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The Potential for Grid Defection of Small and Medium Sized Enterprises Using Solar Photovoltaic, Battery and Generator Hybrid Systems

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Abstract:

Grid-tied solar photovoltaic (PV) systems enable lower cost electricity for small and medium size enterprises (SMEs) than they are currently paying for grid electricity in the U.S. These economic realities threaten conventional electric utilities, which have begun manipulating rate structures to reduce the profitability of distributed generation (DG), as well as putting arbitrary caps on DG in their service territories. SMEs may reduce electricity costs, if they can grid defect with hybrid captive power systems made up of solar, battery and generator subsystems. This paper analyzes the technical and economic viability for hybrid solar systems deployed in the commercial sector to enable self-generation. Specifically, for the first time, the economics of grid defection are analyzed for three case studies of SMEs in the northern U.S., which represent a challenging technical case because of long dark winters, but also have high utility costs. The results of the simulations make it clear that grid defection is already viable for SMEs with the current prices for all components in the solar hybrid system. These results were consistent across scale, load-profile, and utility rate. These economic projections included no government incentives or subsidies and can thus be considered extremely conservative for the specific case studies. Policy changes are discussed for

electric utilities to avoid the potential of a utility death spiral in this and similar performing locations.

Keywords: photovoltaic; hybrid system; battery; grid defection; autoproduction; captive power

1. Introduction

In order to prevent global climate change from dangerous destabilization of both nature [1-5] and human conflict [6-8] enormous quantities of carbon-free energy are both possible and required to maintain energy-intensive civilization [9-12]. To be truly sustainable and avoid negative externalities associated with non-renewable alternative energy sources like nuclear power [13-17], this power will need to be supplied by sustainable energy sources like solar photovoltaic (PV) technology [18]. PV converts sunlight directly into electricity with a minimum of environmental externalities [18]. Fortunately, because the learning curve of the PV industry [19-22] has resulted in continuous cost reductions [23,24], the result is a current spot price of PV modules of US\$0.20/W as of April 2019 [25]. With several technical improvements already available such as black silicon [26-28] the International Renewable Energy Agency (IRENA) predicts that the prices will fall by another 60% in the next decade [29]. However, even at current prices, any scale of PV provides a levelized cost of electricity (LCOE) [30] lower than the net metered cost of the grid [31] and with storage costs can go lower [32-36].

In some regions, using PV and storage allows for grid defection already [37,38], while in others with less favorable environmental conditions it is necessary to develop hybrid systems with another source of power [39,40]. Grid defection, where utility customers autoproduce (self-generate) their own electricity, obviously represents a threat to conventional electric utility models [41] and with major fractions of some regions possessing the potential to lower utility rates by either net metering or defection [42], utilities are in a difficult position. Setting electricity rates for a zero marginal cost grid is challenging and some of the changes to rate structures could be honest and logical [43]. However, some utilities actively discourage net

metering by altering rate structures as well as modeling, using legal maneuvers, shifting control, using demand and monthly charges, and setting distributed generation (DG) caps [44]. In a recent study, where most states (30 out of 50) have utilities claiming retail reimbursement for excess electricity generation for DG, only 4 of the 166 utilities analyzed actually implement full net metering [45]. It should, of course, be pointed out there is significant debate in the literature on the appropriateness of net metering, the value of solar and how to set DG rates [46-55]. For the purposes of this study, what the appropriate rate structure should be is less important than the fact that if net metering were fully enabled there would be significantly less incentive for grid defection.

Previous work has shown that the LCOE of a hybrid PV systems allows for captive power and is already competitive with grid utility rates for the residential sector even in challenging environments like the northern U.S. [42]. However many residential customers do not have access to the capital to take advantage of the investment opportunity [42]. Large businesses do have access to the capital and are already commonly investing in solar on a large scale by taking advantage of economies of scale. For example, Google already hit a 100% renewable energy target [55] and WalMart has made a substantial investment in solar [56]. The options for smaller businesses are more constrained because of lack of i) scale, ii) multinational status, and iii) flexible capital. Small and medium sized enterprises (SMEs) are in a situation more akin to an upper middle-class residential home owner – paying high utility prices while having access to the capital to invest in hybrid systems.

This paper is an extension of past research that aims to fill the knowledge gap on the potential of grid defection between the residential sector and large industry by analyzing the technical and economic viability for hybrid solar systems deployed in the commercial sector to enable self-generation. This study specifically examines the economics of grid defection for three case studies of SMEs in the northern climate. The hybrid cogeneration systems evaluated consist of a PV array, battery storage, and natural gas generator. Using current prices of components of this system, along with the load profiles of three representative commercial enterprises, sensitivity analyses are run on these capital costs and the costs of

natural gas to determine the LCOE of a hybrid cogeneration system. This is compared to current and expected utility prices. The results are analyzed, and conclusions are drawn on the potential for hybrid solar systems.

2. Methods

This model will examine the point when grid defection with a PV + battery + generator hybrid system will reach grid parity for SMEs in the Upper Peninsula (UP) of Michigan. The western UP is part of the *taiga* biome (i.e. boreal forest or snow forest), which is one of the more harsh environments in the U.S. due to low solar fluxes, long relatively-dark winters, and large snow accumulation. For this paper SMEs will be considered in the range of 10 kW – >200 kW based on Upper Peninsula Power Company (UPPCO) rates. The UP is known for long and harsh winters with snowfall often exceeding 6.35 m (250 inches) in a winter [57], which makes the operation of a hybrid system more technically challenging than in most other locations in the U.S. because of the severely reduced PV generation during the winter as compared to more temperate climates [58].

The Hybrid Optimization Model for Electric Renewable (HOMER) Pro Microgrid Analysis tool was used to simulate PV + battery + generator hybrid systems deployed in three types of SMEs. HOMER 3.12.5 was used here and has previously been validated experimentally in many types of distributed generation systems [59-63]. HOMER is the micropower optimization hourly simulation model, which simulates different system configurations and generates a list of feasible configurations sorted by net present cost along with output to compare configurations and evaluate them on both economic and technical grounds using sensitivity analysis. The basic modeled PV + battery + generator system has been described previously in detail for smaller residential systems where the generator was a combined heat and power (CHP) unit [39]. This dispatch strategy follows that of a load following system. When the PV array can supply the load, it will be the only component of the system used to supply the load. If the PV array generates greater energy than is required by the load, the excess will be used to charge the battery. If the energy supplied by the PV array is less than the load, the battery will first be used to cover the difference. If these two in tandem are not enough, the battery is

disconnected, and the generator is used with the PV. If the PV and generator are supplying more than the load, the excess is used to charge the battery. Once the battery is charged, the generator is shut off for a time. Finally, if PV and the generator are not enough to meet the requirements of the load, the battery will also be used in the system.

2.1 UP Case Study

The UP is located between the Lower Peninsula of Michigan to the south, Wisconsin to the west, and Lake Superior to the North. The UP is a rural area, consisting of just around 3% of Michigan's population, while being 29% of the state's land area [64]. Most of the year heating in businesses is required and even in the heat of summer; air conditioning is rarely needed [42]. The cost of electricity in the UP is much higher than the national average, in the case of residential costs it is more than twice the national average [52]. The electricity rates for commercial buildings in the UP is 14.72¢/kWh, which is 33.57% higher than the Michigan average rate of 11.02¢/kWh [65] and is 42.72% greater than the national average rate of 10.33¢/kWh [66].

Net metering is available and was offered by UPPCO, however they reached the government mandated minimum of 1% and are no longer accepting interconnection applications for any form of distributed generation. Essentially, this means that UPPCO customers that want to install PV must have systems isolated from the UPPCO grid.

The three case studies that will be analyzed here represent typical SMEs that are in the different scales of loads (<10kW, 10kW-200kW, >200kW) and SMEs that are present and common in the UP: 1) small office building, 2) stand-alone retail building, and 3) a large hotel. A complete economic profile of the different SMEs and their loads was not available, however, the case studies represent common observed load profiles and businesses in the area (e.g. partially because the utility rates are high heavy manufacturing working on a 24 hour/day continuous cycle is less common than a small stand-alone retail building or office for example).

2.1.1 Estimating Electricity Consumption in the UP

The three cases cover three different energy rates provided by UPPCO as well as represent common types of businesses for the area of interest. The hourly load profiles for each of the three cases can be found at [67] and are shown in Figure 1. The average commercial electricity consumption in Michigan is 6,159 kWh/month which is 1.27% less than the national average of 6,238 kWh/month [65]. It is interesting to note that the amount of electricity consumed is less than the national average, but costs well more than the national average.

Figure 1: Daily electric load profiles for the three case studies: 1) small office, 2) stand-alone retail, and 3) large hotel [67].

2.1.2 Electricity Rates in the UP

Three case studies will be evaluated for three different plans that are offered by UPPCO and summarized in Table 1: C1, which is a general commercial electric plan for buildings that have an average load under 10 kW; P1, which is another general commercial plan for businesses that have an average load between 10 kW and 200 kW; and CP-U which is a general commercial plan for businesses with an average load above 200 kW [68]. For the

CP-U plan rates, this analysis uses UPPCOs 'secondary rate, which is for businesses receiving secondary voltage deliveries under 6 kV.

Table 1. UPPCO rates summarized for C1, P1 and CP-U plans [68].

Rate plan	C1	P1	CP-U
Service Charge/year [\$]	204	420	3000
Energy Charge [\$/kWh]	.05760	0.01801	0.09003 peak 0.05854 off peak
Energy optimization surcharge [\$]	4.25	42.65	578.3
Power Supply Cost Recovery (\$/kWh)	0.00399	0.00399	0.00399
Demand Charge (\$ per kW)	N/A	4	2.60
Power Supply Service (Non-Capacity Capacity \$/kWh)	0.08924 0.02181	1.87 7.32 (per kW) (\$0.0847/kWh)	4.94 6.11 (per kW)
kWh max kW	62171.8 14.83	278205 94.12	2265562 679.47
Effective Rate * [\$ /kWh]	0.1541	0.112	0.094
* The effective rate is calculated using the average energy charge associated with each plan, the distribution service charge, power supply service charge, power supply cost, and the energy optimization surcharge as laid out by the UPPCO rate book.			

The rates associated with these plans have been steadily increasing over the past 10 years for modernization of the utility infrastructure and operational systems and are summarized in Figures 2 and 3 [69] and correspond with the rates in Michigan [70]. The energy mix for the utility is 39% coal, 27% nuclear, 13% gas, 21% hydro, 5% renewable fuels, and less than 1% solar, which makes it slightly less dependent on coal, nuclear, and natural gas than the regional average and about 20% more hydroelectric [71]. This is an issue that has been

gaining public attention as the electric rates in the state of Michigan is already 16.76% higher than the national average for the residential district, and 5.68% higher than the national average for the commercial sector [66]. The rates in the UP are even higher than the rest of Michigan, especially in the UPPCO service territory, which is 40.54% higher than the rest of Michigan, and 64.56% higher than the national average [65]. This higher electric rates should be noted.

Figure 2: Service charge rates for UPPCO plan.

Figure 3: Electric energy charge rates for UPPCO plans.

2.2 Hybrid System design

Following the approach of by [39,40,42], a generic hybrid system was designed to meet the load profile of the three types SMEs in the UP, consisting of a PV array, natural gas generator, and battery storage subsystems. In the modeling the load would always be able to met by appropriate sizing of the generator.

2.2.1. PV system

The initial installed costs for the PV system will be modeled at a rate of \$1.83/Wdc, which is the current national average cost of commercial PV systems that includes capital and project development costs [72]. The PV system is over-sized due to the reduced solar hours in the winter, which will cause some amount of excess energy in the summer months. The solar flux for the Houghton/Hancock area (located in the central Keweenaw Peninsula in the northern part of the UP) from the NREL National Solar Radiation database which is typical meteorological year (TYM3) data averaged between 2005-2014 was used [73]. Due to

economy of scale and increasing efficiencies of PV the cost per watt is projected to reach \$0.28/W to \$0.46/W by 2025 [74].

2.2.2. Generator system

This paper will not be looking into the optimization of the dispatch strategies and design of hybrid systems as they have been discussed at length [74-78]. Many of these former studies used cogeneration with combined heat and power (CHP), but this technology is still not readily commercially available with support in the UPPCO service territory, so here less-efficient but readily available natural gas generators are sized so that they can supply any energy shortage from the PV array or battery. Because generators operate at discrete levels, the size of the unit will need to be large enough to cover the difference between the need of the load and the energy produced by the PV array and what is present in the battery. All the systems are assumed to come with a standard 15-year warranty with varying operational hours. The model dispatch strategy will minimize use of the generator unit, which will keep the run time low leading to a longer life as well as keeping the fuel costs and corresponding greenhouse gasses (GHG) emissions to a minimum. While natural gas generator units as well as CHPs run on natural gas produce GHG emissions they still are generally smaller compared with GHG that are produced by power plants that feed into the grid [77]. This is because the combined energy utilization from the CHP (both heat and electricity) is greater than power plants that do not make use of heat, even if their electric conversion rate is higher than that of the CHP. In the future, this may not be the case of centralized power plants in the U.S. begin to use more combined heat and power.

For the simulations run for this study, natural gas generators were used and were sized according to the peak load of each case. For the 1) small office building, 2) stand-alone retail building, and 3) large hotel a 20kW, 60kW, 762kW generator was used, respectively. There was a 15-year replacement cost factored into the system cost in the simulation. The generator will only be used when the energy provided by the solar and battery system are less than the required load of the building. For operation and maintenance cost (O&M), \$2.8/MWh was

assumed based on previous research [40]. So this O&M cost broken down into a working hour of 8 hours per day for 5 days each week gives \$0.08 per operating hour. This will later be used in HOMER simulation.

2.2.3. Storage

Due to the northern latitude and climate of Houghton Michigan, the storage system will be sized to cover half a day of no sun when at full charge. This way in the long winter, when the solar flux for this area is lower, the system will be able to last longer on the PV array + battery without using the natural gas generator. This will increase the renewable energy percentage of the system, as the natural gas generator is the only component of the system that is not a renewable energy source. During the winter in the U.P. the median solar flux is $1,000\text{W/m}^2$ for under 2 hours/day, this is for 5 months of the year. During this time the natural gas generator is used to meet the load demand and charge the batteries for the amount that the PV array is not able to, and during the summer months when solar energy is more prevalent the generator will be used less, which will in turn extend the life of the generator. The dispatch strategy for this type of arrangement was discussed in detail elsewhere [79-84].

The average cost for a battery for a lithium-ion storage system is \$209/kWh and is set to decrease down to under \$100/kWh by 2025 according to Bloomberg New Energy Finance [85]. This also falls within Euro100-200/kWh near term projections in the literature [86].

The lifetime of the battery was assumed to be 10 years [40] and this replacement cost was factored into the simulation and considered for optimization.

2.3 Simulations

This study will be using the simulation software HOMER to calculate the levelized cost of electricity (LCOE) [30] of the cogeneration system and compared to the utility rates from UPPCO. The price of natural gas will be modeled at the most recent price for commercial customers in Michigan that is \$0.28/m³ [87].

It was assumed that all commercial installations will be financed by a loan with a 2.99% interest rate from the non-profit program Michigan Saves [88], which helps businesses fund alternative energy options. The cost of natural gas was modeled to include the current price up to the worst-case price projected in Energy Information Administration projections throughout the entire U.S.[89].

Table 2. Sensitivity analysis variables and increments.

Variable	Low	High	Increment
PV System Cost (USD/Wp)	0.5 [29]	2.0 [90]	0.25
Natural Gas Prices (USD/m ³) [Note: 1m ³ of NG = 0.0353 MMbtu)	0.20 [89]	1.0 [89]	0.2
Battery Storage (USD/kWh)	100 [85]	225 [85]	25
Minimum Renewable Energy Fraction (%)	10	80	5
Interest Rate (%)	2	6	1

3. Results and Discussion

3.1 Results

This section will discuss the results from the simulations as described in Section 2.3. Each specific case will be discussed individually, looking at the results of whether grid defection for commercial enterprises is currently viable, as well as looking to the future using projected

prices. The different case studies represent different increments in size of the total power of the systems.

3.1.2 Small Office Building Case

The small office building in Houghton, MI had a peak load of 14.83 kW and a yearly use of roughly 62,000 kWh. This would put the building into UPPCO's general commercial service plan (C1), which is available for any commercial customer with a peak load less than 25 kW. When all fees are included this plan has an effective rate of \$0.15/kWh. It is notable that using current prices for the hybrid system, the LCOE was \$0.138/kWh, which is 8% less than the current utility rate. This price was found using current prices of the components and natural gas (from Section 2); however, the system had a renewable energy fraction of 20%. The highest renewable energy fraction that was achieved using current prices while still being under the effective rate for the C1 plan was 35%.

The results of the simulations are summarized in Figures 4, 5, and 6. In Figure 4 the sensitivity of the LCOE of the hybrid system is shown for varying the PV cost while maintaining the costs of the natural gas (NG) constant and as a function of the battery price multiplier. Figure 5 shows the same analysis for battery costs. In all cases, the solar hybrid system provides lower cost energy than the grid at current natural gas prices.

Figure 4: Cost of electricity for small office building on the C1 plan, incrementing the price of PV panels and holding the cost of NG constant.

Figure 5: Cost of electricity for small office building on the C1 plan, incrementing the price of the battery storage subsystem while holding the natural gas cost constant.

Figure 6: Cost of electricity for small office building on the C1 plan, incrementing the price of natural gas as well as PV and battery costs.

In Figure 6, it is clear that the escalation of the natural gas costs has a significant detrimental effect on the LCOE of the hybrid system. Although currently the hybrid system is less expensive than utility rates, the sensitivity range of the PV and battery component costs can only maintain a lower LCOE if the natural gas costs remain under \$0.35/m³.

3.1.3 Stand Alone Retail Building Case

The second case of a stand-alone retail building in Houghton MI had a peak load of 94.12 kW and a yearly use of roughly 278,205 kWh. This would put the stand-alone retail building into UPPCO's light and power service plan (P1). The P1 plan is available for any commercial customer with a peak load between 25 kW and 200 kW. When all fees are included the P1 has an effective rate of \$0.112/kWh. The results are summarized in Figures 7, 8 and 9, where the LCOE is shown for incrementing the PV multiplier for different battery costs, the same for incrementing the battery costs for different PV costs, and then for incrementing natural gas

costs. Similarly to the small office case study, at current natural gas costs all the costs of the solar hybrid systems result in lower LCOE costs than current grid electricity. Using current prices for the hybrid system the LCOE is \$0.106, which is 5.3% less than grid electricity under the C1. This is done with a 5% renewable energy fraction. The highest renewable energy fraction that was achieved using current prices was 10%.

Figure 7: Cost of electricity for a stand-alone retail building on the P1 plan, incrementing the price of natural gas as well as PV and battery costs.

Figure 8: Cost of electricity for a stand-alone retail building on the P1 plan, incrementing the price of battery.

Figure 9: Cost of electricity for a stand-alone retail building on the P1 plan, incrementing the price of natural gas as well as battery and PV costs.

Again, when the cost of natural gas increases the solar hybrid system provides a lower LCOE if the gas costs remain under \$0.25/m³.

3.1.4 Large Hotel Building Case

The third case study is for a large hotel building in Houghton, MI, which has a peak load of 679.47 kW and a yearly use of roughly 2,265,562 kWh. This would put the building into UPPCO's large commercial and industrial service plan (CP-U). The CP-U plan is available for any commercial customer with a peak load above 200 kW. This plan when all fees are included had an effective rate of \$0.094/kWh. Using current costs for the solar hybrid system the LCOE will be \$0.067, which is substantially less expensive (28.7%) than the CP-U, just as it was for the C1 and P1 plans. The highest renewable energy fraction that had a LCOE under \$0.094/kWh was 20% at \$ 0.093621/kWh. Figures 10-12 summarize the results, where again Figures 10 and 11 show that the solar hybrid system is always substantially less costly than grid electricity. Figure 12 shows that the gas costs would need to increase to \$0.3/m³ for the hybrid system to be uncompetitive with grid electricity.

Figure 10: Cost of electricity for a large hotel building on the CP-U plan, incrementing the price of PV.

Figure 11: Cost of electricity for a large hotel building on the CP-U plan, incrementing the price of battery.

Figure 12: Cost of electricity for a large hotel building on the CP-U plan, incrementing the price of natural gas as well as PV and battery costs.

For a hybrid system with current costs, the net present costs for the larger systems is shown in Table 3. The net present cost includes the initial capital investment, fuel costs, operating costs, and replacement costs. The net present cost, return on investment, savings per year, and total lifetime savings are summarized in Table 3 below.

Table 3: Economic summary of hybrid system in stand-alone retail and a large hotel.

	Stand-alone retail	Large Hotel
Net Present Cost [\$]	370,192.2	2,812,102
Grid Service Costs [\$/25years]	778,974	5,324,070.70
Saving/Year [\$ /year]	2,114.36	8291.96
Total Lifetime Savings [\$]	52859	207,299
Initial Capital	52,371	905,278
Renewable Energy	6.18	10.1

Fraction [%]		
ROI [%]	7.7	4.1

From Table 3, the return on investment is positive in all cases. The renewable energy fractions are relatively modest, for the lowest costs, but as the PV-generated fraction increases the impact of natural gas prices on total costs decrease, thereby giving business owners security from price volatility. For the smallest loads considering grid defection, use of a generator was still profitable compared to grid electricity.

3.2 Discussion

The results of the simulations make it clear that grid defection is already viable for commercial enterprises in Houghton MI with the current prices for all components in the solar hybrid system although at a relatively low renewable energy fraction. These results were consistent across scale, load-profile, and utility rate. It should be emphasized that these economic projections included no government incentives or subsidies of any kind and can thus be considered extremely conservative. This was done to eliminate any risk due to policy changes at the U.S. federal level, which would make the estimates provided here inaccurate. In addition, the prices for some of the components (PV and battery [91]) are projected to decrease significantly in the next five years, which will give customers an even greater return on investment and a greater fraction of energy coming from the sun. There is thus also a clear need to improve both PV and battery performance to further help decrease these costs to enable a higher renewable energy fraction.

The solar hybrid systems are even more profitable than the simulations would indicate because of the available tax incentives. First, the renewable energy tax credit allows the system owner to effectively reduce system costs by 30% [92]. This federal investment tax credit is available at 30% through 2019 and steps down to 26% in 2020, 22% in 2021, and then after reduces to 10% for commercial and industrial systems [93]. In addition, business owned systems are also eligible for MACRS (Modified Accelerated Cost Recovery System) 5 years of 100% bonus depreciation for systems installed after September 27, 2017 [94]. This

means that the whole solar hybrid project's applicable tax depreciation is accelerated to the first year of the system's commissioning [95]. This is important for SMEs as they see comparatively more value because electricity expenses are paid with after-tax dollars. In addition, states offer various solar energy property tax incentives, providing various amounts of tax exemptions on commercial and industrial solar PV systems [96]. A final tax incentive opportunity is for SMEs installing PV to use the creation of Opportunity Zones [97]. This mechanism allows for [97]: 1) the temporary deferral of including gross income for gains that are reinvested in a qualified opportunity fund and 2) exclusion of up to fifteen percent of gain on original investments, that are deferred by the investment in the qualified opportunity fund if held for seven years, 3) the taxpayer may elect to exclude the post-acquisition gains on investments from gross income in qualified opportunity funds that are held for at least ten years and 4) opportunity zone tax benefits can be layered on top of the Renewable Energy Investment Tax Credits and accelerated depreciation to make an even better investment.

A certain risk associated with the projected cost of the system is the cost of natural gas. Due to the low renewable energy fraction for the system, most of the energy is coming from the generators, which means that currently the variable that will have the biggest effect on the LCOE of the systems is natural gas. The projected cost of natural gas in most cases for the next five years are to increase and in the best case remain the same as current prices [98]. The production of natural gas is projected to grow at a rate constant with consumption. The price of gas does have a significant effect on the LCOE of the system, if the price of gas were to raise to \$1/m³, 5 times the current cost, it would multiply the cost per kWh by just over 3 times the value stated above in every case. That said, natural gas cost increases would also be expected to raise utility rates at a comparable rate, so this risk is somewhat mitigated. It can be further mitigated moving from a simple natural gas generator to cogen, which is far more efficient. However, to be sustainable because of the leak rates associated with the natural gas infrastructure other types of hybrid systems should be explored.

The results shown in this paper are favorable now, and with the declining costs of components commercially sized cogeneration will continue to be more attractive to SME's.

As interest in these types of systems increase the prices of components will continue to decline. This decrease in system costs coupled with the projected increase of grid utility prices could lead to a positive feedback loop, otherwise known as the utility death spiral [99]. The possibility of a utility death spiral is especially possible in the U.P. of Michigan due to the extraordinarily high utility rates that are present [42], which is the reason that a cogeneration system is already viable.

To combat this potential scenario, and to offer customers a choice to receive more energy from renewable sources UPPCO has announced the UPPCO Green program [58]. This plan offers energy from hydro, wind, solar, and biomass sources and says that as demand increases more renewable energy will be added. This program is a way for customers to buy “blocks” of renewable energy from this plan, which is a way for customers to invest in renewable sources that will be fed into the grid. The renewable energy from this program is fed directly into the grid, not to individual customers, and will not decrease the amount of money customers are paying for electricity as it is an extra fee that will be added to customers’ bills should they choose to participate in it. This, however, results in an increase costs for consumers to purchase lower-cost electricity, so it may not be overly convincing to SMEs. As SMEs grid defect in bulk this will also be expected to raise rates on remaining electricity customers, driving a utility death spiral that SMEs catalyzed. To avoid this, another approach electric utilities like UPPCO could take would be to lift the cap on DG to enable grid-tied net-metered systems and actively support such PV systems. This would keep customers for grid defection and maintain the existence of their companies. At the same time it would allow SMEs that do want to decrease their costs to obtain much higher renewable energy fractions economically by installing large net-metered PV systems.

Future work in this area that would be of interest would be to conduct the same simulations in other areas in the country and in other countries with different energy costs and annual solar fluxes. For example, similar work was shown to be promising in Nigeria [100]. These systems, however, had a relatively small renewable energy fraction. For systems that are pure solar+battery systems, grid defection is significantly more technically challenging [101-

103]. In order to overcome this challenge and move the renewable energy fraction to 100%, future work is needed to look at climate neutral generators (e.g. wood chip cogen units, biogas generators, and other forms of storage) and their potential to couple to PV and conventional battery-based storage systems.

4. Conclusions

Based on the results of this study it is clear that it is already technically and economically viable for all scales of commercial utility customers to install a solar, battery and natural gas hybrid electricity generation system. All SMEs would profit from grid defection with current system component prices and without taking into account any federal or state incentives. In addition, the price of gas does have a significant effect on the LCOE of the system, if the price of gas were to increase five fold, it would increase the cost per kWh three fold. The natural gas costs would also raise utility rates, so this risk is somewhat mitigated. Taken all together, these results would indicate that mass grid defection is eminent without policy changes. As prices go down on solar hybrid system components and more customers decide to become auto-generators and grid defect, electric utility rates increase as time goes on. This makes it even more attractive for customers to defect from the grid, and will allow for a greater renewable energy fraction of the power supply. Currently defecting from the grid presents a large upfront cost, but a large return on investment, but this initial investment will continue to decrease as more time, money, and public support for renewable energy research increases. Electric utilities should consider making grid-tied net metering more attractive to SMEs so they remain customers to avoid a utility death spiral.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Highlights

- Northern US small & medium size enterprises (SMEs) self generation economics
- Grid defection via hybrid solar photovoltaic, battery & generator technically viable
- At current costs grid defection with solar hybrid system profitable
- Utilities can encourage distributed generation to prevent utility death spiral
- Grid defection is slightly sensitive to natural gas costs