CARBON NEUTRALITY AT CALVIN UNIVERSITY

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Abstract

Calvin University committed to become carbon neutral by 2057 when former President Michael Le Roy signed the American College and University Presidents' Climate Commitment (ACUPCC) in 2017. In 2026, Calvin withdrew from the ACUPCC to reduce costs. The Environmental and Energy Sustainability Committee (EESC) commissioned research, implemented by Facilities, to create a realistic plan for carbon neutrality and propose an earlier carbon neutrality date. This report analyzes Calvin's carbon emissions from 2002-present, projects future emissions, and proposes a feasible path to carbon neutrality sooner than 2057. To become carbon neutral, Calvin University needs to offset the projected future Scope 1 (natural gas) emissions of 7920 tonneCO_2/year. Options evaluated included wind power, air- and ground-source heat pumps, building efficiency, solar power, and carbon offsets. Given analysis of feasible options toward carbon neutrality, we recommend procuring high-quality carbon offsets using energy cost savings from a build-out of rooftop solar, funded by a Calvin Solar Revolving Fund (CSRF). Using this strategy, Calvin would become carbon neutral by 2047 under a high offset cost scenario ($93/tonne$CO_2$) and 2038 under a low offset cost scenario ($29/tonne$CO_2$).

* These authors contributed equally to this work.

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Introduction

In 2017, former Calvin University President Michael Le Roy signed the American College and University Presidents' Climate Commitment (ACUPCC), pledging Calvin to become carbon neutral by 2057. By 2026, no formal carbon neutrality plan had been adopted. During this time, semester-long projects by Engineering 333 (Thermal Design) classes have studied topics like natural gas consumption, renewable electricity generation, a new carbon neutrality date, and green revolving funds. In Summer 2026, the Environmental and Energy Sustainability Committee (EESC) commissioned research, implemented by Facilities, to determine a strategy for carbon neutrality in response to Calvin withdrawing from the ACUPCC for cost saving purposes. The Summer 2026 research was co-funded by Facilities and the Engineering Department's Sustainable Engineering Research Fund.

This report satisfies the 5 goals of the Summer 2026 research:

1. assess Calvin's carbon footprint,
2. evaluate emissions reduction strategies,
3. develop scenarios and timelines for achieving carbon neutrality,
4. create a framework for sustainability planning, and
5. recommend a realistic carbon neutrality target date.

Current Carbon Footprint

Calvin University's historical emissions have been evaluated by three different tracking systems as shown in Figure 1 below. Figure 2 shows historical emissions with projected future emissions. The total projected emissions that Calvin University must offset to achieve carbon neutrality are 7920 tonneCO_2/year. Refer to Appendix C for more information about Calvin's historical emissions and current carbon footprint.

Carbon Neutrality Strategy

Wind power, air- and ground-source heat pumps, building efficiency, solar power, and carbon offsets were evaluated as potential routes to carbon neutrality. The two most feasible options are solar power and carbon offsets.

We propose that solar build-out and carbon offset spending be financed with a green revolving fund, perhaps called the Calvin Solar Revolving Fund (CSRF). We recommend a solar array first be installed on Hekman Library, costing just under $800k. Annual energy cost savings would be routed into CSRF for further installations of solar arrays until solar build-out is complete. Solar build-out would be complete when annual energy cost savings exceed the annual cost of carbon offsets. CSRF would then switch from funding solar build-out to paying for carbon offsets. More information on CSRF can be found in Appendix E.

The type and cost of carbon offsets that Calvin should purchase can be guided by our proposed carbon offset purchasing recommendations. A summary of the carbon offset purchasing guidelines follows, and more information can be found in Appendix F under Recommendations.

1. Practice “responsible investing” when procuring carbon offsets. Specifically, purchase offsets with co-benefits.
2. Purchase offsets that have a B or better rating from third-party agencies or researchers.
3. Purchase offsets in a manner that is budget-neutral to the university (via CSRF).

For more information on strategy alternatives and our proposed carbon neutrality strategy refer to Appendix H.

Scenario Timeline

Under the proposal described above, a CSRF cash flow model for a high carbon offset cost scenario showing installation of rooftop solar arrays can be seen in Figure 3 below. A low carbon offset cost scenario is shown in Figure 4 below.

Sustainability Planning Framework

This document proposes a replicable framework for future sustainability planning. See Appendices H and I for information on a potential staff position for sustainability activities.

Proposed Carbon Neutrality Date

We propose an earlier carbon neutrality year of 2047 based on the CSRF cash flow model with the price of carbon offsets at \$93/tonneCO_2. If the price of carbon offsets is lower than the high-cost scenario, the carbon neutrality date can be earlier, as soon as 2038 under the low-cost scenario of \$29/tonneCO_2.

Conclusion

Given analysis of options for carbon neutrality, we recommend procuring high-quality carbon offsets using energy cost savings from a build-out of rooftop solar, funded by a Calvin Solar Revolving Fund (CSRF) with an initial donation of about $800k. Calvin could become carbon neutral by 2047 under a high carbon offset cost scenario, and 2038 under a low carbon offset cost scenario.

Figures

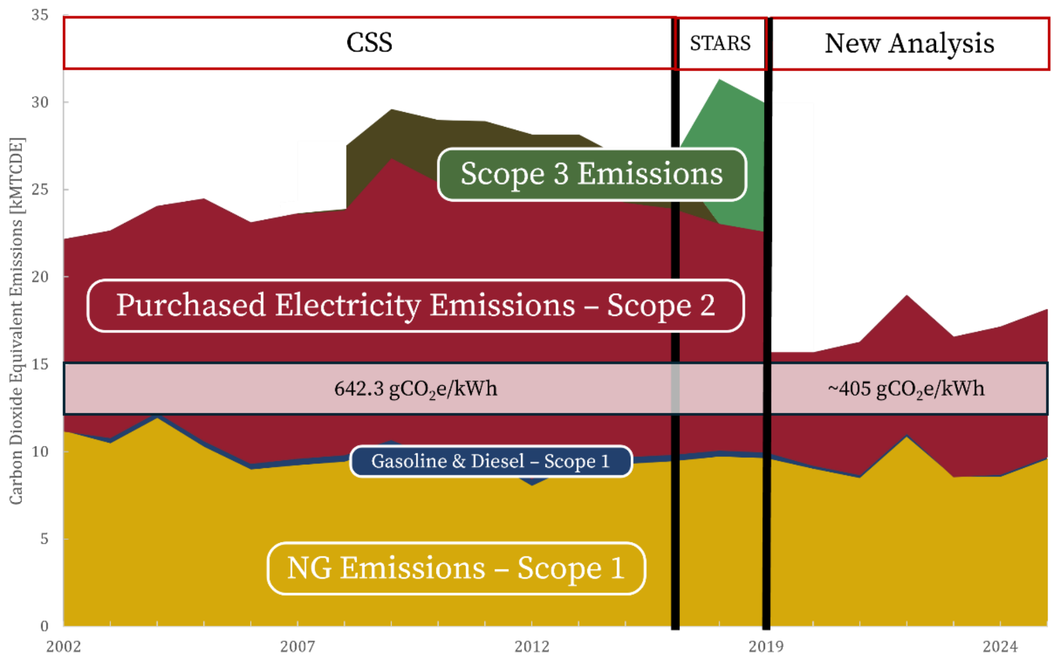

Figure 1: Scopes 1, 2, and 3 historical emissions from the Calvin Sustainability Scorecard (CSS), Sustainability Tracking, Assessment & Rating System (STARS), and the new Summer 2026 Analysis (New Analysis) based on natural gas consumption, transportation fuel consumption, and electricity consumption. For more details, see Appendix C.

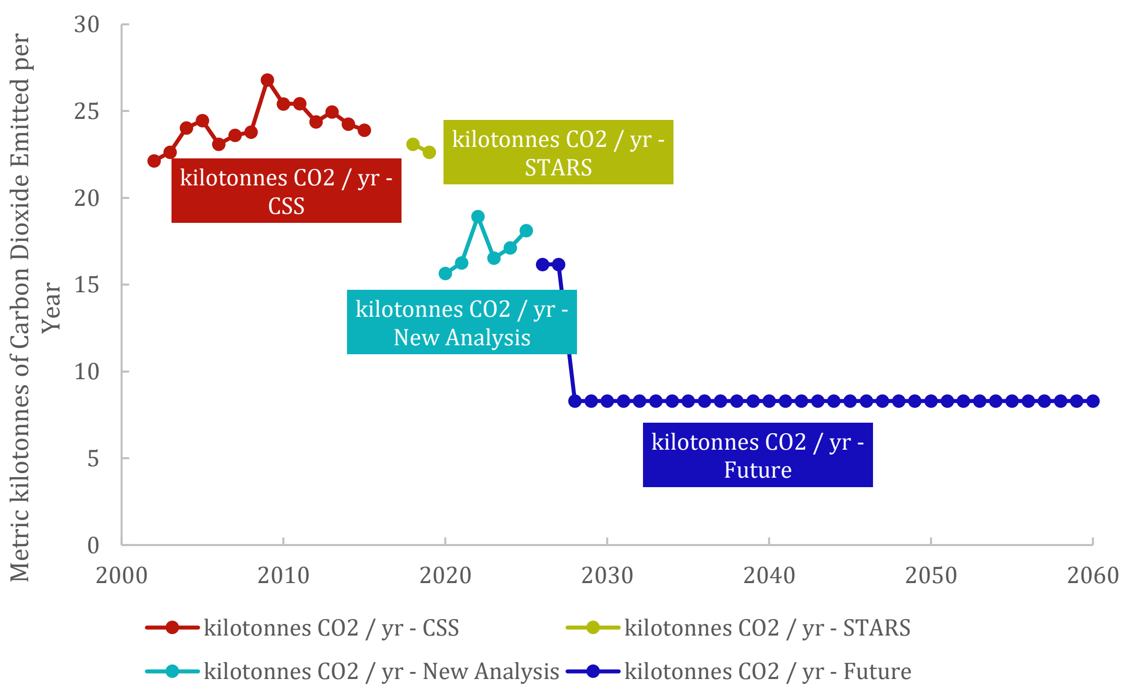

Figure 2: Total historical emissions and projected future emissions for Calvin University. For more details, see Appendix C.

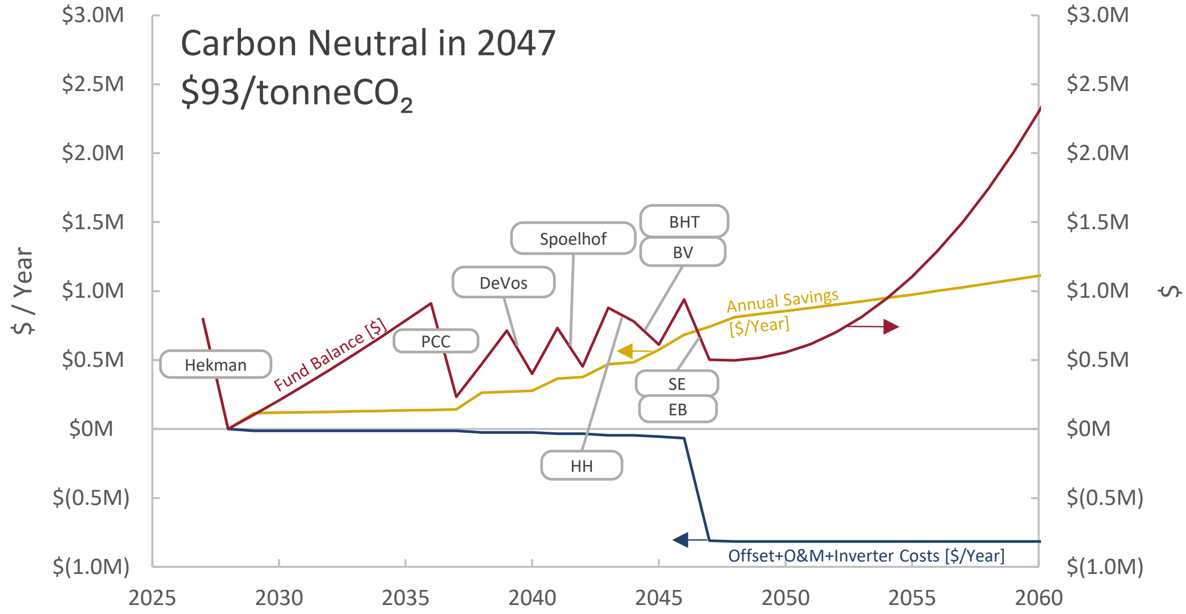

Figure 3: Cash flow model for CSRF, reaching carbon neutrality in 2047 when carbon offsets begin to be paid for at $93/tonneCO_2$. For more details, see Appendices E and I.

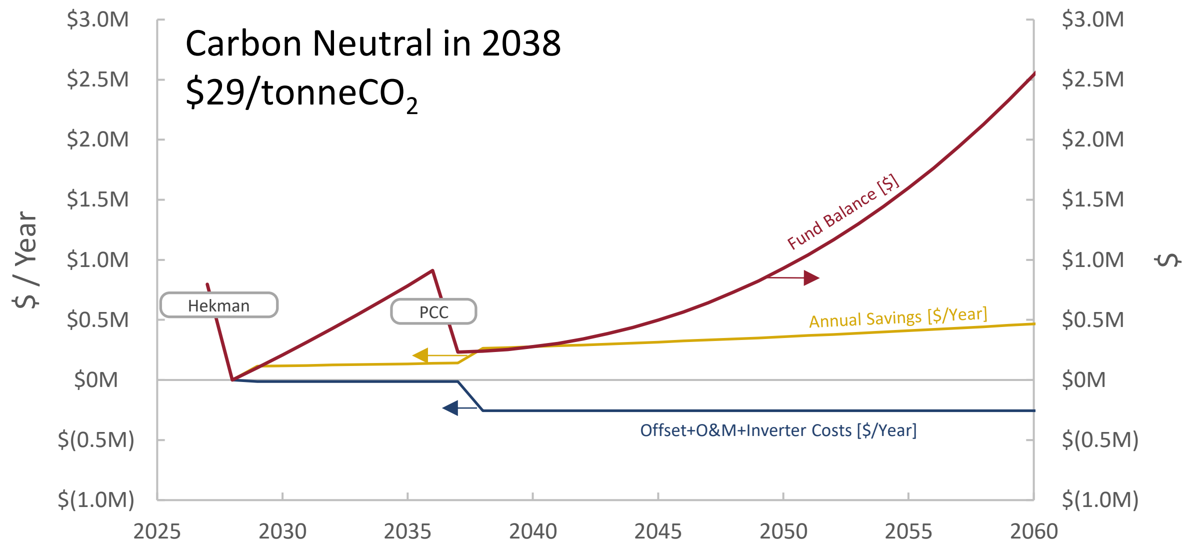

Figure 4: Cash flow model for CSRF with a $29/tonneCO_2$ carbon offset price. For more details, see Appendices E and I.

Appendix A: Geothermal Heating and Cooling

1 Introduction

One method of eliminating Scope 1 emissions on Calvin University's campus could be by retaining the current hot water and steam loop system and replacing natural gas-fired boilers with ground-source heat pumps (GSHPs), more commonly known as a geothermal system. Scope 1 emissions include the natural gas used in boilers. Paired with carbon-free electricity, this system would provide a route to eliminating a significant amount of Calvin's gross emissions without purchasing carbon offsets. However, Calvin's GSHPs for the newly built football locker room have encountered problems. First, unfavorable geological conditions led to double the expected amount of bores. Financial and logistical problems also arise when considering GSHPs. Second, implementation costs were estimated to be 70–400 times higher than Calvin's annual 2025 Scope 1 offset cost. Third, Calvin's residential campus leaves little room for drilling the estimated fourteen-acre bore field. Due to these constraints, we are not pursuing geothermal heating and cooling as a component of carbon neutrality at Calvin.

The remainder of this appendix is structured as follows. Section 2 discusses data sources and methods. Section 3 describes results of applying the methods of Section 2 to the data. Section 4 discusses the results and conclusion. References and appendices follow, providing supplementary information.

2 Data Sources and Methods

Data on previous geothermal analysis of Calvin's heating system were collected from Professor Matthew Kuperus Heun's ENGR333 classes in 2022 and 2023 (ENGR 333B, 2022) (ENGR 333-A, 2022) (ENGR-333 Section B, 2023). Information about Oberlin College's geothermal system was obtained from numerous sources, including Oberlin's own news reporting (Office of Communications, 2021) and a subdomain focused on carbon neutrality (Sustainable Infrastructure Program at Oberlin College & Conservatory, n.d.). Public records were accessed through the STARS tracking system for Calvin University (Calvin University, 2022) and Oberlin College (Oberlin College, 2025) to determine floor space requirements for heating and cooling. Satellite images of Oberlin and Calvin's campuses were accessed and analyzed using Google Earth. Rough estimates for carbon offset prices were obtained from Senken, a carbon offset procurement platform (Senken, 2026).

Two cost estimates for GSHPs on Calvin's campus were compiled. A high cost of $112,682,506 (Office of Communications, 2021) and low cost of $60,000,000 (ENGR 333-A, 2022) were used to compare installation costs with the cost of carbon offsets. The low estimate was a result of Facilities' past internal estimates, coupled with a 2023 estimate from ENGR333-A. The high estimate was calculated by multiplying Oberlin's installation cost by the ratio between Calvin's and Oberlin's building area requiring heating and cooling.

Required bore field area was estimated for Calvin using the assumption that bore field area is directly proportional to building floor space requiring heating. Since floor areas of both universities were already known, only Oberlin's bore field area was left to be determined. Area of Oberlin's bore field was estimated with Google Earth's area calculation tool.

By multiplying a high and low carbon offset cost – \$29/tonneCO_2 and \$93/tonneCO_2, respectively (Senken, 2026) – by Calvin's 2025 Scope 1 emissions, annual Scope 1 offset costs were calculated. Dividing upfront geothermal cost by annual CO_2 offset cost resulted in four ratios. Each ratio represents number of years offsetting Calvin's 2025 Scope 1 emissions before the total cost equaled or exceeded the installation cost of GSHPs.

3 Results

Results are displayed in Figure A1 and Table A1 below.

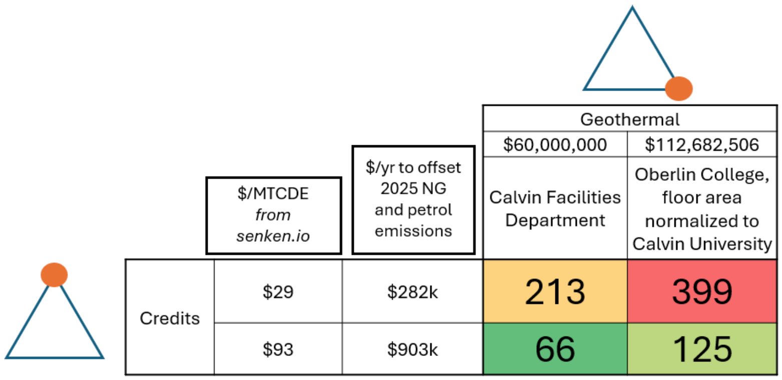

Figure A1: Comparison between geothermal and carbon offsets, time spent paying for equivalent offsets before installation cost of geothermal system is reached shown in years.

Table A1: Building floor area, geothermal system cost and bore field area for Calvin University and Oberlin College.

	Oberlin College	Calvin University
Campus Building Floor Area [ft^2]	2,748,285	2,212,026
Geothermal System Cost [$2026]	$140,000,000	$112,682,506
Bore Field Area [acres]	18.0	14.4

4 Discussion & Conclusion

Projected lifetime for above-ground components of a GHSP is 25–30 years, far sooner than the quickest time spent paying for equivalent offsets before installation cost of geothermal system is reached, shown in Figure A1. When it comes time to replace geothermal system components, they will have already cost more than achieving the same CO_2 removals through carbon offsets. Calvin also does not have a single field in proximity to campus large enough to contain a 14.4 acre bore field, leading to several smaller bore fields spread around campus. In addition, if Calvin cannot drill to Oberlin's 600-foot depth, more area will be necessary to achieve the same heating capacity. If this option had been pursued further, possible bore fields are highlighted in Appendix A4. We are not pursuing geothermal energy further for our research due to high projected cost and high geological uncertainty.

A1: Geothermal Heating Technology

A geothermal system, also called a ground-source heat pump (GHSP), provides a carbon-free way of heating a building using a hot water loop. GHSP systems have high upfront cost due to the bore field requirements. Wells are drilled to a depth where the ground temperature is constant year-round and water circulates through the wells, emerging at 55 °F. The 55-degree water exchanges heat with a refrigerant, which in turn is compressed to a high temperature. Heat then flows from the refrigerant to water in the campus loop, which is used for heating buildings.

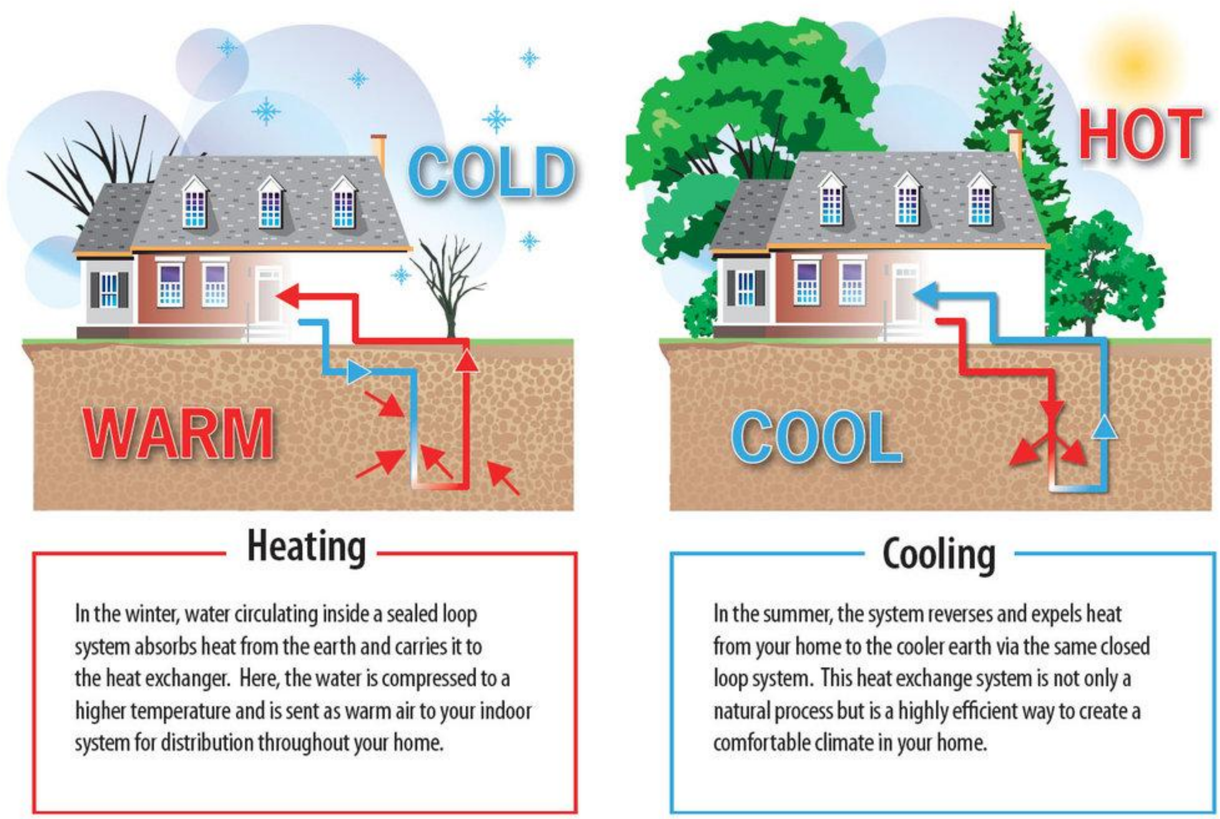

Figure A1.1: Geothermal heating and cooling overview.

A2: ENGR 333 Analyses

In Fall 2022, Professor Matthew Kuperus Heun asked the Engineering 333-A and 333-B classes what it would look like for Calvin University to move away from natural gas heating and adopt a carbon-free solution. A different group of students, in Fall 2023, was asked how soon Calvin could be carbon neutral, and what types of approaches would lead the university there. In Fall 2024, sections A and B examined what a Calvin-owned solar farm would look like, examining both on- and off-campus options. GSHPs were a component of the 2022 and 2023 analyses and provided much of the basis for this report's geothermal research. Solar PV energy was a sizable portion of the 2023 analysis and the entirety of the 2024 analysis.

Table A2.1: 2023 Carbon Neutrality GSHP and ASHP system cost estimate.

System	PEC (in 2023$)	Number of Boreholes	Borehole Area (ft^2)
Heating Loop 1	$21,956,250.00	1,335	534,000
Heating Loop 2	$2,353,750.00	110	44,000
Facilities Loop	$1,840,000.00	28	11,200
KE ASHP	$3,250,000.00	-	-
Total Cost (in 2023 $)	$29,400,000.00	1,473	589,200

Table A2.2: 2022 GHSP and ASHP system cost estimate.

System	**Capital Cost [$]**	**Heating Load [tons]**	**Number of Boreholes**	**Borehole Area [ft^2]**
Heating Loop 1	$21,956,250	3,050	1,335	534,000
Heating Loop 2	$2,353,750	250	110	44,000
KE Apartments	$1,920,000	78	35	14,000
Facilities Buildings	$1,840,000	64	28	11,200
Off-Campus Housing	$228,600	3	N/A	N/A
Total:	**$28,298,600**	**3,445**	**1,508**	**603,200**

A3: Comparisons Between Oberlin College and Calvin University

To estimate the bore field area required and installation cost for Calvin's campus, a ratio between Calvin's building area and Oberlin's building area was calculated. This ratio is 0.805. Multiplying Oberlin's borefield area (Figure A3.3) and installation cost by 0.805 is how estimates for Calvin's bore field area and installation cost were obtained. Figures A3.6 and A3.7 show building areas for each campus.

Figure A3.1: Satellite image of Oberlin's North Athletic fields. Taken on Oct 26, 2015.

Figure A3.2: Satellite image of Oberlin's North Athletic fields. Suspected borefield location has visible change in color and texture. Taken on March 14, 2025.

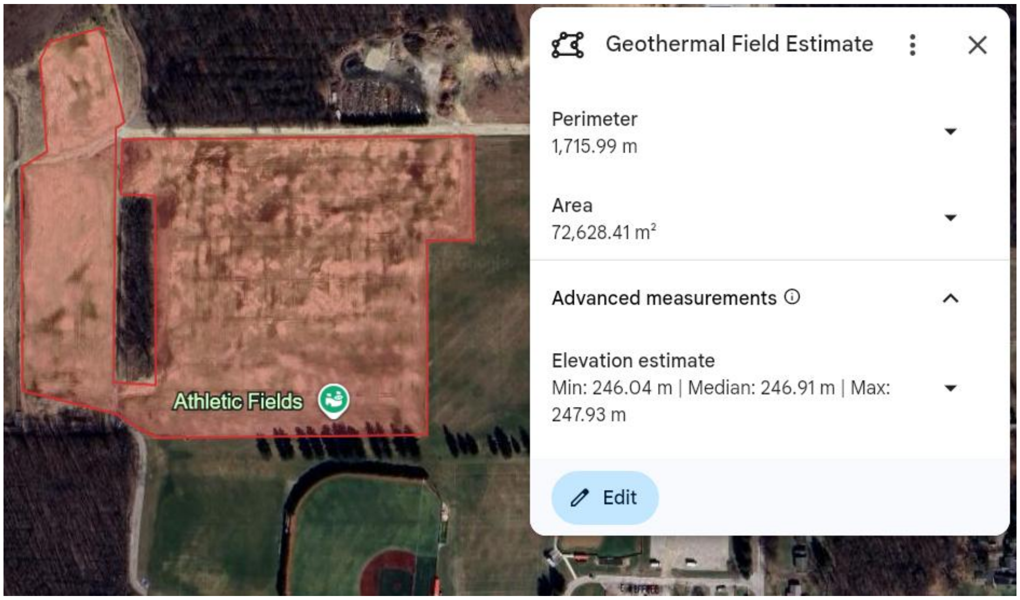

Figure A3.3: Area of Oberlin's suspected borefield, calculated using Google Earth.

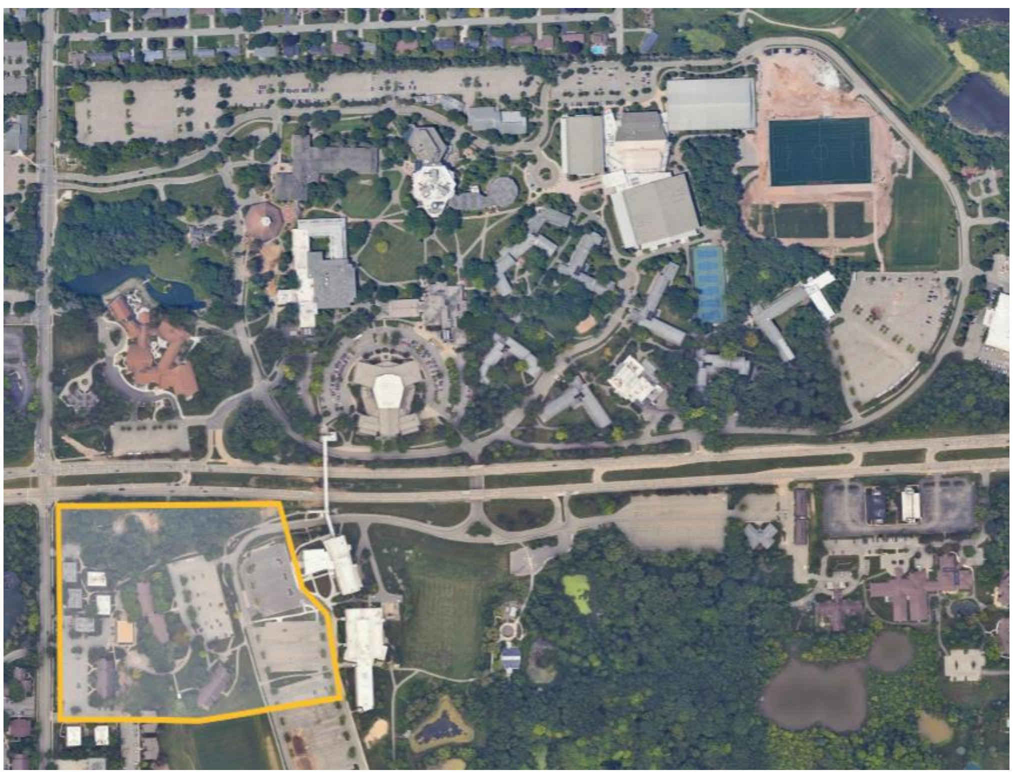

Figure A3.4: 72,000 m^2 area superimposed on Calvin's campus.

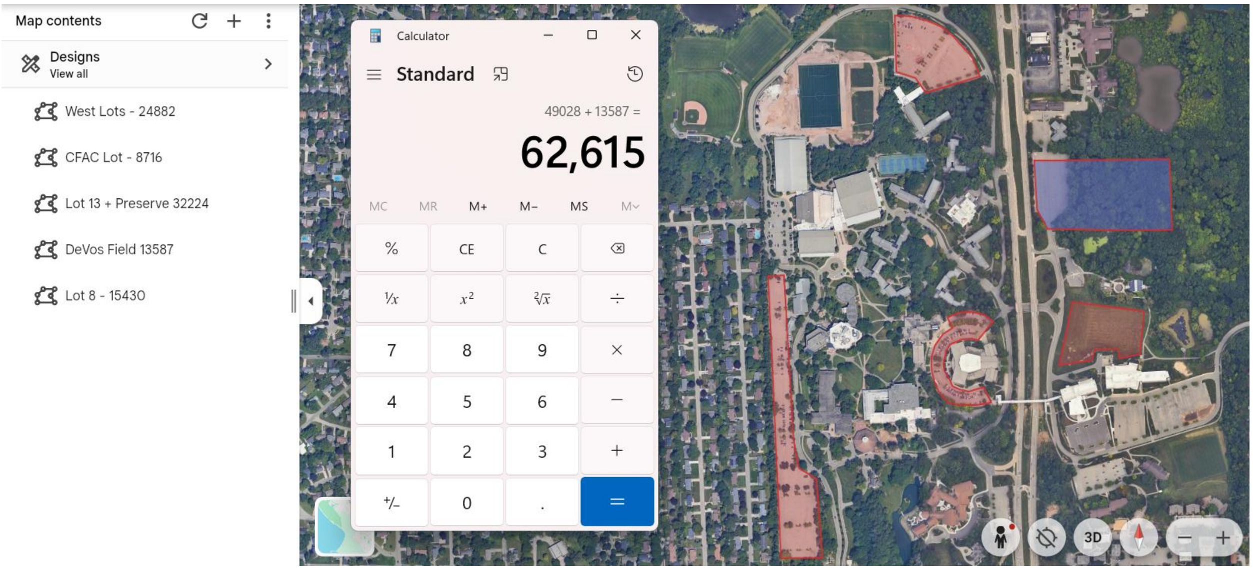

Figure A3.5: Potential borefield locations on Calvin's campus.

Figure A3.6: Oberlin College building area, retrieved from STARS report.

Figure A3.7: Calvin University building area, retrieved from STARS report.

Appendix B: Solar Feasibility

1 Introduction

One method of offsetting Scope 1 emissions on Calvin University's campus is to install solar panels to replace energy bought from Consumers Energy, using the energy cost savings to buy carbon offsets. The electricity bought under Scope 2 is expected to be carbon free in the near term, so only Scope 1 emissions were evaluated. Although this does not directly reduce Scope 1 emissions, it provides a realistic financial avenue for Calvin University to become net zero using both solar energy and carbon offsets. The solar panels recently installed on Van Noord provided information for estimating the cost of panels and the energy production for other rooftops on Calvin University's campus. The analysis showed that solar panels are a feasible route to carbon neutrality. The remainder of this appendix is structured as follows. Section 2 discusses data sources and methods. Section 3 describes results of applying the methods of Section 2. Section 4 discusses the results and conclusion. Appendices follow.

2 Data Sources and Methods

Information about previous rooftop solar projections was collected from the 2024 ENGR-333A class report on solar farm feasibility for Calvin University (ENGR 333 Section A, 2024). See Appendix B1: Preliminary Calculations for specific numbers. Identical metrics were evaluated on the recent Van Noord arena solar installation for comparison, and data from both were used in calculations. Rooftop area estimates were obtained using Google Earth. High and low estimates for carbon offset prices were retrieved from Senken's website (Senken, 2026). A multiplier between zero and one was then estimated for each roof, accounting for obstructions, shade, or unsuitable areas for solar installation.

The 2024 ENGR-333 report estimated initial investment ($\$$), rooftop area (A_{roof}), total investment per watt ($\$/W_{peak}$), and annual energy per cost ($kWh_1/\$$). Using these data, annual energy production (kWh_1), peak power (W_{peak}), and roof power density (W_{peak}/A_{roof}) were calculated for the five roofs examined in the 2024 ENGR-333 report: Venema Aquatic Center, Van Noord Arena, DeVos Communication Center, Prince Conference Center, and Hekman Library. Surface power density, investment per watt, and annual energy per cost values for the 333 report and the real Van Noord installation were compared and found to be very similar. See Appendix B1: Preliminary Calculations.

Next, the percentage of Calvin's 2021 Scope 1 CO_2 emissions that can be offset using annual cost savings from installing solar on one roof ($\%CO_2$) is given by

$$A_{roof} \times \phi \times \frac{W_{peak}}{A_{roof}} \times \frac{kWh_1}{W_{peak}} \times E_{cost} \times \frac{1}{CC_{cost}} \times \frac{1}{\gamma} = \%CO_2 \qquad \text{(B1)}$$

where ϕ is the multiplier mentioned above, E_{cost} is the average cost of energy, CC_{cost} is the cost of one carbon offset, and γ is the annual mass of CO_2 emissions.

Performing this calculation for each rooftop on Calvin's campus and summing the results gives the overall percentage of emissions each year that can be offset with money saved by producing our own solar energy.

3 Results

Results of applying Equation B1 to each roof and summing the answers are displayed in Table B1 below.

Table B1: Percent of 2021 Scope 1 emissions offset with predicted solar savings.

		Surface Power Density	
		Van Noord	333 Flat Roof
		15 W/ft²	7 W/ft²
Cost of Carbon Offsets	\$29/tonneCO_2	503%	235%
	\$93/tonneCO_2	157%	73%

4 Discussion & Conclusion

The predicted percentage of 2021 Scope 1 emissions that could be reduced using carbon offsets bought with energy cost savings from solar panels ranged from 75% to 517%. This range is highly dependent on the cost of carbon offsets and the surface power density of the roofs.

B1: Preliminary Calculations

Ratios derived from Van Noord solar array project information and the 2024 ENGR-333 report were important metrics used for many calculations. These ratios included total investment ($) per peak watt ($W_{peak}$), W_{peak} per unit area (ft^2), and annual energy yield (kWh_1) per W_{peak}. Table B1.1, Table B1.2, and Table B1.3 below display inputs for each ratio.

Table B1.1 shows results of dividing kWh_1 by W_{peak}. The blue cell (1.33 kWh_1/W_{peak}) was found using the 2024 ENGR-333 Report projections and then used to determine the kWh for one year for the Van Noord installation. The 2024 ENGR-333 Report value was used due to not having a full year of data from the Van Noord solar panels.

Table B1.1: Calculation for Annual Energy Yield per Peak Watt Ratio.

		kWh_1	**W_{peak}**	**kWh_1 / W_{peak}**
2024 333-A Projections	Venema	500655	369623	1.35
	Van Noord	643575	485717	1.33
	DV	253582	184802	1.37
	Prince	353509	262501	1.35
	Hekman	367733	253392	1.45
Real Installation	Van Noord	751593	567240	1.33

Table B1.2 shows the rightmost column, power density, as the quotient of the W_{peak} column and the Roof Area column. The values for power density differed by over a factor of 2. Lower values around 7 W/ft^2 only occur for roofs that are considered flat. Higher values occur on roofs that were considered as angled. The flat and angled distinction may account for the wide range of values. Therefore, both values of 7 W/ft^2 and 15 W/ft^2 were used in further calculations.

Table B1.2: Calculation for Peak Wattage per Unit Area Ratio.

		Roof Area [ft^2]	**W_{peak}**	**W_{peak}/ Roof Area**
2024 333-A Projections	Venema	20291	369623	18.22
	Van Noord	26426	485717	18.38
	DV	25528	184802	7.24
	Prince	41700	262501	6.29
	Hekman	32847	253392	7.71
Real Installation	Van Noord	36102.24	567240	15.71

Table B1.3 calculated the total investment per peak watt in the rightmost column. Although the 333 projected values are within a small range, the value used for further calculations was an average of the 333 values for the DeVos, Prince and Hekman, then increased by the same percentage as the Van Noord investment per peak watt did from projection to installation. The value used for further calculations was \$1.64 per W_{peak}.

Table B1.3: Calculation for Total Investment per Peak Watt Ratio.

		Cost [\$]	**W_{peak}**	**\$/W_{peak}**
2024 333-A Projections	Venema	\$465,725.43	369623	\$1.26
	Van Noord	\$607,145.97	485717	\$1.25
	DV	\$290,139.23	184802	\$1.57
	Prince	\$351,750.69	262501	\$1.34
	Hekman	\$369,952.69	253392	\$1.46
Real Installation	Van Noord	\$799,214.00	567240	\$1.41

B2: Rooftop Multipliers and Constants

Each roof has a different fraction of area that is usable for solar panels depending on the shade of objects or trees around it, obstructions on the roof that make it impossible to put solar panels in place, strength of roof, etc. A multiplier between 0 and 1 was applied to estimate the usable roof area for solar panels. There are a few multipliers that are zero because of known feasibility issues from the 2024 ENGR-333 Report. Table B2.1 lists the multipliers estimated for each roof.

Table B2.1: Calvin University buildings and their respective roof areas, multipliers, and reason for multiplier estimate.

Building	Roof Area [ft^2]	Multiplier	Reason
Hekman	39309	0.95	Roof Obstructions
Spoelhof Center	54035	0.6	Trees
DeVos	31166	0.85	Multi-Level Roof
PCC	42057	0.9	2024 333 DeRooy Class; Multi level
North Hall	23076	0.5	2024 333 DeRooy Class
Engineering Building	21475	0.7	Trees
SD Power Plant	5338	0.4	Trees and Vents on Roof
Science Building	24955	0	Roof Obstructions
DeVries Hall	17738	0.5	Roof Obstructions and Multi Level
Commons	25620	0	Construction Plans
Commons Annex	10218	0	Construction Plans
CFAC	68403	0	Structural Integrity Issues
Hiemenga hall	50256	0.5	Roof Obstructions
Chapel	18149	0	Steep
DeWit Manor	4838	0.7	Trees
Seminary	59382	0	Separate from Main Campus
KHVR	36225	0.15	Trees
BB	20728	0	Trees
NVW	22961	0.8	Trees
Knollcrest Dining Hall	29260	0	Construction Plans
RVD	22329	0.5	Trees
BHT	30831	0.6	Trees
BV	20110	0.9	Trees
SE	19971	0.6	Trees
PhiChi	11925	0.35	Trees and 50% Angled North
Theta/Epsilon	17516	0.25	Trees
Alpha	4899	0.9	Trees
Beta	4576	0.2	Trees
Gamma	4985	0.3	Trees
Delta	4955	0.9	Trees
Kappa	4949	0.7	Trees

B3: Solar Panel Specifications

Panel specifications data were given from facilities for the panels that were installed on Van Noord. The dimensions can be seen in Figure B3.1 and Table B3.1: Solar panel dimensions.. The W_{peak} can be found in Table B3.2. These were used for a comparison for the W_{peak} per ft^2 ratio found in Appendix B1: Preliminary Calculations.

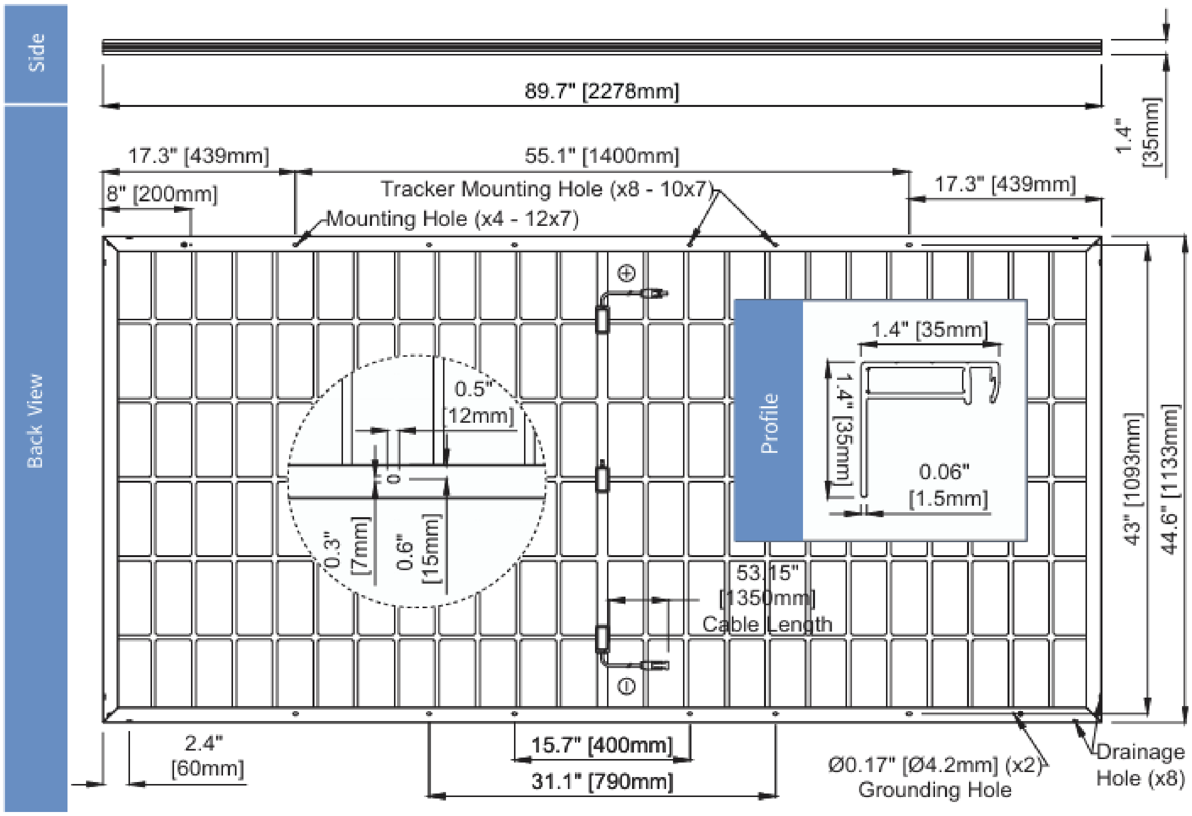

Figure B3.1: Dimensions of solar panel when viewing from the back.

Table B3.1: Solar panel dimensions.

MECHANICAL PROPERTIES / COMPONENTS	METRIC	IMPERIAL
Module weight	28.5 kg ± 0.2 kg	62.8 lbs ± 0.4 lbs
Dimensions (H x L x D)	2278 mm x 1133 mm x 35 mm	89.7 in x 44.6 in x 1.4 in
[illegible]	[illegible]	[illegible]

Table B3.2: Solar panel peak wattage and other information.

ELECTRICAL SPECIFICATIONS		580		
Test Conditions		STC	BSTC	NOCT
Module Power (Pmax)	Wp	580	632.8	428.2
Maximum power voltage (Vpmax)	V	44.27	44.27	40.73
Maximum power current (Ipmax)	A	13.10	14.29	10.51
Open circuit voltage (Voc)	V	52.27	52.32	48.08
Short circuit current (Isc)	A	13.85	15.11	11.12
Module efficiency	%	22.4%		
Maximum system voltage (VDC)	V	1500		
Series fuse rating	A	30		
Power Tolerance	Wp	0 to +10		
Bifaciality Factor	%	80 ± 10		

Performance conditions: Measurement tolerance ≤ 3% • Standard Test Conditions (STC): 1000 W/m², AM 1.5, Temperature 25 °C • Nominal Operating Cell Temperature (NOCT): 800 W/m², AM 1.5 • Bifacial Standard Test Conditions (BSTC): 1000 W/m2 + φ × 135 W/m2 , φ = 80 % , AM 1.5 • Electrical characteristics may vary by ±5%.

B4: 2024 ENGR 333 Analyses

Appendix A2: ENGR 333 Analyses gives an overview of the Engineering 333 projects. The 2023 and 2024 classes both greatly focused on solar PV energy. In Fall 2024, Professor Matthew Kuperus Heun's Engineering 333 class (groups A and B) examined what a Calvin-owned solar farm would look like. The values used from these reports are in Table B4.1 and Table B4.2. The Engineering 327 class also studied the feasibility of certain buildings' ability to support the added weight of solar panels. These findings are in Table B4.3 below and were used for estimating the multipliers explained in Appendix B2: Rooftop Multipliers and Constants.

Table B4.1: 2024 ENGR 333 group A roof type, area, and slope of six different buildings.

Location	Roof Type	Area (ft^2)	Slope
CFAC	Flat	13492	0:0
Venema	Angled	20291	6:12
VanNoord	Angled	26426	6:12
Hekman	Flat	32847	0:0
DeVos/Business	Flat	25528	0:0
Prince	Flat	41700	0:0

Table B4.2: 2024 ENGR 333 group A table with solar projections for four buildings' roofs.

Building	Total Initial Investment ($)	Total Initial Investment Per Watt ($/W)	First Year Energy (kWh/$)	Payback (years)	ROI (%)	CN (%)	IRR (%)
Venema	465,725.43	1.26	1.075	11.50	89.33	0.96	7.72
VanNoord	607,145.97	1.25	1.060	11.61	89.19	1.24	7.60
DeVos/ Business	290,139.23	1.57	0.874	14.30	63.52	0.49	5.38
Prince	351,750.69	1.34	1.005	12.50	79.75	0.67	6.25
Hekman	369,952.69	1.46	0.944	13.10	73.89	0.67	6.81
Total	**2,084,714.01**	**6.88**	**4.958**	**14.30**	**80.00**	**4.03**	**6.82**

Table B4.3: 2024 ENGR 327 summary of findings of structural viability.

Covenant Fine Arts Center	Not viable for solar panel mounting
Prince Conference Center & Hotel	Conference center viable, hotel unknown
North Hall	Likely viable
Devos Communications Center	Viable for solar panels
Business Building	Viable for solar panels mounted with a ballast system
Venema Aquatic Center	Viable for solar panels
Van Noord Arena	Likely viable
Hekman Library	Viable for solar panels
Hiemenga Hall	

Appendix C: Historical and Projected Carbon Emissions

1 Introduction

Calvin's carbon emissions were calculated per year from 2002 to 2025 in three categories: Scope 1, Scope 2, and Scope 3. Scope 1 emissions result from on campus natural gas and vehicle fuel combustion. Scope 2 emissions result from electricity purchased. Scope 3 emissions cover indirect emissions ranging from purchasing, waste, employee and student commutes, and more. For this research, Scope 3 will not be included in future carbon emissions projections due to inconsistent metrics and difficulty in attaining appropriate data. We chose 2021 as the base or reference year for prospective comparison was decided to be 2021 with the total carbon emissions being 16,250 metric tonnes of carbon dioxide equivalent (MTCDE). By 2030, Calvin expects to eliminate Scope 2 emissions through a clean energy agreement with Consumers Energy. Scope 1 emissions are expected to decrease due to more efficient boilers but will remain Calvin's main source of CO_2 emissions after 2030.

The remainder of this appendix is structured as follows. Section 2 discusses data sources and methods. Section 3 describes results of applying the methods of Section 2. Section 4 discusses the results and conclusion. Appendices follow, providing supplementary information.

2 Data Sources and Methods

Usage and emissions data from 2002-2015 were retrieved from the Calvin Sustainability Scorecard. See Appendix C3: CSS Reporting. Data used include electricity usage, corresponding emissions, and carbon coefficients. A carbon coefficient is a ratio that measures emissions per product. Usage, emissions, and carbon coefficients were also retrieved for natural gas. The CSS also includes emissions resulting from flights purchased by the university.

Emissions data for 2018 and 2019 were retrieved from publicly available STARS reports (C4: STARS Reports). Though STARS reports date back to 2017, there are no data from 2016 and 2017.

2020-2025 natural gas, transportation fuel, and purchased electricity data were retrieved from Calvin Facilities, and are shown in Appendix C5.

Emissions data were grouped by scope, years were grouped by reporting framework, and the data set was plotted. Future Scope 2 emissions were calculated using the average annual electricity usage from 2020-2025 and the 2025 carbon coefficient. This projection stays constant until dropping to zero when Calvin begins purchasing carbon-free electricity from Consumers Energy – our model shows this happening in 2030. Future natural gas emissions were calculated using an average from 2021-2025, then subtracting the projected energy savings from new boilers installed in 2026. Future petrol emissions were calculated by projecting the average usage value from 2002-2019, since Facilities has low confidence in the accuracy of 2021-2025 petrol usage data.

3 Results

Figure C1 and Figure C2 present the results below.

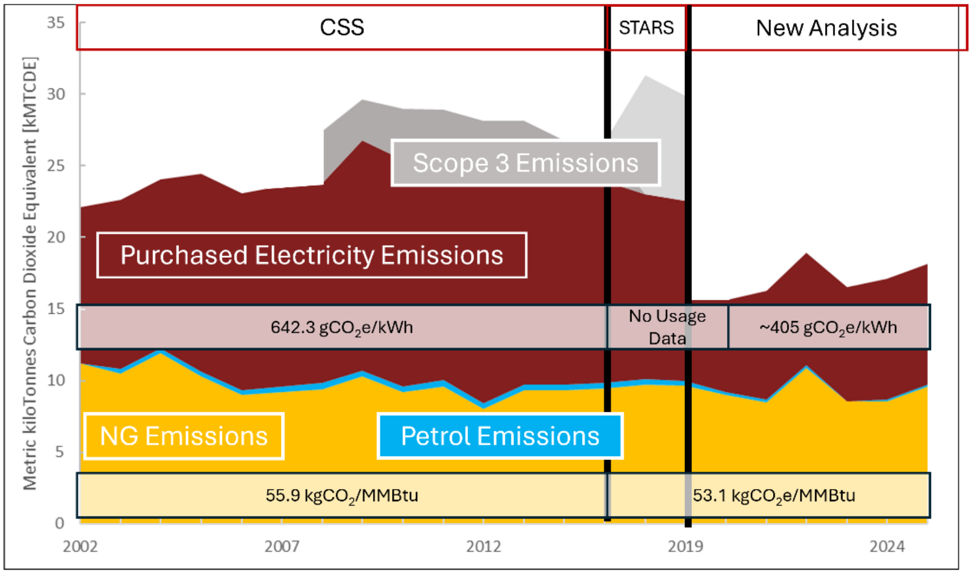

Figure C1: Scope 1, 2, and 3 carbon equivalent emissions per year since 2002.

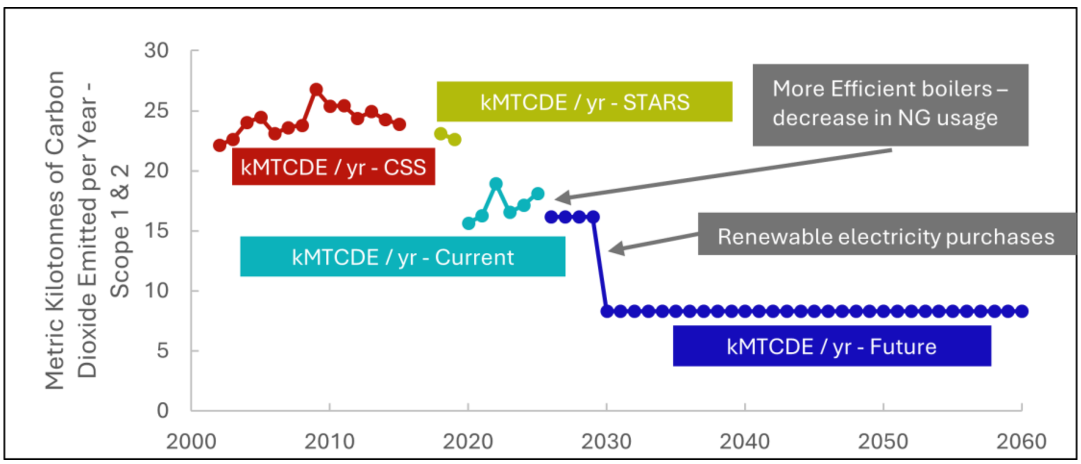

Figure C2: Scopes 1 & 2 CO_2 emissions per year with projected emissions from 2002-2060.

4 Discussion & Conclusion

Natural gas carbon emissions and emissions resulting from purchased electricity are the two major contributors to Calvin's total carbon footprint. Scope 3 emissions were accounted from 2007 to 2020 only. These data were obtained through CSS and STARS reports. Future projections for Scopes 1 and 2 include a decrease in 2026 due to more efficient boilers. There is a sharp decrease in 2030 that accounts for the switch to clean energy from Consumers Energy. The constant emissions from 2030 to 2060 assumes consistent use of natural gas and fuel, the last component in Calvin's carbon footprint. Conclusions are as follows. First, because of the unreliability in the process of obtaining much of the Scope 3 data, including obtaining employee and student commuting data from surveys, it will not be included in further research. Second, a base year for annual carbon emissions will be 2021, based on the reliability of the data and the ability to calculate emissions in the same manner in the future. Third, decreasing net Scope 1 emissions will be the emphasis of future research.

C1: Scopes 1, 2, and 3

Carbon emissions are categorized as Scope 1, Scope 2, or Scope 3 emissions. Scope 1 emissions are direct emissions that occur from sources on Calvin University's campus. Scope 2 emissions are indirect emissions that result from Calvin's energy and utility purchases. Scope 3 emissions cover all other indirect emissions ranging from purchasing, waste, employee and student commutes, and more. Specifically, Calvin's Scope 1 emissions result from natural gas burned on campus and petrol bought by Facilities for vehicle use. Scope 2 emissions result from electricity purchased from Consumers Energy. Previously in the CSS and STARS reports, Scope 3 included solid waste, student and faculty commutes, and Calvin-purchased flights. However, Scope 3 will not be included in prospective total carbon emissions due to inconsistent metrics and difficulty in attaining appropriate data. Table C1.1 is a summary of what is included in Scopes 1, 2, and 3. Table C1.2 and Table C1.3 list the Scope 1 and Scope 2 yearly carbon emission values. Due to STARS only reporting emission values, rather than usage values, there are no natural gas or electricity usage data for 2018 and 2019.

Table C1.1: Scope 1, Scope 2, and Scope 3 emissions producers.

Scope 1	Scope 2	Scope 3
• Natural Gas • Gasoline • Diesel	• Consumers Energy Electricity	• N/A

Table C1.2: Scope 1 natural gas and fuel usage converted to carbon emissions using coefficients.

	NG Emissions		Direct Transportation Emissions
	Usage [MMBtu]	kMTCDE	kMTCDE
Calvin Sustainability Scorecard Data	200085	11.18	0.0000
	187559	10.48	0.3204
	213257	11.92	0.3302
	183897	10.28	0.3382
	160746	8.99	0.3377
	165099	9.23	0.3833
	168606	9.43	0.4058
	184078	10.29	0.3968
	164731	9.21	0.4098
	171881	9.61	0.4234
	143892	8.04	0.4062
	166382	9.30	0.3918
	177433	9.30	0.4129
	169203	9.46	0.3758
STARS SIMAP reporting		9.72	0.3640
		9.62	0.3469
	170000	9.03	0.1997

	NG Emissions		Direct Transportation Emissions
	Usage [MMBtu]	kMTCDE	kMTCDE
Data from 2026 Student Neutrality Summer Interns	159891	8.49	0.1845
	204570	10.86	0.1931
	161521	8.58	0.0019
	161036	8.55	0.1469
	180275	9.57	0.1437

Table C1.3: Scope 2 energy usage and conversion to MTCDE using carbon coefficients.

		Purchased Electricity	
	Year	Usage [kWh]	MTCDE
Calvin Sustainability Scorecard Data	2002	17049600	10.95029
	2003	18417600	11.8289
	2004	18355200	11.78882
	2005	21542400	13.83584
	2006	21451200	13.77726
	2007	21786042	13.99232
	2008	21751798	13.97033
	2009	25073310	16.1036
	2010	24589308	15.79275
	2011	23985236	15.40478
	2012	24795756	15.92534
	2013	23756597	15.25793
	2014	22642329	14.54228
	2015	21923414	14.07151
STARS SIMAP reporting	2018		12.94847
	2019		12.60035
Data from 2026 Student Neutrality Summer Interns	2020	15965950	6.418791
	2021	18845222	7.576345
	2022	19579973	7.871737
	2023	19809021	7.963821
	2024	20588741	8.434795
	2025	20529329	8.409224

C2: Carbon Coefficients

Carbon coefficients are used to calculate the carbon dioxide equivalent (CO_2e) emitted from various fuels and energy. Table C2.1 lists the carbon coefficients for natural gas, gasoline, diesel, and purchased electricity. All coefficients corresponding to 2002-2015 were retrieved from the Calvin Sustainability Scorecard from Facilities, originally compiled by Professor Matthew Kuperus Heun. The Michigan electricity carbon coefficients were listed for 2023-2025 as seen in Figure C2.1 (Electricity in Michigan in 2025, n.d.). The 2023 coefficient was also used for 2020-2022.

Table C2.1: Carbon coefficients for natural gas, purchased electricity, gasoline, and diesel.

Substance	Years Used	CO2e?	Value	Units
Natural Gas	2002-2015	N	55.9	kg CO2/MMBtu
Natural Gas	2015-	Y	53.1	kgCO2e/MMBtu
Electricity	2002-2015	N	642.3	gCO2 / kWh
Electricity	2020-2023	Y	402.0	gCO2eq/kWh
Electricity	2024	Y	409.7	gCO2eq/kWh
Electricity	2025-	Y	409.6	gCO2eq/kWh
Gasoline	2002-2015	N	8.800	kg CO2e/gallon
Gasoline	2020-	Y	8.780	kg CO2e/gallon
Diesel	2002-2015	N	10.070	kg CO2e/gallon
Diesel	2020-	Y	10.210	kg CO2e/gallon

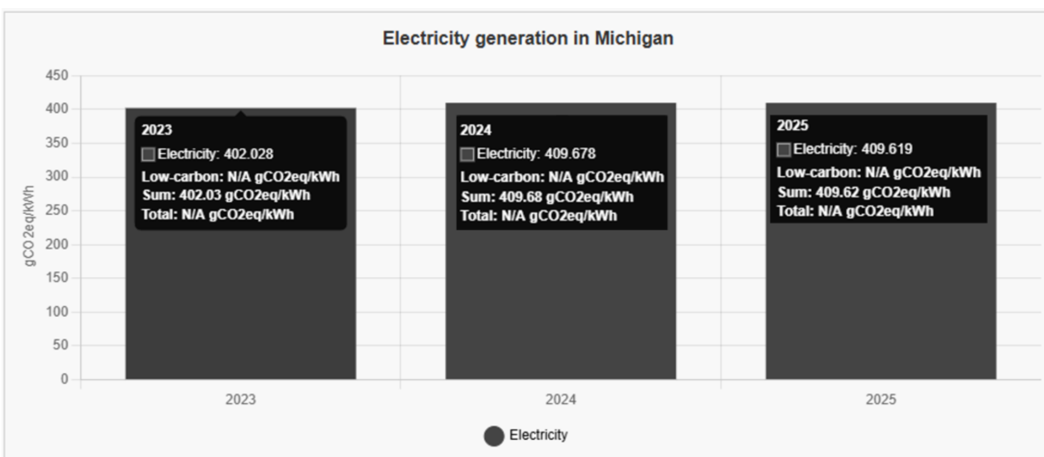

Figure C2.1: Electricity carbon coefficient for 2023-2025.

For emissions from 2020 onward, new natural gas, gasoline, and diesel carbon coefficients were calculated. Using 2025 Emission Factors calculated by UNH-SIMAP (UNH-SIMAP, 2025), carbon dioxide, methane, and nitrous oxide emission factors were retrieved (See Table C2.2). Global Warming Potential (GWP-100) values from the United Nations Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6) were also retrieved (Smith, et al., 2021), see Table C2.3. GWP-100 is a metric used to compare how much heat different greenhouse gases trap in the atmosphere, relative to carbon dioxide. For one gas, the product of GWP-100 and the corresponding emission factor equals carbon coefficient with units of CO_2 equivalent (CO_2e) per usage. These factors were used in Table C2.1 above.

Table C2.2: SIMAP 2025 emission factors with natural gas, gasoline, and diesel highlighted in yellow.

2025 Emission Factors | SIMAP

Category	Carbon dioxide (CO2)	Methane (CH4)	Nitrous oxide (N2O)	Biogenic CO2	Nitrogen oxides (NOx)
On-Campus Stationary Sources: Residual Oil (#5-6)	11.240756 kg CO2/gallon	0.0015793 kg CH4/gallon	0.000095 kg N2O/gallon		0.006767 kg NOx/gallon
On-Campus Stationary Sources: Distillate Oil (#1-4)	10.185423 kg CO2/gallon	0.0014494 kg CH4/gallon	0.000087 kg N2O/gallon		0.006210 kg NOx/gallon
On-Campus Stationary Sources: Natural Gas	52.91 kg CO2/MMBtu	0.0052753 kg CH4/MMBtu	0.000106 kg N2O/MMBtu		0.030711 kg NOx/MMBtu
On-Campus Stationary Sources: LPG (Propane)	4.8345305 kg CO2/gallon	0.0008099 kg CH4/gallon	0.0000487 kg N2O/gallon		0.003626 kg NOx/gallon
On-Campus Stationary Sources: Coal (Steam Coal)	1,735.8474 kg CO2/short	0.1907858 kg CH4/short ton	0.0286179 kg N2O/short ton		15.9458 kg NOx/short ton
On-Campus Stationary Sources: Incinerated Waste	178.6 kg CO2/short ton	0 kg CH4/short ton	0.1342282 kg N2O/short ton	201.4 kg	2.472076 kg NOx/short ton
On-Campus Stationary Sources: Wood Chips	0 kg CO2/short ton	5.5327137 kg CH4/short ton	0.07377 kg N2O/short ton	1639.50747 kg	0.527414 kg NOx/short ton
On-Campus Stationary Sources: Wood Pellets	0 kg CO2/short ton	5.5327137 kg CH4/short ton	0.07377 kg N2O/short ton	1639.50747 kg	0.527414 kg NOx/short ton
On-Campus Stationary Sources: Grass Pellets	0 kg CO2/short ton	5.5327137 kg CH4/short ton	0.07377 kg N2O/short ton	1639.50747 kg	0.527414 kg NOx/short ton
On-Campus Stationary Sources: Residual BioHeat	8.727133 kg CO2/gallon	0.0015327 kg CH4/gallon	0.000092 kg N2O/gallon	2.18178316 kg	0.006567 kg NOx/gallon
On-Campus Stationary Sources: Distillate BioHeat	8.032257 kg CO2/gallon	0.001429 kg CH4/gallon	0.000086 kg N2O/gallon	2.00338045 kg	0.006122 kg NOx/gallon
On-Campus Stationary Sources: Ethanol	0 kg CO2/gallon	0.000352 kg CH4/gallon	0.000111 kg N2O/gallon	5.75 kg	
Direct Transportation Sources: Gasoline Fleet	8.78 kg CO2/gallon	0.0002567 kg CH4/gallon	0.000213 kg N2O/gallon		0.00935 kg NOx/gallon
Direct Transportation Sources: Diesel Fleet	10.21 kg CO2/gallon	0.0001480 kg CH4/gallon	0.000258 kg N2O/gallon		0.02624 kg NOx/gallon
Direct Transportation Sources: Natural Gas Fleet	52.91 kg CO2/MMBtu	0.014 kg CH4/MMBtu	0.000412 kg N2O/MMBtu		0.044716 kg NOx/MMBtu
Direct Transportation Sources: E85 Fleet	2.2828 kg CO2/gallon	[illegible] Plot Area g CH4/gallon	0.000135 kg N2O/gallon	4.255 kg	0.009212 kg NOx/gallon
Direct Transportation Sources: B5 Fleet	9.6995 kg CO2/gallon	[illegible] g CH4/gallon	0.000246 kg N2O/gallon	0.4725 kg	0.026238 kg NOx/gallon

Table C2.3: IPCC global warming potential values for CO2, methane, and nitrous oxide.

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7.SM.6 Tables of Greenhouse Gas Lifetimes, Radiative Efficiencies and Metrics

Chapter 7 Supplementary Material

Table 7.SM.7 | Greenhouse gas lifetimes, radiative efficiencies, global warming potentials (GWPs), global temperature potentials (GTPs) and cumulative global temperature potentials (CGTPs). GWPs given for 20-year, 100-year and 500-year time horizons. GTPs and CGTPs given for 50-year and 100-year time horizons. Note CGTP has units of years and is applied to a change in emissions rate rather than a change in emissions amount. Also shown are absolute values of GWPs and GTPs (AGWPs and AGTPs), in units of picowatt years per square metre per kilogram (1 pW = 10^{-12} W) or picokelvin per kilogram (1 pK = 10^{-12} K). Radiative efficiencies for CH_4 and N_2O given in this table do not include chemical adjustments (values including chemical adjustments are given in Table 7.15). For SF6 the assessed lifetime from Section 2.2.4.3 is used, all other lifetimes are taken from Hodnebrog et al. (2020).

Name	Formula	Lifetime (yr)	Radiative Efficiency ($W m^{-2} ppb^{-1}$)	AGWP-20 ($pW m^{-2} yr kg^{-1}$)	GWP-20	AGWP-100 ($pW m^{-2} yr kg^{-1}$)	GWP-100	AGWP-500 ($pW m^{-2} yr kg^{-1}$)	GWP-500	AGTP-50 ($pK kg^{-1}$)	GTP-50	AGTP-100 ($pK kg^{-1}$)	GTP-100	CGTP-50 (yr)	CGTP-100 (yr)
Major Greenhouse Gases															
Carbon dioxide	CO_2		1.33×10^{-5}	0.0243	1	0.0895	1	0.314	1	0.000428	1	0.000395	1		
Methane[1]	CH_4	11.8	0.000388	1.98	81.2	2.49	27.9	2.5	7.95	0.00473	11	0.00212	5.38	2730	3320
Nitrous oxide	N_2O	109	0.0032	6.65	273	24.5	273	40.7	130	0.124	290	0.0919	233		

C3: CSS Reporting

The Calvin Sustainability Scorecard (CSS) is a carbon accounting framework developed by Professor Matthew Kuperus Heun and monitored until 2015. The CSS recorded natural gas, transportation fuel, and electricity usage from 2002 onward. Beginning in 2008, flights paid for by Calvin were also tracked. Carbon coefficients corresponding to each usage metric were also recorded in the CSS. Table C3.1 and Table C3.2 display the data retrieved from Calvin Facilities.

Table C3.1: Natural gas and electricity data from CSS.

Note	Source	Quantity	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Natural Gas																
Natural G	Dan Slager, Physical Plant	Natural Gas (ccf, hundred cubic feet)	2000851	1875587	2132569	1838972	1,607,461	1,650,990	1,686,060	1,840,780	1,647,310	1,718,810	1,438,920	1,663,820	1,663,820	1,692,030
Natural G	Dan Slager, Physical Plant	Natural Gas (MMBTU, million BTUs)		Plot Area				165,099	168,606	184,078	164,731	171,881	143,892	166,382	177,433	169,203
		Natural Gas (cubic feet)	200085100	187558700	[illegible]	183897200	160,746,100	165,099,000	168,606,000	184,078,000	164,731,000	171,881,000	143,892,000	166,382,000	166,382,000	169,203,000
	From Ken Piers sustainability study in 2007, 1 tonne CO2 generated by 1	cf nat gas/tonne CO2	17889	17889	17889	17889	17,889	17,889	17,889	17,889	17,889	17,889	17,889	17,889	17,889	17,889
		CO2 from natural gas (tonnes)	11185	10485	11921	10280	8,986	9,229	9,425	10,290	9,209	9,608	8,044	9,301	9,301	9,459
		Building Area for Natural Gas (ft^2)	1855764	1861069	1861069	1861069	1,871,809	1,871,809	1,904,584	2,227,915	2,239,225	2,239,225	2,239,225	2,239,225	2,239,225	2,266,435
		Nat. Gas CO2 Intensity (kg CO2/ft^2)	6.03	5.63	6.41	5.52	4.80	4.93	4.95	4.62	4.11	4.29	3.59	4.15	4.15	4.17
	Fall Day 10 report for the year shown. For example, the Sept 2008 Day 1(	Students for Natural Gas (students)	4330	4332	4186	4189	4199	4224	4171	4092	3991	3,967	4,008	4,034	3,993	4,000
		Nat. Gas CO2 Intensity (tonnes CO2/student)	2.58	2.42	2.85	2.45	2.14	2.18	2.26	2.51	2.31	2.42	2.01	2.31	2.33	2.36
Electricity																
Substatio	Dan Slager, Physical Plant	Electricity (kW-hr)	17,049,600	18,417,600	18,355,200	21,542,400	21,451,200	21,786,042	21,751,798	25,073,310	24,589,308	23,985,236	24,795,756	23,756,597	22,642,329	21,923,414
	From http://www.miloslick.com/EnergyLogger_files/State_Electricity_and	kW-hr/tonne CO2	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1557	1558
		Students for Electricity (students)	4330	4332	4186	4189	4,199	4,224	4,171	4,092	3,991	3,967	4,008	4,034	3,993	4,000
		Electrical intensity (kW-hr/student)	3938	4252	4385	5143	5,109	5,158	5,215	6,127	6,161	6,046	6,187	5,889	5,671	5,481
		CO2 from electricity (tonnes)	10950	11829	11789	13836	13,777	13,992	13,970	16,104	15,793	15,405	15,925	15,258	14,542	14,072
		Building area for Electricity (ft^2)	1586124	1586124	1586124	1586124	1,586,124	1,586,124	1,586,124	1,909,455	1,914,760	1,914,760	1,914,760	1,908,390	1,914,760	1,914,760
		Electrical intensity (kW-hr/ft^2)	10.7	11.6	11.6	13.6	13.52	13.74	13.71	13.13	12.84	12.53	12.95	12.45	11.83	11.45
		Electricity CO2 Intensity (kg CO2/ft^2)	6.90	7.46	7.43	8.72	8.69	8.82	8.81	8.43	8.25	8.05	8.32	8.00	7.59	7.35
		Electricity CO2 intensity (tonnes CO2/student)	2.53	2.73	2.82	3.30	3.28	3.31	3.35	3.94	3.96	3.88	3.97	3.78	3.64	3.52
		Peak Demand (kW)										4940				

Table C3.2: Fuels, flights, and totals data from CSS.

Fuels																
	Nola Nielsen, Physical Plant	Diesel fuel purchased (gal)		4878.7	5810.90	6280.10	5,133	6,996	7,497	6,084	6,299	6,713	5,728	5,862	7,274	5,818
	http://www.epa.gov/oms/climate/420f05001.htm	CO2 from diesel (lbs/gallon)		22.20	22.20	22.20	22.20	22.20	22.20	22.20	22.20	22.20	22.20	22.20	22.20	22.20
		CO2 from diesel (lbs)		108307.14	129001.98	139418.22	113,955	155,302	166,429	135,074	139,838	149,029	127,162	130,141	161,478	129,162
		CO2 from diesel (tonnes)		49.23	58.64	63.37	51.80	70.59	75.65	61.40	63.56	67.74	57.80	59.15	73.40	58.71
	Nola Nielsen, Physical Plant	Regular fuel purchased (gal)		30750.90	30796.50	31161.70	32,426	35,460	37,435	38,035	39,267	40,333	39,510	37,727	38,504	35,961
	http://www.epa.gov/oms/climate/420f05001.htm	CO2 from regular (lbs/gal)		19.40	19.40	19.40	19.40	19.40	19.40	19.40	19.40	19.40	19.40	19.40	19.40	19.40
		CO2 from regular (lbs)		596567.46	597452.10	604536.98	629,064	687,914	726,237	737,881	761,780	782,460	766,494	731,902	746,968	697,638
		CO2 from regular (tonnes)		271.17	271.57	274.79	285.94	312.69	330.11	335.40	346.26	355.66	348.41	332.68	339.53	317.11
		Total fuel emissions (diesel + regular) (tonnes)		320.40	330.21	338.16	338	383	406	397	410	423	406	392	413	376
		Total fuel emissions (diesel + regular) (kg)		320398	330206	338161	337,736	383,280	405,757	396,798	409,826	423,404	406,207	391,838	412,930	375,818
		Building Area for fuel (ft^2)	1889746	1895051	1895051	1895051	1,905,791	1,905,791	1,932,736	2,258,187	2,269,497	2,269,497	2,269,497	2,269,497	2,269,497	2,296,707
		Fuel emissions intensity (kg CO2/ft^2)		0	0	0	0.18	0.20	0.21	0.18	0.18	0.19	0.18	0.17	0.18	0.16
	Fall Day 10 report for the year shown. For example, the Sept 2008 Day 1(	Students for Fuels (students)	4330	4332	4186	4189	4199	4224	4171	4092	3991	3,967	4,008	4,034	3,993	4,000
		Fuel emissions intensity (tonnes CO2/student)		0	0	0	0.08	0.09	0.10	0.10	0.10	0.11	0.10	0.10	0.10	0.09
Flights																
	Lindsey Jetter, Jane Prins	Calvin-paid flights (miles)							12,522,961	9,712,753	12,249,045	11,958,811	12,980,894	10,993,686	8,575,902	9,518,598
	Used to be Jane Prins (2008-2010)	CO2 emissions for flight miles (lbs/mile)							0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
		Calvin flight emissions (lbs)							8,014,695	6,216,162	7,839,389	7,653,639	8,307,772	7,035,959	5,488,577	6,091,903
		Calvin flight emissions (tonnes)							3,643	2,826	3,563	3,479	3,776	3,198	2,495	2,769
		Calvin flight emissions (kg)							3,643,043	2,825,528	3,563,359	3,478,927	3,776,260	3,198,163	2,494,808	2,769,047
		Building Area for fuel (ft^2)	1889746	1895051	1895051	1895051	1,905,791	1,905,791	1,932,736	2,258,187	2,269,497	2,269,497	2,269,497	2,269,497	2,269,497	2,269,498
		Flights CO2 intensity (kg CO2/ft^2)							1.88	1.25	1.57	1.53	1.66	1.41	1.10	1.22
		Students for flights (students)	4330	4332	4186	4189	4,199	4,224	4,171	4,092	3,991	3,967	4,008	4,034	3,993	4,000
		Flights CO2 intensity (tonnes CO2/student)							0.87	0.69	0.89	0.88	0.94	0.79	0.62	0.69
Totals																
4 -->		Total CO2 Emissions (tonnes CO2)	22135	22634	24040	24454	23,101	23,605	27,444	29,616	28,974	28,915	28,151	28,149	26,751	26,675
5 -->		CO2 intensity (tonnes CO2/student)	5.11	5.22	5.74	5.84	5.50	5.59	6.58	7.24	7.26	7.29	7.02	6.98	6.70	6.67
6 -->		CO2 intensity (kg CO2/ft^2)	12.93	13.26	14.01	14.43	13.66	13.95	15.85	14.48	14.11	14.06	13.75	13.73	13.03	12.91
		Source: Calvin Sustainability Scorecard														

C4: STARS Reports

In 2017, Calvin began tracking emissions with The Sustainability Tracking, Assessment & Rating System (STARS), a program used by higher education institutions to create public, transparent, sustainability reports. This corresponds to the same year that former President Michael LeRoy signed the American College & University Presidents' Climate Commitment (ACUPCC).

Calvin submitted STARS reports in 2016, 2017, 2019, 2020, and 2022. 2016 and 2017 STARS reports used 2014 and 2015 data, respectively, from the CSS (Calvin College, 2016) (Calvin College, 2017). 2019 and 2020 STARS reports used usage data collected in 2018 and 2019, respectively (Calvin University, 2019) (Calvin University, 2020). The 2022 STARS report (Calvin University, 2022) also references data collected in 2019, since 2020 and 2021 data were heavily affected by COVID-19 and didn't provide an accurate assessment of the university's carbon neutrality goals. Data sourced from STARS reports include emissions from natural gas and electricity usage and Scope 3 emissions. Links to STARS reports and their corresponding years can be found in the References.

C5: Facilities Natural Gas, Fuel, and Energy Data

Facilities provided data from 2020-2026. Table C5.1, Table C5.2, and Table C5.3 list the summarized annual data from Facilities for natural gas (NG), fuel, and electricity respectively. Facilities did not have any data for diesel consumption in 2023.

Table C5.1: Annual natural gas usage from Constellation and Symmetry Energy Solutions.

	Constellation		Symmetry Energy Solutions	
Year	NG Usage [MMBtu]	Cost [$/MMBtu]	NG Usage [Therms]	Cost [$/Therms]
2021	83590	2.95	763013	0.3235
2022	80681	2.95	1238888	0.3235
2023	84153	2.95	773682	0.2675
2024	83054	2.95	779823	0.2675
2025	136588	4.01	436874	0.2675
2026	95484	4.01	N/A	N/A

Table C5.2: Annual fuel consumption.

Year	Unleaded [gallons]	Diesel [gallons]	kgCO2e
2020	16778.79	4986.07	199703
2021	15304.73	4777.05	184514
2022	16821.66	4311.82	193147
2023	216.85	0	1918
2024	12202.88	3787.7	146900
2025	12021.07	3634.81	143719

Table C5.3: Annual energy consumption from Consumers Energy.

Year	Annual Campus Power Consumption [kWh]	Notes
2026	6869718	Through April 30, 2026
2025	20529329	
2024	20588741	
2023	19809021	
2022	19579973	
2021	18845222	
2020	15965950	

Appendix D: Solar Revolving Fund Feasibility

1 Introduction

One method of offsetting Scope 1 (natural gas and transportation fuel) emissions on Calvin University's campus is to install solar panels to replace energy bought from Consumers Energy, using the energy cost savings to buy carbon offsets. (See Appendix B: Solar Feasibility.) One financially feasible path towards this goal is to implement a solar revolving fund. This idea is inspired by the Calvin Energy Recovery Fund (CERF), a revolving fund where energy savings are re-invested from CERF-funded efficiency projects. There are many other organizations that have green revolving funds. (See Appendix D2: Green Revolving Funds.) Figure D1 models the proposed Calvin Solar Revolving Fund (CSRF). Revenue includes seed money (donation) and solar savings, and expenses include solar panel installation and annual carbon offset costs.

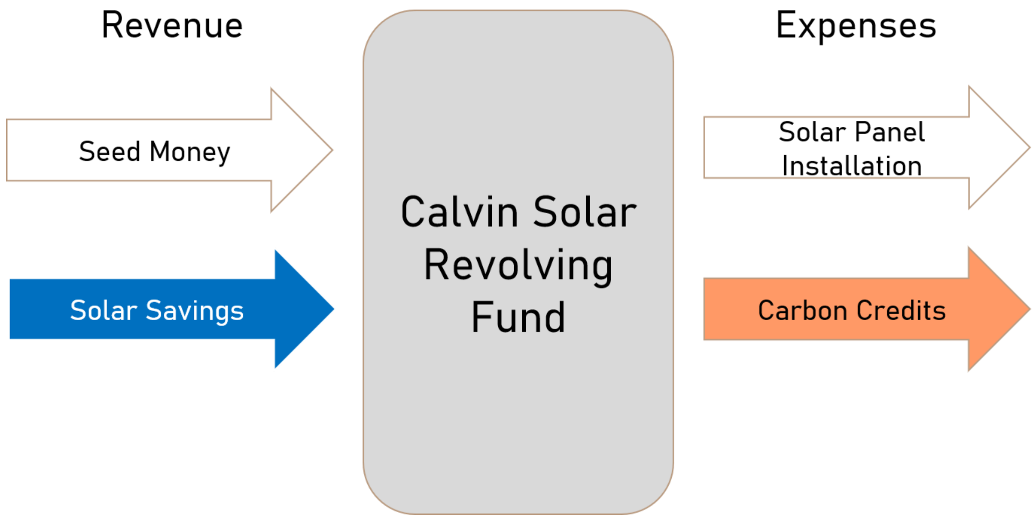


Figure D1: Revolving fund revenue sources and expenses.

A feasible solar revolving fund would enable enough savings to buy offsets within 25 years, the lifetime of the solar panels installed.

The remainder of this appendix is structured as follows. Section 2 discusses data sources and methods. Section 3 describes results of applying the methods of Section 2. Section 4 discusses the results and conclusion. Appendices follow, providing supplementary information.

2 Data Sources & Methods

Analysis in this appendix is heavily based on initial solar feasibility research shown in Appendix B. Future emission projections from Appendix C: Historical and Projected Carbon Emissions were also used. Panel degradation and electricity price were data obtained from Facilities.

Three models were created for the proposed CSRF, using high and low estimates for both roof power density and carbon offset cost. Refer to

Appendix B: Solar Feasibility for more information. No model was created for the low energy density – high carbon offset cost scenario because, as seen in Table B1, we could not save enough money through electricity production to be carbon neutral under those conditions. Each model was structured as follows: assume a solar array on Hekman Library is funded by a donor and generates renewable electricity for the campus. Money saved by generating our own electricity instead of purchasing carbon-free electricity from Consumers Energy is routed back into the fund. The year after the fund balance eclipses the installation cost of an array on the next-largest roof (say, Prince Conference Center), that array is installed using funds from the CSRF. This process continues until the total annual energy cost savings are enough to pay for carbon offsets to offset Calvin's annual Scope 1 emissions. Thereafter, no additional panels are purchased. Electricity cost savings are spent on offsets.

3 Results

Table D1 lists the results of each scenario. Appendix D1: displays the results of each scenario individually in a time series graph.

Table D1: Years from first solar panel installation to carbon neutrality.

		Energy Density	
		15 W/ft^2	7 W/ft^2
Price of Carbon Offsets	\$29/tonneCO_2	8	15
	\$93/tonneCO_2	18	N/A

4 Discussion & Conclusion

A CSRF is a feasible financial path to attaining carbon neutrality. The number of years it takes until the CSRF can be used for carbon offset costs depends on the energy density of the solar panels and the cost of carbon offsets. In the most optimistic scenario, 15 W/ft^2 roof power density and \$29/tonneCO_2 carbon offset price, it would only take 8 years, while the worst-case scenario, 15 W/ft^2 power density and \$93/tonneCO_2 carbon offset price, took 18 years. Even after the fund is used to cover carbon offset costs, the CSRF balance will continue to increase slowly because of the excess solar panel coverage. All three scenarios analyzed were within the 25-year lifespan of solar panels.

D1: Four Scenario Results

The cash flow models from Table D1 can be seen in Figure D1.1 below.

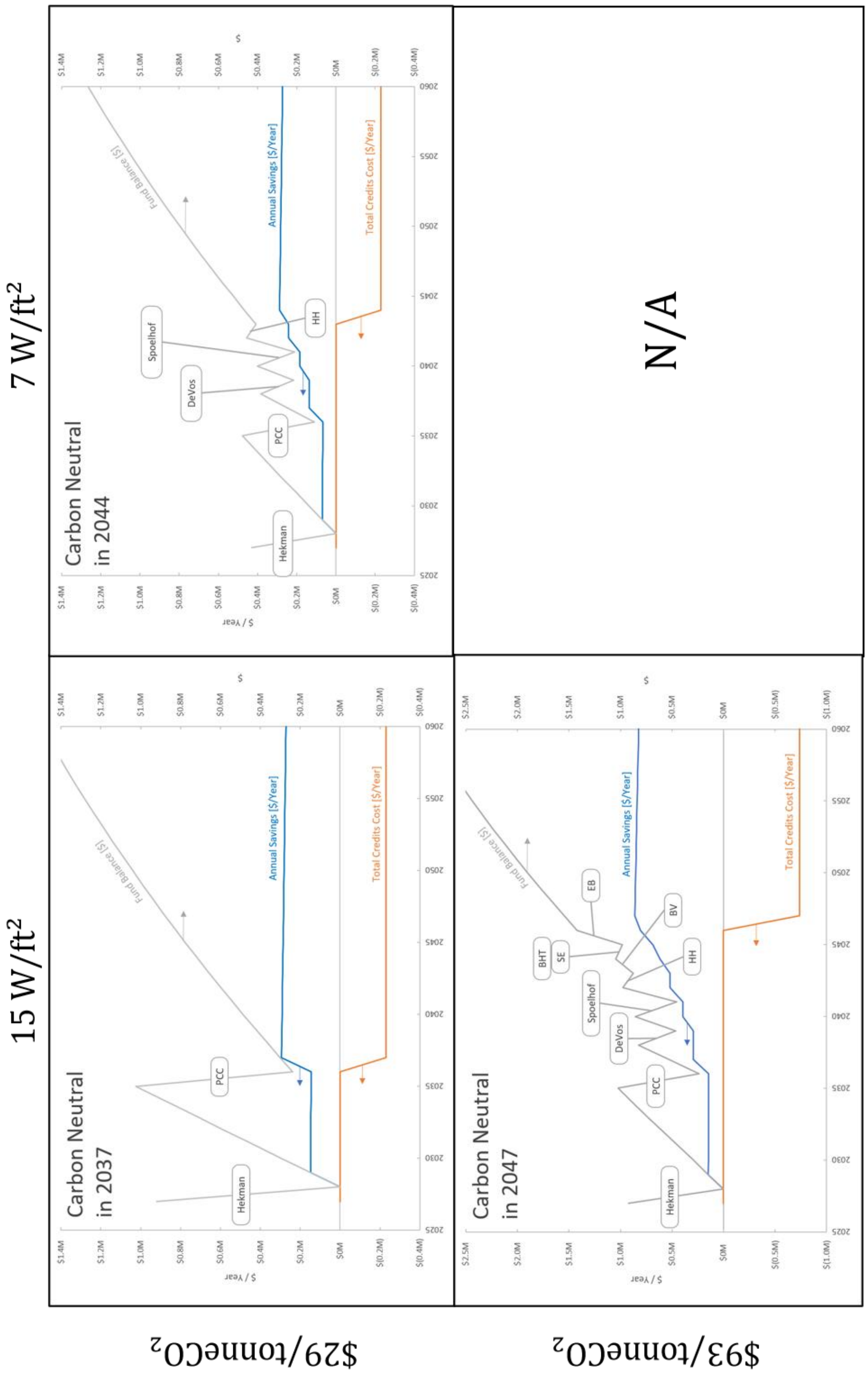


Figure D1.1: Cash flow models for three of the four solar revolving fund scenarios.

D2: Green Revolving Funds

A green revolving fund (GRF) is a funding model used by organizations to finance energy-efficient infrastructure projects, commonly found in academia. A GRF begins with an amount of seed money that is set aside by the organization. Then, money from the fund is used to research and implement projects that save the organization money and energy. Examples range from LED lighting upgrades to solar panel installations, to electrical control system upgrades and everything in between. Once a project is implemented, its energy and cost savings are carefully monitored. Cost savings are routed back into the fund until the project cost has been fully paid back, never depleting the value of the fund. Some funds, like the Calvin Energy Recovery Fund at Calvin University receive energy savings for some years after full payback is achieved, growing the size of the fund. An illustration of CERF can be seen below in Figure D2.1.

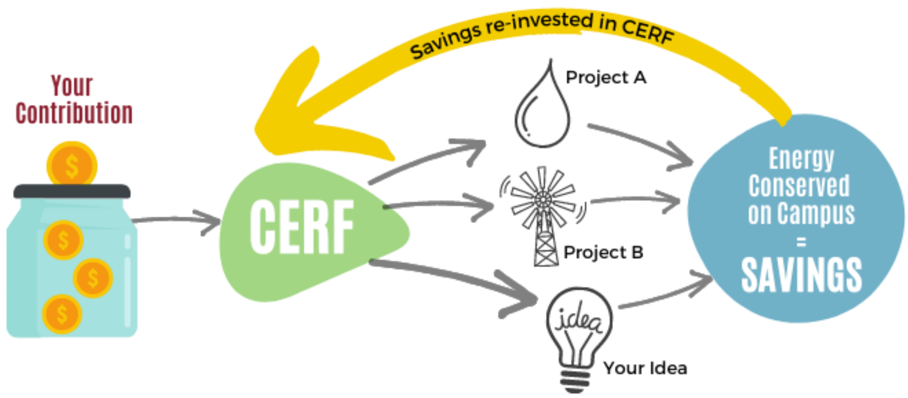


Figure D2.1: CERF illustration for a revolving fund.

Academic institutions with GRFs include Harvard University, Temple University, Western Michigan University, University of Oregon, Hope College, and Calvin University. The first GRF implemented in United States academia was by Western Michigan University in 1980.

Appendix E: Calvin Solar Revolving Fund Scenarios

1 Introduction

This appendix is a refinement of Appendix D: Solar Revolving Fund Feasibility. One method of offsetting Scope 1 (natural gas and transportation fuel) emissions on Calvin University's campus is to install solar panels to replace electricity bought from Consumers Energy, using the energy cost savings to buy carbon offsets. (See Appendix B: Solar Feasibility.) One financially feasible path towards this goal is to implement a Calvin Solar Revolving Fund (CSRF). (See Appendix D: Solar Revolving Fund Feasibility.) Two options for the seed money for this fund are getting a donation or using Calvin University's endowment. This money would either fund the initial roof with solar panels or be used to buy a cogeneration (Cogen or CHP) system for financial gain. The CSRF revenue includes donations or money from the endowment and solar or Cogen savings. The CSRF expenses include solar panel installation and annual carbon offset costs.

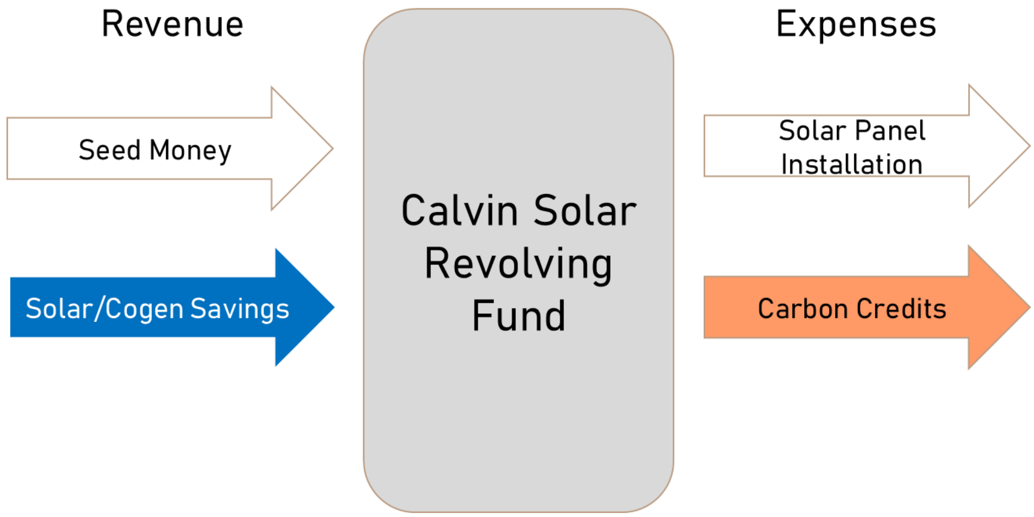


Figure E1: Revolving fund revenue sources and expenses.

Our analysis shows that CSRF would enable enough savings to buy offsets within 10 or 25 years, the lifetime of the Cogen system or initial solar panels installed.

The remainder of this appendix is structured as follows. Section 2 discusses data sources and methods. Section 3 describes results of applying the methods of Section 2. Section 4 discusses the results and conclusion. Appendices follow, providing supplementary information.

2 Data Sources & Methods

Analysis in this appendix is heavily based on initial solar and solar revolving fund feasibility research in Appendix B and Appendix D respectively. The power density values in Appendix D were refined and are not inconsistent with values provided by Greg Oliver from Agathon. A production ratio was also applied to determine a more reasonable energy production based on the type and angle of each roof. Table E1 lists the refined values for energy density and production ratios.

Table E1: Energy density and production ratios for each type and angle of roof.

	South	East/West	Flat
Energy Density [W/ft²]	15	15	13
Production Ratios [%]	100%	90%	85%

The criteria for endowment repayments were obtained from Dirk Pruis, the CFO of Calvin University. Cogen information can be found in Appendix E1.

Eight scenarios were developed based on the cost of carbon offsets, whether the seed money was from a donation or the endowment, and whether the seed money was used to fund the first solar array or a cogeneration system.

3 Results

Table E2 below lists the results for each scenario. Each scenario's cash flow model can be found in Appendix E1.

Table E2: Years until carbon neutrality for all eight scenarios.

		Donation		Endowment	
		Cogen	Hekman Solar	Cogen	Hekman Solar
Price of Carbon Offsets	$29/tonne CO_2	1	9	1	15
	$93/tonne CO_2	1	18	1	23

4 Discussion & Conclusion

Each of the eight scenarios fell within the 10- or 25-year lifespan of the first Cogen or solar arrays installed. The scenarios where Cogen is used to initiate the solar revolving fund are all able to pay for carbon offsets the following year after installation. Using the endowment to fund the solar arrays delays the carbon neutrality date significantly because of the payments back to the endowment. The only drawback to using a Cogen system is that the natural gas needed to run it will add to the Scope 1 emissions that it is financially offsetting, but the financial gain easily covers the cost for the carbon offsets of the additional emissions.

E1: Eight Scenarios Results

The models of the results from Table E2 in 3 Results above can be seen below in Figure E1.1 and Figure E1.2

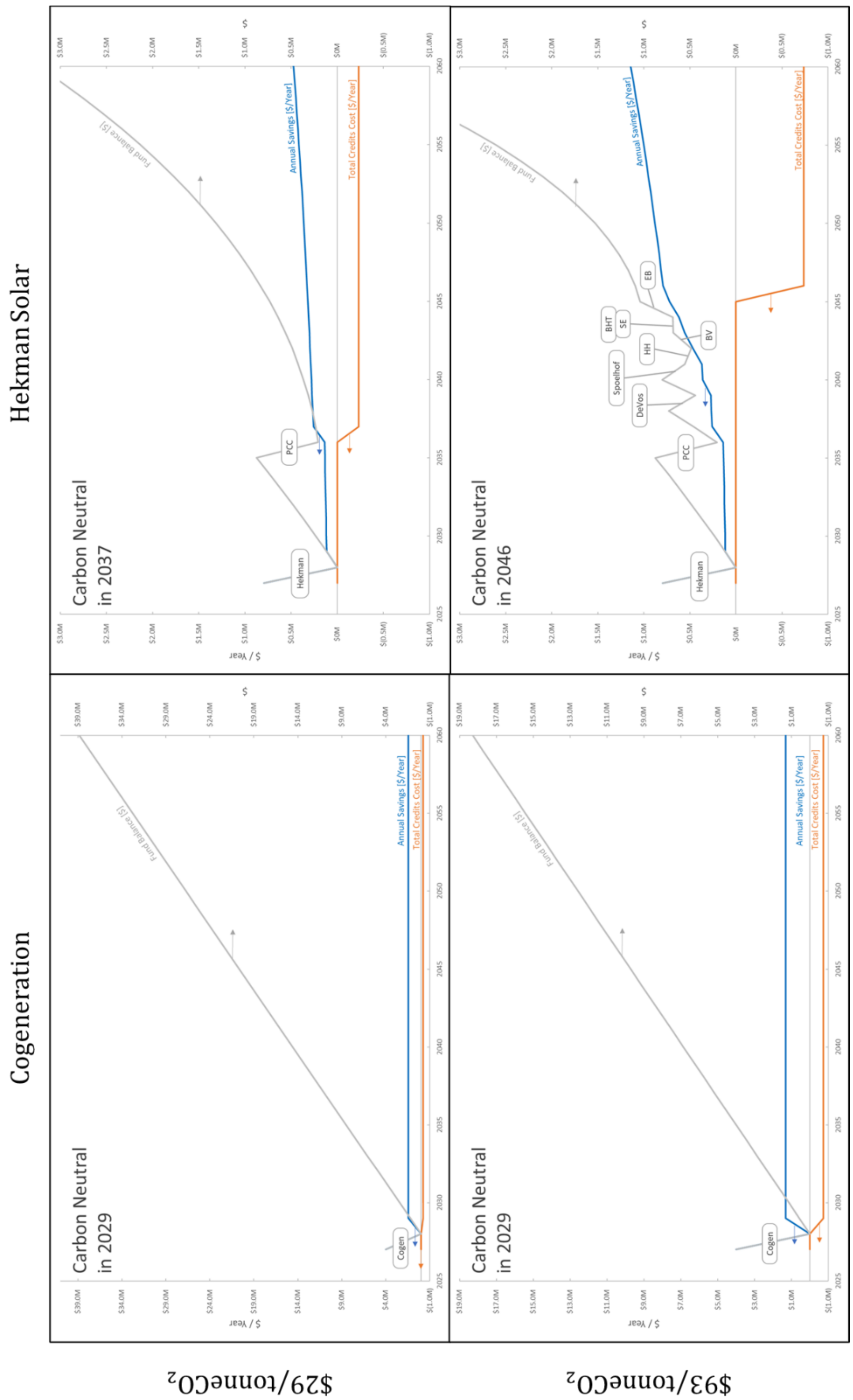


Figure E1.1: Donation seed money-based scenarios.

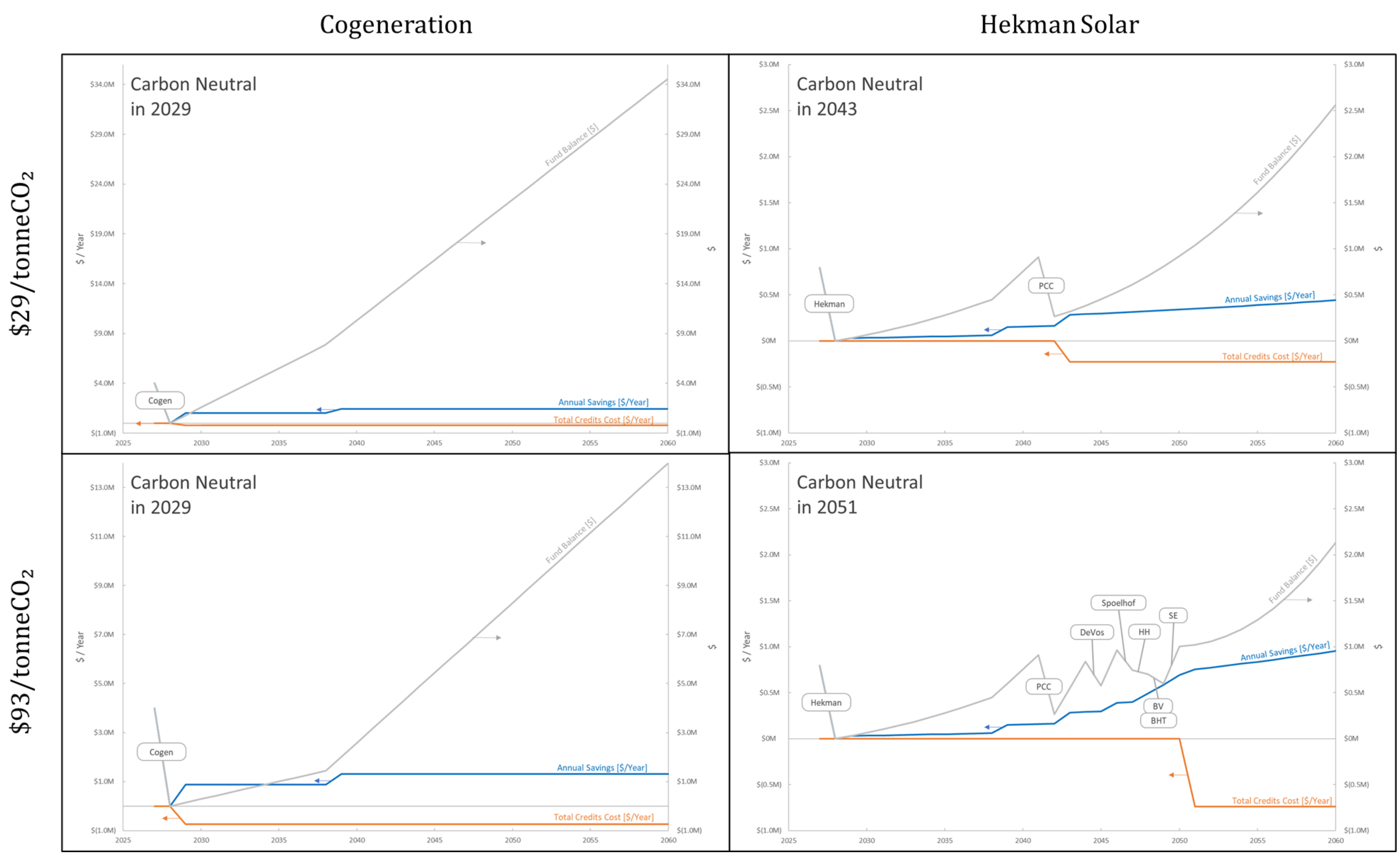


Figure E1.2: Endowment seed money-based scenarios.

E2: Cogeneration

Cogeneration (Cogen) or combined heat and power (CHP) is the process of making electricity and useable heat from a single source. Many Cogen systems run on natural gas, a fuel that Calvin University is already using in boilers. By recovering waste heat from the generator, overall efficiency increases 15-40% (What is Cogen?, 2026). Assuming a 1 MW CHP system, a reciprocating engine would be a recommended type of Cogen system due to the smaller size. A 1-MW CHP system costs around $4 million, an estimate from the ratio $4000/kW from the U.S. Energy Information Administration (Distributed Generation, 2024).

A Cogen system would provide many advantages to Calvin. First, a Cogen system reduces the amount of electricity purchased from the grid, creating a financial benefit. It also decreases dependence on the electrical grid, providing energy security during emergencies. Due to power generation being on-site, it reduces the energy lost to distribution inefficiencies.

The main disadvantages of a Cogen system are that Scope 1 emissions will increase and there may be excess heat.

Appendix F: Carbon Offsets

Introduction

Carbon offsets are a way for businesses, institutions, and individuals (emitters) to offset their emissions by paying for emissions reductions elsewhere. These emissions reductions result from projects like afforestation, conversion from fossil fuels to clean energy, and technology-based carbon removals. For more information on offsets, see Appendix F1. It often proves to be very difficult for an institution to become carbon neutral on its own, due to cost, lack of expertise, etc. Thus, purchasing carbon offsets can be a very important step for colleges and universities to become carbon neutral. Calvin University intends to become carbon neutral and may consider purchasing offsets to cancel out Scope 1 emissions. (Scope 2 emissions will be eliminated by purchasing carbon-free electricity.) However, many carbon reduction or removal projects do not offset the amount of emissions they claim. Knowing that offsets may be unreliable, we propose guidelines and criteria for carbon offset purchasing that are in line with Calvin's mission and Statement on Sustainability.

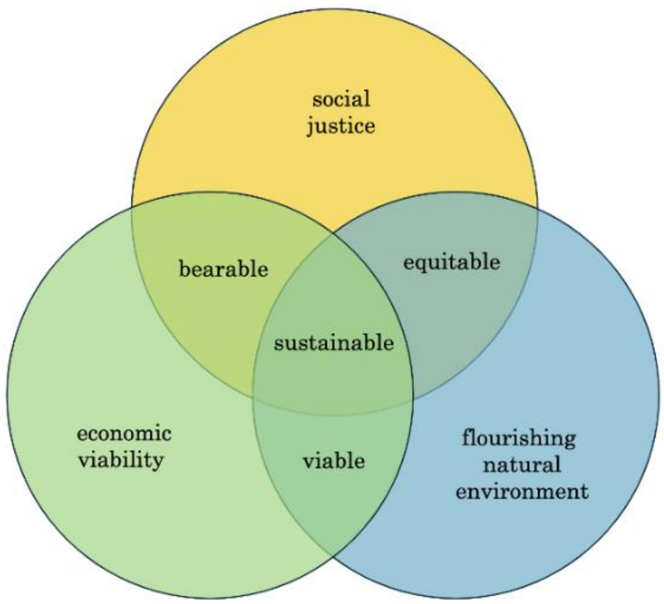


Figure F1: Three pillars of sustainability, from Calvin University's 2025 Statement on Sustainability.

Calvin's deep commitments to environmental sustainability can be seen in the Statement on Sustainability (SoS), endorsed by the Board of Trustees in 2025. Calvin states that "we have rooted our environmental sustainability work in a vital faith expressed through academic rigor as well as practical action" (Calvin University, 2025). The three pillars of sustainability – "flourishing natural environment, social justice, and economic viability," are shown in Figure F1 and feature prominently in Calvin's SoS. The pillars, along with the rest of the SoS, should inform the types of carbon offsets that Calvin University purchases. Furthermore, these three pillars are tied to Calvin's mission of "[equipping] students to think deeply, to act justly, and to live wholeheartedly as Christ's agents of renewal in the world" (Calvin University, 2013). We think deeply, making economically and financially wise decisions. We act justly, promoting social justice wherever Calvin has a presence. And we act as agents of renewal, furthering God's already-but-not-yet vision of a new heaven on Earth.

This appendix discusses the three pillars of sustainability defined above, stating guiding principles for carbon offset purchasing after each section, concluding with a summary.

Environmental: Renewal & A Flourishing Natural Environment

Calvin promotes environmental sustainability expressed through "practical action," (Calvin University, 2025) as seen in the SoS. This idea of "practical action" has close ties to the principle of *additionality* in the carbon offset industry. Additionality is the idea that all offsets issued by a carbon offset project must be *additional to* what would have been removed or reduced under business-as-usual practices. Let's assume, for example, a utility plans to install a solar PV array and decommission a coal plant of equal size. An offset project developer wants to pay the utility to triple the size of that PV array and decommission an equivalently sized coal plant, so they can sell carbon offsets resulting from the decrease in emissions from coal-powered electricity to solar PV electricity. The offset project developer can only sell offsets resulting from their 2/3rds of the solar array, since that amount of emission decrease would not happen if there weren't a carbon offset project.

Additionality is difficult to assess for projects that reduce deforestation in the global south – known as REDD projects – because forests are a part of the natural environment. REDD stands for "reducing emissions from deforestation and forest degradation in developing countries" (What is REDD+?, n.d.). According to a 2023 study, the difference between business-as-usual sequestration and sequestration with an offset project is often overestimated by REDD project developers (West, et al., 2023). This leads to over-crediting, when more offsets are assigned to a project than what is actually achieved. See Appendix F4 for further information on analysis from West et al.

REDD projects are not the only project type that suffers from over-crediting. Improved cookstove projects suffer over-crediting due to subpar data recording practices. In 2024, researchers from UC Berkeley examined "how well the five cookstove offset methodologies that have generated almost all cookstove offset credits to date quantify the climate benefits of improved cookstove projects" (Berkeley Carbon Trading Project, n.d.). They found that due to the lack of strict crediting methodologies, many developers assume pre-project baseline fuels to emit far more carbon than reality, overestimating the difference between pre- and post-project carbon intensity of cooking. Many developers also use surveys and in-person observations to estimate amount of stove usage. These methods are unreliable and do not produce accurate results due to various known survey biases. Researchers' findings list information about the study, recommendations for project developers and credit buyers, a list of "quality projects," and health benefits of cookstoves.

However, with proper offset methodologies, cookstove projects can be an excellent high-quality offset with great co-benefit opportunities. The UpEnergy Beyond Biomass cookstove project has earned a "A" rating from BeZero, uses loggers embedded in electric pressure cookers and induction stoves to track real-time usage data and is approved under Gold Standard's metered cookstove methodology. Reference Appendix F5 for more information on how cookstove projects are monitored.

Offset project developers and marketplaces have potential bias setting pre-project baselines. Knowing that project developers often overstate the amount of carbon removed by their projects, there is a need for an outside organization to examine offset projects. External ratings agencies like BeZero Carbon, Sylvera, and Calyx Global fill this need. These are organizations contracted by buyers to examine the credibility of certain offset projects. Each of these agencies rate a project from D (low quality) to AAA (highest quality), similar to bond ratings. The better the rating, the higher the likelihood the project delivers its promised carbon emission reductions.

Based on environmental analysis, the following principles are proposed should Calvin participate in the voluntary carbon offset market:

1. Purchasing REDD+ carbon offsets that have been reviewed by external offset ratings agencies.
2. If purchasing offsets from cookstove projects, ensure that they are verified by UC Berkeley or follow recommendations from West, et al (2023).
3. Prefer to purchase carbon offsets from projects with a rating greater than BB and no lower than B from Calyx Global, BeZero, or Sylvera.

Social: Acting Justly and Promoting Justice

The Calvin University Statement on Sustainability makes the claim that "for any system or process to be truly sustainable, it must be sustainable for all who are touched by it. Thus, environmental sustainability seeks equity and social justice, so that all people may receive the benefits of healthy air, water, and soil, as well as healthy diets" (Calvin University, 2025). We must invest in projects that are both good for the Earth, and good for all who live there, too.

Investors commonly purchase shares of companies exclusively for financial gain. However, investments affect the daily operations of the investee. Wise investors choose to invest in companies that they believe are doing good work in the world, a practice called "responsible investing." Responsible investing can also be applied to carbon offset purchasing. It is easy to purchase carbon offsets without consideration of the offset projects themselves. By practicing "responsible investing," Calvin can invest in carbon offset projects that bring social benefits to the communities in which they are implemented. These benefits are called *co-benefits*, because they come alongside the main benefit of removing or reducing greenhouse gas emissions.

Social justice can be a co-benefit of many offset projects. For example, though some cookstove projects have questionable environmental value, nearly all projects have positive social effects. Improved cookstove projects aim to either switch to a less carbon intensive fuel option or increase heating efficiency of stoves so they burn less non-renewable fuel. Emission avoidance comes from these projects by reducing the amount of non-renewable fuel burned in stoves. Typically, the burden of fuel purchasing and collecting falls unequally on women and children in the rural communities where these projects are implemented. Cookstove projects allow for women and children to spend less time on fuel collection and invest time in other activities, like education, income generation, and leisure. More information about how cookstove projects calculate the amount of carbon emissions avoided is in Appendix F5.

Another co-benefit of carbon offset projects can be providing educational opportunities to university students. In an interview with us, American University stated that they offset the carbon emissions resulting from a study abroad trip to Kenya with carbon offsets from a cookstove project, also in Kenya. Similar to American University, Calvin could purchase offsets supporting communities that Calvin is already connected to, bringing climate awareness and social justice to students in the classroom. Relationships between these communities and Calvin can be deepened, creating an environment for service-learning.

Additional co-benefits of offset projects include the United Nations' Sustainable Development Goals (UN SDGs). The UN SDGs are a list of 17 goals agreed upon by all UN member states in 2015. They are meant to combat climate change, preserve our forests and oceans, improve education and health, reduce inequality, and grow economies. (The 17 Goals, n.d.) Four example SDGs that align with Calvin's Statement on Sustainability are listed below.

i. SDG 1: *End poverty in all its forms, everywhere.*
ii. SDG 4: *Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.*
iii. SDG 7: *Ensure access to affordable, reliable, sustainable and modern energy for all.*
iv. SDG 10: *Reduce inequality within and among countries.*

Many offset projects have co-benefits that align with the UN SDGs. Every project that is verified using Gold Standard methodology supports some SDGs, and the Gold Standard marketplace shows which specific SDGs are co-benefits on each project listed. Figure F1.2 in Appendix F1 shows co-benefits of the *WithOneSeed Community Forest Programme* project on the Gold Standard Marketplace.

Based on analysis of social factors surrounding carbon offset projects, the following principles are proposed:

1. Practice "responsible investing" when procuring carbon offsets.
2. Prefer to purchase carbon offsets that promote social justice in affected communities by advancing United Nations Sustainable Development Goals 1, 4, 7, and 10.
3. Prefer to purchase carbon offsets in locations where Calvin has a presence, whether for study abroad experience, alumni presence, or otherwise.

Financial: Viability Through Thinking Deeply

Higher financial cost could be a trade-off for higher quality offsets, more favorable social benefits, preferred location, or other positive characteristics. But no matter the offset cost, Calvin must be able to still support "the promotion of secure, healthy, and meaningful human lives" (Calvin University, 2025) in the people it serves. For example, a high-cost high-durability direct air carbon capture offset may be firmly supported by the pillar of a flourishing natural environment but could cost upwards of \$400/tonneCO_2. This steep cost may endanger the university's programs in a time of budgetary constraint. The cost of offsets that Calvin will be able to purchase may depend on the funding source. If, for example, a proposed Calvin Solar Revolving Fund provided funding for offsets, the annual cost of offsets must not exceed the annual profit of the fund.

Another way that Calvin can choose to spend money in pursuit of being carbon neutral is by purchasing carbon offsets from an organization that has already curated a portfolio of offsets. This "hands-off" approach to the voluntary carbon market (VCM) would involve purchasing offsets from an organization like CNaught or Cool Effect (CNaught, 2026) (Cool Effect, 2026). Many universities take this approach, including Catawba College and Dickinson College. Drawbacks of this approach include not being able to select specific projects, an increased cost due to broker fees, and level of disconnection from the offset projects. Benefits to this approach include less time required to research offset projects and benefiting from the expertise of a professional familiar with navigating the carbon offset market.

The alternative to a "hands-off" approach is an "in-house" verification system, taking available information about carbon offset projects and using criteria proposed in this report to find offset projects that fit. This system would give Calvin 100% control over the projects in its offset portfolio, allowing the university to take a bespoke approach to offset purchasing. An "in-house" approach could be implemented by a sustainability officer.

Based on analysis of financial viability, the following principles are proposed:

1. Purchase carbon offsets in a budget-neutral manner, paired with a sustainability-related funding source.
2. Appoint a sustainability officer – supported by a sustainability-related funding source – to manage future sustainability planning and offset purchasing.

Recommendations

The following principles have been constructed and proposed through a mission-driven approach to sustainability. They intend to align Calvin University's participation in the voluntary carbon market with goals and commitments outlined in the Statement on Sustainability.

1. Practice "responsible investing" when procuring carbon offsets.
2. Appoint a sustainability officer – supported by a sustainability-related funding source – to manage future sustainability planning and offset purchasing.
3. Purchase carbon offsets in a budget-neutral manner, paired with a sustainability-related funding source.
4. Prefer to purchase carbon offsets from projects with a rating greater than BB and no lower than B from Calyx Global, BeZero, Sylvera, or other equivalent rating agency.
5. Prefer to purchase carbon offsets that promote social justice in affected communities by advancing United Nations Sustainable Development Goals 1, 4, 7, and 10.
6. Prefer to purchase carbon offsets in locations where Calvin has a presence, whether for study abroad experience, alumni presence, or otherwise.
7. Purchase REDD+ carbon offsets that have been reviewed by external offset ratings agencies.
8. If purchasing offsets from cookstove projects, ensure that they are verified by UC Berkeley or follow recommendations from West, et al (2023).

Example Projects

Following are three projects that match the proposed principles above.

GS- 11352: EcoSafi Clean Cooking Program – Kenya

Project details on the Gold Standard Registry are found here.

In May 2024, BeZero issued an 'A' rating for the EcoSafi cookstove project in Kenya. This project gives extra-efficient stoves to households, and then households purchase special fuel for these cookstoves from EcoSafi. Gold Standard certified that this project advances UN SDGs 3, 5, 7, and 13. In addition, Calvin regularly travels to Kenya on study abroad offerings, such as the summer Leadership in Kenya course, the Nursing Dept.'s winter off campus trip, and spring break trips with the Clean Water Institute. Offsets from this project were purchased at \$35/tonneCO_2.

CDM-2834: Mokpo Landfill Gas Recovery Project for Electricity Generation – Korea

Project details on the UNFCC CDM database are found here.

In April 2023, BeZero issued an 'A' rating for this project. Methane from the Mokpo Landfill in South Korea is used to produce electricity for the grid instead of being flared off or released into the atmosphere. This project does not advertise certain co-benefits, but it does advance SDGs 7, 9, and 13. Calvin has a large alumni presence in South Korea, as well as a large portion of the international student body. In addition, the Calvin Capella is touring South Korea in June 2027. Price unknown for offsets from this project.

CAR-1513: AgriCapture Soil Enrichment #1 – United States

Project details on AgriCapture's website can be found here.

In July 2025, BeZero issued an 'A' rating for this agricultural methane avoidance project. Different irrigation practices are used to reduce field flooding and anaerobic conditions, leading to less methane being produced. This project supports SDGs 2, 13, 6, and 15. Regreener, a carbon offset supplier, shows an indicative price of $25-$55/tonneCO_2.

F1: Overview of Carbon Offsets

Introduction

Carbon offsets are a way for businesses, institutions, and individuals (emitters) to offset their emissions by paying for emissions elsewhere. Every American academic institution that has achieved carbon neutrality has purchased some amount of carbon offsets to do so. Carbon offsets are verified by various third parties. Verifiers ensure the offset project developer is taking enough CO_2 out of the atmosphere, keeping CO_2 sequestered long enough, and meeting their own separate requirements. Each carbon offset is directly tied to a physical project, and projects can be categorized as avoidance or removal projects. Prices of carbon offsets on the voluntary market vary wildly and depend on market supply and demand, category and source of offset, and customer sentiment.

Types of Offsets

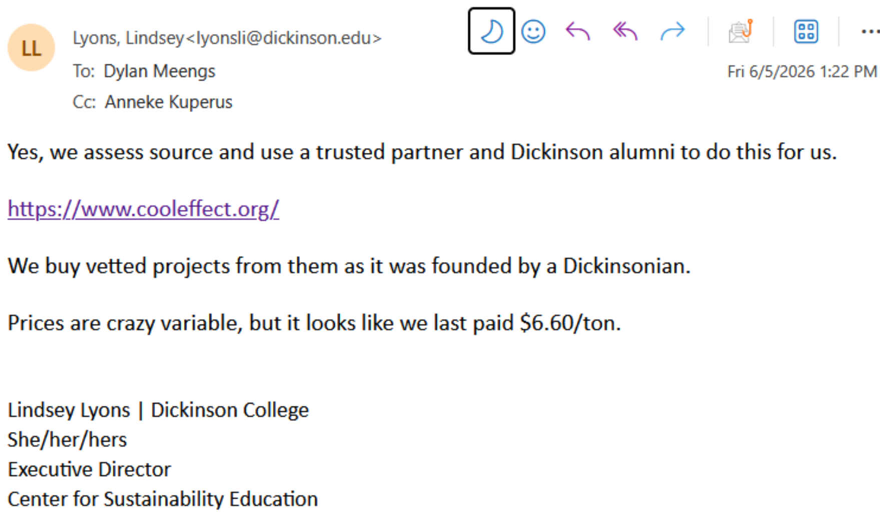
Removals and avoidances are the two types of carbon offset projects that all projects can be categorized by. Projects are also commonly categorized as nature-based or technological projects. Removal projects sequester carbon from the atmosphere and store it. Nature-based removal project examples include afforestation and restoring coastal mangrove ecosystems. Examples of technology-based removal projects include direct air carbon capture and storage (DACCS), biomass carbon removal and storage, and enhanced rock weathering (U.S. Department of Energy, n.d.). Avoidance projects are based on the idea that some industries and areas will continue to emit carbon dioxide unless an intervention is taken to stop these emissions. Avoidance projects include decreasing deforestation, managing off gassing at unregulated landfills, and building renewable energy infrastructure. Any project categorized as REDD+ is an avoidance project and stands for "reducing emissions from deforestation and forest degradation in developing countries." (What is REDD+?, n.d.)

Validation, Measurement, and Verification Process

Before they can be sold on a market, carbon offsets go through various processes that are meant to ensure that the offset meets standards of the registry it is to be listed on. First, a third-party verifier, called a Validation and Verification Body (VVB), audits the proposed project. According to Verra, the organization behind the Verified Carbon Standard (VCS), "during validation, a VVB determines whether a project meets all rules and requirements from the [registry] programs. Once validation has been concluded, the project proponent may submit the project for registration with the respective program. During verification, a VVB confirms that the outcomes set out in the project documentation have been achieved and quantified according to the requirements of the respective standard". (Verra, n.d.) A baseline is also set before the project begins, against which future emissions performance is measured. After third-party validation, the project – along with the proper number of offsets – is then registered and listed publicly on a registry database.

Pricing Carbon Offsets

The registry then sells carbon offsets from each project in one-tonne sections. Offsets for a tonne of carbon, otherwise known as a metric tonne of carbon dioxide equivalent (MTCDE), can cost anywhere from $6.60, as seen in Figure F1.1 below, up to over $500 for direct air carbon capture (Sylvera, 2026).


LL
Lyons, Lindsey<lyonsli@dickinson.edu>
To: Dylan Meengs
Cc: Anneke Kuperus
Fri 6/5/2026 1:22 PM

Yes, we assess source and use a trusted partner and Dickinson alumni to do this for us.

https://www.cooleffect.org/

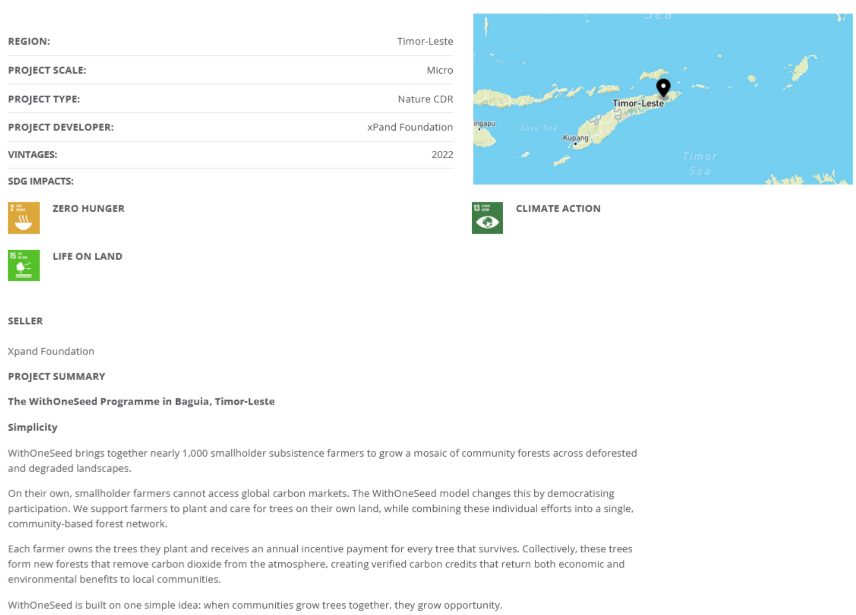
We buy vetted projects from them as it was founded by a Dickinsonian.

Prices are crazy variable, but it looks like we last paid $6.60/ton.

Lindsey Lyons | Dickinson College
She/her/hers
Executive Director
Center for Sustainability Education

Figure F1.1: Email from Lindsey Lyons, Dickinson University.

For our analysis, initial carbon offset cost estimates were obtained from online marketplaces and verifiers. Gold Standard, a carbon offset verifier and marketplace, sells offsets for as high as $90 per metric tonne of CO_2e (MTCDE) from the *WithOneSeed Community Forest Programme* in Timor-Leste (see Figure F1.2) and as low as $10/MTCDE from various wind power projects in Turkey, India, and Pakistan. Senken, a carbon offset procurement platform that "[analyzes] every climate project using 600+ data points and [selects] only the top 5% of the market," states that their corporate buyers pay an average of £25-80/MTCDE, seen in Figure F1.3, (Senken, 2026) or $USD 29-93/MTCDE. Using this information, $29 and $93 were chosen as cheapest and most expensive carbon offset costs.


REGION: Timor-Leste
PROJECT SCALE: Micro
PROJECT TYPE: Nature CDR
PROJECT DEVELOPER: xPand Foundation
VINTAGES: 2022
SDG IMPACTS:
ZERO HUNGER
CLIMATE ACTION
LIFE ON LAND

SELLER

Xpand Foundation

PROJECT SUMMARY

The WithOneSeed Programme in Baguia, Timor-Leste

Simplicity

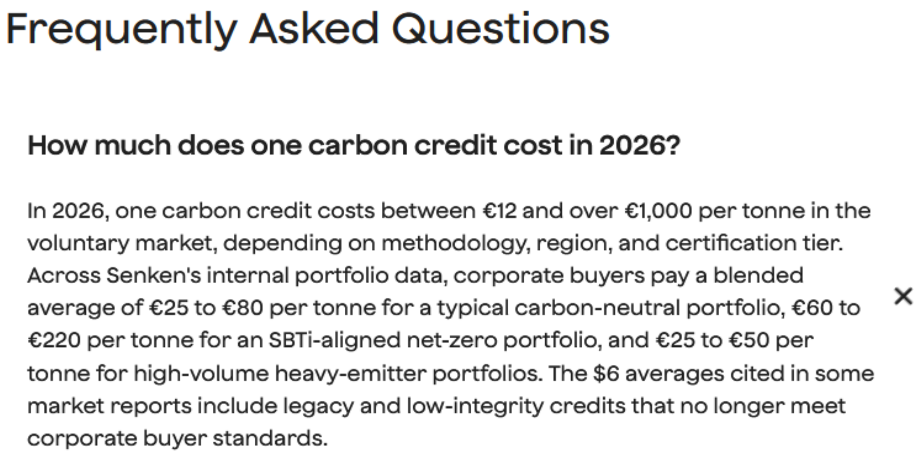
WithOneSeed brings together nearly 1,000 smallholder subsistence farmers to grow a mosaic of community forests across deforested and degraded landscapes.

On their own, smallholder farmers cannot access global carbon markets. The WithOneSeed model changes this by democratising participation. We support farmers to plant and care for trees on their own land, while combining these individual efforts into a single, community-based forest network.

Each farmer owns the trees they plant and receives an annual incentive payment for every tree that survives. Collectively, these trees form new forests that remove carbon dioxide from the atmosphere, creating verified carbon credits that return both economic and environmental benefits to local communities.

WithOneSeed is built on one simple idea: when communities grow trees together, they grow opportunity.

Figure F1.2: $90/MTCDE Carbon Offset from goldstandard.org.


Frequently Asked Questions

How much does one carbon credit cost in 2026?

In 2026, one carbon credit costs between €12 and over €1,000 per tonne in the voluntary market, depending on methodology, region, and certification tier. Across Senken's internal portfolio data, corporate buyers pay a blended average of €25 to €80 per tonne for a typical carbon-neutral portfolio, €60 to €220 per tonne for an SBTi-aligned net-zero portfolio, and €25 to €50 per tonne for high-volume heavy-emitter portfolios. The $6 averages cited in some market reports include legacy and low-integrity credits that no longer meet corporate buyer standards.

Figure F1.3: Senken carbon offset cost reporting.

Marketplaces

There is an overwhelming amount of carbon offset marketplaces that offsets can be purchased from. Some marketplaces, like marketplace.goldstandard.org and Cool Effect (used by Dickinson College) sell offsets on an individual basis and make it very easy for people to offset their own travel or general living emissions. Each project that is featured on these marketplaces is verified by a credible VVB, lists permanence, vintage years (the year the project took place), and other information about the project itself. You can then purchase offsets directly from the website online. Other marketplaces, like CNaught (used by Catawba College) and Regreener, publicly advertise the projects they sell, but purchases are completed through personal contact with the marketplace. CNaught advertises three set portfolios with prices of $20, $16, and $12/MTCDE, seen below.

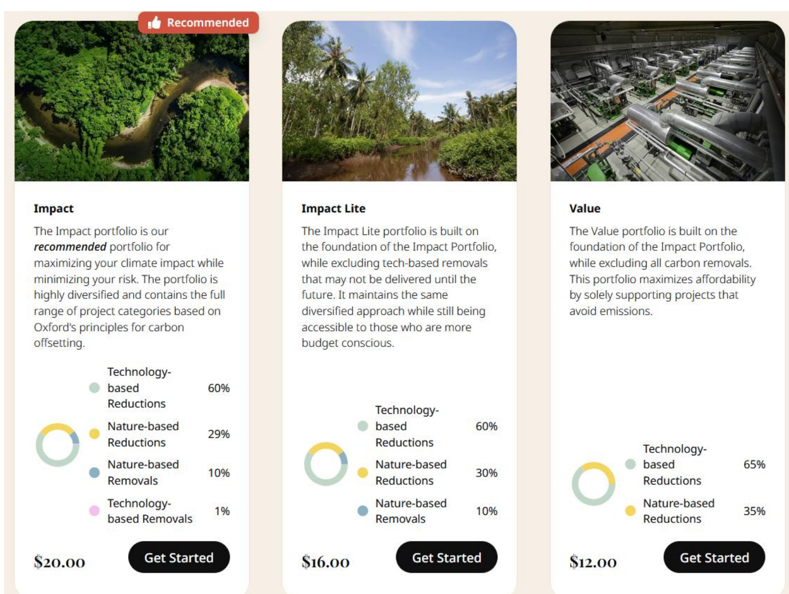


Figure F1.4: CNaught carbon portfolio costs and makeups.

F2: Second Nature Best Practices

This appendix is a short overview of Second Nature's whitepaper on use of carbon offsets in academia, titled Carbon Markets & Offset Guidance and published on March 12, 2025. Second Nature says of themselves, "Second Nature is a 501c3 nonprofit organization committed to accelerating climate action in, and through, higher education. Founded in 1993, the organization has worked with over 4,000 staff and administrators at hundreds of colleges and universities nationwide." Second Nature also leads the Climate Leadership Network, a group of institutions that have signed one of their Climate Commitments. One of these commitments is the Presidents' Climate Commitment, formerly known as the ACUPCC. This white paper states best practices, recommended practices, and minimum requirements for institutions looking to use carbon offsets as part of a decarbonization strategy. *We recommend that Calvin should follow all minimum requirements, even though it is no longer an ACUPCC signee.*

Creating an internal carbon pricing scheme as a part of a climate action strategy is listed as a best practice. This can be useful in multiple ways. Applying a carbon proxy price consists of applying this factor to a cost associated with a financial decision, allowing the less-tangible effect of carbon emissions to be interpreted as a more tangible impact of increased financial cost. Another method of carbon pricing is also implementing a carbon levy, where revenue is redistributed throughout the institution through a tax based on carbon emissions. For more information, see Second Nature's Carbon Pricing Toolkit.

Second Nature also discusses carbon markets, with much overlap with Appendix F1. A minimum requirement relating to compliance-based and voluntary markets follows here: "Campus participation in compliance markets or the voluntary market remains equally fraught. Neither compliance nor voluntary schemes can be considered a purer approach to offsetting, and campuses are urged to engage deeply with not only the intentions of the particular program but also the impacts of its mechanisms. ... In general, Second Nature cautions campuses not to assume that compliance markets are a sure bet of guaranteed emissions reductions than voluntary ones."

Though Second Nature's guide does not provide any more "minimum requirements" than what it stated in this report, it provides much more background knowledge on types of offsets, emissions reduction strategy, and short case studies of other universities that are further along the carbon neutral journey than Calvin. Any questions in these areas should first look to examine this report for information.

F3: Carbon Offset Project Examples

Following is a list of projects that are aligned with the criteria for offset purchasing.

Tradewater Refrigerant Destruction – Thailand

- Project details can be found here.
- This project destroys stored refrigerants that have high global warming potentials and are at risk of leaking into the atmosphere.
- This project does not provide social benefit to communities, but it can provide educational benefit to university students through education about global warming and super-warming gases like R-134a, R-12, and other refrigerants like Freon.
- BeZero Rating: A (ACR937)
- There is no regulatory incentive to destroy refrigerants, in contrast with methane destruction from landfills. Tradewater's projects have excellent additionality because of this fact.
- Price: $21/MTCDE – Can purchase from Tradewater's website. Bulk/corporate price may be lower.

EcoSafi Clean Cooking Program – Kenya

- Project details are found here.
- This project supplies extra-efficient clean-burning cookstoves fueled by sugarcane waste products to communities currently using dirty biomass-burning stoves.
- BeZero Rating: A (GS11352)
- This project is certified by Gold Standard to support UN SDGs 3, 5, 7, and 13.
- EcoSafi uses the Gold Standard Metered & Measured methodology and MoFuSS fNRB values to determine accurate offset metrics.
- Price: $35/MTCDE. Source

AgriCapture Soil Enrichment #1 – United States

- Project details can be found here.
- This project reduces methane production on rice farms by using sustainable agricultural practices when watering fields.
- BeZero Rating: A (CAR1513)
- Supports UNSDGs 2, 6, 13, and 15.
- Price: $25-$55/MTCDE. Source from Regreener.

F4: Literature Review: West, et al.

A 2023 study led by the University of Cambridge and VU Amsterdam found that "reducing emissions from deforestation and forest degradation in developing countries" (What is REDD+?, n.d.) (REDD+) projects using Verra's voluntary REDD+ protocol inflated the amount of greenhouse gas (GHG) emissions they claimed to offset (West, et al., 2023). Verra is the organization behind the Verified Carbon Standard, a group of methodologies used to determine how many carbon offsets result from specific projects. Researchers state that according to pre-project estimates by project developers, "up to 90.5 million carbon offsets could potentially have been generated by these 18 REDD+ projects through 2020. Yet 61.7 million of these offsets (68%) would have originated from projects that have not significantly reduced deforestation (and carbon emissions) compared with their [synthetic controls (SCs)]. The remaining 28.8 million offsets (32%) would have originated from projects likely associated with some avoided deforestation, but not to the extent expected by the project developers." West at al. further states that when replacing pre-project baselines with new baselines determined in research, "only 6.4 million (7%) of the 90.5 million expected offsets from the REDD+ projects would be associated with additional carbon emission reductions."

West et al. concludes that the current methodologies that are used by registries to create pre-project baselines are not robust enough. The issues with the methodologies are broken down into four categories: "poor foresight, adverse site selection, limited room for adjustments over time, and 'gaming'" (West, et al., 2023). Poor foresight and adverse site selection can be fixed by using baseline methodologies that more accurately represent future deforestation than historical trends and taking proper caution when selecting sites that may be more conducive to deforestation than other similar sites. Next, baselines are typically fixed for a period of 10 years, making it difficult to change baselines that may be affected by new legislation or other external factors. Lastly, West et al. found that flexibility in methodologies may have been exploited by developers for their own financial gain.

This study was reviewed by Verra, who found West et al. to contain "patently unreliable conclusions" (Verra, 2023). Verra found that the West et al. study constructed their baselines, called SCs, without accounting for forest type, agricultural practices, or any socioeconomic practices whatsoever. Verra also claims that West et al. used a dataset that has been shown to be unreliable for REDD projects.

We have determined that Calvin should not use the West et al. study alone to steer away from REDD projects. Instead, we should be aware that many REDD projects must be analyzed by more than just project developers and registries. VVBs and third party ratings agencies like Calyx, Bezero, or Sylvera can do this job well.

F5: Cookstove Offsets

Cookstove projects are a highly beneficial type of offset project when done properly. They can reduce carbon emissions, slow deforestation, and provide women and children access to education. One major drawback of cookstove projects, however, is the tendency to over-credit the amount of emissions that are truly reduced due to loose methodologies and poor data collection. Key variables for determining the GHG emissions mitigated include fraction of non-renewable biomass (fNRB), user households, stove usage, and fuel consumption.

Calculating an accurate fNRB value is essential to properly estimating the amount of emissions reduced from a cookstove project. Replacing a biomass burning stove with a clean fuel stove reduces emissions by bringing the amount of non-renewable biomass to zero. Non-renewable biomass is defined as "[coming] from sources where the rate of harvesting exceeds natural regrowth, such as from degraded or disappearing forests" (Wilkman, Krikorian, & Smith, Technical Explainer: Clean and Improved Cookstove Carbon Credits, 2025). fNRB is the portion of biomass fuel that is not classified as renewable. A higher baseline fNRB value means that more non-renewable fuel is being replaced by clean fuel, leading to greater emissions reductions. UC Berkeley identified fNRB as the most important factor in accurately calculating emissions reductions from cookstoves. They found that under methodologies they studied, developers were allowed to calculate their own fNRB value. Researchers recommend using localized fNRB values from MoFuSS, a database of results from the most recent and most rigorous fNRB assessment completed by the UN. (Gill-Wiehl, Kammen, & Haya, 2024)

Stove usage and user households are two more key data points when calculating the amount of offsets produced. Historically, these data points have been collected by survey or making educated guesses. However, as access to the internet through satellite and cellular data becomes more widespread, real-time monitoring through systems embedded in the stoves has become the standard for accuracy. Gold Standard's metered cookstove standard has been shown to not over-credit projects. Researchers recommend purchasing offsets from projects with this methodology.

Appendix G: Efficiency

1 Introduction

One method of reducing Scope 1 emissions and modernizing campus infrastructure is to implement various efficiency measures to reduce natural gas usage. These measures include installing double-paned windows, better roof insulation, wall insulation, thermostatic radiator valves (TRVs), and energy recovery ventilators (ERVs). Efficiency measures that reduce electricity usage, like smart power strips and variable frequency drives (VFDs), are not included because they do not reduce Scope 1 emissions. Scope 1 emission reduction projects were analyzed in two ways: (a) calculating the simple financial payback period and (b) comparing to carbon offsets on the $/tonne$CO_2$ metric.

The remainder of this appendix is structured as follows. Section 2 discusses data sources and methods. Section 3 describes results of applying the methods of Section 2 to the data. Section 4 discusses the results and conclusion. Appendices follow, providing supplementary information.

2 Data Sources & Methods

Data sources for each efficiency project can be found in Appendices G1-5. Data and analysis were also heavily influenced by the 2022 ENGR-333B class report on natural gas CO_2 emissions reduction (ENGR 333B, 2022).

To find the natural gas reduction for double paned windows, wall insulation, and roof insulation, Equation G1 below was used. The U-factor has units of $\frac{\text{Btu}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$. The heating degree days (HDD) were taken from Table 16-5 in the Heat and Mass Transfer book (Cengel & Ghajar) for the location of Lansing, Michigan. The area (A) was the cross-sectional area of the project installations.

$$\Delta Q = (U_{old} - U_{new}) \cdot A \cdot HDD \qquad \text{(G1)}$$

To find the natural gas reduction for TRVs and ERVs, the approximate natural gas usage was found for the applicable buildings and multiplied by an expected percent reduction due to efficiency implementation.

Simple payback was calculated from the cost and annual cost savings using Equation G2 below. The costs per tonne of CO_2 reduced over the projects' lifetime were then found using Equation G3.

$$\text{Payback} = \frac{\text{Cost}_{\text{initial}}}{\Delta Q \cdot \text{Price}_{\text{NG}}} \qquad \text{(G2)}$$

$$\frac{\$}{\text{tonneCO}_2} = \frac{\text{Cost}_{\text{initial}}}{\text{tonneCO}_{2\,\text{Lifetime}}} \qquad \text{(G3)}$$

3 Results

Figure G1, Figure G2, and Table G1 show the simple payback, warranty duration, and cost per tonne of CO_2 reduced over project lifetime.

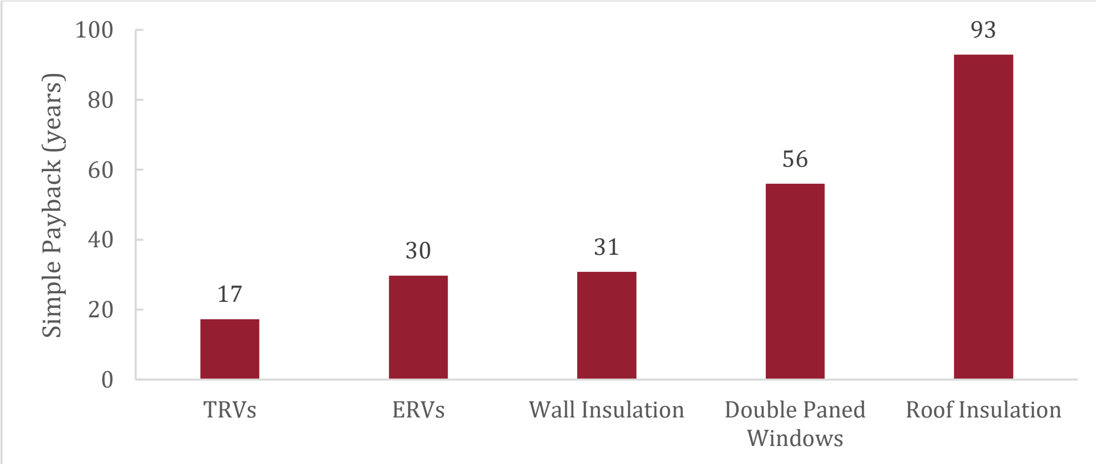


Figure G1: Simple payback for each efficiency project.

Table G1: Warranty duration for each efficiency project.

	TRVs	ERVs	Wall Insulation	Double Paned Windows	Roof Insulation
Warranty (Years)	5	10	20	20	20

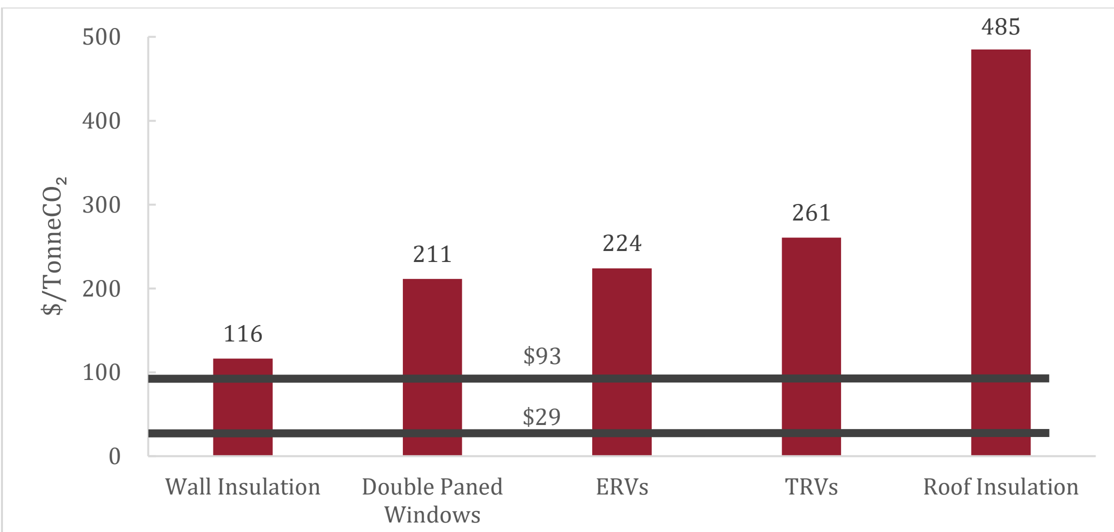


Figure G2: Cost per tonne of CO_2 reduced over the lifetime of an efficiency project compared to the cost of carbon offsets.

4 Discussion & Conclusion

The simple payback for each of the projects is greater than the warranty lifetime. The equivalent cost from the projects for reducing a tonne of CO_2 is much greater than a typical cost range for carbon offsets. There can be many reasons for pursuing efficiency, but efficiency is not the most cost-effective way to pursue carbon neutrality. Due to the high cost of the efficiency projects, Calvin University should choose to pursue a more financially prudent path to carbon neutrality.

G1: Double-Paned Windows

Installing double-paned windows is a way to reduce heat loss through windows. Calvin has single-paned windows in all the dorms except Kalsbeek-Huizenga-van Reken (KHvR). Therefore, this research analyzed window replacements in all dormitories apart from KHvR.

Much of the double-paned window analysis was based on the 2022 ENGR-333B report (ENGR 333B, 2022). This report included a quote on the cost of 1500 windows from Pella Windows at $829,439.40. The cost per window used in the Summer 2026 analysis was $625, an average from GlassAdvisor, but not inconsistent to the cost estimate in the 333 report (Window Comparison Guide, n.d.). The total upfront cost to install double-paned windows used in the Summer 2026 analysis is $\text{Cost}_{\text{initial}} = \$937{,}500$.

Equation G1 was used to find the heat transfer reduction through double-paned windows in comparison to single glazed windows. The size and type of window replacements were assumed to be 4' x 6' double-paned sliding windows ($A = 24 \text{ ft}^2$). The U-factor of double paned windows used was $U_{new} = 0.30 \frac{\text{BTU}}{\text{hr·ft}^2\text{·°F}}$, the average of the range $0.28 \frac{\text{BTU}}{\text{hr·ft}^2\text{·°F}}$ to $0.32 \frac{\text{BTU}}{\text{hr·ft}^2\text{·°F}}$ from Prime Home Remod (Kroll, n.d.). The single-pane U-factor used was $U_{old} = 1 \frac{\text{BTU}}{\text{hr·ft}^2\text{·°F}}$. The calculation can be seen in Equation G1.1 below.

$$\Delta Q = \left(1 \frac{\text{BTU}}{\text{hr} \cdot \text{ft}^2 \cdot \text{°F}} - 0.30 \frac{\text{BTU}}{\text{hr} \cdot \text{ft}^2 \cdot \text{°F}}\right) \cdot 24 \text{ ft}^2 \cdot 16{,}5816 \frac{\text{hr} \cdot \text{°F}}{\text{Year}} \cdot \frac{1 \text{ MMBtu}}{1{,}000{,}000 \text{ BTU}} = 4179 \frac{\text{MMBtu}}{\text{Year}} \quad \text{(G1.1)}$$

Equation G2 was used to find the simple payback period. The price of natural gas used was $\text{Price}_{\text{NG}} = \$4.00854/\text{MMBtu}$, a price provided by Facilities. The calculation can be seen in Equation G1.2 below.

$$\text{Payback} = \frac{\$937{,}500}{4179 \frac{\text{MMBtu}}{\text{Year}} \cdot \frac{\$4.00854}{\text{MMBtu}}} = 56 \text{ Years} \quad \text{(G1.2)}$$

Equation G3 was used to find the cost per unit of emission reduction. The warranty for double-paned windows was found to be 20 years from Renuity (Arcas, 2025). The carbon coefficient is $53.1 \frac{\text{kgCO}_2}{\text{MMBtu}}$. More information on the carbon coefficients can be found in Appendix C2: Carbon Coefficients. The calculation can be seen in Equation G1.3 below.

$$\frac{\$}{\text{tonneCO}_2} = \frac{\$937{,}500}{4179 \frac{\text{MMBtu}}{\text{Year}} \cdot 53.1 \frac{\text{kgCO}_2}{\text{MMBtu}} \cdot \frac{1 \text{ tonneCO}_2}{1000 \text{ kgCO}_2} \cdot 20 \text{ Year}} = \frac{\$211}{\text{tonneCO}_2} \quad \text{(G1.3)}$$

Detailed calculations can be found in the Carbon Neutral Research team in the Scenarios folder and then the Efficiency folder. The calculations are contained in the Excel spreadsheet named Efficiency Scenarios and the Double-Paned Windows tab within that workbook. It can also be found here: Efficiency Scenarios.xlsx.

G2: Wall Insulation

Calvin University does not have wall insulation in the dorm buildings. According to the 2022 ENGR-333B report, the walls are made of 4" brick, 8" concrete blocks, and 1" mortar. Due to the lack of insulation, installing any insulation would decrease heat loss from the walls. It is difficult and a time-intensive process to install insulation, drywall, and paint. At the suggestion of facilities, we analyzed an all-in-one wall board with insulation and a finish in layers.

The estimated cost was given by facilities to be $1,200 per dorm interior wall. The number of dorm rooms was approximately 1120 based on the Beets wing of the dorm Beets-Veenstra (BV) multiplied by the number of dorm wings at Calvin. Based on these assumptions, the total initial cost is $1,344,000.

Equation G1 was used to find the heat transfer reduction through the wall after insulation was installed. The wall board assumes 1 inch of polyiso insulation with an R-value of $6.5\,\frac{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}{\text{Btu}}$ is added to the inside of the wall along with a thin 0.25-inch layer of plastic-like material with an R-value of $0.2\,\frac{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}{\text{Btu}}$ (Commercial Insulation Products, n.d.). Using these R-values, the U factors were found to be $U_{old} = 0.346\,\frac{\text{BTU}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$ and $U_{new} = 0.079\,\frac{\text{BTU}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$. The total vertical cross-sectional area of the dorms is $A = 245{,}764\ \text{ft}^2$. The calculation can be seen in Equation G2.1 below.

$$\Delta Q = \left(0.35\,\frac{\text{BTU}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}} - 0.08\,\frac{\text{BTU}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}\right)\cdot 245{,}764\ \text{ft}^2\cdot 16{,}5816\,\frac{\text{hr}\cdot{}^\circ\text{F}}{\text{Year}}\cdot\frac{1\ \text{MMBtu}}{1{,}000{,}000\ \text{BTU}} = 10{,}890\,\frac{\text{MMBtu}}{\text{Year}} \quad \text{(G2.1)}$$

Equation G2 was used to find the simple payback period. The price of natural gas used was $\text{Price}_{\text{NG}} = \$4.00854/\text{MMBtu}$, a price provided by Facilities. The calculation can be seen in Equation G2.2 below.

$$\text{Payback} = \frac{\$1{,}344{,}000}{10{,}890\,\frac{\text{MMBtu}}{\text{Year}}\cdot\frac{\$4.00854}{\text{MMBtu}}} = 31\ \text{Years} \quad \text{(G2.2)}$$

Equation G3 was used to find the cost per unit of emission reduction. The warranty is taken to be 20 years (What to Look for in an Insulation Warranty, 2014). The carbon coefficient is $53.1\,\frac{\text{kgCO}_2}{\text{MMBtu}}$. More information on the carbon coefficients can be found in Appendix C2: Carbon Coefficients. The calculation for cost per unit of emission reduction can be seen below in Equation G2.3.

$$\frac{\$}{\text{tonneCO}_2} = \frac{\$1{,}344{,}000}{10{,}890\,\frac{\text{MMBtu}}{\text{Year}}\cdot 53.1\,\frac{\text{kgCO}_2}{\text{MMBtu}}\cdot\frac{1\ \text{tonneCO}_2}{1000\ \text{kgCO}_2}\cdot 20\ \text{Year}} = \frac{\$116}{\text{tonneCO}_2} \quad \text{(G2.3)}$$

Detailed calculations can be found in the Carbon Neutral Research team in the Scenarios folder and then the Efficiency folder. The calculations are contained in the Excel spreadsheet named Efficiency Scenarios and the Wall Board Insulation tab within that workbook. It can also be found here: Efficiency Scenarios.xlsx

G3: Roof Insulation

Many of Calvin University's buildings could benefit from the installation of new roof insulation. The cost estimate used was $3.50/$ft^2$, the low end of the range from Prestige Roofing LLC (Guide to Commercial Roof Insulation, 2024). The roof area of 33 buildings was estimated using Google Earth, with the total cross-sectional area being $A = 733{,}632\ \text{ft}^2$. The calculation for total initial cost can be found below in Equation G3.1

$$\text{Cost}_{\text{initial}} = 733{,}632\ \text{ft}^2 \cdot \frac{\$3.50}{\text{ft}^2} = \$2{,}567{,}712 \qquad \text{(G3.1)}$$

Equation G1 was used to find the heat transfer reduction through the roof after insulation was installed. The type of insulation was assumed to be spray foam with an R-value of 5.6 $\frac{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}{\text{Btu}}$ per inch (Guide to Commercial Roof Insulation, 2024). The thickness was assumed to be 12", an estimate provided by Facilities. This would replace 4" rigid insulation with an R-value of 4 $\frac{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}{\text{Btu}}$ per inch that was assumed based on the 2022 ENGR-333B report. The original R-value of the roof was taken to be 18.04 $\frac{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}{\text{Btu}}$, including the 4" rigid insulation (ENGR 333B, 2022). Using these R-values, the U factors were found to be $U_{old} = 0.055 \frac{\text{Btu}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$ and $U_{new} = 0.014 \frac{\text{Btu}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}$. Based on these assumptions, the calculation for net heat transfer reduction from natural gas can be seen in Equation G3.2 below.

$$\Delta Q_{NG} = \left(0.06\ \frac{\text{BTU}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}} - 0.01\frac{\text{BTU}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}\right)\cdot 733{,}632\ \text{ft}^2 \cdot 16{,}5816\ \frac{\text{hr}\cdot{}^\circ\text{F}}{\text{Year}}\cdot\frac{1\ \text{MMBtu}}{1{,}000{,}000\ \text{BTU}} = 4986\ \frac{\text{MMBtu}}{\text{Year}} \qquad \text{(G3.2)}$$

To find the heat transfer reduction in the summer, Equation G1 was used, and the cooling degree days (CDD) were substituted for HDD. Information on CDD came from BizEE for the weather station ID KGRR and using a base temperature of 75°F (Degree Days Calculated Accurately for Locations Worldwide, n.d.). Based on these assumptions and those found above, the calculation for net heat transfer reduction for electricity can be seen in Equation G3.3 below.

$$\Delta Q_{Elec} = \left(0.06\ \frac{\text{BTU}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}} - 0.01\frac{\text{BTU}}{\text{hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}}\right)\cdot 733{,}632\ \text{ft}^2 \cdot 5520\ \frac{\text{hr}\cdot{}^\circ\text{F}}{\text{Year}}\cdot\frac{1\ \text{MMBtu}}{1{,}000{,}000\ \text{BTU}}\cdot\frac{293.07\ \text{kWh}}{1\ \text{MMBtu}} = 48648\ \frac{\text{kWh}}{\text{Year}} \qquad \text{(G3.3)}$$

Equation G2 was used to find the simple payback period. The price of natural gas used was Price_{NG} = \$4.00854/MMBtu, a price provided by Facilities. The cost savings from the electricity reduction was accounted for in the denominator. The price of electricity used is \$0.19/kWh, a price provided by Facilities. The calculation can be seen below in Equation G3.4.

$$\text{Payback} = \frac{\$2{,}567{,}712}{\left(4986\frac{\text{MMBtu}}{\text{Year}}\cdot\frac{\$4.00854}{\text{MMBtu}}\right) + (48648\frac{\text{kWh}}{\text{Year}}\cdot\frac{\$0.19}{\text{kWh}})} = 93\ \text{Years} \qquad \text{(G3.4)}$$

Equation G3 was used to find the cost per unit of emission reduction. The warranty duration is 20 years (What to Look for in an Insulation Warranty, 2014). The calculation was made and can be seen in Equation G3.5 below.

$$\frac{\$}{\text{tonneCO}_2} = \frac{\$2{,}567{,}712}{4986\frac{\text{MMBtu}}{\text{Year}}\cdot 53.1\frac{\text{kgCO}_2}{\text{MMBtu}}\cdot\frac{1\ \text{tonneCO}_2}{1000\ \text{kgCO}_2}\cdot 20\ \text{Year}} = \frac{\$485}{\text{tonneCO}_2} \qquad \text{(G3.5)}$$

Detailed calculations can be found in the Carbon Neutral Research team in the Scenarios folder and then the Efficiency folder. The calculations are contained in the Excel workbook named Efficiency Scenarios and the Roof Insulation tab within that workbook. It can also be found here: Efficiency Scenarios.xlsx.

G4: Thermostatic Radiator Valves (TRVs)

Thermostatic Radiator Valves (TRVs) are devices that are installed individually to a radiator to automatically maintain a desired room temperature through the control of hot water flow to that radiator. This is another efficiency improvement that can be installed specifically in the dorms. Students in the dorms often complain that the rooms are overheated and open their windows to lower the temperature in their rooms. To reduce excessive heating, TRVs would be installed so each student can control the temperature in their rooms.

The expected cost of a TRV unit is $300 and would be installed on each dorm room's radiator. This value was taken from the average of three sources (Thermostatic Radiator Valve Cost and Price Breakdown 2026, 2026) (Thermostatic Radiator Valve Cost Breakdown and Typical Prices 2026, 2026) (Thermostatic Radiator Valve Cost Guide for U.S. Homeowners 2026, 2026). The number of dorm rooms was approximately 1120 based on the Beets wing of the dorm Beets-Veenstra (BV) multiplied by the number of dorm wings at Calvin. Based on these assumptions, the total initial cost is $\text{Cost}_{\text{initial}}$ = $336,000.

The heat transfer reduction calculation can be found in Equation G4.1 below. The natural gas usage for the dorms was approximated using the ratio of the gross square footage of the dorms to the campus total building gross square footage. The energy savings expected are 15% of natural gas used in dorms, another average from three sources (Do Thermostatic Radiator Valves Save Energy?, 2026) (Cholewa, Siuta-Olcha, & Balaras, 2017) (EU Study Shows Energy Savings Potential of Thermostatic Radiator Valves, 2018).

$$\Delta Q = 149{,}199\frac{\text{MMBtu}}{\text{Year}}\cdot\frac{479{,}270\text{ ft}^2}{2{,}208{,}316\text{ ft}^2}\cdot 15\% = 4857\ \frac{\text{MMBtu}}{\text{Year}} \tag{G4.1}$$

Equation G2 was used to find the simple payback period. The price of natural gas used was Price_{NG} = $4.00854/MMBtu, a price provided by Facilities. The calculation can be seen below in Equation G4.2.

$$\text{Payback} = \frac{\$336{,}000}{4857\frac{\text{MMBtu}}{\text{Year}}\cdot\frac{\$4.00854}{\text{MMBtu}}} = 17\text{ Years} \tag{G4.2}$$

Equation G3 was used to find the cost per unit of emission reduction. The warranty on a TRV is 5 years (Manufacturer's Warranty On: Danfoss TRV, 2018). The calculation can be seen below in Equation G4.3.

$$\frac{\$}{\text{tonneCO}_2} = \frac{\$336{,}000}{4857\frac{\text{MMBtu}}{\text{Year}}\cdot 53.1\frac{\text{kgCO}_2}{\text{MMBtu}}\cdot\frac{1\text{ tonneCO}_2}{1000\text{ kgCO}_2}\cdot 5\text{ Year}} = \frac{\$261}{\text{tonneCO}_2} \tag{G4.3}$$

Detailed calculations can be found in the Carbon Neutral Research team in the Scenarios folder and then the Efficiency folder. The calculations are contained in the Excel spreadsheet named Efficiency Scenarios and the TRVs tab within that workbook. It can also be found here: Efficiency Scenarios.xlsx.

G5: Energy Recovery Ventilators (ERVs)

Energy Recovery Ventilators (ERVs) exchange stale indoor air with fresh outdoor air while transferring the heat and moisture to reduce energy consumption to the fresh air.

The average cost for a commercial rooftop ERV unit is $12,000 (Energy Recovery Ventilation System Cost and Typical Price Ranges 2026, 2026). The assumption was made that each air intake vent would need an ERV and that there are approximately three units per building. There were 34 buildings. Based on these assumptions, the total initial cost is $\text{Cost}_{\text{initial}}$ = $1,224,000.

The heat transfer reduction calculation can be found in Equation G5.1 below. To find the energy consumption of academic and service buildings, the ratio of gross square footage of those buildings to the total campus building gross square footage was multiplied by expected total expected natural gas usage. The expected energy savings for these buildings are 10% of the total energy consumption (ERVs in Schools: Increase Fresh Air, Not Energy Bills, 2025).

$$\Delta Q = 149{,}199 \frac{\text{MMBtu}}{\text{Year}} \cdot \frac{1{,}523{,}527 \text{ ft}^2}{2{,}208{,}316 \text{ ft}^2} \cdot 10\% = 10{,}293 \frac{\text{MMBtu}}{\text{Year}} \qquad \text{(G5.1)}$$

Equation G2 was used to find the simple payback period. The price of natural gas used was $4.00854/MMBtu ($\text{Price}_{\text{NG}}$), a price provided by Facilities. The cost savings accrued from the lowered use of AC were not included in the calculations. The calculation can be seen below in Equation G5.2.

$$\text{Payback} = \frac{\$1{,}224{,}000}{10{,}293 \frac{\text{MMBtu}}{\text{Year}} \cdot \frac{\$4.00854}{\text{MMBtu}}} = 30 \text{ Years} \qquad \text{(G5.2)}$$

Equation G3 was used to find the cost per unit of emission reduction. The warranty duration for an ERV is 10 years (Technology That Lets You Breathe Easy, n.d.). The calculation can be seen below in Equation G5.3.

$$\frac{\$}{\text{tonneCO}_2} = \frac{\$1{,}224{,}000}{10{,}293 \frac{\text{MMBtu}}{\text{Year}} \cdot 53.1 \frac{\text{kgCO}_2}{\text{MMBtu}} \cdot \frac{1 \text{ tonneCO}_2}{1000 \text{ kgCO}_2} \cdot 10 \text{ Year}} = \frac{\$224}{\text{tonneCO}_2} \qquad \text{(G5.3)}$$

Detailed calculations can be found in the Carbon Neutral Research team in the Scenarios folder and then the Efficiency folder. The calculations are contained in the Excel spreadsheet named Efficiency Scenarios and the ERVs tab within that workbook. It can also be found here: Efficiency Scenarios.xlsx.

Appendix H: Carbon Neutrality Strategy

There are many routes that Calvin University could take to become carbon neutral. Air-source heat pumps can eliminate natural gas heating emissions and bring air-conditioning to more buildings on campus at the same time. Wind turbines can generate clean electricity year-round. Ground-source (geothermal) heat pumps can electrify campus heating and cooling with a longer lifespan than air-source. On-campus efficiency projects improve building envelopes and reduce wasted energy in our heating and cooling systems. Rooftop-mounted solar panels bring clean electricity to campus and can even extend the lifetime of roofs. Carbon offsets provide a financial mechanism to decrease Calvin's net emissions by funding projects around the globe that remove or reduce carbon emissions. The purpose of this appendix is to evaluate potential routes toward carbon neutrality and justify our proposed carbon neutrality strategy.

It is important to note that green electricity generation methods – such as wind turbines and solar panels – do not reduce long-term carbon emissions. Calvin plans to purchase carbon-free electricity from Consumers Energy beginning in 2028, eliminating Scope 2 emissions. However, on-campus green electricity projects can provide energy cost savings because clean electricity generated on-campus is cheaper than grid-generated clean electricity. On-campus generation also decreases reliance on an electricity grid that is more strained than ever.

Wind energy and air-source heat pumps were quickly ruled out of contention as routes toward carbon neutrality. Calvin's location is classified as "Poor" for wind power generation by NREL, as seen in Figure H1a below. Air-source heat pumps, shown in Figure H1b, carry a high maintenance burden, have lower effectiveness in extreme cold, and would significantly decrease aesthetic value of campus buildings. Neither of these options were examined further.

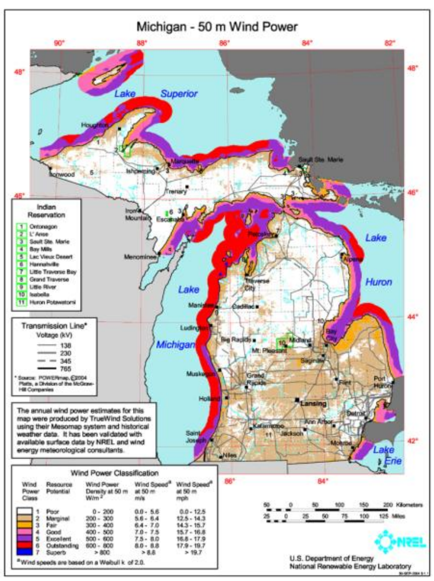


Figure H1a: NREL Michigan wind resource map.

Figure H1b: Air-source heat pumps installed on a building.

Ground-source (geothermal) heat pumps eliminate the need for burning natural gas and instead use electricity. Combined with purchasing carbon-free electricity, a geothermal system would eliminate all Scope 1 and 2 emissions for Calvin. However, due to installation costs of over $60 million, geologic uncertainty, and high land needs, geothermal heat pumps were not pursued for carbon neutrality. In-depth analysis on geothermal heat pumps can be found in Appendix A.

On-campus efficiency projects can provide a dual benefit to Calvin. They can both decrease carbon emissions and modernize aging campus infrastructure. Projects analyzed include double-paned windows, wall and roof insulation, thermostatic radiator valves (TRVs), and energy recovery ventilators (ERVs). Notable exclusions include variable frequency drives (VFDs) for AC motors, LED lighting upgrades, and smart power strips. Excluded projects would not reduce carbon emissions long-term since they reduce electricity usage, which will be carbon-free in 2028. Analysis compared the cost of efficiency projects to carbon offsets and calculated financial payback. Due to payback periods being greater than warrantied lifetime, and \$/tonneCO_2 reduced being greater than the cost of offsets, efficiency was ruled out as a method of achieving carbon neutrality. Further analysis is shown in Appendix G.

Rooftop-mounted solar panels were examined for financial savings. Rooftop mounting was found to be more favorable than ground mounting or covering parking lots due to lower construction costs. 34 rooftops across Calvin's Knollcrest campus were analyzed to determine solar capacity, installation cost, and annual energy cost savings. The most favorable 9 roofs were selected for further financial modeling and analysis. Analysis showed that with these roofs, energy cost savings could reach over $800,000/yr by 2048, proving ample funding for sustainability projects. Detailed descriptions of analyses can be found in Appendices B, D, and E.

Carbon offsets, also known as carbon credits, were also examined. Offsets allow an organization to become carbon neutral by funding carbon removal/reduction projects around the globe. Carbon offsets are readily available and come at much more feasible costs than a geothermal installation or efficiency projects. A range of \$230,000/yr to \$740,000/yr (based on prices of \$29/tonne CO_2 and \$93/tonne CO_2) was determined for an annual carbon offset cost based on projects available on Gold Standard Marketplace, Cool Effect, Tradewater, and internal portfolio estimates from Senken, an offset provider serving German corporations. It also became clear that if Calvin were to pursue an offset-based carbon neutrality path, it would need purchasing guidelines aligned with Statement on Sustainability, mission statement, and vision. Guidelines for carbon offset purchasing and further analysis are detailed in Appendix F: Carbon Offsets.

Funding for carbon offset purchases would be provided by energy cost savings resulting from build-out of rooftop solar arrays. This build-out would follow a revolving fund model, perhaps called the Calvin Solar Revolving Fund (CSRF). CSRF would cover installation costs, inverter replacement costs, and panel maintenance. Once annual CSRF profit eclipses the annual cost of carbon offsets, the fund can begin to pay for carbon offsets. Using this model, it would take between 11-20 years from the first solar installation to reach carbon neutrality, depending on carbon offset prices. A cash-flow model of CSRF at an annual carbon offset cost of $740,000/yr is shown in Figure H2. Further analysis on CSRF can be found in Appendices D and E.

The possibility of a staff position overseeing sustainability activities at the university to be funded by CSRF was analyzed. Analysis showed that the earlier CSRF begins funding a sustainability manager, the later Calvin's carbon neutrality date becomes. See Appendix H1 for more details.

Given analysis of feasible options toward carbon neutrality, we recommend procuring quality carbon offsets using energy cost savings from a build out of rooftop solar, funded by a Calvin Solar Revolving Fund (CSRF).

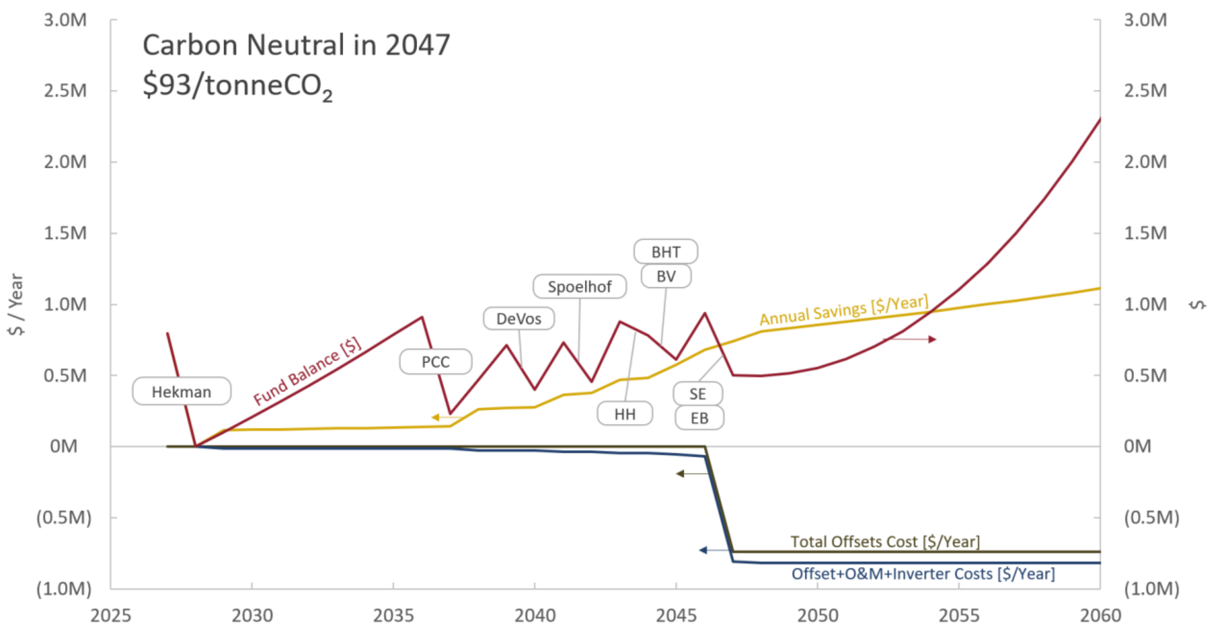


Figure H2: Cash-flow model of CSRF projecting carbon neutrality in 2047.

H1: Sustainability Manager Details

The following is a description of a potential Sustainability Manager position at Calvin University. Included are a job description, salary, and portion covered by CSRF. This position was modeled assuming an annual salary of $80,000 with benefits costing another $32,000 (40% overhead). This annual total of $112,000 would increase by 3% year-over-year. CSRF would cover half of this position and half would be covered by Facilities. A sample job description is as follows.

Sustainability Manager/EHS Position

The Sustainability Manager is shared between Calvin Facilities and the Calvin Solar Revolving Fund (CSRF). The Sustainability Manager oversees university sustainability planning, and manages current sustainability organizations and initiatives on campus. They also work with Facilities to manage Environment & Sustainability Governance (ESG) targets and ensure regulatory compliance.

Duties for CSRF include but are not limited to:

- Creating and implementing mission-driven initiatives aligned with university's carbon neutrality goals
- Tracking university resource usage, like electricity, water, and natural gas through a carbon emissions framework
- Meeting with student sustainability groups and promote collaboration between university staff and student initiatives (Earthkeepers, Biology Dept. Sustainability Committee, EESC, etc.)
- Researching and procuring carbon offsets aligned with Calvin's mission, Statement on Sustainability, and carbon neutrality plan
- Promoting and educating students, staff, and faculty on sustainable practices (new technology, composting, energy efficient HVAC practices, etc.)

EHS- and ESG-related duties to be determined at a later date.

Sustainability Manager Timing

Though CSRF has capacity to support a Sustainability Manager, the position's start date has implications for when Calvin becomes carbon neutral. Below is a table showing that the earlier CSRF is used to fund half of a Sustainability Manager's salary, the later the carbon neutrality date becomes.

Table H1.1: Sustainability manager funding start compared with carbon neutrality year.

Sustainability Manager Start Year	Carbon Neutrality Year
2029	2056
2033	2052
2035	2051
2037	2049
2040	2049

Appendix I: CSRF Add-Ons

1 Introduction

The Calvin Solar Revolving Fund (CSRF) was introduced to fund the purchase of carbon offsets for Calvin to achieve carbon neutrality. More information on CSRF and carbon neutrality can be found in Appendix E. Additional add-ons for CSRF funding were considered including Operations and Maintenance (O&M) costs for the solar systems, inverter replacement costs for the solar systems, a half-time sustainability manager (SM), and roof replacement or repairment costs. Although these expenses extend the date at which Calvin could become carbon neutral, they help the university address other Facilities' concerns.

The remainder of this appendix is structured as follows. Section 2 discusses data sources and methods. Section 3 describes results of applying the methods of Section 2 to the data. Section 4 discusses the results and conclusion. Appendices follow, providing supplementary information.

2 Data Sources & Methods

Analysis of the add-ons for the CSRF was heavily dependent on information provided by Facilities. O&M costs for the solar systems were estimated at $1200/array provided by Facilities from Greg Oliver of Agathon, the contractor for the solar array on Calvin's Van Noord Arena. The inverter costs are estimated at $0.24/Watt, the high end of the range from Angi (Loveland, 2026). The SM's salary was estimated at $112,000/year by Facilities. CSRF is expected to cover half of the full-time position at a cost of $56,000/year. Roof costs on a per building basis were provided by Facilities. The initial CSRF seed money expected for the cost of a solar array on Hekman Library is $800k.

O&M and inverter costs were combined as an annual cost for installed arrays. Inverters for solar arrays need to be replaced every ten years (Loveland, 2026). Therefore, replacement costs were divided by ten and added to the annual expenses.

The SM position is first funded by CSRF in 2037. For more information on the SM, refer to Appendix H1. The SM position is added to CSRF expenses in addition to O&M and inverter costs.

The roof costs add-on assumed the initial roof cost for Hekman Library was included in the CSRF seed money, bringing the initial cost to $1.9M. The subsequent roof costs are funded by CSRF in addition to the initial cost of a solar array. Roof costs were added in addition to O&M and inverter costs, but not in addition to SM costs.

3 Results

Cash flow models for each add-on can be seen below in Figure I1, Figure I2, and Figure I3. Carbon neutrality dates are shown in each figure. The results are high carbon offset cost scenarios with a carbon offset price of $93/tonne$CO_2$. Other scenarios can be found in Appendices I1, I2, and I3.

4 Discussion & Conclusion

CSRF can fund each of the add-ons and still reach carbon neutrality. These add-ons help address Facilities' concerns, but with the effect of a later carbon neutrality date. Roof costs are the only add-on that extends the carbon neutrality date past 2057. Therefore, roof costs should be taken from other funding sources, if possible, but not at the expense of waiting for a solar array to be installed.

Figures

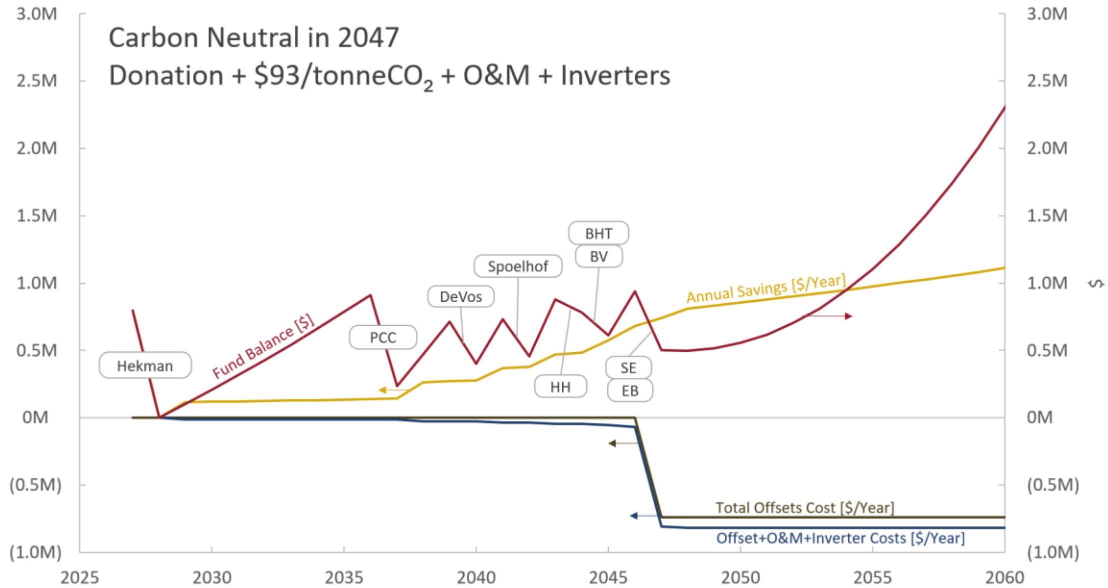


Figure I1: Cash flow model of CSRF with O&M and inverter costs, with a carbon neutrality date of 2047.

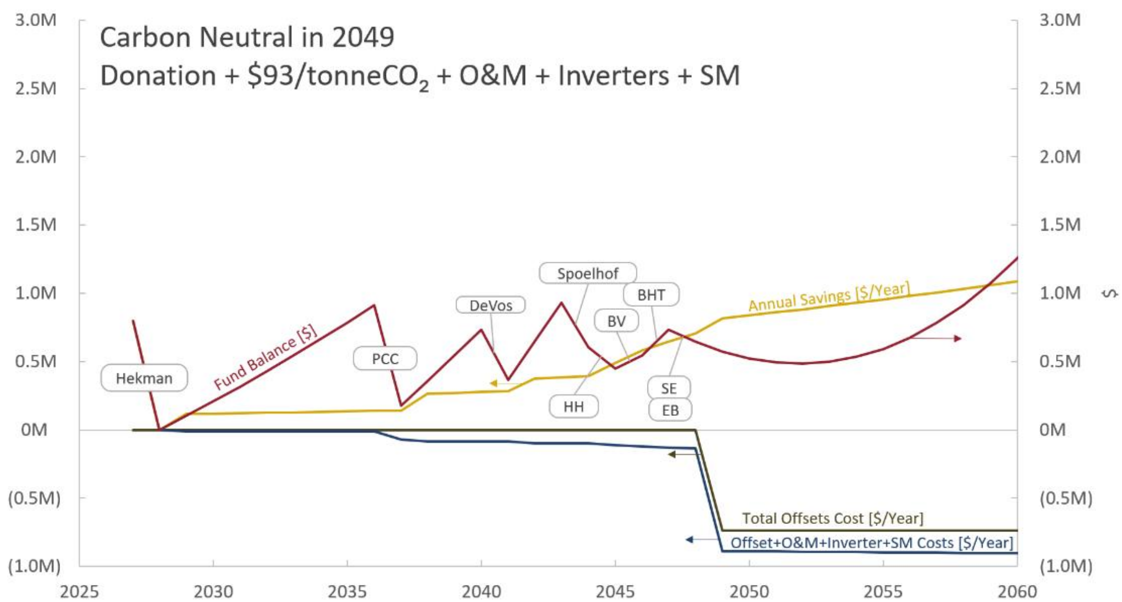


Figure I2: Cash flow model with SM, O&M, and inverter costs, pushing the carbon neutrality date to 2049.

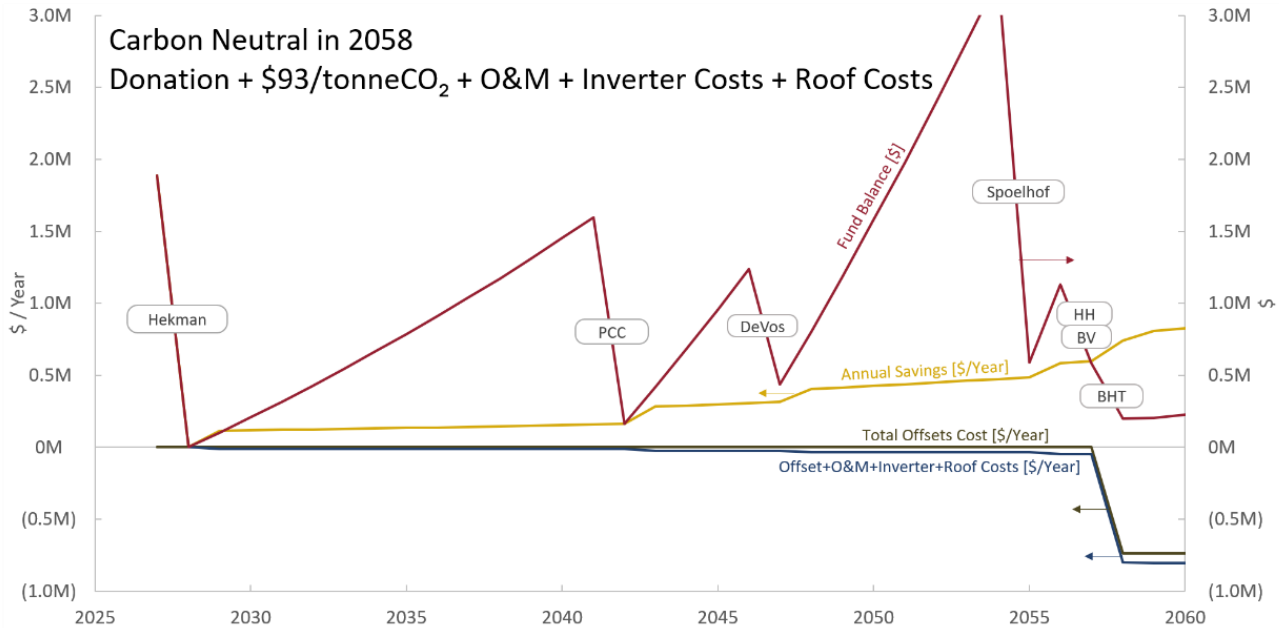


Figure I3: Cash flow model with roof, O&M, and inverter costs, pushing the carbon neutrality date to 2058.

I1: O&M and Inverter Costs

O&M and inverter costs were combined as an annual expense for CSRF. The various scenarios can be seen below in Figure I1.1.

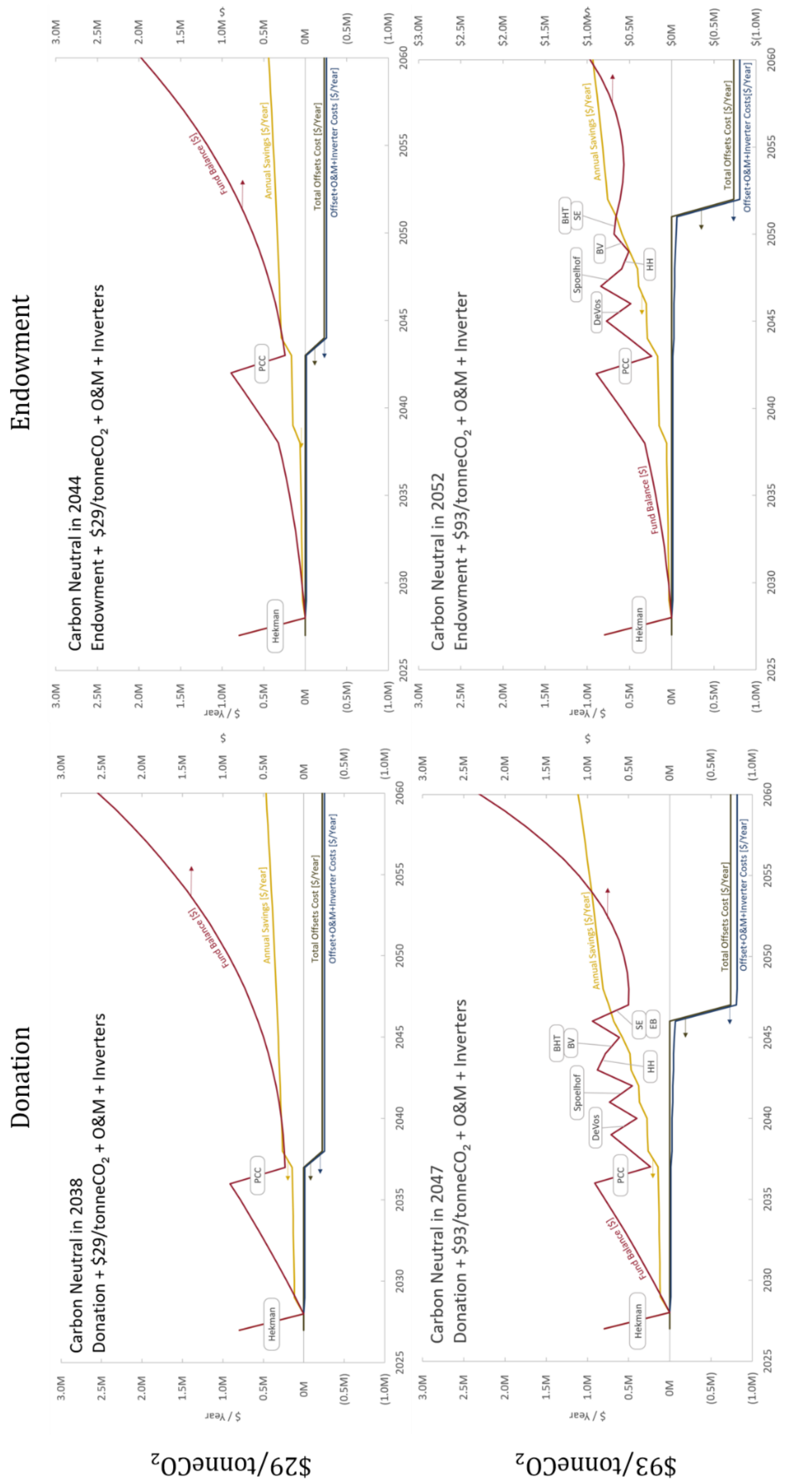


Figure I1.1: CSRF with O&M and Inverter add-ons.

I2: Sustainability Manager

The results for each scenario for the SM add-on can be seen in Figure I2.1 below.

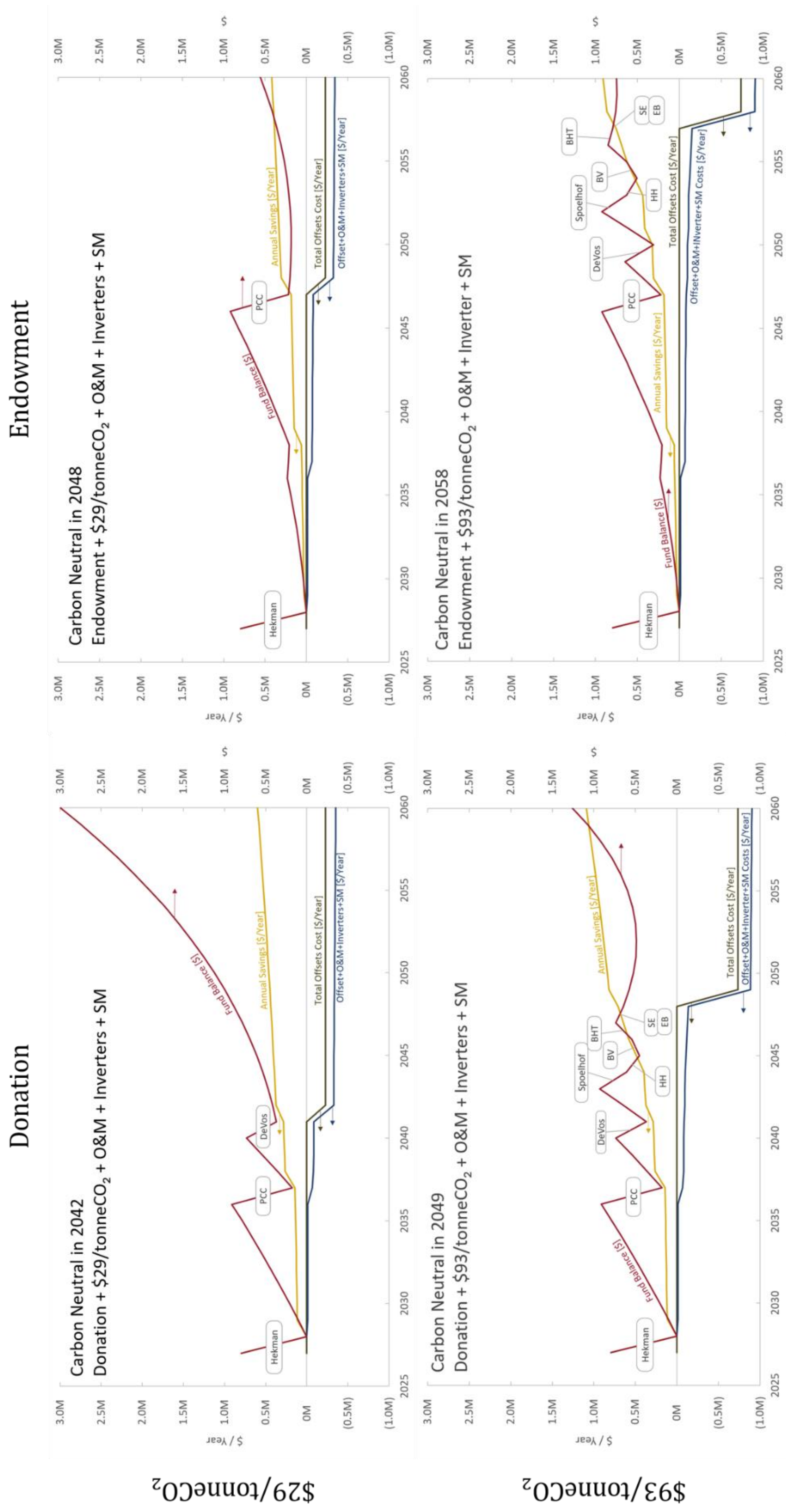


Figure I2.1: CSRF with SM add-on scenarios.

I3: Roof Replacement and Repair Costs

The results for each scenario for the roof costs add-on can be seen in Figure I1.1 below.

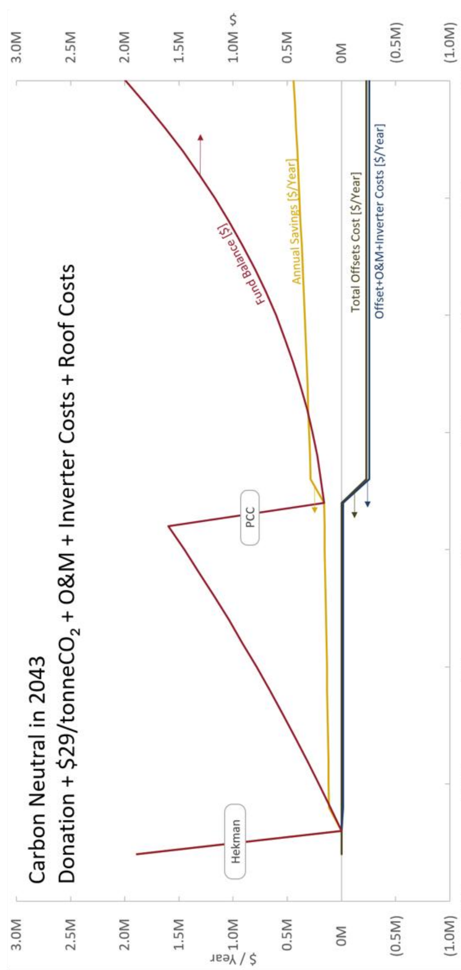
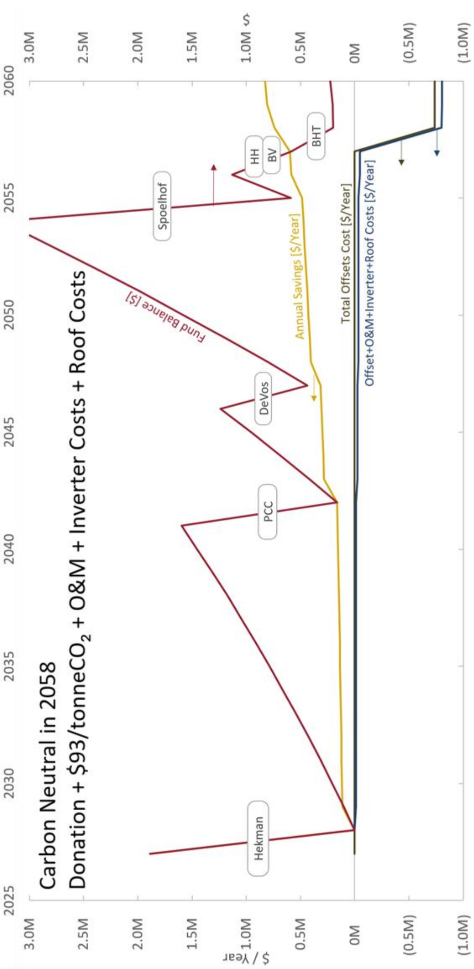
	Donation	Endowment
$29/tonne$CO_2$		N/A
$93/tonne$CO_2$		N/A

Figure I3.1: CSRF with roof costs add-on.

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