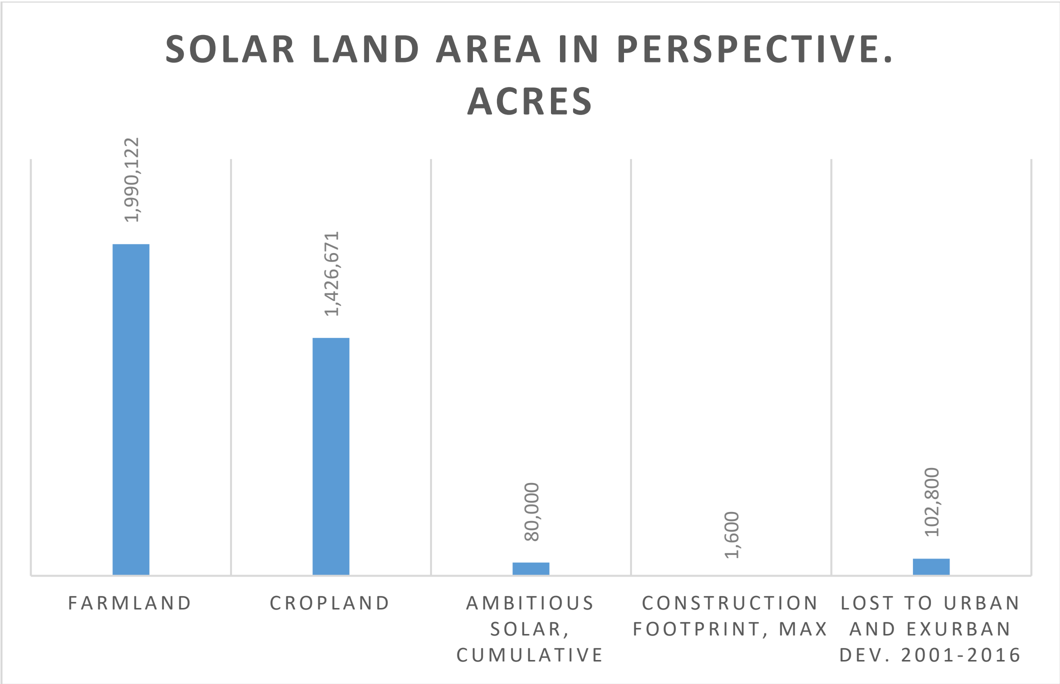

Figure S-5: Total Maryland agricultural land (including woodland and pasture land) and cropland in 2017, cumulative land for solar by the year 2040 for an ambitious renewable energy scenario, the cumulative construction footprint of the solar installations, and land lost to urban and exurban development between 2001 and 2016

Figure S-6: The construction footprint of solar is a very small fraction of the solar installation – 0.2% to 2%. Sheep can graze almost everywhere else, including under the panels.
Photo courtesy of The American Solar Grazing Association, with permission

Figure S-7: Lush vegetation on a solar grazing farm
Photo courtesy of The American Solar Grazing Association, with permission

Figure S-8: Bifacial vertically-installed solar panels: Solar Farm, Donaueschingen, Germany
Photo credit: Next2Sun GmBH, Germany, with permission

Figure S-9: Cattle grazing near vertical bifacial solar panels: Solar Farm Foran I (Ireland)
Photo credit: Next2Sun GmBH, Germany, with permission

I. Introduction

This report explores whether farmland use for food and fiber production, solar energy, and farmer prosperity could be joined to the benefit of all three. It also discusses policies that would be needed in both the agricultural and energy sectors to create such a framework. The analysis in this report is Maryland-focused; however, the general approach to solar on farmland is broadly applicable to farming communities across the United States.

This report examines the potential for solar photovoltaics to generate electricity on agricultural land while contributing to the following goals (it being understood that it has to be profitable from the solar point of view as well):

- It should be economically beneficial to farmers, and should protect the farming interests of farmers who lease land;
- It should maintain land in agriculture;
- It should be ecologically beneficial to the farmland and the ecosystem of which it is a part, in addition to the benefit of reducing greenhouse gas emissions in the electricity sector; in other words, it should contribute to the preservation and enhancement of soil and ecosystem health.[6]
- It should benefit rural communities economically.

In order to clarify the potential magnitude of the land-use issue, we examine these constraints in a scenario where solar energy would be a major contributor, about 50%, to Maryland's electricity supply by about the year 2040. We also look at a shorter time horizon, the year 2030 and the goal for solar energy that is already in Maryland law – 14.5% of electricity sales.[7]

Solar is the most plentiful energy resource in Maryland; the generation potential is far greater than any potential future requirements. At present, essentially all the fuels used in Maryland, both for electricity production and direct use in transportation, industry, and buildings, are imported from outside the state. Petroleum-fueled transportation and use of fossil fuels for space and water heating in buildings would have to be converted mainly to electricity supplied by renewable sources in order to achieve a low-emissions energy sector.[8] Utility-scale solar and onshore wind are the most economical of new electricity sources, according to the most recent evaluation by Lazard,[9] a Wall Street firm. The focus on solar derives in part from that economic competitiveness.

a. Electricity system context

Our purpose here is to explore the conditions under which solar energy, farmer and rural community prosperity, and ecological improvement, including healthy soils on farms, can be made compatible. The

[6] According to the National Resource Conservation Service, "Soil health, also referred to as soil quality, is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. This definition speaks to the importance of managing soils so they are sustainable for future generations. To do this, we need to remember that soil contains living organisms that when provided the basic necessities of life - food, shelter, and water - perform functions required to produce food and fiber." The NRCS also defines the foundation of soil health according to five principles: "soil armor, minimizing soil disturbance, plant diversity, continual live plant/root, and livestock integration." NRCS Soil Health, viewed on May 6, 2020.

[7] Maryland Clean Energy 2019

[8] A detailed analysis of a transition to a renewable energy system in Maryland can be found in Makhijani 2016, which also includes data on the state's wind and solar energy potential.

[9] Lazard 2020.

relevant issues are examined in the context of a Maryland energy system in which renewable electricity will play a much larger role, for instance due to the electrification of transportation and of space and water heating in buildings.

Hour-by-hour modeling of a Maryland electricity sector consisting primarily of solar and wind energy indicates that seasonal balance – approximately equal generation over the summer and the winter – optimizes the amount of load that these variable resources can directly supply, reducing the need for storage.[10] Total electricity requirements would depend on the vigor with which efficiency is implemented and the extent of electrification of transportation and of building space and water heating.[11] A future requirement of renewable electricity of 80 million megawatt-hours of electricity per year (compared to about 60 million currently) is a reasonable number for purposes of evaluating possible land use scenarios. Technical considerations indicate that half of this, or 40 million MWh, should come from solar energy if significant seasonal imbalances in variable energy supply are to be avoided.

Solar electricity can be generated using panels installed on rooftops of residential and commercial buildings as well as on ground-mounted installations. The latter can be in urban areas as well as rural areas, in which case they may also be on agricultural land depending on policy, economic, ecological, zoning, and other considerations. According to National Renewable Energy Laboratory estimates, the technical potential for rooftop solar in Maryland (all technically suitable buildings) is about 30 million MWh.[12] The technical potential for urban utility-scale solar at the same panel efficiency is estimated at 43 million MWh;[13] these would be medium- and large-scale ground-mounted installations. However, only a fraction of the technical potential can be economically realized due to a variety of limitations, including cost. As a result, while the combined rooftop and urban utility-scale technical potential is high, about 70 million MWh, the economic potential can be expected to be much lower. For instance, the National Renewable Energy Laboratory estimated in 2016 that the economic potential of distributed solar was only about 18.4% of the technical potential.[14] Thus, despite the high technical potential, ground-mounted solar in rural areas is still likely to be required for a fully renewable electricity sector in which solar energy plays a major role. Even so, there should be good arguments for doing ground-mounted solar on *agricultural land* in addition to energy-sector considerations. Those arguments can be summarized as follows:

- Larger-scale solar installations have economies of scale relative to rooftop and medium-scale (up to a few megawatts) solar that would mean lower cost renewable energy for Marylanders;

[10] Makhijani 2016.
[11] Maryland has pursued increased electricity sector efficiency via its EmPOWER program. "The new EmPOWER Maryland is a state-level initiative aimed at reducing Maryland's electricity usage 25 percent by 2020" relative to a 2007. MEA 2020. The program provides incentives for better insulating homes and purchasing more efficient water heaters and other appliances. For more details on long-term efficiency potential see also Makhijani 2016.
[12] NREL 2016 estimate (Table 6, p. 35) adjusted for 20% panel efficiency.
[13] NREL 2012 estimate adjusted for 20% panel efficiency.
[14] Calculated from NREL Economic Potential 2016, Table 8, p. 46, "Primary Case 2" or "Primary Case 3". The relationship between technical potential and economic potential is not fixed; it depends on a variety of cost factors, including costs of the renewable energy source and alternative supply sources.

- The capacity of distribution feeders is limited; high saturations of solar capacity on distribution feeders would require major new investments, making electricity more expensive for everyone;
- A mix of scales is desirable: small- and medium-scale installations are essential for creating a renewable electricity system that is also resilient; large-scale installations are important to reduce costs and hence provide affordable electricity to households, businesses and industries that is also renewable;
- Installations distributed in urban and rural areas that meet local electricity requirements can reduce transmission and distribution losses, other things being equal;
- Land for solar in urban areas would tend to be more expensive than land rural areas.

These are important considerations, especially since economical and reliable electricity supply is critical to the functioning of any modern economy. Despite that, there is also a good argument that there is a significant social (and potentially economic) cost to using food- and fiber-producing land exclusively for solar. That is the central reason that this report addresses solar energy on agricultural land with the additional goals set forth in the introduction: farmer prosperity, ecological benefits, and enhancement of soil health. Climate benefits from lower CO_2 emissions and lower energy costs would be a result of achieving these goals. Obviously, in order for solar to be built on farmland (or any other location), it has to work economically for the solar developer/owner as well.

b. Agricultural land context

It is essential to put ground-mounted solar that might be put on farmland in the overall context of the farmland in the state. Protection of prime farmland[15] has been considered critical objective; therefore, the area of prime farmland in each of Maryland's regions is also estimated as a matter of interest. *However, since soil health can be improved on all farmland and farms on prime farmland also need better profitability and economic resilience, this report explores approaches that would accomplish these objectives whenever solar is sited on any farmland, including prime farmland. No broad prohibition of solar on prime farmland is envisioned here provided dual-use is required.*

In 2017, there were 12,429 operating farms in Maryland, with a total area of 1,990,122 acres, making average farm size about 160 acres.[16] Of the 1.426 million acres of cropland, about 1.29 million acres were harvested. There were also 317,000 acres of woodland, less than 10% of which was grazed; there were about 133,000 acres in permanent pasture.

[15] The Natural Resources Conservation Service (NRCS) defines the term "prime farmland" as follows: "Land that has the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops and is also available for these uses. It has the soil quality, growing season, and moisture supply needed to produce economically sustained high yields of crops when treated and managed according to acceptable farming methods, including water management. In general, prime farmlands have an adequate and dependable water supply from precipitation or irrigation, a favorable temperature and growing season, acceptable acidity or alkalinity, acceptable salt and sodium content, and few or no rocks. They are permeable to water and air. Prime farmlands are not excessively erodible or saturated with water for a long period of time, and they either do not flood frequently or are protected from flooding." NRCS Prime Farmland, viewed on 2020-07-03.

[16] Census of Agriculture – Maryland 2017. Agriculture-related data are from this source unless otherwise specified.

The breakdown of agricultural land is shown in Table I-1.

Table I-1: Summary of agricultural land use in Maryland, 2017

Crop	Acres (rounded)	Percent	Comments
Cropland, harvested acres	1,290,212	64.8%	Over half the acreage is on the Eastern Shore
Cropland used for pasture	19,715	1.0%	
Cropland – idle, used for cover crops, etc.	116,744	5.9%	
Subtotal cropland	*1,426,671*	71.7%	
Woodland	316,647	15.9%	Including 25,340 acres used for pasture
Permanent pasture and grazing	133,321	6.7%	About half the acreage is in North Central and Western Maryland
Farmsteads, buildings, livestock facilities	113,483	5.7%	
Total	1,990,122	100%	

Source: Census of Agriculture for Maryland 2017

Almost half of the agricultural land in Maryland is on the Eastern Shore, which has less than 10% of the state's population. More than half the harvested cropland is also in this region, which also hosts a substantial majority of row-crops, mainly corn and soybeans, grown in the state.[17] The Eastern Shore of Maryland is also the center of Maryland's large poultry industry, which accounts for almost half of the value of agricultural products produced in the state.[18]

c. Farmland data detail

According to the Farmland Information Center, there were 801,600 acres of "prime agricultural land" in Maryland in 2007, down from 827,500 acres in 2002 – a decline of 25,900 acres in five years. The NRCS Natural Resource Inventory states that Maryland's prime farmland is concentrated on the Upper Eastern Shore (Talbot, Caroline, Queen Anne's Kent, and Cecil counties) and the North Central Maryland counties of Carroll, Frederick, and Washington.[19] Overall, somewhere between 42 and 47 percent of

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[17] Maryland Agriculture Summary 2016, pp. 7, 20

[18] Census of Agriculture, Maryland 2017, Table 2

[19] Farmland Information Center 2020. The overall amount of farmland in Maryland is estimated at about 5% less than the Maryland Census of Agriculture. The Farmland Information Center data on prime farmland are not consistent with NRCS estimates for 1997 (we do not have both sets for a later year). The former estimate for 1997

farmland statewide appears to be in the prime farmland category, with larger fractions in the above-mentioned counties in the Upper Eastern Shore and North Central regions of Maryland.

Maryland has had a program since 1977 to protect prime farmland from development to ensure food production capacity. A state agency, the Maryland Agricultural Land Preservation Foundation, acquires easements to ensure this protection. By 2019 such protection covered 318,215 acres across the state. In 2019, the Foundation acquired easements for 5,430 acres.[20]

In considering ground-mounted solar deployment, it is essential to have a regional breakdown since the different types of agricultural land are unevenly distributed across the state. Table I-2 shows region by region estimates of farmland, prime farmland, conservation reserve – and the balance of non-prime agricultural land. We have disaggregated the estimates into the following regions:

1. The Upper Eastern Shore: Caroline, Cecil, Kent, Queen Anne's Talbot counties;
2. The Lower Eastern Shore: Dorchester, Somerset, Wicomico, and Worcester counties;
3. North Central Maryland: Carroll, Frederick, Montgomery, and Washington counties;
4. Western Maryland: Allegany and Garrett counties;
5. Southern Maryland: Calvert, Charles, Prince George's, and St. Mary's counties;
6. Central Maryland: Anne Arundel, Baltimore, Harford, and Howard counties.

Prime farmland is shown because discussion of solar siting is sometimes oriented to preventing solar installations on such land. The orientation of this report is that dual-use should be required, along with soil health improvement, whenever solar is located on any farmland, whether it is prime farmland or not. Further, the economic orientation is toward improving farm profitability and economic resilience. In this context, a general exclusion for any category of farmland, becomes moot. It is nonetheless of some interest to calculate the fraction of farmland that would be needed even for ambitious solar development.

d. Loss of agricultural land to development

Maryland, like other states, has continued to lose farmland to other uses, notably to urban, suburban and exurban development. According to detailed data compiled in a "State of the States" report, the American Farmland Trust has estimated that, between 2001 and 2016, Maryland lost 30,200 acres of farmland to "urban and highly developed land use"; another 72,600 acres of farmland were "converted to low-density residential use." This amounts of a total of 102,800 acres of farmland lost to urban, suburban, and ex-urban development in just 15 years.[21]

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was 868,000 acres of prime farmland, while the NRCS Natural Resources Inventory estimate for the same year was 1,133,400 acres. NRCS-NRI 1997. However, the Farmland information Center also has a broader category than "prime farmland" called "Nationally Significant agricultural land." The 2001 estimate for this category was 1,224,700 acres, which is closer to the NRCS-NRI estimate for 1997.

[20] MALPF 2019, Tables 6 and 7

[21] Farm Information Center 2020.

Table I-2: Breakdown of agricultural land for the year 2017 in Maryland with estimates for prime and non-prime farmland area by region

	Upper Eastern Shore	Lower Eastern Shore	North Central MD	Western MD	Southern MD	Central MD	Total
Total cropland	489,657	272,111	381,036	55,905	93,354	134,608	1,426,671
Pastured cropland, idle, cover crops, etc.	30,894	25,267	39,418	10,596	13,148	14,134	133,457
Harvested cropland	458,763	246,844	341,618	45,309	80,206	120,474	1,293,214
Woodland	64,711	77,266	55,548	44,933	45,009	29,180	316,647
Permanent Pasture	13,866	4,240	57,206	19,617	11,653	26,739	133,321
Farmstead land	24,496	25,787	26,349	5,184	12,359	19,308	113,483
Total farmland	592,730	379,404	520,139	125,639	162,375	209,835	1,990,122

Source: 2017 Agricultural Census of Maryland, Table 8. NRCS/NRI data and Farmland Information Center (footnote 17 above).

Note 1: Statewide, NRCS-NRI provides prime farmland percentage estimates of the total prime land in various areas, excluding urban, federal, and water areas of the state. But these include forested and non-farmland areas not directly translatable farmland area. However, their relative magnitudes in the various regions and overall can be used: statewide, 23%; Upper Eastern Shore 28% (~57% of farmland); the three North Central counties: 31% (~63% of farmland); Southern Maryland 18% (~37% of farmland); and Western Maryland 2% (~4% of farmland). Approximate values were inferred for the Lower Eastern Shore (~50% of farmland) and Central Maryland (~15% of farmland) as residual values. NRCS-NRI 1997

II. Land requirements for solar photovoltaics

a. Land per unit of solar capacity

The amount of land required per megawatt of ground-mounted solar capacity will vary by topography, the amount of land required for buffers, and other considerations. For the purposes of assessing the scenarios in this report are based on 8 acres of land per megawatt AC (MW-ac) of solar capacity for a single-axis tracking system.[22] One MW-ac would generate between about 2,000 and 2,100 MWh of electricity per year, depending on where in Maryland the installation is built.[23] This means that a single acre of solar would generate 250 to about 260 MWh of electricity per year.[24]

The construction footprint – concrete or steel in the ground, concrete pads, etc. -- is much smaller; it varies from a fraction of one percent to 2% at the higher end.[25] The vast majority of the rest of the solar installation land can be used for a variety of agricultural purposes, except row crops, depending on the design of the installation and other factors (see Chapter IV).

This small construction footprint relative to the overall land requirement for the solar installation is illustrated in Figure II-1, which shows a typical ground-mounted solar grazing installation; sheep can even graze or rest under the panels. An association has been formed to promote joining solar photovoltaics with grazing farm animals: The American Solar Grazing Association.

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[22] The area could range from 6 to 9 acres per MW-ac. This range is based on a review of ground-mounted solar installations from 125.5 kW to 20 MW in the Maryland, Delaware, Virginia region. SEIA Solar Map 2020. See also NREL 2013 for solar area requirements. The Interim report of Governor Hogan's Task Force on Renewable Energy Development and Siting used 8 acres per MW-ac. Hogan Task Force 2019, pdf p. 138. We assume single-axis tracking systems. This is normal spacing that could accommodate pollinator-friendly plants and grazing sheep. Other kinds of agriculture may require greater spacing. Cultivation of vegetables, berries, etc. would generally require site specific and crop specific optimization of the solar and agricultural aspects. It should also be noted that increasing solar panel efficiency will decrease land requirements per unit of electricity generation, all other things being equal.

[23] We have used the PVWatts Calculator tool of the National Renewable Energy Laboratory to estimate solar generation. Available online at https://pvwatts.nrel.gov/pvwatts.php

[24] Generation per acre will grow with increasing panel efficiency. We have not taken this reduction of land area requirements into account.

[25] Estimated from photographs of ground-mounted solar installations, including those shown in the present report and from Greentumble 2018. The size of the construction footprint in for a specific installation depends on soil type, solar installation design, slope of the land, and whether the solar system tracks the sun or not. Tracking systems can be single-axis or double-axis tracking. This report assume single-axis tracking solar systems for generation and land-use estimates.

Figure II-1: A Ground mounted solar installation, showing small construction footprint; the panels also provide shade. Source: The American Solar Grazing Association; with permission.

For the land to be restored to unrestricted use after its solar generation use has ended, provision must be made for removing all the equipment as well as the footings. In order to ensure this, a decommissioning fund is essential. Annual payments into such a fund of about 1% of the value of the electricity produced over a typical 25-year life of a solar farm would be sufficient.[26] Such payments are assumed in the calculations in the report so as not to overestimate the economic benefits of solar to farmers. Other decommissioning guaranties are also possible (see Section III.e).

Another agricultural use is shown in Figure II-2, where the panels are raised (relative to a solar grazing with sheep) to allow partial sunshine beneath for cultivation of vegetables on a Massachusetts solar installation. This illustrates that a solar installation can be planted with a variety of crops; however, when more sunshine is needed, panels must be raised. This necessitates a cost optimization procedure to determine the balance between agricultural production and solar installation cost. Figure II-2 shows a post-driven solar structure, which is different from that shown in Figure II-1. The post type of structure could be used to graze cows on a solar installation land, provided the panels are suitably arranged. Options include (i) raising the panels, which increases cost; (ii) protecting the parts under the panels from cattle ingress with an electric fence; (iii) installing bifacial fixed vertical solar panels that are oriented east-west, with spacing sufficient to allow grazing and agricultural machinery.[27]

[26] NYSERDA 2019, p. 155 (pdf p. 157), Table 1 provides an estimate for a 2 megawatt system. In the calculations in this report, about 25% ($20,000) has been added to this cost to account for engineering, not included in the NYSERDA table, and for unforeseen expenses.
[27] This approach has been developed by a German company Next2Sun. Next2Sun Concept 2020

Figure II-2: Raised solar PV at the University of Massachusetts to allow for cultivation under the panels, showing post-driven, panel-mounting structure.
Photo credit: Dr. Emily Cole, personal photo archive, with permission.

Dual-axis solar installations have their panels are mounted on poles nine or ten feet high – about the same height as in Figure II-2, and spaced more widely than single axis trackers. The dual-axis tracking approach may therefore enable an expansion of the range of agricultural activities on solar installation land. Their ground clearance, however, is low at the maximum tilt position.[28] The solar tracking increases electricity generation and offsets at least some of the added cost of taller panel mounts. Grazing sheep is already being done in solar arrays using this configuration, as for instance at the University of Queensland solar array in Australia.[29]

Figure II-3 shows rotational grazing being done on a solar installation with the usual solar arrangement: south-facing panels. In this arrangement generation (on a sunny day) increases steadily after sunrise, peaks in the middle of the day, and declines thereafter. In the last few years, a new option for agriculture with solar has been developed in Germany that appears to be more suitable for a wider array of agricultural activities without significant increase in solar installation costs. The technology involves the use of bifacial solar panels, which generate electricity on both faces of the panel. They are installed

[28] Ward, personal communication 2021
[29] Sibson 2016

vertically, in a fixed array facing east-west, so that the highest generation is in the late morning and late afternoon hours with a dip in the middle of the day (Figure II-4). There are several installations in Europe but none in the United States as of the date of preparation of this report.

Figure II-3: Solar sheep farm with rotational grazing
Photo credit: The American Solar Grazing Association, with permission.

Figure II-4: Vertical, East-West solar panel configuration

Photo Credit: Next2Sun, GmBH, with permission

The design shown in Figure II-4 is likely to be amenable to a wider range of agriculture than the usual south-facing panels, because the panels do not have to be raised, and raising panels increases solar cost. A vertical panel configuration allows direct sunshine between the rows in the middle part of the day – that is, essentially on the whole solar installation. Its viability, relative to a south-facing system will depend, of course, on relative cost. The costs for a 2-megawatt vertical array, quoted to this author by the company, Next2Sun, were about $0.73 per watt-dc, plus the cost of leasing the land. The vertical arrangement typically takes 25% more land than a south-facing array to enable the rows to be spaced so as not to shade one another.[30] Translating these numbers into a U.S. context is complex since there are no Next2Sun projects in the United States as yet (January 2021). U.S. costs tend to be higher than German ones; the generation per watt using the vertical configuration will be lower than the single axis tracking systems evaluated in this report. However, winter generation would increase in environments with snow cover during much of the winter, due to the reflection of sunlight onto the bifacial panels and the fact that snow would not accumulate on them; this attribute would also reduce maintenance costs. But the vertical panel approach would reduce the capital cost of solar compared to raising panels significantly to allow for a broad array or horticultural activities and therefore may be more promising under some circumstances.[31] In sum, while the vertical panel approach appears promising for expanding agrivoltaic options, demonstration projects to evaluate it, including cattle grazing and horticulture, are needed under U.S. conditions.

b. Solar scenarios

Maryland has a solar renewable portfolio requirement for the year 2030 amounting to 14.5% of electricity sales. Electricity declined from 2005 to 2012 butt have been steady since then (allowing for weather-related variations) due to increasing efficiency encouraged by Maryland programs and as part of a general national trend. However, with intensive transportation electrification, which is being encouraged by the state, electricity sales are likely to rise even with existing uses becoming more efficient.[32] The details are not important for the purposes of examining land use in broad brush strokes to provide an idea of the scale of land-use that might be involved. Two scenarios for the growth of solar energy in Maryland are used to examine the impacts on solar land needs in the state.

The two scenarios are as follows: [33]

- *The 2030 Renewable Portfolio Standard Scenario:* The 2019 Clean Energy Jobs Act requires that 14.5% of Maryland electricity sales in the year 2030 come from solar energy. Recent data

[30] Cost discussion based on personal email communication, Meyer 2020. Exchange rate used: $1.20 = 1 euro.
[31] NREL Dual-Use Cost 2020, Chapter V. This report evaluates capital cost of ground-mounted solar by themselves and in agrivoltaic mode, but not the overall economics of agrivoltaic operations.
[32] Makhijani 2016.
[33] The values for solar generation are meant to be illustrative of the amounts to be expected, given the state's electricity sector and overall climate goals, rather than precise scenarios. The aim is to provide order of magnitude estimates of land required if half the solar were ground-mounted on agricultural land. A detailed roadmap for a renewable electricity system in Maryland by 2050 is discussed in Makhijani 2016. Events since then have indicated a need for a faster transition to a renewable electricity system.

indicate that this translates into about 9 million megawatt-hours (MWh) of electricity per year.[34] We use 10 million MWh/year of solar to account for growth in electric transportation, combined with pursuit of existing efficiency policies. We assume half of the solar generation in 2030, or 5 million MWh/year, would be on farmland, while the rest would on rooftops, brownfields, etc. as an example of balanced solar development.

- *The Statewide Solar Scenario:* This assumes a fully renewable electricity system in the state, by about 2040, with electrification of most transportation and building heating.[35] Half the electricity would come from solar and half of that would be ground-mounted solar on farmland; this is an illustrative fraction that provides an indication of how widespread economic benefits to farmers might be.. In this case farmland generation would amount to one-fourth of overall electricity requirements – about 20 million MWh per year.

Table II-1 shows the land requirements for the two scenarios in acres and as a fraction of total farmland and also of non-prime farmland. It also includes estimates of the construction footprint in both cases. Construction footprints vary considerably, depending on the nature of the terrain, the soil, and the design of the solar installation, from a fraction of 1% to about 2%. We have used 2%. to be conservative.

Table II-1: Cumulative solar installation area and construction footprint, for the years 2030 and about 2040

	% solar	% ground-mounted	MWh/y solar ground mounted	Area, acres (Note 3)	Fraction of ag land	Fraction of non-prime ag land	Construction footprint of solar, acres, (Note 4)	Construction footprint % of farmland
2030 RPS	14.50%	50%	5,000,000	20,000 (Note 1)	1.0%	2.0%	400	0.02%
100% renewable, around 2040	50%	50%	20,000,000	80,000 Note 2)	4.0%	8.0%	1,600	0.08%

Note 1: 2030 generation assumed to be 70,000 MWh with partially electrified transportation and continued efficiency programs
Note 2: 2040 generation assumed to 80,000 MWh of renewable electricity, with mainly electrified transportation and continued efficiency programs
Note 3: 8 acres per MW-ac and 2,050 MWh/year-MW-ac generation (first year). Total acreage is rounded.
Note 4: The construction footprint of ground mounted solar can vary from a fraction of 1% to about 2%. We have used 2% to be conservative.

It is clear that even for extensive solar development scenarios only a small fraction of the agricultural land is required. That holds even if solar is restricted to non-prime, non-conservation land (which we do not recommend since soil health can be improved on all farmland) – about 1% of farmland or 2% of non-prime land if half the 2030 renewable portfolio standard's solar requirement is met with farmland ground-mounted solar. The corresponding figure for a fully renewable electricity sector where half the

[34] Retail sales in Maryland in 2018 were 62.1 million MWh. Maryland State Electricity Profile 2018, Table 8.
[35] Overall electricity use is assumed to be about 80 million MWh in about 2040 with mainly electrified transportation and continued efficiency programs plus partial electrification of buildings. Renewable peaking is included; renewable fuels for displacement of fossil fuels in industry are not included. Based on Makhijani 2016, Figure VIII-18, less 13 million MWh for hydrogen production for uses other than peaking generation. One-fourth of this would be from ground-mounted solar on farmland, requiring just under 10,000 MW-ac. This would require, in round numbers, about 80,000 acres of land. Hydrogen use for other purposes than peaking is not included.

electricity is solar – and half of that is ground-mounted – is about 80,000 acres, which is about 4% of farmland; if it is all on non-prime farmland, it would be 8% of non-prime farmland in Maryland. The construction footprint for the 2040 scenario would be about 1,600 acres at most. Note that the two scenarios do not have the same pace of solar development. A fully renewable electricity system with electrified transportation and buildings would require about double the rate of solar that is in the current Renewable Portfolio standard for the year 2030. For comparison, more than 100,000 acres of farmland were lost to urban and exurban development between 2001 and 2016 (Section I.d. above).

It is important to restate in this context that it is not the aim of this analysis to advocate for any particular amount of such construction; rather the two scenarios chosen are practical and compatible with a renewable electricity sector in Maryland. The policies needed to achieve these goals are discussed in Chapter V. The actual fraction of solar on farmland will depend on a great many factors, including these policies, and the extent to which farmers see their interest as overlapping with healthy soils practices along this particular path, relative to others.

III. Solar energy and farm profitability

We consider three different projects of different scales that have different economic implications as examples of the types of projects that could be considered:

1) A corn-soybean rotation commodity crop 1000-acre farm without solar compared to 900 acres corn-soybeans and solar on 100 acres;[36]

2) A 300-acre dairy operation with no solar compared with dairy production on 284 acres and net-metered solar on 16 acres;

3) A one-acre solar installation on a small 10-acre diversified specialty crop farm.

These examples are not meant as designs for specific projects. Rather they are realistic sketches of projects designed to estimate the value of joining solar with agriculture. Siting and farmland protection are discussed in Chapters IV and V.

a. Corn-soybean rotation, with and without solar

Consider a 1,000-acre unirrigated farm in a typical corn-soybean rotation. The comparison would be as follows:

- **Corn-soy rotation plus solar**: 100 acres (10%) of the land would be used for the solar installation and 900 acres would be used for the corn-soy rotation.
- **Corn-soy rotation without solar**: In this case all 1,000 acres are used for a conventional corn-soy rotation.

Costs for growing corn and soybeans were obtained from University of Maryland Extension estimated budgets for 2020. Yields vary a great deal; the calculations in the present example use a value of 170 bushels per acre for corn and 50 bushels per acre for soybeans. The prices of commodity crops are highly variable. The impact of solar is better understood if assessed with different crop prices. The approach used here was to use the best two-successive-year combination of corn-soy prices and the worst combination respectively, using annual average prices in the 2016-2019 period.[37] Yields and costs were assumed to remain the same.

Using the annual average price is a simplifying assumption. The calculations also do not take into account any government payments, payments for conservation practices, etc. Such payments would be available in any case. Since a large fraction of Maryland farmland is farmed using a corn-soybean rotation, the conclusions about the role of solar are significantly affected by these assumptions. This is especially the case since solar-related revenues on 10% of the land are larger than typical profits from the corn-soy rotations.

In the solar case, there would be suitable provisions for healthy soils practices on the 100 acres of the solar installation. These could include a variety of farming activities. One possibility is a suitable seed

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[36] A part of a farm of this size may be owned, while the rest is leased; thus the land may not be continuous. This is not material to the economic calculations so long as the 100 acres assumed for solar are on one continuous parcel.
[37] The profound economic shocks caused by the COVID-19 pandemic included significant declines in corn and soybean prices in the first half of 2020. These declines have not been taken into account; prices recovered in the latter part of 2020.

mix of pollinator-friendly plants combined with rotational grazing of sheep. Details are discussed in Chapter IV. The lease payment to the landowner is free and clear of any obligations for maintenance, insurance, etc. That would be done by the owner of the solar farm.[38] Thus, the only material factor for the landowner is the lease payment, which would increase revenues, and the 100 acres less in commodity crops, which would decrease them. The profitability of the solar installation would be the responsibility of the developer, presumably worked out before the lease is sought.

For the landowner, the most important driver in considering solar is the lease payment per acre. If solar is to be confined to a small fraction of a farm operation's land, then the lease payment has to be large enough to justify giving over control of the land to the solar operation for a long period of time – generally 20 years or more. The nature of the terrain and the value of the land are factors in the determination of the lease payment. But a critical driver for the feasibility of megawatt-scale solar projects is how close the land is to a substation or transformer where the electricity generated can be fed into the electricity grid. The size of the solar installation can also make a difference:

> A 10-acre site next to a substation outside of an urban area with high land prices might be justified in asking $2,000 per acre. Even in rural areas of North Carolina or California where demand for small solar sites is high, rent over $1,000/acre would be common by a substation with capacity. Larger tracts over 100 acres for major power plant projects commonly rent at $300 to $500 an acre across Texas and normally around the $500/acre range across most of the Southeast. Large tracts can fetch upwards of $800/acre in Illinois, Virginia and the Carolinas depending on numerous factors. High priced, large tracts in California's Central Valley often go for $1,000 per acre.[39]

The reference calculation uses $1,000 per acre for a lease rate; sensitivity calculations use a range of $500 to $2,000. Public incentives can be provided to encourage solar on farmland that is not near a substation, but otherwise preferable from a public policy point of view for non-solar benefits. This is further discussed in Chapter V on policy.

The margins in commodity row crop farming are usually thin. Profits are from $100 to $200 per acre.[40] Adverse events that cause commodity prices to fall, such as during the early part of COVID-19 pandemic crisis or extreme weather, are perilous for farmers. This lack of predictability increases pressure on farmers and creates incentives for converting farmland to more remunerative purposes, such as suburban and exurban development.

Table III-1 shows that with just 10% of the farm in solar (with suitable provisions and incentives for revenue neutral agricultural practices), farm profitability can be increased about two-and-a-half times in years of favorable grain prices and almost four times when grain prices are unfavorable. More importantly, income from a solar lease can stabilize revenues so that there are net profits even in years of low prices. A large part of the attractiveness for farm profitability is that solar lease revenues are essentially risk free to the farmer; the price, of course, is that the solar fraction of the land is not accessible to the farmer for grain cultivation for a long period. This is one important reason to limit solar to a small fraction of any farm operation.

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[38] We also assume in this and the other examples that the costs for making the solar land suitable for agricultural activities would also be part of the development of the solar installation.

[39] Strategic Solar Group 2018

[40] Calculated from the U MD Extension 2020 crop budgets for conventional, non-irrigated corn at 170 bushels per acre at $4/bushel and soybeans at 50 bushels per acre at $10 per bushel; rounded to one significant figure. Government payments or subsidies not included.

Table III-1: Profitability of corn with and without solar leasing revenues

	Year 1		Year 2		Annual average over two years	
	corn + solar	corn only	soy + solar	soy, no solar	Corn +soy + solar	Corn + soy only
Yield bu/acre	170	170	50	50		
Crop Revenue $/acre	$655	$655	$468	$468	$561	$561
Costs $/acre	$594	$594	$347	$347	$470	$470
Grain cultivation costs, $	$534,222	$593,580	$311,859	$346,510	$423,041	$470,045
Acres in grain	900	1,000	900	1,000	900	1,000
Acres in solar	100	-	100	-	100	
Two years with favorable grain prices						
Price $/bu	$3.85	$3.85	$9.35	$9.35		
Revenue from grain	$589,050	$654,500	$420,750	$467,500	$504,900	$561,000
Profit from grain	$54,828	$60,920	$108,891	$120,990	$81,860	$90,955
Solar lease revenue, $/year	$100,000	0	$100,000	0	$100,000	0
Total profit $/year	$154,828	$60,920	$208,891	$120,990	$181,860	$90,955
Total profit $/acre-year	$155	$61	$209	$121	$182	$91
Two years with adverse grain prices						
Price, $/bu	$3.70	$3.70	$8.93	$8.93		
Grain revenue, $/year	$566,100	$629,000	$401,850	$446,500	$483,975	$537,750
Grain profit, $/year	$31,878	$35,420	$89,991	$99,990	$60,935	$67,705
Solar lease revenue, $/year	$100,000	$0	$100,000	$0	$100,000	0
Total profit, $/year	$131,878	$35,420	$189,991	$99,990	$160,935	$67,705
Total profit $/acre-year	$132	$35	$190	$100	$161	$68

Source for costs of conventional corn in Maryland: U MD Extension 2020

Table III-2 summarizes the results showing profits per acre per year with and without solar, for years with favorable and adverse grain prices.

Table III-2: Annual average profit per acre, averaged over a corn-soy rotation with and without solar

	With solar on 10% of land	No solar	% profit relative to no solar
Favorable grain prices	$190	$91	209%
Adverse grain prices	$161	$68	238%
% change favorable to adverse	-15%	-26%	

Table III-2 shows that the decline in profits is less steep when solar lease revenues provide a fixed cushion. Moreover, profits are consistently higher with only 10% of the land taken up by the solar installation. This provides an indication that agricultural production and farm profitability can be joined with solar energy to the benefit of farmers, including by increasing a farm's financial resilience.

The above calculations are based on a moderate value of solar lease revenue of $1,000 per acre per year. Table III-3 shows the impact on farm profits as a function of lease revenues ranging from $500 to $2,000 per acre per year. There is a significant increase in farm profits even at the lower end of lease revenues.

Table III-3: Impact of lease rate on annual farm profitability in a corn-soy rotation – solar on 10% of land compared to no-solar for a 1,000 acre farm

	Lease revenue $/acre	Annual lease revenue	Total profit per year	Total profit $/acre	% profit relative to no solar
$500/acre lease	$500	$50,000	$131,860	$132	145%
$1,000/acre lease	$1,000	$100,000	$181,860	$182	200%
$2,000/acre lease	$2,000	$200,000	$281,860	$282	310%
No Solar	$0	$0	$90,955	$91	100%

It is to be noted that the calculations assume a fixed lease revenue in current dollars. In other words, lease revenues would not escalate with inflation. Contracts can have escalator clauses in leases; in such cases the positive impact on profitability of solar would be greater than shown in Tables III-1 though III-3.

The above calculations are based on the assumption that the farmer owns the land on which the solar is located and therefore gets the lease revenue. It would also apply to most farmers who own some of the farmland they cultivate and lease the rest, provided the solar is on the land they own.[41] It does not apply to cases where a farmer leases all the land they operate. Given the financial attractiveness of leasing land for solar installations, protecting farmland and maintaining it in agricultural production also involves protecting lessees and enabling them to continue to farm. This is addressed in more detail in Chapter V on policy. Suffice it to say here that the most important policy in this regard would be to restrict the fraction of any farm operation that can be in solar to a small fraction of the total farmland (such as 20% or less). For the purposes of this report, a "farm operation" is defined as a contiguous land parcel with the same owner.[42]

b. A dairy operation with and without solar

There is also the option of owning a solar installation rather than leasing land to a solar developer. Such an option can be attractive if the installation is covered by Maryland's aggregate net metering policy, which limits the size of eligible installations to 2 megawatts or less. This involves some risks – borrowing the funds, operating and maintaining the solar installation, and ensuring that the purchasers of electricity pay for it. But these risks can be minimized in a variety of ways, as discussed below. This section analyzes a 300-acre dairy operation without solar and the same operation, but with 16 acres in

[41] Less than 800 of the more than 12,000 farms in Maryland are fully leased. The rest are wholly or partly owned by the farmers operating the land. Census of Agriculture for Maryland 2017, Table 53.

[42] Land categorized in the agricultural census that "farmsteads, homes, buildings, livestock facilities, ponds, roads, wasteland, etc." is not included in the term "farm operation" for purposes of this report. It is 5.7% of the farmland in Maryland. Census of Agriculture for Maryland 2017, Table 8. Some of this land may be suitable for smaller solar facilities as well as rooftop solar. It is excluded here since the focus is on the ways in which solar could be joined with food and fiber production.

solar, with sheep grazing on this solar land.

Under Maryland's "Aggregate Net Metering" rule, a solar installation connected to any farm electric meter can also have other farms, government entities (including schools and colleges), and non-profits (including churches) for a virtual solar connection. [43] The other entities are billed as if they are connected to solar but do not actually have an actual electrical connection to the solar installation (often referred to as "virtual net metering" as distinct from consumption that is physically netted at one production and consumption location only). The maximum size of the solar array allowed under the Aggregate Net Metering rule is 2 megawatts-ac (MW-ac), the size used in this example. The following parameters were used in the calculation for a reference case; in addition, sensitivity analyses were also done:

- **Dairy operation**: A dairy operation of 300 acres of grazing land was assumed. In the solar case, 16 acres, or 5.3% of the farm, was used for solar and grazing sheep and the rest for grazing. Without solar, all 300 acres were for grazing.[44]
- **Solar grazing**: A solar grazing model was assumed; payments by the solar owner (in this case, the dairy farmer) to the owner of the sheep were taken to be $600 per acre of the solar installation.[45] This offsets part of the maintenance costs due to the elimination of all or nearly all mowing and all or almost all pesticide applications, which are often made under the panels where mowing is difficult. Investments of $30,000 to enable the grazing, including for water and for movable fencing to enable rotational grazing, were included in solar installation costs.
- **Cost of solar**: The capital cost of the solar was taken to be $1.40 per watt-dc. Solar costs have been declining and are expected to continue to decline substantially.[46] Assumed cost of capital: 8.5% per year. A degradation of solar generation of 0.5% per year was taken into account. 1% of revenues from the sales of electricity are conservatively assumed to be put in an escrow fund for decommissioning when solar generation ends (including potential lease extension).
- **Federal investment tax credit**: A federal investment tax credit of 22% is assumed. Under a bill passed in December 2020, the tax credit will be 26% for projects that start construction by the end of 2022 and 22% for projects whose construction starts by the end of 2023. The tax credit declines to a permanent 10% after that. See Section III.d below for a sensitivity analysis relating to solar costs and tax credit rates.
- **Solar renewable energy credits**: It is assumed that all solar renewable energy credits would be sold in advance (usually at the time of commissioning) so as to reduce the initial cost and capital requirements; they are sold at a discount relative to market value.
- **Tax equity investors**: Many farmers may not have sufficient tax liability to benefit from the investment tax credit as well as the accelerated depreciation available to solar investors. In such

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[43] Maryland Codes; the Aggregate Net Metering clauses are at 20.20.10.07 and 20.50.10.08

[44] Referred to below as "dairy farm" or "dairy operation."

[45] Lewis Fox, a solar grazier, gave a $400 to $600 per acre range for payment to solar graziers. The upper end of this range reduces solar profits; it is used here as a conservative approach to comparing a dairy farm with solar and one without it. Lewis Fox, 2020 (personal email communication).

[46] SEIA 2020 and a source in the solar industry. The National Renewable Energy Laboratory publishes projections of the cost of various electricity generation technologies every year. The most recent projections (NREL ATB 2020) for the capital cost of a fixed-tilt commercial rooftop system for 2022 and 2030 (moderate case) are $1,610 and $1,032 per kW-ac respectively. The corresponding values for a single-axis tracking, ground-mounted utility scale installation are $1,210 and $832. A 2 MW-ac ground-mounted, single-axis system would be somewhere between these two values – the medians are about $1.40 and $1.00 per watt-dc for 2022 and 2030 (rounded up to the nearest ten cents per watt-dc). The estimated rate of the decrease in the capital cost of solar is about 5.3% per year between 2018 and 2025.

cases it is normal to sell the tax benefits to "tax equity investors" at a discount, which enables those investors to make a profit.[47] A 20% discount was used. Another option would be for farmers to own the solar jointly in order to avail themselves of the tax benefits without involving a tax equity partner, thus keeping all the tax benefits within the community.

- **Revenue from electricity sales**: Aggregate net metering values solar electricity at the retail rate. The electricity is not required to be delivered physically except to at least one building or utilization point on the farm. The rest of the delivery can be virtual – via the electricity bill. Profitability evidently depends on the retail rate. The variation of profitability in each major utility territory in Maryland was examined. A 20% discount relative to the retail rate was assumed to make the solar electricity attractive to institutional buyers like schools, universities, local governments, and other farmers; that would enable contracts in advance of commissioning or earlier, at the planning stage, making a farm operation-owned solar system much more practicable. The assumption is that the discount would be maintained relative to utility rates for the life of the contract; it lifts the uncertainty from the farmer's shoulders associated with billing customers and collecting from them (see Chapter V).
- **Inflation rate**: An inflation rate of 2% in electricity rates was assumed. Sensitivity calculations were done for 0% and 4% inflation rates. An inflation rate of 2% was also used for milk prices. The average annual inflation rate in milk prices between 1997 and 2019 was 1.57%.[48]

Overall, these assumptions tend to underestimate the profit to the farm operation from owning solar. Still, the profits are robust. Table III-4 shows the results of the analysis in detail, including average profits over 15 years and over the full 25 years. Solar profits are lower during the period when the loan is being paid off. The loan period assumed is 15 years. The typical life of a solar installation is 25 years; it is often longer. As a result the average profits in the first 15 years are lower than in the next ten. It is clear that solar on just 5.3% of the land increases average profits significantly in all cases. The amount depends centrally on electricity rates at which the electricity is sold to third parties – that is on the utility electricity rate and the discount relative to that rate offered to purchasers.

Table III-4: Dairy farm revenues, costs, and profits with and without solar, 5 year-averages (Note 1)

	Milk (284 acres) + solar (16 acres)			Milk only (300 acres)
	BGE/Delmarva	Pepco	Potomac Edison	
Average annual solar revenues (Note 2)	$268,003	$238,400	$211,365	N/A
Average annual solar costs	($188,703)	($188,703)	($188,703)	N/A
Net annual profit from solar	$79,299	$49,697	$22,662	N/A
Average annual profit from milk sales (Note 3)	$31,662	$31,662	$31,662	$33,481
Total annual average net profit	$110,961	$81,359	$54,324	$33,481
Annual average profit per acre	$370	$271	$181	$112
% increase in profit, solar relative to no solar	231%	143%	62%	N/A

Note 1: Revenues, costs, and profits averaged over 15 years; future revenue streams discounted at 5%. Inflation in electricity and milk prices 2%. Loan for solar at 8.5% with a term of 15 years.
Note 2: Solar leases assumed to be 25 years. Profits increase substantially after loan is paid off in Year 15. Profits averaged over 25 years would be double those shown in the BGE/Delmarva areas, 2.5 times in the Pepco area, and 3.5 times in the

[47] Smaller scale projects may have to be bundled together to get suitable terms from tax equity investors. The state could provide the assistance in such bundling, for instance via the Maryland Clean Energy Center, provided its capacity is boosted to provide such services.
[48] Prices for Milk 2020. The inflation rate cited is the consumer price index for milk.

Potomac Edison area. BGE and Delmarva commercial electricity rates were about the same. The lower of the two rates was used for the revenue calculations. BGE/Delmarva: $110/MWh; Pepco: $97/MWh; Potomac Edison: $87/MWh. As noted in the text, the net sales revenues were assumed to be 21% lower – 20% lower because of discounts offered to electricity purchasers and 1% for administrative costs.
Note 3: Milk data from University of Maryland Extension spreadsheets for 2011 and 2014-2016 (U MD Milk 2011, U MD Milk 2014-2016). Milk price assumed $17 per cwt. Added revenues, for instance from sale of cattle = 15% of milk revenues. Milk per cow: 21,000 lb./year, with 1.35 cows per acre. Cost per cow $4,000/year, kept constant in current dollars to account for increases in farm operation efficiency. We assume the cost per cow to be the same in both cases, since the number of cows is almost the same.
Source: IEER calculations.

Figure III-1 shows the annual costs, electricity revenues, and milk revenues on a 300-acre dairy farm with 16 acres in solar in the BGE or Delmarva utility territories, which together account for more than half the customers in Maryland. Note the jump in profits after 15 years, the assumed term of the solar loan. Figure III-1 also shows the results for the utility areas in Maryland with well over half the total customers (BGE or Delmarva). These are also the areas with the highest commercial electricity rates, and therefore the highest profits for a solar owner under the Aggregate Net Metering system. Profits increase greatly when the loan for the solar installation is paid off after 15 years. Loan payments represent by far the largest cost element of owning and operating a solar electricity system. Milk revenues would be reduced by about 5% due to the smaller grazing area for cattle.

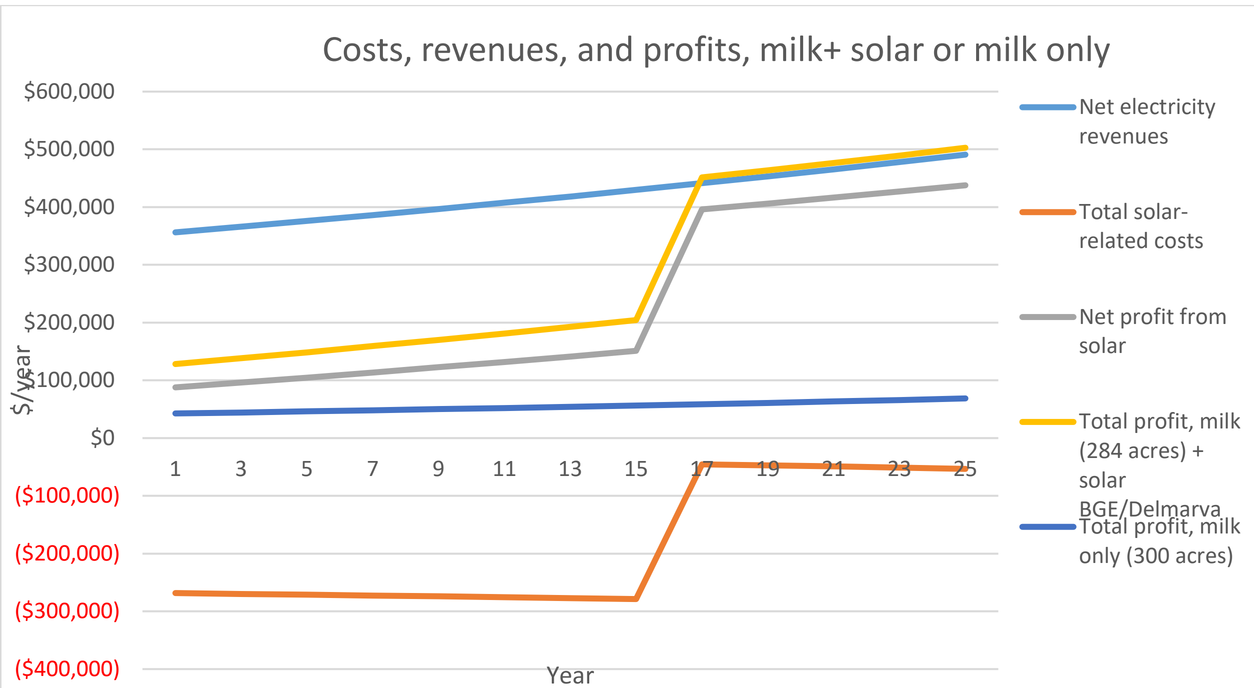

Figure III-1: Revenues and costs in a 300-acre dairy farm with solar on 16 acres, in the BGE or Delmarva utility territory, and without solar in current $. The loan period ends in Year 15, after which the profit increases significantly

Figure III-2 compares the profits over time for the same dairy farm with and without solar in the four major utility areas in Maryland; BGE and Delmarva are shown as one since their prices for commercial electricity are close.

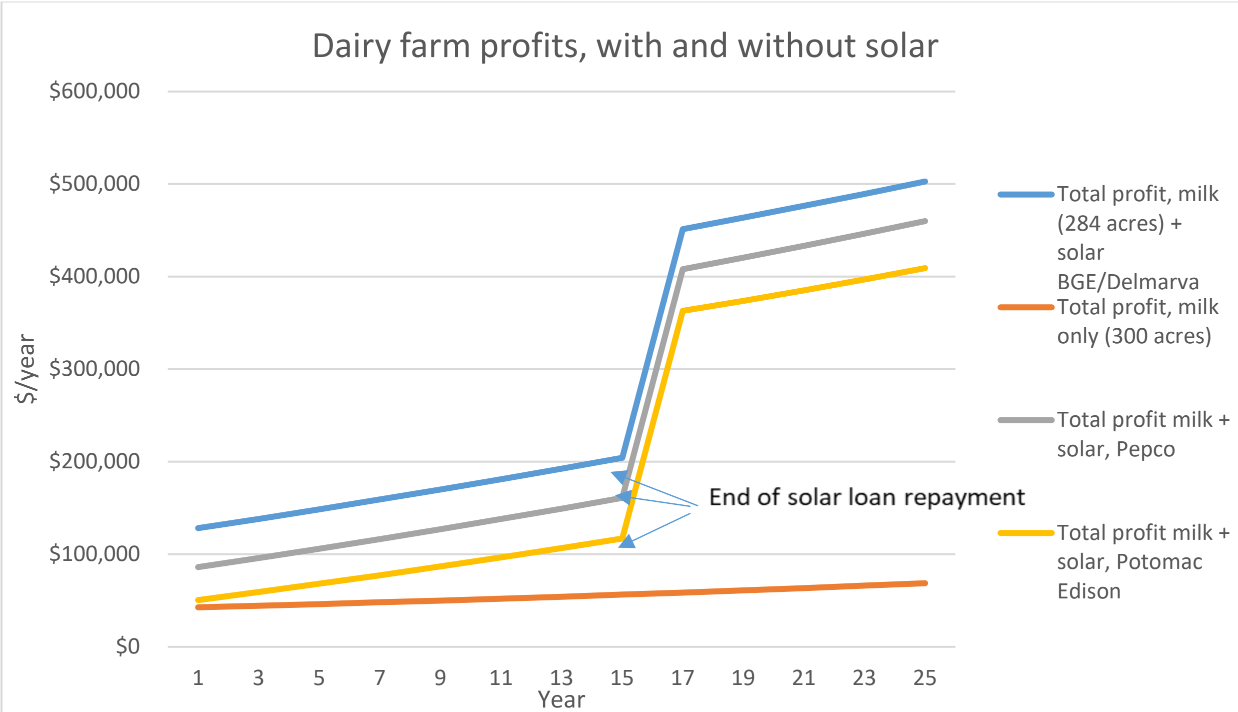

Figure III-2: Dairy farm profits with and without solar at three utility rates: BGE/Delmarva, Pepco. and Potomac Edison 284 acres milk +16 acres solar or 300 acres milk. Profits with solar jump at the end of the loan period

Other than electricity price realized, the most important parameters for solar to contribute to dairy farm profits with positive cash flow from the first year are the capital cost of the solar and the inflation rate in electricity prices relative to inflation in milk prices. Table III-5 shows the sensitivity calculations at 0%, 2%, and 4% inflation in realized electricity prices, while milk prices rise at 2% per year. The illustration is for the Potomac Edison territory because that is where, under current price assumptions, solar profits would be lowest. Even so, the profitability of solar remains robust even under the most adverse assumption of 0% increase in electricity revenues.

Table III-5: Sensitivity of profits to electricity price inflation rate, percentages relative to no solar

	Potomac Edison region		
	0% inflation	2% inflation	4% inflation
Annual average profit $/acre, 15 years	$127	$181	$224
% increase, 15-year average	8%	62%	111%
Annual average profit $/acre, 25 years	$280	$297	$312
% increase in profit, 25-year average	172%	203%	235%

A zero inflation rate in electricity prices means flat revenues. As is evident from Table III-5, this is the most adverse case. If electricity sales prices rise faster than milk prices, profitability will increase more relative to the no-solar case. It is important to recall in this context that it is assumed that the owner of the solar (in this case the dairy farm operation) provides the purchaser with a guarantee of 20% cheaper electricity relative to the standard service provided by the utility in order to secure a long-term contract for electricity sales. A long-term sales contract with an institutional customer would be bankable in the sense that it would enable the farm owner better loan terms or even enable a loan for the substantial amount needed for a 2-megawatt solar installation.

Table III-5 shows profits only in the Potomac Edison region. Electricity prices in the BGE, Delmarva, and Pepco are higher; the profits in these cases would therefore be higher than for the Potomac Edison case.

c. Solar on a small farm

More than half the farms in Maryland are less than 49 acres.[49] They produce a large variety of crops – including vegetables, fruits, and flowers. Their economics are complex and varied. Small farms (less than fifty acres) are highly diverse in their structure and income, making it impossible in the context of this report to give reasonable estimates of the percentage by which revenues or profits would increase.

Some small farms raising high value produce intensively may have gross revenues in the tens of thousands of dollars per acre. At the other end, most small farms had relatively low total sales. About 6,000 such farms, about half of Maryland's total of 12,492, had sales of less than $5,000 in 2,017.[50] As in the previous example of a larger solar installation on a dairy farm, the assumption is that the farmer would sell all the Solar Renewable Energy Credits as well as the tax benefits to investors so as to minimize the capital investment required. At the smaller scale, solar would cost more per unit of capacity than the larger 2-megawatt installation discussed for the dairy farm. As a result, the economics are more dependent on the utility territory in which the farm is located. The best profitability, at current rates, would be in the BGE and Delmarva areas, followed by the Pepco area. The lower rate in the Potomac Edison area would make the project riskier or potentially uneconomical at the $1.60 per watt-dc price assumed. At $1.40 per watt-dc, the economics would be comparable to the situation in the Pepco area. The National Renewable Energy Laboratory's solar cost projections estimate a decrease of costs at roughly 5% per year; at that rate a one-acre solar installation would be economically attractive throughout the state in a few years.

While many small farms have small sales volumes, there are also intensively cultivated small farms that have revenues per acre that can be many times that of a commodity crop or dairy farm. The siting of solar on such farms would need special consideration; it may not be viable in cases where solar profits per acre are not significantly greater than those from intensive vegetable and flower cultivation.

Figure III-3 shows that even a one acre net metered installation could produce substantial profits; their relative impact on farm economics would depend on the specifics of the small farm operation.

[49] Census of Agriculture, Maryland 2017, Table 9, pdf, p. 28
[50] Census of Agriculture, Maryland 2019, Table 1, pdf p. 17

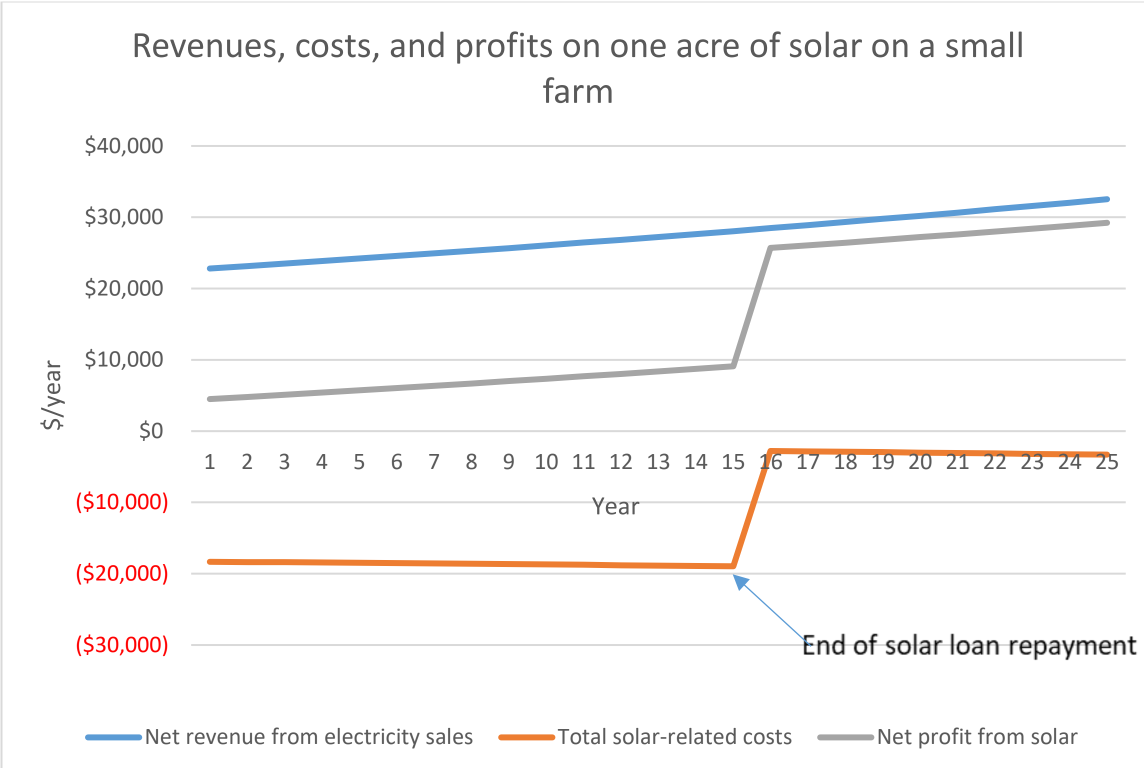

Figure III-3: Revenues, tax benefits and solar costs for a 125 kW-ac ground-mounted, single axis tracking solar installation on a small farm on the Eastern Shore in the Delmarva utility region. Gross capital cost assumed to be $1.60 per watt-dc, with maintenance costs at $12 per kW-year.

d. Sensitivity analysis

The analysis of farm-operation-owned solar has used costs on the higher side to be conservative – that is to examine profits at solar costs somewhat more than the typical current cost and without taking into account the steady decline in costs that continues to occur. Further, the analysis used a 22% federal Investment Tax Credit; the credit is 26% for projects that start construction before the end of 2022, 22% if construction begins by the end of 2023, and 10% after that. This sensitivity analysis examines farm-operation-owned solar cost at which the profits would be similar to that estimated at a 22% tax credit were that credit to decline to 10%.

- **Dairy operation case**: For the dairy operation example (Section III.b above), the solar cost used was $1.40/watt-dc. Were the investment tax credit 10%, the cost would have to be about $1.25/watt-dc to yield about the same profit. The National Renewable Energy Laboratory estimates about a 5% reduction in cost per year for the commercial ground-mounted category of solar;[51] on this basis, the cost of a $1.40/watt-dc installation in 2020 would decline to about $1.20/watt-dc by 2023. As a result, solar profitability can be expected to be about the same or greater than that shown in Section III.b starting in 2024 when the tax credit declines to 10%.

[51] NREL ATB 2020

- **Small farm case**: The same conclusion applies to the example of a one-acre solar installation on a small diversified farm (Section III.c above). The cost used in the analysis was $1.60/watt-dc. A decrease of price to $1.40/watt-dc would keep profits about the same. Using the estimated 5% per year cost decrease, the cost of a $1.60/watt-dc system would decline to $1.37/watt-dc in 2022. As a result, solar profitability can be expected to be higher than that shown in Section III.c in 2024 and later, when the tax credit declines to 10%.

This sensitivity analysis indicates that the profits for future project would be expected to be greater than those estimated even when the tax credit declines to 10% because of declining solar costs.

Farm profits in the example of solar on a corn-soy operation in Section III.a are unaffected by changes in the investment tax credit since the farm operation would derive its revenues by leasing the land for solar. In this case, increases or decreases in profits would be experienced by the owner of the solar. This may indirectly affect lease rates; however, it is unlikely to affect them negatively, given the continued decline of solar photovoltaic costs.

e. Decommissioning[52]

Farmland used for ground-mounted solar installations is generally under long-term leases – such as 25 years. A full range of options for this land at the end of the lease period requires decommissioning – and therefore a financial assurance of sufficient funds for that purpose at the end of the lease period.

One way to ensure sufficient decommissioning funds is to maintain an escrow account and build up the required sum by contributing to it each year until the end of solar generation period, which would correspond to the end of the lease, unless it is renewed. The cost of contributing to such an escrow fund – 1% of gross electricity revenues[53] – was included in the analyses above. To enable the full range of farming, decommissioning must include removal of the footings for the panel structures as well as concrete pads and other similar structures. Reseeding of the area is included in the decommissioning.

Lease renewal or technology improvements may result in a decommissioning fund larger than is needed. The solar owner should be able to adjust payments into the escrow fund based on such considerations, as determined by, say, a county council or other (third) party responsible for ensuring decommissioning. Other approaches to ensuring decommissioning are possible. All involve a financial guarantee by the solar installation owner to a third party, notably to the government of the county in which the solar is located that complete decommissioning will be carried out.

[52] Research on adoption of agrivoltaics by farmers indicates assurance of complete decommissioning and restoration of land is essential for the widespread acceptance of agrivoltaics by farmers. Pascaris, Schelly, and Pearce 2020.

[53] Based approximately on NYSERDA 2019, Table 1, p. 162

IV. Farmland solar: profitability, rural economic health, equity, and soil health

The three single-farm examples in the previous chapter provide vignettes of potential impact of solar on farm profitability. This chapter explores the breadth of the potential economic impact on farming and the possible connections with soil and ecosystem health. These considerations provide the framework for the policy considerations in the next chapter.

a. Potential economic impact

In Section II.b. we considered two scenarios for solar on farmland – one oriented to Maryland's 2030 solar Renewable Portfolio Standard, which is part of state law, and the other to a possible renewable electricity system by 2040. The land use impacts of these scenarios, in each of which half the solar would be on farmland, were examined in Section II.b.; a summary is shown in Table IV-1.

Table IV-1: Implications for farming of solar development on farmland

	2030 Renewable Portfolio Standard	2040 Renewable Electricity System	Comments
Solar fraction	14.50%	50%	
Farmland fraction of solar	50%	50%	Assumption for purposes of illustration
Farmland area in solar, acres	20,000	80,000	Note 1
Average fraction of farm operations in solar	10%	10%	Note 1
Total area of farm operations that have solar acres	200,000	800,000	Note 2
Average area of farm operation hosting solar	150	250	Assumed for purposes of illustration. Note 3
Number of farm operations hosting solar	1,333	3,200	Note 3
Fraction of farms hosting solar	11%	26%	
Net profit/lease revenue per acre	$1,000	$1,000	Note 4
Farm operation profits from solar $/y	$20,000,000	$80,000,000	@$1,000 per acre in solar
Average solar profit per farm operation	$15,000	$25,000	

Note 1: The vast majority of the area in solar would be used for farming activities.
Note 2: 90% of the area in traditional farming, in addition for the farming-related activities on the solar installation.
Note 3: The 2030 numbers assume a larger share of community solar than other types of installations. The 2040 illustration implies ~2000 systems of 100 to 300 kW, ~1,000 systems of 1.5 to 2 MW, and a few hundred averaging 25 MW. This is one potential combination; a number of others are possible. Aggregate net metering would have to be expanded to accommodate these numbers.
Note 4: Net revenues would be much higher for solar that is owned by the farm operation and the electricity sold under Maryland's Aggregate Net Metering rule. See Sections III.b. and III.c.

The economic basis for Table IV-1 is illustrated by the three types of farm operations with solar analyzed in Chapter III. A key parameter is the average fraction of a farm that is devoted to solar, among the farm operations that choose to have it. The upper limit for that fraction proposed as a matter of policy in this report is that *no more than* 20% of a farm operation could be in solar, with possible exceptions, including when interconnection costs would be very high for the specific parcel of land (see Section V.d. below). The average over many installations would be considerably less – Table IV-1 assumes an average of 10%.

Table IV-1 shows that thousands of farms in Maryland could benefit significantly and become more profitable and economically resilient with solar on a small fraction of the farms that host solar. To accomplish that the typical solar installation should be of a few megawatts or less. If solar targets for a renewable electricity system are reached by a few large installations, the benefits would be gathered by a tiny minority of landowners. For instance, the entire 2040 solar amount could be built on just 40 installations of 500 MW; each one would occupy 2,000 acres. There are well over 100 farms in Maryland that are more than 2,000 acres, so such an arrangement is possible in theory. But many of the economic and ecological benefits of distributed solar would not be realized compared to the approach illustrated in Table IV-1. That requires some limitations on acreage and fraction of any farm that could be in solar. Exemptions might be warranted in some circumstances (see Chapter V).

With the numbers as in Table IV-1, 90% of the land farm operations with solar would be used for normal farming activities; almost all the rest would be used for solar-compatible farming activities. In other words, 99% or more of the land of farm operations with solar would remain in farming-related activities. This is because the construction footprint of solar is very small (2% or less of the solar installation land) and the vast majority of the rest of the land can be used for agricultural activities.

A fully renewable electricity system by 2040 with the solar components assumed in that scenario would mean that several thousand farm operations could have solar, boosting their bottom lines significantly and stabilizing their profits in times of low commodity prices of other economic disruptions of agriculture. The actual number would depend on a number of factors, including the extension of net metering policy, the availability of credit for farmers to own solar and sell it to third parties by virtual net metering, the ease and security of electricity sales contracts, and the ease and security of using the solar installation land for farming-related activities either by the farm operation or by a third party. The types of activities are discussed in Section c. below.

Under Maryland law, total net metering capacity in the state is limited to a total of 1,500 MW, including residential, commercial, and community solar installations. Maryland has not yet reached this limit but may do so in the next few years.[54]

Many studies have shown that the value of solar electricity is greater than electricity rates.[55] Given that (i) community solar is in its initial stages, (ii) the combining solar and farmland in a manner that would

[54] Estimated from the SEIA Maryland Fact Sheet 2020.
[55] Environment America compiled 11 studies that looked at the value of solar electricity; eight concluded that it was greater than electricity rates; the three that concluded otherwise were commissioned by utilities. Hallock and

systematically benefit Maryland agriculture is still in its infancy, and (iii) solar has large climate and other environmental benefits, the net metering cap should be significantly expanded. A doubling to 3,000 MW would give sufficient time to consider options and alternatives in the context of the value of solar energy to Marylanders and to the state's climate and economic goals.

Community solar owned by farmers under Maryland's Aggregate Net Metering system also has the potential to best increase farm profits with solar on just a few percent of the land (Sections III.b. and III.c. above). Policies to encourage it, such as low-interest loans and facilitating long-term contracts for the sale of electricity to institutions such as colleges and government agencies would go a long way to spreading the benefits to thousands of farms and to increasing the economic resilience of farming in the state (Section V.c. below).

b. Jobs

Creating thousands of solar installations in rural areas would be part of a fundamental technical restructuring of the electricity system to accommodate hundreds of thousands of solar generating on rooftops, variable electricity supply sources, storage devices, and the integration of solar with much larger scale wind resources. In addition, the business model of the utilities would have to be changed to accommodate the large numbers of consumers who would also become electricity producers. The details are beyond the scope of the present report; there are many publications that have discussed such transitions. A detailed technical-economic roadmap for Maryland can be found in a set of publications of the Institute for Energy and Environmental Research.[56]

The focus in this report is on farmland and rural communities. The development of solar power on the order of ten thousand megawatts in rural areas over the next twenty years would give a significant boost to the economies of the rural areas and counties of the state. Currently, Maryland imports about 40% of its electricity generation, exporting a good deal of money to the places where that electricity is generated. Generating more of it within the state would keep that money within the state, increasing its domestic economic output and the jobs that go with it.

Construction of 10,000 MW of ground-mounted solar in rural areas of Maryland by 2040 in the 100% renewable electricity scenario by 2040 would create about 2,400 steady jobs in the United States. Most of these jobs are associated with the construction and design of the plants and associated activities and are therefore local to the area where the solar is designed and built. There would be an additional 3,000 jobs in operating and maintaining the solar installations on farmland when the capacity is fully built.[57]

Sargent 2015, pp. 5-6. We assume that distributed solar of 2 MW or less would continue to be compensated at rates comparable to net metering even if the net metering policy is changed.

[56] IEER 2015 to 2018.

[57] Job estimates based on Makhijani 2016. See Tables X-1 and X-2 (pp. 196-197) and the associated text. Steady jobs are calculated by first calculating "job-years" – the total number of full-time workers (in all categories) multiplied by the number of years it would take to complete the work being estimated. In this case, the estimates are for 10,000 MW of solar capacity, amounting to 40,000 job-years. Since this would be done over 20 years, the number of steady jobs is estimated at 2,000. The maintenance jobs increase steadily proportional to capacity. The construction jobs do not disappear with completion of construction if it is properly spaced. Construction over a 20-

Two major categories of jobs are involved: the first includes design and construction and all the activities associated with that. The second involves operating and maintaining the solar installations. Many of the operations and maintenance (O&M) jobs normally involve activities such as mowing to keep the vegetation in check. In the farm-centered solar analyzed in this report, many of these jobs would actually be farm-related such as rotational sheep grazing which would displace much or all of the mowing maintenance, and planting and harvesting other crops suitable to the specific solar plant being designed.

Figure IV-1 shows the growth of jobs in the scenario where solar on farmland would supply about a quarter of the state's electricity requirements by 2040. As noted, the pace of solar development in Maryland in this scenario would be about double Maryland's present legislated target of 14.5% of electricity sales by 2030. The jobs shown in Figure IV-1 would approximately level off or possibly slightly decline after the transition to renewable electricity is complete in 2040. O&M jobs would remain about the same, because solar capacity would level off. Construction jobs would continue to the extent that solar panels are replaced. There would be added jobs in decommissioning to the extent that that occurs; new solar construction would be needed to replace the decommissioned solar installations.

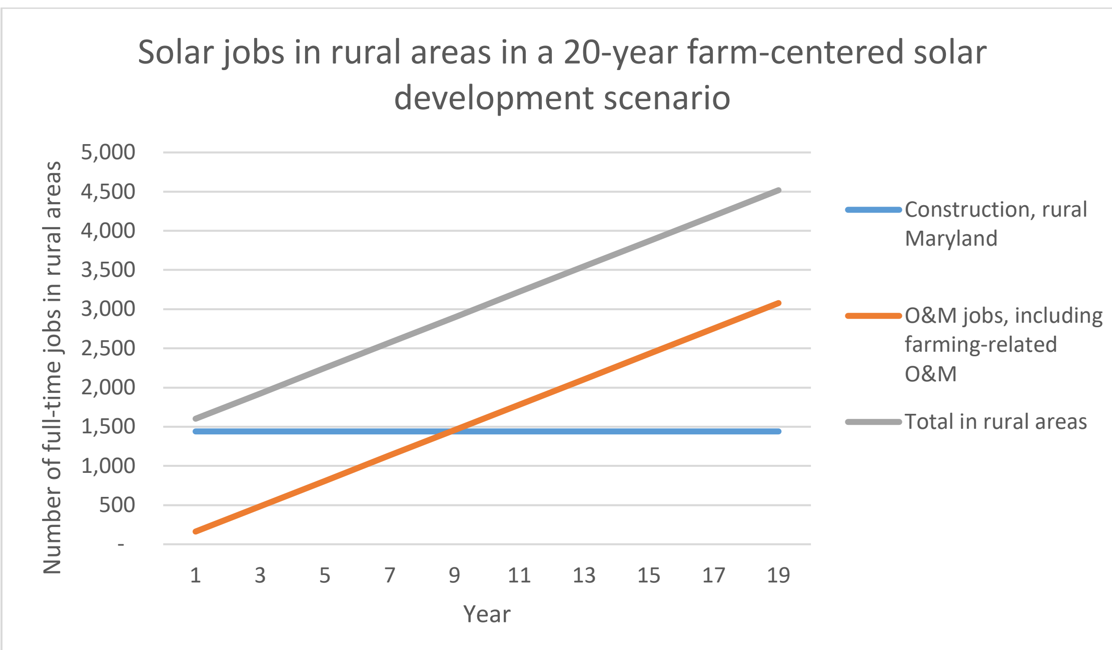

Figure IV-1: Growth of steady jobs as a result of development of 10,000 MW-ac of solar on in Maryland farmland over a 20-year period
Source: IEER calculations based on Tables X-1 and X-2 in Makhijani 2016

to 25-year period would mean that some plants built in the earlier part of the solar program would need to be retired and replaced. If they are completely retired there would be decommissioning jobs. Costs of decommissioning have been included; the associated jobs are not estimated here.

A joint food, agriculture, energy, and climate policy would include development of the infrastructure for the more diverse agriculture, as for instance in processing of sheep and lambs, wool production (in case grazing for that purpose is pursued on a significant scale, and more farm to table market opportunities. All these areas imply additional job creation in the state's rural areas.

Finally, there is a larger energy system transformation implicit in a transition to an electricity system based mainly on solar and wind energy. It involves the development of a smart grid – which entails, among other things, building a communication system in parallel with the electricity system – an electric transportation infrastructure, a fundamental upgrade of the distribution system, and an electrification of existing buildings. All of these aspects would mean more jobs in rural areas as well as in suburban and urban areas throughout the state.

c. Types of farming on solar farmland

The potential for using the land on which a solar photovoltaic installation is built for a variety of farming types and outputs has already been demonstrated – and that variety is growing as experimentation and demonstration continues. Much of the impetus for this experimentation has come from reasonable concerns that ground-mounted solar installations in agricultural areas would reduce the land available for food, feed, and fiber production. These apprehensions were well-founded in the examples where the land acquired for solar installations was simply covered with gravel or planted with shallow-rooted grasses, controlled by mowing and herbicides. Zoning restrictions and public opposition set the stage for the creativity that has shown that farming, food, production, and solar electricity generation can be successfully joined.[58]

The obvious should first be noted: not all types of farming can be done on the land of a solar installation at the present time. Specifically, commodity row crop, like corn, would require panels to be mounted at heights far greater than normal, increasing solar costs significantly.[59] Within this limitation, solar installation land can be used for a variety of agricultural, horticultural, apicultural, and grazing uses and even combinations of these uses.

The field of farming activities on solar farmland is still relatively new, especially in the United States. The following is a list of practices found in various places around the world, including the United States:

- **Pollinator-friendly planting, including under the panels.** Official pollinator-friendly scoring systems and designations have been developed in several states to ensure that minimum environmental criteria are met.[60]

[58] While this report is focused on solar as the renewable energy resource, the same general considerations apply to wind-generated electricity.
[59] The Fraunhofer Institute has been experimenting with solar panels mounted very high to enable all kinds of agriculture underneath. One initiative will experiment with growing apple trees on a solar farm. Scully 2020.
[60] Pollinator Scorecard 2019

- **Grazing sheep** reduces mowing, a normal maintenance requirement on solar installations; grazing on solar installations has been common in the UK for many years, and is spreading rapidly in some parts of the United States;[61]
- **Combined grazing and pollinator-friendly planting:** Specific mixes of pollinator friendly plants suitable for grazing sheep can be combined, such as the trade-marked mix of seeds known as Fuzz & Buzz™ marketed by Ernst Conservation Seeds;
- **Other livestock:** Cattle can be grazed on solar installations, though this requires raising the panels or installing them in a vertical configuration; raising poultry in movable coops is another option.
- **Horticulture:** (see Figure II-2 in Section II.a.) – Vegetables, flowers, etc. could be grown; in this case panels have to be raised somewhat, increasing solar cost, but providing high-value food output.[62] Dual-axis solar installations, which are normally installed on nine or ten foot poles, even when there is no agriculture, may provide another approach to solar implementation that is amenable to a wider range of farming activities.
- **Mushrooms** – they are suited to shade; an example: a 4-megawatt solar installation in Japan also grows 40 tons of cloud-ear mushrooms;[63]
- **Saffron** – the Center for Saffron Research & Development at the University of Vermont has started an experiment growing saffron – crocus flowers – on a solar installation.[64]

Combining solar with farming activities in systematic ways has come to the fore as the need for land for economical solar development has grown. To some extent, construction of large-scale solar installations in ways that have been destructive of the land's agricultural value has provided much of the impetus for the development of agrivoltaics. Much research, development, and experimentation remains to be done. The varieties of crops that can be grown profitably will likely expand in the coming years. Reduction of the cost of raising panels and consideration of the joint economics of selling farm products and electricity (as in the case of the solar vegetable farming mentioned above) will create new opportunities. Some of them will also arise from the considerations that have come to the fore during

[61] Examples can be found on the website of the American Solar Grazing Association, solargrazing.org. Cattle grazing may require raising the panels. In that case, considerations similar to joining vegetable cultivation with solar would apply: solar would be higher cost due to greater structure costs; these costs could be offset by revenues from grazing cattle.

[62] Ryan 2017. This experimental solar farm in Massachusetts grows "kale, Swiss chard, lettuce, beans, broccoli and peppers." Yields of some plants during the dry year, 2016, were higher than the control plot with no panels, but not for others. Herbert 2018. Simulations of agrivoltaic vegetable cultivation with various configurations of solar installation (ground-mounted but spaced out, stilt mounted at two panel densities) show that optimization of commercial horticulture and solar is complex and depends on whether there is net-metering, the specific solar configuration, and the vegetable yields to be expected in each specific case; lettuce cultivation was modeled. Dinesh and Pearce 2016.

[63] Peters 2017.

[64] Ludt 2019.

the COVID-19 pandemic: shortening food supply chains, producing more food locally, and more production aimed at farm-to-table marketing.[65]

New technical developments aimed specifically at agrivoltaics will likely smooth the way. For instance, one experiment is using semi-transparent solar panels, which absorb shorter wavelengths of sunlight (blue, violet) and let the orange and red through for the plants below. Electricity and plant production were both somewhat diminished but the combined value of solar + spinach and solar + basil was higher.[66] The East-West vertical panel configuration (see Figure II-4 in Chapter II above) may help expand the economic potential. The specific economics of balancing any increased cost of the solar installation with the agricultural output on the same land depends on many factors, including climate, soil, and the specific crops involved. Such a balancing would probably be less complex if the farm operation owned the solar, so that the costs and revenues from both can be optimized by the same party. Solar shade can also increase resilience, as an Arizona example shows:

> Agrivoltaics probably won't be feasible for large-scale, single-crop farms that rely on heavy machinery. But preliminary results already suggest it can significantly boost the yields of certain plants in hotter-than-average years. At the Arizona site, cherry tomato yields are doubled and require less water when grown in the shade of solar panels.
>
> …
>
> Agrivoltaics could help offset the impacts of extreme weather by reducing water use, increasing food yields, and limiting the negative effects of heat on solar panels.
>
> Low-impact solar development does require additional up-front planning and expenditures, but—according to the data gathered by InSPIRE researchers so far—offers surprisingly robust benefits over time. [67]

"Solar grazing," as it has come to be known, is often contracted out by the owner or operator of the solar farm to a sheep-raising operation. The latter brings the sheep, manages the grazing, gets the use of the land, and gets paid for the service. The solar installation owner has reduced maintenance costs since mowing is greatly reduced or eliminated. The business has grown so much in recent years that an industry association has been established – the American Solar Grazing Association, which has published generic contracts for interested parties.[68]

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[65] The varied opportunities for agrivoltaics – and an indication of how new the field is – are illustrated by a recent research paper examining how solar generation on farmland might enable joint management of groundwater resources where such resources are stressed, food production, and CO_2 emission reductions. Parkinson and Hunt 2020.

[66] Thompson et al. 2020.

[67] NREL InSPIRE 2020. "InSPIRE" stands for "Innovative Site Preparation and Impact Reductions on the Environment."

[68] Two sample generic contracts ("Comprehensive Vegetation Management Approach" and "Limited Vegetation Management Approach") can be downloaded free at https://solargrazing.org/contract/ ; viewed on 2020-08-10.

Some added investment is needed to join solar with farming. For instance, solar grazing with sheep requires an investment in water supply for the sheep. If grazing is to be compatible with healthy soils practices, provision for movable fencing must be made to enable rotational grazing.

Solar sheep grazing can be profitable. According to a solar grazier, in a well-managed solar grazing operation in the Northeast, the sheep owner is paid $400 to $600 per acre to graze a solar installation. Profits and costs are quite variable, depending on the number of lambs per ewe (in turn several factors, including genetics), the location of the solar installations, etc. Gross margins could be in the $500 to $600 per acre range, based on the experience of one solar grazier.[69] However, fees paid to the grazier may vary, as may the costs of grazing, depending on the size and location of the solar installation. Raising sheep, like so much other farming, can be a precarious business. The main point in this context is that solar grazing pays the owner of the sheep for land access, creating new possibilities, while reducing or at least not increasing solar photovoltaic operating and maintenance costs.

Maryland produces very little of the lamb and mutton consumed in the state. Production is on the order of 700,000 pounds per year in 2017. Consumption is roughly ten times higher, based on national average data.[70] Thus, there is plenty of scope to expand lamb production and sheep grazing in Maryland. Were all lamb and mutton to be produced on solar grazing installations, there would be room for about 120,000 additional sheep; at a stocking rate of 3 ewes per acre, the farm area would be 40,000 acres. This is an order of magnitude estimate as stocking rates can vary.

d. Equity and land

Requiring agricultural production when solar installations are built on farmland can make an important contribution to promoting farming as a profession and to equity in access to land. The key is that the solar owner/developer must ensure the proper use of the land in accord with applicable laws and regulations. When farming-related activities are required, new farmers could get access to that land in those cases where the landowners of current lessee do not want to carry out the agricultural activities on the solar land themselves. There is only a moderate amount of experience in this area in relation to solar grazing. The emerging model is that the solar land is contracted to third party solar graziers who have specific maintenance responsibilities in return for the right to graze their sheep and receive a payment for it.[71]

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[69] Estimates are from Lewis Fox, 2020 (personal email communication) using 1.8 lambs per ewe, 3 ewes per acres and $2 per pound of live weight for lambs = $150/lamb sold at the New Holland auction in Pennsylvania.
[70] Assuming 50 pounds per animal (mix of sheep and lambs). 14,110 lambs and sheep were sold in 2017. The inventory was 23,399. Census of Agriculture for Maryland 2017, Table 71. Production based on 50 pounds carcass weight average over all sheep and lambs. Consumption of lamb and mutton in the United States in 2017 was 1.1 pound per person per year. Statista 2019. On this basis, Maryland's consumption would be on the order of 7 million pounds per year. The national picture is similar – the United States imports about three-fourths of the lamb and mutton consumed – 2019 estimates based on USDA import-export data: USDA Trade 2020.
[71] ASGA Contract

It is no secret that the average age of farmers has been rising. In Maryland, the average age of principal operators in 2017 was 58.8 years.[72] The cost of land is a principal, if not the largest, barrier to entry for young farmers.[73] Further, there are deep inequities in land ownership that have intensified over the decades with Black and Indigenous farmers losing and/or being deprived of most of their land. The 1910 Census enumerated 6,372 African-American farmers[74] who owned or sharecropped 358,500 acres of farmland, about a third of which, 122,000 acres, were owned.[75] By 2017, there were just 203 African-American farms on 8,822 acres, or only about 2.5% of the land African-Americans owned and operated in 1910. The corresponding figures for Indigenous farmers in 2017 were just 51 farms and 1,867 acres, a result of intense and longstanding historical injustice.

The historical issues are compounded by well-known inequities in wealth. Thus, along with young people, especially those burdened by student debt, the barriers to purchase of land are immense; even leasing land under these circumstances can be difficult.

If agricultural production were required of solar installations on farmland, granting access to that land for those activities would become a normal part of the development and operation of the solar installation in those cases where the landowner or lessee does not want to engage in the activity on the solar land. The solar grazing business has become so standardized that generic contracts are available online to guide the parties.[76] The solar owners/developers benefit because their maintenance expenses are reduced; sheep owners benefit because they get long-term access to farmland they do not own. Landowners benefit from lease revenues, and even more if they own the solar (2 megawatts or less).

Other parts of the business of farming also require investment of course, but land is the most expensive one by far. The development of agrivoltaics as part of a renewable energy transition *could* provide an important opportunity for new generations of farmers in those cases where the landowners or lessees do not themselves want to carry out the agricultural activities on solar installation land. It will take effort, investment, and prioritization of a redress of historical injustices in public policy to accomplish that. Having 80,000 acres of solar on farmland, more than seven times the amount of land owned or operated by Black and Indigenous farmers in 2017, only indicates the possibility. A number of issues will still remain to be addressed, including access to capital, priorities for access, and a host of technical matters such as land for buildings and access to markets. Dual-use solar opens up possibilities; it will take more work to realize them. There could also be increased farming opportunities for other people of color in rural Maryland.

Solar jobs would pay more than is typical for agricultural work. In 2019, the mid-level wage for an unlicensed solar installer was $23 per hour; it was $28 per hour for a licensed installer; [77] these are 62%

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[72] Census of Agriculture for Maryland 2017, Table 52, pdf p. 54.
[73] Manning 2019
[74] The term employed in the Census at that time was "Colored." It is unclear to this author whether Indigenous farmers were included in this term.
[75] Census 1910, Chapter 3.
[76] ASGA Contract
[77] Solar Foundation 2020, Table 9, p. 36

and 95% higher (respectively) than the $14.30 hourly median wage for farmworkers and agricultural laborers in Maryland as of May 2019.[78]

e. Soil health

On a farm with a solar photovoltaic installation on a fraction of its land, there are two distinct areas of soil health to be considered:

- The health of the soil on the part of the farm used for the solar installation during its lifetime and after it;
- The incentivization of healthy soils practices on the rest of the farm as a result of public investment.

As was discussed in Chapter II, the actual construction footprint of a solar installation is a very small fraction of the area needed to collect the energy – generally 2% or less. Taking into account land for fencing and other uses, on the order of 95 percent of the solar installation land would generally be available for farming activities. The fraction would vary depending on factors such as topography and the specifics of the solar construction and agricultural activity.

What about soil health and its indicators like soil organic matter and biological diversity? Can the health of the soil of a solar installation be maintained or even improved so that a full range of productive farming, including commodity crops, could be grown after the solar installation is decommissioned?

A part of the answer depends, of course, on the initial health of the soil and use of the land. If an area that has been undisturbed forest for decades is cleared for solar photovoltaics, it is likely to degrade, even if good soil health practices are used. That is one important reason not to clear forests for solar. Land, including prime farmland, that has long been in conventional farming with tillage and heavy use of synthetic fertilizers and pesticides is a different matter. The improvement of the health of such soil is a matter of widespread concern, activity and investment, as exemplified, for instance, by Maryland's cover crop program.[79] In such cases, the answer can be positive, though it will, in general, not be automatically so.

The Natural Resource Conservation Service defines the foundation of soil health according to five principles: "soil armor, minimizing soil disturbance, plant diversity, continual live plant/root, and livestock integration."[80] Solar installations are generally not tilled. As a result, the criterion of minimizing soil disturbance is automatically satisfied. When planted with native pollinator-friendly species or other pasture and forage crops, permanent cover can be maintained with plant diversity. With rotational sheep grazing on suitable diverse pollinator species, all five of NRCS's soil health principles would be fulfilled.

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[78] Bureau of Labor Statistics 2019, job classification 45-2092. The range for various agricultural occupations involving field work is $12.65 to $18.21 per hour (excluding supervisory categories).
[79] Maryland Cover Crops 2020
[80] NRCS Soil Health, viewed on May 6, 2020

Solar grazing practice appears to conform to healthy soil principles. There are "[s]mall bald spots…but overall good grazing practices mean close to 100% vegetative cover," according to a professional solar grazier and co-founder of the American Solar Grazing Association, Lexie Hain. She further states that "[s]ynthetic fertilizers and pesticides" are used in much smaller amounts "than in commodity crop farming…and MUCH less often." The occasional use of pesticides consists of "spot spraying of invasive weeds…."[81] As discussed below, when well-managed, there is every reason to expect improved soil health with solar grazing, as measured by indicators such as soil organic matter, as compared with industrial commodity crop farming with tillage and use of synthetic chemicals.

An increase in soil health is neither automatic or guaranteed. For instance, grazing needs to be rotational if soil armor and continual live plants and roots are to be maintained. This requires an investment in movable fencing and watering systems, and in the labor needed to move the sheep every day or every few days.

Given that the systematic establishment of vegetation and its management on solar sites is a recent phenomenon in the United States, data on improvement of key soil health indicators for subsequent agricultural use – soil organic carbon and soil biological activity – is limited. Typically, reliable data for significant changes to these indicators take a few years or more of measurements. Cornell University started a research program on its own research farm including solar (rotational) grazing and pollinators in 2017. Prior to the solar installation, the field had been planted with wheat and legume cover crops. After the solar installation, the site was suitably reseeded; in addition, there were volunteer plants that provided good forage.[82] Measurements on soil organic matter have been made; however, there has not been enough time to develop a long-term set of soil sampling data for reliable conclusions:

> A soil sample was collected and tested on January 20th, 2015. The sample contained low phosphorous, medium potassium, and very high calcium and magnesium levels. The soil pH was 7.5 and the organic matter content 4.5%. The soil sample drawn after a season of sheep grazing on November 16th, 2018 had pH of 7.6 and an organic matter of 6.6%. However, due to the limited duration of the grazing trial (1 grazing season), we cannot conclude that sheep grazing increased soil organic matter.[83]

The Cornell report recommended the following research program for the United States:

> Future studies are needed to assess long term impacts like soil response and pasture quality, and the effects of grazing on pollinator plants or invasive species. A broad variety of soil quality indicators should be measured, such as soil organic carbon sequestration and the possibility of creating carbon sinks through grazing, soil nitrogen responses, and changes in bulk densities. Herbicide use and run-off in traditional vegetation management systems on solar sites should be investigated. The suitability for co-locating grazing with pollinators by the enhancement of pollinator plant species, effective grazing management, and control of invasive species should be explored. An important question for the successful management of solar sites with sheep will be

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[81] Lexie Hain, personal email communication with Arjun Makhijani, 2020-10-27, cited with permission. Caps in the original.
[82] Kocehndoerfer, Hain, and Thonney 2018, p.2.
[83] Kochendoefer, Hain, and Thonney 2018, p. 2

> determining what stocking rates and densities should be chosen. Future research is needed to establish sound recommendations.[84]

However, we do not have to wait for evidence from U.S. research to conclude that ecological and soil benefits can be achieved on solar photovoltaic installations, if they are well-managed. As noted, basic management practices for solar grazing, if the right vegetation is planted, if it is well maintained, and if grazing is rotational, in fact adhere to all five soil health principles.

There is substantial experimental data on the benefits of rotational grazing outside the context of solar photovoltaic installation for increasing soil organic matter, preventing erosion, and reducing runoff.[85] The practice is management intensive – moving animals frequently, including the fencing and water supply; careful observation of pasture regrowth at different times of the year to enable better root growth, etc. Long periods of rest are needed for forage to recover before grazing can be resumed (hence the need for movable fences). Solar grazing practices for healthy soils are no different (see the photographs in Chapter II). The results of the failure to intensively manage soils would also be no different – degraded soils.

Machmuller et al. found that intensive grazing management could result in dramatic increases in soil carbon on degraded lands:

> In a region of extensive soil degradation in the southeastern United States, we evaluated soil C accumulation for 3 years across a 7-year chronosequence of three farms converted to management-intensive grazing. Here we show that these farms accumulated C at 8.0 Mg $ha^{-1}yr^{-1}$, increasing cation exchange and water holding capacity by 95% and 34%, respectively. Thus, within a decade of management-intensive grazing practices soil C levels returned to those of native forest soils, and likely decreased fertilizer and irrigation demands. [86]

Similarly, in a long 22 year experiment, which did not include grazing, Yang et al. found that with the right type of management, planting mixed species grasses can accelerate the increase of soil organic matter and restore degraded lands:

> Agriculturally degraded and abandoned lands can remove atmospheric CO2 and sequester it as soil organic matter during natural succession. However, this process may be slow, requiring a century or longer to re-attain pre-agricultural soil carbon levels. Here, we find that restoration of late-successional grassland plant diversity leads to accelerating annual carbon storage rates that, by the second period (years 13–22), are 200% greater in our highest diversity treatment than during succession at this site, and 70% greater than in monocultures.[87]

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[84] Kochendoefer, Hain, and Thonney 2018, p. 6. Cornell is carrying out a comprehensive research project on solar grazing.
[85] NRCS Soil Secrets 2016
[86] Machmuller et al. 2015
[87] Yang et al. 2019

Coincidentally, the period of this experiment, 22 years, is about the same as a typical solar lease of 20 to 25 years.

Britain has longer experience with agrivoltaic practices and their ecological benefits in terms of biodiversity. A 2016 study compared 11 solar sites that had a variety of practices including pollinator-friendly plants and conservation grazing with control plots just outside the solar arrays. Eight of the 11 sites had sheep grazing on them; the number of sheep is specified for only two of them, which had about 100 sheep. Economic data relating to the grazing are not provided in this survey. The control plots had been part of the same farm and under the same management prior to construction of the solar arrays. The study found consistently greater biodiversity on the solar farms:

> The results of the botanical surveys revealed that overall, solar farms had greater diversity than control plots, and this was especially the case for broadleaved plants. This greater diversity was partly the result of re-seeding of solar farms: where species-rich wild flower mixes had been sown this diversity was greater, but even where agricultural grass mixes had been used diversity was greater as compared to the largely arable control plots.[88]

While the specifics of the biodiversity increase varied, there were consistent overall increases compared to the controls, conservation grazing further increased plant diversity. It should be noted that the study did not find increases for every species compared to controls; some species were not significantly different on solar farms and control plots. The areas of biodiversity measurements included botanical diversity, birds, bees, and butterflies.

There is also research for other types of agriculture and the ways of combining farm profits, renewable energy generation, and ecosystem benefits. Several U.S. national laboratories have created a program called the Innovative Site Preparation and Impact Reductions on the Environment, the InSPIRE project, to explore "the benefits of—and barriers to—low-impact solar development." These include:

- The deep roots of native vegetation….help retain topsoil and improve soil health over time, even in "brownfield" areas with polluted soils. "
- …native and flowering vegetation provides a habitat for native species, especially pollinators and other beneficial insects *that can improve yields at nearby farms*.
- The low-impact approach also benefits solar developers….Native vegetation, if selected appropriately, also requires less ongoing maintenance than traditional gravel or turf grass approaches, as there is less of a need for mowing or spraying.[89]

The areas of agriculture that the InSPIRE program is researching in combination with solar include beekeeping, agriculture, native vegetation, beneficial predators, dryland agriculture, greenhouses with solar, and pollinator habitat.

The crop-solar colocation includes three sites – one each in Massachusetts, Arizona, and Oregon. One remarkable preliminary finding was that yield can increase under certain circumstances. Specifically, in hotter years in Arizona "cherry tomato yields are *doubled and require less water when grown in the*

[88] Montag, Parker, and Clarkson 2016
[89] Quoted from NREL InSPIRE 2020; italics added.

shade of solar panels." In addition, the "shading and increased evaporation provided by a healthy layer of undergrowth can actually cool solar panels, increasing their energy output."[90]

A 2019 paper in *Nature Sustainability* noted broad synergies between solar development and ecosystems, including those where food is grown. In a summary of the paper, its principal author noted the following regarding food systems and solar:

> The [*Nature Sustainability*] paper also highlights food systems as an opportunity for solar techno-ecological synergies. The authors identified 10 potential beneficial outcomes of "agrivoltaic systems," or panels placed within the same land area as agricultural production. These benefits include increased foraging resources for managed and native pollinators, increased water-use efficiency and soil erosion prevention. Solar energy infrastructure can also alter microclimatic conditions that benefit overall crop production with increased water use efficiency, and keep PV systems cooler and operating more efficiently. *Co-siting agriculture and PV systems also results in higher yields of food and solar energy combined compared to when the food and solar energy production were separate*.[91]

Modeling also indicates very substantial benefits. An evaluation of 30 solar sites in the Midwestern United States indicates important increases in ecosystem services when native grasslands are restored and replace conventional monoculture crops. The estimated ecosystem benefits provided by these 30 solar installations so re-vegetated include:[92]

- A 65% increase in carbon sequestration potential, with the long-term sequestration increase estimated at more than 1.5 million tons of carbon (more than 5.5 million tons of CO_2);
- A decrease in erosion (increase in sediment retention) by 46 times;
- An increase in water retention of 19%;
- A tripling of pollinators.

There is still much to be discovered. For example, transparent tinted panels could be used instead of the usual opaque panels that cast a shadow. In an experiment with such panels, researchers found that the overall plant biomass under the panels declined somewhat (varying by plant) but that the above-ground biomass – the mass of basil and spinach leaves and stems – actually increased compared to plants under completely transparent panels. Another important finding was the both the basil and spinach grown under the tinted solar panels had higher protein content compared to the controls (14% and 53% respectively).[93] The decline in root mass is, of course, the bad news aspect of this experiment. There are, as yet, no reported results on fruiting plants.

Yet, we know enough to proceed with suitable protections in the direction of joining solar energy and ground-mounted solar on agricultural land. The most established food systems-solar connection so far is grazing sheep rotationally on solar installation farmland and pollinator-friendly mixes.

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[90] NREL InSPIRE 2020

[91] Hernandez 2019; italics added. The full article is Hernandez et al. 2019.

[92] Walston et al. 2021. See particularly Table 5, which shows how benefits increase over time.

[93] Bryce 2020. The transparent panels were used to provide the same physical conditions in all respects, such as rainfall, other than sunlight.

V. Policy considerations

The goal of this report is to explore whether ground-mounted solar development on agricultural land can be made compatible with protecting land for food, feed, and fiber production, improving soil health, and increasing farm operation profitability. In addition, the report examines opportunities for incentivizing healthy soils practices more widely, based on support for farm-oriented solar. *The clean energy attributes of solar farmland are viewed as collateral benefits of achieving farm-related objectives rather than as a starting point for energy-related objectives.*

The analysis in the forgoing chapters indicates that these objectives can be simultaneously achieved, but that it will take suitable policies and incentives to ensure that it happens. In their absence ground-mounted solar installations can have, and often have had, poor outcomes for the soil. There are clear reasons to expect adverse outcomes for the land without intentional efforts to ensure good ones:

- **Profits**: Companies that build large-scale (or any scale) solar are generally profit-making enterprises that have obligations in regard to the lenders and shareholders. They will therefore locate solar installations at sites where a combination of lower costs and higher prices produces the largest returns.
- **Interconnection points**: While rooftop solar is connected to the grid at the location of the rooftop, larger-scale ground-mounted systems generally require some investment for the connection to the nearest suitable point on the electricity grid. Thus, in the absence of protective policy, if a solar developer can lease agricultural land close to the grid, and the owner is willing, there are powerful incentives for both parties to do it, despite any other considerations. It should also be noted that the costs and delays that could occur at longer distances from the grid connection points can make projects uneconomical.
- **Maintenance costs**: Solar installations are often planted with turf, which is controlled by chemicals and mowing, or covered with gravel. This keeps down maintenance costs but damages the soil and adversely impacts biodiversity.
- **Landowners and lessees**: Revenues from leasing land for large-scale solar development can range from $500 per acre per year to $2,000 per acre per year. This is essentially risk-free money to the landowner, who need not borrow money for seeds, equipment, etc. or have revenues fluctuate with the vagaries of commodity markets. The average rent for land in Maryland in 2017, consisting mainly of a mix of crop production and grazing, was $75 per acre.[94] Leasing land for solar would be especially attractive to non-operating landowners who rent their land but could adversely impact farmers who lease all or most of their land.

a. Context

Ground-mounted solar electricity installations and agriculture are not the only possible uses of land. Specifically, agricultural land near urban areas is under frequent pressure for conversion to urban or low density residential development. Between 2001 and 2016, 30,200 acres of Maryland's agricultural land were converted into the "highly developed and urban land use" category and another 72,600 acres were converted to "low-density residential" use, for a total of 102,800 acres, according to the State of the

[94] Calculated from Tables 4 and 53 in Census of Agriculture Maryland 2017: the total rent for land, including buildings was $61.6 million; the area of land leased was 822,550 acres (based on farming decision authority). Lease payments tend to be larger when the land is used for growing crops compared to grazing. Lease rates vary around this average, depending on location and use of the land.

States survey by American Farmland Trust. This amounts to about 4.3% of the agricultural land examined by the report.[95] For perspective, the total land lost to development in the 15-year period examined in that report is over 25% greater than the ground-mounted solar land area of 80,000 acres*; the land lost to development more than 64 times the construction footprint of that solar.*[96]

Development pressures arise mainly from the much larger revenues that urban and suburban development can bring. The average value of cropland in Maryland in 2019 was $7,370 per acre; pastureland value was $6,580 per acre in the year 2017.[97] An acre in a high-land-value suburban area in Maryland can be worth twenty, fifty, or even a hundred times these agricultural land prices. Such high values for development depend on "location, location, location," as the well-known real estate aphorism has it. Development pressures on land, including prime farmland, arise from that same observation. Well-located land has much higher money values as buildings and blacktop, even as those very uses undermine agricultural production capacity and harm the environment in various ways, described, for instance, by Yale University's Seto Lab:

> The conversion of Earth's land surface to urban uses is one of the most irreversible human impacts on the global biosphere. It hastens the loss of highly productive farmland, affects energy demand, alters the climate, modifies hydrologic and biogeochemical cycles, fragments habitats, and reduces biodiversity….
>
> The environmental impacts of urban expansion reach far beyond urban areas themselves….Urban expansion will affect global climate as well. Direct loss in vegetation biomass from areas with high probability of urban expansion is predicted to contribute about 5% of total emissions from tropical deforestation and land-use change.[98]

Ground-mounted solar can provide revenue streams per unit of land valued between urban/suburban development and use for commodity crops.[99] Solar photovoltaics would generate almost $30,000 worth of electricity per acre per year;[100] a farm in commodity crops, which account for most of the harvested land in Maryland, would typically generate gross revenues under $1,000 per acre. As a result, typical lease revenues from solar are usually far greater than the typical rent obtained for agricultural uses. Such economic considerations provide an opportunity for solar to help keep land that is under

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[95] AFT 2020, Appendix III, p. 63

[96] The renewable energy assumptions are: 50% each for wind and solar and half of solar, or 25% of total electricity generation, from ground-mounted installations.

[97] NASS 2019, p. 10 and p. 14. Pastureland values for 2018 and 2019 were "Withheld to avoid disclosing data for individual operations." (p. 15)

[98] Seto Lab, no date. Reference list implies 2017. See also Bren d'Amour et al. 2017, which is one of the Seto Lab's publications.

[99] There is a large gap in per acre gross revenues between commodity crop gross revenues on the one hand and (generally small) intensive vegetable and flower farms; the latter can have gross revenues in the tens of thousands of dollars per acre, which is the same order of magnitude as the retail value of electricity per acre.

[100] Calculated using an average generation of 2,050 MWh/MW-ac, 8 acres per MW-ac and an average 2018 retail price of electricity for all sectors in Maryland $115.7 per MWh, obtained from the Maryland State Electricity Profile, Table 8. The value of retail electricity varies across the state, depending on the utility serving a particular area.

development pressure rural, *provided there are requirements in place to keep the solar land in farming activities.* However, it is important in this context to protect leaseholders, as noted above.

b. Creating farm-centered solar

Solar siting on farmland has been (and is) often viewed as a withdrawal of food, feed, and fiber producing land from agricultural uses. Without constraints, this has indeed often been the case. But this does not have to be so.. Co-location of a variety of farming activities and solar has been sufficiently demonstrated; the range of options is expanding with research. As discussed in the soil health section of Chapter IV (Section IV.e.), well-managed grazing of sheep on suitable pollinator-friendly mixes satisfies all five soil health principles. Solar grazing and other agricultural activities on solar installations are relatively recent developments in the US, but the evidence so far points in the direction that well-managed farming activities, notably rotational solar grazing, can be expected to improve soil health, especially on land that has previously been tilled and used for industrial commodity crop production.

Well-managed dual use of farmland solar can, with the right policies and incentives, preserve land in agricultural production, improve soil health, and increase farm profitability and resilience. This prospect puts a different cast on how one might regard solar on farmland. Solar photovoltaics have generally been viewed through the lens of renewable energy and mitigation of CO_2 emissions from the energy system. The lower cost of ground-mounted solar compared to roof-mounted installations and inattention to potential land use values has led to a view that food-related land values are in conflict with values related to mitigation of emissions from the energy system. Examples of solar installations that have, in fact, destroyed agricultural land values have provided fodder for this view.

Attempts have been made to reconcile the value of both systems. For instance, Minnesota law encourages pollinator-friendly plants and native perennial vegetation on all but the smallest ground-mounted installations:

> An owner of a ground-mounted solar site with a generating capacity of more than 40 kilowatts may follow site management practices that (1) provide native perennial vegetation and foraging habitat beneficial to gamebirds, songbirds, and pollinators, and (2) reduce storm water runoff and erosion at the solar generation site. To the extent practicable, when establishing perennial vegetation and beneficial foraging habitat, a solar site owner shall use native plant species and seed mixes under Department of Natural Resources "Prairie Establishment and Maintenance Technical Guidance for Solar Projects.[101]

Maryland has similar guidance,[102] inspired by the Minnesota law.

Some of the most thoughtful guidelines for joining farming and solar have been published by the American Farmland Trust, New England. Those guidelines advise priority for solar that is not on farmland, such as rooftop solar, solar canopies and solar installations on brownfields. They also state "that, with proper planning and siting, our agricultural lands can also play a meaningful role in hosting

[101] Minnesota Pollinator Bill 2016.
[102] Maryland Pollinator Friendly 2017.

solar energy while maintaining active and productive agriculture."[103] The emphasis is on dual use of the land:

> *Dual-use, also known as agrivoltaics, is the practice of co-locating solar photovoltaic panels on farmland in such a manner that primary agricultural activities including animal grazing, crop or vegetable production can continue simultaneously on that farmland*.[104]

The guidelines also have specific recommendations for solar on farmland as quoted below:

1. Other farmland and marginal farmland –these are preferred locations for on-farm siting if pursuing a standard ground-mounted solar array; consider dual-use if possible.
2. Actively farmed, unique, or farmland of statewide importance -incentivize dual-use to support continued agricultural activity.
3. Prime farmland - protection of prime soils and prime farmland should be prioritized. If solar projects are proposed on prime soils, they should be agricultural dual-use projects and should also undergo careful review to ensure continued production is prioritized.[105]

The priority for rooftop and other urban residential and commercial solar can be seen as another way of relieving pressure on farmland siting (for a given total amount of solar). In a largely or fully renewable electricity system, resilience will depend to a significant extent on distributed solar installations, including residential and commercial rooftop solar. Such solar, combined with storage can be arranged into microgrids, which can operate with the grid, but can also supply essential loads, such as grocery storage, community centers, and gas stations, during grid outages. Thus, energy considerations also indicate a mix of larger scale rural ground-mounted solar with urban and suburban rooftop and other distributed solar.

The analysis in this report indicates that the evolution of the food-fiber agricultural system and energy system should be considered together.

The COVID-19 pandemic has brought the structural issues in large-scale farming to the fore; they indicate a need for a more resilient and diverse food production system that also promotes healthier soils and provides broader regional ecological benefits. The Northeast Healthy Soils Network calls this a "bioregional" food system approach. Members of the network are

> working hard to develop the final three, interdependent factors of bioregional food system emergence:
>
> - Bioregional markets; food distribution networks to supportive consumer bases
> - Accessible food processing for smaller-scale, diversified farms
> - Government & public interest in investing in ecosystem service farming[106]

[103] AFT New England 2020
[104] AFT New England 2020; italics in the original.
[105] AFT New England 2020; the three points are directly quoted from the AFT guidelines.
[106] Quoted from Watson 2020

The food system, like the energy system, needs to be more distributed compared to the centralized systems that dominate in both areas at present. This would make both more economically and ecologically resilient in the face of challenges that are emerging on top of the normal turbulence that has resulted in frequent family farm economic distress and failure.

Millions of animals were euthanized in the first half of 2020 when large feeding operations (known as CAFOs) could not send their animals to centralized slaughterhouses; small custom local operations turned out to be more resilient when they had access to local slaughterhouses, an important caveat.[107] Small ranchers have been asking for state authority over licensing of slaughter houses for in-state meat sales; this would enable small-scale slaughter houses to operate profitably.[108] Such infrastructure could also become a part of integrating solar with post-COVID-19 farm and food system policy.

With the right incentives and requirements, solar on farmland can be consonant with food and fiber production and with preservation of farmland. Granted that the types of farming activities on solar land are more restricted, at least given the present state of both farming and solar, the range of potential farming types is still broad. Further, the total amount of land required for solar is, in any case, small relative to the total amount of farmland, when note is taken of the fact that a resilient renewable energy system will require a significant fraction of solar to be located in urban areas, including on rooftops, to achieve energy system resilience. Given the necessarily limited solar acreage, it would be a partial marriage of the food and energy systems, but one which could play an important role in reorienting the food system to be more local and resilient and making farming more profitable.

Substantial and secure solar profits from a small fraction of the land but comparable to or greater than commodity crop or grazing operation profits may also enable farmers who want to broaden their farming activities to do so without the risk of going out of business. In brief, with the right policies and investment in infrastructure and marketing, solar on a few percent of farmland could leverage a much broader and more secure food system change.

With incentives and a suitable regulatory framework, the health of the soil can be improved (see Section IV.e). The most important measures to ensure that food and solar on farmland are compatible would be to require the owner of the solar to conform to:

- Dual use of the land with a variety of options, including rotational grazing of sheep with pollinator-friendly seed mixes, beekeeping, growing chickens with movable coops, vegetable cultivation, etc.;
- Soil health improvement measured regularly (every three to five years) against a baseline established prior to construction;
- A decommissioning fund that is sufficient to enable complete decommissioning at the end of solar system operation (Section III.d. above);
- Suitable limitations on setbacks, slope, and erosion.

[107] Carman 2020
[108] Deist 2020

This approach to solar development will need support. The solar industry has had little overlap with the agricultural system, except through leasing of land, though that is changing, as, for instance, with the formation of organizations like the American Solar Grazing Association. Designing efficient and profitable grazing on solar installations requires careful consideration of the needs of the sheep, of seed mixes, water requirements, and the logistics of moving the sheep to achieve the soil health goals provided by rotational grazing. [109] Thus, policies for requiring dual use of solar installation land will need public investment in increasing the capacity of agricultural extension services to support the development of agrivoltaics..

Research and demonstration a significant area that needs support. The agrivoltaics arena is relatively new. The range of food and fiber products that could be profitably grown compatibly with solar could be expanded and tailored to the specifics of the land in question. This is a critical area for public investment in increasing the capacity of agricultural extension services.

A major policy issue regarding solar is the role of farmers who lease some or all of the land on which they farm. About 43% of farmland is leased or rented; however, most of this land is operated by farmers who also own some land. Thus, limiting the fraction of a farm operation in solar would protect the vast majority of farmers. Almost 800 farmers are listed in the 2017 agricultural census as “tenants”; they operate about 190,000 acres of land, for an average of about 240 acres per farm operation.[110]

A straightforward way to protect lessees from major impact would be to limit the fraction of any farm operation that could be in solar and the maximum acreage in solar. The recommendation in this report is that the maximum fraction should be 20% of a farm operation or 400 acres, whichever is smaller, with exemptions possible when circumstances warrant it. (see Section V.d below).[111] Lessees could also have the right of first refusal to carry out the agricultural activities planned on solar installation land. Finally, if young people and historically underserved communities are to avail themselves of the opportunity to have secure access to land, they will likely need support in the form of low-interest loans and technical and other material assistance.

The limitations on total size and fraction of a farm operation that can be in solar also accomplish other goals:

- They allow spreading out of solar profitability benefits over a large number of farms (see Section IV.a.).

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[109] Maryland law and regulations require control of eight noxious weeds: : Johnsongrass, Shattercane, Canada Thistle, Musk/Nodding Thistle, Plumeless Thistle, Bull Thistle, Palmer Amaranth, Tall Waterhemp. Maryland Weeds. Solar graziers, like other agriculturists, would have to control these weeds.

[110] Derived from data in Census of Agriculture for Maryland 2017, Table 53.

[111] The recommendation to limit the area of solar and the fraction of solar on any farm operation differs from the American Farmland Trust, New England recommendation that solar installation size on farmland not be limited when there is dual use. AFT New England 2020. The limitations recommended in this report are primarily oriented to protect lessees and to spread the benefits of solar to a large number of farms.

- Tourism is important to the economies of many rural areas of Maryland. Limiting the size of single installations, along with suitable siting incentives can help accommodate tourism related interests, while focusing on farm profits and healthy soils.

A 400-acre size limit is recommended here is large enough to capture economies of scale. For instance, the annual economic assessment of electricity technologies by the National Renewable Energy Laboratory uses 23 MW-dc as the capacity to evaluate utility-scale solar economics; the area needed would be in the 100- to 150-acre range. However, there may be circumstances where an exemption is warranted, such as those discussed in Section V.d below. While the 400-acre, 20% limits would generally apply, a solar developer could seek an exemption from these limits through the process of obtaining a Certificate of Public Convenience and Necessity (CPCN) by providing suitable reasons relating to the state's environmental, renewable energy, economic, or food system goals at the specific location in question.

c. Policies and Incentives

What kinds of policies and incentives would be needed to ensure the integration of farming and energy when solar is located on farmland? Society would benefit from such an integration; this provides the basis for public policy to create incentives to make sure it happens. Incentives are also appropriate when public policy goals might indicate preferential location of solar installations on certain parcels of land relative to others.[112]

For solar installations of more than 2 megawatts, the principal policy instrument can be the Certificate for Public Convenience and Necessity (CPCN). This is a certification required for almost every power plant above two megawatts. The certificates are issued by the Public Service Commission, which gets advice in its CPCN decision-making from other government agencies, including the Department of Agriculture. The advice of these government agencies is coordinated by the Power Plant Research Program of Department of Natural Resources.[113] The process of getting such a certificate is expensive and time-consuming. This is largely because it was designed for large fossil fuel and nuclear power plants, which generate millions of megawatt-hours (MWh) a year.[114] In contrast, a 5 MW-ac solar installation would generate about 10,000 MWh a year.[115]

Proposals for solar power plants on farmland of more than two megawatts that include pre-approved agricultural activities could have a simplified process of obtaining a CPCN. Government agencies weigh in on the CPCN process via the Power Plant Research Program of the Department of Natural Resources. Solar proposals with an approved dual-use plan would have a shorter, expedited route to a CPCN so far as government agency input was concerned.

A major incentive recommended here is a state investment tax credit corresponding to the increased

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[112] There are already restrictions on solar on conservation reserve land. We assume that they will remain in place.

[113] PSC 2019a, pdf p. 4. On-site generating stations from 2 to 25 MW that use 10% or more of the electricity onsite of 25 to 70 MW that use 80% or more of the electricity on site can apply for an exemption and get a much less onerous construction approval from the Public Service Commission. But few farm operations would be able to consume enough electricity onsite to qualify for the exemptions. Wind power plants up to 70 MW are exempted.

[114] The average electricity generation per power plant of the ten largest in Maryland was almost 4 million MWh/year in 2018, ranging from a low of 1.1 million MWh to almost 15 million MWh. These ten plants generated almost all of the electricity produced within the state. Maryland State Electricity Profile 2018, Table 2B and Table 5.

[115] Assuming it is a single-axis tracking ground-mounted installation.

investment required to meet agrivoltaic standards. For instance, these investments would include water supply for sheep in case of solar grazing, restoration of such topsoil as has to be removed for construction, and approved reseeding of the land.

Usually, the economics of dual use must be worked out on a case-by-case basis unless there are examples available in the local area of a proposed solar installation. The creation of sufficient capacity in extension services to support design of dual-use farming options will be essential for adequate support of integrating solar with farming on a significant scale. As already discussed, with higher panel mounting, a much wider variety of farming, including vegetable cultivation, is possible. It is even possible to use solar land for grazing cattle, with the right breeds and fencing, and possibly, adjustment of panel height. Many types of crops, from mushrooms to mutton, from saffron to salsify, a cool weather root crop, can be pursued on land used for solar installations. Both technical and economic assessments are involved in the design of dual-use solar installations. Expansion of the options will require experimentation, demonstration projects, and careful evaluations of the economic aspects of dual-use solar and, beyond that, multi-use solar. Given the potential for saving farms, protecting farmland from irreversible urban and suburban development, improving soil health and diversifying food and fiber production, a substantial investment is warranted as renewable energy capacity is scaled up.

Smaller scale solar installations (2 MW or less) could benefit from a different array of incentives. Maryland already has an aggregate net metering system under which a solar installation with at least some on-farm consumption can sell electricity to other farmers, government entities or non-profits. The analysis in Chapter III shows that farmer-owned solar could generate thousands or tens of thousands of dollars a year in profits, even when the area of the solar installation is 10% or less of the farm operation.

Building a solar installation requires a large amount of capital and it requires customers to whom the electricity can be sold. Farmers could be given low interest loans to own solar in the same way that Maryland does in the energy arena. For instance, the Department of Housing and Community Development offers loans to the construction industry at just 2% interest for building net-zero-energy homes[116] – homes that generate as much energy as they use on an annual basis. The Maryland Clean Energy Center, a non-profit chartered by the State of Maryland, raises low-cost funds for energy efficiency improvements.[117]

In the calculations for the solar on a dairy farm and on a small 10-area farm, it was assumed that the weighted average cost of capital to build the solar array would be 8.5%, which is typical for commercial work. If loans for farmer-owned solar with dual use for the land were raised via tax-free bonds at 4%, the profits would increase substantially relative to those calculated in Chapter 3, Sections b. and c. In the case of the 2 MW-ac installation, on 16 acres of a 300-acre dairy farm, solar profits in the first year would increase by about two thirds from about $88,000 to about $145,000 (and increase thereafter). Dairy profits of about $40,400 would be only about $2,300 per year less than a full dairy operation because only 16 of the 300 acres would be withdrawn from dairy, leased for solar with grazing done by the landowner, the lessee, or a third party.

[116] DHCD 2020
[117] MCEC Financing 2020

A significant barrier to farm operation ownership of solar under the aggregate net metering program is that, as owners, they must handle the billing to and collections from the parties contracting to purchase the electricity. This barrier can be overcome if the billing and collection can be handled for owners of aggregate net-metered solar by utilities. This approach is already used for corporations that purchase electricity on the wholesale market and sell it to the state's households and businesses. Utilities pay those corporations for the amount billed and, for a small discount, take the risk of collecting from customers.[118] Since utilities must send a bill anyway for recovering the costs for distributing the electricity, the system provides for a single method of payment and collection from customers.

Ownership of aggregate net-metered systems by farmers would also be facilitated if Maryland institutions such as government departments and state universities entered into long-term contracts to purchase electricity from farmer-owned net-metered systems. A discount relative to the retail rate would make it attractive for these institutions to enter such arrangements; a 20% discount relative to the retail rate was factored into the calculations in Chapter III. Three parties benefit: the farmer owner of solar; the solar grazier; and the public institutions that get renewable electricity at a discount. In addition, the public at large gets a variety of economic and ecological benefits. Such contracts would be bankable in that they would make getting loans for the solar simpler and the loan terms better.

Finally, many farms are not well located relative to connection to the electricity grid for solar of sizes that would enable sales of electricity in significant amounts. Grid connection points, other than for very small-scale systems, like residential and small commercial rooftop solar, require a three-phase transformer with a distribution line sufficient to carry the added power or a substation. The electrical line to tie a solar system to the grid can cost a million dollars a mile or more. [119]

Public support for grid-connection expenses would benefit some farm operations that choose to lease land for solar rather than own the installation. The distance from a suitable grid connection is one reason that solar lease payments to landowners can vary a great deal – from $250 to $2,000 per acre per year.[120] Land within the economic distance of a grid-connection point is much more attractive, other things being equal. As a result, public support for excess grid-connection expenses on otherwise suitable plots of land would likely increase the lease payment and increase farm profits.

Figure 8 shows a screenshot of a map from a mapping tool developed by a state task-force. It includes all land within two miles of a 35-kilovolt (kV) (or lower) distribution line and within two miles of a transmission line of more than 69 kV. The red areas are residential; the orange are commercial; the yellow are agricultural; green are wooded.

[118] This approach is known as "Payment of Receivables"; see Peltier and Makhijani 2018.
[119] SolarLandLease 2019
[120] SolarLandLease 2019

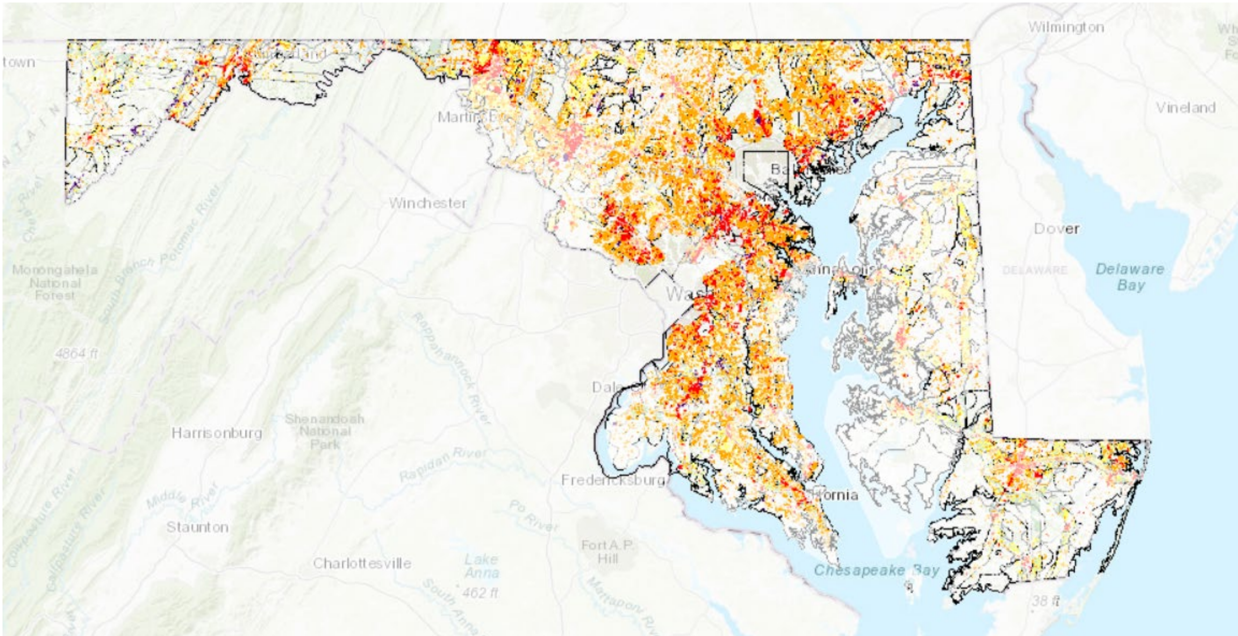

Figure 8: Map of areas within 2 miles of distribution lines of 35 kV or less or within 2 miles of a transmission line of more than 69 kV. Screenshot taken on 2020-09-02. The yellow color designates farmland. Source: Smart DG+ tool

The usefulness of the Smart DG+ tool maps is limited by the lack of information on actual potential interconnection points for various sizes of solar – three-phase transformers for smaller solar installations and substations for the larger ones. The tool also does not provide data on land less than one mile from distribution lines, which further limits its usefulness for solar of a few hundred kilowatts to 2 MW. These are among the most important sizes for widely distributing the benefits of boosting farm profits with solar on a small fraction of a farm operation (Table IV-1 above, including Note 3).[121]

Farms where dual-use might best improve the land, tourist-intensive locations where solar could adversely affect local economies, locations for the creation of public purpose solar microgrids, and locations where other public purposes might be served (as for instance solar on agricultural land with high nutrient loads) may be too distant from a suitable grid connection point for construction of large-scale solar on purely commercial terms. In such cases, consideration could be given to adding the costs of grid connection over the normal costs to the utility rate base. This should not be done lightly, of course, since adding to the costs of electricity impacts households and businesses broadly. But if solar development at specific sites serves enough of a larger public purpose then the public investment can be justified through a CPCN process.

This public support for grid-connection expenses can serve as a means of incentivizing health soils practices on the majority of the farm that is not in solar. When such investments make solar installations economically feasible, they increase whole farm profits and farm economic resilience. As

[121] The tool is not comprehensive and is a “screening guide.” The interconnection detail may have been omitted for a variety of reasons.

was shown in Sections III.b. and III.c farm-owned aggregate net metered solar can enable profits of $5,000 per acre and more if low interest loans are available. At these rates profits from solar on 10% of farmland would range from being comparable to total profits from commodity row crops or grazing on 100% of the land (in the case of land leased for solar) to several times that.[122]

Solar installations of 2 acres or less can be exempted from the requirement of engaging in commercial dual-use agricultural activities if they do not wish to engage in them or if leasing that land to third parties for the same is impractical. Healthy soil requirements, should, however be maintained. Permanent cover, including pollinator friendly plants can be required while leaving any actual commercial activity – apiaries, grazing, vegetables, flowers – up to the farmers themselves or to any third parties to whom the farmers may choose to lease that land.

d. Exemptions

There are two principal reasons for the size limits on solar installations on farmland (the smaller of 20% of a farm operation or 400 acres) recommended in this report:

- To ensure that lessees are not deprived of access to farmland for their usual farming practices;
- To spread the substantial economic benefits of solar on farmland to a large number of farm operations, thereby strengthening farming in general and family farms in particular.

There are however specific circumstances in which exemptions may be warranted. Such exemptions could be granted through the normal (rather than shortened) process of obtaining a Certificate of Public Convenience and Necessity. For instance, it may take ten or twenty million dollars to connect to a very a high voltage transmission line traversing large farms. A larger installation may also offer smaller farms the opportunity of tapping into the same grid connection – an opportunity that would otherwise be essentially non-existent. Where lease revenues are relatively low, a larger acreage, may better be able to stabilize a farming operation such as a dairy farm, while being restricted to a fraction of the farm operation.

Other exemptions may be granted for environmental and agricultural reasons. For instance, many Maryland Eastern Shore farmers apply chicken litter from the poultry industry as fertilizer, which is more economical than industrial synthetic fertilizers. This can be beneficial, but has also caused nutrient management issues, including excess nutrient runoff, with attendant negative effects on the ecology of the Chesapeake Bay. The problem of phosphorous overload is especially important on Maryland's Eastern Shore, and notably on the Lower Eastern Shore, where the bulk of the state's poultry industry is located. As explained below, larger solar installations on such land may enable restoration of the land while maintaining or increasing farm profitability and food production.

[122] As noted, we have not evaluated the comparative profits on intensive specialty crop farms since these are very diverse and variable. Solar on such farms would need to be evaluated on a case-by-case basis.

In 2015, Maryland developed a regulation related to its "Phosphorous Management Tool" (PMT) to comply with the federal Clean Water Act. As of January 2020, the Maryland Department of Agriculture had evaluated 88% of the regulated land, over 1.12 million acres, and found that:[123]

- 10,894 acres on 96 farms, have PMT scores in the 450 to 499 range; mitigation measures to manage the nutrients are required on these farms;
- Another 54,271 acres on 252 farms have scores in the 300 to 449 range, indicating high burdens but not yet requiring special mitigation measures.

Most of these 65,000 acres or so of land are on the Eastern Shore, where most commodity crop farming in Maryland is located (along with the poultry industry). Solar installations on some of this land could provide the profit-basis for exploring potential for remediation. Possibilities include planting of perennial grasses, such as switchgrass and Indiangrass, which can be used for forage[124]; it can also be used for biofuel, while increasing biodiversity and providing other ecosystem services.[125] There does not appear to be data specific to the use of such grasses for phosphorous remediation but cultivation data indicate that potential for switchgrass:

> Current recommended phosphorus and potassium application rates [for switchgrass] differ widely. In Tennessee…phosphorus and potassium applications are not recommended unless soil levels are low. Even when no phosphorus or potassium is applied, it may be appropriate to include an opportunity cost for the phosphorus and potassium removed in the harvested biomass.[126]

This indicates the potential for switchgrass to take up excess phosphorous on land with high nutrient loads; in that case, what is described in the above quote as the "opportunity cost" of depleting the soil of phosphorous would actually be a benefit of reducing phosphorous on land with high loading of this nutrient. There may also be another important potential ecosystem benefit to such a system: enhancing methanotrophic bacteria in the soil; these bacteria consume methane that is present in the air in the pores of the soil. Methane is a powerful greenhouse gas; its warming potential on a 20-year time scale is 84 to 87 times that of carbon dioxide.[127]

A pilot project would enable a proof of this concept to be established while protecting farm profits. Such a project measures would also be consonant with Maryland's 2017 healthy soils law, the central purpose of which is to improve the health of Maryland's soils, including its farmland.[128]

A well-constructed experiment would include control acreage, sections with solar and various mixes of grasses with and without grazing; and sections with other types of agricultural activities. Such an experiment would involve making measurements of soil nutrient loading, nutrient in the runoff, soil carbon, methane destruction rates, biological activity, etc. Since excessive nutrient loading is a

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[123] MDA 2020.
[124] Mitchell and Anderson 2008
[125] Werling et al. 2014
[126] English et al. 2020, p. 224
[127] EPA GWP Fact Sheet
[128] Maryland Healthy Soils Law, 2017

widespread problem, such an experiment may hold ecological as well as economic lessons far beyond Maryland and the Chesapeake Bay watershed of which the Eastern Shore is a part. A recent journal article, authored by a scientist at the University of Maryland Center for Environmental Studies and one at the University of Algarve in Portugal, noted the global nature of this problem:

> Coastal eutrophication caused by anthropogenic nutrient inputs is one of the greatest threats to the health of coastal estuarine and marine ecosystems worldwide. Globally,~24% of the anthropogenic N released in coastal watersheds is estimated to reach coastal ecosystems.[129]

There may be also circumstances where solar on farmland is feasible but not agriculture. An exemption may be granted under these if the solar developer can show, as part of the full (rather than shortened) CPCN process, that agricultural activities are not possible.

e. Benefits to rural communities

Direct economic benefits to rural residents can also be broadened beyond those directly profiting from solar development. For instance, local residents could be provided with investment opportunities in local renewable energy projects. This approach has been used in Denmark to overcome the objections of neighbors who must look at the wind turbines and the changed landscape in their neighborhoods but who do not benefit directly. As part of Danish policy, developers of wind farms are required to offer nearby residents the opportunity to invest in the renewable energy projects. A minimum of 20 percent of the total investment must be offered to community members. To spread the benefits of solar over a larger number of farmers, solar installations could be owned by cooperatives formed for the purpose.

Sufficiently wide adoption of solar grazing could generate many economic opportunities – in expanded animal husbandry, in processing operations, in support occupations such as farm to table marketing, and veterinary medicine.

Rural communities would also benefit from the increased economic opportunities provided by dual-use solar on farmland:

- There would be opportunities for young farmers, as well as Black and Indigenous farmers to enter agriculture without having to purchase land. There are other investment requirements, of course, purchasing the sheep for instance, as well as needs for working capital. But the main hurdle to many new entrants is the cost of land.
- There would be opportunities for jobs and investment in new food system infrastructure, such as processing sheep, and marketing of agrivoltaic food products.
- A renewable energy sector with balance between offshore wind and solar, could create thousands of jobs in solar (see Section IV.b).

The solar and farming investments and associated activities would boost local economies and provide increased revenues for local governments. In some areas, communities hosting large-scale solar

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[129] Malone and Newton 2020

installations are making “Host Community Benefit” agreements with solar developers; these agreements would provide revenues to the communities (county and town councils) in lieu of taxes.[130]

f. Policy development for agrivoltaics

There are strong economic and ecological arguments for joint development of healthier electricity and food systems over the next two decades. It is a complex enterprise that will require consideration of a host of issues in both fields, as well of the views of experts, the public, farmers, businesses, and households.

Two of Maryland’s institutions that consider energy and agricultural issues could help develop agrivoltaics in the state. For energy and climate questions, there is the Maryland Commission on Climate Change. The Commission is an official advisory body, staffed by the Maryland Department of the Environment; it has working groups, including one on mitigation of climate change. Among other things, the Mitigation Working Group develops recommendations for reducing greenhouse gas emissions from the energy sector, including by increasing the amount of renewable energy in the state’s energy mix. Maryland has a Soil Health Advisory Committee, staffed by the Maryland Department of Agriculture (MDA); it includes representatives from across the agricultural and environmental sectors. MDA also has representatives on the Mitigation Working Group of the Climate Commission. A joint committee of the Mitigation Working Group and the Soil Health Advisory Committee could develop proposals for the development of agrivoltaics in the state.

In particular, an electricity system in Maryland that relies mainly on renewable energy will look substantially different from the one in place today. Weather extremes are becoming more frequent. Greater electricity system resilience is therefore a necessity. In the electricity sector, upon which the functioning of all other economic sectors depends, resilience means a lower frequency of outages, shorter duration of outages, and maintenance of essential services during outages. All of these attributes point to a much more distributed grid – more local sources of supply that are more responsive in real time to changing conditions. The need to join these resilience attributes with low-to-zero CO_2 emission sources of supply points to much more solar distributed generation and strategic investments storage – notably battery storage – and the widespread implementation of microgrids, including public purpose microgrids which can support communities in emergencies.

The development of a resilient, renewable grid requires investments in the state’s electricity distribution systems.[131] As it happens, the development of a smart, distributed and resilient grid will also make it possible for rural solar installations to be connected to the grid more economically. For instance, even if the added cost of grid connection is publicly supported, permission for the transmission tie to cross properties that lie between the solar location and the substation must be obtained. A well-developed distributed grid, needed for a resilient and renewable electricity system, would reduce the number of properties to be crossed and the distance to be covered.

[130] See for instance Host Community Benefit Draft 2020
[131] Makhijani 2016, Chapters VIII and IX; within them, see specifically pages 153 and 186.

At the same time, profits from solar designed to promote healthy soils can support a more diversified farm economy. This report has developed two scenarios to show the scale of land use, profits, support for healthy soils, and farming possibilities. The 2040 solar scenario provides a reasonable indication of the potential scope of solar development on farmland – on the order of 80,000 acres. The value of the electricity on this small fraction of land would be almost equal to the entire 2017 agricultural output, including poultry in Maryland -- $2.3 billion compared to $2.5 billion. It would be greatly in excess of the value of all crops harvested, almost $1 billion, while allowing almost all the state's farms to continue the same production as before on 96% of the farmland area; there would be dual-use farm production on almost all the remaining 4%.

Given the magnitude of the climate crisis, the weaknesses in the farming and food systems exposed by the COVID-19 pandemic, strengthening both sectors economically and ecologically would provide benefits to the state beyond the separate development of each sector.

A more immediate policy issue relates to net metering. Much of the opportunity for increased profitability of smaller scale solar (2 MW or less) arises from Maryland's Aggregate Net Metering rule discussed previously. This provides retail value for solar electricity to farmers, with the size of the solar installation limited to a maximum of 2 MW-ac (about 16 acres). A net-metered 2 MW-ac installation would typically yield profits of tens of thousands of dollars per year if owned by the farm operation.

At present there is a cap on total net metered capacity of 1,500 MW on all types of net-metered solar including rooftop residential and solar and ground-mounted solar up to 2 MW-ac. Most of the net-metered capacity under this cap has already been used up for urban residential and commercial installations; very little of that has gone to low-income households. The net metering limit should be doubled to 3,000 MW for all solar installations currently eligible for net metering to enable agrivoltaics development (and community solar and low-income solar access). There are larger regulatory issues associated with a transition to a renewable electricity system. A doubling of the net-metering cap to 3,000 MW represents much less solar than a renewable electricity system will require. It will allow time for the larger transition issues to be addressed while allowing important food system and energy equity goals to be addressed.

g. Sources of funds for incentivizing an agrivoltaics sector in Maryland

A number of different sources of funds could be used to integrate solar, farm profitability, ecological benefits, and healthy soil considerations. The simplest approach is one in which landowners lease their land to solar developers. The landowners get essentially risk-free revenues that are far greater per acre than profits from commodity crop production per acre, where the gross revenues are generally under $1,000 per acre. The situation is more complicated if solar installation reduces production on small, very intensive vegetable and flower cultivation, where revenues per acre can be in the tens of thousands of dollars per acre, but increases electricity revenues at the same time.

Promoting healthy soils and in-state solar are both major goals of the State of Maryland; the use of public funds in enabling them both is thus appropriate.

A number of sources of revenue could be used to support farm-centered solar, even considering the more straitened circumstances created by the COVID-19 pandemic. The potential sources include (putting added expenses of grid-connection into electricity rate base of utilities, increased general revenues from income or wealth taxes, a small gasoline tax – one cent a gallon (amounting to less than $1 per month for typical personal car use) would raise about $30 million a year. This tax is smaller than the typical variation in prices between nearby gas stations. Similar sums could be raised by a charge on electricity amounting to 50 cents per month per household. More progressive revenues sources are possible as well, given the significant ecological and social benefits that would accrue to society at large from dual-use solar. These options are well known – progressive income taxes or a small wealth tax.

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