APPENDIX 15A:
GREENHOUSE GAS ANALYSIS REPORT

Life Cycle Greenhouse Gas Assessment: Chinook Solar Project

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Prepared for: TRC

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Project Summary

The primary objective of this analysis was to determine the potential change in greenhouse gas (GHG) emissions to the atmosphere (in tonnes of CO_2e) that could result from the proposed Chinook Solar Project (Project) located in Fitzwilliam, New Hampshire to be developed by Chinook Solar, LLC. The proposed site for the solar installation is comprised of approximately 132 acres of forest and 24 acres of open land that has been previously cleared. The forested area has not been managed as a working forest.

The Chinook Solar Project would add electricity generation capacity to the state's electricity grid from a renewable source, rather than adding generation capacity via conventional fuel source such as natural gas. As such, the primary focus of this analysis was to model these two-alternative means of adding capacity to determine the relative life cycle GHG emissions of each option and to quantify the potential GHG emission benefits of the Project.

To calculate the potential GHG benefits of the Project, we quantified the change in GHG emissions over the study period associated with two scenarios: 1) leaving the existing forest at the site and adding conventional natural gas-based electricity generation capacity (using a combustion turbine) equivalent to the proposed Project (Baseline Scenario); and 2) converting the forest to a solar panel installation to supply additional generation capacity (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 30 years, which is the expected minimum service life of the Project.

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 100 year Global Warming Potential method (IPCC, 2013). Details of the life cycle inventory (LCI) are summarized briefly in this report.

Solar Installation Scenario

Scenario Description

Under the Solar Installation Scenario, it was assumed that 132 acres of forest is cleared, and a 30 megawatt (MW) solar electricity generation array is installed for a 30-year period. The wood biomass harvested from the forested area was assumed converted into firewood and burned. The 24 acres of open land was excluded from both scenarios as there would be little-to-no change in land use as a result of the solar installation. It was assumed that grass was planted underneath the solar array. It was estimated that the 30 MW solar array could produce approximately 52,036 megawatt hours (MWh) in year 1 (Moody, 2019), with a reduction in energy output of 0.5% per year over the 30-year study period resulting in a total of 1,453,010 MWh over the life of the Project.

Scope of the 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 expected changes to carbon stocks as a result of the land use change.

For the Solar Installation Scenario, we quantified the following over the study period:

- 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, equipment pads, etc.);
- Carbon emissions from forest biomass as a result of burning the harvested firewood;
- Carbon no longer sequestered from the atmosphere due to loss of forest; and
- Life cycle GHG emissions associated with mechanical harvesting activities during site clearing.

Life Cycle Inventory

The stages and data sources for the LCI for the Solar Installation Scenario is summarized in Table 1. Detailed raw data and calculations are provided in Appendix A.

Table 1: Life cycle inventory data sources for modeling the Solar Installation Scenario.

Life Cycle Stage	Data Source	Notes
Manufacturing of solar panels	Ecoinvent 3.3 Database (Wernet, 2016)	Scaled up the Ecoinvent values from an open-ground solar installation with a lower capacity.
Manufacturing of inverters	Ecoinvent 3.3 Database (Wernet, 2016)	Scaled up the Ecoinvent values from an open-ground solar installation with a lower capacity.

Manufacturing of mounting systems	Ecoinvent 3.3 Database (Wernet, 2016)	Scaled up the Ecoinvent values from an open-ground solar installation with a lower capacity.
Manufacturing of fuse box, electric cables and electric meters	Ecoinvent 3.3 Database (Wernet, 2016)	Scaled up the Ecoinvent values from an open-ground solar installation with a lower capacity.
Installation of solar panels and infrastructure at the site	Ecoinvent 3.3 Database (Wernet, 2016)	Scaled up the Ecoinvent values from an open-ground solar installation with a lower capacity.
Maintenance (replacement of inverters once during service life)	Ecoinvent 3.3 Database (Wernet, 2016)	Scaled up the Ecoinvent values from an open-ground solar installation with a lower capacity.
Disposal of solar panels and infrastructure at end of life	Ecoinvent 3.3 Database (Wernet, 2016)	Scaled up the Ecoinvent values from an open-ground solar installation with a lower capacity.
Sequestration of forest carbon at the Project site	(Vermont Agency of Natural Resources, 2017)	Average annual carbon sequestration of New Hampshire forests (based on Vermont sequestration rates) scaled to 132 acres.
Below-ground forest carbon stock	(USFS, 2016)	Average of live below-ground carbon content and soil organic carbon content of New Hampshire forests scaled to 132 acres.
Above-ground forest carbon stock	(USFS, 2016)	Average above-ground carbon content of New Hampshire forests scaled to 132 acres.
Harvesting of trees during site clearing	Ecoinvent 3.2 Database (Wernet, 2016)	Modified USLCI process: *Roundwood {GLO}| harvest, primary forest | Alloc Rec, U.*
Conversion of wood into firewood and burning	(Crawford, 2008)	Average CO_2 emissions from burning firewood.
Below-ground carbon sequestration by grasses	(A.J. Franzluebbers, 2001); (Jones, 2004)	Based on soil carbon sequestration rate of Bermuda grass and perennial grasslands.
Above-ground carbon sequestration by grasses	Oliveras et al., 2013; (Immaculada Oliveras, 2014); (Bethany A. Bradley, 2006)	Based on above-ground biomass for grasslands.

Baseline Scenario

Scenario Description

Under the Baseline Scenario, it was assumed that additional electricity generation capacity is added to the state grid by increasing natural gas generation over the 30-year study period by 1,453,010 MWh (equivalent to the total estimated output of the Solar Installation Scenario).

It was assumed that the forest and open space on the proposed Chinook Solar Project site were undisturbed, and that there will be no forest management plan for the site during the 30-year study period. Carbon sequestered by the forest in this scenario is modelled as emissions in the Solar Installation Scenario.

Life Cycle Inventory

The LCI data for natural gas are obtained from the DataSmart library (LTS, 2016), which includes the most up-to-date and detailed LCI data on natural gas production in the United States (US). These data include all the production steps from natural gas extraction and processing to combustion in power plant (simple-cycle-combustion turbine). GHG emissions for combustion in a power plant are based on US Environmental Protection Agency's (EPA) emission factors (EPA, 2016) and the upstream extraction and processing data is based on published sources, such as Skone et al., 2011 and Clark et al., 2011. These data include a conventional and shale gas mix of 54% and 46%, respectively (EIA, 2015). Sensitivity of the results to this data source is tested by considering harmonized median values provided by the National Renewable Energy Laboratory (NREL) (O'Donoughue et al., 2014).

Results

Solar Installation Scenario Results

The results of the GHG emissions assessment for the Solar Installation Scenario are summarized in Table 2 and Figure 1. These results show total GHG emissions across the full 30-year life of the Project expressed in tonnes of CO_2e.

Table 2: Life cycle greenhouse gas emissions for the Solar Installation Scenario for generation of 1,453,010 MWh of electricity over 30 years, including contribution analysis for the key sources of GHG emissions in the project life cycle

Life Cycle Stage	GHG Emissions (tonnes of CO_2e)
Solar Panels and Infrastructure	61,275
Firewood	37,488
Lost Forest Carbon (below-ground & annual sequestration)	7,511
Forest Clearing / Harvest	166
Carbon Sequestration, planted grasses	-1,194
Total Life Cycle Emissions	**105,245**

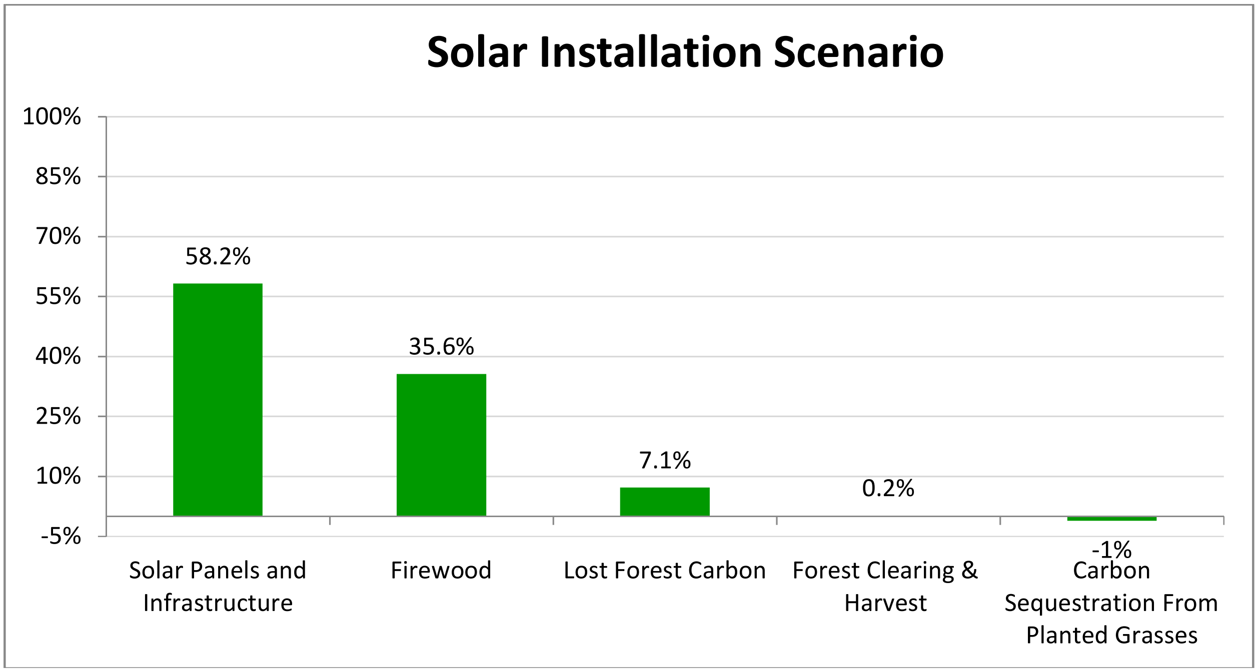

Figure 1: Life Cycle GHG Emissions for Solar Installation Scenario per 1,453,010 MWh

Total GHG emissions for generating 1,453,010 MWh of electricity from the Solar Installation Scenario over the 30-year study period are approximately 105,245 tonnes of CO_2e. The primary sources of emissions are the manufacturing, installation, maintenance, and disposal of the solar panels and the related infrastructure, accounting for about 58.2% of the life cycle GHG emissions. Among these, manufacturing of the panels is the main contributor to the total GHG emissions. The emissions associated with transformation of cleared trees into firewood and combusting that firewood are the second largest contributor to total GHG emissions at about 35.6%.

Baseline Scenario Results

The results of the GHG emissions assessment for the Baseline Scenario are outlined in Table 3. A breakdown of the life cycle impacts by stage is provided in Appendix B.

Table 3: Life cycle greenhouse gas emissions for the Baseline Scenario for generation of 1,453,010 MWh of electricity over 30 years using average U.S. natural gas

Life Cycle Stage	GHG Emissions (tonnes of CO_2e)
Natural gas electricity (US/46% shale gas)	1,142,551
Total Life Cycle Emissions	**1,142,551**

Results of the GHG emissions assessment for adding natural gas electricity generation capacity to the ISO-NE grid show that this would result in 1,142,551 tonnes of CO_2e over 30 years.

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 1,453,010 MWh of electricity generation capacity by either the Solar Installation Scenario or the Baseline Scenario using natural gas. Results of the screening analysis (Figure 2) indicate that significant reductions of nearly 91% in GHG emissions could be achieved by pursuing the Solar Installation Scenario.

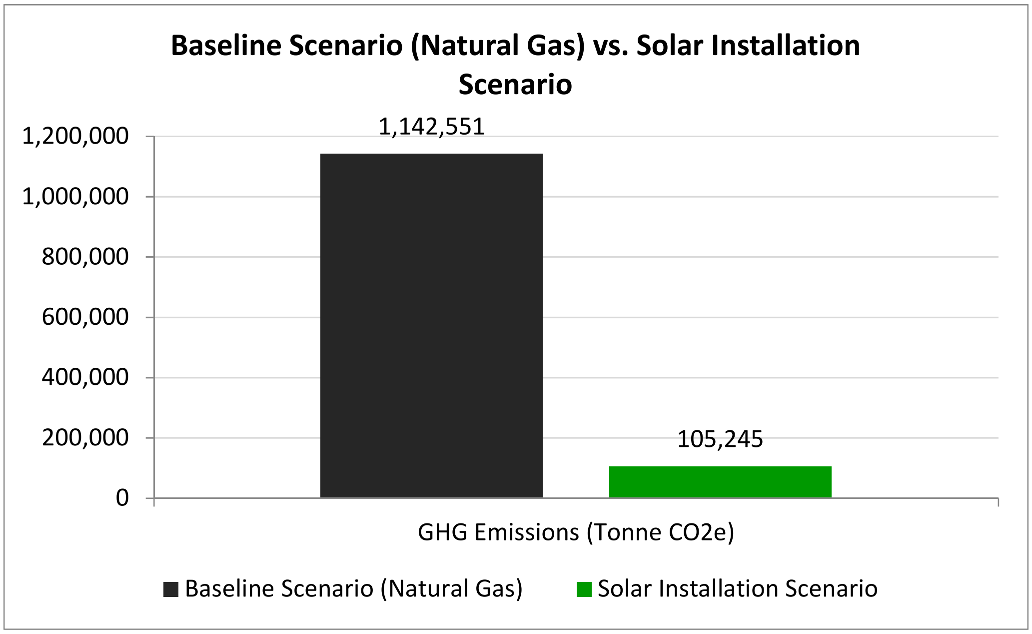

Figure 2: Life Cycle GHG Emissions for Baseline Scenario (Natural Gas) vs. Solar Installation Scenario per 1,453,010 MWh

Sensitivity to Natural Gas Data

The DataSmart process for natural gas electricity generation, using a 46% shale gas feedstock mix, gives a result of 750 grams (g) CO_2e/kilowatt hour (kWh). To test the sensitivity of the results to this data source, we considered the NREL's harmonized median life cycle GHG values of 670 g CO_2e/kWh for a combustion turbine and 450 g CO_2e/kWh for a combined-cycle turbine (O'Donoughue et al., 2014). The results with the median harmonized values for combustion turbine show that per 1,453,010 MWh, life cycle GHG emissions are 973,517 tonnes of CO_2e. These values are about 24% lower than the DataSmart values for natural gas. When these harmonized values are compared with the Solar Installation Scenario, we find that the solar scenario still has about 89% lower GHG impacts.

With the harmonized median GHG value of 450 g CO_2e/kWh for a combined-cycle turbine, we find that per 1,453,010 MWh, the GHG emissions are 653,855 tonnes of CO_2e. These values are about 43% lower than the DataSmart values for natural gas. When these harmonized values are compared with the Solar Installation Scenario, we find that the solar scenario still has about 84% lower GHG impacts.

Conclusions

Results of the screening life cycle GHG assessment of the Chinook Solar Project indicate that substantial GHG emissions reductions of 84-91% could be achieved over the 30-year study period relative to adding natural gas generation capacity.

These significant reductions in GHG emissions can be achieved with the solar installation despite the proposed land use change for the 132 acres of forest at the site, and despite annual reductions of 0.5% in energy output over the study period beyond year 1. Results of the assessment show that the potential GHG emissions associated with converting this forested land to solar electricity production are significantly smaller than the life cycle GHG emissions associated with electricity from average U.S. natural gas generation. This is a result of the high efficiency of the solar installation which requires minimal fossil energy in its lifecycle.

Given the lost carbon dioxide sequestration over the life of the facility due to tree clearing and the carbon dioxide emitted from manufacturing the solar equipment, the estimated payback period is about three years.

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Appendix A: Forest Carbon Calculations

Above-Ground Carbon

Amount:	**18698.77155**	**MT CO2e**	
Above-ground carbon/acre New Hampshire forest land:	142	MT CO2e/acre	*Source: USFS 2016*
Chinook Solar site acres to be cleared:	132	acres	*Source: TRC*

Below-Ground Carbon

Amount:	**3236.685171**	**MT CO2e**	
Below ground carbon and soil organic carbon / acre New Hampshire forest land:	24.5	MT CO2e/acre	*Source: USFS 2016*
Chinook Solar site acres to be cleared:	132	acres	*Source: TRC*

Tree Harvesting for Site Clearing (Solar Installation Scenario)

Amount:	**7,133**	**m3**	
SimaPro Process:	*Softwood logs with bark, harvested at medium intensity site, at mill, US PNW*		
Comment:	Process includes diesel consumption, use of lubricants for machinery, and transportation offsite		
Total volume of above-ground biomass, live trees	248,164,172	m3	*Source: USFS 2016*
Total area of New Hampshire forest land	4,592,382	acres	*Source: USFS 2016*
Average New Hampshire volume of live trees	54.04	m3/acre	*Source: USFS 2016*
Chinook Solar site acres to be cleared:	132	acres	*Source: TRC*

Lost Carbon Sequestration due to Site Clearing

Amount:	**4,277**	**MT CO2e**	
Annual carbon sequestration in New Hampshire forest based on Vermont sequestration rates:	4,959,772	MT CO2e	
Total area of New Hampshire forest land	4,592,382	acres	*Source: USFS 2016*
Carbon sequestration/ acre Vermont applied to New Hampshire forest land/ year	1.08	tons/acre/year	*Source: Vermont Forest Carbon Assessment 2017**
Chinook Solar site acres to be cleared:	132	acres	*Source: TRC*
Life of project	30	years	*Source: TRC*

*(NH sequestration data unavailable)

Appendix B: Life Cycle Emissions of Natural Gas Electricity Production, by stage

Life cycle emissions from producing 1 MWh via Natural Gas electricity generation

Life Cycle Stage:	**GHG Emissions (tonnes of CO2e)**	**%**
Natural gas, burned in power plant (US/46% shale gas)	0.537	68%
Natural gas, supply (US/46% shale gas)	0.249	32%
Total Life Cycle Emissions	**0.786**	**100%**

Life cycle emissions from producing 1,453,010 MWh via Natural Gas electricity generation

Life Cycle Stage:	**GHG Emissions (tonnes of CO2e)**	**%**
Natural gas, burned in power plant (US/46% shale gas)	776,935	68%
Natural gas, supply (US/46% shale gas)	365,616	32%
Total Life Cycle Emissions	**1,142,551**	**100%**