Expansion of Utility-Scale Solar Power Generation on Agricultural Land

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Abstract

Despite increasing public and legislative interest surrounding conversion of agricultural land to utility-scale photovoltaic (UPV) projects, to date there has been little empirical analysis of the actual extent of UPVs on agricultural land. We overlay a photovoltaic database with cropland and soil databases to identify prior use, quality, and geographic distribution of UPV acreage. Based on this data, UPVs account for 0.02% of all land acres and 0.04% of agricultural land as of 2021, and 0.39% of UPV acres are on agricultural land. UPVs have taken up 0.03% of cropland acres in both the not prime and prime quality classes. The largest UPV acreages are in California, Texas, North Carolina, and Florida. States in the Cornbelt show relatively low concentrations of UPV acreage on agricultural land. Based on the ratio of UPV share of acreage to crop shares of acreage, citrus is particularly over-represented in UPV conversions and corn and soybeans under-represented. Depending on the choice of projection approach using trend analysis of the existing data, 0.13% to 0.40% of agricultural land will be converted to UPVs by 2050. With 0.3% of UPV acres co-existing with grazing and haying, agrivoltaics is a rare choice to date for conversion of land to utility scale solar projects.

Keywords: solar panels, utility-scale photovoltaics, agriculture, crops, GIS, agrivoltaics, land use change, 2024 Farm Bill, corn, soybeans

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Introduction

The Biden Administration has set a goal of decarbonizing the U.S. electricity grid by 2035 (US DOE, 2022). The U.S. Department of Energy estimates that to provide 1 terawatt of electricity-generating capacity to the grid via solar power by 2035 would require approximately 0.3% of US land area (U.S. DOE, undated). Notwithstanding this seemingly small number, solar projects may compete with agricultural uses for land because the same attributes that make land appropriate for solar energy (plentiful sun, flat land) are also attractive for agriculture (ibid.). In fact, also according to the U.S. Department of Energy, about 90% of projected solar photovoltaic (PV) deployment by 2050 is expected to be generated from utility-scale PV (UPV) projects in rural areas (US DOE, 2021). As a result, UPV installations could have impacts on agricultural land use and rural communities. In principle, while UPVs may conflict with agricultural use of land, in some situations, they could be compatible with continued agricultural use of the land – aka “agrivoltaics”, and allow farmers to sell both electricity and agricultural products (Goldberg, 2023).

While large scale modern field crop production techniques may not be readily compatible with UPV structures on the same land unit, specialty crops and livestock may be. In arid regions in particular, UPVs could provide synergistic agricultural benefits, such as shade for pollinators (Walston et al, 2018), reduced plant drought stress, and greater food production (Barron-Gafford et al., 20109). But others are not so sanguine. Detractors assert that UPV projects hasten loss of farmland and cause soil erosion (e.g. Hollingsworth, 2022) or increases farmland value (Chang and Lin, 2023), thus pricing young and beginning farmers out of the market (Chalmers, 2023). Policies at the state or local levels have even been put in place to create roadblocks to PV installations. For instance, Virginia passed legislation in 2022 in which projects to be permitted starting in 2025 will require as a condition for a permit for “small renewable energy” projects that if there will be a significant adverse impact on wildlife, historic resources, prime agricultural soils, or forest lands, the applicant must also submit a mitigation plan for public comment period (Virginia, 2022). The bill specifies that a “disturbance” of more than 10 acres of prime agricultural soils or more than 50 acres of contiguous forest lands fall under this rule. At the Federal level, H.R.4257 – “No Solar Panels on Fertile Farmland Act of 2023”, introduced into the House of Representatives in 2023, would amend Internal Revenue Code to exclude property and facilities located on prime farmland from certain credits relating to renewable energy production and investment. Senate Bill 798 – “Protecting Future Farmland Act of 2023”, introduced into subcommittee in 2023 also seeks restrictions on UPV installation on prime farmland. As of May 1, 2024, the House’s 2024 Farm Bill requires the USDA to study the impacts of solar installations on prime, unique, or statewide or locally important farmland.

Legislation actions questioning or limiting installation of UPVs on agricultural land are not limited to the U.S. The governing coalition in Italy has submitted to both houses of Parliament legislation to limit the installation of UPVs on agricultural land (Fonte, Amante, Landini, 2024; Chiesa, 2024) despite the government also have presented plans to triple installed renewable energy capacity by 2030, although the proposed legislation may not apply to agrivoltaics (ibid.).

To date there have been little analysis of the actual extent of UPVs on agricultural land. As a basis for effective policymaking on the intersection between food and solar energy uses of agricultural land, we need at minimum to know where are the lands on which UPV uptake is occurring, the existing agricultural uses of those lands, and the soil quality of that land. To date, little work has been done on these topics. We overlay a photovoltaic database with cropland and soil databases to identify prior use, quality, and geographic distribution of UPV lands.

Data sources and empirical approach

For acres of UPV we use as digitized boundaries the United States Large-Scale Solar Photovoltaic Database (Fujita et al., 2023). Data on land use is from the 2009 Cropland Data Layer (CDL) (NASS, 2023) at the 30 meter grid level. The Gridded Soil Survey Geographic Database (GSSURGO, 2024) provides soil quality measures at the 30 meter grid level. The UPV data covers 1986-2021. However, acres in UPV projects were effectively near 0 until around 2010. Hence, we use land use data in 2009 to identify prior use of acres now with UPV.

To identify the prior land use and soil quality of acres now with UPV, we overlay the UPV data with the CDL land uses and the SSRUGO farm classes to quantify acreage. We compare these results with the conterminous US overlay of the CDL land use and SSURGO soil quality variables to compare UVP prior uses to national summaries (Table 1a).

To simplify both the CDL land uses and SSURGO farm classes we aggregate the more detailed data into nine and two classes respectively. We aggregated over 120 land uses into nine categories including three cropland categories (Crop, Fallow or Idle cropland, and Christmas trees, orchards and other tree crop categories. We simplify the 25 soil quality farm class categories by aggregating soil types into “not prime farmland” (abbreviated as “not prime” in the text) and “Prime or of state or local importance” (abbreviated as “prime” in the text). Prime lands include map units that are greater than 50% Prime farmland, or Lands of Statewide, Local, or unique importance. Not prime farmland includes map units in the SSRUGO database that contain less than 50% of prime land.

Prime farmland, as defined by the U.S. Department of Agriculture, is land that has the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops and is available for these uses. It could be cultivated land, pastureland, forestland, or other land, but it is not urban or built-up land or water areas (NRCS, undated). The soil quality, growing season, and moisture supply are those needed for the soil to economically produce sustained high yields of crops when proper management, including water management, and acceptable farming methods are applied. In general, prime farmland has an adequate and dependable supply of moisture from precipitation or irrigation, a favorable temperature and growing season, acceptable acidity or alkalinity, an acceptable salt and sodium content, and few or no rocks. The water supply is dependable and of adequate quality. Prime farmland is permeable to water and air. It is not excessively erodible or saturated with water for long periods, and it either is not frequently flooded during the growing season or is protected from flooding. Slope ranges mainly from 0 to 6 percent.

In some areas, land that does not meet the criteria for prime or unique farmland is considered to be farmland of statewide importance for the production of food, feed, fiber, forage, and oilseed crops ((NRCS, undated). The criteria for defining and delineating farmland of statewide importance are determined by the appropriate State agencies. Generally, this land includes areas of soils that nearly meet the requirements for prime farmland and that economically produce high yields of crops when treated and managed according to acceptable farming methods. Some areas may produce as high a yield as prime farmland if conditions are favorable. Farmland of statewide importance may include tracts of land that have been designated for agriculture by State law.

Data Analysis

According to the UPV database, the vast majority of UPV acres as of 2021 are on "greenfield" land, representing 309,950 acres out of 313,700 UPV acres. The 3,750 UPV acres in the non-greenfield land categories in the solar database are abandoned mine land, landfill, PCSC, land covered by the Resource Conservation and Recovery Act, superfund land, and other previous, current or suspected contaminated land and that may include prior manufacturing and industrial facilities, processing plants, landfills, and mining sites, among others. Greenfield acres are lands that may have previously been wildland, urbanized, cultivated, or reclaimed lands and are the focus of this analysis.

We overlay the UPV greenfield acres with the soil quality and land use databases to link agricultural lands with UPV. Table 1a presents statistics on total and UPV acres by farm quality and land use classes. Table 1b drills down to just agricultural lands, as we define for the purposes of this paper. As of 2009, in Table 1a, total land across the two land quality classes was 1.9 billion acres[1], with 298 million acres being cropland, and of that 249 million acres are prime cropland (12.9% of total acres across both quality classes), per columns A and B. Columns C and D cover UPV installations on agricultural land over 2010-2021. The 309,953 acres in UPV on all lands in Table 1a represents 0.02% of total land. UPV represent double the share of agricultural land, although the share is still small – the 119,902 acres in UPV on agricultural lands in Table 1b represents 0.04% of total agricultural land. Comparing the bottom cell in column C of Tables 1a and 1b, we see that 39% of UPV acres are on agricultural land, a proportionately high share given that agricultural lands represent 17% of total lands in our database.

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[1] The 1.9 billion acres total land area is 6% lower than contiguous land area from U.S. Census as the CDL leaves out some land types from its calculations.

While total acreage is 1.8 times higher than in prime land, total prime acres in UPV is higher than on non prime land – 189,999 acres on prime versus 120,954 acres on non prime land (Column C in Table 1a). Part of the reason that prime land has the greater share of UPV acres could be a preference for developers of UPV to site closer to urban areas, and for the tendency of prime land to be closer to urban areas, given that towns in the first place tended to form close to quality farming areas.

While prime cropland acres are 12.9% of total acres across in both quality classes, 26.5% of UPV acres are on prime cropland (columns B and D in Table 1a). However, some of this disparity is simply due to cropland being the largest acreage by land use category in the prime lands class. If one looks at UPV's share of total agricultural acres by land use in a quality class (Column E in Tables 1a and 1b), one can see that UPVs took over 0.03% of cropland acres in both the not prime and prime quality classes. Under the not prime quality class, *Christmas Trees, Orchard, Tree Crops* and *Fallow/Idle Cropland* account for the largest shares of UPV acres, at 0.07% each. In the prime quality class, *Christmas Trees, Orchard, Tree Crops* and *Fallow/Idle Cropland* also account for the largest shares of UPV acres, at 0.15% and 0.07%, respectively.

Table 1a. Total and UPV Acres by Farm Quality and Land Use Classes

Farm Quality Class	Land Use Category	A. Acres	B. Share of Total Acres	C. UPV Acres	D. Share of Total UPV Acres	E. UPV Share of Total Acres in Quality Class
Not prime farmland	Aquaculture	70,780	0.0%	0	0.0%	0.00%
	Barren, Shrubland, Other	428,766,609	22.1%	72,571	23.4%	0.02%
	Christmas Trees, Orchard, Tree Crops	908,007	0.0%	665	0.2%	0.07%
	Crop	48,901,263	2.5%	12,347	4.0%	0.03%
	Developed	50,592,229	2.6%	2,951	1.0%	0.01%
	Fallow/Idle Cropland	7,482,340	0.4%	4,914	1.6%	0.07%
	Forest or forested wetland	448,720,362	23.1%	10,617	3.4%	0.00%
	Grassland/Pasture	241,814,711	12.5%	16,764	5.4%	0.01%
	Herbaceous Wetlands	14,609,966	0.8%	125	0.0%	0.00%
	Total	1,241,866,267	64.0%	120,954	39.0%	
Prime or of State or Local importance	Aquaculture	107,265	0.0%	0	0.0%	0.00%
	Barren, Shrubland, Other	66,165,127	3.4%	34,968	11.3%	0.05%
	Christmas Trees, Orchard, Tree Crops	2,993,894	0.2%	4,423	1.4%	0.15%
	Crop	249,343,549	12.9%	82,213	26.5%	0.03%
	Developed	56,636,362	2.9%	3,431	1.1%	0.01%
	Fallow/Idle Cropland	21,132,345	1.1%	15,339	4.9%	0.07%
	Forest or forested wetland	136,280,275	7.0%	17,065	5.5%	0.01%
	Grassland/Pasture	160,885,801	8.3%	30,948	10.0%	0.02%
	Herbaceous Wetlands	4,261,201	0.2%	612	0.2%	0.01%
	Total	697,805,819	36.0%	188,999	61.0%	

Grand Total	1,939,672,085	100.0%	309,953	100.0%	

Note: Acres are as of 2009, and UPV installations cover 2010-2021.

Table 1b. Total Agricultural and UPV Acres by Farm Quality and Land Use Classes

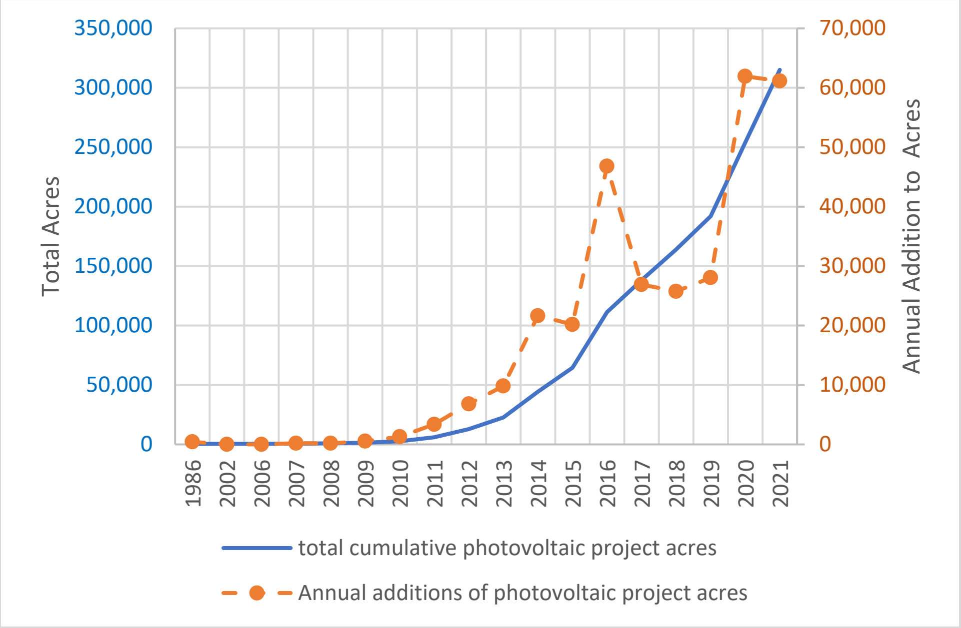
Farm Quality Class	**Agricultural Land Use Category**	**A. Ag Acres**	**B. Share of Total Ag Acres**	**C. UPV Acres on Ag Land**	**D. Share of Total UPV Acres**	**E. UPV Share of Total Ag Acres in Quality Class**
Not prime farmland	Christmas Trees, Orchard, Tree Crops	908,007	0.0%	665	0.2%	0.07%
	Crop	48,901,263	2.5%	12,347	4.0%	0.03%
	Fallow/Idle Cropland	7,482,340	0.4%	4,914	1.6%	0.07%
	Total	57,291,611	17.3%	17,926	15.0%	
Prime or of State or Local importance	Christmas Trees, Orchard, Tree Crops	2,993,894	0.2%	4,423	1.4%	0.15%
	Crop	249,343,549	12.9%	82,213	26.5%	0.03%
	Fallow/Idle Cropland	21,132,345	1.1%	15,339	4.9%	0.07%
	Total	273,469,788	82.7%	101,975	85.0%	
Grand Total		330,761,399	100%	119,902	100%	

Figure 1a shows total acres and annual additions of acres in UPVs on all lands. Installations rise from near zero around 2010. Annual additions to UPV acres rose in most years subsequently except for the large drop from 2016 to 2017 due to an expiration of a federal tax credit in 2016 (SEIA, 2017), although installations in 2017 were still higher than in 2015.

According to SEIA (2024a), commercial solar in 2023 grew 19% over 2022, suggesting that growth continues to be strong since 2021. Government policies such as the Inflation Reduction Act are expected to spur UPVs installations over the next several years (SEIA, 2024b), but market conditions such as expectations of prices of alternative energy sources and technological development are also among the many factors that determine UPV market projections. Figure 1b shows total acres and annual additions of acres in UPVs on agricultural lands. The general shape of the cumulative acres function in Figure 1b is similar to that in Figure 1a.

The data in LBNL (2023) indicates that megawatts per acre are relatively constant from 2010-2022, at 0.20-0.22 MW/acre. While the available data on UPV acres does not cover 2022, the total megawatts of capacity is 11,000 in 2022, suggesting 55,000 acres of UPVs that year, which is a 17 percent increase over 2021 total acres, and is the same as the percentage change in UPV acres from 2020 to 2021.

Figure 1a. Total Acres and Annual Additions of Acres in UPVs on all lands



Data source: Source: United States Large-Scale Solar Photovoltaic Database, 2021

Figure 1b. Total Acres and Annual Additions of Acres in UPVs on Agricultural Lands

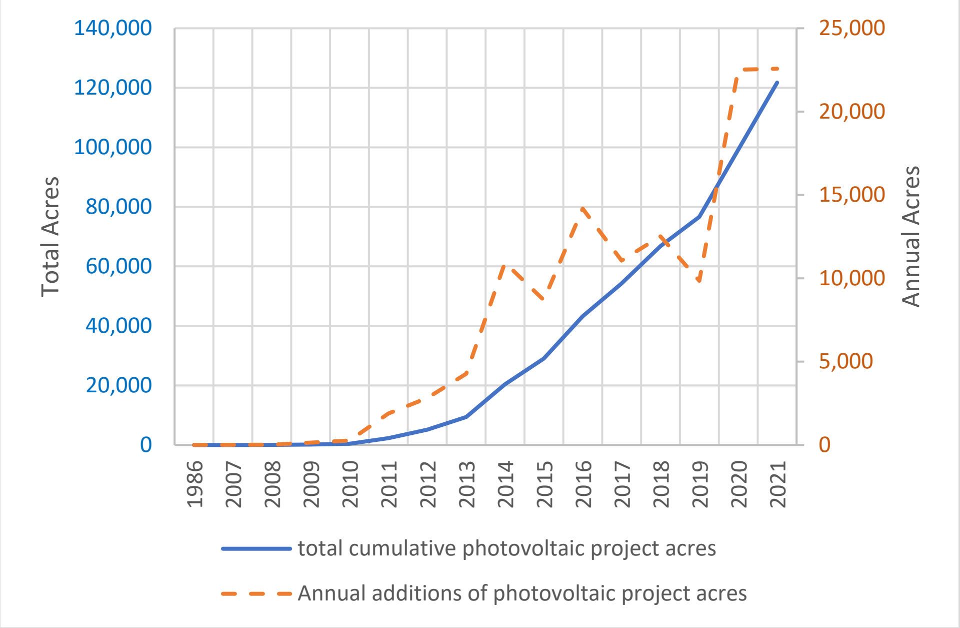
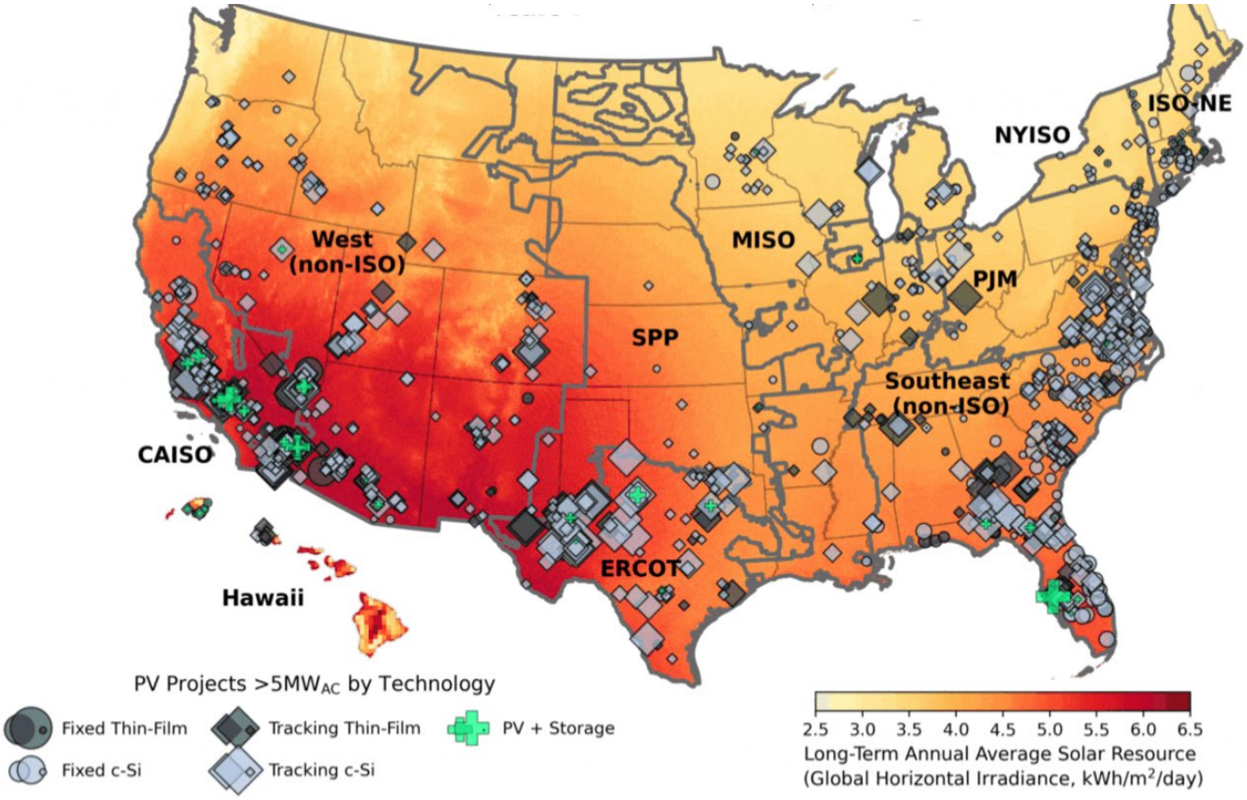


Figure 2 shows the geographic location of all UPV projects on all types of land, as of 2021 (LBNL, 2023). Aside from any policy initiatives, which are not depicted by the maps, two factors appear to significantly factor into determine the location of individual projects: 1) projects tend to be in regions of the country with higher levels of solar resource (the color scale in the map); and 2) heavier concentrations near urban areas, particularly on the Eastern Seaboard, although California shows a heavy concentration inland in the Central and San Joaquin Valleys.

Figure 2. Locations of UPV Projects Built Through 2021



Source: Lawrence Berkeley National Lab

Figure 3a shows acres of UPVs on all land by state, using the same data as in Table 1 and Figure 1. The largest acreage values are in California, Texas, North Carolina, and Florida. States in the Cornbelt show relatively low concentrations of UPV acreage on land. Figure 3b, which shows acres of UPVs on agricultural land by state, shows the same basic pattern as Figure 3b.

Figure 3a. UPV Acres on all Greenfield Land types by State, 2010 - 21

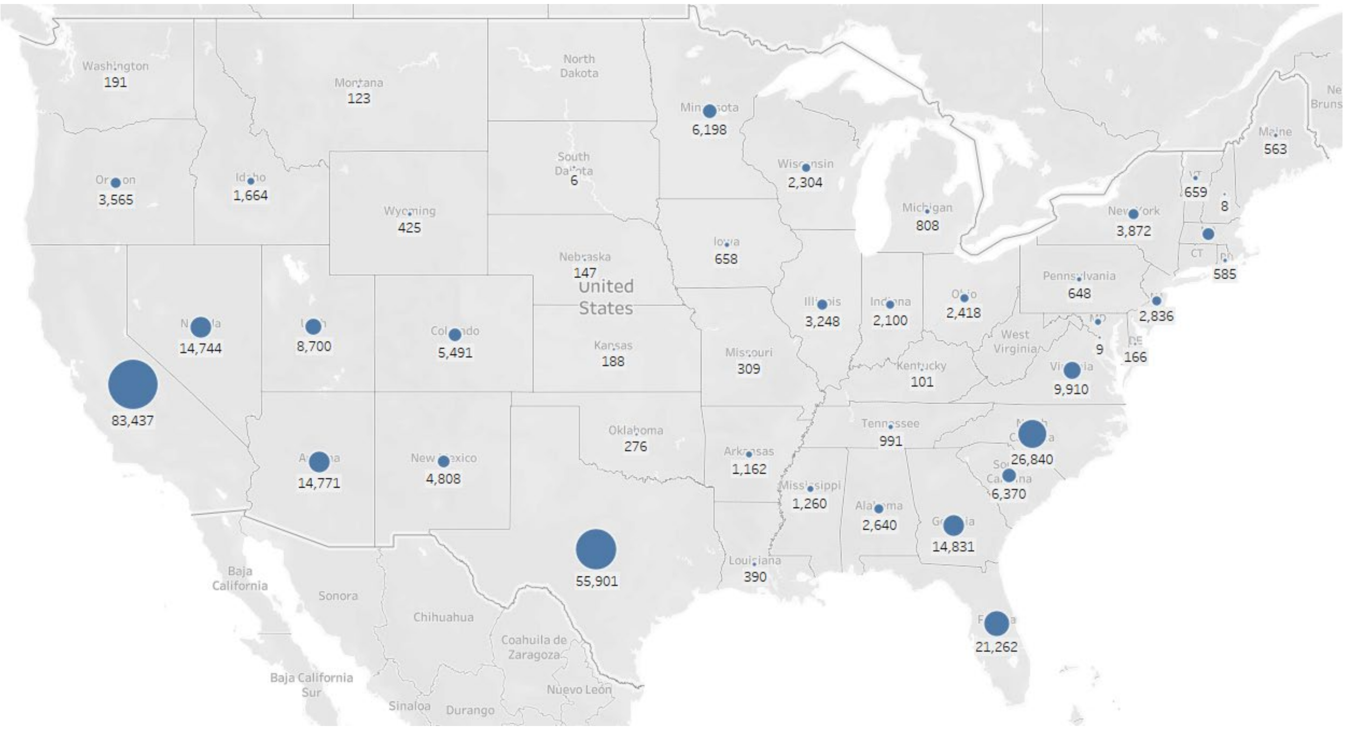


Figure 3b. UPV Acres installed on Agricultural Lands , 2010 – 21

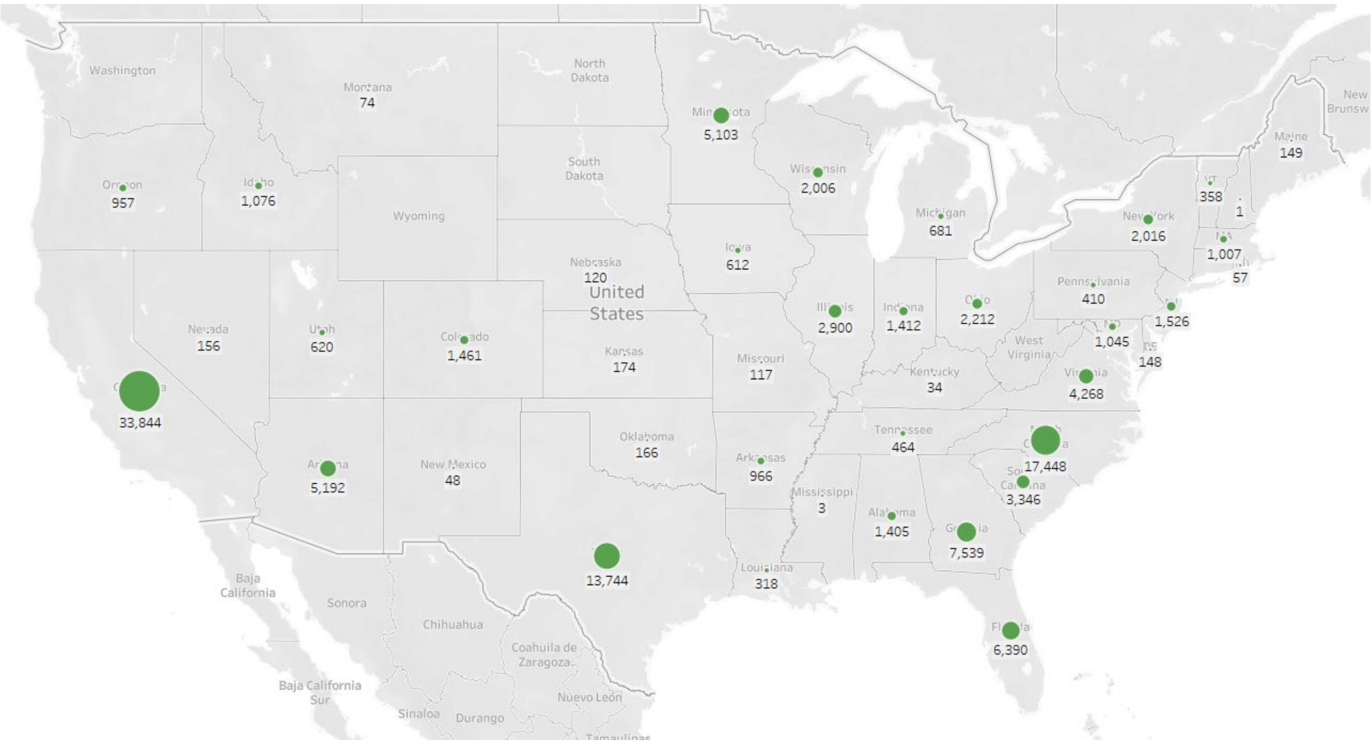
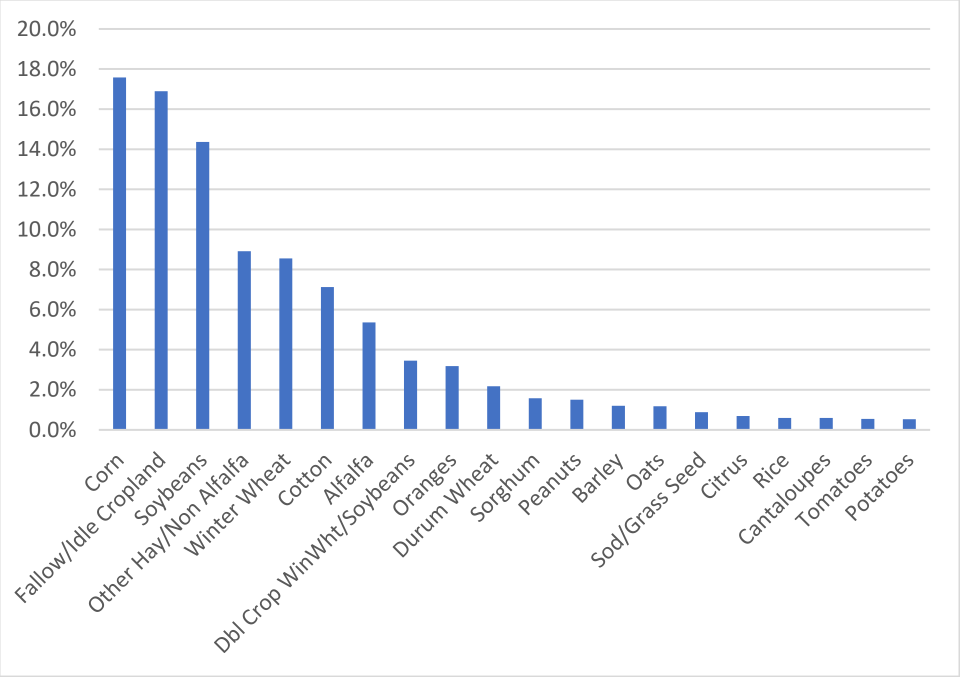


Figure 4 disaggregates UPV acres by their previous agricultural commodity uses, which is defined in this context as land previously in in crops, fallow/idle cropland, Christmas trees/orchards, hay and alfalfa, and sod (119,902 acres total), with the smallest allocations of commodity acres (3.1% in total) being left out for the sake of clarity. Corn acreage represents the largest share of acres, followed by fallow/idle cropland and soybeans. Specialty commodities have the lowest shares of UPV conversions. However, the prominence of field crops in the total shares of UPV conversions is simply a function of those uses being large acreage categories in the agricultural land use database.

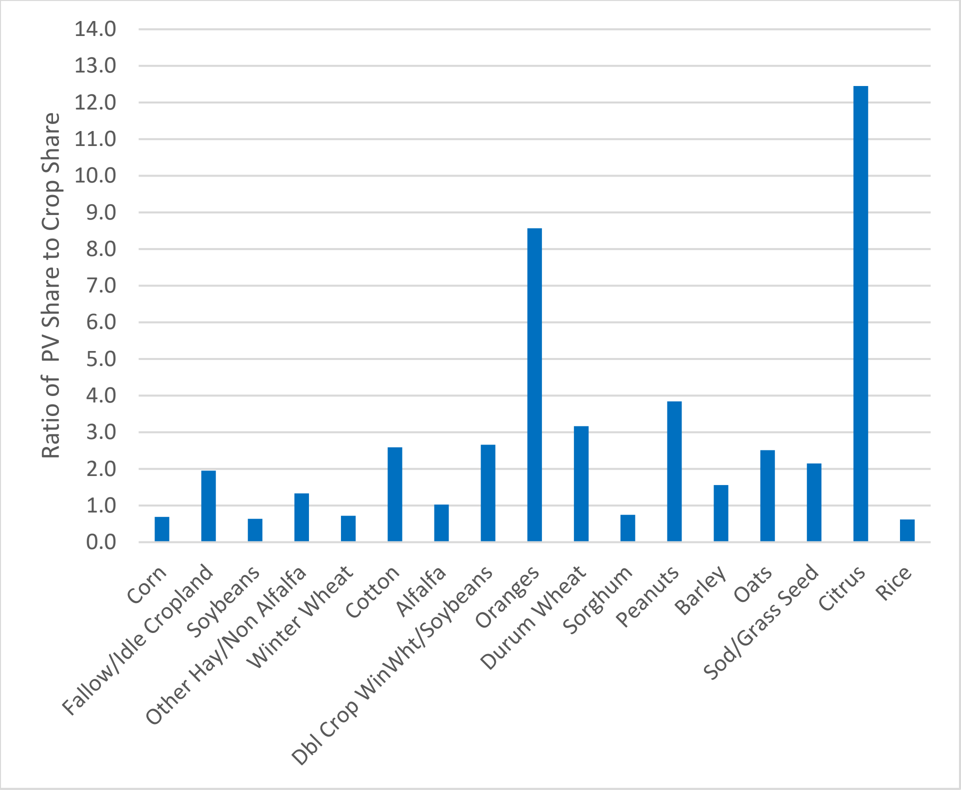
Figure 4. Share of solar project acres over 2010-2021 by previous crop agricultural commodity use



Note. The commodity uses in the table account for 96.9% of land previously in crops, fallow/idle cropland, Christmas trees/orchards, hay and alfalfa, and sod (119,902 acres total).

Figure 5 presents the UPV acreage intensity by agricultural commodity, which we define as the ratio of the share of UPV acres by commodity to the commodity as share of total crop acres. If the ratio equals one for a commodity, the share of the UPV acres in that commodity is of the same as the commodity's share of total crop acres. Based on this measure, corn and soybean acres are under-represented among commodity acres converted to UPV but durum wheat, barley, and oats are over-represented. Some southern field crops like cotton and peanuts are over-represented. Oranges and other citrus are particularly over-represented. The over-representation of southern field crops and citrus is likely reflected by the prominence of sunnier and more southern regions in the UPV acres, as per figures 1 and 2. Perhaps one possibility for the relatively high representation of citrus acres could be high costs of water as well as the availability of degraded agricultural land for solar conversion in California's Central and San Joaquin Valleys (Roth, 2019),

Figure 5. UPV Acreage Intensity by Agricultural Commodity, 2010-2021



Note: This statistic is the Share of Photovoltaic Project Acres by Commodity divided by the Crop as share of total crop acres. Value ratio of 1 means that the crop's share of photovoltaics acres equals the share of total cropland acres in that crop. A value greater than 1 means that the commodity is over-represented in photovoltaics at the national level.

Discussion and Conclusion

While UPVs account for only 0.02% of all land acres and 0.04% of agricultural land as of 2021, their annual growth rate over 2010-2021 suggests relatively rapid expansion at current growth trends. The cumulative growth functions in both Figures 1a and 1b are nonlinear with positive first and second derivatives. Starting from 2013, both functions can be approximated with linear interpolation over two segments – one over 2013-2019 and the second and steeper segment over 2019-2021. Alternatively, a quadratic model can capture the positive first and second derivatives, and does so with an adjusted R-squared of 0.99 for both Figures 1a and 1b. For the cumulative function for UPV on all lands, the annual growth in UPV acres over 2013-2019 is 29,320 acres and 61,539 acres over 2019-2021. For the cumulative function for UPV on agricultural lands, the annual growth in UPV acres over 2013-2019 is 11,422 acres and 22,544 acres over 2019-2021. For projecting a linear trend into the future, we treat a linear trend regression over 2013-2019 as the lower bound, a linear regression over 2019-2021 as the middle bound trend, and a quadratic trend estimated over 2013-2021 as the upper bound.

The figures in the appendix depict actual UPV acres and projected UPV acres to 2050 for both all (greenfield) lands and for agricultural lands. A major caveat to projections is that they are function of the chosen functional form, which is of course unknown for the future, and of the existing data. For UPV acres on all land types, projecting the linear lower (middle) bound annual growth in UPV acres means 515,779 (869,080) UPV acres in 2030 and 808,983 (1,484,468) UPV acres in 2040 on all lands. These figures translate into a 0.04% to 0.08% share of agricultural land converted to UPV by 2040. For UPV acres on agricultural lands, projecting the linear lower (middle) bound annual growth in UPV acres means 202,730 (324,619) UPV acres in 2030 and 316,950 (550,060) UPV acres in 2040 on agricultural lands. These figures translate into a 0.10% to 0.17% share of agricultural land converted to UPV by 2040. With the linear trend models, by 2050, 0.06% to 0.11% of all land type types will be converted to UPV acres and 0.13% to 0.23% of agricultural lands will be converted. With the quadratic model, projecting UPV acres on all lands leads to 961,555 acres in 2030, 2,111,147 acres in 2040, and 3,704,386 acres in 2050. These translate into 0.11% of all acres in 2040 and 0.19% in 2050. Again with the quadratic model, projecting UPV acres on agricultural acres leads to 356,397 acres in 2030, 766,006 acres in 2040, and 1,328,688 acres in 2050. These translate into 0.23% of agricultural acres in 2040 and 0.40% in 2050.

The Department of Energy estimates that to achieve the renewable energy goal of their decarbonization scenario for the U.S. means 3,577,662 acres of UPVs in 2030, 7,437,108 in 2040, and 10,291,802 acres in 2050 (DOE, 2021). These targets are substantially higher than the projections of UPV on all acres even from our upper bound (quadratic) model. Clearly, UPV acres will have to increase at rates faster than seen over the existing data. Note that the Inflation Reduction Act was passed in 2022, and as such, the impacts on UPV acreage expansion due to its incentives for UPV projects will not be reflected in the existing data.

As of 2021, 39% of total UPV acres were on agricultural land. Assuming the share of total UPV acres on agricultural land stays the same over time, for 1,395,288 acres of UPV land to be agricultural in 2030 from the 119,902 acres in 2021 means 141,710 annual additional UPV acres on agricultural land. This growth is 12.4 times higher than our lower bound growth scenario, 6.3 times higher than our middle bound growth scenario, and 5.4 times faster than our upper bound growth scenario. Growth rates would have to be even higher over 2030-2040, and while the quadratic trajectory narrows the gap, the target growth over that span is still 3.7 times higher. Nonetheless, if these UPV targets could be met, these would account for 0.4%, 0.9%, and 1.2% of acres in agricultural land in 2030, 2040, and 2050, respectively.

From a political-economic perspective, resistance to UPVs on agricultural land is similar in concept to resistance to urbanization of agricultural land, with critiques involving both environmental and economic aspects.[2] However, a distinguishing feature of UPV projects compared to urbanization is that the former may allow some joint agricultural uses more easily than urbanization (vertical agriculture aside), at least in principle. Conversion of land to urban uses tends to be irreversible except perhaps in the very long run. However, some UPV installations on agricultural land may also make reversion to agriculture difficult, with energy companies removing topsoil for grading or adding a layer of sand on the surface (Huffstutter and Walljasper, 2024). Further, UPV construction that involves clearing and grading large sections of agricultural land can lead to significant erosion and major runoff of sediment into waterways if stormwater controls at the site are inadequate (US DOJ, 2022).

In principle, agrivoltaics system allow land to be jointly used for agricultural purposes and UPVs. Agrivoltaic facilities make use of the land between panel rows and surrounding arrays for agricultural uses (i.e., crop production or grazing) and/or ecosystem services (e.g., pollinator habitat) (Fujica, 2023) by elevating the panels high enough to clear the crops and configuring them to allow agricultural operations. While agrivoltaics systems may play a significant role in the future of UPV installations, based on the UPV data used here, at present they are a minor portion of UPV acres. In the data used here, only 0.64% of UPV installations over 2010-2021 are characterized as agrivoltaic. Of the 1,979 acres surrounding panels that are characterized as

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[2] Utility-Scale Photovoltaics are not the only form of renewable energy that has detractors. Hydroloelectric generation has long faced pushback due to environmental impacts such as on fish populations, and wind generation faces criticism as well from an environmental or ambient standpoint (e.g., Wei, Wenz, and Auffhammer, 2024).

agrivoltaics, 53% are designated for ecosystem services and 44% as grazing or grazing and ecosystem service. Only 54 acres were characterized as crops or crops and ecosystem services.

A drawback of agrivoltaics from an energy production standpoint is that such projects may require greater spacing of solar panels than dedicated UPV-only projects (Riaz et al., 2021; Alam et al., 2023), and thus, lower energy output per acre. Construction and maintenance costs per kilowatt may also be higher for argi-voltaic installations, with panels need to be elevated 10 to 15 feet above the soil, increased difficulty in cleaning the panels, etc. (ibid.). On the other hand, the agrivoltaics installations can provide some benefits to agriculture, such as increased shade, which can increase yields under certain conditions.

It should not be surprising that a large portion of utility scale photovoltaic (UPVs) are installed on land categorized as agricultural. As already noted, the same attributes that make land appropriate for agriculture (plentiful sun, flat land) are also attractive for solar energy projects, along with the convenience of agricultural lands already being readily accessible to transportation networks and other infrastructure. From a purely economic standpoint, land will go to its highest and best use. In a stylized model, the farmer will maximize the present value of the future stream of profits over the decision to dedicate land to agriculture, leasing the land to energy companies for exclusive use as UPV projects, or some combination of the two (i.e agrivoltaics), or letting it go fallow/idle, less the costs of any externalities of agricultural and solar energy production that public policy forces the producer to internalize. The concept might be much like maximization under uncertainty and irreversibility (e.g., Dixit and Pindyck, 1994), where irreversibility from the farmer’s standpoint is the treatment of potential irreversible changes to the farmland associated with photovoltaics installation as sunk costs that cannot be recovered if the farmer changes his or her mind about allowing the land to be leased for UPVs.

With 0.3% of UPV acres co-existing with grazing and haying, agrivoltaics is a rare choice to date for conversion of land to utility scale solar projects. If the possibility of agrivoltaics systems is even offered by energy companies, farmers appear to have found the returns to crop production plus lower energy lease payments to be less desirable than leasing the land for standard UPV projects. Energy companies in turn have less incentive to push agrivoltaics projects as their energy output per acre is likely to be lower and costs per kilowatt installed likely higher than for UPV projects. It could be the case that changing market conditions in agricultural and renewable energy markets along with diffusion of agrivoltaic technology innovations could also drive demand for more agrivoltaic projects. Nonetheless, at present the current low utilization of agrivoltaics systems suggests that if society wants more of these systems, public policy will have to play a role, say through subsidies for their installation or mandates for more utility scale solar projects to be agrivoltaic. The subsidy approach naturally requires a funding source and the mandate approach could have unintended consequences such as depressing expansion of utility scale solar installations. Another policy alternative is to prohibit or discourage UPV projects on agricultural lands, as discussed in the introduction. Using the acreage data in Table 1a and 1b, taking the figure for total acres of all greenfield land types and subtracting off UPV acres on all land types and subtracting the 330,761,399 agricultural acres leaves over 1.6 billion non agricultural acres on which to build UPV projects, of which the DOE's scenario goal for UPV acreage would require 0.64% of the remaining acreage. While plenty of nonagricultural acreage appears to be available for UPV projects, limiting UPVs to nonagricultural land will likely slow expansion of UPV acres as it is clear from the data that energy leasing companies find agricultural land desirable for UPVs, given that 39% of such projects are on agricultural land despite agricultural lands being 17% of the total land base.

Except perhaps for some specific regions, with only 0.04% of agricultural acres converted to UPV, it is likely too early in the UPV growth cycle for econometric analysis at disaggregated levels such as the county to predict conversion of agricultural land to UPVs. However, this assessment could change in several years if policy and market conditions drive a rapid increase in UPV projects. Nonetheless, our preliminary analysis will help to inform the academic community, the public, and policymakers about the extent of UPV installations on agricultural lands, including where UPV installations are occurring geographically and on what types and quality of crop land. This analysis represents a necessary stepping-stone to future analysis of the economic and environmental trade-offs for farmers, farming-dependent communities, and consumers between electricity generation and agricultural production.

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Appendix. Projections of Utility-Scale Photovoltaic Acres

Figure A.1. Projections of UPV Acres on all Lands

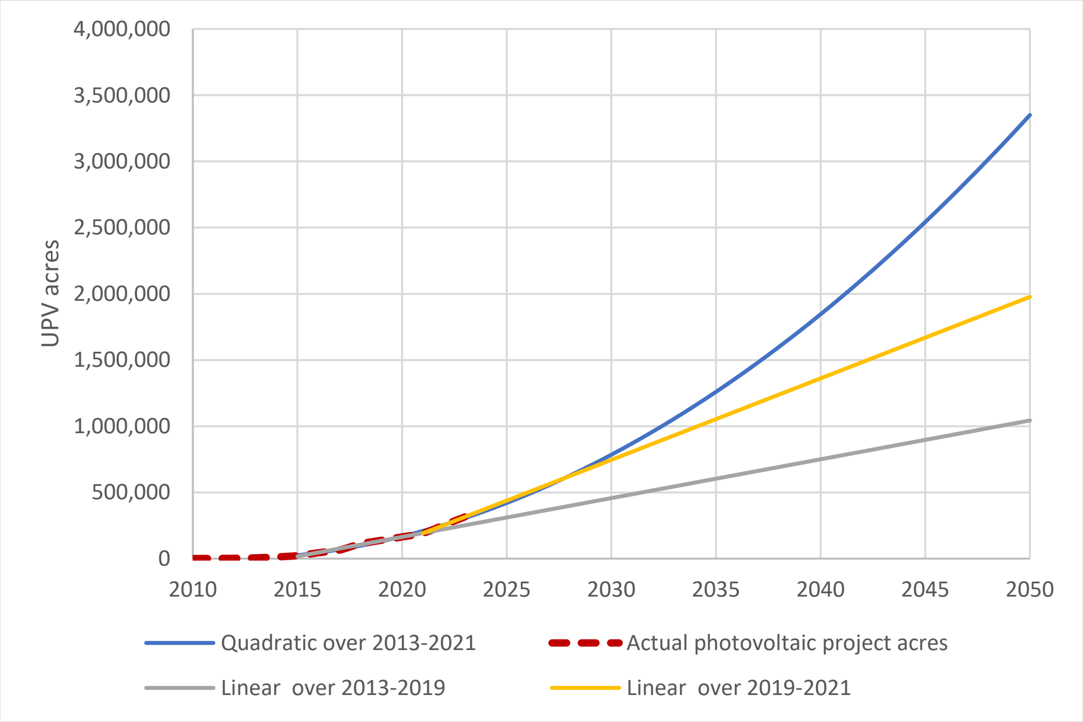

Figure A.2. Projections of UPV Acres on Agricultural Lands