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Life Cycle Greenhouse Gas Assessment: Coolidge Solar Project

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Prepared for: Ranger Solar

Prepared by: Nathan Ayer, Sam Boduch, Lise Laurin

EarthShift Global, LLC
37 Route 236, Suite 112 Kittery, ME 03904
207-608-6228
nathan@earthshiftglobal.com

Project Summary

The primary objective of this analysis was to determine the potential change in greenhouse gas (GHG) emissions to the atmosphere (in MT of CO_2e) that could result from the proposed Coolidge Solar I, LLC (Coolidge Solar) installation in Ludlow, Vermont. The proposed site for the solar installation is a partially forested area that has historically been managed for forest products (e.g. firewood) and continues to be a managed, working forest at the time of this project. The current forester for the property has provided a recent forest management plan to inform this study.

The Coolidge Solar project is being proposed as a means to add electricity generation capacity to the New England grid from a renewable source, rather than adding generation capacity via conventional feedstocks such as natural gas. As such, the primary focus of this analysis was to model these two alternative means of adding capacity to the New England grid to determine the relative life cycle GHG emissions of each option and quantify the GHG emission benefits of the Coolidge Solar project. In addition, we have compared the relative GHG emissions of generating electricity from the Coolidge Solar project to the 2014 ISO-NE and Vermont Ownload grid mixes.

To calculate the GHG benefits of this solar installation, we quantified the change in GHG emissions to the atmosphere over the study period associated with: 1) maintaining the current forest management regime at the site and adding conventional electricity generation capacity equivalent to the proposed project to the New England grid (baseline scenario); and 2) converting the forest site to a solar panel installation to supply additional generation capacity to the New England grid (solar installation scenario). The difference between these two values is an estimate of the GHG reduction that the project can expect to achieve. The study period for this analysis was 20 years, which is the expected minimum service life of the solar installation.

The life cycle GHG emissions calculations for both scenarios were modeled in SimaPro LCA software (www.pre.nl) and the results were calculated using the 2013 IPCC Global Warming

Potential method. Details of the life cycle inventory (LCI) are summarized briefly in this report and more detailed raw data and calculations are included in an accompanying spreadsheet (Appendix A).

Solar Installation Scenario

Scenario Description

Under the solar installation scenario, it was assumed that 38.5 forested acres within the approximately 90-acre Project site in Ludlow, VT were cleared, and a 20MW solar electricity generation array was installed to supply renewable electricity to the New England grid for a 20-year period. The electricity generated in the solar installation scenario was assumed to be supplied as additional capacity to the ISO-NE grid.

It was estimated that the 20MW solar array could produce approximately 32,000 – 33,000 MWh/year, for a total of 640,000 MWh over the life of the project (Note: for the purposes of the GHG emissions assessment we rounded the output down to 32,000 MWh/year to be conservative). Wood biomass harvested from the site was assumed to be transported offsite and fully combusted, releasing carbon to the atmosphere in year 1 of the study period. A second scenario was modeled in which the wood biomass harvested from the site was assumed to go into long-term carbon storage via wood products, etc. such that this carbon is not released to the atmosphere during the 20-year study period. The results of the GHG emissions assessment for the solar installation scenario were then compared with the generation of an equivalent amount of electricity (i.e. 32,000 MWh/yr. or 640,000 MWh total over 20 years) from natural gas or the existing ISO-NE and Vermont Ownload grids.

Scope of GHG Emissions Assessment

The scope of the GHG emissions assessment for the solar installation scenario included the life cycle emissions associated with the solar technology, as well as the implications of changes to forest carbon stocks as a result of the land use change.

For the solar installation scenario, we quantified the following over the study period:

- Carbon emissions from harvested biomass and land clearing (including above-ground carbon, live below-ground carbon, and soil organic carbon);
- Life cycle GHG emissions associated with mechanical harvesting activities during site clearing;
- Life cycle GHG emissions of manufacturing, transporting, installing, maintaining and decommissioning key solar installation components, including the solar panels, inverters, and other infrastructure (e.g. mounting racks, wiring, mounting pads, etc.);
- Carbon no longer removed from the atmosphere due to loss of forest carbon sequestration.

Life Cycle Inventory

The life cycle inventory for the solar installation scenario is summarized in Table 1. More detailed raw data and calculations are provided in the accompanying spreadsheet (Appendix A).

Table 1. Life cycle inventory data sources for modeling the solar installation scenario.

Life Cycle Stage	Data Source	Notes
Solar array manufacturing, installation, maintenance and disposal	Calculated from Ranger Solar data and Ecoinvent 3.2	Ecoinvent process: *Photovoltaic plant, 570 kWp, multi-Si, on open ground*
Harvesting of trees during site clearing	United States Department of Agriculture (2016)	Modified USLCI process: *Harvesting, softwood logs with bark, medium intensity, US PNW*
Emissions of above-ground carbon	U.S. Forest Service	Average above-ground carbon content of Vermont forests scaled to 38.5 acres
Emissions from live below-ground carbon and soil organic carbon	U.S. Forest Service Clarke et al. 2015 Nave et al. 2010	Average of live below-ground carbon content and soil organic carbon content of Vermont forests scaled to 38.5 acres and modified based on published value for emissions of below-ground carbon content during site disturbance
Loss of forest carbon sequestration	Vermont Department of Forests, Parks and Recreation (2015)	Average carbon sequestration of Vermont forests on an annual basis scaled to 38.5 acres

The LCI data for the solar installation was derived by scaling up the values from an open-ground solar installation with a lower capacity. The Ecoinvent data set used includes GHG emissions associated with:

- Manufacturing of solar panels;
- Manufacturing of inverters;
- Manufacturing of mounting systems;
- Manufacturing of fuse box, electric cables and electric meters;
- Installation of solar panels and infrastructure at the site;
- Maintenance (replacement of inverters once during service life);
- Disposal of solar panels and infrastructure at end of life.

Forest harvesting and forest carbon values were derived from United States and Vermont government sources on average values for Vermont forests and adapted to the size of the Coolidge site (see Appendix A).

Baseline Scenario

Scenario Description

Under the baseline scenario, it was assumed that additional electricity generation capacity is added to the New England grid by increasing natural gas generation over the 20-year study period by 640,000 MWh (equivalent to the total output of the solar installation scenario). It was assumed that the forest on the proposed Coolidge Solar site was left as is, and that the current forest management regime for the site is maintained over the 20-year study period. The assumed harvest regime was the annual removal of 20 cords (72.5 m^3) of firewood which was assumed to be combusted each year.

Scope of GHG Emissions Assessment

The scope of the GHG emissions assessment for the baseline scenario included the life cycle emissions associated with average U.S. natural gas electricity generation, as well as the implications of changes to forest carbon stocks as a result of the firewood harvest and carbon sequestration by standing trees at the site.

For the baseline scenario, we quantified the following over the course of the study period:

1. Carbon sequestration by the existing forest (above and below-ground biomass) over the course of the study period, assuming current forest management regime;
2. Carbon emitted from wood harvested for firewood;
3. Carbon emitted from firewood harvesting activities (i.e. mechanical harvesting);
4. Life cycle GHG emissions associated with adding electricity generation capacity on the New England (ISO-NE) grid equivalent to the proposed project based on average U.S. natural gas generation.

Life Cycle Inventory

The life cycle inventory for the baseline installation scenario is summarized in Table 2. More detailed raw data and calculations are provided in the accompanying spreadsheet (Appendix A).

Table 2. Life cycle inventory data sources for modeling the baseline scenario.

Life Cycle Stage	Data Source	Notes
Life cycle emissions (including combustion) for natural gas electricity generation	US-EI 2.2 (EarthShift LLC. 2013)	Amalgamated database of newly developed data, expanded USLCI data, and modified Ecoinvent 2.2 data.
Harvesting of trees for firewood	Site forest management plan	Modified USLCI process*: Harvesting, softwood logs with bark, medium intensity, US PNW*
Emissions from combusted firewood	U.S. Forest Service and site forest management plan	Adapted above-ground carbon content from solar installation scenario to reflect firewood harvest
Carbon sequestration at forest site	Vermont Department of Forests, Parks and Recreation (2015)	Average carbon sequestration of Vermont forests on an annual basis

Natural gas electricity production was modeled using a process for average U.S. natural gas electricity generation from the US-EI database. This process has the most up-to-date U.S. data on natural gas extraction (including hydraulic fracturing). The US-EI data set for natural gas electricity generation is based on supply chain data from Clark et al. (2011) as used in the GREET model from the Argonne National Laboratory and includes:

- Well field infrastructure;
- Construction fuel consumption;

- Well completion emissions;
- Conventional natural gas extraction;
- Shale gas extraction from hydraulic fracturing;
- Pipeline transport;
- Power plant infrastructure; and
- Power plant emissions.

Data on the annual firewood harvest were obtained from the forest management plan submitted to the Vermont ANR for the Coolidge site. Data on the carbon emissions from combustion of the firewood was derived by scaling the total above-ground carbon at the site to the size of the firewood harvest. Carbon sequestration by the forested site was estimated from average carbon sequestration per acre for the Vermont forest. Further details of these calculations are provided in Appendix A.

Results

Solar Installation Scenario Results

The results of the GHG emissions assessment for the solar installation scenario are summarized in Table 3. These results show total GHG emissions across the full 20-year life of the project expressed in metric tons (MT) of CO_2e.

Table 3. Life cycle greenhouse gas emissions for the solar installation scenario for generation of 640,000 MWh of electricity over 20 years, including contribution analysis for the key sources of GHG emissions in the project life cycle.

Life Cycle Stage	GHG Emissions (MT CO_2e)
Solar Panels and Infrastructure	47,050
Harvesting of trees	113
Above-ground carbon	5,650
Live below-ground carbon and soil organic carbon	1,760*
Loss of carbon sequestration	1,408
Total Life Cycle Emissions	**56,000**

**Note – Based on an average of 35% loss rate of below ground and soil organic carbon during site clearing. This value could vary from 500 MT to 3,020 MT depending on assumed carbon emission rate.*

Total GHG emissions for generating 640,000 MWh of electricity from the solar installation scenario over the 20-year study period are approximately 56,000 MT of CO_2e. The primary source of emissions is the manufacturing, installation, maintenance, and disposal of the solar panels and related infrastructure, accounting for just under 85% of the life cycle GHG emissions. The primary source of GHG emissions within the solar technology life cycle is the manufacturing of the panels. The GHG emissions associated with the land use change from forest to solar installation accounted for approximately 16% of total emissions, with the emissions associated with removal and combustion of above-ground biomass being the second largest contributor to total GHG emissions at approximately 10%.

As noted in the LCI description, for the purposes of this screening analysis, we used published average values from United States and Vermont government reports to characterize the forest carbon changes that could result from this project as opposed to collecting primary data and carrying out more detailed forest carbon analysis. These values are conservative, in that they generally reflect forests of higher quality/higher carbon storage than the forested parts of the Coolidge Solar site; however, in an effort to test the sensitivity of the study results to these average data, we modeled additional solar installation scenarios in which the above and below-ground carbon values and the loss of carbon sequestration values were varied. Based on the literature, a high-end below ground carbon loss rate would be 60%, which would only increase the life cycle GHG emissions for the solar installation by approximately 1,300 MT CO_2e to 57,200 MT CO2e. A doubling of assumed forest carbon sequestration potential would increase life cycle GHG emissions by 1,400 MT CO_2e to 57,300 MT CO2e, and a doubling of above-ground carbon content from the average Vermont values would increase life cycle GHG emissions by 10%, which would increase the life cycle GHG emissions by 5,650 MT CO2e to 62,000 MT CO2e. Assuming the highest emissions from above and beyond-ground carbon stocks results in life cycle GHG emissions for the solar installation of 64,300 MT CO2e.

Baseline Scenario Results

The results of the GHG emissions assessment for the baseline scenario are outlined in Table 4.

Table 4. Life cycle greenhouse gas emissions for the baseline scenario for generation of 640,000 MWh of electricity over 20 years using average U.S. natural gas.

Life Cycle Stage	GHG Emissions (MT CO2e)
Natural gas electricity (US/23% shale gas)	512,000
Harvesting and combustion of firewood	1,620
Total Life Cycle Emissions	**514,000**

Results of the GHG emissions assessment for adding natural gas electricity generation capacity to the New England grid show that this would result in over 500,000 MT of CO2e over 20 years. Approximately 67% of the emissions associated with natural gas electricity production are from combustion at the power plant, while the remaining 33% of emissions originate from the upstream extraction and processing of natural gas. The US-EI database includes the most up-to-date LCI data on natural gas production in the U.S., in particular the emissions associated with the inclusion of shale gas from hydraulic fracturing as part of the fuel mix. Results of the assessment also indicate that the emissions associated with harvesting and combustion of firewood from the forested site are negligible relative to the life cycle emissions of natural gas electricity, accounting for less than 1% of life cycle emissions.

It is noted that the life cycle GHG emissions associated with electricity from natural gas may vary depending on the source of fuel and the combustion technology used. A sensitivity analysis was conducted on the generation of 640,000 MWh of electricity using Ecoinvent 3.2 processes for global average combined cycle natural gas technology, and global average conventional natural gas generation. Results of this analysis were 286,000 MT CO2e and 453,000 MT CO2e, respectively, indicating that even on the lower end of the potential emissions from natural gas generation the life cycle emissions are still significantly higher than the solar installation. It is our view, however, that the US-EI data are the most representative of current U.S. technology and fuel sources.

Comparative Results

Solar Installation Scenario vs. Baseline Scenario

The primary objective of this analysis was to quantify the relative life cycle GHG emissions for adding 640,000 MWH of electricity generation capacity to the New England grid by either the solar installation scenario or the baseline scenario using conventional natural gas generation. Results of the screening analysis (Figure 1) indicate that significant reductions in GHG emissions could be achieved by pursuing the solar installation scenario, ranging from 87.8% to 89.3% reductions depending on forest carbon assumptions.

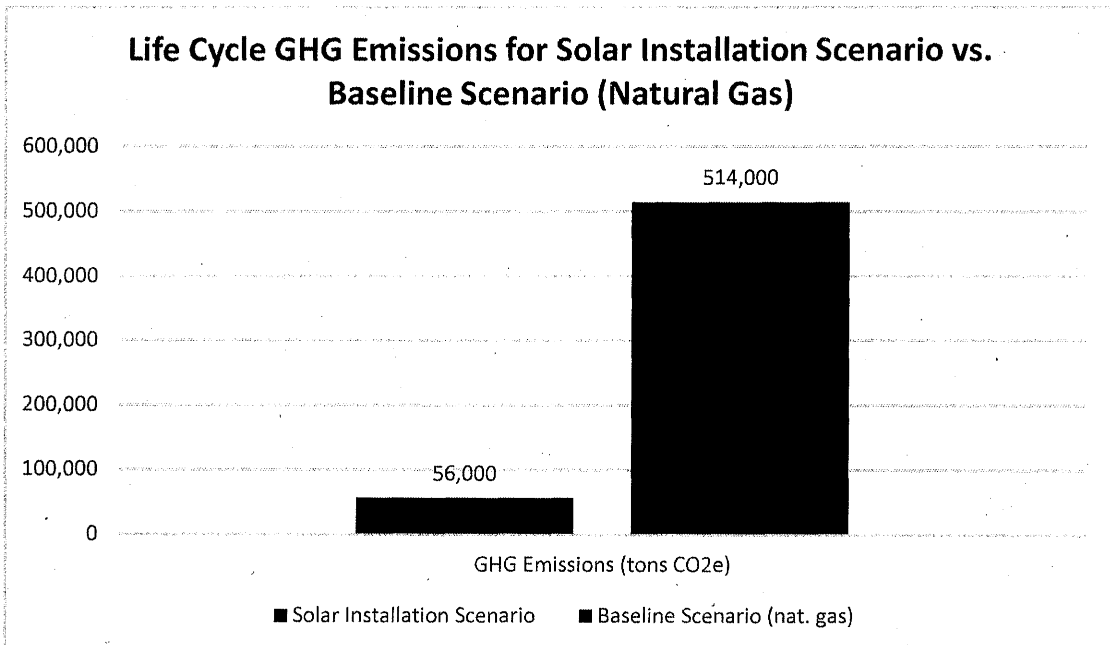

Figure 1. Comparative life cycle GHG emissions of the solar installation scenario relative to electricity generation from adding natural gas generation (U.S. average, including 23% shale gas) capacity to the existing New England grid.

Solar Installation vs. Current NE and VT Grids

A secondary objective of this analysis was to understand how the life cycle GHG emissions of generating electricity with this type of solar installation compare with electricity produced by the current New England and Vermont grid mixes. Results of the screening analysis indicate that the solar installation scenario results in significant GHG benefits relative to the existing grids. A summary of this analysis is provided in Figure 2. A detailed breakdown of the grid mixes and the database processes used to model them is provided in Appendix A.

EarthShift Global, LLC

37 Route 236, Suite 112, Kittery, Maine 03904 | ph: +1 (207) 608-6228 www.earthshiftglobal.com

The results in Figure 2 include a range of possible results for the existing grids, including fully modeled life cycle GHG emissions using US-EI data for upstream and combustion emissions, and a comparison with combustion-only GHG emissions data (Vermont's Ownload) provided by the Vermont Agency of Natural Resources. In either case, the solar installation scenario can achieve significant GHG reductions relative to the current electricity grids modeled. Relative the ISO_NE grid, electricity generation with the Coolidge solar installation would result in reductions of 73 – 80%. Relative to the Vermont Ownload grid, the solar installation would result in reductions of 35 – 50%.

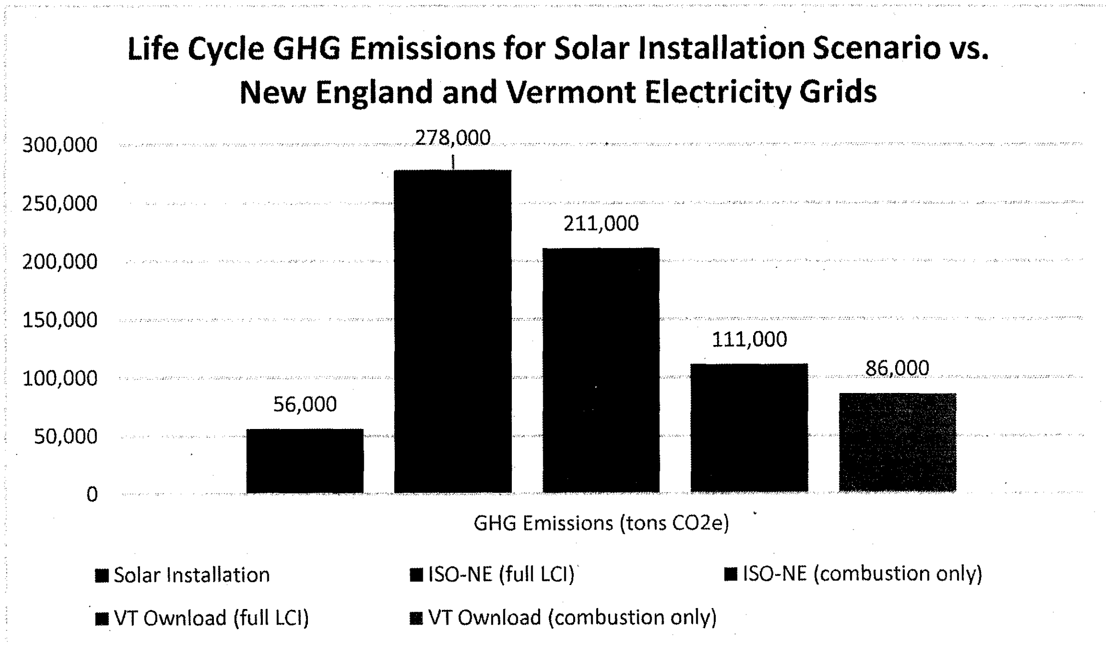

Figure 2. Comparative life cycle GHG emissions of the solar installation scenario relative to electricity generation from the existing New England and Vermont grids. Analysis for the ISO-NE and VT Ownload grids includes full LCI results and combustion-only results.

It is important to note that comparison of the solar installation results with the "combustion-only" results is not an ISO 14044 compliant comparison, as the system boundary for the solar system includes the full life cycle emissions, while the combustion-only values exclude the upstream emissions from raw material extraction and processing. Despite this difference in system boundaries, the reductions in GHG emissions for the solar installation relative to the existing grids are still significant, and inclusion of the full life cycle emissions for the ISO-NE and Vermont Ownload grids would increase the reductions.

Conclusions

Results of the screening life cycle GHG assessment of the Coolidge Solar installation indicate that substantial GHG emissions reductions of close to 90% could be achieved over the 20-year study period relative to adding natural gas generation capacity to the New England grid. The results also show that relative to the existing electricity grids in Vermont and New England, substantial GHG emission reductions of up to 80% could be achieved over the life of the solar installation. The reductions relative to the Vermont Ownload are particularly notable given the relatively low-emission sources of electricity used to supply the Vermont grid. Nearly 45% of the grid is supplied by hydropower, while another 20% of the grid is supplied by a mix of renewables including wind, solar, and biomass.

These significant reductions in GHG emissions can be achieved with the solar installation despite the proposed land use change for the 38.5 acres of forested land at the site. Results of the assessment show that the potential GHG emissions associated with converting this forested land to solar electricity production are orders of magnitude smaller than the life cycle GHG emissions associated with electricity from average U.S. natural gas generation, or from current ISO-NE and Vermont Ownload grids. This is a result of the relatively small area of forest to be cleared, and the relatively low carbon sequestration potential of the site as currently managed. Sensitivity analysis showed that a doubling of forest carbon sequestration potential for the site had negligible effects on the study results.

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