COMMUNITIES LEAP
U.S. DEPARTMENT OF ENERGY

HPC3
HIGHLAND PARK COMMUNITY CRISIS COALITION

Soulardarity

Avalon Village

PARKER VILLAGE

Prefeasibility Analysis of Behind-the-Meter Distributed Energy Resources in Highland Park, MI

Highland Park Pathways to Power

Tucker Oddleifson, Kapil Duwadi, Erik Pohl, Patrick Gibbs, Shibani Ghosh, Chrissy Scarpitti, and Liz Weber

National Renewable Energy Laboratory

March 2024

DOE/GO-102024-6115

Notice

This work was authored by the National Renewable Energy Laboratory (NREL), operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the DOE's Communities LEAP (Local Energy Action Program) Pilot.

The analysis results are not intended to be the sole basis of investment, policy, or regulatory decisions.

This analysis was conducted using the NREL REopt Model (http://www.reopt.nrel.gov). REopt is a techno-economic decision support model that identifies the cost-optimal set of energy technologies and dispatch strategy to meet site energy requirements at minimum lifecycle cost, based on physical characteristics of the site and assumptions about energy technology costs and electricity and fuel prices.

This analysis relies on site information provided to NREL that has not been independently validated by NREL.

Definitions

Term	Definition
ComStock™	A NREL tool for generating predicted electric load profile data for commercial buildings
Cost-effective	Refers to a system that saves money over the lifespan of the system
Critical Load	The critical load is the electric load that must be met during a grid outage
Investment Tax Credit (ITC)	Tax credits provided for solar PV and battery projects. Currently, the base ITC for solar and battery projects is 30% with the potential for increased ITC percentages based on project location. Tax-exempt entities, such as government entities, can receive the ITC as a cash payment through the direct pay option.
kW	Unit for kilowatts
Lifecycle Capital Cost	The total capital cost for a project, considering both initial purchases and replacements all in present value
MACRS	Modified Accelerated Cost Recovery System; Under MACRS, the capitalized cost of PV and batteries is recovered over a specified life (e.g., 5 years for PV systems) by annual deductions for depreciation. MACRS Bonus Depreciation is another name for an additional first year depreciation deduction (60% in 2024) provided by section 168(k).
Net Present Value (NPV)	The value a system provides over the course of its lifetime compared with a business-as-usual case where no technology is implemented. A positive NPV means the system saves money.
Off-grid	Not connected to the power grid and operating independently from the power grid
Outflow Credit	Credit that can be earned when exporting power back onto the grid to offset a customer’s utility bills
Solar PV nameplate capacity	The installed capacity of a solar PV system. Note, solar PV is also referred to as just PV.
Resilience	The ability for a building or microgrid to withstand a power grid outage by generating and distributing its own power
ResStock™	An NREL tool for generating predicted electric load profile data for residential buildings
Solar PV (PV)	Solar photovoltaics (photovoltaics); panels that generate electricity when exposed to sunlight
Techno-economic	Referring to analysis that considers both the technical aspects of a system and the predicted economic performance of the project.
Typical Meteorological Year (TMY) solar radiation data	TMY solar radiation data is based on multiple years of historical radiation data rather than just a single year. Used in modeling power output from solar panels, TMY data can help to avoid overestimating or understanding power output due to variations in year-to-year solar radiation.

Slide Deck Contents

Definitions: Results Terminology

Term	Definition
PV	The DC nameplate capacity (in kW) of the PV system recommended by REopt
Battery	The kW and kWh rating of the Lithium-Ion battery system
Carbon Free Electricity (CFE) %	The predicted percentage of the electricity demand that is met by electricity derived from the PV panels on site.
PV Exported Energy	The energy, in units of kWh, that is exported from the system to the grid. The outflow credit is based on this exported energy.
PV Curtailed Energy	Curtailed electricity refers to the electricity that the PV panels generate above what is required to meet the site's demand and/or charge the battery. Often it is most economical to build PV systems that curtail electricity. The curtailed energy in kWh is listed in this row.
Net Present Value (NPV) ($)	The Net Present Value computed as the Lifecycle Cost (LCC) of the business-as-usual case subtracted by the LCC of the evaluated case
Lifecycle Capital Cost ($)	"Net capital costs for all technologies, in present value, including replacement costs and incentives." (REopt.jl Documentation website)
Year 1 Utility Costs ($)	The cost of electricity (including the demand and energy cost) from the utility during year one
Year 1 Utility Savings ($)	Compared with the business-as-usual case, the savings in electricity costs when the evaluated scenario is implemented
% of the year that a **4-hr* outage would be survived** *Various outage durations were evaluated in addition to 4-hour outages	These values are generated by post-processing the REopt results using REopt's outage simulator. The outage simulator uses the results from the REopt run (battery charge levels, generator fuel availability, PV output, critical load profile, etc.) to predict how many hours the energy system can meet the critical load for all hours of the year.
Predicted PV Land area	The total predicted area of the solar PV system in acres

Project Background

About Communities LEAP

- The U.S. Department of Energy's Communities LEAP (Local Energy Action Program) pilot supports community-driven action plans for clean energy-related economic development.
- This opportunity is open to low-income, energy-burdened communities that experience environmental justice challenges and/or direct economic impacts from reducing reliance on fossil fuels.
- Communities LEAP reflects the Biden-Harris Administration's commitments to:
  - Combat climate change through community-led transitions toward a more equitable and sustainable future.
  - Deliver 40% of the overall benefits of federal climate, clean energy, affordable and sustainable housing, clean water, and other investments to communities that have been historically marginalized, underserved, and overburdened by pollution.

Project Context

Highland Park, Michigan, community members face frequent, long-duration power interruptions due largely to the aging distribution system serving the area and the legacy design standards used in its construction. These interruptions can impede daily life for residents and may pose threats to individuals who rely on electricity for heating, cooling, and other basic life needs.

Highland Park community stakeholders sought support from the National Renewable Energy Laboratory (NREL) to develop strategies for providing increased resilience for homes and key community infrastructure.

Conducting this analysis with key insight from the community stakeholders, we aimed to understand the technical opportunities and economic costs for creating resilience at a variety of building types in Highland Park.

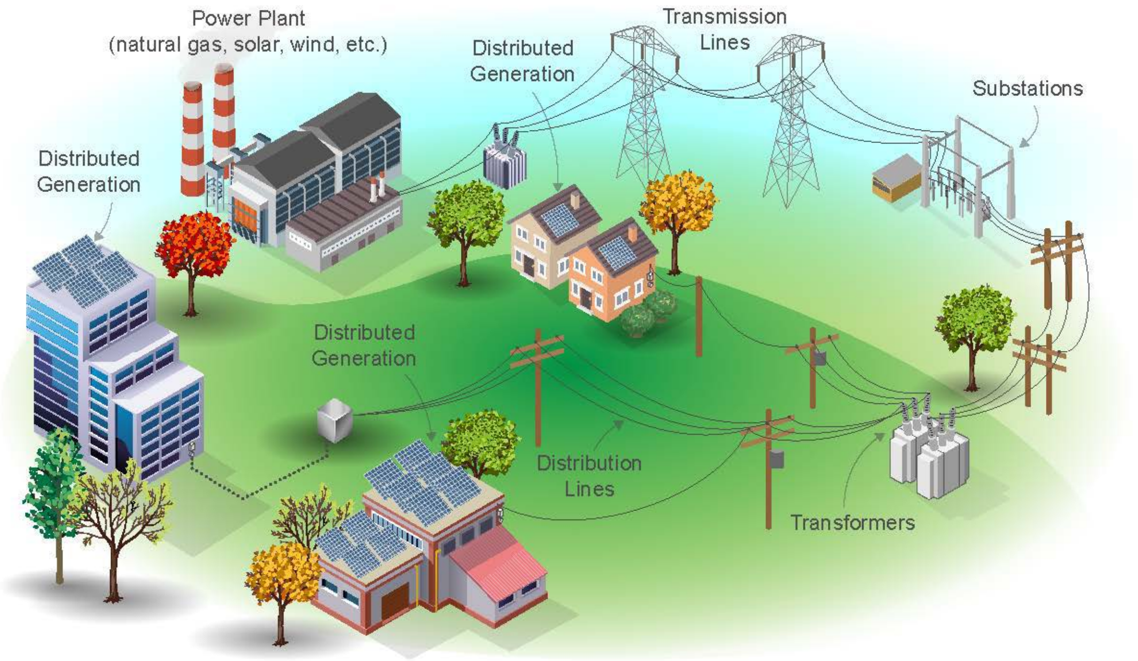

Illustration of the "grid" from utility power plant, transmission, distribution, to distributed energy resources. Illustration by Alfred Hicks, NREL 65851

Communities LEAP Scoping Context

Through the Communities LEAP Pilot, NREL engaged the Highland Park Stakeholder Coalition to scope technical assistance work areas to address their energy needs and goals.

This slide deck addresses the highlighted objectives in Task 3 under Grid Analysis.

A . City-Wide Solar Street Lighting and Policy Analysis	B. Grid Analysis	C. Community Choice : Home Energy Improvements
• Task 1: Solar Street Lighting Financial Model Review • Task 2: Due Diligence References • Task 3: Implemented Case Studies • Task 4: Master Plan Gap Analysis • Task 5: Zoning Code + Applications Gap Analysis • Task 6: Review Proposed Solar Ordinance	• Task 1: Determine Existing Load Profile + Feeder Model (reference case) • Task 2: Grid Analysis (limitations and capacity under three growth scenarios) • Task 3: Prefeasibility Analysis of 3 Actionable Behind Meter Projects	• Task 1: Support a coalition-facilitated selection process • Task 2: Housing Characteristics and Energy Burden Analysis

Analysis Objectives

NREL used the REopt® platform to evaluate the techno-economic potential of adding solar PV, electric storage, and/or diesel generators at the following locations in Highland Park, Michigan:

1. A typical residential and commercial building in Highland Park
2. Earnest T. Ford Recreation Center
3. Parker Village microgrid

The analysis goals focused on the ability of solar PV, electric storage, and/or diesel generators to reduce electricity costs and improve site resilience.

Key Findings from the Analysis

Analysis #1: Typical Residential and Commercial Buildings

- The analysis identified cost-effective sizing of solar PV for typical residential and commercial buildings in Highland Park. The full cost of this scenario was $1,652 for residential and $52,617 for commercial. Solar PV was cost-effective for both building types.
- Batteries appear to be able to accomplish the 24-hour resilience target for residential and commercial buildings when paired with solar PV. The full cost of this scenario was $8,656 for residential and $70,347 for commercial.
- When considering an upgraded electrification scenario for the residential building, full costs for a PV and battery system increases to $15,722 for the resilience scenario.
- Batteries were not cost-effective in non-resilience scenarios.

Analysis #2: Recreation Center

- The analysis identified that solar PV is cost-effective for the recreation center, but the economic benefits depended on the type of outflow credits utilized. The system sizing ranged from 26 to 100 kW of PV and the economic benefit ranged from $23K to $52K.
- Solar PV and batteries could be implemented to accomplish the estimated resilience targets of 12 to 72 hours. The predicted full cost ranges from $586K to $750K, depending on the outflow credit type.
- However, diesel generators paired with PV appear to be a more cost-effective solution. PV with generator scenarios had a predicted full cost ranging from $105K to $195K.

Analysis #3: Parker Village Microgrid

- With enough area for solar PV, Parker Village could likely operate as an off-grid microgrid. But isolating from the grid would result in a predicted $11.6M increase in full costs relative to predicted energy costs if relying entirely on grid power.
- If the microgrid is connected to the grid, then solar PV, batteries, and/or generators could be implemented to survive 3-day grid outages, with a cost difference ranging from -$551K to -$4.1M compared with the business-as-usual scenario.
- In a grid-connected scenario, solar PV appears to be cost-effective if implemented by itself with a size of 285 kW.
- Depending on the technologies implemented and if the microgrid is grid-connected or off-grid, the predicted full costs ranged from $178,497 to $11,280,006. Note that further analysis should be performed on quantifying the site-specific costs for microgrid infrastructure like distribution lines and switchgears.

REopt Inputs and Assumptions

REopt Overview

NREL's REopt platform suggests optimized technology sizing and dispatch strategies based on a variety of inputs into the model. Figure 1 summarizes the inputs and outputs of the REopt model.

The inputs for the models were collected based on discussions with community stakeholders, research, and industry knowledge.

The following slides in this section summarize inputs and assumptions used for each of the three analyses. Parameters that were specific to each analysis are listed in the relevant analysis section.

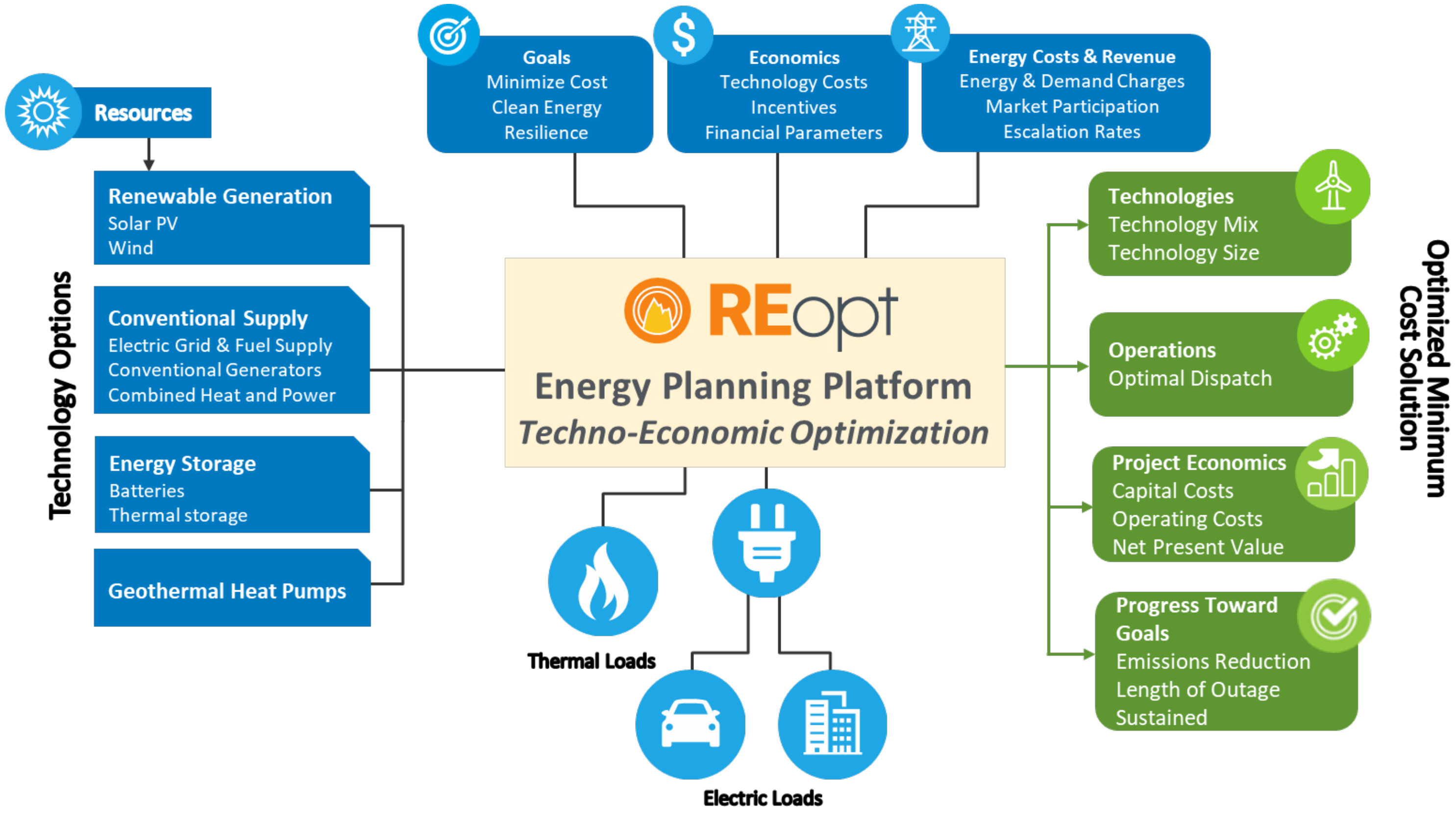

Figure 1. Diagram of REopt's inputs and outputs

Utility Rate Assumptions

Commercial Rate

Parameter	Value
Rate Schedule	Rate Schedule No. D3, General Service Rate, Full-Service Customers Date of Utility Tariff Data: April 2023
Energy Charge	$0.13983/kWh*
Demand Charge	None
Monthly Charge	$11.25/kWh Previously: Approximately $90 (approximation based on utility bill data from the recreation center)

*This rate includes the base rate of $0.12233/kWh listed in the DTE Electric rate book and the $0.0175/kWh Power Supply Cost Recovery rate listed on the April 2023 utility bill for the recreation center.

Residential Rate

Parameter	Value
Rate Schedule	DTE Rate Schedule No. D1, Full-Service Customer Effective Date Range: 11/25/2022 – 12/14/2023
Energy Charge	$0.15229/kWh for first 17 kWh per day $0.17171/kWh excess per day** Adder: $0.0175/kWh Power Supply Cost Recovery rate
Demand Charge	None

**The residential rate was used in Analysis #1 to model an averaged electric load provided by DTE. For simplicity of the model and given the approximations inherent in an averaged electric load, the second daily tier was not considered in the analysis. The 12.8% increase in energy costs in the second tier was deemed inconsequential given that the average total electricity use per day for each residential scenario in Analysis #1 was:

Scenario 1A: 15.6 kWh
Scenario 1B: 15.6 kWh
Scenario 3A: 23.1 kWh
Scenario 3B: 23.1 kWh

Financial Assumptions

Economic Inputs	Assumptions
Analysis period	25 years
Ownership model	Typical residential and commercial buildings: Direct ownership Earnest T. Ford Recreation Center: Third-party financing Parker Village microgrid: Direct ownership
Discount rate (owner and developer)	5.64% (Annual Technology Baseline, NREL 2022)
Electricity cost escalation rate	1.9%/year (A value selected between the predicted commercial and residential nominal electricity price increases as shown in Annual Energy Outlook 2023 – Energy Prices by Sector and Source, U.S. EIA 2023a.)
Tax rates	Typical residential and commercial buildings: 26% Earnest T. Ford Recreation Center: 0% Parker Village microgrid: 26% Developer: 26% (implemented for the recreation center due to third-party financing)

Solar Photovoltaics (PV) Modeling Assumptions

Solar PV Inputs	Assumptions
System type	Fixed tilt (residential or commercial)
Solar resource profile	Typical Meteorological Year (TMY) weather file from National Solar Radiation Database (NSRDB)
Azimuth	180° (south-facing)
System losses	14%
O&M costs	$17/kW/year (Annual Technology Baseline, NREL 2021)
Incentives	30% Investment Tax Credit (ITC) MACRS: 20% bonus fraction*, 5 years, 50% ITC reduction Note: MACRS was not applied to the residential scenarios in Analysis #1.
PV power density	Flat roof top or ground mount: 0.003 acres/kW Residential angled roof: 0.01 kW/sq. ft. (REopt User Manual v9, page 31)

*A 20% bonus fraction was modeled because the estimated construction year was 2026 (Internal Revenue Service (IRS) 2023).

The following parameters are specified in the sections for Analysis 1, 2, and 3:

1. Area available for PV
2. PV tilt
3. PV capital costs

An approximate solar PV power density (acres/kW) for fixed tilt PV was predicted using the method below. Note, this analysis assumes a solar PV array with panels that are 1m wide and 1.63m tall:

1. From NOAA's Solar Calculator (NOAA, n.d.), the sun elevation at 10 a.m. on December 21, 2023, was determined to be 15.64 degrees. This value was then rounded to 15 degrees and, using trigonometry, the interrow spacing to prevent self-shading between the panels was predicted to be 3.877 meters.
2. Using NREL's Detailed PV Model in the System Advisor Model, the power density of a PV system with interrow spacing of 3.872 m was to identified to be approximately 0.003 acres/kW.

Battery Storage Modeling Assumptions

Battery Inputs	Assumptions
System type	Lithium-ion battery
Rectifier & inverter efficiencies	96% (Patsios et al. 2016)
Internal Efficiency Fraction	97.5% (Patsios et al. 2016)
Minimum state of charge	20% (Patsios et al. 2016) Note: The minimum state of charge was increased to varying percentages above 20% for resilience scenarios in order to improve the battery's ability to withstand the target outage duration.
Capital costs	$388/kWh + $775/kW (Wood Mackenzie Power & Renewables and the Energy Storage Association 2021)
Replacement costs (year 10)	$220/kWh + $440/kW (Wood Mackenzie Power & Renewables and the Energy Storage Association 2021)
Incentives	ITC: 30% MACRS: 20% bonus fraction*, 7 years, 50% ITC reduction MACRS was not applied to the residential scenarios in Analysis #1 because MACRS is only applicable for businesses.
Minimum Size	For the resilience scenarios, the minimum power rating (kW) was set to 1.2 times the maximum critical load** in kW
Can the grid charge the battery?	Yes

*The MACRS bonus fraction was set to 20% because the construction of the project was estimated to be in 2026 (IRS 2023).

**The critical load is the electric load that must be met during a grid outage. For this analysis, the critical load was estimated as a percentage of the existing load.

Microgrid Cost Assumptions

The construction of a microgrid will require additional components and infrastructure such as distribution lines, a microgrid controller, and/or switchgears. Designing a microgrid was beyond the scope of this prefeasibility analysis, but the costs were estimated based on research by Giraldez et al. 2018.

The estimated increase in lifecycle capital costs for a microgrid in the resilience scenarios was $238,265 times the maximum critical load (MW).

Resilience Benefits

In the resilience modelling in this analysis, an economic value of lost load (VoLL) during an outage was not considered. A VoLL would aim to quantify the benefits provided during a grid outage, such as refrigeration for food that would otherwise spoil. In this analysis without a VoLL, the Net Present Values of resilience scenarios only reflect costs for purchasing and maintaining the equipment and the costs offset from purchasing electricity from the grid. Future analysis could aim to quantify the economic benefits of resilience to quantitatively justify the expense of creating a resilience center.

However, there may be resilience benefits that are difficult to include in a cost-benefit analysis, such as the value of providing an air-conditioned space for community members during a grid outage. These services may need to be considered qualitatively in decisions related to the investments into a microgrid for resilience.

Backup Generator Modeling Assumptions

Generator Inputs	Assumptions
System type	Diesel
Installed cost	$650/kW (U.S. Army Corps of Engineers 2021; Generac n.d.)
Fuel cost	$3.61/gallon (U.S. EIA 2023b)
Fuel availability	Recreation center: 250 gallons (estimated availability) Parker Village Microgrid: refer to scenario descriptions
Fixed O&M	$20/kW (Generac n.d.)
Variable O&M	$0/kWh (Lazard 2017). (Note: 2020 version doesn't include diesel analysis). "For an output of 250–1,000 kW, the Key Assumptions table lists a variable O&M of $0.01/kWh. The emergency generator modeled in the REopt web tool is expected to have limited use, therefore the default for these costs is set to $0/kWh." (Anderson et al. n.d.)
Minimum turndown	0%
Minimum size for resilience	1.2 x maximum critical load (kW)

Analysis #1: Typical Residential and Commercial Buildings

Definitions

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kW	Unit for kilowatts
Lifecycle Capital Cost	The total capital cost for a project, considering both initial purchases and replacements all in present value
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Definitions: Results Terminology

Term	Definition
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PV Exported Energy	The energy, in units of kWh, that is exported from the system to the grid. The outflow credit is based on this exported energy.
PV Curtailed Energy	Curtailed electricity refers to the electricity that the PV panels generate above what is required to meet the site’s demand and/or charge the battery. Often it is most economical to build PV systems that curtail electricity. The curtailed energy in kWh is listed in this row.
Net Present Value (NPV) ($)	The Net Present Value computed as the Lifecycle Cost (LCC) of the business-as-usual case subtracted by the LCC of the evaluated case
Lifecycle Capital Cost ($)	“Net capital costs for all technologies, in present value, including replacement costs and incentives.” (REopt.jl Documentation website)
Year 1 Utility Costs ($)	The cost of electricity (including the demand and energy cost) from the utility during year one
Year 1 Utility Savings ($)	Compared with the business-as-usual case, the savings in electricity costs when the evaluated scenario is implemented
% of the year that a **4-hr* outage would be survived** *Various outage durations were evaluated in addition to 4-hour outages	These values are generated by post-processing the REopt results using REopt’s outage simulator. The outage simulator uses the results from the REopt run (battery charge levels, generator fuel availability, PV output, critical load profile, etc.) to predict how many hours the energy system can meet the critical load for all hours of the year.
Predicted PV Land area	The total predicted area of the solar PV system in acres

Background

Typical residential and commercial buildings were modeled for two purposes:

1. To provide an estimate for the community for the cost-effective solar PV sizes and the cost of resilience for a typical residential building and commercial building.
2. To provide data for the power flow modelling conducted for Task #2 in the Grid Analysis technical assistance work area (as seen on Slide 6).

DTE Electric provided the average hourly, year-long load profiles for a residential building and commercial building in Highland Park. These load profiles were used to model a "typical" building.

In addition, as part of the Home Energy Improvements technical assistance work area (as seen on Slide 6), an electric load profile was estimated for a residential building with building upgrades and electrification. Electrification refers to converting equipment, such as space heating equipment, from fossil fuel-based systems to electrically powered systems. The residential building with "upgraded electrification" was also modeled.

Analysis #1: Key Inputs

In addition to the inputs defined on the REopt Inputs and Assumptions section, the following inputs were used in the analysis for the typical residential and commercial homes:

	Residential	Commercial
Cost of PV per kW	$2,525/kW (NREL 2023 Annual Technology Baseline estimate for 2026 for residential PV)	$1,673/kW (NREL 2023 Annual Technology Baseline estimate for 2026 for commercial PV)
Roof Area	776 sq. ft. (estimate)	33,000 sq. ft. (estimate)
Incentives for solar PV and batteries	30% ITC	30% ITC PV MACRS: 5 years, 20% bonus fraction, 50% ITC reduction Battery MACRS: 7 years, 20% bonus fraction, 50% ITC reduction
Energy Charge	DTE Rate Schedule No. D1, Full-Service Customers	Rate Schedule No. D3, General Service Rate, Full-Service Customers
Net Metering – Rider 18	$0.0835/kWh (first 17 kWh per day) $0.10292 excess (This was not included in the model due to the small size of the solar PV systems. Refer to the results tables to see the average daily exported energy.)	$0.07913/kWh
Critical load during an outage	Predicted using ResStock data	25% of normal load
PV tilt	15 degrees	25 degrees
Maximum PV size (Based on Rider 18 PV power output restrictions)	N/A, the total power output from the PV did not exceed the building load in all scenarios	60.25 kW
Microgrid upgrade costs	$238,265 times the maximum critical load in MW (Giraldez et al. 2018). Note: There may be additional costs for site-specific distribution and microgrid infrastructure	

Analysis #1: Electrification Scenarios

Figures 2 and 3 below show the baseline and upgraded electrification load profiles for the residential building. The upgraded electrification affects the load profile differently throughout the year. In the winter, the load profile increases due to the electrification of the space heating equipment. In the summer, the loads decrease, likely due to improvements in the building's construction and equipment efficiency.

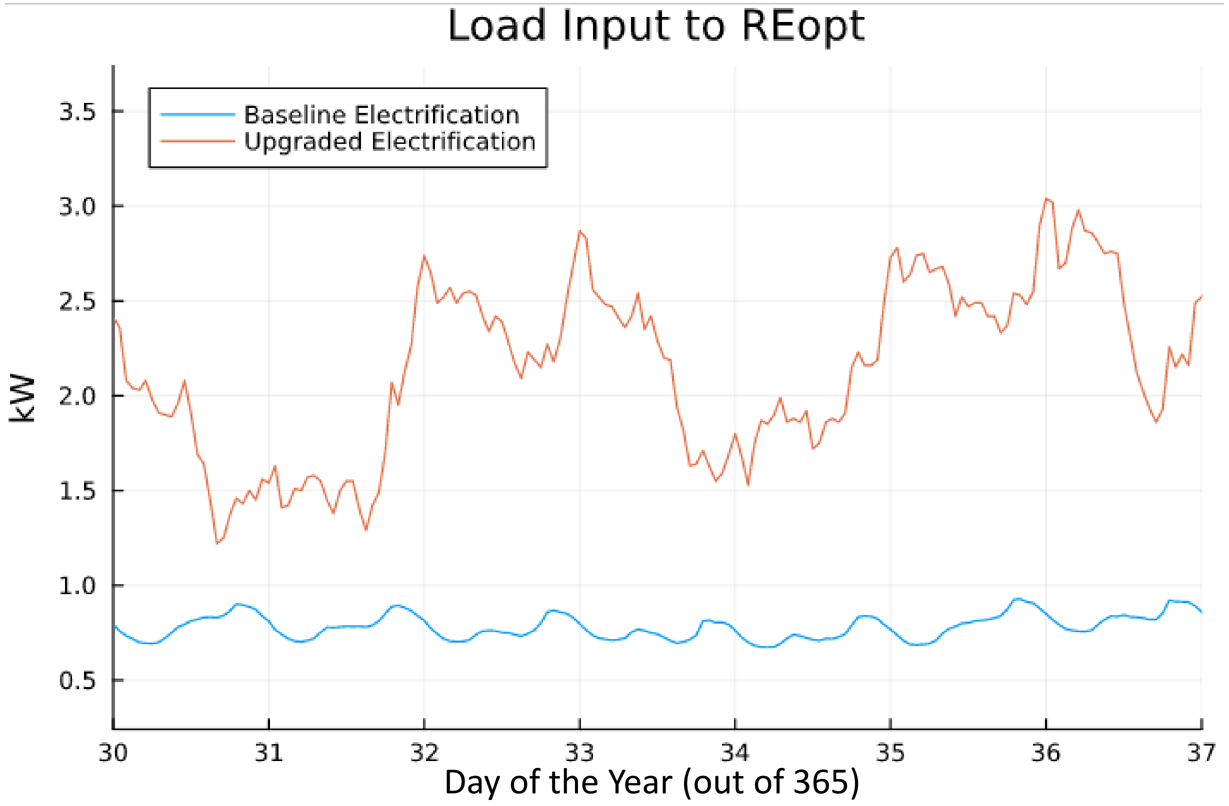


Figure 2. Winter Load, shown for 1 week

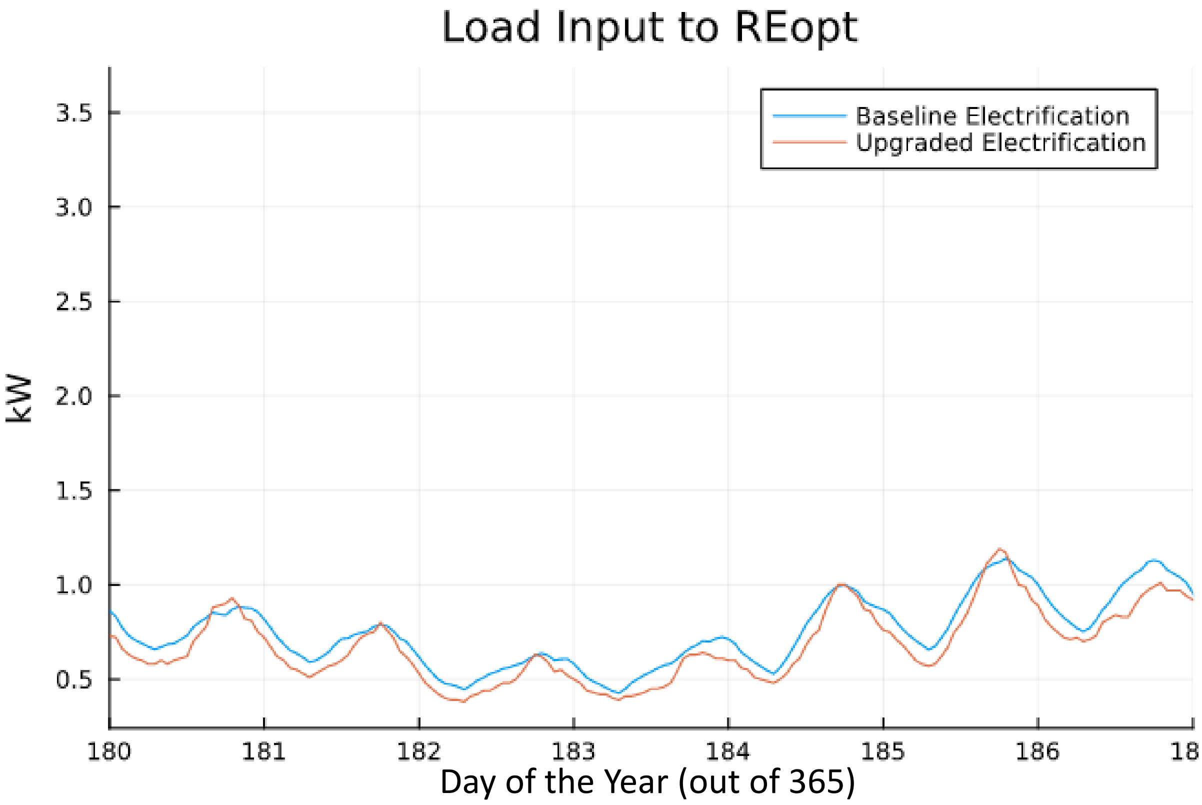


Figure 3. Summer Load, shown for 1 week

Analysis #1: Critical Load Prediction for the Residential Building

Based on discussions with the community stakeholders, the critical load for a typical residential building would include the following equipment:

- Air conditioning (for a quarter of a 2,200-square-foot home)
- Space heating (for a quarter of a 2,200-square-foot home; only considered in the scenario with upgraded electrification because the existing heating technologies are assumed to be fuel-based)
- Freezer
- Refrigerator
- Additional electronics (lights, wifi, portable electrics, etc.) estimated as a 400-W constant load

Data from ResStock was used to estimate the load profiles of air conditioning, space heating, and operating the freezer and refrigerator. The air conditioning and space heating loads are shown in more detail in Figure 5 on the next slide.

Figure 4 to the right compares ResStock's normal load for a home and the estimated critical load which was used as the critical load in this analysis. Note that the normal load predicted using ResStock is larger than the average load provided by DTE.

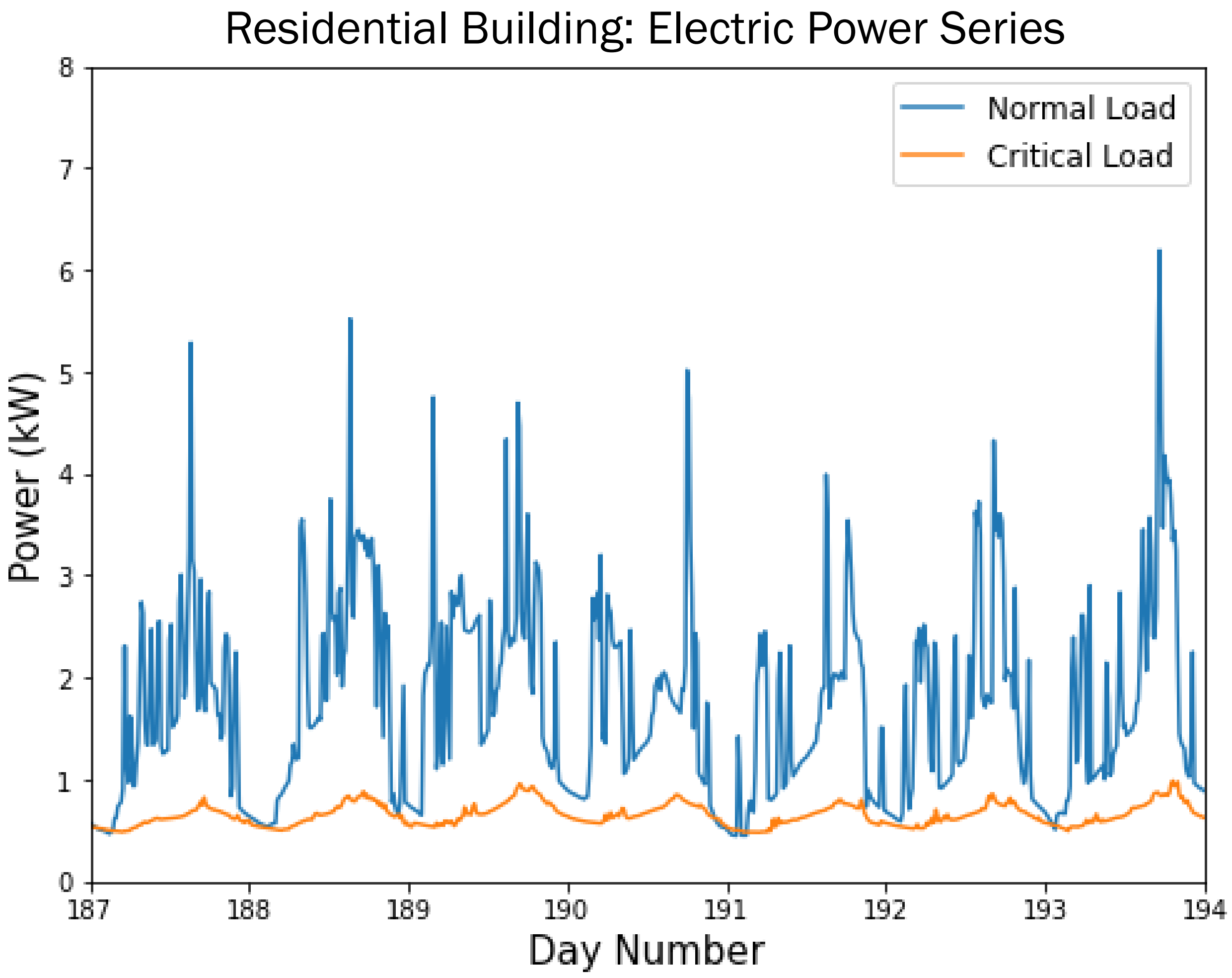


Figure 4. Predicted critical load for a typical residential home

Analysis #1: Critical Load Prediction for the Residential Building

For reference, the electric load data from ResStock used to predict the heating and cooling loads is shown in more detail in Figure 5. This data shows increased heating loads during the colder months and increased cooling loads during the summer months. For critical loads, these heating and cooling loads were scaled to represent a quarter of a 2,200-square-foot home.

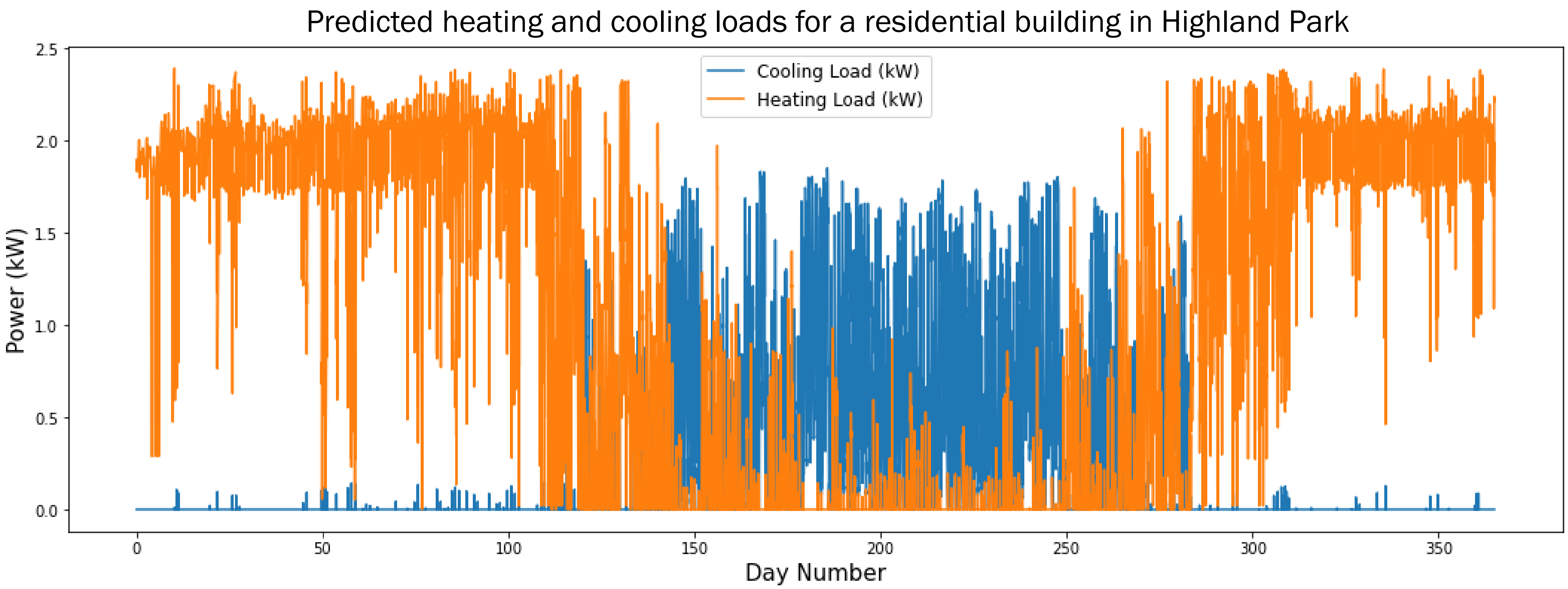


Figure 5. Predicted electric heating and cooling loads

Analysis #1: Outage Modeling

The resilience scenarios targeted maintaining the critical load for 24 hours.

In REopt, resilience was modeled as a two-step process:

1. A single outage was included in the optimization model on October 27 and the battery minimum state of charge was increased above 20% to increase resilience readiness. During this outage, all of the critical load was required to be met.
2. Additional resilience modeling was conducted using REopt’s outage simulator. The outage simulator uses the results from the REopt run (battery charge levels, generator fuel availability, PV output, critical load profile, etc.) to predict how many hours the energy system can meet the critical load for all hours of the year. Four-, 12-, and 24-hour outages were modeled in the outage simulator. During these outages, all of the critical load was required to be met.

Analysis #1: Results for the Residential Building, Baseline Electrification

The baseline electrification scenario evaluated the electric load provided by DTE for a residential building.

The results for the typical residential building with the baseline electrification are shown to the right.

Due to the small load profile of the average residential building, the suggested solar PV size is small. Achieving the resilience goals leads to a negative NPV, which means the system will not save the owner money over the lifespan of the technology.

	1A	1B
Description	**Cost Optimal PV + Battery - updated**	**24-hour Resilience - updated**
Solar PV (kW)	1.12	2.52
Battery	0 kW/0 kWh	1.4 kW/14.2 kWh
Carbon Free Electricity %	24.19%	52.38%
NPV ($)	410	-4,285
Predicted PV area	112 sq ft	252 sq ft
PV exported energy (kWh)	106	150
PV curtailed energy (kWh)	0	0
Year 1 PV energy produced (includes curtailed energy) (kWh)	1,445	3,247
Year 1 total building energy use (kWh)	5,680	5,680
Lifecycle Capital Cost ($)	2,030	9,639
Year 1 utility costs ($)	749	484
Year 1 utility savings ($)	215	480
% of year that a **4-hr outage would be survived**	N/A*	100.00%
% of year that a **12-hr outage would be survived**	N/A	100.00%
% of year that a **24-hr outage would be survived**	N/A	97.00%
Average daily exported power (kWh); for days when power was exported	0.639	1.824
Maximum daily PV energy exported (kWh)	2.404	4.853

*The predicted outage survivability is not applicable for non-resilience scenarios because microgrid upgrade costs were not considered in non-resilience scenarios.

Analysis #1: Results for the Residential Building, Upgraded Electrification

The results for the residential building with upgraded electrification are shown to the right.

The Net Present Value is negative for the resilience scenario. Note that the solar PV and battery systems are sized larger for the upgraded electrification resilience scenario compared to the baseline electrification resilience scenario due to the fact that the critical load profile is larger in the winter.

	Scenario 3A	Scenario 3B
Description	**Cost Optimal PV + Battery - updated**	**24-Hour Resilience - updated**
Solar PV (kW)	1.15	4.62
Battery	0 kW/0 kWh	1.7 kW/27.7 kWh
Carbon Free Electricity %	16.74%	64.67%
NPV ($)	409	-8,596
Predicted PV area	115 sq ft	462 sq ft
PV exported energy (kWh)	119	1,145
PV curtailed energy (kWh)	0	0
Year 1 PV energy produced (includes curtailed energy) (kWh)	1,482	5,944
Year 1 total building energy use (kWh)	8,419	8,419
Lifecycle Capital Cost ($)	2,083	17,471
Year 1 utility costs ($)	1,210	700
Year 1 utility savings ($)	219	729
% of year that a **4-hr outage would be survived**	N/A	100.00%
% of year that a **12-hr outage would be survived**	N/A	100.00%
% of year that a **24-hr outage would be survived**	N/A	97.00%
Average daily exported power (kWh); for days when power was exported	0.756	5.932
Maximum daily PV energy export (kWh)	3.103	18.824

Analysis #1: Results for the Commercial Building

The results for the typical commercial building are shown to the right.

The Net Present Value is positive for both the Cost Optimal PV + Battery scenario and the 24-Hour Resilience scenario. Note: The resilience scenario for the commercial building only considers 25% of the normal load to be critical.

	2A	2B
Description	**Cost Optimal PV + Battery**	**24-Hour Resilience**
Solar PV (kW)	60.25	60.25
Battery	0 kW/0 kWh	5.4 kW/44.9 kWh
Carbon Free Electricity %	94.96%	94.02%
NPV ($)	31,584	16,700
Predicted PV area	0.1808 acres	0.1808 acres
PV exported energy (kWh)	41,624	36,380
PV curtailed energy (kWh)	0	233
Year 1 PV energy produced (includes curtailment) (kWh)	80,113	80,113
Year 1 total building energy use (kWh)	80,234	80,234
Lifecycle Capital Cost ($)	52,617	70,347
Year 1 utility costs ($)	7,388	6,736
Year 1 utility savings ($)	4,833	5,485
% of year that a **4-hr outage would be survived**	N/A	100.00%
% of year that a **12-hr outage would be survived**	N/A	100.00%
% of year that a **24-hr outage would be survived**	N/A	96.00%
Average daily PV export (kWh), only considering days with PV export	124.3	116.2
Maximum daily PV export (kWh)	277.9	261.8

Analysis #1: Results

Analysis was conducted for the typical residential building with the baseline electrification to explore the economics of constructing a larger PV system.

Results, shown in the table to the right, demonstrate that increasing the solar PV size yields a lower NPV.

	1	2	3
Description	**Optimal Size**	**PV = 1.5 kW**	**PV = 2 kW**
Solar PV (kW)	1.12	1.5	2
Battery	0 kW/0 kWh	0 kW/0 kWh	0 kW/0 kWh
Carbon Free Electricity %	24.19%	32.33%	43.10%
NPV ($)	410	346	142
Predicted PV area	112 sq ft	150.0 sq ft	200.0 sq ft
PV exported energy (kWh)	106	337	758
PV curtailed energy (kWh)	0	0	0
Year 1 PV energy produced (includes curtailed energy) (kWh)	1,445	1,931	2,574
Year 1 total building energy use (kWh)	5,680	5,680	5,680
Lifecycle Capital Cost ($)	2,030	2,713	3,617
Year 1 utility costs ($)	749	710	677
Year 1 utility savings ($)	215	255	287
Average daily exported power (kWh); for days when power was exported	0.639	1.286	2.615
Maximum daily PV exported (kWh)	2.404	4.565	7.499

Data Provided for Power Flow Analysis

PV and battery sizing and dispatch data was provided to the power flow team for power flow analysis as part of Task 2 in the Grid Analysis portion of this project (as seen on Slide 6). Data from an earlier REopt analysis was provided to the power flow team prior to several updates to the REopt modeling assumptions presented here. The list below summarizes the differences, but as seen in the table below, the technology sizing did not differ significantly.

Different assumptions:

1. For the residential analysis and the commercial analysis, the grid was not allowed to charge the battery.
2. For the commercial analysis, a 60% MACRS bonus fraction for PV and battery was used.
3. For the commercial analysis, the typical commercial building used a different cost breakdown for the D3 General service than indicated in the "REopt inputs and assumptions" section. This rate was based on a utility bill from earlier in the year for the recreation center and did not include several small components of the electricity tariff.
4. The commercial PV sizes were limited to 61 kW instead of 60.25 kW.

The results shown in the table below demonstrate that these assumptions had a minor impact on the results provided for the power flow analysis compared with the corrected results.

	Optimization Goal	Electrification Scenario	Results for the Power Flow Analysis	Corrected Results shown in previous slides
Residential Scenario 1.A	Cost Optimal PV + Battery	Baseline	PV: 0.90 kW Battery: 0	PV: 1.12 kW Battery: 0
Residential Scenario 1.B	24-Hour Resilience	Baseline	PV: 2.05 kW Battery: 1.2 kW/13.8 kWh	PV: 2.52 kW Battery: 1.4 kW/14.2 kWh
Commercial Scenario 2.A	Cost Optimal PV + Battery	Baseline	PV: 61 kW Battery: 0	PV: 60.25 kW Battery: 0
Commercial Scenario 2.B	24-Hour Resilience	Baseline	PV: 61 kW Battery: 4.7 kW/38.2 kWh	PV: 60.25 kW Battery: 5.4 kW/44.9 kWh
Residential Scenario 3.A	Cost Optimal PV + Battery	Upgraded	PV: 0.92 kW Battery: 0	PV: 1.15 kW Battery: 0
Residential Scenario 3.B	24-Hour Resilience	Upgraded	PV: 3.96 kW Battery: 1.3 kW/30.3 kWh	PV: 4.62 kW Battery: 1.7 kW/27.7 kWh

Key Takeaways From Analysis #1

The analysis of typical residential and commercial buildings identified several key takeaways:

1. The analysis identified cost-effective sizing of solar PV for typical residential and commercial buildings in Highland Park. The full cost of this scenario was $1,652 for residential and $52,617 for commercial. Solar PV was cost-effective for both building types.
2. Batteries appear to be able to accomplish the 24-hour resilience target for residential and commercial buildings when paired with solar PV. The full cost of this scenario was $8,656 for residential and $70,347 for commercial.
3. When considering an upgraded electrification scenario for the residential building, full costs for a PV and battery system increases to $15,722 for the resilience scenario.
4. Batteries were not cost-effective in non-resilience scenarios.

Analysis #2: Earnest T. Ford Recreation Center

Definitions

Term	Definition
ComStock™	A NREL tool for generating predicted electric load profile data for commercial buildings
Cost-effective	Refers to a system that saves money over the lifespan of the system
Critical Load	The critical load is the electric load that must be met during a grid outage
Investment Tax Credit (ITC)	Tax credits provided for solar PV and battery projects. Currently, the base ITC for solar and battery projects is 30% with the potential for increased ITC percentages based on project location. Tax-exempt entities, such as government entities, can receive the ITC as a cash payment through the direct pay option.
kW	Unit for kilowatts
Lifecycle Capital Cost	The total capital cost for a project, considering both initial purchases and replacements all in present value
MACRS	Modified Accelerated Cost Recovery System; Under MACRS, the capitalized cost of PV and batteries is recovered over a specified life (e.g., 5 years for PV systems) by annual deductions for depreciation. MACRS Bonus Depreciation is another name for an additional first year depreciation deduction (60% in 2024) provided by section 168(k).
Net Present Value (NPV)	The value a system provides over the course of its lifetime compared with a business-as-usual case where no technology is implemented. A positive NPV means the system saves money.
Off-grid	Not connected to the power grid and operating independently from the power grid
Outflow Credit	Credit that can be earned when exporting power back onto the grid to offset a customer's utility bills
Solar PV nameplate capacity	The installed capacity of a PV system. Note, solar PV is also referred to as just PV.
Resilience	The ability for a building or microgrid to withstand a power grid outage by generating and distributing its own power
ResStock™	An NREL tool for generating predicted electric load profile data for residential buildings
Solar PV (PV)	Solar photovoltaics (photovoltaics); panels that generate electricity when exposed to sunlight
Techno-economic	Referring to analysis that considers both the technical aspects of a system and the predicted economic performance of the project
Typical Meteorological Year (TMY) solar radiation data	TMY solar radiation data is based on multiple years of historical radiation data rather than just a single year. Used in modeling power output from solar panels, TMY data can help to avoid overestimating or understanding power output due to variations in year-to-year solar radiation.

Definitions: Results Terminology

Term	Definition
PV	The DC nameplate capacity (in kW) of the PV system recommended by REopt
Battery	The kW and kWh rating of the Lithium-Ion battery system
Carbon Free Electricity (CFE) %	The predicted percent of the electricity demand that is met by electricity derived from the PV panels on site
PV Exported Energy	The energy, in units of kWh, that is exported from the system to the grid. The outflow credit is based on this exported energy
PV Curtailed Energy	Curtailed electricity refers to the electricity that the PV panels generate above what is required to meet the site's demand and/or charge the battery. Often it is most economical to build PV systems that curtail electricity. The curtailed energy in kWh is listed in this row.
Net Present Value (NPV) ($)	The Net Present Value computed as the Lifecycle Cost (LCC) of the business-as-usual case subtracted by the LCC of the evaluated case
Lifecycle Capital Cost ($)	"Net capital costs for all technologies, in present value, including replacement costs and incentives." (REopt.jl Documentation website)
Year 1 Utility Costs ($)	The cost of electricity (including the demand and energy cost) from the utility during year one
Year 1 Utility Savings ($)	Compared with the business-as-usual case, the savings in electricity costs when the evaluated scenario is implemented
% of the year that a **4-hr* outage would be survived** *Various outage durations were evaluated in addition to 4- hour outages	These values are generated by post-processing the REopt results using REopt's outage simulator. The outage simulator uses the results from the REopt run (battery charge levels, generator fuel availability, PV output, critical load profile, etc.) to predict how many hours the energy system can meet the critical load for all hours of the year.
Predicted PV Land area	The total predicted area of the solar PV system in acres

Analysis #2: Background

The City of Highland Park aims to create a resilience hub at the Earnest T. Ford Recreation Center, located at 10 Pitkin St. in Highland Park, to provide services to the community during grid outages.

This techno-economic analysis was conducted to evaluate the cost-effectiveness of achieving the resilience targets using solar PV, batteries, and/or diesel generators. The cost-effectiveness of a solar PV-only installation without resilience considerations was evaluated as well.

Analysis #2: Earnest T. Ford Recreation Center

Based on discussions with the Highland Park Communities LEAP Coalition members, five areas were identified as possible locations for solar PV installations. These areas are shown in Figure 6, and the estimated area available for PV is shown in the table below.

PV Space	Estimated Area Available for PV
Roof 1	0.18 acres
Roof 2	0.11 acres
Land Area 1	0.64 acres
Land Area 2	0.18 acres
Land Area 3	0.91 acres
Total	2.02 acres

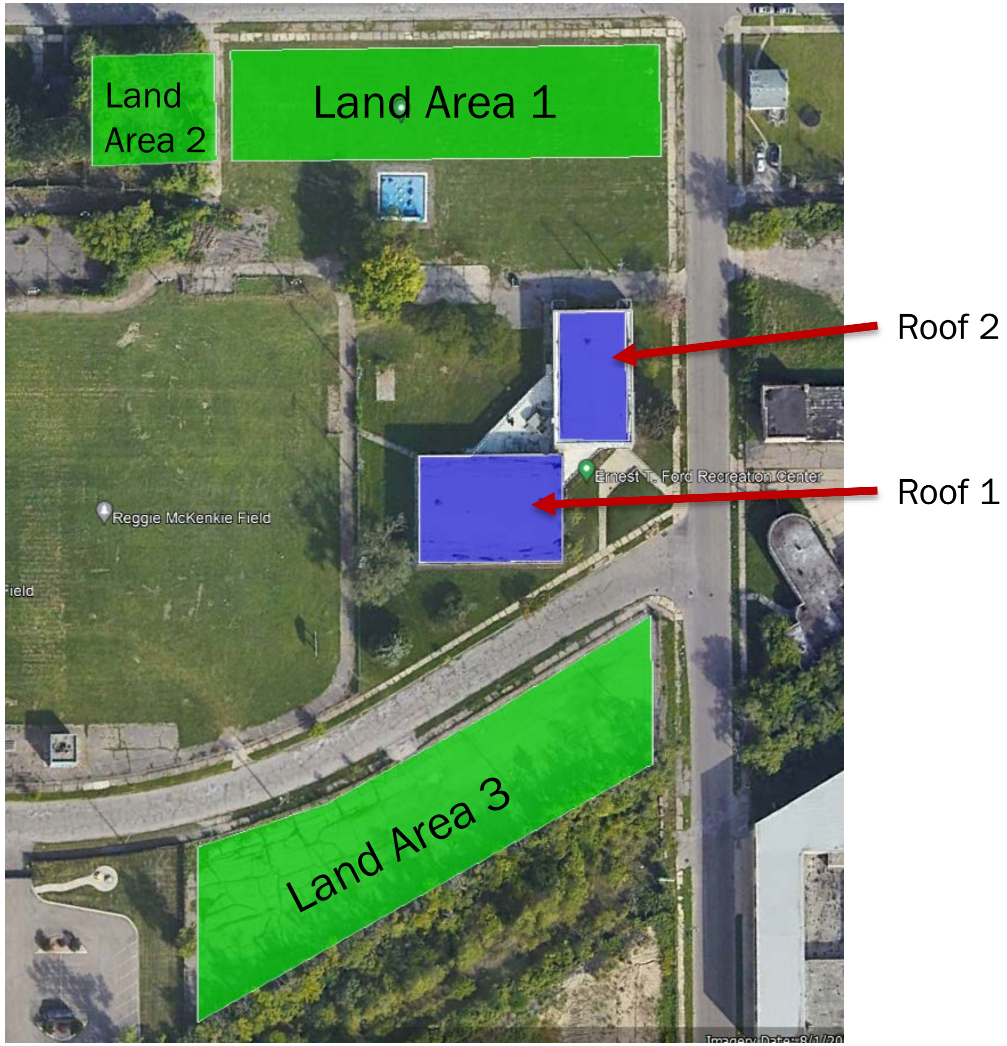


Figure 6. Area available for solar PV near the recreation center

Utility Rate Assumptions

DTE Electric, the electric utility serving Highland Park, offers two programs for customers to receive outflow credits when exporting electricity to the grid:

1. Rider 18 provides an outflow credit for electricity exported to the grid from a renewable energy source. The installed system cannot be sized to provide above the building's annual electricity demand and cannot exceed 150 kW. For the D3 General Service, the outflow credit is $0.07913 per kWh. For the D.1/D1.6 Residential Service, the outflow credit is $0.08350 per kWh for the first 17 kWh per day, and $0.10292 per kWh for the remainder (DTE Electric 2018).

2. Through Rider 14, customers can receive an outflow credit at the wholesale electricity price for electricity exported to the grid using an electric generation system sized up to 100 kW. The system does not need to be renewable and the system size is not limited by the site's electricity usage (DTE Electric 2018).

Analysis #2: Key Inputs

In addition to the inputs defined on the REopt Inputs and Assumptions section, the following inputs were used in the analysis for the recreation center:

Parameter	Value
Net Metering	Rider 18 Rider 14
PV cost per kW	$1,716/kW Source: Based on PV cost data (Wood Mackenzie. 2022.)
PV area	0.003 acres/kW
PV tilt	23 degrees
Area available for PV	2.02 acres
Critical Load	Based on analysis shown in the following slides.
Utility Rate	Rate Schedule No. D3, General Service Rate, Full-Service Customers (sheet D-18.00 in DTE Rate Book)
Microgrid upgrade costs	$238,265 times the maximum critical load in MW (Giraldez et al. 2018). Note: There may be additional costs for site-specific distribution and microgrid infrastructure.
Generator fuel available	500 gallons

Analysis #2: Prediction and Modeling of the Outflow Credits

The Rider 14 outflow credit is based on the wholesale cost of electricity. Therefore, the outflow credit was predicted based on the hourly Annual Real-Time Locational Marginal Pricing (LMP) from 2022 at the Michigan Hub reported by the Midwest ISO (MISO n.d.). Note, the 2022 data was shifted to maintain day-of-year consistency with 2018 because the ComStock data is based on days from 2018.

With Rider 14, the predicted average outflow credit is $0.06585/kWh, but the value varies significantly as shown in Figure 7. With Rider 14, the solar PV size was limited to 100 kW based on the Rider 14 limit.

With Rider 18, the outflow credit for commercial buildings is $0.07913/kWh. With Rider 18, the size of the solar PV was limited to 75 kW to prevent total solar generation from exceeding the annual building energy use.

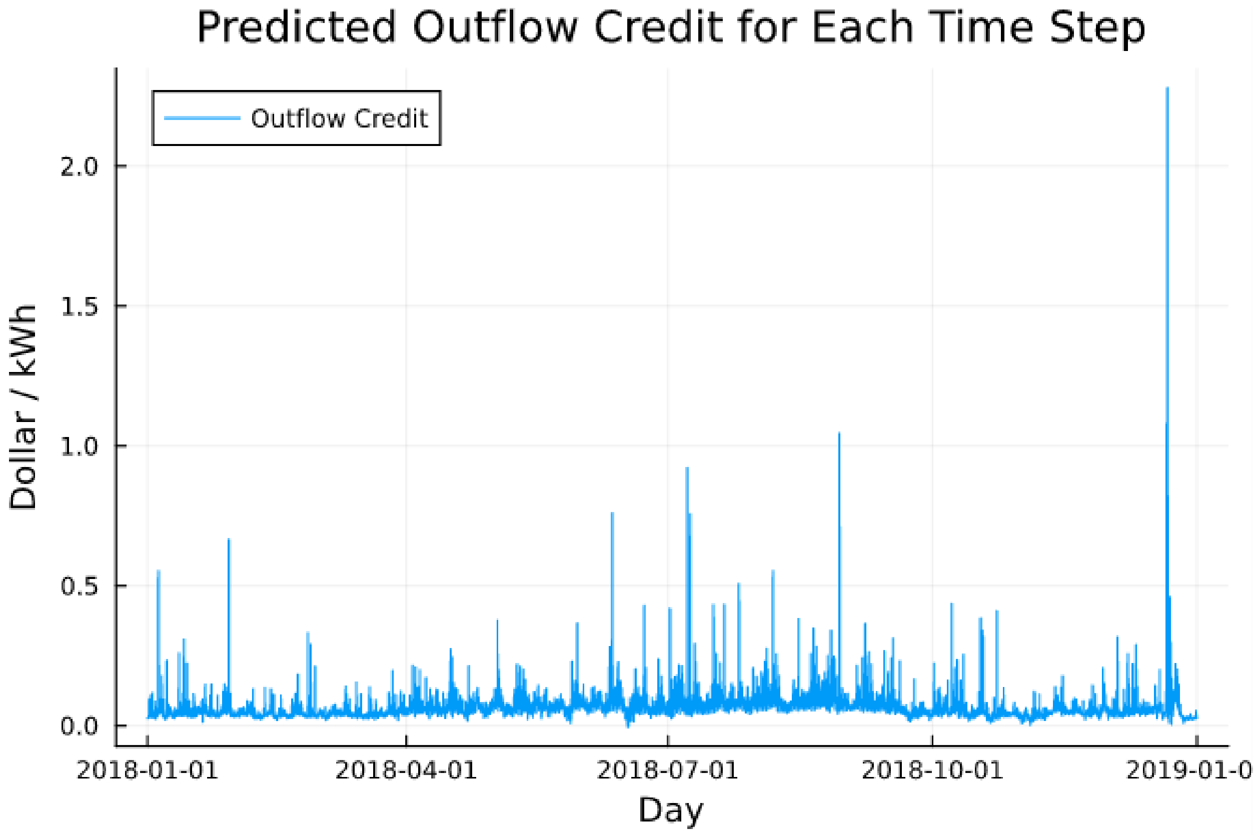


Figure 7. The predicted outflow credit through Rider 14

Analysis #2: Resilience Objectives

As communicated by the Highland Park Communities LEAP Coalition members, the recreation center includes pool tables, TV sets, exercise equipment, table games, and a basketball court. The center is available for activities such as basketball games, meetings, and parties.

During a power outage, the goals for the site include the following:

1. Serve as a large public cooling center by running AC units, or a warming center by running furnaces.
2. Provide refrigeration with two industrial kitchen refrigerators to prevent food-waste and/or preserve sensitive medicines.
3. Provide power for internet and device charging.
4. Offer the possibility of an overnight stay for residents without power at their residences.

The goal is to survive grid outages lasting 12-72 hours.

Analysis #2: Scenario Summary

The scenarios evaluated in Analysis #2 are summarized in the table below.

Each scenario was evaluated with Rider 14, Rider 18, and no outflow credits.

Scenario	Description
3.1	Cost optimal PV only
3.2	PV + Battery with 12-hour resilience
3.3	PV + Battery + Generator with 12-hour resilience
3.4	PV + Battery with 72-hour resilience
3.5	PV + Battery + Generator with 72-hour resilience

Analysis #2: Load Profile Generation

A year of the recreation center's monthly utility bills were used to predict the electric load profile of the building. To generate an electric load profile for the recreation center, a similar building was located in NREL's ComStock database and each month of the ComStock data was scaled to match the actual electric usage of the building. Figures 8 and 9 show the generated load profile for one week and one year, respectively.

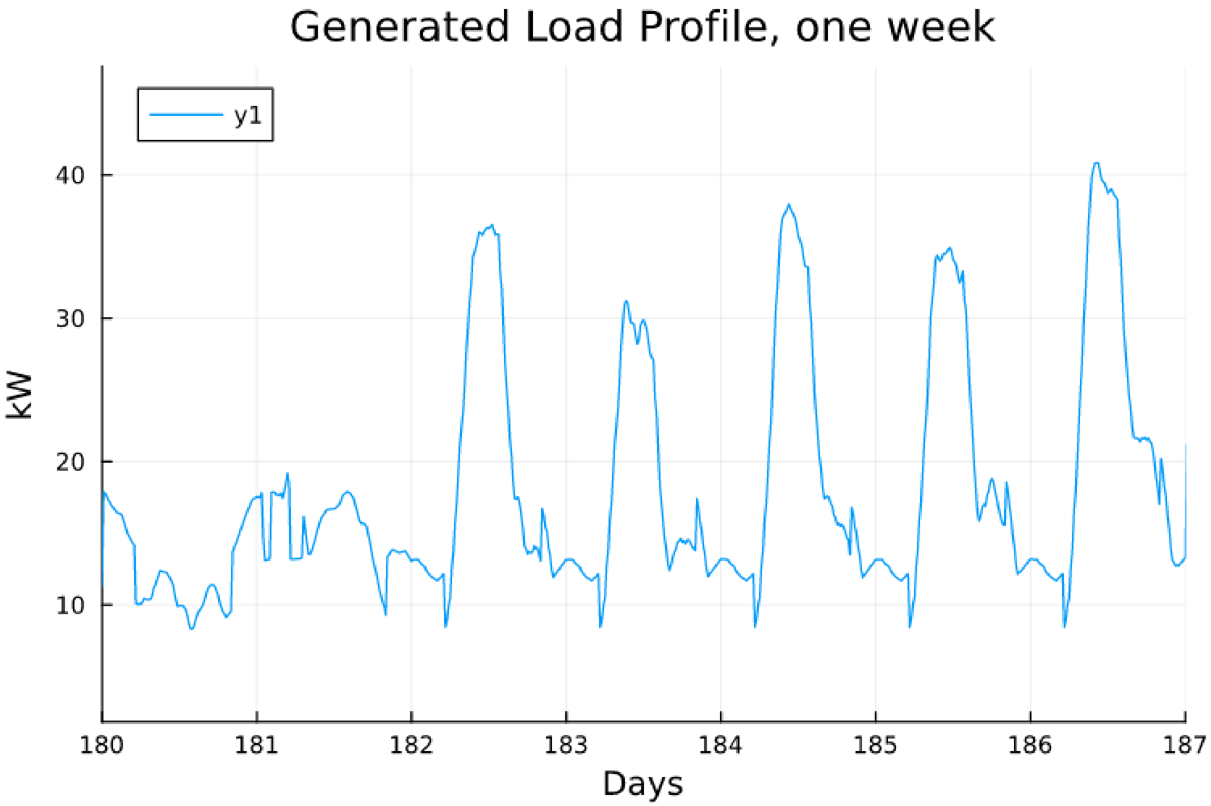


Figure 8. Predicted electric load profile for the recreation center, shown for one week

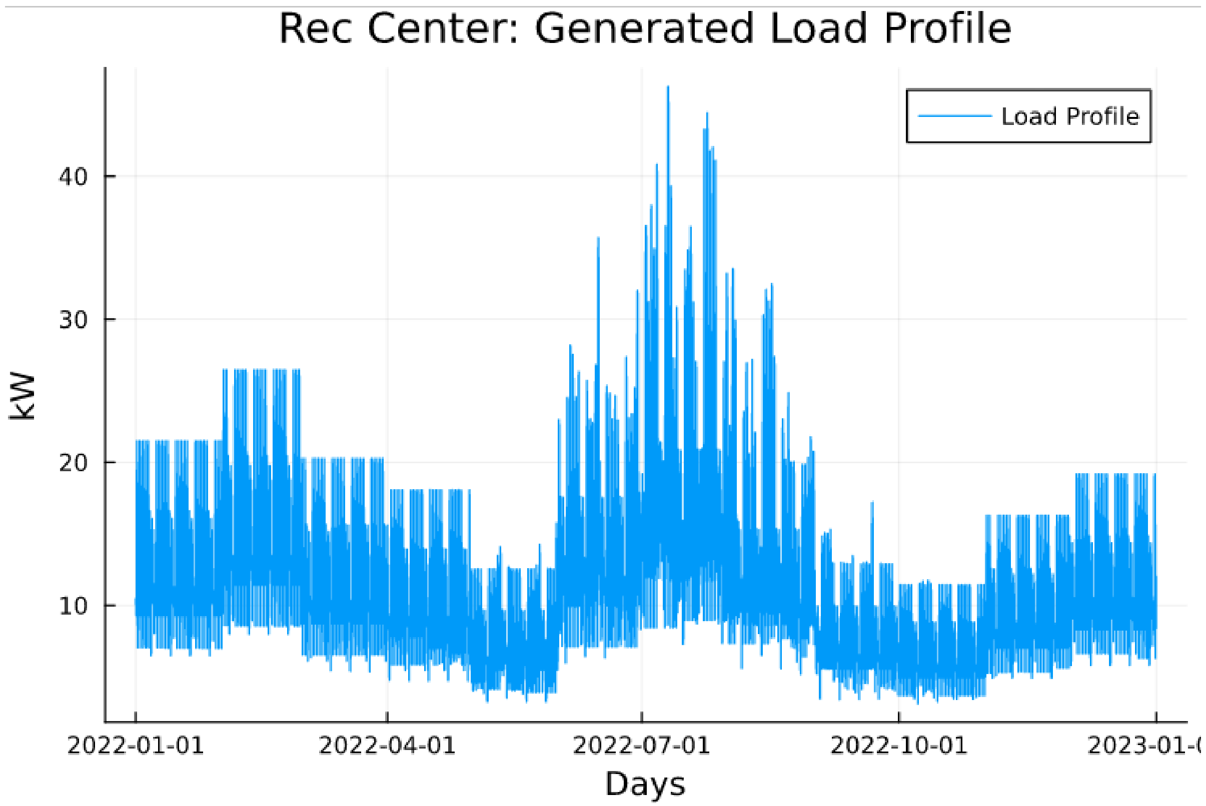


Figure 9. Predicted electric load profile, shown for the entire year

Analysis #2: Predicting Critical Loads for Resilience

The table below summarizes the additional three resilience services provided by the recreation center and the methods used to estimate the electric loads of those services. It was assumed that during a grid outage, the building would experience the historical building loads plus these three additional resilience services. Figure 10 shows the increase in load predicted when providing resilience services. Note that space and water heating were considered to be performed by gas.

Resilience Service	Estimation Method
Additional Cooling Demand	Thermal modelling of the building was outside the scope of this project, so the following method was used to predict the increase in power required for cooling. For an estimated 200 people, the cooling demand was increased by 100 W per person. Using a typical air conditioning Coefficient of Performance (COP), this cooling demand was translated to an increase in electricity demand during days 100 through 300 of the year. This results in an estimated constant of 6.897 kW of power for additional cooling during days 100 through 300.
Two Industrial Refrigerators	The load for two industrial refrigerators was based on a 15-minute refrigeration load profile from a modeled full-service restaurant in the ComStock database. The ComStock load profile for refrigeration was multiplied by 2.
Device Charging and Internet	Estimated as a flat load of 2 kW.

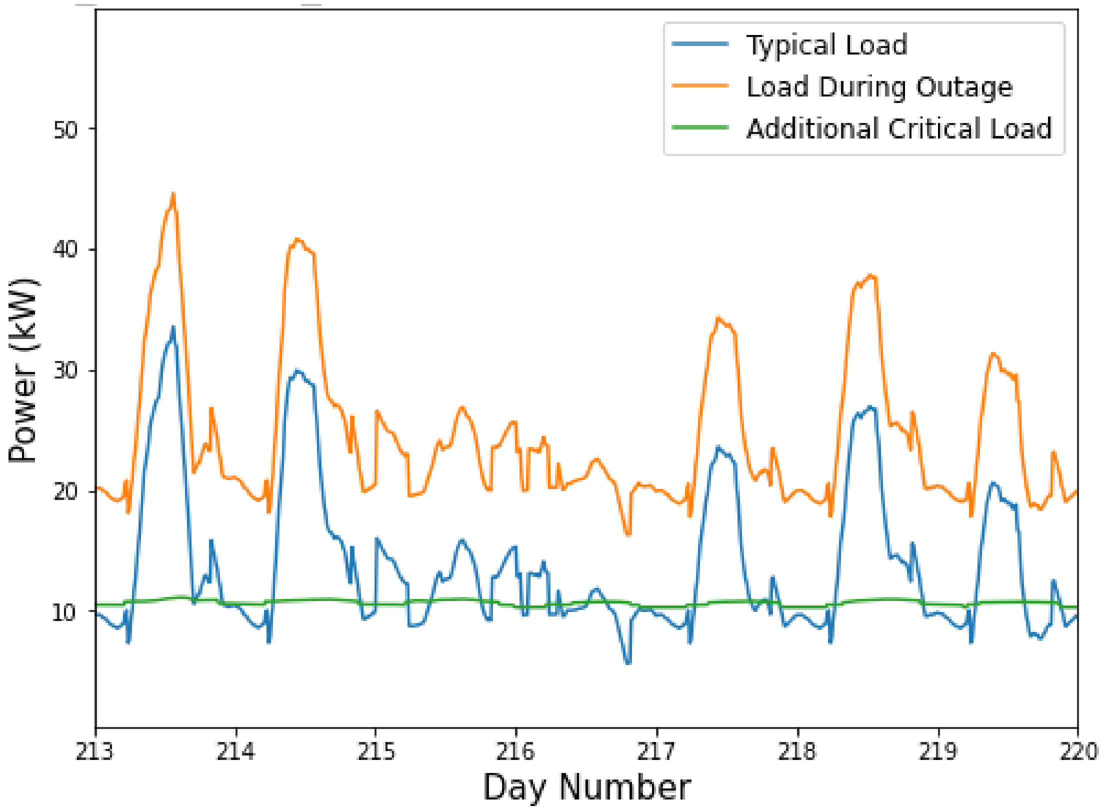


Figure 10. Normal load and critical load of the resilience center

Analysis #2: Results (With Rider 14 for Grid Exports)

All resilience scenarios lead to a negative NPV. The resilience scenarios with the least negative NPVs are the scenarios using a diesel generator.

When a generator is considered, the battery is not cost-optimal and the same system size is optimal for both the 12-hour and the 72-hour resilience scenarios.

When using only PV and battery for resilience, the maximum PV size is reached, which likely causes the battery to be larger to meet resilience targets.

	3.1.a	3.2.a	3.3.a	3.4.a	3.5.a
Description	**Cost optimal PV only**	**PV + Battery: 12-hour resilience**	**PV + Battery + Generator: 12-hour resilience**	**PV + Battery: 72-hour resilience**	**PV + Battery + Generator: 72-hour resilience**
Solar PV (kWdc)	100	100	100	100	100
Battery	0 kW / 0 kWh	68.7 kW / 264.8 kWh	0 kW / 0 kWh	68.7 kW / 1,110.5 kWh	0 kW / 0 kWh
Generator	0	0	69	0	69
NPV ($)	52,121	-93,563	-45,561	-415,002	-45,561
Lifecycle Capital Cost ($)	121,040	297,148	195,002	638,910	195,002
Year 1 utility costs ($)	9,122	5,546	9,114	3,140	9,114
Year 1 utility savings ($)	5,869	9,444	5,876	11,851	5,876
% of year that a **6-hr outage is survived**	7	100	100	100	100
% of year that a **12-hr outage is survived**	0	98	100	100	100
% of year that a **72-hr outage is survived**	0	13	100	96	100
Predicted PV Land area	0.3	0.3	0.3	0.3	0.3
Carbon Free Electricity %	125.89%	122.73%	125.89%	120.64%	125.89%

Note: Resilience scenarios include the estimated microgrid upgrade costs of $238.265/peak critical load (kW).

Analysis #2: Results (With Rider 18 for Grid Exports)

All resilience scenarios lead to a negative NPV. The resilience scenarios with the least negative NPVs are the scenarios using a diesel generator.

For all scenarios, the maximum PV size under the Rider 18 constraints, 75 kW, is reached.

When a generator is considered, the battery is not cost-optimal and the same system size is optimal for both the 12-hour and the 72-hour resilience scenarios.

	3.1.b	3.2.b	3.3.b	3.4.b	3.5.b
Description	**Cost optimal PV only**	**PV + Battery: 12-hour resilience**	**PV + Battery + Generator: 12-hour resilience**	**PV + Battery: 72-hour resilience**	**PV + Battery + Generator: 72-hour resilience**
Solar PV (kWdc)	75	75	75	75	75
Battery	0 kW / 0 kWh	68.7 kW / 264.8 kWh	0 kW / 0 kWh	68.7 kW / 1,462.7 kWh	0 kW / 0 kWh
Generator	0	0	69	0	69
NPV ($)	49,353	-107,419	-48,329	-581,151	-48,329
Lifecycle Capital Cost ($)	90,780	266,888	164,742	750,955	164,742
Year 1 utility costs ($)	9,119	5,884	9,112	4,036	9,112
Year 1 utility savings ($)	5,871	9,107	5,879	10,955	5,879
% of year that a **6-hr outage is survived**	N/A	100	100	100	100
% of year that a **12-hr outage is survived**	N/A	97	100	100	100
% of year that a **72-hr outage is survived**	N/A	5	100	97	100
Predicted PV Land area	0.225	0.225	0.225	0.225	0.225
Carbon Free Electricity %	94.41%	91.80%	94.41%	90.27%	94.41%

Note: Resilience scenarios include the estimated microgrid upgrade costs of $238.265/peak critical load (kW).

Analysis #2: Results (No Outflow Credits for Grid Exports)

Without any outflow credits, the net present value is reduced for each of the scenarios compared to scenarios utilizing Rider 14 and Rider 18. This difference is driven by the inability of the solar PV to export extra power to the grid and earn economic benefits from doing so.

The only exception is when the PV and battery are used to meet the 72-hour resilience target. With Rider 18, the PV size is limited to 75 kW. This causes scenario 3.4.b (which uses Rider 18) to have a larger battery and a more negative NPV compared to 3.4.c in the table to the right, which does not include outflow credits.

	3.1.c	3.2.c	3.3.c	3.4.c	3.5.c
Description	**Cost optimal PV only**	**PV + Battery: 12-hour resilience**	**PV + Battery + Generator: 12-hour resilience**	**PV + Battery: 72-hour resilience**	**PV + Battery + Generator: 72-hour resilience**
Solar PV (kWdc)	25.86	49.8	25.86	115.77	25.86
Battery	0 kW / 0 kWh	68.7 kW / 284.8 kWh	0 kW / 0 kWh	68.7 kW / 933.6 kWh	0 kW / 0 kWh
Generator	0	0	69	0	69
NPV ($)	22,722	-134,638	-74,958	-418,460	-74,958
Lifecycle Capital Cost ($)	31,306	244,444	105,269	586,499	105,269
Year 1 utility costs ($)	11,182	7,300	11,174	2,503	11,174
Year 1 utility savings ($)	3,809	7,691	3,817	12,488	3,817
% of year that a **6-hr outage is survived**	0	100	100	100	100
% of year that a **12-hr outage is survived**	0	97	100	100	100
% of year that a **72-hr outage is survived**	0	0	100	95	100
Predicted PV Land area	0.0776	0.1494	0.0776	0.3473	0.0776
Carbon Free Electricity %	27.23%	55.01%	27.23%	90.25%	27.23%

Note: Resilience scenarios include the estimated microgrid upgrade costs of $238.265/peak critical load (kW).

Analysis #2: Outflow Credits Discussion

Data shown in the table to the right suggest that investments in solar PV or a resilience hub would have the highest net present value under Rider 14. This suggests that Rider 14 would be the most cost-effective compared with Rider 18 and no outflow credits.

Summary table of NPVs ($) for each scenario and outflow credit type:

Outflow Credit Type	Cost optimal PV only	PV + Battery: 12-hour resilience	PV + Battery + Generator: 12-hour resilience	PV + Battery: 72-hour resilience	PV + Battery + Generator: 72-hour resilience
Rider 14	52,121	-93,563	-45,561	-415,002	-45,561
Rider 18	49,353	-107,419	-48,329	-581,151	-48,329
No outflow credits	22,722	-134,638	-74,958	-418,460	-74,958

Key Takeaways From Analysis #2

The analysis of the Earnest T. Ford Recreation Center identified several key takeaways:

1. The analysis identified that solar PV is cost-effective for the recreation center, but the economic benefits depended on the type of outflow credits utilized. The system sizing ranged from 26 to 100 kW of PV and the economic benefit ranged from $23K to $52K.
2. Solar PV and batteries could be implemented to accomplish the estimated resilience targets of 12 to 72 hours. The predicted full cost ranges from $586K to $750K, depending on the outflow credit type.
3. However, diesel generators paired with PV appear to be a more cost-effective solution. PV with generator scenarios had a predicted full cost ranging from $105K to $195K.

Analysis #3: Parker Village Microgrid

Definitions

Term	Definition
ComStock™	A NREL tool for generating predicted electric load profile data for commercial buildings
Cost-effective	Refers to a system that saves money over the lifespan of the system
Critical Load	The critical load is the electric load that must be met during a grid outage
Investment Tax Credit (ITC)	Tax credits provided for solar PV and battery projects. Currently, the base ITC for solar and battery projects is 30% with the potential for increased ITC percentages based on project location. Tax-exempt entities, such as government entities, can receive the ITC as a cash payment through the direct pay option.
kW	Unit for kilowatts
Lifecycle Capital Cost	The total capital cost for a project, considering both initial purchases and replacements all in present value
MACRS	Modified Accelerated Cost Recovery System; Under MACRS, the capitalized cost of PV and batteries is recovered over a specified life (e.g., 5 years for PV systems) by annual deductions for depreciation. MACRS Bonus Depreciation is another name for an additional first year depreciation deduction (60% in 2024) provided by section 168(k).
Net Present Value (NPV)	The value a system provides over the course of its lifetime compared with a business-as-usual case where no technology is implemented. A positive NPV means the system saves money.
Off-grid	Not connected to the power grid and operating independently from the power grid
Outflow Credit	Credit that can be earned when exporting power back onto the grid to offset a customer’s utility bills
Solar PV nameplate capacity	The installed capacity of a PV system. Note, solar PV is also referred to as just PV.
Resilience	The ability for a building or microgrid to withstand a power grid outage by generating and distributing its own power
ResStock™	An NREL tool for generating predicted electric load profile data for residential buildings
Solar PV (PV)	Solar photovoltaics (photovoltaics); panels that generate electricity when exposed to sunlight
Techno-economic	Referring to analysis that considers both the technical aspects of a system and the predicted economic performance of the project
Typical Meteorological Year (TMY) solar radiation data	TMY solar radiation data is based on multiple years of historical radiation data rather than just a single year. Used in modeling power output from solar panels, TMY data can help to avoid overestimating or understanding power output due to variations in year-to-year solar radiation.

Definitions: Results Terminology

Term	Definition
PV	The DC nameplate capacity (in kW) of the PV system recommended by REopt
Battery	The kW and kWh rating of the Lithium-Ion battery system
Carbon Free Electricity (CFE) %	The predicted percentage of the electricity demand that is met by electricity derived from the PV panels on site
PV Exported Energy	The energy, in units of kWh, that is exported from the system to the grid. The outflow credit is based on this exported energy.
PV Curtailed Energy	Curtailed electricity refers to the electricity that the PV panels generate above what is required to meet the site’s demand and/or charge the battery. Often it is most economical to build PV systems that curtail electricity. The curtailed energy in kWh is listed in this row.
Net Present Value (NPV) ($)	The Net Present Value computed as the Lifecycle Cost (LCC) of the business-as-usual case subtracted by the LCC of the evaluated case
Lifecycle Capital Cost ($)	“Net capital costs for all technologies, in present value, including replacement costs and incentives.” (REopt.jl Documentation website)
Year 1 Utility Costs ($)	The cost of electricity (including the demand and energy cost) from the utility during year one
Year 1 Utility Savings ($)	Compared with the business-as-usual case, the savings in electricity costs when the evaluated scenario is implemented
% of the year that a **4-hr* outage would be survived** *Various outage durations were evaluated in addition to 4-hour outages	These values are generated by post-processing the REopt results using REopt’s outage simulator. The outage simulator uses the results from the REopt run (battery charge levels, generator fuel availability, PV output, critical load profile, etc.) to predict how many hours the energy system can meet the critical load for all hours of the year.
Predicted PV Land area	The total predicted area of the solar PV system in acres

Analysis #3: Background

The Communities LEAP Coalition members requested an analysis for a microgrid at Parker Village, a development with housing and community spaces that is currently being designed and constructed. The development plans to have a mix of housing, business space, and community spaces, as well as charging stations for electric vehicles.

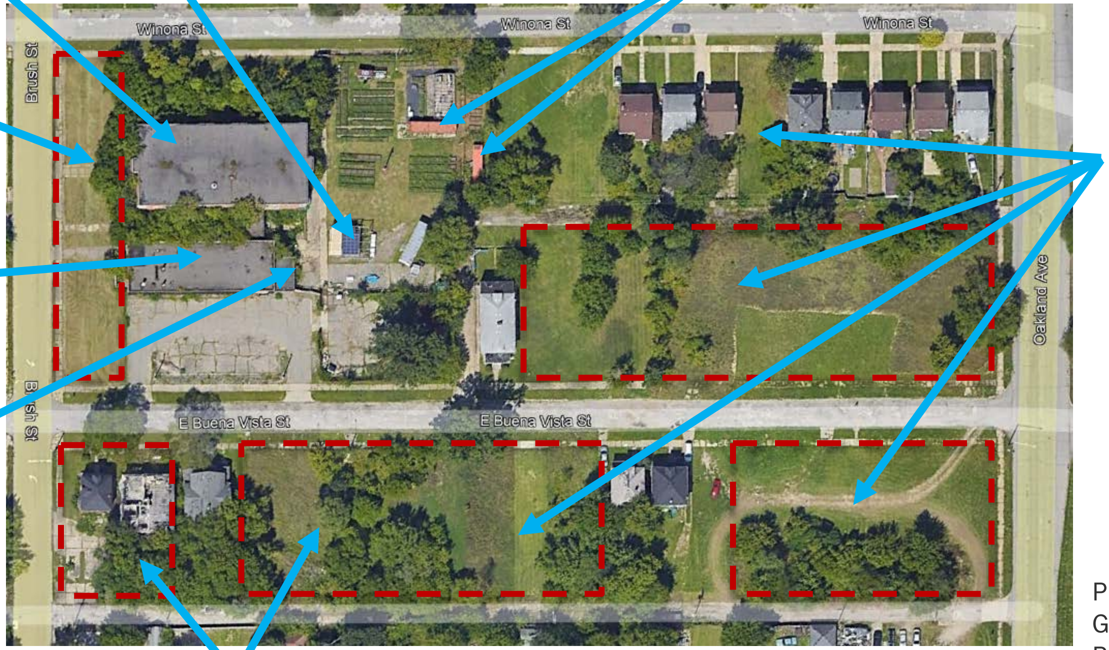
This techno-economic analysis was conducted to evaluate the cost-effectiveness of several scenarios:

1. Creating a fully off-grid microgrid.
2. Implementing solar PV for cost savings.
3. Providing resilience for a grid-connected microgrid.

Since Parker Village is still in development, some inputs to the REopt model, such as the building load profiles, were not available. In cases where input data was not available, best estimates were used.

Analysis #3: Site Description

Figure 11 shows a proposed plan for Parker Village based on discussions with Parker Village leadership.



Building B: containing a media company, coworking space and makerspace, and offices (3 stories)

Parking lot: containing solar PV Carports, EV chargers for the EV bus loop*, fence with lights, and a security office

Building A: containing an event center for concerts, lectures, and events (1-story)

Two-car solar charger for public use

Existing 4.5 kW of solar PV for the cafe (not part of the microgrid)

Solar PV on a shipping container for the aquaponics system and a greenhouse (not part of the microgrid)

Space for single-family homes (each with solar PV)

Photo from Google Earth Pro

Space for Four-Family Rehab, Fourplex Residential, and Duplex Residential Buildings

Figure 11. Map of the Parker Village infrastructure plan

*The EV bus loop, described later in this section of the slide deck, will be a bus loop through the Highland Park community. Michigan Clean Cities provided a preliminary estimate for the electric load for charging the EV buses at the Parker Village microgrid.

Analysis #3: Site Description

The size of the land area shown in the blue box in Figure 12 was measured to be 7.85 acres in Google Earth Pro.

Several of the REopt scenario results suggest PV sizes that would exceed the current land area available. In these cases, PV would need to be located at a different location.

Figure 12. Measured area, shown for a size reference

Photo from Google Earth Pro

Analysis #3: Key Inputs

In addition to the inputs defined on the REopt Inputs and Assumptions section, all of the following inputs were used in this analysis for Parker Village:

Parameter	Value
PV cost per kW	Both fixed tilt PV and carport PV were included in the model: $1,201/kW for fixed tilt PV (prediction for a 1,000 kWdc system in 2026) (Wood Mackenzie. 2022.) $2,367/kW for carport PV (prediction for a 1,000 kWdc system in 2026) (Wood Mackenzie. 2022.)
PV area	Carport PV: 0.24 acres available Fixed tilt PV: Did not restrict area available
PV tilt	23 degrees
Critical Load	100% of the existing load, unless otherwise noted
Microgrid upgrade costs	$238,265 times the maximum critical load in MW (Giraldez et al. 2018). Note: There may be additional costs for site-specific distribution and microgrid infrastructure
Battery	For grid-connected resilience scenarios when there isn't a generator, SOC minimum fraction is 40% and minimum battery kW is 1.2 x maximum critical load
For off-grid scenarios	Minimum Load Met = 99%
Grid Distribution	Rider 14 and Rider 18 opportunities are not applicable because Rider 14 and Rider 18 limit the PV size to 100 kW and 150 kW, respectively. PV export from the site likely cannot be utilized unless multiple meters and interconnection points are used.
Electric Tariff	D3 General Service, Full-Service Customer

Analysis #3: Microgrid Planning

The table below summarizes the predicted energy use from each of the buildings in the microgrid. Except for the EV Loop and EV chargers, this data was estimated using data from NREL's ResStock and ComStock databases.

Building	Number	Details	Estimated Annual Energy Use
Single-Family Homes	18	1,600 sq. ft. (average)	per unit: 15,232 kWh
Four-Family Rehab (4 units each)	1	4,800 sq. ft. (1,200 per unit)	per unit: 16,124 kWh
Fourplex Residential (4 units each)	1	6,000 sq. ft. (1,500 per unit)	per unit: 12,629 kWh
Duplex Residential	1	4,000 sq. ft. (2,000 per unit)	per unit: 16,838 kWh
Community Resource Center (Building A)	1	1 story, estimated 4,521 sq. ft.	59,653 kWh
Community Resource Center (Building B)	1	3 stories, 26,766 estimated sq. ft. (8,922 sq. ft. per floor)	288,957 kWh
Lynn Townsend Center	1	20,000 sq. ft. (Estimate)	259,438 kWh
Security Office	1	In a retrofit shipping container with an estimated area of 320 sq. ft.	4,222 kWh
EV Bus Charging for the EV Loop	1	Data provided by Michigan Clean Cities	53,042 kWh
2 Public Level 2 EV chargers and 2 Carport EV chargers	1	Data estimated using NREL's EVOLVE tool	2,081 kWh
Perimeter Lighting	N/A	Estimated using a load profile from the exterior lighting from an office building in the ComStock database.	52,985 kWh
		Total Predicted Annual Energy (kWh)	**1,143,242 kWh** (including all res. units)

- Note: The Café, Aquaponics Garden, Greenhouses, and Refit Shipping Container Structures were not included in this microgrid analysis because they will be separate from the microgrid.
- Space heating, water heating, and cooking appliances were modeled as electric. Space heating was modeled as an air source heat pump where the data existed in ComStock or ResStock.

Analysis #3: EV Bus Electric Charging Load Profile Prediction

Michigan Clean Cities provided a preliminary estimate for the electric load for charging the EV buses at the Parker Village microgrid. These EV buses will be part of an EV Bus Loop in Highland Park. Seven days of the interval data are shown in Figure 13 to the right.

This charging load was added to the total site load for the Parker Village microgrid.

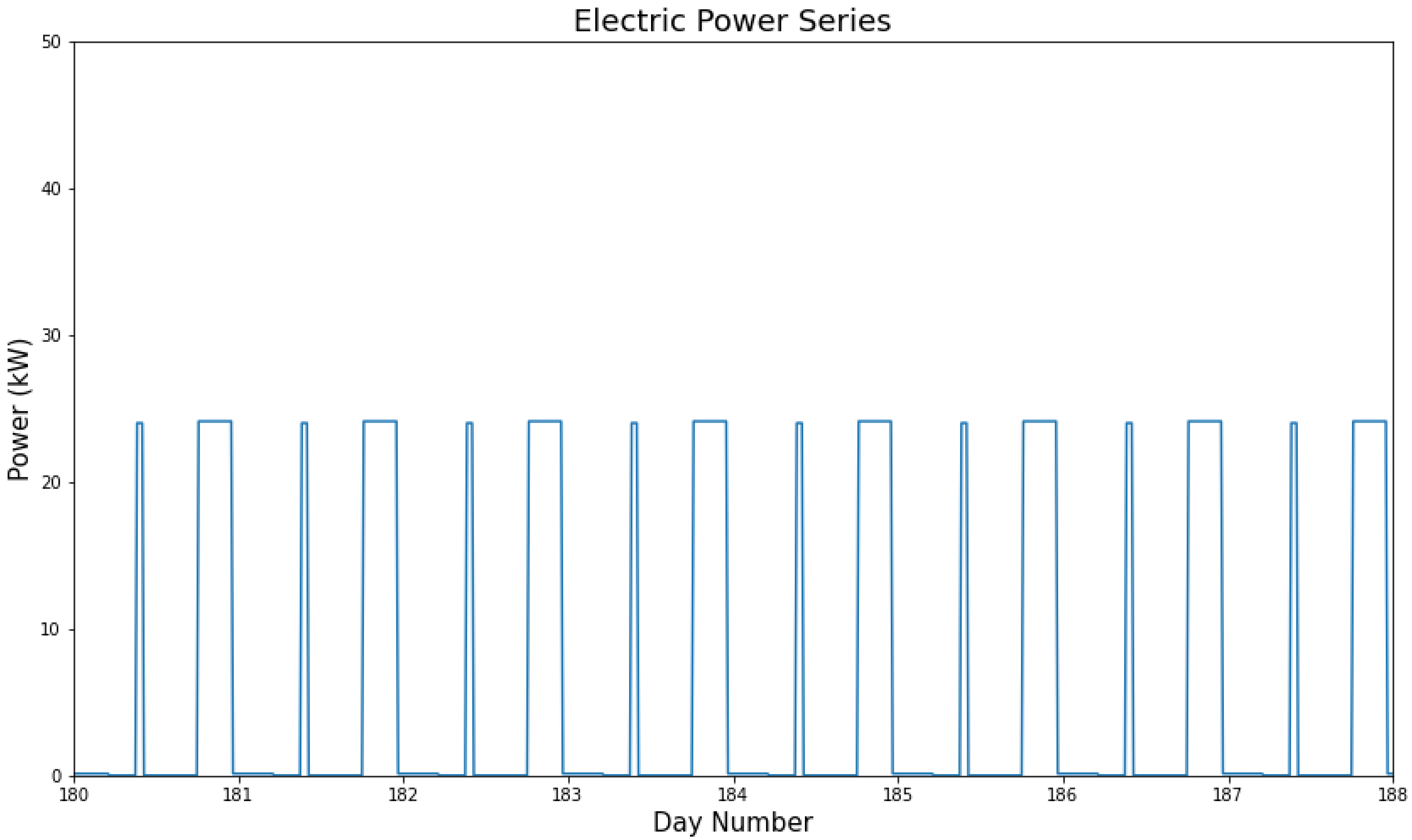


Figure 13. One week of the year-long estimated load

Analysis #3: Estimation of EV Charging Loads

NREL's EVOLVE tool was used to predict the 15-minute interval power consumption from four Level-2 chargers at Parker Village, which will be separate from the EV bus chargers. Figure 14 shows the predicted electric load during two days of the year-long profile. Each Level 2 charger had a max power of 7.6 kW.

The following key inputs were used in the modelling:

	Car Type 1	Car Type 2
Number of vehicles	200	100
Charging methods	At-home charger* and the Level 2 chargers	Only the Level 2 chargers
Weekday travel miles	20–30 miles	30–50 miles

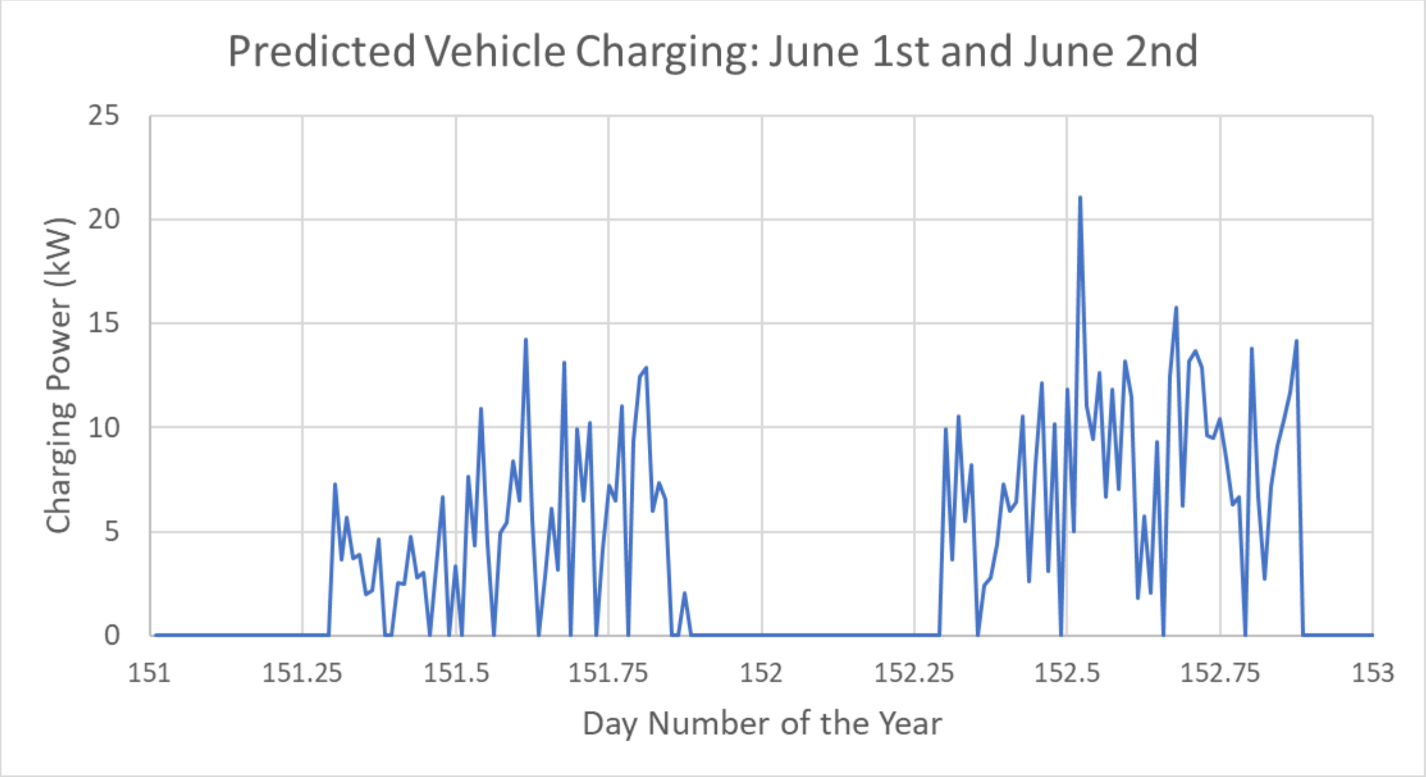


Figure 14. Two days from the entire year interval prediction

*The electricity demand from the at-home chargers was not included in the load profile because those chargers are located at the car owners' homes.

Analysis #3: Electric Load Profile Prediction

Figure 15 shows the predicted aggregated load profile (15-min interval) for the microgrid for seven days of the year-long profile.

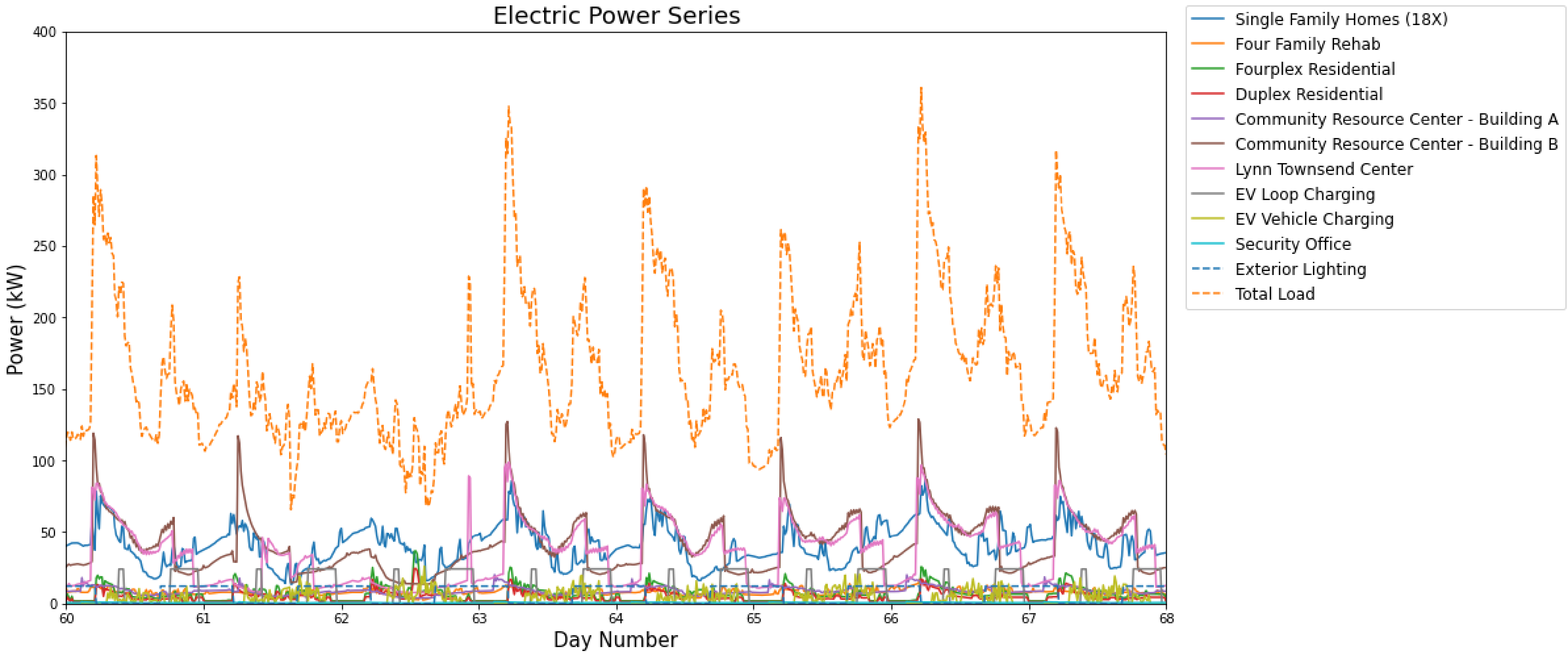


Figure 15. One week of the predicted load for each load type and the total load

Analysis #3: Electric Load Profile Prediction

Figure 16 shows the predicted aggregated load profile (15-min interval) for the microgrid for seven days of the year-long profile. To better highlight the individual loads, this plot does not show the total load.

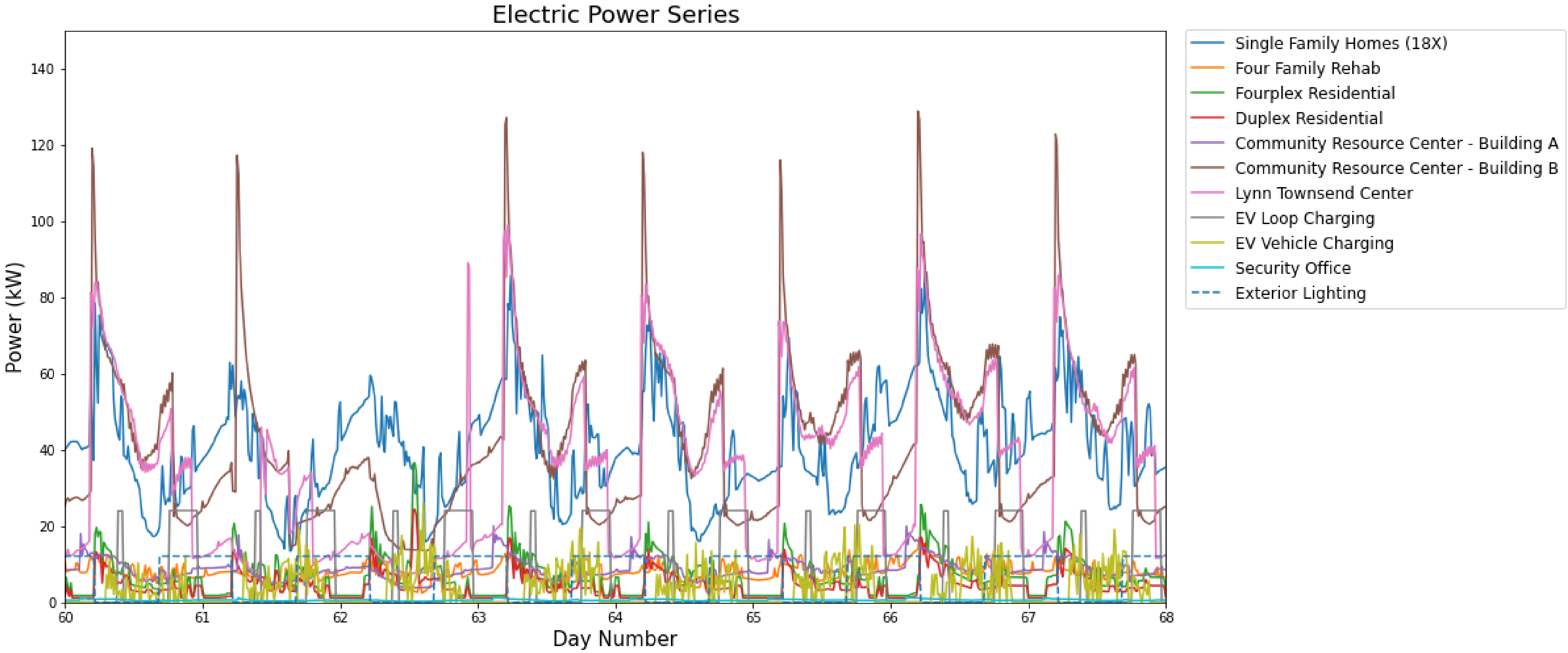


Figure 16. One week of the predicted load for each load type

Analysis #3: Electric Load Profile Prediction

Figure 17 shows the predicted aggregated load profile (15-min interval) for the microgrid for the entire year.

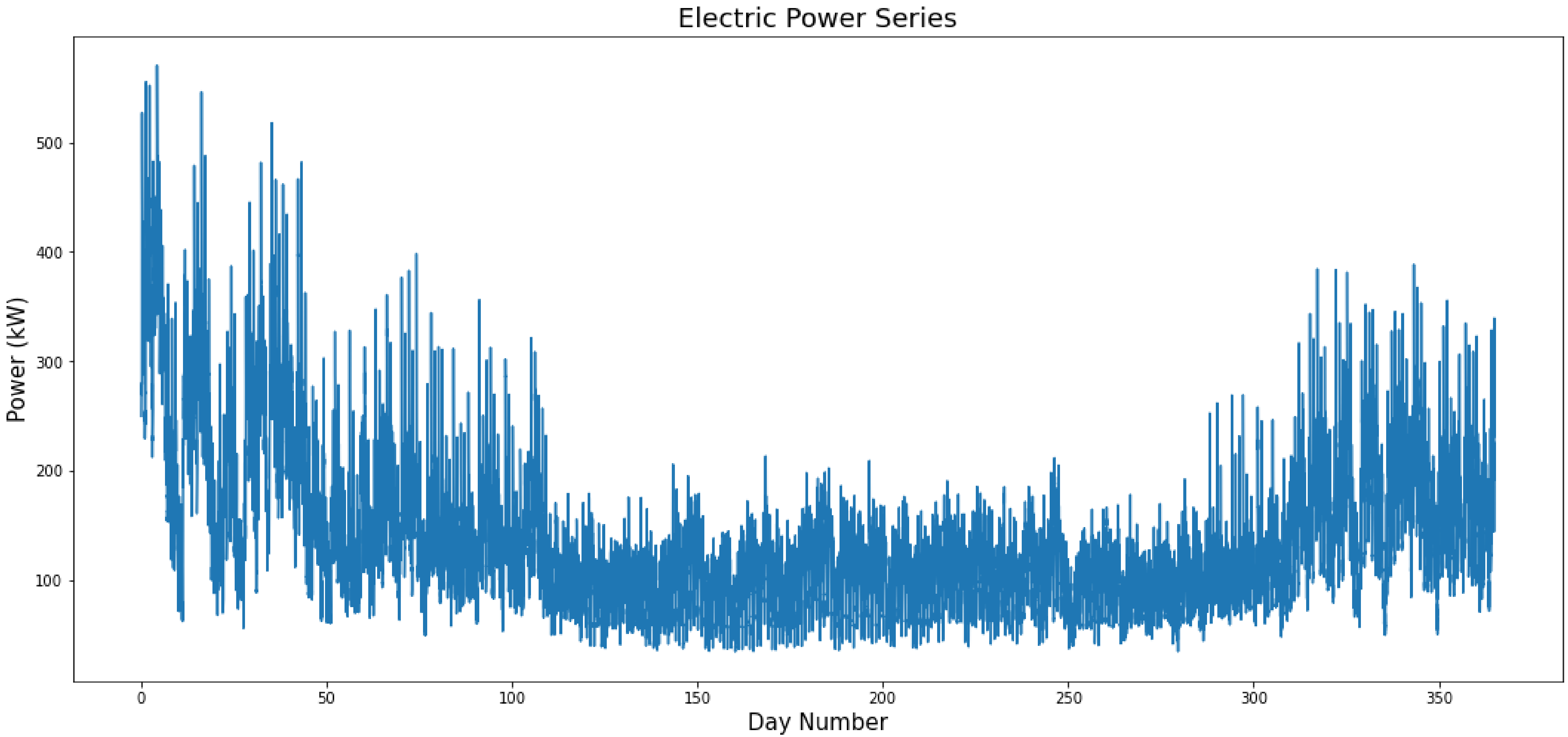


Figure 17. The total predicted load for the entire year

Analysis #3: Scenario Summary

The scenarios evaluated in Analysis #3 are summarized in the table below.

Scenario	Description
1a	Off-grid, PV + Battery
1b	Off-grid, PV + Battery + Diesel generator (2,000-gal fuel available annually)
1c	Off-grid, PV + Battery + Diesel generator (10,000-gal fuel available annually)
2a	Cost optimal PV-only without microgrid upgrade costs (grid connected)
2b	Full carport PV, cost-optimal battery, and cost-optimal fixed tilt PV system without microgrid upgrade costs (grid connected)
3a	PV + Battery with 3-day outage with 50% critical load (grid connected)
3b	PV + Battery with 3-day outage (grid connected)
3c	PV + Battery + Generator with 3-day outage and 2,000 gal of fuel available annually (grid connected)

Note:

- The carport PV system was assumed to be built for all scenarios except for Scenario 2a.
- Resilience scenarios include the estimated microgrid upgrade costs of $238.265/peak critical load (kW).

Analysis #3: Results

	1a	1b	1c	2a	2b	3a	3b	3c
Description	Off-grid, PV + Battery	Off-grid, PV + Battery + Diesel generator (2,000-gal fuel available annually)	Off-grid, PV + Battery + Diesel generator (10,000-gal fuel available annually)	Cost optimal PV and Battery without microgrid upgrade costs (grid connected)	Full carport PV, cost-optimal battery, and cost-optimal fixed tilt PV system without microgrid upgrade costs (grid connected)	PV + Battery with 3-day outage with 50% critical load (grid connected)	PV + Battery with 3-day outage (grid connected)	PV + Battery + Generator with 3-day outage and 2,000 gal of fuel available annually (grid connected)
PV – Fixed Tilt (kW-DC)	10,568.99	4,861.79	2,490.44	284.59	204.45	1,272.63	2,626.85	202.89
PV – Carport (kW-DC)	80	80	80	0	80	80	80	80
Battery	2,110.8 kW / 10,550.5 kWh	1,055.1 kW / 10,735.1 kWh	713.9 kW / 5,321.1 kWh	0 kW / 0 kWh	0 kW / 0 kWh	561.7 kW / 4,493.6 kWh	1,124 kW / 8,990.3 kWh	0 kW / 0 kWh
Generator (kW)	0	684	684	0	0	0	0	684
Carbon Free Electricity %	98.88%	96.65%	87.73%	24.20%	24.23%	75.76%	90.30%	24.17%
NPV ($)	-11,624,416.75	-7,057,846.00	-3,312,005.77	235,972.27	188,028.54	-1,431,090.92	-4,058,468.59	-551,264.96
Lifecycle Capital Cost ($)	11,280,006.15	7,759,705.60	4,449,524.35	178,496.87	227,096.66	2,644,398.63	5,242,414.03	806,769.64
Total PV energy generated before curtailment (kWh)	13,996,124	6,438,281	3,297,992	376,871	270,750	1,685,293	3,478,635	268,685
Total annual energy consumption (kWh)	1,175,610	1,175,610	1,175,610	1,175,610	1,175,610	1,175,610	1,175,610	1,175,610
Year 1 utility costs ($)	0	0	0	125,604	125,551	39,488	17,339	123,130
Year 1 utility savings ($)	164,684.56	164,684.56	164,684.56	39,783.87	39,836.19	125,900.03	148,048.36	42,257.40
Survival % of **4-hr outage**	N/A	N/A	N/A	N/A	N/A	100	100	100
Survival % of a **12-hr outage**	N/A	N/A	N/A	N/A	N/A	100	100	100
Survival % of a **3-day outage**	N/A	N/A	N/A	N/A	N/A	95	96	100
Survival % of a **5-day outage**	N/A	N/A	N/A	N/A	N/A	91	91	95
Predicted PV area – fixed tilt	31.707	14.5854	7.4713	0.8538	0.6134	3.8179	7.8805	0.6087
Predicted PV area - carport	0.24	0.24	0.24	0	0.24	0.24	0.24	0.24

Key Takeaways From Analysis #3

The analysis of the Parker Village microgrid identified several key takeaways:

1. With enough area for solar PV, Parker Village could likely operate as an off-grid microgrid. But isolating from the grid would result in a predicted $11.6M increase in full costs relative to predicted energy costs that relied entirely on grid power.
2. If the microgrid is connected to the grid, then solar PV, batteries, and/or generators could be implemented to survive 3-day grid outages, with a cost difference ranging from -$551K to -$4.1M compared with the business-as-usual scenario.
3. Solar PV appears to be cost-effective if implemented by itself with a size of 285 kW.
4. Depending on the technologies implemented, predicted full costs ranged from $178,497 to $11,280,006. Note that further analysis should be performed on quantifying the site-specific costs for microgrid infrastructure like distribution lines and switchgears.

Conclusions

Conclusion

This slide deck summarized results from NREL's techno-economic analysis for solar PV, batteries, and/or diesel generators at four locations within Highland Park, Michigan:

1. A typical residential building in Highland Park
2. A typical commercial building in Highland Park
3. Earnest T. Ford Recreation Center
4. Parker Village microgrid

In summary, opportunities for cost savings likely exist for each of the sites through the implementation of solar PV. The analysis predicts that resilience and off-grid capabilities are mostly not cost-effective from a bill savings perspective.

However, this analysis did not include a full analysis of resilience benefits. Additional analysis may quantify the value of resilience measures for the community or identify community benefits that may be difficult to describe in terms of economic value. Next steps in this resilience analysis could include:

1. Continue defining the services provided during a grid outage for the buildings in this analysis based on community feedback.
2. Predicting how those services may provide economic impact, such as preventing the spoilage of food, and considering those impacts in the economic analysis.
3. Understanding additional benefits provided by a resilience hub that may be difficult to quantify, such as space cooling or heating for community members, and including these benefits in decisions around the creation of resilience hubs.
4. Additional resources for these steps are:
    1. NREL's Customer Damage Function Calculator (https://cdfc.nrel.gov/)
    2. The following article on prioritizing facilities for resilience: https://reopt.nrel.gov/prioritizing-facilities.html

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Thank you

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DOE/GO-102024-6115 • March 2024