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Value of Energy Continuity for Commercial Photovoltaic Systems with Battery Storage

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Abstract

This paper presents a model that computes the payback period of photovoltaic systems with battery storage (PVBS). The model, termed SPPEEDI (SAIDI Payback Period Evaluation for Extended Duration Interruption), incorporates savings from avoided business interruption with utilization of PVBS. While the PVBS system can produce clean energy and maintain energy continuity, its prohibitive cost of installation is a barrier to widespread adoption. By using the SPPEEDI model and incorporating avoided business interruption in evaluating PVBS payback periods, the model allows for a more accurate estimate of the return on investment for PVBS. This analysis identifies key grid outage thresholds where commercial PVBS could be a better investment than conventional photovoltaic systems.

Keywords: *Commercial battery storage, photovoltaics, energy continuity, SAIDI, electric grid interruption,*

1. Introduction

Business continuity should be considered when analyzing the value of photovoltaic systems with battery storage (PVBS). Grid interruption can be very costly to businesses and PVBS can maintain electricity throughout an outage, preventing potential business interruptions and related financial losses. Accurate evaluation of payback periods requires that the value of energy continuity during grid outages be taken into account. This paper introduces a model, termed SPPEEDI (SAIDI Payback Period Evaluation for Extended Duration Interruption), that more accurately evaluates payback periods of PVBS by taking avoided lost revenue from grid outages into consideration. By comparing investments in PVBS to investments in PV, this paper identifies grid outage levels necessary for PVBS to surpass PV as an investment opportunity.

To account for grid outages, the SPPEEDI model uses the System Average Interruption Duration Index (SAIDI), an international standard used to quantify reported outage duration. SAIDI represents the annual cumulative amount of grid interruption experienced by the average customer. It is calculated by dividing the total minutes of sustained customer interruption (interruptions over 1-5 minutes, depending on the local definition) (CPUC 2015, NERC 2010) in a given year by the number of total customers served by the utility (eq. 1). Thus, this measure provides an estimate of the average number of minutes of sustained grid downtime a single customer would experience in a given year. Outages shorter than "sustained customer interruptions" are defined as momentary outages and are not considered in this analysis.

$$\frac{\text{Sum of annual sustained interruption durations for all customers}}{\text{Total number of customers served}} = \text{SAIDI} \qquad \text{(eq. 1)}$$

SAIDI is useful for estimating losses to individual customers and can be translated into the additional value of PVBS as avoided losses. Many commercial entities track these statistics themselves for internal use. For application in analyzing investments in PVBS for a single business, internally collected data is often more reliable than utility provided data and can provide customized estimates of PVBS payback periods when applied to the SPPEEDI model. Although the quality of reported SAIDI data is inconsistent and often incomplete (LaCommare & Eto, 2004), it can be useful as a broad average. Readers can replace SAIDI figures and financial loss estimates used in this analysis directly with internally collected data for more accurate estimates of PVBS payback periods on a case-by-case basis. In this analysis, the SPPEEDI model is applied to a broad range of reported SAIDI values reflecting 12-years of reported outage data covering 150

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US utilities (Larsen et al. 2014). A range of 0-15,000 minutes of SAIDI was chosen for this analysis to reflect the content of this data set.

2. Methodology

2.1. Case Study Specifications

This analysis uses a commercial sector case study because commercial losses from grid interruption far outpace losses in the residential and industrial sectors, making up 72% of total losses in the US in 2004 (LaCommare & Eto, 2004). Since Walmart has already introduced PV installations on a large scale to existing stores to cut energy costs and was ranked #1 in installed solar capacity among commercial entities in the US in 2014 (SEIA 2014), it is reasonable to assume Walmart would continue to invest in solar, specifically PVBS if it becomes a more attractive investment than PV. Hence, a typical Walmart Supercenter will serve as the analysis case study. For this case study, nine scenarios are considered, taking into account variability in solar insolation and total installed system costs. These scenarios can be seen in Table 1.

Table 1: Walmart Superstore Case Study Scenarios

Current costs, Low Insolation	Current costs, Medium Insolation	Current costs, High Insolation
Near-term costs, Low Insolation	Near-term costs, Medium Insolation	Near-term costs, High Insolation
Long-term costs, Low Insolation	Long-term costs, Medium Insolation	Long-term costs, High Insolation

Solar insolation levels of 4.5 $kWh/m^2/d$, 6.0 $kWh/m^2/d$ and 7.5 $kWh/m^2/d$ are used for this study. These values were chosen by creating a histogram of the continental US solar insolation data (NREL 2015b). It was determined that 63% of the data points fall between 4.5-7.5 $kWh/m^2/d$, with a mean of 5.1 $kWh/m^2/d$ and a standard deviation of 1.2 $kWh/m^2/d$. To calculate the total installed system costs of silicon solar panels and lithium ion battery systems, three investment levels are analyzed using current cost estimates (2014 values, NREL 2015a, DOE 2013c), near-term (2020 values, NREL 2015a, DOE 2013b) and long-term (2035 values, NREL 2015a, DOE 2013b) cost projections. The values are compared using real 2015 dollars.

The analysis also takes into account annual operation and maintenance costs (SAM 2015), increasing cost of electricity over time (SAM 2015), panel degradation (SAM 2015), and discount and inflation rates (SAM 2015). To calculate the value of energy produced, the average cost of commercial electricity in the US (EIA 2015) is used. The value of avoided grid interruption is quantified by the amount of revenue that would have been lost had the business been forced to close due to grid outage. Model input values can be found in Table 2.

2.2. Analysis Calculations

The SPPEEDI model executes the following equations in Excel in order to calculate payback periods in all nine scenarios with grid outages varying between 0 –15000 minutes at intervals of 10 minutes.

The SPPEEDI model calculates the avoided revenue losses from using PVBS systems for energy and business continuity during grid outages. Before the losses can be calculated, the average revenue per minute is calculated by dividing Walmart’s annual total sales by the total number of Walmart stores (SBRI 2015, eq. 2). This analysis doesn't take into account that this average includes Walmart stores of different sizes. The current average is assumed to be sufficient for use in the case study.

$$\frac{\text{Walmart annual total sales}\left(\frac{\$}{\text{year}}\right)}{\text{\# of Walmarts}\times 365\left(\frac{\text{days}}{\text{year}}\right)\times 24\left(\frac{\text{hours}}{\text{day}}\right)\times 60\left(\frac{\text{minutes}}{\text{hour}}\right)} = \text{Revenue per minute}\left(\frac{\$}{\text{min}}\right) \quad \text{(eq. 2)}$$

Table 2: Model Inputs (real 2015 dollars)

		References
Battery Storage Installed Costs		
Current Installed Costs (2014)	\$1025/kWh	DOE 2013c
Near-term Installed Costs (2020)	\$256/kWh	DOE 2013b
Long-term Installed Costs (2035)	\$154/kWh	DOE 2013b
Photovoltaics Installed Costs		
Current Installed Costs (2014)	\$2760/kW	NREL 2015a
Near-term Installed Costs (2020)	\$2500/kW	NREL 2015a
Long-term Installed Costs (2035)	\$1750/kW	NREL 2015a
Insolation Values		
Low	4.5 kWh/m^2/d	NREL 2015b
Medium	6 kWh/m^2/d	NREL 2015b
High	7.5 kWh/m^2/d	NREL 2015b
Other Model Inputs		
Walmart Supercenter Revenue per Minute	\$181	Eq. 2
Installed PV Capacity	2600 kW	Eq. 5
Installed Battery Storage	17,400 kWh	Eq. 7
PV Energy Density	148.5 W/m^2	SPR 2015
Walmart Supercenter Average Square Footage	18,300 m^2	SBRI 2015
Walmart Annual Total Sales	\$405 billion	SBRI 2015
Number of Walmart Stores	4255	SBRI 2015
Annual Average Energy Use of Retail Buildings	231.4 kWh/m^2	EIA 2006
Cost of Electricity (\$/kWh)	\$0.1075	EIA 2015
Annual Increase in Cost of Electricity	5%	SAM 2015
Annual PV Degradation Rate	0.5%	SAM 2015
PVBS System Lifetime	25 years	SAM 2015
PV System Lifetime	25 years	SAM 2015
Annual O & M Costs	\$20/yr/kW	SAM 2015
Discount Rate	5.5%	SAM 2015
Inflation Rate	2.5%	SAM 2015

Average revenue per minute for the case study is then multiplied by total annual duration of grid outage experienced, using SAIDI, to find annual avoided revenue losses (eq. 3). The annual avoided revenue losses represent the revenue that would have been lost if PVBS had not been installed. This value will later be applied directly towards paying back the initial cost of the system as savings. This value is calculated for each year throughout the lifetime of the system, in this case 25 years, adjusting for net present value by incorporating inflation and the discount rate. This equation is not applied to PV systems without battery storage because they stop functioning in the case of grid interruption due to safety regulations common throughout the world (IEA 2009), and therefore do not provide energy continuity during grid outage. Net present value was also taken into account by incorporating annually compounding inflation and the discount rate.

$$\text{Revenue per minute } \left(\frac{\$}{\text{min}}\right) \times \text{Annual SAIDI} \left(\frac{\text{minutes of outage}}{\text{year}}\right) = \text{Annual avoided revenue losses} \left(\frac{\$}{\text{year}}\right) \quad \text{(eq. 3)}$$

Sullivan et al. (2009) explores the financial losses incurred during grid outages, finding a range of \$8.1-\$93.3/kWh for electrical interruption cost at multiple outage durations for medium and large commercial and industrial customers, with an average cost per kWh across all outage durations of \$28.04/kWh. The Walmart Superstore case study under consideration assumes an electrical interruption cost of \$22/kWh, a value consistent with the results from Sullivan et al. The interruption cost per unit energy (\$/kWh) is found by dividing the average revenue per minute (eq. 2) by the energy use per minute (eq. 4). The energy use per minute is calculated directly from annual energy use from the Walmart case study (Table 2), assuming that energy use is evenly distributed throughout each day and throughout the year. These values are taken from the first year after investment, with subsequent years being impacted by a discount rate and inflation.

$$\frac{\text{Average revenue per minute}}{\text{Average energy use per minute}} = \text{Interruption cost per unit energy } \left(\frac{\$}{\text{kWh}}\right) \quad \text{(eq. 4)}$$

It is important to note the large range for electrical interruption costs found by Sullivan et al. Depending on the commercial activities, the vulnerability to grid outages can vary by an order of magnitude. The analysis shown in this paper explores an average risk. However, the SPEEDI model can easily be modified to analyze any electrical interruption costs by simply modifying the input parameters in Table 2. This is particularly attractive to businesses that already have estimates for revenue losses during grid outages.

The installed PV capacity for both PVBS and PV is calculated by dividing the annual average energy use by the average annual solar insolation (eq. 5). The annual average energy use is found by multiplying the annual average energy use of retail buildings in the US per m^2 (EIA 2006) by the average Walmart Supercenter floor space (SBRI 2015). The insolation level of 4.5kWh/m^2/d was chosen for sizing the system because it is the lowest insolation included in this analysis and ensures that all systems considered produced enough electricity to supply the Walmart Supercenter case study's needs. The roof space requirements of the system are calculated by multiplying the system size by the average energy density of a range of common solar panels (SPR 2015, eq. 6). The result requires a capacity of at least 2578 kW, with a 2600 kW PV system used for this analysis covering 17,372 m^2, fitting within typical Walmart Supercenter rooftop constraints (SBRI 2015). System losses beyond the photovoltaic efficiency, such as losses in the inverter and wiring, are not considered in this analysis for simplicity.

$$\frac{Annual\ average\ energy\ use\left(\frac{kWh}{year}\right)}{Solar\ insolation\left(\frac{kWh}{m^2 day}\right)\times\frac{365\ days}{year}\times\frac{1\ m^2}{1\ kW}} = Installed\ PV\ Capacity\ (kW) \qquad \text{(eq. 5)}$$

$$\frac{\text{Installed PV capacity (kW)}}{Energy\ density\ \left(\frac{kW}{m^2}\right)} = PV\ system\ roof\ space\ requirements\ (m^2) \qquad \text{(eq.6)}$$

The installed battery storage for the PVBS system is calculated based on surviving a 36-hour break in grid access, the average time of cloud cover during a hurricane (NOAA 2015), at normal electricity consumption levels without losing power. This is done by multiplying the average hourly energy use by a 36-hour break in grid access (eq. 7). Battery discharge factors are not included in this analysis for simplicity.

$$\frac{\text{Annual average energy use}\left(\frac{\text{kWh}}{\text{year}}\right)}{\frac{365\ \text{days}}{\text{year}}\times\frac{24\ \text{hours}}{\text{day}}}\times 36\ \text{hours} = \text{Installed battery storage (kWh)} \qquad \text{(eq. 7)}$$

The annual electricity production by the PV and PVBS systems is then calculated by multiplying the installed capacity by the selected insolation levels, taking panel degradation into account (eq. 8). Without battery storage, revenue flow is assumed to cease during periods of outage. It was also assumed that the PV system without battery storage would stop functioning during grid downtime, as is the current practice in the United States and around the world (IEA 2009). Although the battery-connected PVBS would continue to operate during grid interruption, demonstrating "islanding" capability, production during grid outage was also assumed to be zero because heavy cloud cover during extreme weather would severely limit production. The solar production during outage needs to be subtracted from annual production of both PV and PVBS for this reason (eq. 9).

$$\big(\text{PV installed capacity(kW)} - \text{Degradation (kW)}\big)\times\text{solar insolation}\left(\frac{\text{kWh}}{\text{m}^2\text{d}}\right)\times\frac{1\ \text{m}^2}{1\ \text{kW}}\times\frac{365\ \text{days}}{1\ \text{year}} = \text{Uncorrected annual electricity production}\left(\frac{\text{kWh}}{\text{year}}\right) \qquad \text{(eq. 8)}$$

$$\text{Uncorrected annual solar production}\left(\frac{\text{kW}}{year}\right) - \text{Average energy production}\left(\frac{\text{kWh}}{\text{min}}\right)\times\text{Annual SAIDI}\left(\frac{\text{minutes of outage}}{\text{year}}\right) = \text{Annual electricity production}\left(\frac{\text{kWh}}{\text{year}}\right) \qquad \text{(eq. 9)}$$

The value of the PV electricity production is then calculated by multiplying the average cost of electricity from the grid by the Annual PV electricity production (eq. 10). Annual PV savings can be viewed as profit from electricity that is sold into the grid or savings from electricity not purchased from the grid. Depending on local net metering regulations, prices for electricity purchased from the grid and sold to the grid may differ and should be accounted for when considering other case studies. In this case, they are assumed to be equal. Net present value is also taken into account by incorporating annually compounding inflation and the discount rate, as well as annual predicted increases in electricity cost.

$$\text{Annual electricity production}\left(\frac{\text{kWh}}{\text{year}}\right)\times\text{grid electricity cost}\left(\frac{\$}{\text{kWh}}\right)=\text{Annual PV savings}\left(\frac{\$}{\text{year}}\right)$$
(eq. 10)

The annual avoided revenue losses (eq. 3) and annual PV savings (eq. 10) are then added to find annual total savings (eq. 11). This sum represents the total amount of value received from PV solar production and avoided grid outage each year. The annual avoided revenue losses and annual PV savings are assumed to be evenly distributed throughout the year. Please note that companies can substitute annual avoided revenue losses with their own internally collected figures on outage losses at this point to tailor the SPPEEDI model to analyzing PVBS investments in their own particular situation.

$$\text{Annual avoided revenue losses}\left(\frac{\$}{\text{year}}\right)+\text{Annual PV savings}\left(\frac{\$}{\text{year}}\right)=\text{Annual total savings}\left(\frac{\$}{\text{year}}\right)$$
(eq. 11)

The initial cost of the PVBS system is calculated by multiplying the cost of PV panels per kW by the capacity to be installed, multiplying the cost of battery storage by the capacity to be installed, and adding these two products (eq. 12). For conventional PV systems, the installed battery storage capacity is set to zero.

$$\text{PV panel cost per kW}\left(\frac{\$}{\text{kW}}\right)\times\text{Installed PV capacity (kW)}+$$
$$\text{Battery cost per kWh}\left(\frac{\$}{\text{kWh}}\right)\times\text{Installed battery storage capacity (kWh)}=\text{Initial system cost (\$)}$$
(eq. 12)

The cumulative total savings is then calculated for each year of system operation for each SAIDI value. The whole year payback periods are found with a LOOKUP function that identifies how many years there are before the cumulative total savings exceeds the initial investment cost of the system (eq. 13).

$$\sum_{\text{year}=1}^{\text{Payback period (years)}}\text{Annual total savings (\$)}>\text{Initial system cost (\$)}$$
(eq. 13)

To find payback periods with greater resolution, linear interpolation is used.

2.3. Model Limitations

The SPPEEDI model is based on losses from sustained grid outage, which despite being a large part of costs caused by grid outage, has less total financial impact nationwide in the US than momentary outage. Momentary outages are responsible for 67%, while sustained interruptions account for only 33% of total losses from outages in the US (LaCommare & Eto 2004). In its present form, the SPPEEDI model may underestimate outage losses by not incorporating losses from momentary outages. The SPPEEDI model may also underestimate grid outage losses because extended loss may be compounding, yielding higher loss as duration increases (NARUC 2013b).

A number of other potential financial losses from grid outage are not considered in SPPEEDI, although their financial impact is likely to be smaller than that of either momentary outages or revenue losses (LaCommare & Eto 2004). Lost product, food spoilage, damage to equipment, lack of productivity, restart costs, and data loss can add additional financial loss from grid outages. Furthermore, labor costs could add to losses, if overtime pay is necessary for made-up time, or deduct from losses if worker hours are cut as a result. In calculating financial loss, the SPPEEDI model also does not take into account high-resolution variations, such as season, day of the week, and time of day of outages. The value of supply management optimization (e.g. storing energy at times of low energy prices and selling energy to the grid at time of high energy prices) is also not incorporated into the model and may have an impact on payback periods of PVBS. Opportunity cost of investments in PVBS over competing energy continuity technologies, such as diesel generation, could impact payback period as well. Although the diesel generator is the current standard backup power system for commercial applications, Hotchkiss et al. (2013) showed that microgrids are less likely to survive an outage relying on diesel generators than on PVBS and can create significant costs from both installation and fuel consumption (NARUC 2013a).

The inputs used in this analysis present uncertainty. Future cost projections of PV and battery storage, electricity, and annual operation and maintenance could be effected by many economic or technological factors. Current cost estimates are also averages that may not apply accurately in all regions and in all applications.

While including all of these dimensions in future iterations of the SPPEEDI model could improve accuracy, it is likely to complicate calculations and may decrease broad applicability as companies would have to collect more extensive data for analysis. The current model allows for ease of use and functions with minimal inputs. By inputting data that many companies may already have at hand, this model can easily be applied to investments in PVBS based on the reader's needs.

3. Results

To show the impact of incorporating grid disruption on payback periods, the results compare the payback periods for conventional grid-attached solar systems (PV), PVBS omitting SAIDI, and PVBS including SAIDI. Next, to provide context to the model, PVBS and PV payback periods are compared based on US national SAIDI statistics (Larson 2014). Lastly, the relationship between SAIDI and payback period is explored by showing percent change in payback period for investments in PVBS as a function of SAIDI.

Figure 1: The payback period of PVBS decreases with increases in SAIDI, surpassing the payback period of PV at a SAIDI of 2640 minutes for near-term costs, and medium insolation.

3.1. The Value Of Incorporating Grid Outage

Figure 1 illustrates the change in payback periods by incorporating SAIDI when analyzing the value of PVBS. Without SAIDI (green line), the payback period of PVBS is always higher than that of PV (red line) because of its higher initial investment cost. However, when incorporating SAIDI (blue curve), the payback period for PVBS decreases with additional avoided outage duration, improving on the investment potential in places vulnerable to grid interruption. At the point where the blue curve crosses the red line, PVBS becomes a better investment than PV and has a shorter payback period with SAIDI being taken into account. Current evaluations do not account for SAIDI and are represented by the green curve. The valuation represented by the blue curve internalizes the value of energy continuity and more accurately portrays the investment potential of PVBS. The two PVBS curves diverge significantly as SAIDI continues to increase, showing that PVBS investment analyses in areas vulnerable to extreme weather will be strongly impacted by this novel evaluation.

Table 3: Investments in PVBS vs PV (These are the amounts of SAIDI minutes required for PVBS to become a better investment than PV in different cost scenarios and at different levels of solar insolation)

	Low Insolation	Medium Insolation	High Insolation
Current Cost	7750 minutes	10820 minutes	11690 minutes
Near-term Cost	2090 minutes	2640 minutes	3200 minutes
Long-term Cost	1640 minutes	2120 minutes	2590 minutes

Figure 2: Although high solar insolation decreases payback periods, PVBS financially outperforms PV better in areas of low insolation. Values shown are derived from near-term cost projections.

Table 3 shows the minimum annual SAIDI values required for an investment in PVBS to outperform conventional PV financially. In all scenarios, PV systems without battery storage have the shortest payback period assuming a SAIDI of 0 minutes, where there is no grid interruption throughout the year or SAIDI is not considered. However, at higher levels of SAIDI, PVBS has a shorter payback period than PV. With system costs decreasing, as is predicted in the near and long- term, investments in PVBS outperform PV with increasingly lower SAIDI values. Higher insolation values favor PV systems relative to PVBS (Figure 2). PV systems rely solely on energy production for revenue; whereas, PVBS revenues also incorporate avoided revenue losses from grid interruption. Note the slight upward slope of the PV payback period lines (dark red). This is because PV systems cease functioning during periods of grid outage, losing revenue and increasing payback periods. The effect of this on payback periods is weak compared to that of grid downtime, mainly because the value of electricity production per minute is much lower than the value of avoided revenue losses from grid downtime per minute, as can be seen in Table 4.

Table 4: Value of 1 Minute of Grid Interruption (For each minute of grid interruption, the value of avoided lost revenue from business continuity due to PVBS far exceeds losses from the PV system not producing electricity)

PV Production	-$1.06
Avoided Lost Revenue	$181

Figure 3 shows payback periods in current, near-term, and long-term cost conditions at medium insolation levels. PVBS becomes more competitive at predicted long-term cost levels, because the price of batteries is expected to drop faster than the price of PV. As the cost of batteries continues to account for a smaller portion of the total cost, PVBS becomes competitive with PV at even lower levels of SAIDI.

Figure 3: As prices decrease in the near- and long-term cost scenarios, PVBS becomes competitive with PV at much lower levels of SAIDI. Values shown are derived from medium insolation scenarios.

3.2. Payback Periods With US National SAIDI Values

In a study containing 12 years of data from over 150 utilities nationwide in the United States, Larsen et al. (2014) reported that SAIDI including outages resulting from extreme weather averaged 372.2 minutes in the US. The minimum, maximum, median, and mean of this data set are run through the SPPEEDI model to find nationally relevant payback periods based on actual conditions (Tables 5-7). The "Impact of SAIDI on Payback Period" column in Tables 5-7 shows the percent change in payback periods at each level of grid interruption relative to the base case with no grid interruption. This impact is calculated in eq. 14. The mean, while at the lower end of the SAIDI scale used in this analysis, shows an impact of SAIDI on payback periods between 6.0% and 9.5%. Although the reported maximum value has very short payback periods, this is representative of only a single year at a single utility and does not represent the data as a whole, as shown by the median being lower than the mean. This also points to the fact that although adoption of the SPPEEDI model would accelerate PVBS's progress towards achieving grid parity even at low levels of SAIDI, it will have the most impact on businesses in areas that experience higher SAIDI values, such as those vulnerable to extreme weather or located in regions with unreliable grid access.

$$\left(1 - \frac{\text{PVBS payback period with SAIDI (years)}}{\text{PVBS payback period base case (years)}}\right) \times 100\% = \text{Percent change in PVBS payback period (\%)} \quad \text{(eq. 14)}$$

Table 5: At low insolation (4.5 kWh/m^{2}d), including SAIDI in evaluating PVBS investment decreases the payback period by 8% on average based on near-term cost projections, but could have an impact as high as 84% in regions vulnerable to extreme weather and grid outages.

US National SAIDI Statistics (2000-2012) at Low Insolation	SAIDI (outage minutes)	Payback period (years)			Percent Change in Payback Period		
		Current Costs	Near-term Costs	Long-term Costs	Current Costs	Near-term Costs	Long-term Costs
PVBS Base Case	0	>25	22.1	15.5	NA	0	0
Minimum	1.2	>25	22.1	15.5	NA	~0	~0
Median	173.0	>25	21.3	14.8	NA	-3.8%	-4.5%
Mean	372.2	>25	20.4	14.0	NA	-8.0%	-9.5%
Maximum	14,437.6	9.1	3.8	2.4	NA	-83.0%	-84.3%
PV Base Case	0	15.363	14.084	10.222	0	0	0
PV Mean	372.2	15.377	14.097	10.231	+0.093%	+0.093%	+0.096%

Table 6: At medium insolation (6.0 kWh/m^{2}d), including SAIDI in evaluating PVBS investment decreases the payback period by 6.9% on average based on near-term cost projections, but could have an impact as high as 80% in regions vulnerable to extreme weather and grid outages.

US National SAIDI Statistics (2000-2012) at Medium Insolation	SAIDI (outage minutes)	Payback Period (years)			Percent Change in Payback Period		
		Current Costs	Near-term Costs	Long-term Costs	Current Costs	Near-term Costs	Long-term Costs
PVBS Base Case	0	>25	17.0	11.7	0	0	0
Minimum	1.2	>25	17.0	11.7	~0	~0	~0
Median	173.0	>25	16.5	11.3	NA	-3.2%	-3.8%
Mean	372.2	>25	15.9	10.8	NA	-6.9%	-7.9%
Maximum	14,437.6	9.5	3.6	2.3	NA	-79.1%	-80.3%
PV Base Case	0	11.641	10.639	7.647	0	0	0
PV Mean	372.2	11.650	10.646	7.653	+0.071	+0.071%	+0.073%

Table 7: At high insolation (7.5 kWh/m^{2}d), including SAIDI in evaluating PVBS investment decreases the payback period by 6% on average based on near-term cost projections, but could have an impact as high as 75% in regions vulnerable to extreme weather and grid outages.

US National SAIDI Statistics (2000-2012) at High Insolation	SAIDI (outage minutes)	Payback Period (years)			Percent Change in Payback Period		
		Current Costs	Near-term Costs	Long-term Costs	Current Costs	Near-term Costs	Long-term Costs
PVBS Base Case	0	>25	13.8	9.4	0	0	0
Minimum	1.2	>25	13.8	9.4	NA	~0	~0
Median	173.0	>25	13.4	9.1	NA	-2.8 %	-3.2%
Mean	372.2	>25	13.0	8.8	NA	-6.0%	-6.8%
Maximum	14,437.6	8.1	3.4	2.2	NA	-75.5%	-76.7
PV Base	0	9.360	8.538	6.104	0	0	0
PV Mean	372.2	9.366	8.543	6.107	+0.056%	+0.057%	+0.057

Figure 4 shows the percent change of payback periods for PVBS at different costs and levels of grid outage at medium insolation. This figure draws from the same data as Tables 5-7 and is also calculated using eq. 14. The current cost curve (blue) is set apart from the near- and long-term cost curves because at this cost, the PVBS system does not pay itself off within its 25-year lifetime at SAIDI levels below 2770 minutes.

Fig. 4: The percent change in payback periods from additional SAIDI increases dramatically with additional grid interruption, making investment in PVBS particularly attractive to potential customers in areas vulnerable to grid outage.

4. Conclusion

The model developed for this study incorporates avoided revenue losses from grid outages in evaluating payback periods of investments in PVBS. Grid outages, measured as minutes of SAIDI, can significantly affect payback periods of PVBS and should, therefore, be considered in valuation and investment decisions. Such valuation of investments in PVBS more accurately portrays pertinent financial considerations by internalizing impacts on business continuity of such an investment. Including SAIDI in PVBS valuation also inevitably improves prospective investment in this technology, as grid outages are a consistent challenge of doing business in a grid-connected environment. PVBS can be a better financial investment than PV as well as a more reliable energy continuity measure than backup diesel generators. PVBS investment evaluations are impacted most by including SAIDI in regions vulnerable to extreme weather, as these are the areas that experience the greatest benefits from bolstered energy continuity. Payback periods of PVBS are effected between 6.0-9.5% by incorporating average US national SAIDI values, with outliers experiencing as much as 84% shorter payback periods. As climate change continues to increase the severity and frequency of storms throughout the world (Fischer and Knutti 2015; IPCC 2013), investments in these systems may become even more attractive. The SPPEEDI model, although applied in this study to the United States, can be applied internationally as well. Countries with unreliable grid service or vulnerability to extreme weather would particularly benefit from this model. This model is also very applicable for private industry, allowing businesses to input their own company-specific internal data to calculate the value of an investment in PVBS for themselves. This robust analysis of the value of PVBS can help investors make more informed decisions regarding solar energy and battery storage systems.

5. References

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