The Distribution and Potential Ecological Impact of Solar Fields in Massachusetts

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Keywords: Solar Fields, Massachusetts, Deforestation, Landfill

Abstract

Since the late 2000s, there has been a substantial increase in solar energy production in Massachusetts due to state-sponsored renewable energy incentive programs. As a result, hundreds of solar fields have been constructed throughout Massachusetts in order to reduce the state's dependency on fossil fuels. While there is typically a positive connotation with renewable energy, the negative ecological impacts of solar field installation have rarely been studied. The two goals of this project were to determine which land cover categories have been converted to solar fields and to assess whether solar fields have been built on or near lands with ecological significance. The results show that forest is the most common land cover to be converted to solar fields in Massachusetts. In the southeastern portion of Massachusetts, solar fields are being built in close proximity to wetlands, critical natural landscapes, and areas of species conservation concern. To reduce deforestation, the authors recommend that future solar fields be built on capped/closed landfills. Also, environmental monitoring should take place in southeastern Massachusetts to better understand the impacts of solar fields on species' habitats and mobility.

Introduction

Solar energy, although utilized as a tool for many centuries, was first captured in the United States of America (U.S.A) by a photovoltaic cell (PV) in the 1950s (History, n.d.). Over the next few decades, further technological advancement pushed increases in the efficiency of solar cells, as well as their availability. By the 1970s, solar was a dominant source of power used in satellites and spacecraft. Coinciding with the formation of the U.S. Department of Energy in 1977, PV research was further boosted by the creation of the Solar Energy Research Institute (SERI) in Colorado, now the National Renewable Energy Laboratory, as the first ever federal facility organized specifically for the research and development of solar power (Laboratory History, n.d.). In more recent history, solar energy accounted for 1% of global energy used in 2015, and the number of solar installations in the U.S.A. passed 1 billion in 2016 (History, n.d.).

In Massachusetts, the solar industry is largely based around state-sponsored incentive and rebate programs, such as the Renewable Energy Trust. This "rebate program provided an incentive to customers in the form of a $/kW payment once a solar facility was built" (Solarisworking, n.d.). In 2009, there was only 3 megawatts (MW) of solar energy produced in the state. Then-Governor Deval Patrick set a statewide goal for solar energy usage, at 250 MW of solar by 2017, along with several programs including the Green Communities and Green Jobs Acts. These programs were quite successful, and Massachusetts passed the 250 MW bar well before 2017. This led the Department of Energy Resources set a new goal of 1600 MW by 2020 that is also expected to be reached (Massachusetts Solar Loan Program, n.d.). Additionally, the price of solar has dropped dramatically. Between the years of 2007 and 2013, there was an approximate 50-70% drop in price (Rogers & Wisland, 2014). While this drop was most significant for large scale projects, it was still quite large for residential and commercial projects, and is expected to continue dropping as the solar industry aggressively expands.

With this extensive expansion of solar usage, many are interested in the ecological impacts of solar installations. These interests are primarily based around the types of land chosen for installation, and the impacts they may have on the environment. With estimated land requirements for PV installations ranging from 3.5-10 acres per MW produced, this is a valid concern for installation impact on protected, forested, agricultural, or even aquatic land types (Environmental Impacts of Solar Power, n.d.) (Grippo *et al* 2015). Studies have shown that different types of PV installations have different land use requirements, as plants with sun-tracking capabilities may have increased efficiency on similar acreage compared to fixed panel installations (Ong *et al*, 2013). Land disruptions can be minimized and avoided by completing an extensive analysis of possible ecological impact prior to installation. Land already subject to disuse or degradement, such as closed landfills, could be prioritized for installation (Solar Power Plants: Large-Scale PV, n.d.). The benefits of this land use transition have already been realized in many locations. The town of Dennis, located on Cape Cod in eastern MA, chose to install a 6 MW solar field the area atop the town's closed landfill, making it one of the largest community-hosted photovoltaic projects in MA with anticipated savings projected to reach $500,000 annually for the next 20 years (Dennis Solar Farm, n.d.). While solar PV installations provide a reliable and sustainable alternative energy source, careful analysis should guide the choice in location to minimize the direct ecological and environmental impact of the installations.

Study Area

Massachusetts is over 60% forest cover (3.1 million acres) and is the 8th most forested state in the USA, with almost 80% of its forests privately owned (UMass Amherst, 2018). It is the 3rd most densely populated state, and loses over 13 acres of open space (forests and field) to development every day (Mass Audubon, 2014). A map of MA and the distribution of the solar fields can be seen in Figure 1.

Data pre-processing

All the data analyzed in this research is presented in table 1. In order for this study to obtain meaningful results, some data pre-processing was necessary. A dataset of Massachusetts solar fields from the U.S Energy Information Administration was the focal point of all analysis conducted in this research. A 350-meter buffer was created around each solar field location point (the rationale for this is explained in detail in the methods section). Massachusetts land use from 2005 was downloaded from MassGIS, and land cover from 2015 was provided by Clark University's Human Environment Regional Observatory. Since the 2005 land use dataset had more categories than the 2015 land cover dataset, the 2005 land use categories were consolidated to match the land cover categories in the 2015 land cover dataset in order to make the two datasets comparable. A digital elevation model (DEM) of Massachusetts was downloaded from MassGIS and converted to slope in ArcMap. All other layers seen in table 1 did not require pre-processing before analysis. It is also important to note that the BioMap2 dataset from MassGIS contained the critical natural landscape, species conservation concern, and wetlands data layers.

Methods

To assess which land uses have been most commonly converted to solar fields and how solar field construction has impacted Massachusetts habitats, the solar field location dataset was intersected with land use data as well as various environmental and conservation variables. The solar field dataset consisted of point locations of the nearest address or municipality associated with solar fields, as opposed to shapefile polygons that represented the true extent of each solar field. In order to include the extent of each solar field as well as some surrounding land, 350m buffers were created around each solar field point location. This modified solar field dataset was more appropriate for analysis than point locations because it enabled the visualization of land use and environmental effects relating to solar field construction. Considering that substantial solar energy development occurred after 2009 due to state-sponsored green energy incentivisation, a land use dataset from 2005 proved to be useful in determining the previous land use of current solar field locations. To determine which land use types have been converted to solar fields since the late 2000s, the first step was to clip 2005 and 2015 land use datasets to the solar field buffer shapefile. Zonal statistics were then calculated for the clipped land use datasets. This operation revealed the most common land uses within 350 meters of current solar fields. From these results, we determined which land uses the solar fields are commonly replacing (interpreted from 2005 land use data), as well as how land use is transitioning near solar fields after they are constructed (interpreted from 2015 land cover data). Visual assessment of certain sites in Google Earth over time helped verify the land use changes.

To determine if solar fields are disrupting habitats and important ecological processes, the solar field buffer polygons were intersected with the following environmental and conservation data layers: slope, aquifers, species critical linkages, critical natural landscape, species conservation concern, wetlands, major roads, and landfills/waste disposal.

Results

Distribution. The distribution of solar fields in MA is fairly disperse (Figure 1), with a large portion in central Massachusetts, and several more in the southeastern portion of the state (Plymouth and Bristol county). Analysis of the U.S. Energy Information Administration's data showed that the average MW Output by Town was 4.18 MW. 85 towns had a sum of 0-3 MW, while 47 had sums 3-6 MW, and outputs larger than 6 MW decreased substantially afterwards (Figure 2). Spencer was the town with the largest MW output at 22.1 MW (Figure 3), due to a recently installed 20.1 MW solar field. The recently installed SJA Solar LLC-Solterra Monastery is the largest solar field in MA. (Figure 18).

Land Cover. The results of this study indicate that the most common land cover type that is being transitioned to solar fields is forest (Figure 4). In 2005, forest was the most common land cover in 66% of the buffers surrounding the areas that solar fields were installed by 2017, while in 2015 forest cover was the most common land class in only 30.9% of land surrounding solar fields. This is a decrease of 35.13%. This study also suggests that a large portion of the surrounding area was transitioned into residential, which increased by 24.28% in areas near solar fields over the ten year period. Pasture/cropland was the other notable change in land cover over the time period, which increased by 4.63%.

Intersection of buffers with variables. Intersection analysis of 7 variables had varying amounts of significance. A summary of percentage of solar fields that intersect with each variable can be seen in Figure 12, while hotspot maps for each variable are shown in Figures 5-11. 68.7% of solar fields in MA are above aquifers, or 156 total fields (Figure 5). 48.0% intersect with critical linkages, or 109 total fields (Figure 6). 43.2% intersect with critical natural landscape, or 98 total fields (Figure 7). 36.1% intersect with species conservation concern, or 82 total fields (Figure 8). 14.5% intersect with Wetlands, or 33 total fields (Figure 9). 18.1% of solar fields are in direct proximity to major roads, or 41 total fields (Figure 10). 11.9% intersect with closed/capped landfills, or 30 total fields (Figure 11).

Slope. The mean slope of land that solar fields were located was 4.02 degrees, with 120 fields between 0-4 degrees (Figure 13).

Discussion

The results of this study show that there is a large amount of deforestation to build solar fields in MA. Two examples of deforestation due to solar field construction can be seen in Figures 14 and 15. Deforestation causes significant ecological impacts such as habitat loss and fragmentation. Additionally, the loss of trees creates areas that are no longer able to sequester carbon while releasing oxygen. The 35.13% decrease of forest land cover in areas surrounding solar fields from 2005 to 2015 is not a promising trend for the future.

Another concern is the high abundance of solar fields in southeastern MA (Plymouth and Bristol County), which highly intersects with the environmental variables used in this study (critical linkages, critical natural landscape, species conservation concern and wetlands). This area of MA has a large amount of forest cover, is not as densely populated as central and eastern MA, and has high importance as it is a highly suitable ecological area for varying species throughout the area. We recommend that more intense environmental monitoring and regulation take place in this portion of MA before more damage is done to these ecologically valuable areas.

An interesting minor trend found in this study indicates that some pastures/croplands are being converted to solar fields. An example of pasture/cropland being converted to solar fields can be seen in Figure 16.

We recommend that future solar fields are built on capped/closed landfills. Currently there are only 30 solar fields in these areas. There are 346 total closed/capped landfills in MA, which means there are 316 potential spots for solar fields to be installed. These areas are already deforested, making them highly suitable. An example of a solar field on a capped/closed landfill can be seen in Figure 17.

Conclusion

Solar fields are usually seen as completely beneficial to combating climate change; however, the results of this study show that depending on the location of where solar fields are installed, there can be serious ecological impacts. Forest is the most common land use being converted to solar fields, and a large amount of solar fields are in ecologically valuable areas, with a common hotspot in the southeastern portion of MA (Plymouth and Bristol County). This should be a major concern for environmentalists and conservationists, and should be cause for more regulation to take place. We recommend that solar fields be built on capped/closed landfills as these areas are numerous, have already been deforested, and have had their ecological impacts be sustained by the environment.

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Figures

Data Name	Description	Source	Type	Year
Solar Fields	Shapefile of solar fields in MA	U.S. Energy Information Administration (EIA)	Point	2017
Land Use	40 land use types	MassGIS	Polygon	2005
Land Cover	17 land cover types	HERO Program	Raster	2015
County boundaries	Boundaries of the 14 counties in Massachusetts	MassGIS	Polygon	2007
Critical Linkages	Points representing potential road passage structures (contingent units)	UMass Amherst. Critical Linkages Project, Phase 1	Point	2012
BioMap2	Based on biodiversity conservation	MassGIS	Polygon	2010
Elevation	Terrain surface elevation	MassGIS	Raster	2005
Aquifers	Underground water sources of high, medium and low yield	MassGIS	Polygon	2007
MassDEP Solid Waste Diversion and Disposal	Locations of land disposal of solid waste	MassGIS	Polygon	2016
MassDOT Roads	All public and many private roadways in Massachusetts and includes designations for Interstate, U.S. and State routes.	MassGIS	Line	2018

Table 1: Data used in analysis.

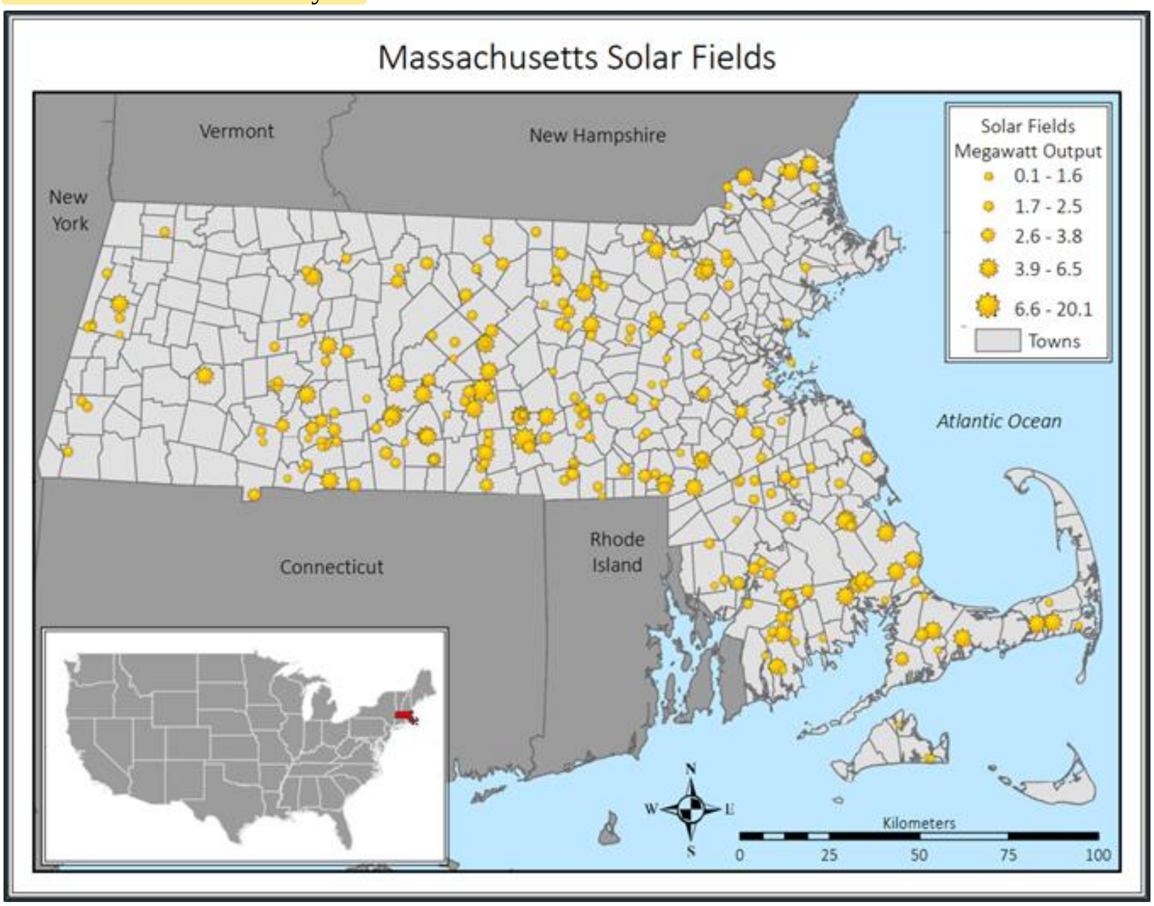


Figure 1: All Solar Fields in MA in 2017, from the U.S. Energy Information Administration online data.

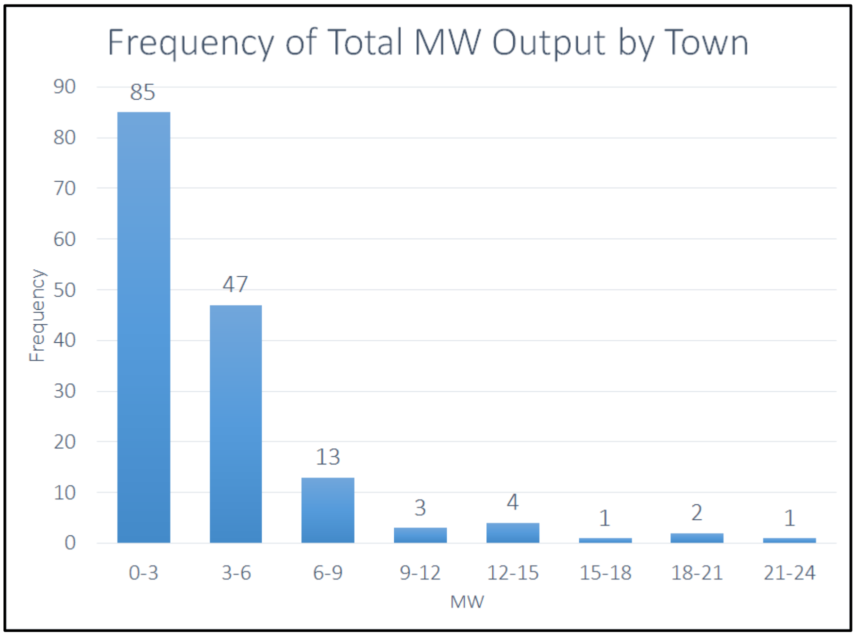


Figure 2: Frequency of Total MW Output by Town after all solar fields in each town were summed.

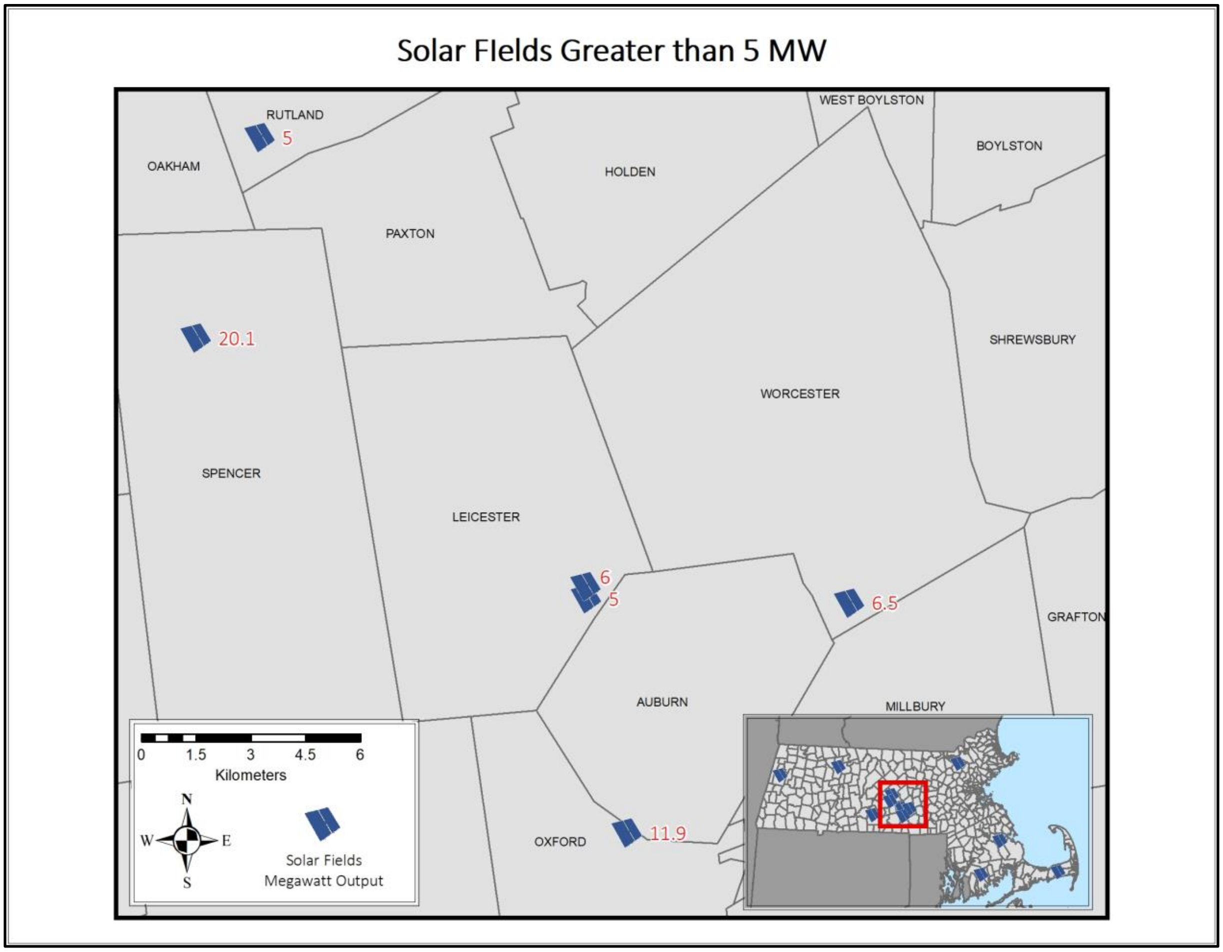
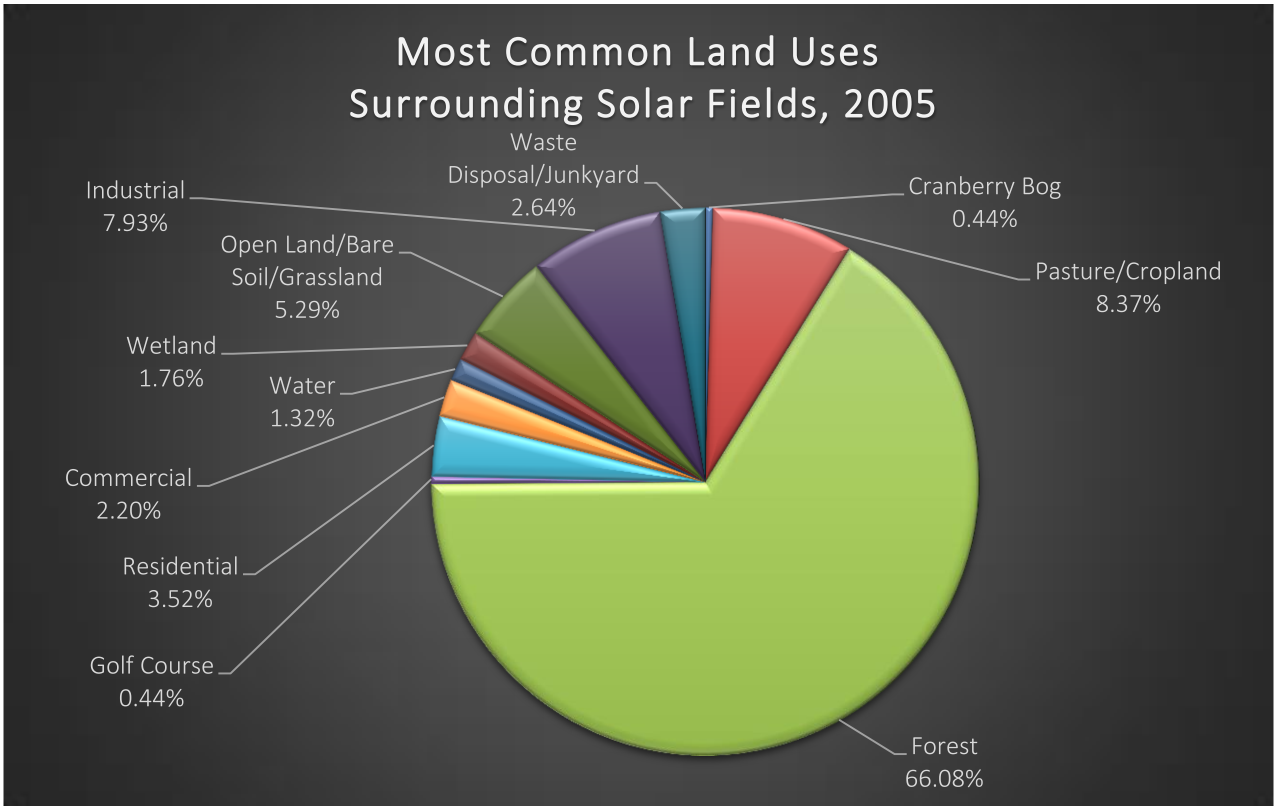


Figure 3: Hotspot of Solar Fields with a MW output greater than 5 (14 in total).



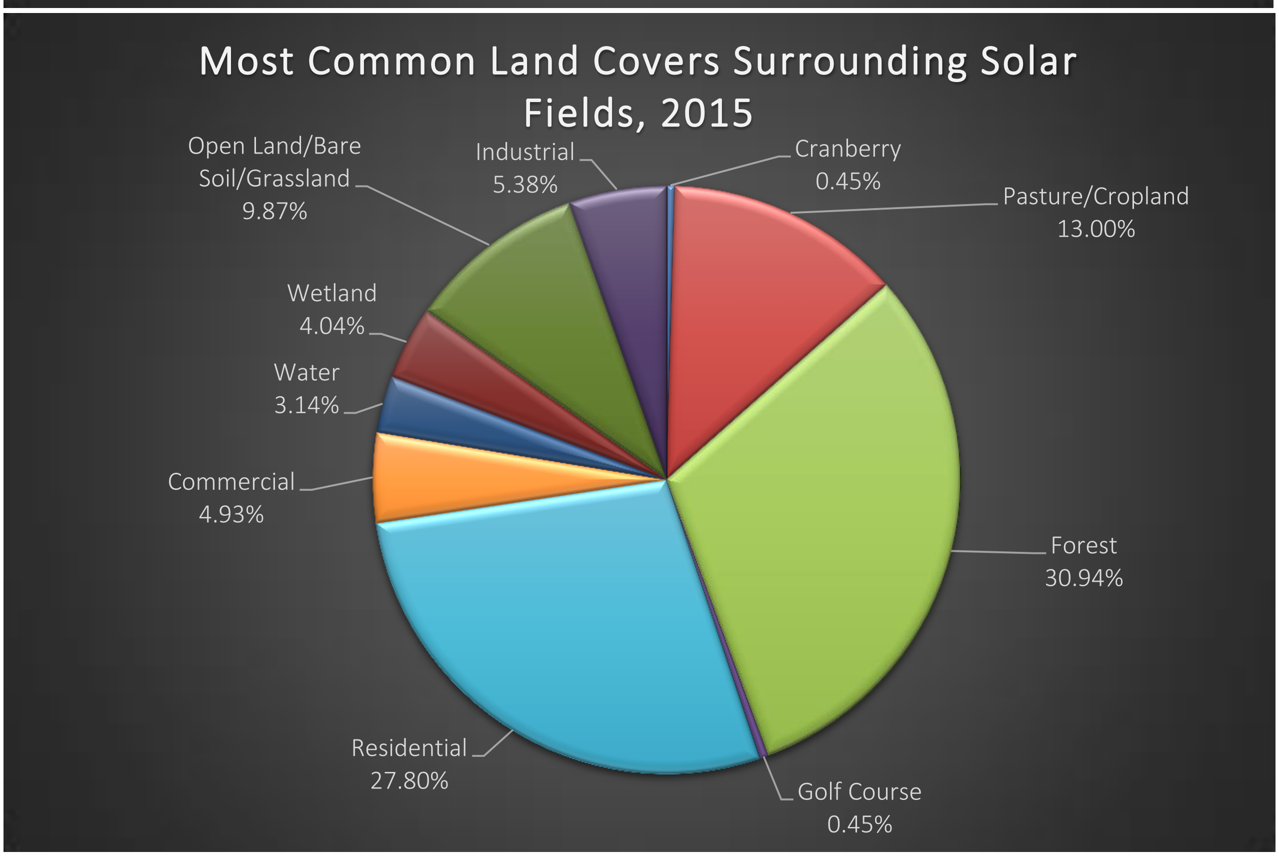


Figure 4: Most common land use surrounding solar fields, 2005 (top). Most common land cover surrounding solar fields, 2015 (bottom).

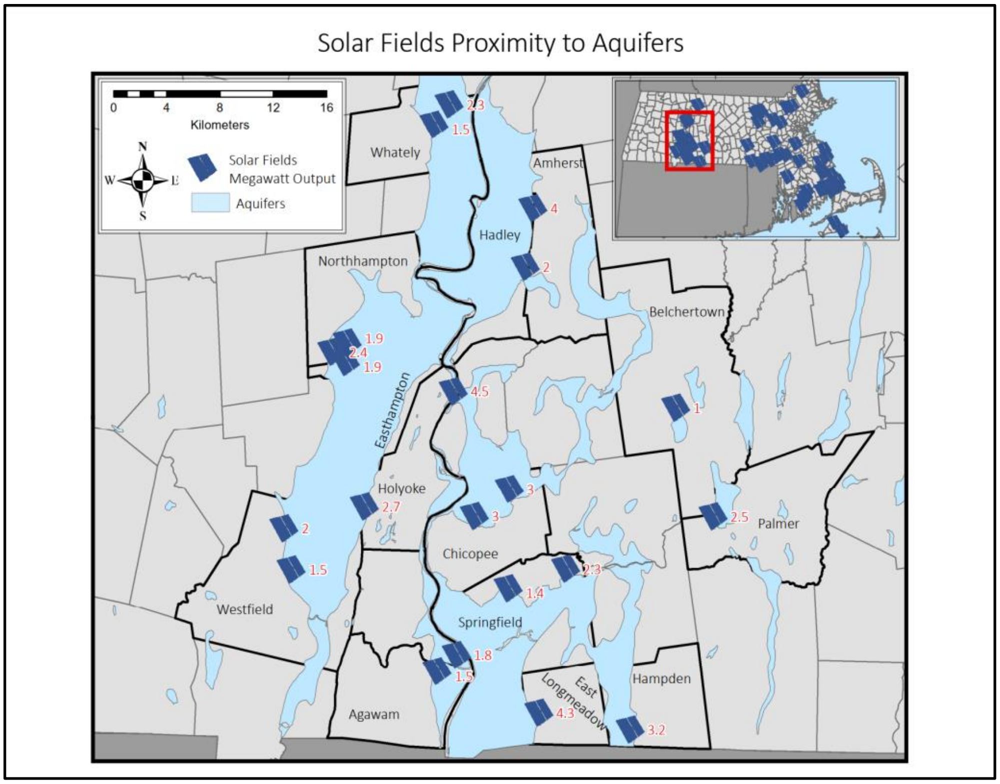


Figure 5: Hotspot map of solar fields that intersect with aquifers in western MA. 68.7% of Solar Fields intersect with Aquifers (156 in total).

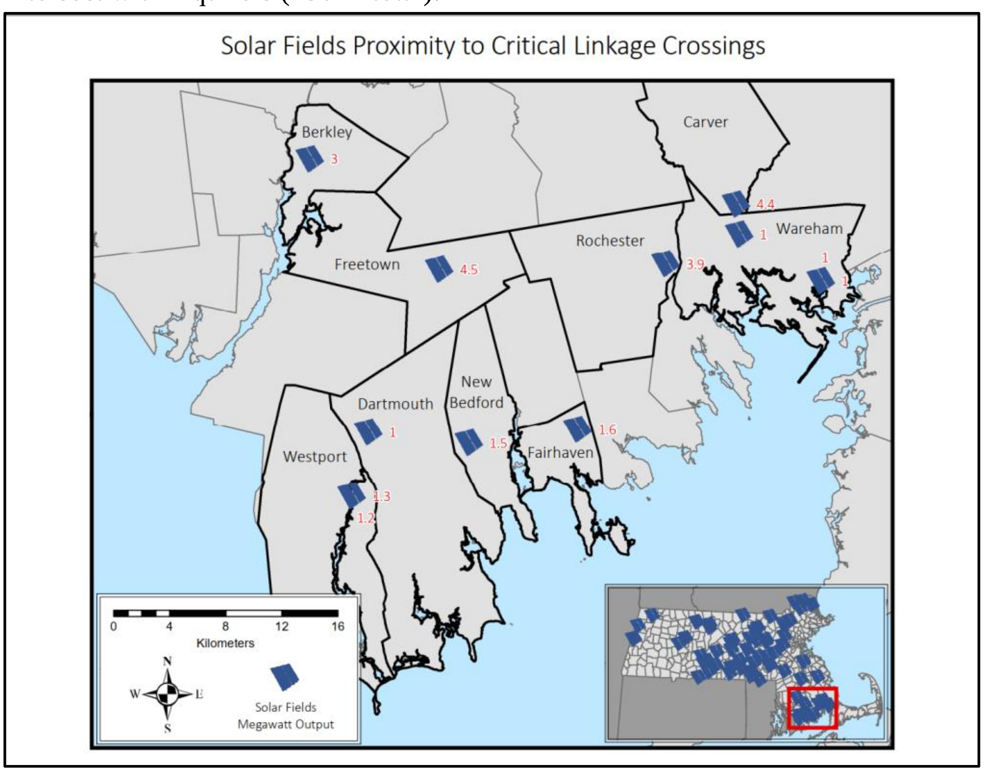


Figure 6: Hotspot map of solar fields that intersect with critical linkages in southeastern MA. 48% of Solar Fields intersect with critical linkages (109 in total).

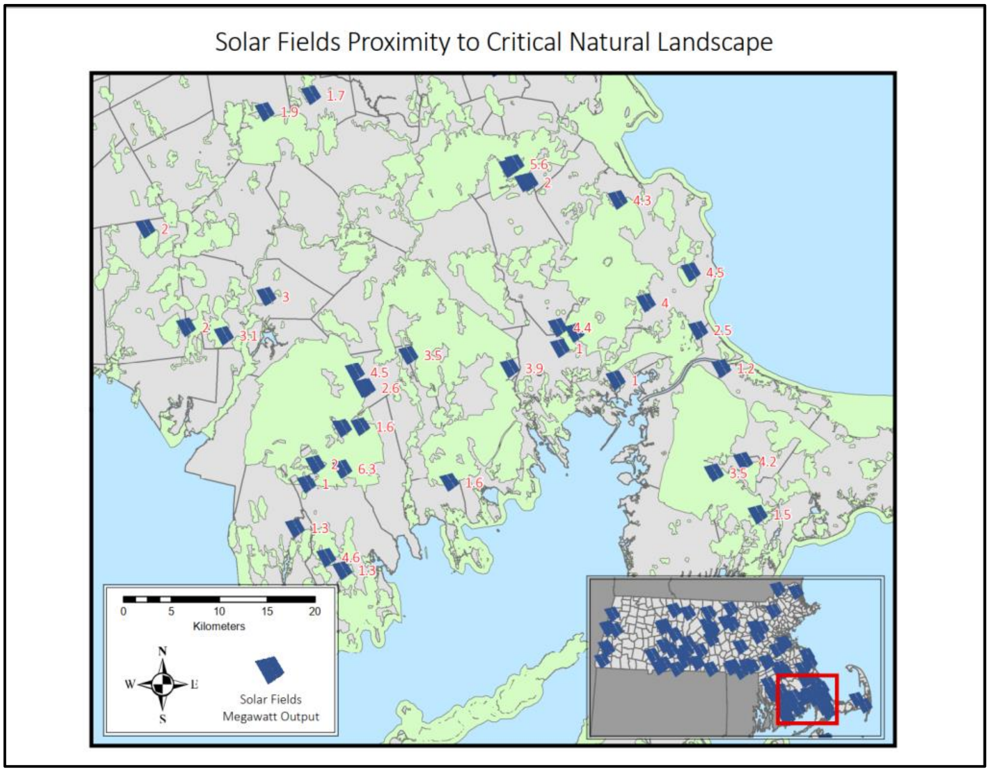


Figure 7: Hotspot map of solar fields that intersect with critical natural landscape in southeastern MA. 43.2% of Solar Fields intersect with critical natural landscape (98 in total).

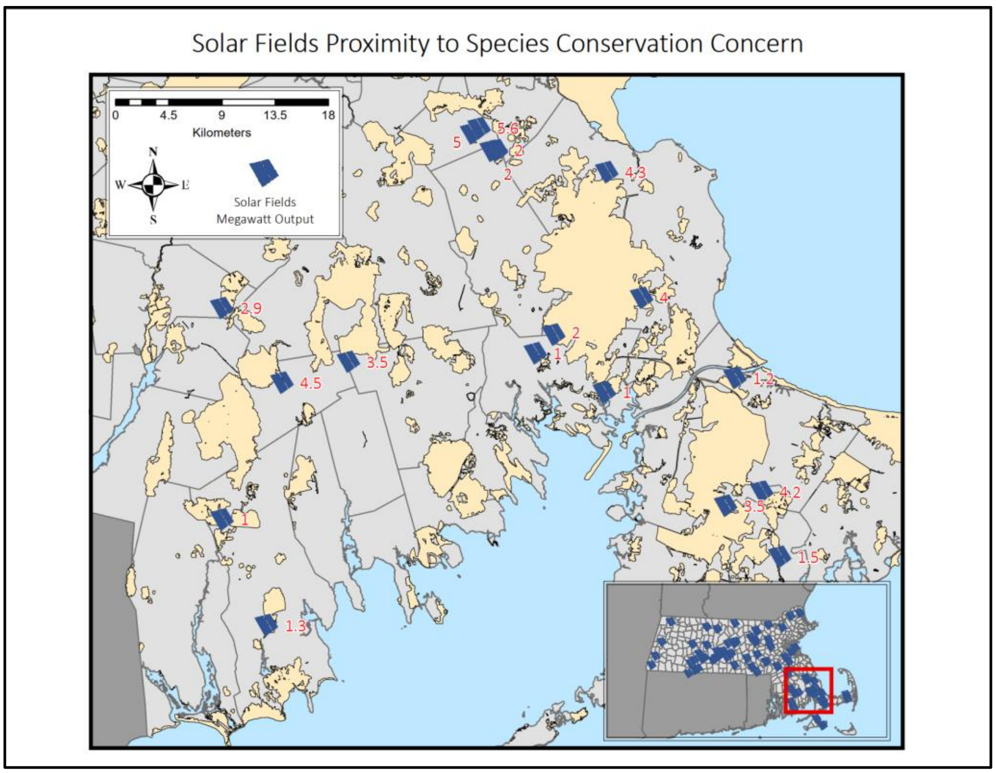


Figure 8: Hotspot map of solar fields that intersect with species conservation concert in southeastern MA. 36.1% of Solar Fields intersect with species conservation concern (82 in total).

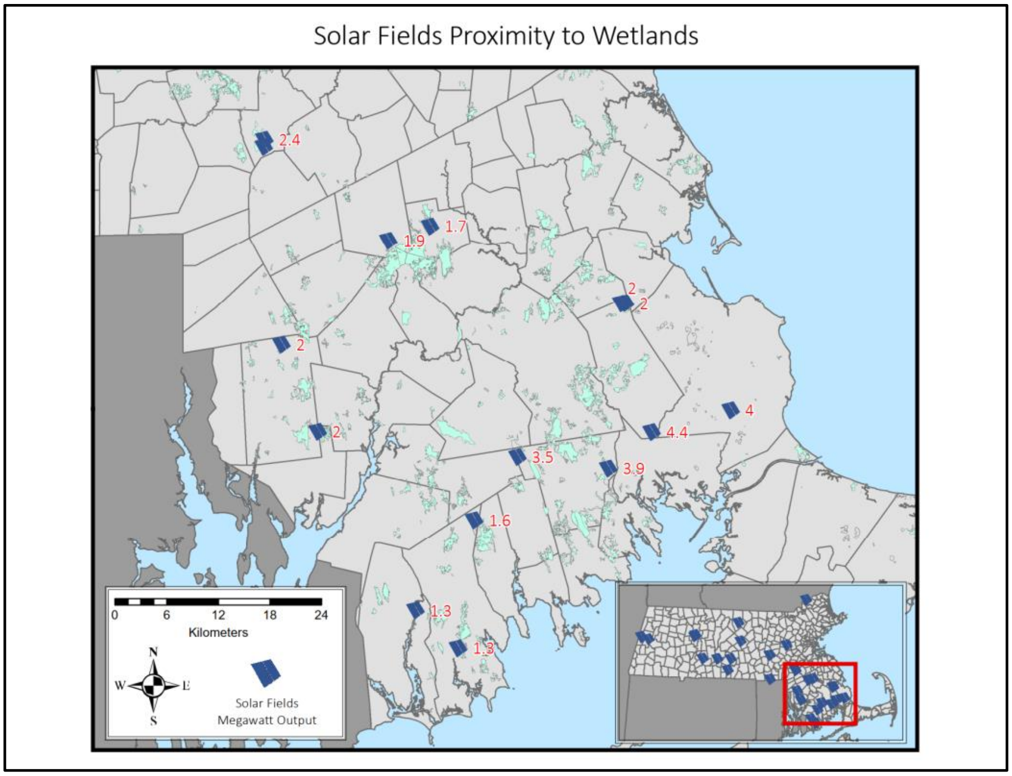


Figure 9: Hotspot map of solar fields that intersect with wetlands in southeastern MA. 14.5% of Solar Fields intersect with wetlands (33 in total).

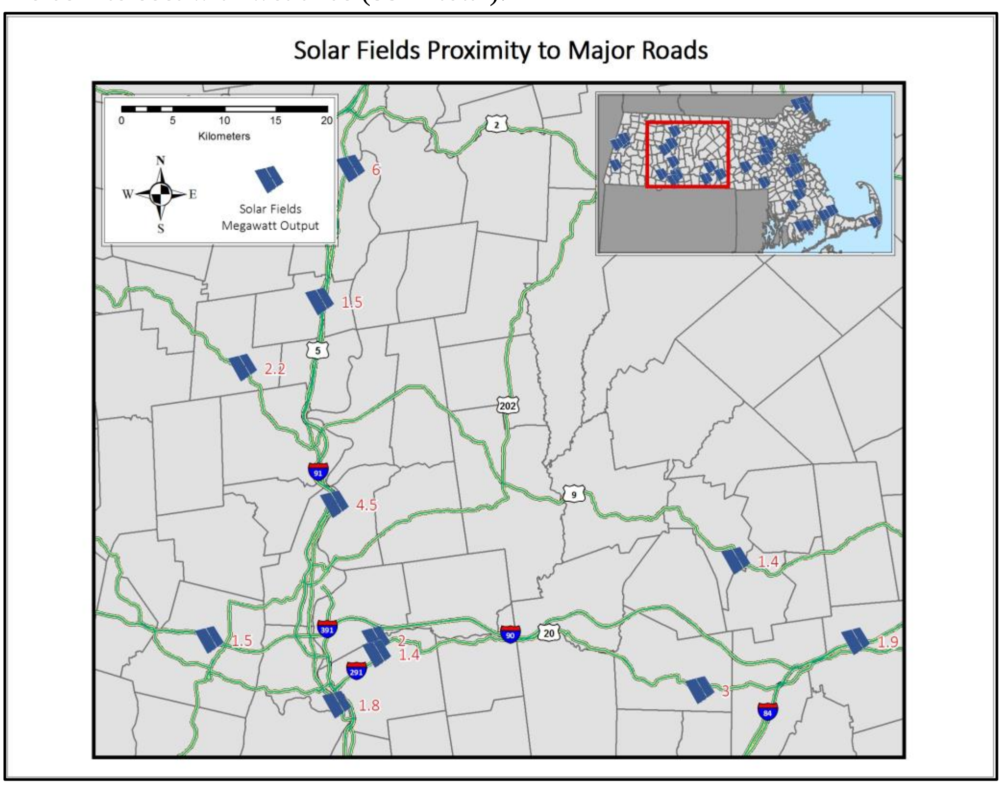


Figure 10: Hotspot map of solar fields near major roads in western MA. 18% percent of Solar Fields are near major roads (41 in total). The major roads shown here are I-90, I-91, and Route 9.

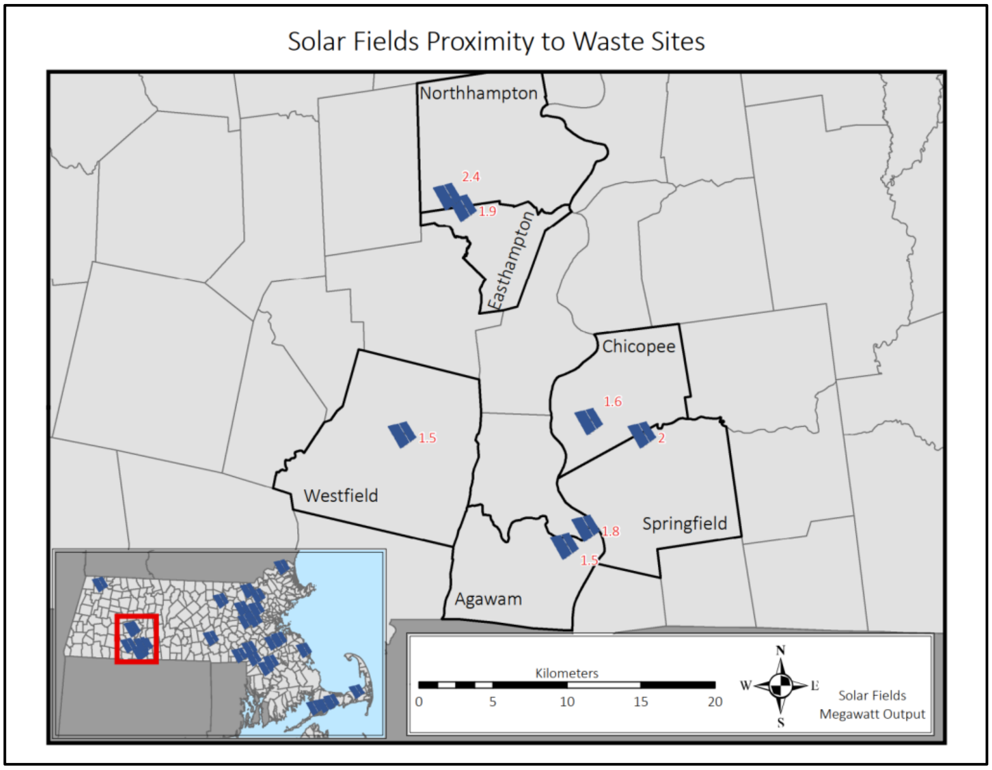


Figure 11: Hotspot map of solar fields that intersect with waste disposal facilities in western MA. 11.9% of Solar Fields intersect with waste disposal facilities that are capped/closed (30 in total).

Rank	Variable	%
1.	Aquifers	68.72
2.	Critical Linkages	48.02
3.	Critical Natural Landscapes	43.17
4.	Species Conservation Concern	36.12
5.	Roads	18.06
6.	Wetlands	14.54
7.	Waste/Landfill	11.86

Figure 12: Percentage of solar fields that intersect with each variable, ranked.

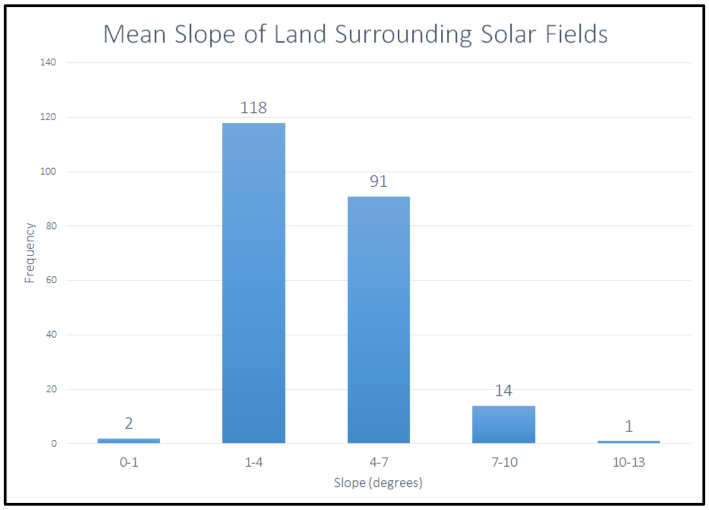


Figure 13: Histogram of mean slope of land surrounding solar fields.

Figure 14: An example of deforestation to build solar fields in Plymouth, MA. A 4.0 MW output field. 2005, 97% forest cover within buffer (left), 2018, a large portion deforested (right). Images from Google Earth Pro.

Figure 15: An example of deforestation to build solar fields in Dartmouth, MA. A 4.6 MW output field. 2005, 91% forest cover within buffer (left), 2018, 54% forest cover within buffer (right). Images from Google Earth Pro.

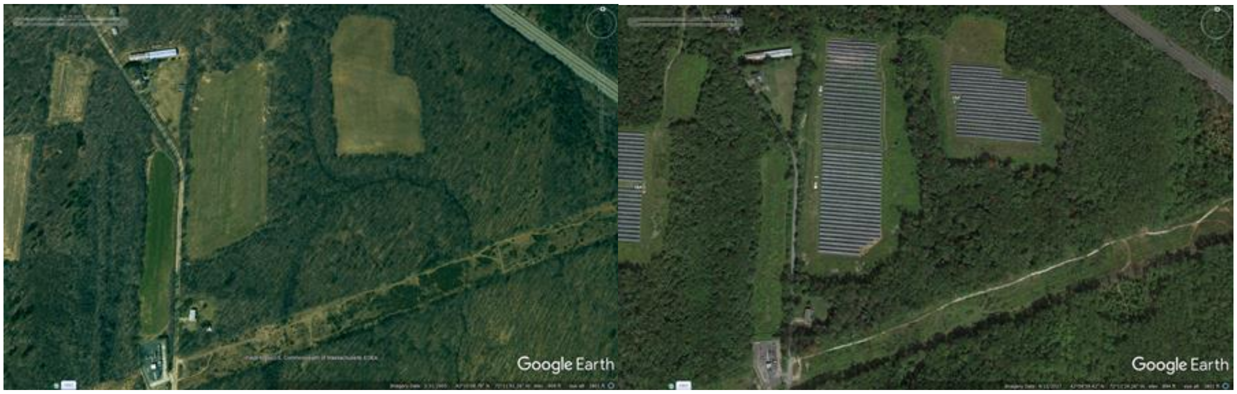


Figure 16: An example of cropland being converted to solar fields in Warren, MA. A 4.0 MW output field. 2005, 75% cropland within buffer (left), 2018, large portion converted to solar fields (right). Images from Google Earth Pro.


Figure 17: An example of a capped/closed landfill being converted to solar fields in Plainville, MA. A 4.9 MW output field on a slope of 9.7 degrees. 2005 (left), 2018 (right). Images from Google Earth Pro.

Figure 18: A 20.1 MW Solar Field in Spencer, MA. 2005 (left), 2017 (right). Images from Google Earth Pro.