Weathering the storm: Microgrid feasibility studies for municipal applications

Maddie Koolbeck, Slipstream
Lee Shaver, Slipstream
Jeannette LeZaks, Slipstream

ABSTRACT

As climate change normalizes extreme weather events, grid and community resiliency are increasingly challenged. Municipalities face a growing need to protect the continuity of critical government and emergency services. Municipalities are also setting aggressive clean energy goals to combat climate change. Microgrids can help achieve clean energy goals and provide resilient electric systems for critical services. Barriers to microgrid adoption include lacking knowledge of configuration, costs, and benefits within municipalities, and lacking standardization of microgrid design, implementation, and controls.

As part of a state-funded grant, we completed feasibility studies on existing sites in two cities in Wisconsin to assess microgrid options, educate community stakeholders, and identify ways to overcome barriers. One microgrid would be used to power government buildings that provide key functions during emergencies, including snow removal, road maintenance, sewer maintenance, police and fire support functions, and mapping services. The other would power critical loads in the city's library, allowing it to serve as a Community Resiliency Center (CRC) for residents in the event of a large-scale power failure or emergency. Our study compared system configurations and costs, and quantified resiliency and environmental benefits. We also considered how solar PV could be expanded or integrated into both microgrids.

This paper includes lessons learned about most applicable tools and best methodologies and processes when assessing microgrid feasibility. We hope the results of the feasibility studies can inform other communities' processes and help facilitate more successful discussion of microgrids and CRCs installations in other municipalities.

Introduction

Municipalities face a growing need to protect the continuity of critical government and emergency services as climate change normalizes extreme weather events. Municipalities are also setting aggressive clean energy goals to combat climate change. Microgrids can help achieve clean energy goals and provide resilient electric systems for critical services and community resiliency centers.

In 2021, two cities located in Dane County Wisconsin, Sun Prairie and Madison, initiated microgrid feasibility studies through funding from the Wisconsin Office of Energy Innovation. Analysis was performed by Slipstream. The feasibility study for each city compared system configurations and cost and quantified resiliency, environmental, and grid benefits for a battery energy storage system (BESS) and other distributed energy resources (DER). However, the two cities have distinct differences in community size, operational goals for the microgrid, existing infrastructure at the site, and stakeholder engagement.

Throughout a six-month process, each community defined the needs and functions for its microgrid and analyzed several system configurations and the associated costs and benefits. The communities also engaged a wide range of stakeholders to identify shared goals. The goals of the study included:

- Define and identify the functions the microgrid should serve during an emergency
- Analyze the ability of existing and planned infrastructure (such as buildings and PV arrays) to be incorporated into the microgrid
- Identify potential BESS capacity and duration and analyze the benefits and costs
- Compare BESS options with diesel or natural gas generators in terms of performance, cost, and environmental impact
- Forecast the ability of the microgrid to meet environmental targets including renewable energy, emissions, and fleet electrification

In this paper, we provide details on the two sites and an overview of our methodology, including analytical tool selection, data collection, and stakeholder engagement. We then summarize our results, highlighting the differences between the two sites and lessons learned for other municipalities considering their own resiliency needs.

Background on the Two Sites

Sun Prairie and Madison both approached the feasibility analysis with the goal of identifying options for a specific existing site in their communities, while also learning more about microgrid considerations for any future sites. The sites selected by each community had distinct functions: Sun Prairie selected their library for a Community Resiliency Center and Madison selected a campus of three buildings that house their streets divisions and engineering operations.

Sun Prairie

Sun Prairie is a city in the Madison-metropolitan area with roughly 33,000 residents. It is served by a municipal utility, Sun Prairie Utilities. The feasibility study is focused on utilizing the Sun Prairie Library as a Community Resiliency Center (CRC). A community resiliency center is defined as a facility that provides emergency heating and cooling, cold storage of breast milk, vaccines, or medicines, and plug power for computers, cellphones, and medical equipment (Public Service Commission of Wisconsin 2021).

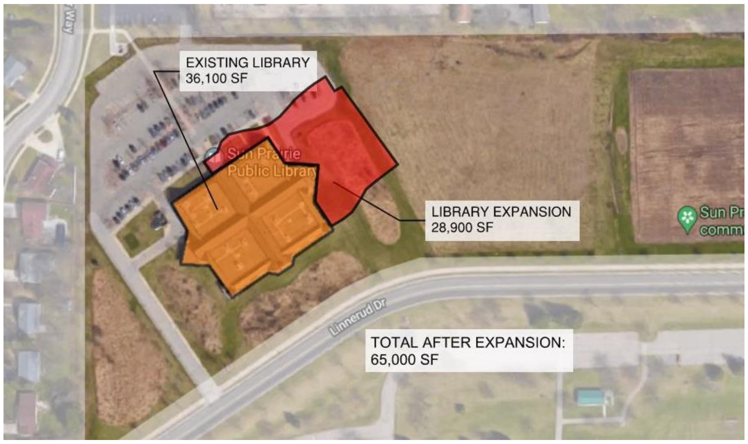

Figure 1. Sun Prairie Library (orange) showing planned expansion (red)

The Sun Prairie Library is 36,000 square feet and has no existing DER assets (Figure 1). The city is currently engaged in a design and construction project with plans for a major renovation[1] which will increase the library to 65,000 square feet and add a solar PV array by 2024. This study evaluated how a microgrid could fit into the design and construction plans to enable the library to serve as a CRC.

The goals of the study were to evaluate integrating a solar PV array and BESS into a microgrid and comparing their benefits and costs, as compared to adding a fossil fueled back-up generator at the site. Sun Prairie wanted to better understand the system configurations needed to provide emergency heating and cooling, lighting, refrigeration, electric vehicle charging, and plug power for medical equipment or charging of essential devices. The analysis considered the ability of the microgrid to provide those services for four hours and up to an entire day.

The analysis also considered how a highly energy efficient building design, including a fully electric HVAC option, would impact the energy load in the future and how it would impact the performance of the microgrid. In parallel to the library analysis, the city inventoried all diesel generators and associated city facilities to inform development of a larger plan around resiliency.

Madison

The City of Madison is the second-largest city in Wisconsin, home to 255,000 people. The city has a goal for city operations to be emissions neutral by 2030. As part of that goal, the city has been installing solar PV arrays at several sites.[2] The city is served by an investor-owned utility, Madison Gas and Electric. The microgrid study focused on three adjacent city-owned facilities that already have solar PV and back-up generators on-site (Figure 2).

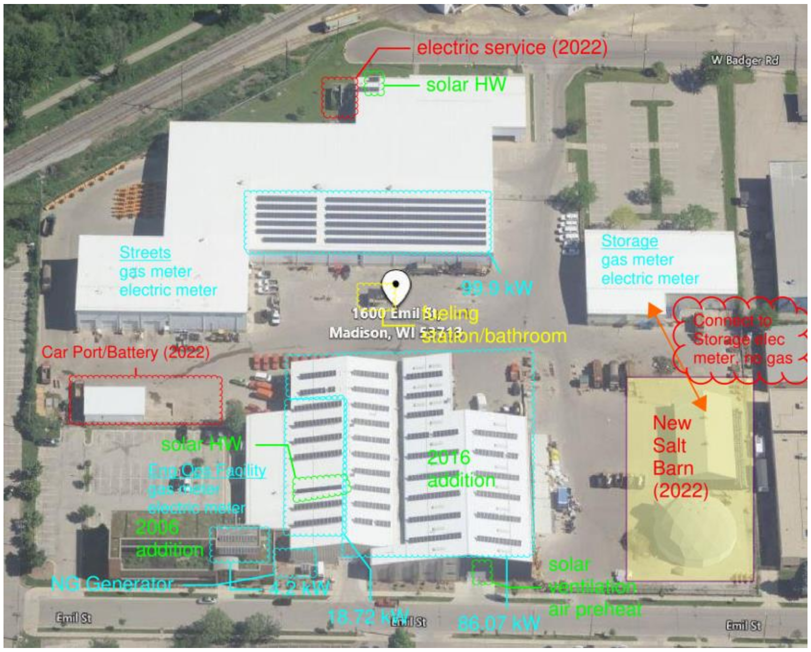

Figure 2. Site layout at the proposed Madison microgrid site.

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[1] For details of the project, see: https://www.sunprairiepubliclibrary.org/library_expansion

[2] Progress towards this goal is documented here: https://www.cityofmadison.com/engineering/facilities/energy/solar-locations

The facilities house Madison’s streets division and engineering operations and are city headquarters for several critical government functions: snow removal, emergency support services, road maintenance, and sewer maintenance. The facilities currently have 209 kW of solar PV installed, with an additional 200 kW of additions planned through 2023, which would maximize the roof capacity at the site. Most of the inverters are compatible with SunSpec Modbus and could likely be integrated with any future microgrid. The sites also have a newer 300-kW natural gas generator and an older 100-kW diesel generator, which is near end-of-life.

The site houses over 200 vehicles and gas-operated machines, including both heavy-duty and light-duty vehicles, which the City of Madison plans to electrify over the next 10 years. The microgrid feasibility study analyzed how the expanded electric vehicle (EV) fleet with managed charging would impact the performance and configuration needs of the microgrid, both while grid connected and during outages.

Methods

We conducted both feasibility studies with a set of four analysis stages and ongoing stakeholder engagement. We started by identifying tools to evaluate microgrid system configurations, costs, and benefits. We evaluated seven tools and their ability to optimize assets and dispatch to meet the critical functions of each microgrid. We then collected energy, cost, technology, and site data to use as inputs in the analysis. Finally, we ran several initial scenarios through the selected analysis tool and compared the high-level results to identify a set of alternatives for each site. The final step was to summarize the associated costs and benefits for the final scenarios.

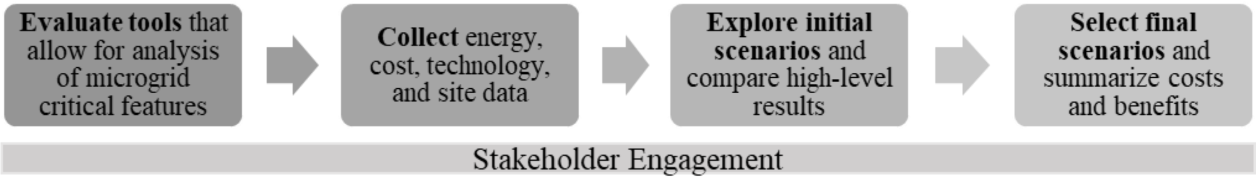


Figure 3. Methods summary: Key phases in the feasibility studies

Stakeholder Engagement

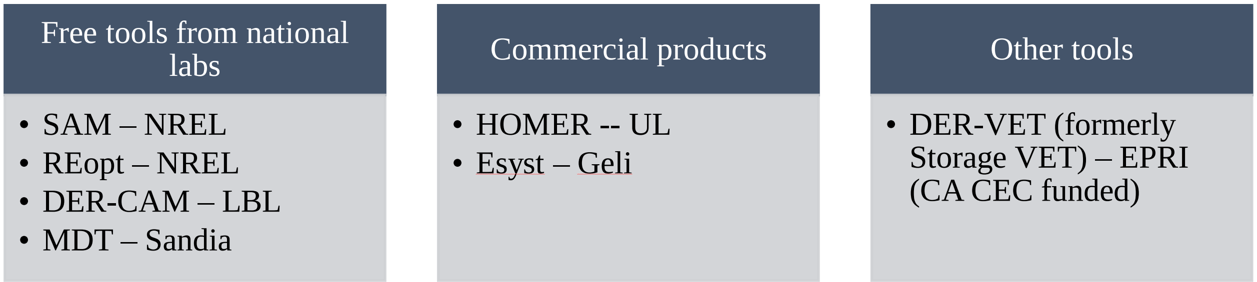
Stakeholder engagement was a critical, ongoing task throughout the study. Each municipality developed a stakeholder group, which consisted of facility staff, city sustainability managers, and operations managers. The stakeholder group assisted with data collection efforts and provided essential feedback on the objectives of the microgrid and which scenarios were most feasible and in-line with city goals for renewable energy and resiliency. The stakeholder groups were instrumental in answering critical questions, such as:

- How does the site fit into the larger city resiliency plan? What are the key functions the microgrid should be able to power during outages or emergency events?
- What lengths of outages should the microgrid be able to cover?
- Would the city be interested in a co-ownership model with the local utility?
- How does this site fit into larger city goals for renewable energy? Are there specific emissions or renewables targets the site needs to meet?

In addition to the staff stakeholder group, we also engaged the local utilities in discussions. Involvement of the utilities was essential to understand any size restrictions, applicable financial rates and benefits, and the utility’s interest in co-ownership models.

Tool Selection

A literature review provided a list of seven tools capable of microgrid and DER scenario analysis (Krah 2019 and Tozzi et al 2017). The tools fall into three categories; the categories and tools are listed in Figure 4.



Free tools from national labs	Commercial products	Other tools
SAM – NREL REopt – NREL DER-CAM – LBL MDT – Sandia	HOMER -- UL Esyst – Geli	DER-VET (formerly Storage VET) – EPRI (CA CEC funded)

Figure 4. Microgrid analysis tools and categories.

Once the candidate tools had been identified, we developed a critical features matrix for the two sites to use when evaluating each tool. The features that were evaluated and the desired criteria for each site are shown in Table 1. Features are listed roughly in order of importance to the analysis.

Table 1. Microgrid analysis tool critical features and criteria for each site.

Feature	**Madison requirement**	**Sun Prairie requirement**
Back-up generator	Model the existing natural gas generator	Optimize for diesel generator size
Resiliency analysis	Satisfy minimum load and duration for backup coverage	
Existing PV analysis	Model existing PV capacity	n/a
Custom load profile	Model a known hourly load profile	
Load growth	Model load growth (due to fleet electrification)	n/a
BESS modeling	Optimize for BESS capacity, duration, and dispatch. Consider BESS degradation.	
Hourly results	Provide hourly dispatch results to allow for supplemental financial and environmental analysis	
Optimization	Optimization algorithm should select component size and dispatch to maximize life-cycle benefits.	
License	Free and open-source products preferred to allow for dissemination of results across stakeholders.	

Next, we reviewed the literature about these tools and consulted documentation and user forums to determine whether each tool met these requirements. To simplify the analysis, a qualitative approach was taken, shown in Table 2. For each tool, we determined if the requirement was fully met, partially met, or not met, represented through filled, half-filled, and unfilled Harvey balls, respectively. In some cases, we could not determine if a requirement was met, or we ended our evaluation after identifying the tools did not meet the more critical requirements. In these cases, the associated cell in the matrix is left blank.

Table 2. Critical feature matrix for the seven microgrid analysis tools considered.

Critical features	**DER-VET**	**REopt**	**HOMER**	**DER-CAM**	**SAM**	**ESyst**	**MDT**
Back-up generator	◐	◐	●	●	○	○	○
Resiliency	●	●	●	◐	○	○	●
Existing PV	●	●	●	●	◐	◐	◐
Custom load profile	●	●	●	◐	●	●	◐
Load growth	◐	○	●	-	●	-	-
BESS modeling	●	◐	●	◐	●	●	-
Hourly results	●	●	●	○	●	○	-
Optimization	◐	●	●	●	◐	○	●
License	●	●	○	◐	●	◐	◐

Based on the analysis, we decided to proceed with REopt and DER-VET. While HOMER meets more requirements, stakeholders believed an open-source license was more important to the project, so that the analyses could be turned over to the stakeholders following the study to allow them to build on this research.

Some obstacles with the two selected tools remained. Both REopt and DER-VET by default assume diesel-fueled generators, requiring fuel prices and efficiencies to be input as $/gallon and gallons/kWh, respectively. For Madison, we addressed this issue by converting from the known values of $/therm and therms/kWh for the natural gas generator, as well as performing a literature review to confirm that differences in performance curves between the two technologies do not have a material impact on the results.

The inability to model load growth was a key limitation of REopt in the case of Madison, where fleet electrification over time will increase the electric load. To address this, we performed several analyses that tested different electric vehicle load requirements. In contrast, DER-VET allowed electric vehicles to be added to the site on a year-by-year schedule.

While both tools consider the impact of battery degradation over time, DER-VET (which was originally developed as a storage model) provided more robust modeling of the BESS which allowed for several different strategies to address degradation, including augmentation over time, oversizing, full replacement, and modular replacement (EPRI 2021). REopt only allows for full replacement based on a pre-set lifetime.

Finally, REopt allowed emissions costs to be modeled for CO_2, NOx, SO_2, and PM2.5, both for on-site and grid sources. These costs can be included in the objective function, in contrast to DER-VET, which only reports totals without factoring costs into the objective.

Several other differences between the two tools, outside of the critical feature matrix, are shown in Table 3. We ultimately relied primarily on REopt, which had an easy-to-use web interface, robust API (application programming interface, allowing the use of a scripting language to programmatically run scenarios), and pre-filled defaults based on NREL research.

Table 3. Qualitative differences between DER-VET and REopt

	DER-VET	**REopt**
Pros	• Focus on grid interaction • Detailed modeling of load growth • Detailed reliability and financial reports	• Web-based, simple to use and share • Well supported, with an API • Research-based default values • Focus on emissions
Cons	• Highly detailed inputs required • Comparatively complicated and slow to run • Limited support	• Some overly simplified assumptions • Cannot model load growth

Data Collection

We began by gathering existing data from the cities and supplemented with market data or modeling where needed. Table 4 details the primary data points we collected from each of the cities. The most important items were the interval energy data (to develop load profiles), energy rates, net metering constraints, on-site equipment specifications, and generation profiles. The other data points enabled a more site-specific analysis, but market data was used when a city did not have the data.

Table 4. Primary data collection categories and items

Building/Equipment Data	Utility	Financial Data
• Mechanical and electrical drawings • Planning documents • On-site fuel usage • Generator maintenance records • PV generation profile (interval data) • Technology specifications • Fleet annual usage and electrification plans	• Energy rates and demand charges • Net metering constraints • Wholesale rates for excess PV • Interval energy data • Historical outage history	• Discount rates • Operations and maintenance costs • Upfront costs • Fuel escalation rates • O&M escalation rates • Technology lifetimes

Market research included conversations with manufacturers and review of sources such as PVWatts, AFLEET, manufacturers' specifications, utility rate schedules and research reports. We utilized EIA data to review average outages for the utilities and to compile a list of major outages and duration from severe weather in the Midwest over the last several years.

In addition to the data collection, this phase also included modeling energy use for the expanded Sun Prairie Library and for vehicle electrification at the City of Madison buildings. The energy use modeling[3] for Sun Prairie accounted for the additional square footage and

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[3] Conducted with Slipstream's Sketchbox modeling tool

considered two very efficient HVAC systems: (1) a traditional variable air volume (VAV) system with natural gas-fired hot water reheat and (2) an all-electric variable refrigerant flow (VRF) system. We also modeled a critical load profile for energy use during an outage. To model the critical load profile, we utilized Clean Coalition's VOR123 methodology, with their definition of Tier 1, Tier 2, and Tier 3 loads to determine resiliency needs in the library (Lewis 2021). Tier 1 loads are most critical and need power all the time, such as emergency lighting, exit signs, and enough heat to prevent pipes from freezing. Tier 2 loads should have power if they do not threaten Tier 1 loads, and Tier 3 is everything else needed to operate at 100 percent capacity. Tiers 1,2,3 profile represents full load during outages and includes heating and cooling setbacks and slightly lower lighting use. The final critical load profile utilized Tiers 1 and 2 to include refrigeration and additional plug load needs (**Error! Reference source not found.**).

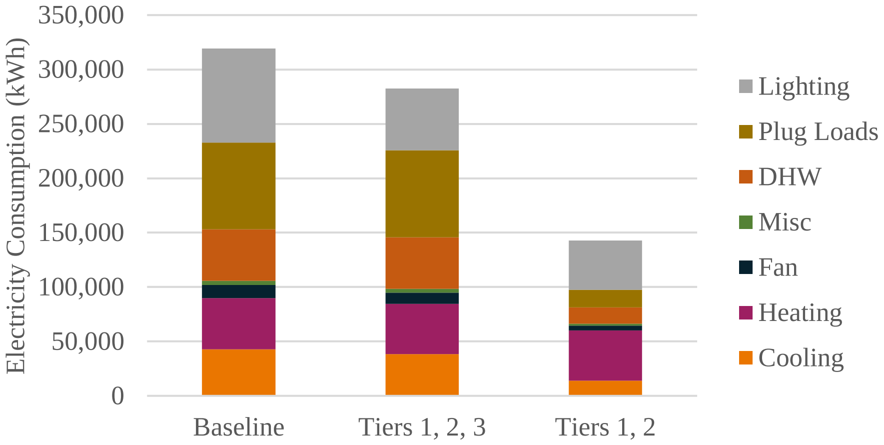

Figure 5. Electric consumption by end-use for the all-electric SPPL energy model, showing normal and emergency operations.

The vehicle electrification modeling estimated annual kWh needed for charging based on current mileage. We then split electrification into two phases: Phase 1 vehicles are ones that will be electrified in the near-term (5 to 10 years) and Phase 2 vehicles are ones that will be electrified in the long-term (10+ years). Phase 1 included all passenger vehicles, pickup trucks, and a small set of miscellaneous equipment (117 vehicles total), while Phase 2 included all heavy-duty vehicles and the rest of the miscellaneous equipment (an additional 105 vehicles). Eight electric vehicles are already housed at the site.

To develop a daily charging profile for the two phases, we adapted the model developed in Borlaug et al 2021, which looked at three different charging strategies for three different fleet types. For the City of Madison, we applied a minimum power charging strategy (where vehicles charge slowly for the duration of time while they are off shift) to most vehicles, with an immediate charging strategy for 10% of vehicles to cover vehicles which must be always close to a full charge to accommodate city operational needs. Figure 6 shows the hourly charging profile for the two phases.

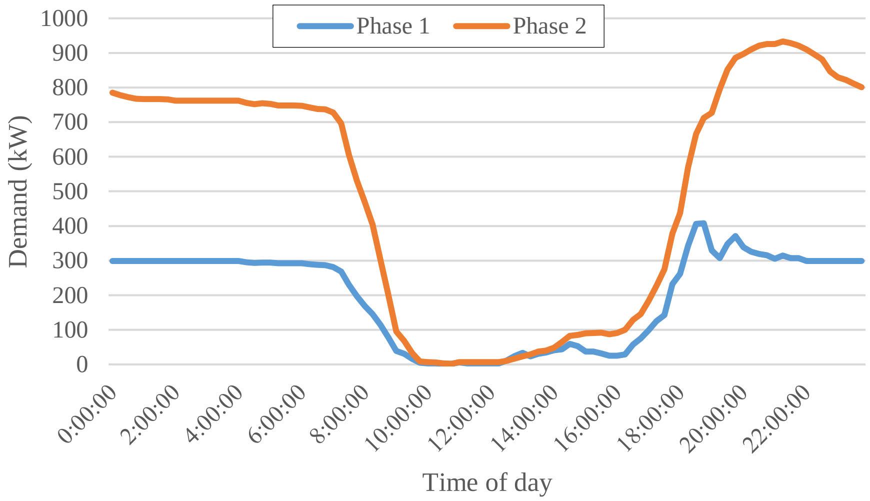

Figure 6. Electric vehicle average hourly load profiles: Phase 1 and 2 electrification

For both sites there remains uncertainty around the final load profile, as the design of the library is not yet finalized, and the fleet electrification schedule for Madison is still being developed. In both cases, the assumptions we used are considered a best guess, and will be provided to each city at the conclusion of the studies to be used as a baseline for updating.

Scenario Analysis

We used REopt for most of our scenario and resiliency modeling. We input the technology of interest, any resiliency or environmental goals, energy cost data, and a custom load profile. The tool then finds the least-cost option that satisfies the goals and provides system size, system financial, and resiliency data.

To model resiliency, the tool requires the user to input the length and timing of an outage which the optimal system should be able to withstand. The tool then finds the least-cost option system that can withstand an outage for the designated length of time during a specified time of the year, while still providing the load required. For example, the user would input an outage of four hours from 1 pm to 5 pm on a summer day that must be able to be covered by the system. Using that system size, the tool then evaluates resiliency (or length of outage the system could sustain) for all other hours of the year to allow for a comparison across seasons.

Results

After we completed our initial analysis of scenarios and obtained stakeholder feedback of preliminary results, we identified a set of leading alternative system configurations for each community. Detailed inputs and performance outputs for each community's top alternatives are described in this section.

Sun Prairie System Configuration Options

The City of Sun Prairie's final alternatives included a system that can sustain a four-hour outage at full-load (Tiers 1, 2, and 3) and a system that can sustain a 24-hour outage at critical load (Tiers 1 and 2). The city considered both a VAV system with natural gas-fired hot water reheat and an all-electric VRF system. To simplify the results, we focus on the all-electric options in this report. Table 5 lists the key inputs for the two final all-electric scenarios. We utilized a summer outage during June as a constraint but then model how the system performs in terms of resiliency across the year.

Table 5. Sun Prairie alternatives: inputs

Inputs	**4-Hour Full Load**	**24-Hour Critical Load**
Heating system	All-electric VRF system	All-electric VRF system
Rate structure	Time-of-use	Time-of-use
Critical loads	Tiers 1, 2, 3	Tiers 1 and 2
Outage length	4 hours	24 hours
Outage timing	June 19 1-5 pm	June 19 1 pm – June 20 1 pm
Renewable energy requirement	No constraint	No constraint
Health and climate costs	Not included	Not included

Table *6* shows the performance outputs for the Sun Prairie alternatives. The system sized to withstand a 24-hour outage with critical load increases the battery capacity compared to the smaller sized system and solar size decreases slightly. The net present value included in these scenarios uses a three percent discount rate and only includes energy and demand cost savings as benefits. As a result, the smaller-sized system (four-hour) has higher net present values as it has lower upfront costs. However, the smaller system has a significantly lower average resiliency and would likely have a lower net present value than the 24-hour system if resiliency benefits were included.

Table *6*. Sun Prairie alternatives: performance outputs

Scenario	**4-Hour Full Load**	**24-Hour Critical Load**
PV size (kW)	144	128
BESS capacity (kW)	28	26
BESS energy (kWh)	45	128
Annual Percent Renewable Energy	54%	48%
Resiliency Hours (Average)	3.5	35
Net present value ($)	$27,000	$7,200
Simple Payback	17.2	18.9

To explore resiliency in more depth, we compared each scenario's probability of surviving various outage lengths (Figure 7). As expected, the system designed to withstand a 24-hour outage performs has a higher probability of surviving outages of longer lengths. For example, at an outage length of ten hours, the four-hour system has less than a ten percent chance of surviving the outage while the 24-hour system has roughly a 55 percent chance.

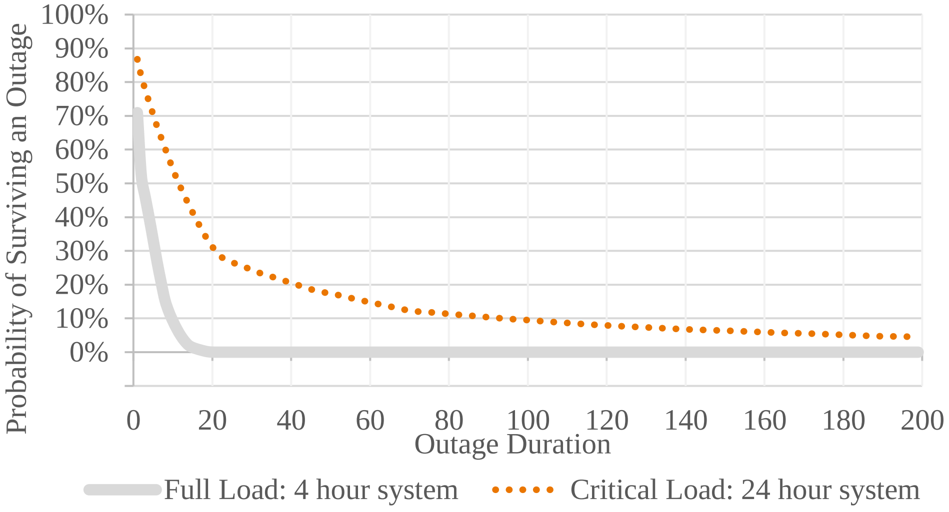

Figure 7. Sun Prairie Alternatives: Probability of Surviving Outages

We also compared how resiliency varies across the year for each of the systems. The general finding was that the length of an outage a system can sustain is highest during the shoulder seasons. This corresponds to when solar production is high and critical load requirements are low as little space conditioning is needed. In the summer and winter, it becomes more difficult to cover outages of longer lengths. Figure 8 illustrates this pattern for the system designed to withstand a 24-hour outage.

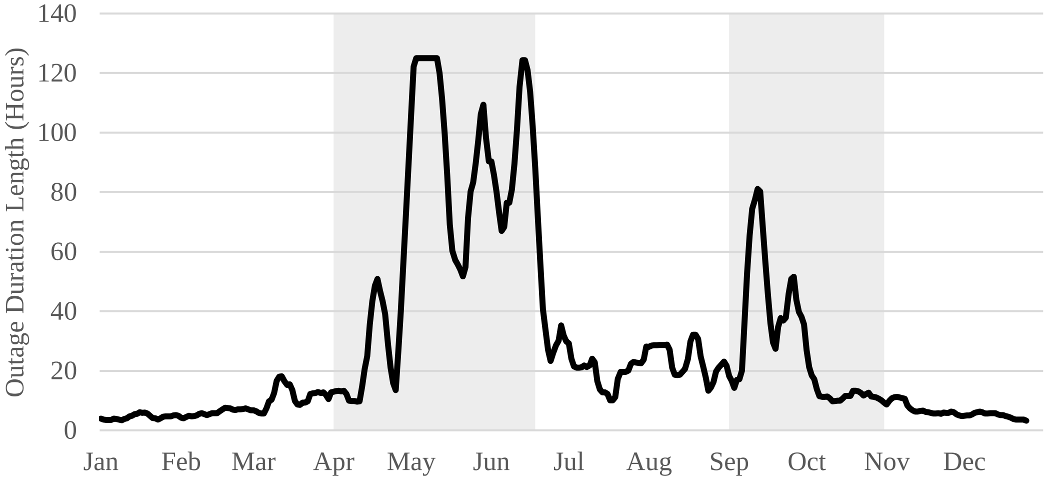

Figure 8. Length of outage system can sustain across the year: 24-hour critical load system

Madison System Configuration Options

As an existing facility with existing distributed energy resources and an electric vehicle fleet, the analysis for the City of Madison was considerably different from Sun Prairie. Several assumptions are already included in the base case, limiting the scenario selection process. First, the three electric services which exist on the site will be merged into a single service, allowing all buildings to share loads and resources. Second, the existing 300 kW natural gas-burning generator will remain and is sufficiently sized to support the full building load today (prior to additional fleet electrification). Third, the maximum solar capacity on site has been calculated as

483 kW, all of which will be installed prior to any microgrid implementation work. Finally, there is limited space for a battery energy storage system – two 40-foot storage containers are likely the largest which could be installed, which would support a 10 MWh system (Fu et al 2018).

With these constraints in mind, we analyzed four scenarios to understand the range of possibilities for the facility as the fleet is electrified, compared to the base case with only the existing facility load. As the fleet electrifies, a larger portion of the load will become critical to operations during outages. Scenarios are modeled first with an upper limit on storage capacity, then with a fixed capacity of 10 MWh, to understand the range of options between these two extremes. Table 7 lists the inputs that vary between the scenarios.

Table *7*. Madison alternatives: Inputs

Inputs	**Base case**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Normal load profile	Facility	Facility + phase 1 EVs	Facility + phase 1 EVs	Facility + phase 2 EVs	Facility + phase 2 EVs
Critical load profile	Facility	Facility	Facility	Facility + phase 1 EVs	Facility + phase 1 EVs
Battery constraint	<10 MWh	<10 MWh	=10 MWh	<10 MWh	=10 MWh
Annual kWh	552,000	1,780,000	1,780,000	5,430,000	5,430,000

Table 8 illustrates the performance outputs for the five alternatives for City of Madison's microgrid. As the load increases with no battery constraint, a larger battery is required to optimize the cost-effectiveness of the system, but the average resiliency hours decrease. When specifying a larger battery from the outset to ensure greater resiliency, the net present value quickly becomes negative (though this value does not account for savings in vehicle fuel). The emissions reduction is more significant with the larger battery (and does not account for additional emissions savings from electrifying the fleet). As the City of Madison reviews these results and plans for the future of the microgrid at the site, factors such as the value of resiliency, emissions reduction goals, and BESS financing options will need to be considered.

Table *8*. Madison alternatives: Outputs

Scenario	**Base case**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
BESS capacity (kW)	40	49	417	73	1,308
BESS energy (kWh)	52	65	10,000	96	10,000
Initial Capital Costs	$51,000	$63,000	$4,203,000	$94,000	$4,894,000
Net present value	$5,700	$8,200	-$6,272,000	$7,500	-$5,443,000
Simple Payback	0	0	17	1	>25
Annual Total Renewable Energy	110%	34%	33%	11%	11%
Lifecycle CO_2 emissions (tons)	-1,300	22,400	19,600	92,700	84,800
Emissions reduction	-	2%	14%	1%	9%
Resiliency Hours (Average)	218	218	3,240	10	97

Lessons Learned

In addition to the recommended microgrid configurations for each community, we also identified several lessons learned about the analysis process. These lessons learned are listed here and described in further detail in this section.

1. Pick the appropriate analysis tool for the project.
2. Ensure that a microgrid fits within your larger municipal resiliency plan.
3. Prioritize data collection and start early (and consider implementing a data collection plan across critical facilities).
4. Identify and inventory the critical loads of the site with stakeholder input.
5. Dedicate time to defining the monetary value of resiliency to the facility.
6. Run several scenarios to be able to visualize tradeoffs before determining key alternatives.

Pick the appropriate analysis tools for the project

There are several analysis tools available which can be used to analyze and optimize microgrid and DER projects, with varying strengths and weaknesses. When beginning a feasibility study, it is important to understand the capabilities and purpose of each tool to make sure that the appropriate tool (or tools) is used for the analysis. Performing this comparison early in the project with feedback from stakeholders is important to make sure everyone understands the project objective and how different tools can be used to analyze the options available to meet that objective.

In addition to the technical capabilities of each tool, it is also important to consider things like the interface, license, and how the tool connects to other project efforts. For this project, REopt's open-source license and API were important; for other projects, tools which can interface with microgrid controllers (such as Esyst) or more detailed financial models (such as Homer and DER-VET) may be preferrable.

Ensure that a microgrid fits within your larger city resiliency plan

Being intentional about the needs of the microgrid and how it fits into a larger community resiliency plan is vital to developing applicable alternatives through a feasibility study. As the Madison streets and engineering site has generators onsite, it had relatively well-defined critical load and resiliency needs. However, the Sun Prairie CRC required more thought around the services and benefits a microgrid on-site would provide the community. Important considerations included the energy needs for key services to be provided, such as heating and cooling, charging stations, or electric vehicle charging.

Along with this, it is important to define how the microgrid contributes to the city's larger resiliency plan. For example, Sun Prairie considered if there was vital equipment that could be brought to the library during an outage to power important city functions. It also examined how the services the library would provide would be a part of a larger resiliency plan.

The involvement of multiple stakeholders, including facility staff, community members, and emergency operations staff can aid in this process and ensure that the microgrid addresses the needs for the parties impacted. Leader et al. (2021) provides a framework which can be used to guide these discussions.

Prioritize data collection and start early

The quality and quantity of primary data collected directly impacts the relevance and robustness of the results for the proposed microgrid. Key data to collect should cover the building energy loads (both electric and natural gas). Electric interval data should be collected where available or a robust plan for estimating an hourly load profile and calibrating this to actual usage should be developed. If electrification of vehicles or natural gas-burning heating equipment is planned, determine how to translate the available data (typically annual or monthly) into hourly intervals. To meet the objectives of resilience and financial performance, a microgrid needs to carefully balance loads, sources, and storage elements, all of which fluctuate in real-time. Having robust interval data is vital for determining technology sizes when backup power is a requirement of the microgrid. After completing this exercise for the planned microgrid, it is highly recommended to implement a data collection plan for other critical municipal facilities, to aid in future resiliency planning.

We also found that there are several intricacies to the required inputs of the tools, including financial data, rebates at the utility, state, and federal level, current utility rate and potential utility rates. For that reason, it is important to budget time to collect data, review and organize the data, and determine additional inputs.

Identify and inventory the critical loads of the site

The amount of load that must be sustained during an outage is a key factor in the size of storage required for a microgrid, and the resulting financial feasibility of the system. Both Madison and Sun Prairie scenarios showed that only powering critical loads during outages greatly improved the financial performance of the system. To address this need, it is important to take the time to identify and quantify what energy uses are essential to serve the needs of the site during an outage.

For the Sun Prairie microgrid, we utilized Clean Coalition's VOR123 methodology. The methodology suggests that most buildings can split their load into three tiers. The stakeholders at the library identified which rooms in the library and which plug loads fit into each category. To supplement this estimation, sites could also utilize submetering to fully understand the hourly profile of critical loads.

If a building has vital electric vehicles on-site, an extra consideration is to determine which vehicles would require charging during outages or other emergencies. Identifying the critical load profile of these vehicles will be highly specific to the facility and the municipality; this is an emerging area of research where best practices are still being developed. In some cases, vehicle to grid (V2G) may also be an option, where the stored energy in certain vehicles could be used to charge critical vehicles or provide power for the facility.

Dedicate time to defining the monetary value of resiliency to the facility

The results presented in this paper did not include the value of resiliency as the stakeholders wanted to understand the financial payback when only including direct cost savings. However, the value of a microgrid is directly related to its ability to provide resiliency, and our scenario analysis illustrated that it could often change the conclusions around which system was most cost-effective in the long-term.

Methods to value resiliency often do not consider long-term outages, so work to decide how much resiliency is valued by the community should be completed in future projects. NREL's Customer Damage Function Calculator is one bottom-up approach to consider while valuing resiliency.

Run several scenarios to visualize tradeoffs

There is significant benefit in running multiple scenarios through the optimization tools to visualize tradeoffs and identify the top priorities of the system. Microgrids are an emerging technology, and a feasibility study is often the first time that a municipality has examined the potential for this type of system. The comparison of results from multiple scenarios can help municipalities better understand the capabilities of the system, and the financial impact of renewable energy or resiliency constraints. The concrete performance results of the various scenarios can then fuel further municipal discussions and decisions about the most important constraints for the system, including upfront costs, ability to sustain an outage, or total renewable energy contribution. For both municipalities, the high-level results from the initial scenario runs helped them hone in on the top considerations for the final alternatives of interest.

Conclusion

These feasibility studies of two microgrids provided detailed information that will help the municipalities consider the potential for improved resiliency and renewable energy. We identified top alternative system configurations for each of the communities and analyzed the financial, resiliency, and renewable energy performance. The feasibility studies are a first step for municipalities to consider how they can ensure continuity of services and community centers for residents during extreme weather events and power outages. The lessons learned about most applicable tools, best practices for analysis methodology and stakeholder engagement process, and tradeoffs can inform other communities and help facilitate more successful considerations of microgrids and CRCs for municipalities across the nation.

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