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Microgrid/Nanogrid Project Proposals using HOMER Energy for Economic, Performance, and Environmental Optimization and Estimates.

T. DASTALFO
University of Pittsburgh
USA

J. PETTI
Dominion Energy
USA

K. KELLY-PITOU
University of Pittsburgh
USA

G. REED
University of Pittsburgh
USA

SUMMARY

The concepts behind Hybrid Optimization of Multiple Energy Resources (HOMER) were started at the National Renewable Energy Laboratory (NREL) over 25 years ago and taken commercial in 2009 becoming the independent company HOMER Energy LLC. HOMER is a microgrid/nanogrid (MG/NG) analysis and optimization software that helps planners make optimal decisions with regards to quantity and type of electrical and thermal generating resources used at a facility. HOMER can provide a high-level analysis of different possible MG/NG system designs, and presents useful data that pertains to hourly load profile, generation capabilities, economics, and emissions, eliminating the need for customized cost-benefit models. NG's are becoming an increasingly important part of modern power systems due to increases in data gathering and increased sensor use [1]. HOMER Energy is a valuable tool to further MG/NG projects from an initial discussion/proposal to being funded and built thanks to its powerful cost benefit, system functionality, and environmental impact analysis tools.

The work in this paper details how HOMER Energy was used to successfully propose a NG project in Millvale, Pennsylvania. The goal of the project was to renovate the old Loyal Order of the Moose Lodge to develop a community resilience center. The community resilience center will showcase how renewable energy can help contribute to lowered costs, levels of carbon emissions, and also increased reliability. As a special point of emphasis, the evaluation looked to see how Direct Current (DC) system designs could help contribute to one of the lowest-carbon commercial installations in the City of Pittsburgh. To achieve these goals, a NG was proposed with photovoltaic (PV) power, battery storage, a power converter, a grid connection, and a DC bus within the building. The proposal was accepted, and the project is currently in the process of being funded and planned.

KEYWORDS

Nanogrid (NG), Microgrid (MG), Proposal, Optimization, Projection, Hybrid Optimization of Multiple Energy Resources (HOMER), Estimates

thomas.dastalfo@pitt.edu

INTRODUCTION

The technological advances that are being made in the power industry are perhaps the industry's most dynamic in an already impressive, but traditionally conservative, history of innovation. Whether discussing new power electronics topologies, the integration of smart grid operations, or the possibility to use direct-current (DC) transmission, the discussions contributing to the "ideal grid" are becoming more complicated by the day. At the same time as these rapid technology deployments, there is also an increased push for a cleaner and smarter grid. Consumers are increasingly more concerned about their environmental impact, industry and government alike have called for emissions reductions goals for present day and in the future, sparking a growth in renewable energy integration and monitoring of carbon emissions.

Both renewable energy integration and lowered levels of environmental impact call for new methods and equipment previously unseen in the traditional centralized power system. Nanogrids (NGs) are a rising trend that incorporate both renewable energy and smart controls to operate a system more efficiently. NGs can monitor energy generation and load demand with sensors, then use the data to more effectively meet the dynamic needs of the system. NGs also offer the possibility of selling power produced on-site to the power grid when demand on the grid is high, or offer the possibility of automatically programming deferrable loads, such as dishwashers for example, to be run at a time when demand on the grid is low. NGs can then be connected to form a "grid of microgrids," thus allowing higher penetrations of the positive effects of NGs into the local energy portfolio. Additionally, DC-based Distributed Energy Resources (DER's) and loads combined with MG/NG installations and storage have begun being used as replacements for traditional back-up generation assets in systems where resilience and continuity of power is paramount. Recently, it has also been proposed that microgrids (MGs), or independent power systems, can also be used to help increase broader resiliency in urban environments, but also be placed strategically to help increase the amount of renewables within the broader grid system, and thus, help contribute to broader decarbonization efforts [2]. This was a primary driving factor behind proposing a DC NG at the Millvale Moose, to renewably and efficiently increase system resiliency in a flood prone area, and to prove the NG DC concept that could promote wide scale urban decarbonization, increased renewable penetration, and resilience even in power outage prone areas.

The benefits of MGs and NGs are already being harnessed in commercial systems. U.C. Irvine Campus Smart Grid (SG) is an example of a MG project. This SG incorporates solar, battery storage, a MG controller, a central natural gas combined heat and power plant (CHP plant) and a grid tie. A benefit analysis of this project found that the UC Irvine Campus SG is highly successful in a number of areas. This analysis defined a benefit/cost ratio where benefit was a qualitatively determined value that depends on the sum of all benefits a certain component brings to the MG, which is then weighed versus the monetary cost of that component. The natural gas CHP plant provided a benefit/cost ratio of 4.0, where most of the benefit comes from meeting almost all of the campus' heat and electricity from cheap and efficient natural gas. The ~3.6 MW of solar installations had a benefit/cost ratio of 3.2, which mostly stemmed from the reduction in CHP plant output during the day, as PV generation is highest during this time. The MG controller showed the highest benefit/cost ratio of any component in the system, having an astounding benefit/cost ratio of 212. This stems from increasing MG islanding and reconnection capability, increased efficiency of islanded and grid-tied operation, increasing resiliency of the surrounding neighbourhood due to local generation, and increased efficiency and reliability of the overall system. Finally, the lithium-ion battery storage had a benefit/cost ratio of 6.8, which mainly stems from the fact that it was able to provide energy to cover for small transient mismatches between load and generation [3]. This benefit analysis shows the large positive impact on system performance that comes from having a controllable MG, and also that solar and battery storage work well together within a MG system. However, this benefit analysis did not consider environmental benefits and weigh it against cost; it only considered system performance versus cost. This lack of environmental analysis is a gap that HOMER Energy is able to fill, even in the proposal stage.

The Millvale Moose project was proposed using similar components as the UC Irvine Campus SG project, albeit on a NG scale. The Millvale Moose project proposal also included a DC bus within the building, so that energy could be saved by avoiding unnecessary DC-AC inversions, as the much of the generation and load is DC. The performance/cost benefits of the UC Irvine Campus SG project also apply to the smaller scale Millvale Moose NG project. However, with HOMER Energy, the team from Pitt was also able to analyse the environmental benefits of the project in the proposal phase and weigh them versus cost and performance. The community of Millvale is flood prone which compromises the reliability of the power distribution grid in the area [4]. Flooding is most prone in the spring through early fall but, HOMER analysis shows that the NG has the generating and storage capability to stay islanded from the grid almost 24/7, and even produce surplus energy for the community at times. The Moose NG is in a unique position to be a showcase in the greater Pittsburgh area for renewable energy and DC NG systems, acting as a model for others to follow.

PROJECT DESCRIPTION AND SIMULATION INPUTS

The Millvale Moose is a 10,000 ft^2 community space located at 112 Sherman St. in Millvale, PA. The purpose of the Moose's Energy Modernization Project is to upgrade an old building into a resilient, efficient, and technologically advanced facility for the local community. This project will serve as an example and model for others on the smart power technologies that exist right now and are ready for widespread installation. The result of the widespread use of these technologies being a cleaner, smarter, and more efficiently powered community of the future.

Millvale Moose's daily average electricity usage during March-August 2017 is 52.49 kWh, according to Duquesne Light Co. metering data. HOMER's load profile database was harnessed to scale this data to the load profile of a small office building (5500ft^2) in the Pittsburgh area. The price of electricity is 6.61 cents/kWh for a building of this class. The proposed solar array on the roof, quoted by Energy Independent Solutions (EIS), is 30.45 kW max capacity, at a total up front cost of $75,250, with a maintenance charge of $8,000 coming 20 years after installation. This comes out to $400 for O&M each year. This means that the solar array costs on average $2,471.26/kW of installed solar or $2.47/W. However, since there are 87 panels total at 350W each, which comes out to $864.94/panel (.350 kW). Based on the data from EIS Solar, these solar panels have a de-rating factor of 80%. The azimuth angle of the proposed setup is 216 degrees or 36 degrees west of south. The tilt angle on the panels is 10 degrees. The DC-AC inverter, costs ~$5,000, and has a 15-year life cycle, coming to ~$.17/W. This data was used as the HOMER simulation parameters. Storage is provided by the sonnenBatterie 12kWh Li-ion battery system that costs ~$13,000 each and has a life cycle of ~20 years. This comes out to about $1,083/kWh for battery storage.

Additionally, The National Renewable Energy Laboratory (NREL) climate data on solar irradiance for the Pittsburgh area was input to calculate PV system generating capabilities, hour by hour, for an entire simulated year. The simulation output optimized the system by choosing the best components based on best system Net Present Cost (NPC), best environment impact (Renewable Penetration), and overall system performance for a variety of different combinations of solar and storage systems.

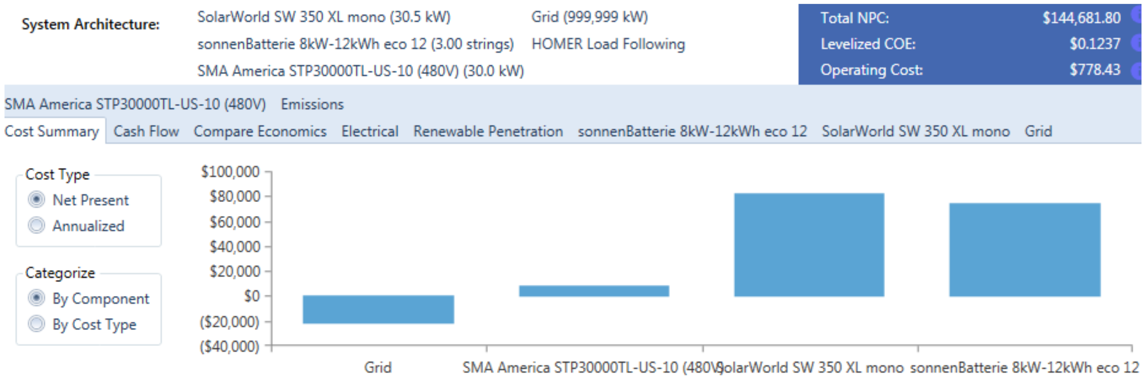
The results of a specifically chosen combination of solar, storage, and converter sizes are shown in all five figures in the next section. The simulation results of a multitude of different system component combinations were sorted by hand, because NPC is HOMER's default optimization parameter but there are other important parameters in the proposal, such as renewable penetration, environmental impact, and the system performance of each combination of system components. The owners of the Moose and the foundations funding the project expressed strong interest in having the best positive environmental impact and system performance, with NPC being the least important factor as long as upfront costs were reasonable.

In the HOMER simulations the system uses load following controls, meaning energy is only bought from the grid when there is not enough being generated by PV or available in battery storage to meet the load demand. This model also assumes a grid sellback price of $.05/kWh when overproduction occurs and there is no tax credit refund on the solar generation, as the Moose is run by a non-profit organization. The best system, based on optimization using the three criteria described above, utilized 30.45 kW of solar generation, 36 kWh of Li-ion battery storage, and a 30 kW power inverter (DC-AC). The capital costs, replacement costs, and O&M costs for all of the system components were taken from manufacturer websites, company quotes, or expert estimations.

Other systems used larger amounts of battery storage in order to island for longer periods of time, but this had little effect on positive environmental impact and had a strong negative effect on NPC, especially upfront costs. The maximum amount of solar was used for the available space on the rooftop of the Moose. Additionally, the load was kept on an AC bus for this simulation, because there is a lack of commercially available bi-directional DC-AC converters to model the system with, and also because there as a lack of commercially load components (lighting, motors, computers, EV chargers, etc.) that will currently run off of a DC bus even though these loads may be inherently DC. These technologies all currently must be fed AC, and in their connection to the AC bus they include rectifiers that rectify the AC to DC. This is unnecessary conversion and is created unnecessary conversion losses but is currently standard industry practice because DC buses are not common technology yet. This is something that is expected to change in the near future [5].

HOMER ENERGY SIMULATION RESULTS

Figure 1 shows the NPC of the system including the three components described above, including 15-year replacement costs for the batteries and converter and operation and maintenance costs of the system. Grid value is generating revenue because the model assumes $.05/kWh grid buyback price. Includes all system components at the top.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Grid	$0.00	$0.00	($22,651.28)	$0.00	$0.00	($22,651.28)
SMA America STP30000TL-US-10 (480V)	$5,000.00	$6,729.34	$0.00	$0.00	($2,734.34)	$8,995.00
SolarWorld SW 350 XL mono	$75,249.78	$0.00	$7,987.06	$0.00	$0.00	$83,236.84
sonnenBatterie 8kW-12kWh eco 12	$39,000.00	$57,951.95	$26,137.05	$0.00	($47,987.73)	$75,101.27
System	$119,249.78	$64,681.29	$11,472.82	$0.00	($50,722.07)	$144,681.83

Figure 1: The NPC of proposed NG

Figure 2 shows the Millvale Moose's hourly load usage, scaled for the average day in each month of the year. Modeled/scaled around HOMER's default commercial load profile, assuming July peak load. The peak load on extreme days is about 5.47 kW.

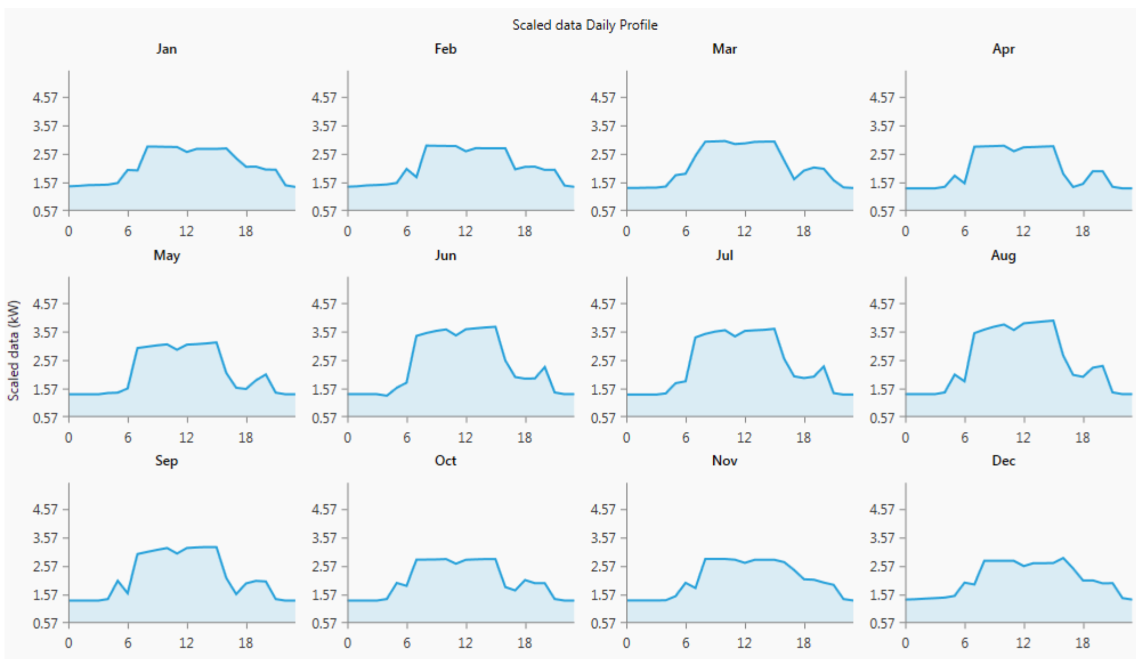


Figure 2: Millvale Moose Daily load profile.

Figure 3 shows a plot of this, this, and this throughout a week in July. The yellow line is estimated hourly solar production for 06/29-07/5 using 30.5 kW of solar panels, NREL solar irradiance data for Millvale, PA. The green line is the amount of power sold to the grid. The red line is estimated hourly load for same time period. Finally, the blue line is the amount of energy stored in the batteries at any given hour during this time period (scale on top right [kWh]), showing how batteries keep the building powered at night and during low solar irradiance days, without having to buy grid power.

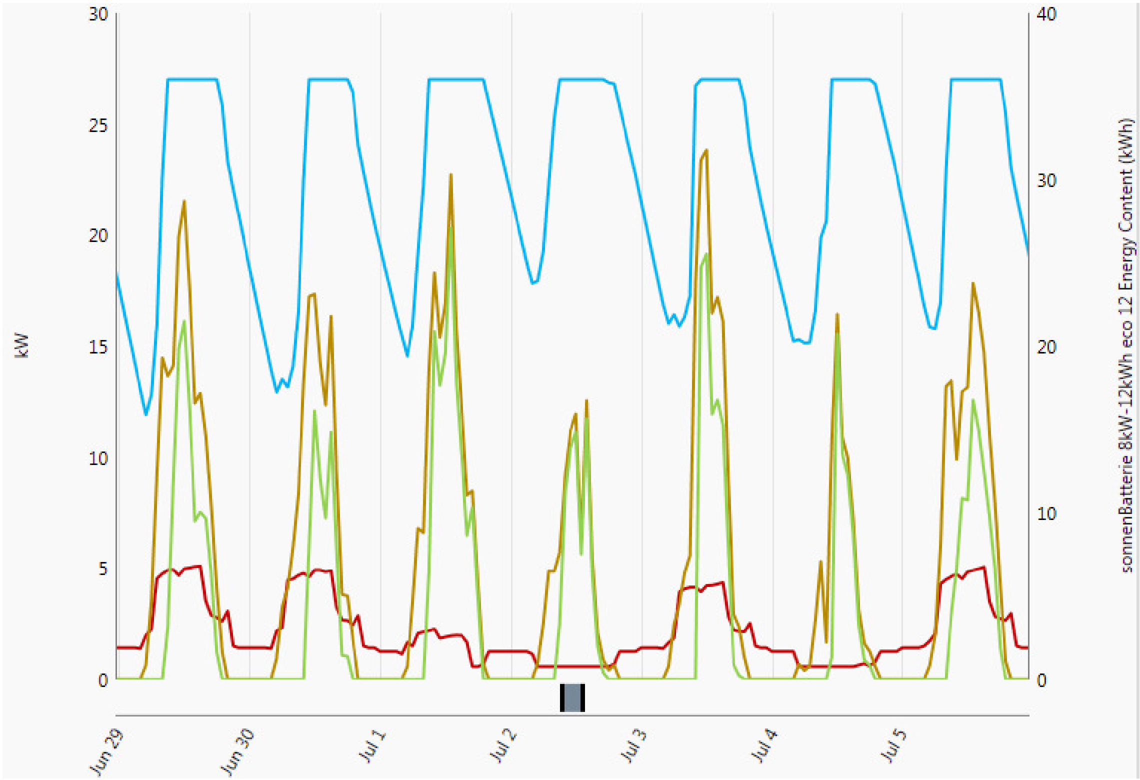


Figure 3: Hourly solar production, load, energy storage, and power sold to grid for the Moose.

The following three figures contain three graphs that demonstrate the solar power production vs. power bought from grid for the Moose NG. Figure 4 shows that the amount of solar production, ~35,500 kWh/year, far outweighs the amount of energy that must be purchased from the grid, ~2,101 kWh/year.

Production	kWh/yr	%
SolarWorld SW 350 XL mono	35,470	94.4
Grid Purchases	2,101	5.59
Total	37,572	100

Consumption	kWh/yr	%
AC Primary Load	19,159	53.5
DC Primary Load	0	0
Grid Sales	16,644	46.5
Total	35,803	100

Quantity	kWh/yr	%
Excess Electricity	0	0
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	94.1
Max. Renew. Penetration	2,546

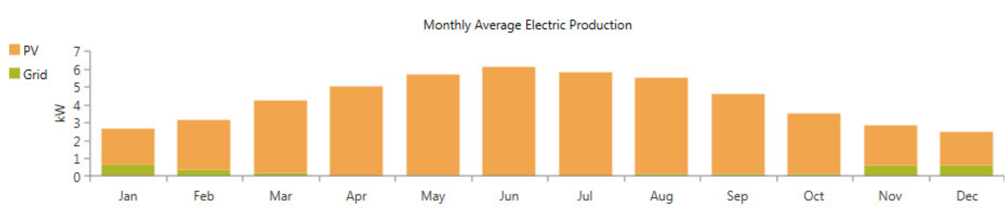


Figure 4: The sources of energy consumed by the Millvale Moose.

Figure 5 shows how much solar energy is produced each hour each day of the projected year based on imported NREL solar irradiance data for the local area.

Quantity	Value	Units
Rated Capacity	30.5	kW
Mean Output	4.05	kW
Mean Output	97.2	kWh/d
Capacity Factor	13.3	%
Total Production	35,470	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	27.1	kW
PV Penetration	185	%
Hours of Operation	4,385	hrs/yr
Levelized Cost	0.0718	$/kWh

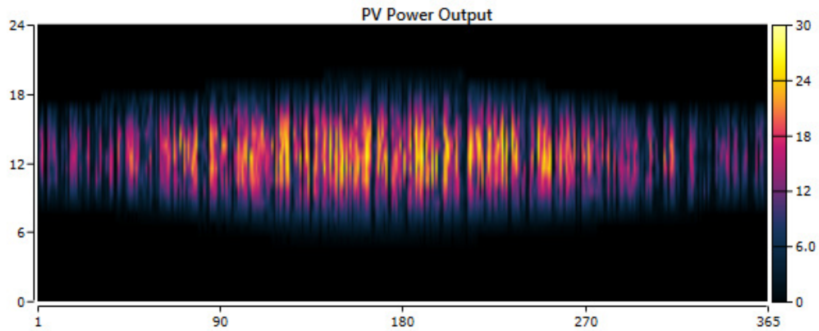


Figure 5: The projected daily/hourly solar production for the system for an average year.

From Figure 6, it can be seen that the batteries have enough capacity to smooth out a day or two of low solar irradiance during the peak production season without having to buy power from grid, but not in winter when solar irradiance is low for months at a time. This is when buying some power from grid becomes necessary to improve system resiliency in the case of multiple days of low solar irradiance, which is common in Pittsburgh winters. It also shows that during the summer months, during peak flooding season, the NG system is almost entirely self-sufficient and able to be islanded, increasing system resiliency in a flood prone area during the height of flooding season.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
June	0	2,515	-2,515	0	($125.75)	$0
July	0	2,379	-2,379	0	($118.95)	$0
August	111	2,035	-1,924	5	($94.41)	$0
September	104	1,559	-1,456	4	($71.12)	$0
October	100	928	-827	4	($39.75)	$0
November	449	407	42	4	$9.30	$0
December	451	146	305	4	$22.50	$0
Annual	2,101	16,644	-14,543	5	($693.32)	$0

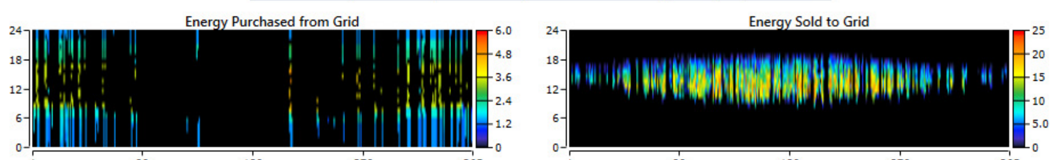


Figure 6: Graphs showing the daily/hourly purchases and sales of energy between the Moose and the grid.

Finally, Figure 7 shows the projected environmental impact of the system. These numbers are achieved by assuming default HOMER average values of 632 g/kWh CO_2, 2.74 g/kWh SO_2, 1.34 g/kWh NO from typical centralized generation plant fuels, such as coal and natural gas. The proposed Moose NG would achieve negative values for CO_2, SO_2, and NO because it actually supplies far cleaner renewable energy to the local grid than it purchases through its grid tie. In summary, on top of being almost completely self-sufficient, the simulation has shown that the Moose NG will also be a local small renewable power generation source for the grid.

Quantity	Value	Units
Carbon Dioxide	-9,191	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	-39.8	kg/yr
Nitrogen Oxides	-19.5	kg/yr

Figure 7: The positive environmental impacts of the 30.45 kW solar/storage/converter/grid-tie system for Moose NG.

CONCLUSIONS

HOMER Energy was utilized to create a NG system and analyze it based on system projections in terms of economic, environmental, and performance results. This paper shows that HOMER software, which uses a dual-economic and environmental optimization model, shows that there are benefits beyond just the technology and performance of MG/NGs. This simulation helps to understand and quantify the environmental benefits that NGs can also bring, specifically in areas where the grid's main generation sources are still heavily carbon-based, such as the Pittsburgh area. This case-study also shows that using NGs for broader community resilience efforts, aka strategically locating-them in places of vulnerability, can help a city and community to become more prepared for storm situations; save money on energy; and reduce their environmental footprint. To put data to these statements, the HOMER simulations projected that economically, even without tax incentives, the solar system on the Moose would generate an average of $693 per year just by selling electricity to the grid, as seen in Figure 6. The simulation also projected that over 25 years the PV system would generate about $22,000, as seen in Figure 1. Both are without even considering the money saved by not having to pay for electricity most days. Environmentally, the simulation projected that the Moose would have a negative carbon footprint of about -9,100 kg CO_2/year, by selling large amounts clean energy to supply the local grid, as seen in Figure 7. It also shows that in the average year, 94% of the Moose's load demand satisfied by on site solar, as seen in Figure 4. System performance predictions can be seen in Figure 3, where an hourly system prediction in July shows that for the whole week shown, the NG system did not need to purchase any energy from the grid and could have feasibly been islanded for a whole week, in the height of flood season, adding resilience to the system and the community. These results were used to successfully propose this project to a group of investors active in the Millvale community and to representatives of multiple local foundations. The success of this proposal shows the potential impact HOMER simulations can have in increasing the penetration of MG/NGs and thus promoting urban decarbonization, renewable penetration, and resilience, helping to create the grid of the future.

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