Estimating the Net Change in Carbon Dioxide Emissions for Solar Projects in Massachusetts

September 2021 – White Paper

Applied Economics Clinic

Prepared for: Borrego

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I. Introduction

This Applied Economics Clinic white paper—prepared on behalf of Borrego—estimates the net change in carbon dioxide (CO_2) emissions of Borrego's proposed solar projects at three sites located in Wareham, Massachusetts. The net emission savings of these proposed solar projects is the sum of "positive" CO_2 emissions savings from the electric grid due to renewable energy generation and "negative" CO_2 emissions due to land-use conversion from forestland to grassland.

These types of estimates are used in permitting applications to assess the potential environmental impact of proposed projects in an effort to mitigate damage to the environment. Increasingly, states like Massachusetts and New York are asking for information on the lifetime and/or net emissions impacts of infrastructure projects. Renewable energy projects displace greenhouse gas emitting fossil-fuel-based electric generation but may also add some lifetime emissions from materials, construction, or site preparation. Net emissions analysis clarifies the lifetime impact of a project, like a new solar farm, on greenhouse gas emissions.

Section II of this white paper summarizes the findings of the net emissions analysis for Borrego's proposed solar projects in Wareham, Massachusetts. Sections III and IV provide a closer look at the estimated CO_2 emissions due to land-use conversion and CO_2 emissions savings from the electric grid, respectively.

II. Net Emissions Benefit and Summary of Findings

Borrego's proposed Wareham solar projects produce a net benefit to the grid: emission savings after netting out increased emissions and sequestration losses from land-use changes. The renewable energy produced by the proposed projects more than offsets the emissions impact from converting from forestland to grassland to make way for these developments (see Table 1). At the three proposed sites, renewable energy generated displaces approximately 64,600, 86,600, and 107,300 metric tons CO_2, respectively, over the next 20 years. Clearing trees and planting grass at the three sites results in an emissions impact of roughly 15,000, 21,000, and 27,200 metric tons CO_2, respectively, over the 20-year time period. The result is a net benefit of 49,500, 65,700, and 80,100 metric tons CO_2 savings at the three project sites. Borrego's proposed projects offset four times more CO_2 emissions than are emitted in their development.

Table 1. Twenty-year net CO_2 grid benefit of Borrego's proposed Wareham projects

Project Site	Acreage	Grid Benefit (Emission Savings)	Emissions from Land Use Conversion	Net Benefit (Emission Savings)
		(cumulative metric tons CO_2, 2021-2040)		
27 Charge Pond Road	40.1	64,572	-15,038	**49,534**
150 Tihonet Road	49.2	86,624	-20,962	**65,662**
140 Tihonet Road	65.3	107,269	-27,170	**80,099**
TOTAL	**154.6**	**258,465**	**-63,170**	**195,295**

These calculations are likely conservative in that they do not include (i) new carbon sequestration resulting from the meadow that will grow beneath the panels and (ii) future sequestration when the forest regenerates after project decommissioning (young, growing forests sequester carbon at a considerably higher rate than mature forests).

III. Emissions from land-use conversion at Wareham project sites

Borrego's three proposed projects in Wareham, Massachusetts—27 Charge Pond Road, 150 Tihonet Road, and 140 Tihonet Road—would result in a net emission increase from biomass and soil due to the land-use conversion from forestland to grassland (with a portion of that land covered by built infrastructure such as solar panels and access roads). The total emissions impact includes:

- CO_2 emissions from carbon sequestration losses in biomass and soil;
- End-use emissions from burning felled trees as firewood; and
- Net emissions from drained organic soils from changes in vegetation cover.

Each of the three sites are currently forested land that would be cleared and converted to grassland to develop Borrego's proposed solar projects. The twenty-year cumulative emissions impact broken down by emissions type are shown in Table 2 for each of the project sites.

Table 2. Twenty-year cumulative emissions impact due to land-use conversion at Borrego's proposed Wareham projects

Project Site	Biomass Sequestration Losses	Biomass End-Use Emissions	Soil Carbon Sequestration Losses	Soil Carbon Emissions	Total Emissions Impact from Land Use Conversion
	(cumulative metric tons CO_2, 2021-2040)				
27 Charge Pond Road	-4,031	-1,011	-10,119	122	**-15,038**
150 Tihonet Road	-7,891	-968	-12,092	-12	**-20,962**
140 Tihonet Road	-9,381	-1,833	-15,811	-145	**-27,170**
TOTAL	-21,303	-3,812	-38,021	-34	-63,170

Biomass sequestration losses and biomass end-use emissions

Borrego's three proposed Wareham sites contain various tree species that currently provide carbon sequestration benefits. The removal of these trees would result in additional CO_2 emissions due to the loss of future carbon sequestration. The removed trees would no longer be able to store new CO_2 each year resulting in a net increase in annual greenhouse gas emissions. In addition, carbon that is currently stored in the existing trees (commonly referred to as "carbon stocks") would be released into the atmosphere if any of the felled timber were burned.

The estimated annual CO_2 emissions due to future biomass sequestration losses are presented in Table 3. (Please see the Methodology section below for a more detailed discussion of the development of these estimates.) Tree removal at the proposed Wareham sites would result in carbon sequestration losses of approximately 4,000, 7,900, and 9,400 metric tons CO_2, respectively, from 2021 to 2040.

Table 3. CO_2 emissions due to biomass sequestration losses at Borrego's proposed Wareham projects

Project Site	Acreage	Biomass Carbon Sequestration Losses (*metric tons CO_2, 2021-2040*)	
		Annual	20-Year Total
27 Charge Pond Road	40.1	-202	-4,031
150 Tihonet Road	49.2	-395	-7,891
140 Tihonet Road	65.3	-469	-9,381
TOTAL	**154.6**	**-1,065**	**-21,303**

Borrego assumes that 65 percent of the felled timber across the Wareham project sites will be chipped on-site with the remainder to be used as firewood (20 percent) or sawmill lumber (15 percent). The portion of the felled timber that will become firewood will release the stored carbon as CO_2 emissions once it is burned. The estimates of these end-use emissions are presented in Table 4. Burning the felled timber as firewood would result in CO_2 emissions of 1,000, 1,000, and 1,800 metric tons, respectively, at the three project sites.

Table 4. CO_2 emissions from biomass end-use at Borrego's proposed Wareham projects

Project Site	Weight of Burned Timber (*metric tons*)	Emissions from Biomass End-Use (*metric tons CO_2, 2021-2040*)	
		Annual	20-Year Total
27 Charge Pond Road	544	51	1,011
150 Tihonet Road	525	48	968
140 Tihonet Road	997	92	1,833
TOTAL	**2,067**	**191**	**3,812**

Methodology

To estimate the total CO_2 emissions from biomass sequestration losses, AEC quantified the difference between current and future carbon stocks of forests located at each of the Wareham project sites over a 20-year period. AEC was provided with site-specific data by Jeffrey D. Golay on tree characteristics for each of the proposed Wareham project sites broken down by tree species and diameter-at-breast height (DBH) measurements where applicable.[1] The three Wareham sites contain the following tree species: white pine, pitch pine, white oak, black oak, red maple, paper birch, and bigtooth aspen.[2]

[1] Personal communication with Jeffrey D. Golay (Massachusetts Licensed Forester #399) accompanied with forestry reports of each project site dated March 4 and 5, 2021.

[2] White pine and pitch pine are both classified as softwood trees, while the other species are classified as hardwood trees. White pine was the most abundant tree species across the three sites accounting for two-thirds of total trees.

To estimate the current carbon stock of the forest on each Wareham site, AEC converted the weight of living biomass (i.e., aboveground and belowground) from short tons to metric tons for each tree species at each DBH measurement, then calculated the standard dry weight of the trees by multiplying the total biomass weight (aboveground and belowground) by the dry weight ratio of 72.5 percent, an average calculated for temperate tree species—the types of trees present at the three project sites.[3,4] Although the average dry weight ratio is for aboveground biomass, AEC applied it to both above- and belowground biomass due to the absence of a dry weight ratio for the belowground carbon stock pool. AEC used this average dry weight ratio across species due to the absence of species-specific dry weight ratio information for the trees located on the sites.

AEC calculated the carbon content of the trees by multiplying the dry weight of the trees by carbon factors of 0.521 and 0.498 for hardwood and softwood trees, respectively, then converted the carbon stock from C to CO_2 emissions by multiplying by the molar mass ratio of CO_2 to C (44 units CO_2/12 units C ≈ 3.67).[5]

To calculate the future carbon stock of the forests on the Wareham project sites, AEC first estimated the rate of tree growth over the 20-year analysis period and the relationship between DBH and biomass weight for each tree species (see below for further details on these steps in the methodology). The project site's 2040 carbon stock was projected from the current carbon stock based on these factors. Finally, AEC estimated the CO_2 emissions due to biomass sequestration losses at each Wareham site by subtracting the future carbon stocks from the current carbon stocks for each site (see Table 5).

Table 5. Current and future biomass carbon stocks at Borrego's proposed Wareham projects

Project Site	Biomass Carbon Stocks (*metric tons CO_2*)		
	Current Carbon Stocks in 2021	Future Carbon Stocks in 2040	Biomass Carbon Sequestered from 2021-2040
27 Charge Pond Road	5,054	9,085	4,031
150 Tihonet Road	4,838	12,729	7,891
140 Tihonet Road	9,166	18,547	9,381
TOTAL	**19,059**	**40,361**	**21,303**

To estimate tree growth, AEC used a simplified, linear growth rate formula, where the rate of growth is a function of a tree's age and DBH. AEC estimated the average growth rate for trees located on the Wareham project sites by dividing the mean DBH measurements of each species by the average age of each species, then (due to the small sample size) averaged across tree species resulting in an average growth rate of roughly 0.14 inches per year. AEC approximated the total tree growth over the 20-year analysis period by multiplying the average growth rate (0.14 inches per year) by twenty years to yield a total 20-year growth of approximately 3

[3] University of New Mexico. "How to calculate the amount of CO_2 sequestered in a tree per year". Available at: https://www.unm.edu/~jbrink/365/Documents/Calculating_tree_carbon.pdf

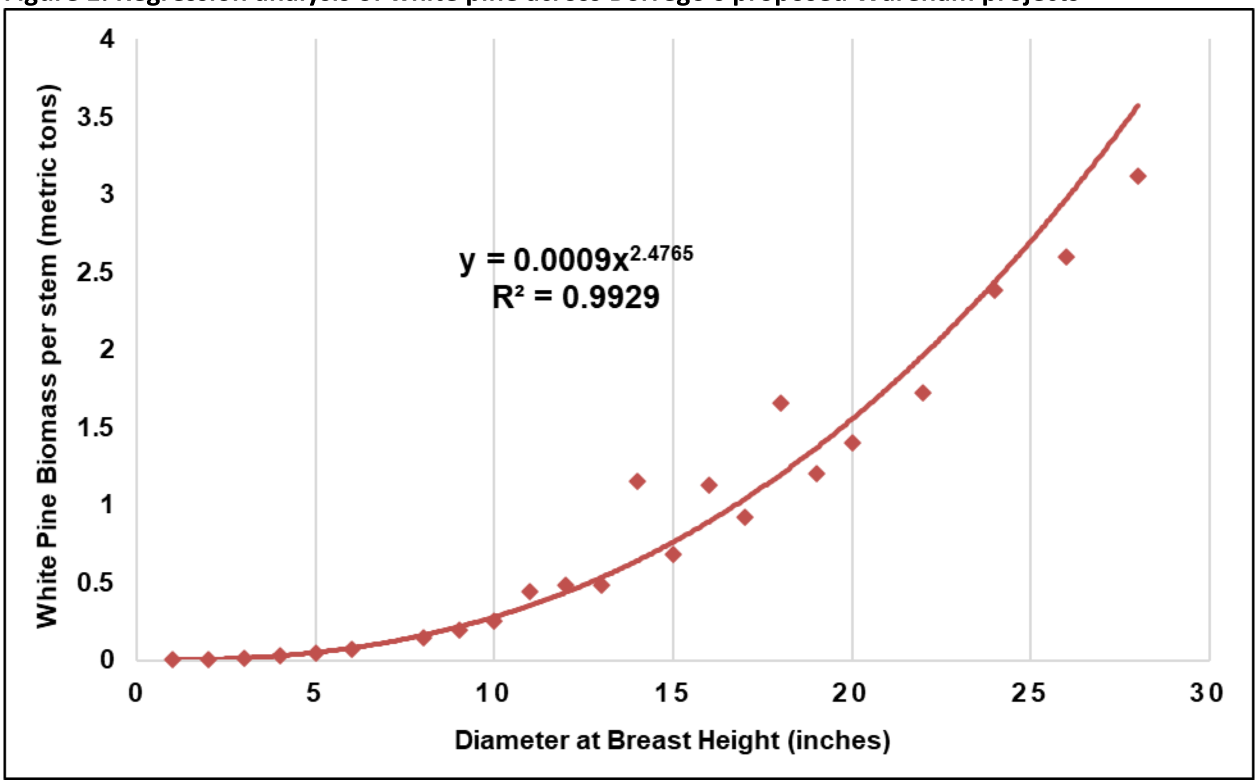
[4] DeWald, Scott J., Scott Josiah, and Becky Erdkamp. 2005. "Heating with wood: Producing, harvesting and processing firewood." Cooperative Extension, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln. Available at: https://outreach.cnr.ncsu.edu/ncwood/documents/NebraskaFirewoodGuide.pdf

[5] Earth Labs. November 11, 2019. "Living in a Carbon World – Part B: Carbon Storage in Local Trees". Available at: https://serc.carleton.edu/eslabs/carbon/1b.html

inches in DBH.

To estimate the relationship between total biomass and DBH, AEC conducted a regression analysis by tree species to construct species-specific allometric equations.[6] To determine this allometric relationship, AEC calculated the total biomass per stem across the three Wareham sites for each tree species by dividing the total biomass (in metric tons) by the total number of stems at each DBH measurement, then regressed that ratio against the DBH measurements. The resulting allometric equations measure the biomass-per-stem ratio as a function of DBH across the three sites for each tree species (see Figure 1 for the white pine regression analysis).

Figure 1. Regression analysis of white pine across Borrego's proposed Wareham projects



To estimate the CO_2 emissions from timber end-use, AEC considered the expected end-uses for the felled trees from the three project sites. Borrego assumes that 65 percent of the felled timber across the three projects will be chipped on-site, while 20 percent will be used as firewood, and 15 percent will be used for sawmill lumber. Since firewood is the only end-use that is likely to result in CO_2 emissions from burning, AEC multiplied the current 2021 carbon stocks (in metric tons of CO_2) at each project site from Table 5 above by 20 percent to calculate the maximum amount of CO_2 emissions that could be released from burning the felled trees allocated for firewood. These emission estimates represent the total amount of CO_2 that would be released under the conditions of "complete" combustion of the firewood.[7] Incomplete combustion of the firewood, however,

[6] Allometric equations are commonly used in forestry to describe the relationship between tree characteristics. The allometric equations used in this analysis were in the form of a power function (i.e., $Biomass = a * DBH^b$). Source: Picard, Saint-André, & Henry. 2012. *Manual for building tree volume and biomass allometric equations: from field measurement to prediction.* Cirad; FAO. Available at: http://www.fao.org/3/i3058e/i3058e.pdf

[7] Complete combustion of wood occurs when there are sufficient oxygen levels resulting in all stored carbon to be released as CO_2.

would result in a small portion of the stored carbon to be released as carbon monoxide and other carbon-based pollutants. The ratio of CO_2 released during combustion relative to other carbon-based pollutants is known as the "combustion efficiency"—which is estimated to be greater than 90 percent but varies based on the type of wood burned and the conditions of the fire.[8] Due to this uncertainty, AEC made the conservative assumption that all carbon stored in the felled trees is released as CO_2 emissions, which provides a maximum estimate for end-use emissions.

Comparison to EPA methodology

This section makes a one-to-one comparison between AEC's biomass carbon sequestration calculations described above and the methodology used by the U.S. Environmental Protection Agency (EPA). The EPA provides a different, more generic methodology for calculating the net annual change in biomass carbon stocks. The EPA methodology produces a generic estimate of the change in annual carbon stocks for forestland anywhere in the United States of 0.52 metric tons carbon (C) sequestered per hectare per year.[9] The EPA's estimate includes carbon sequestration from five different carbon pools: aboveground biomass, belowground biomass, dead wood, litter, and soil (including mineral and organic soil). As part of its analysis, EPA calculates carbon stocks for aboveground biomass, belowground biomass, and soil. AEC's analysis of soil CO_2 emissions is presented in the next section of this memo and is thus excluded from this comparison. In addition, AEC excluded analysis of dead wood and litter due to lack of available data and the fact that that dead wood and litter do not actively sequester carbon like living biomass and soils.

For the purpose of comparison to AEC's biomass sequestration estimates above, AEC modified EPA's forest sequestration factor—0.52 metric tons of C sequestered per hectare per year—to only include carbon sequestered by living biomass (i.e., aboveground and belowground biomass). Although EPA does not provide a breakdown of the annual change in sequestration factor by carbon pool source the agency does provide the breakdown used in estimating its carbon stock density estimate (210 metric tons C per hectare) as shown in Figure 2.[10]

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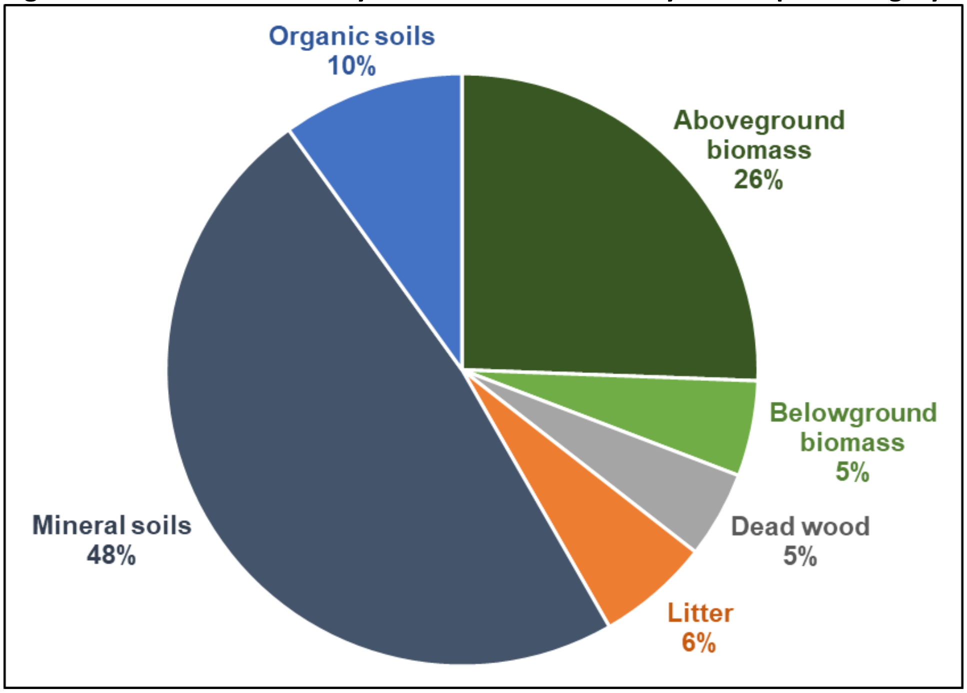
[8] Tsuchiya, Y. No date. *CO/C02 Ratios in Fire*. Institute for Research in Construction. p.519, 522. Available at: https://iafss.org/publications/fss/4/515/view/fss_4-515.pdf

[9] EPA's estimate includes carbon sequestration from five carbon pools: aboveground biomass, belowground biomass, dead wood, litter, and soil (including mineral and organic soils).

[10] U.S. EPA. "Greenhouse Gases Equivalencies Calculator - Calculations and References." Available at: https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

Figure 2. Carbon stock density of U.S. forests in 2017 by carbon pool category



Source: U.S. EPA. "Greenhouse Gases Equivalencies Calculator - Calculations and References." Available at: *https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references*

Using this breakdown, AEC calculated the proportion of total carbon density attributable to living biomass to be 31 percent (the sum of aboveground and belowground biomass percentages in green in Figure 2). This proportion was then multiplied by EPA's total forest sequestration factor (0.52 metric tons C per hectare per year) to result in the sequestration factor for living biomass in U.S. forests of 0.16 metric tons C per hectare per year. This procedure is necessary to modify the EPA's overall forest sequestration factor to account only for the portion that is directly comparable to AEC's biomass calculations.

AEC converted the annual sequestration factor for living biomass (0.16 metric tons C per hectare) from C to CO_2 emissions by multiplying by the molar mass ratio of CO_2 to C (44 units CO_2/12 units C ≈ 3.67). Finally, AEC converted the annual CO_2 emissions factor (due to sequestration losses from living biomass) to a per acre basis (0.24 metric tons CO_2 per acre) and then multiplied this ratio by the acreage of each proposed project site in Wareham.

The tons C per hectare values provided by EPA are a simple method of estimating a U.S. average annual change in biomass carbon stocks based on nationwide inventories that are tailored neither by region or tree species. The rate of carbon sequestration in trees varies greatly between different regions and tree species with climatic conditions playing a major role in carbon storage potential. Without differentiating these characteristics, EPA's methodology falls short in providing an accurate estimate for carbon sequestration at the three Wareham project sites.

AEC's estimates of biomass carbon sequestration rates across the three Wareham sites averages out to roughly 6.74 metric tons CO_2 per acre per year compared to the 0.24 metric tons CO_2 per acre per year derived from EPA's methodology (see Table 6). The rates are different between the project sites because each site has a different composition of both tree species and DBH measurements. The difference between the AEC and EPA rates is largely attributed to the geographical and temporal characteristics of each methodology. AEC's carbon sequestration estimates account for site-specific characteristics by utilizing data collected at each of the three proposed project sites in Wareham, Massachusetts in early 2021, while EPA's methodology utilizes data from 2017 to assess generic U.S. carbon sequestration rates.

Table 6. Comparison of AEC's biomass carbon sequestration rates to EPA's methodology

Project Site	Sequestered Carbon in Biomass (*metric tons CO_2 per acre per year*)		
	AEC Rate	EPA Rate	Difference
27 Charge Pond Road	5.03	0.24	4.79
150 Tihonet Road	8.03	0.24	7.79
140 Tihonet Road	7.18	0.24	6.94
AVERAGE	**6.74**	**0.24**	**6.50**

Soil carbon sequestration losses and soil carbon emissions

Project development on the three Borrego sites affects soil emissions in two ways:

- *Carbon sequestration losses*: a decrease in the carbon sequestration capability after development; and
- *Soil carbon emissions*: an increase in emissions from drained organic soils due to changes in soil characteristics.

Both impacts would occur as a result of the proposed change in land use at the three Wareham sites. The project sites are currently forestland and would be converted to grasslands during construction, with some areas instead hosting the solar infrastructure.

The estimated soil carbon sequestration losses at the project sites are presented in Table 7. The land-use conversion from forestland to grassland results in a decrease in carbon stocks across the three project sites, which is largely attributable to grassland soils holding less carbon than forestland soils.[11] (Please see the Methodology section below for a more detailed discussion of the development of these estimates.)

Table 7. CO_2 emissions due to soil carbon sequestration losses at Borrego's proposed Wareham projects

Project Site	Acreage	Soil Carbon Sequestration Losses (*metric tons CO_2, 2021-2040*)	
		Annual	20-Year Total
27 Charge Pond Road	40.1	-506	-10,119
150 Tihonet Road	49.2	-605	-12,092
140 Tihonet Road	65.3	-791	-15,811
TOTAL	**154.6**	**-1,901**	**-38,021**

[11] Thompson, JR. et al. December 2020. *Land Sector Report: A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study*. Harvard Forest, Harvard University. Prepared for the Commonwealth of Massachusetts. Section 3.7. Available at: https://www.mass.gov/doc/land-sector-technical-report/download

The estimated change in CO_2 emissions from soil carbon emissions at the three project sites is presented in Table 8 below. Drained organic soils release of CO_2 emissions from microbial processes, root respiration, as well as respiration of soil fungi and fauna in the soils.[12] When land is converted from one land use to another (e.g., forestland to grassland), the composition and characteristics of the soil also changes due to the differences in vegetation cover—resulting in a change in the CO_2 emissions that are released by the soils.

The two Tihonet Road projects result in modest increases in CO_2 emissions from soil when converted from forestland to grassland. However, the Charge Pond Road site would result in an *emissions savings* due to the land-use conversion. This emissions savings is primarily due to the greater percentage of land area covered built infrastructure (e.g., solar panels, access roads, etc.). At the Charge Pond Road site, built infrastructure would cover approximately 11 percent, or 4.4 acres, of the converted land area compared to the 5 to 7 percent coverage at the Tihonet Road sites. This higher ratio of built infrastructure at Charge Pond Road, in combination with the relatively small difference emission factors of soil between forestland and grassland, results in lower soil emissions (i.e., an emissions savings) from the land-use conversion.

Table 8. CO_2 emissions from soil carbon emissions at Borrego's proposed Wareham projects

Project Site	Acreage	Emissions from Drained Organic Soils (*metric tons CO_2, 2021-2040*)	
		Annual	20-Year Total
27 Charge Pond Road	40.1	6.1	122.1
150 Tihonet Road	49.2	-0.6	-11.7
140 Tihonet Road	65.3	-7.2	-144.6
TOTAL	**154.6**	**-1.7**	**-34.2**

Methodology

To estimate the change in soil carbon stocks following development of the three solar projects, AEC modified EPA's methodology for calculating changes in soil organic carbon stocks from the conversion of forestland to cropland.[13] To better represent the Wareham project sites, AEC replaced the EPA's generic soil organic carbon factors (metric tons C per hectare) with those for forests and pasture/agricultural land from the *Land Sector Technical Report* prepared for Massachusetts' Executive Office of Energy and Environmental Affairs.[14] AEC multiplied the soil organic carbon density for forests (279.0 metric tons C per hectare) by the *total acreage* of each project site to calculate the current soil carbon stocks. Future soil carbon stocks due to conversion from forestland to grassland were calculated by multiplying the soil organic carbon density for pasture/agricultural

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[12] Oertel, Cornelius, Jörg Matschullat, Kamal Zurba, Frank Zimmermann, and Stefan Erasmi. 2016. "Greenhouse gas emissions from soils—A review." Geochemistry 76, no. 3: 327-352. Available at: https://core.ac.uk/download/pdf/82396671.pdf

[13] US EPA. March 11, 2021. "Greenhouse Gases Equivalencies Calculator - Calculations and References." *Annual Change in Organic Carbon Stocks in Mineral and Organic Soils*. Available at: https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

[14] Thompson, JR. et al. December 2020. Land Sector Report: A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study. Harvard Forest, Harvard University. Prepared for the Commonwealth of Massachusetts. Section 3.7. Available at: https://www.mass.gov/doc/land-sector-technical-report/download

land (122.4 metric tons C per hectare) by the *net acreage* of each project site (i.e., total site acreage less the land area covered by built infrastructure).

The soil carbon stocks were then converted from C to CO_2 emissions by multiplying by the molar mass ratio of CO_2 to C (44 units CO_2/12 units C ≈ 3.67). AEC subtracted the soil carbon stock of forestland (current land use) by the soil carbon stock of grassland (future land use) to calculate the total 20-year change in soil carbon stocks due to land-use conversion (see Table 9).

Table 9. Current and future soil carbon stocks at Borrego's proposed Wareham projects

Project Site	Soil Organic Carbon Stocks from 2021-2040 (*metric tons CO_2*)		
	Forestland Soil Organic Carbon	Grassland Soil Organic Carbon	Total Change in Carbon Stocks from Land Use Conversion
27 Charge Pond Road	16,616	6,497	-10,119
150 Tihonet Road	20,370	8,278	-12,092
140 Tihonet Road	27,058	11,247	-15,811
TOTAL	**64,044**	**26,022**	**-38,021**

To estimate the annual change in emissions from the soil due to land-use conversion, AEC modified EPA's methodology for calculating for estimating emissions from drained organic soils using emissions factors for forestland and cropland.[15] To better represent the conditions at each of the Wareham project sites, AEC replaced EPA's generic emission factor for cropland soils with an average emission factor for grassland soils in temperate climates (3.15 metric tons C per hectare per year).[16] AEC kept EPA's assumed emission factor for forestland soils (2.91 metric tons C per hectare per year) since it already represented the appropriate factor for temperate climates—which was derived from IPCC's 2013 supplement to their 2006 Guidelines for Natural Greenhouse Gas Inventories.[17]

AEC converted the soil emission factors for forestland and grassland from C to CO_2 emissions by multiplying by the molar mass ratio of CO_2 to C (44 units CO_2/12 units C ≈ 3.67). The emissions factors for each land use type were multiplied by the acreage of the project sites to calculate total annual CO_2 emissions from soil. As before, *total acreage* was used to calculate forest soil emissions and the *net acreage*—the total site acreage less the land area covered by built infrastructure—was used to calculate grassland soil emissions (see Table 10). The annual emissions were then multiplied by 20 years to estimate the total soil emissions due to land-use conversion over AEC's analysis period from 2021 to 2040.

[15] US EPA. March 11, 2021. "Greenhouse Gases Equivalencies Calculator - Calculations and References." *Annual Change in Emissions from Drained Organic Soils*. Available at: https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

[16] US EPA. 2020. *Annexes to the Inventory of U.S. GHG Emissions and Sinks*. Table A-212. p.A-392. Available at: https://www.epa.gov/sites/production/files/2020-04/documents/us-ghg-inventory-2020-annexes.pdf

[17] Intergovernmental Panel on Climate Change. 2013. *Methodological Guidance on Lands with Wet and Drained Soils, and Constructed Wetlands for Wastewater Treatment*. Table 2.1. Available at: https://www.ipcc-nggip.iges.or.jp/public/wetlands/pdf/Wetlands_Supplement_Entire_Report.pdf

Table 10. Current and future annual CO_2 emissions from soils at Borrego's proposed Wareham projects

Project Site	Annual Emissions from Drained Organic Soils (*metric tons CO_2 per year*)		
	Forestland Organic Soil Emissions	Grassland Organic Soil Emissions	Total Change in Emissions from Land Use Conversion
27 Charge Pond Road	-173.3	-167.2	6.1
150 Tihonet Road	-212.5	-213.0	-0.6
140 Tihonet Road	-282.2	-289.4	-7.2
TOTAL	**-668.0**	**-669.7**	**-1.7**

IV. Emissions savings benefit from the grid at Wareham project sites

The proposed solar projects at the three sites in Wareham, Massachusetts would produce clean, renewable electricity that would displace fossil fuel generation on the grid. Renewable energy resources like solar cost virtually nothing to operate making them cheaper than conventional gas- and oil-fired electricity generators. By adding renewables to the electric system, the dirtier, more expensive fossil fuel generators that are typically on the margin are no longer needed to meet customer demand.[18] By displacing fossil fuel generation, new renewable energy resources result in lower electric grid emissions.

Grid emissions savings estimates

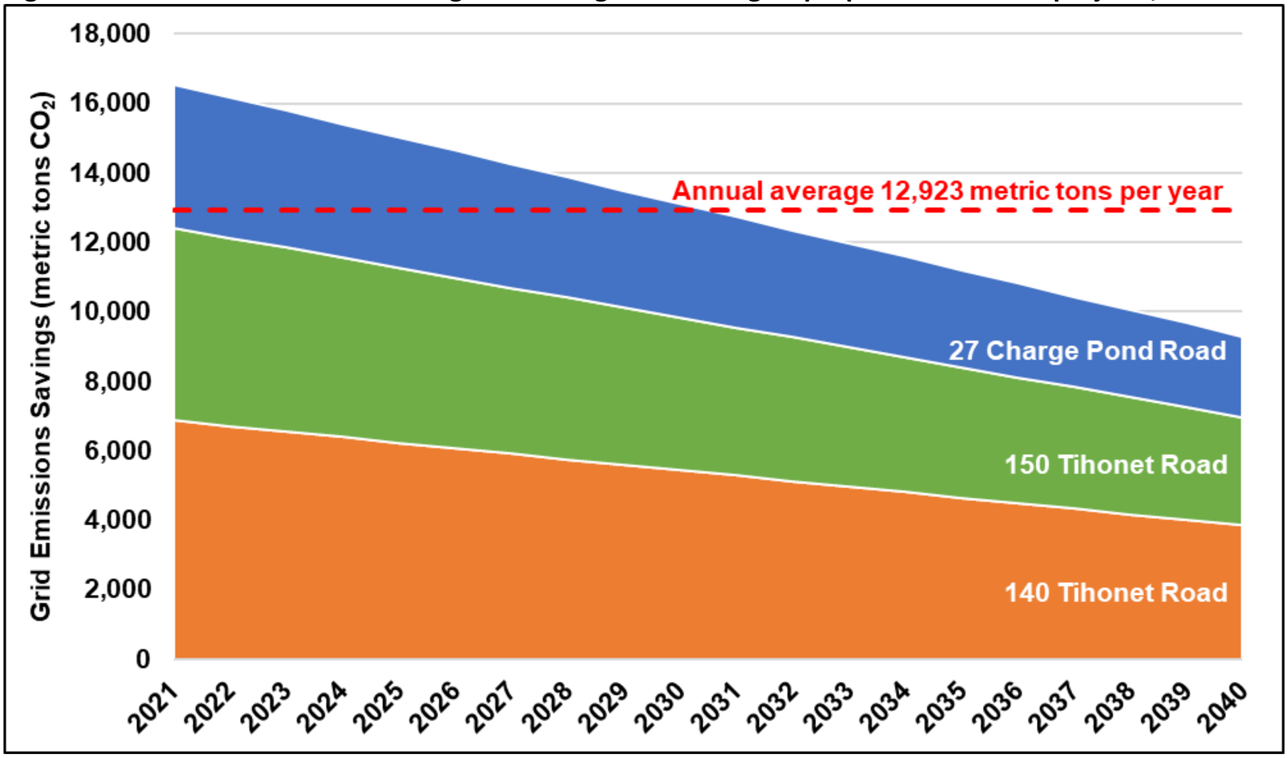
The estimated grid emissions savings from Borrego's proposed Wareham projects are presented in Table 11 and Figure 3 below. (Please see the Methodology section below for a more detailed discussion of the development of these estimates.) In total, the proposed Wareham projects would result in emissions savings from the grid of approximately 258,500 metric tons CO_2 over the 20-year period between 2021 and 2040, or roughly 12,900 metric tons CO_2 annually.

Table 11. CO_2 emissions savings from the grid at Borrego's proposed Wareham projects

Project Site	Project Size (*MW DC*)	Annual Generation (*MWh*)	Grid Emissions Savings (*metric tons CO_2, 2021-2040*)	
			Annual Average	20-Year Total
27 Charge Pond Road	11.6	15,068	3,229	64,572
150 Tihonet Road	15.6	20,214	4,331	86,624
140 Tihonet Road	19.3	25,032	5,363	107,269
TOTAL	**46.4**	**60,315**	**12,923**	**258,465**

[18] The margin is the point at which sufficient electricity is procured in the energy market. The last, and most expensive, generating resource procured to meet customer demand is the marginal resource (or "on the margin") and sets the clearing price for the market.

Figure 3. Annual CO_2 emissions savings from the grid at Borrego's proposed Wareham projects, 2021-2040



Methodology

To estimate the total CO_2 emissions savings from the grid, AEC quantified the greenhouse gas emissions that would be displaced as a result of the proposed solar projects at each of the Wareham project sites based on guidance from Massachusetts Environmental Policy Act Office (MEPA).

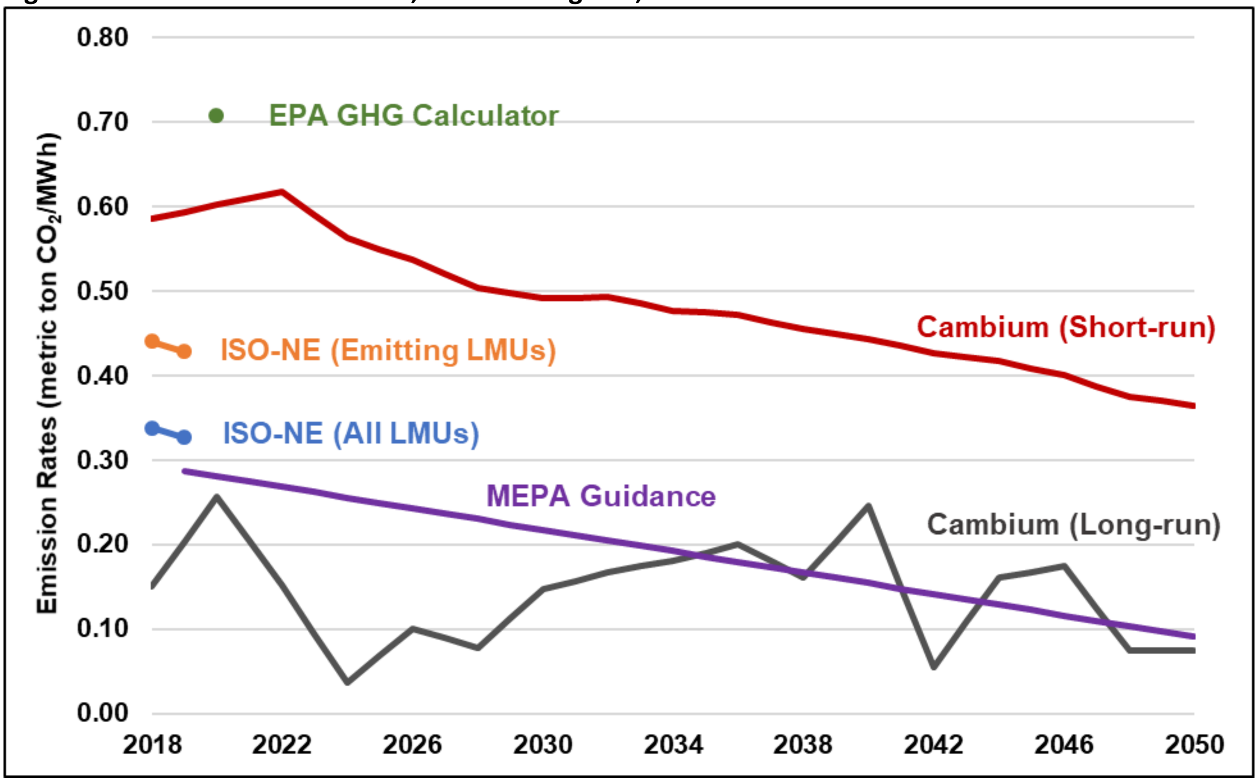
MEPA's guidance[19] directs applicants to use the average emission rate for the grid, which starts at ISO-New England's average emissions rate of 633 lbs per MWh,[20] or nearly 0.3 metric tons per MWh, in 2019 and decreases linearly to an assumed 200 lbs per MWh, or nearly 0.1 metric tons per MWh, in 2050 (see "MEPA Guidance" in Figure 4 below). Based on MEPA's projected emission rate, AEC calculated the annual emissions savings from the grid in metric tons CO_2 by multiplying the grid's average emissions rate in each year by the annual production in MWh of each proposed solar project in Wareham. Finally, AEC calculated the 20-year total emissions savings from the grid of each proposed solar project by summing the annual emissions savings from 2021 through 2040 based on projected emissions rates for each year.

[19] Email correspondence with Alex Strysky at MEPA on June 8, 2021.

[20] ISO-New England. March 2021. "2019 ISO New England Electric Generator Air Emissions Report." Table 1-1. Available at: https://www.iso-ne.com/static-assets/documents/2021/03/2019_air_emissions_report.pdf.

Renewable energy resources reduce emissions by displacing fossil fuel generation that would have otherwise resulted in the emission of greenhouse gases. These "avoided" emissions, or emission savings, are estimated using the emission rate of the marginal resource—the last, and most expensive, generating resource procured to meet customer demand. Figure 4 below compares estimated marginal emission rates from three different sources (i.e., EPA's GHG Calculator, ISO-New England, and the National Renewable Energy Laboratory's (NREL) Cambium model)—covering different geographical boundaries and timeframes, and using different methodologies—alongside MEPA's guidance of using the grid's average emissions rate.

Figure 4. Emission rates from EPA, ISO-New England, and NREL's Cambium



While MEPA recommends the use of an average emission rate, the rest of the emission rate projections shown in Figure 4 are marginal emission rates. The EPA GHG Calculator rate (in green) is an average of marginal emissions as modeled in AVERT for regions throughout the United States.[21] Because New England has lower marginal emissions than most other U.S. regions, the EPA's GHG calculator yields too high of an emission rate to be appropriate for Massachusetts.

[21] US Environmental Protection Agency (EPA). March 2020. "Greenhouse Gas Equivalencies Calculator". Available at: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Marginal emissions for the New England grid (in orange and blue) are measured by ISO-New England, the regional grid operator, in their annual emission reports.[22] The "All LMUs" rates are probably the most comparable for the purposes of calculating emission savings since it includes all generators on the system.[23] ISO-New England's marginal emission rate estimates reflect the New England region as a whole—not Massachusetts specifically—and are only available as historical data; the ISO does not publish emission rate projections.

Cambium[24] is a new model from NREL designed specifically to project avoided marginal emissions from the electric sector over time. NREL's results show projected emissions shrinking over time as more renewables are added to the grid. Cambium estimates both "short-run" and "long-run" marginal emission rates. The Cambium "long-run" marginal emissions (in black) are an attempt to project the effect of persistent change in end-use demand as a result of increased use of renewable energy technologies (e.g., electric vehicle charging, installation of heat pumps, etc.), while considering the structural changes to the grid in response to the change in demand—these estimates are currently experimental and require further development.[25] The Cambium "short-run" emissions (in red) are Massachusetts-specific and shrink over time as expected since they are based on current renewable portfolio standards and emission reduction laws.

MEPA's projected average emission rate is lower than the EPA, ISO-New England, and NREL marginal emission projections. As a result, expected grid emissions displaced by renewables projects are lower and expected net emissions of renewables projects (adding together displaced grid emissions and emissions from project construction and operations) are higher. In the absence of MEPA's guidance, AEC would have chosen NREL's short-run marginal emission rates for use in this analysis: (1) Marginal emissions are the most appropriate methodology to apply to the displaced emissions of a small (relative to the grid) renewable project; (2) only NREL offers long-term projections; and (3) NREL's long-run projections are still underdevelopment and—in our opinion—not yet ready for use in decision-making.

[22] ISO-New England. March 2021. "2019 ISO New England Electric Generator Air Emissions Report." Table 1-2. Available at: https://www.iso-ne.com/static-assets/documents/2021/03/2019_air_emissions_report.pdf

[23] LMU stands for locational marginal unit.

[24] National Renewable Energy Laboratory (NREL). 2020. *Cambium Viewer*. Available at: https://cambium.nrel.gov/

[25] Gagnon, P. et al. 2020. "Cambium Documentation: Version 2020." National Renewable Energy Laboratory (NREL). Available at: https://www.nrel.gov/docs/fy21osti/78239.pdf