http://www.aimspress.com/journal/energy

AIMS Energy, 5(6): 974-996.
DOI: 10.3934/energy.2017.6.974
Received: 13 October 2017
Accepted: 03 December 2017
Published: 11 December 2017

Research article

Investigation of existing financial incentive policies for solar photovoltaic systems in U.S. regions

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Abstract: This paper analyzes some of the existing incentives for solar photovoltaic (PV) energy generation in the U.S. Four types of buildings (e.g., hospitals, large offices, large hotels, and secondary schools) located in five different U.S. states, each having their own incentives, are selected and analyzed for the PV incentive policies. The payback period of the PV system is chosen as an indicator to analyze and critique the effectiveness of each incentive by comparing the payback periods before and after taking the incentive into consideration. Then a parametric analysis is conducted to determine the influence of the variation in key parameters, such as PV system capacity, capital cost of PV, sell back ratio and the performance-based incentive rate, on the performance of the PV system. The results show how the existing incentives can be effectively used to promote the PV systems in the U.S. and how variations of the parameters can impact the payback period of the PV systems. Through the evaluation of the existing incentive policies and the parametric study, this paper demonstrates that the type and level of incentives should be carefully determined in policy-making processes to effectively promote the PV systems.

Keywords: solar photovoltaic; incentive analysis; payback period; parametric analysis

1. Introduction

As a renewable energy, solar photovoltaics have drawn more and more attention all over the world. According to the report of the International Energy Agency (IEA) [1], the world has increased more Solar Photovoltaic (PV) capacity in the four years since 2010 (2014 study) than in the previous four decades before 2010, and in early 2014 the total global capacity overtook 150 gigawatts (GW).

In this report, PV's share of global electricity will reach 16% by 2050, which increases significantly from the 11% goal in the 2010 report.

Despite the fast development of photovoltaic technology, the growth speed of renewable energy capacity, including solar energy, still cannot defeat that of fossil fuel [2,3]. Thus, many scholars focus on improving photovoltaic technology in order to reduce the fossil fuel dependency and to meet a large fraction of increasing electricity demand [4,5,6]. Renno et al. [7] introduced a new method to provide a more accurate evaluation of the electric and thermal production of a point-focus concentration photovoltaic and thermal system. Bianchini et al. [8] carried out 18 months of experiments with 8 different photovoltaic plants. The performance of photovoltaic plants are measured on-site and compared in different environmental conditions. Based on the experimental data, the economic performance is assessed for each photovoltaic plant. Armendariz-Lopez et al. [9] estimated the energy production of photovoltaic technologies on TRNSYS based on a Typical Meteorological Year (TMY). In their research, the energy generation and the cost of the photovoltaic array with different orientations and inclinations were compared. In this comparative analysis, the authors determined the geometric orientations which provide the best life-cycle cost. Adam and Apaydin [10] analyzed the performance of a 500 kWp solar photovoltaic system and explored the contribution of the PV system in reducing the greenhouse gas emission. The result shows that the PV system can reduce the CO_2 emission significantly. Thus, the PV system could be one of the major ways to reduce the CO_2 emission. Kulworawanichpong and Mwambeleko [11] conducted the design and cost analysis of a stand-alone solar photovoltaic system for a rural household as well as identified some common mistakes appearing in the process of sizing, installing and maintaining a solar system. Quesada et al. [12] proposed a tracking strategy for photovoltaic solar system located in high latitude regions and evaluated the performance of the solar tracking photovoltaic panel hourly and seasonally. The result shows that a zenith-set sun tracking strategy is not beneficial for overcast or mostly cloudy days in summer.

In addition, the governments and utility companies of many countries have proposed several incentive polices to promote the application of PV systems. Yuan et al. [13] built a feedback model of China's photovoltaic industry to estimate the influence of investment policy on the developing of PV industry. The result indicates that the investment policy only has a small influence on the price fluctuation and industry overcapacity. De Boeck et al. [14] evaluated the incentive policy for residential PV system installations in the major European markets. In their research, they established a model on the basis of the discounted cash flows of the PV system installation to study the economic viability of a household investment. The result shows that Italy provides the most beneficial incentive polices among the countries studied. Avril et al. [15] assessed the photovoltaic energy policies for five representative countries including France, Germany, Japan, Spain, and the US. The performances of these policies were compared with each other on the basis of financial evaluations. Huo and Zhang [16] reviewed the current development status of the PV industry in China and summarized the experience gained from government interventions including legal framework, market incentives, and manufacturing polices. Based on the overview, they analyzed the future obstacles for the development of PV industry and proposed some suggestions to improve policy interventions. Chou et al. [17] presented a method to evaluate the benefit of installing a PV system with the government financial subsidies, especially feed-in-tariff (FIT) and tax abatement policies. The result shows that the government could promote the development of the PV industry by increasing the FIT prices.

Just like other countries, the United States government and utility companies have proposed many incentive policies to motivate the development of PV systems. This paper provides an analysis of the existing incentives in the U.S. related to photovoltaic (PV) energy generation for selected locations. In this paper, four types of buildings, including hospital, large office, large hotel, and secondary school, located in five different states which each have their own incentives, are selected and analyzed for the PV incentives. Using the EnergyPlus simulation software, the energy consumption of each building is obtained. Then the simulation models of a PV system are established for each building type. The simple payback period, as opposed to discounted payback period, is used for the scope of this analysis since the adjustment of incentives over long-term periods cannot be reasonably predicted. Since the primary focus of this research is effective reduction of payback period through incentives, the simple payback period indicator should serve as effectively as the discounted would for this focus. From the simulation results, the simple payback period of the PV systems in different locations is calculated according to local incentive policies. This payback period is then compared to the one without regard for incentive policies. In this way, the existing incentive policies provided by utility companies in each state are analyzed and critiqued. Finally, a parametric analysis is conducted to investigate the influence of the parameters such as PV system capacity, capital cost of PV, sell back ratio, and the performance-based incentive rate on the performance of the PV system.

2. Solar Photovoltaic Analysis

The energy that can be obtained from a solar photovoltaic system is primarily a function of the performance characteristics of the solar PV modules comprised in the array, with solar radiation and ambient temperature as environmental variables. PV performance characteristics should correspond to the specifications provided by the manufacturer based on experimental tests, and solar radiation data should be obtained from a reliable source that includes data measured over significant periods of time. In this analysis, Typical Meteorological Year 3 (TMY3) data developed and released by National Renewable Energy Laboratory (NREL) is recommended and used. TMY3 provides the users with averaged hourly solar and meteorological data at a specific location derived from the 1961–1990 and 1991–2005 National Solar Radiation Data Base (NSRDB) archives [18]. A defined time step is required for the analysis; one hour is used as the time step in this paper. This section presents an analysis to determine the size of the photovoltaic array according to the methodologies used in Cho and Fumo [19] and Duffie and Beckman [20].

2.1. Solar radiation

The equations proposed to estimate the total solar radiation G_T on the surface of the solar PV array are given in this section. The total solar radiation on the tilted surface of a module is the sum of the direct solar radiation $G_{b,s}$, diffuse solar radiation $G_{d,s}$, and ground reflected solar radiation $G_{r,s}$, which are defined in Eqs. (2), (3), and (4), respectively.

$$G_T = G_{b,s} + G_{d,s} + G_{r,s} \tag{1}$$

$$G_{b,s} = G_b \cos(\theta) \tag{2}$$

$$G_{d,s} = G_d \frac{1+\cos(\beta)}{2} \tag{3}$$

$$G_{r,s} = G_r \frac{1-\cos(\beta)}{2} \tag{4}$$

where θ is the solar angle of incidence and β is the surface tilt of the modules.

The ground reflected solar radiation can be calculated based on the direct and diffuse solar radiation and solar zenith angle as shown in Eq. (5) [21].

$$G_r = (G_b \cos(\Psi) + G_{\mathrm{d}})\rho \tag{5}$$

where Ψ is the solar zenith angle, which is the complementary angle of the solar altitude angle, α_s, and ρ is the ground reflectance. The ground reflectance is assumed to be 0.2, which is the commonly used value in the building energy simulations [21].

2.2. Solar photovoltaic module

The approach proposed in this study uses the model given in Ref. [22] as shown in Eq. (6). The total power levels of the PV array (P_{PV}) are assumed constant over the time step.

$$P_{PV} = A_{surf}\ f_{activ}\, G_T\, \eta_{cell}\, \eta_{invert} \tag{6}$$

where A_{surf} is the net surface area of PV modules, f_{activ} is the fraction of surface area with active solar cells, η_{cell} is the module conversion efficiency, and η_{invert} is the DC to AC conversion efficiency. In general, the PV module conversion efficiency (η_{cell}) can be determined from the manufacturers' specifications.

2.3. Solar availability

The solar maps show the monthly average daily total solar resource information on grid cells, i.e. the solar availability in each location. In solar maps, the values of insolation indicate the solar resource accessible to a photovoltaic panel oriented due south at an angle from horizontal equal to the location latitude, which is a typical orientation used in PV system installation [23].

Figure 1 illustrates the photovoltaic solar resource of the United States, specifically indicating the national solar PV resource potential for all states. In this paper, five locations selected for investigation are Florida, Georgia, Hawaii, Nevada and Vermont. Table 1 shows the representative city as well as maximum and average solar availability for the selected states.

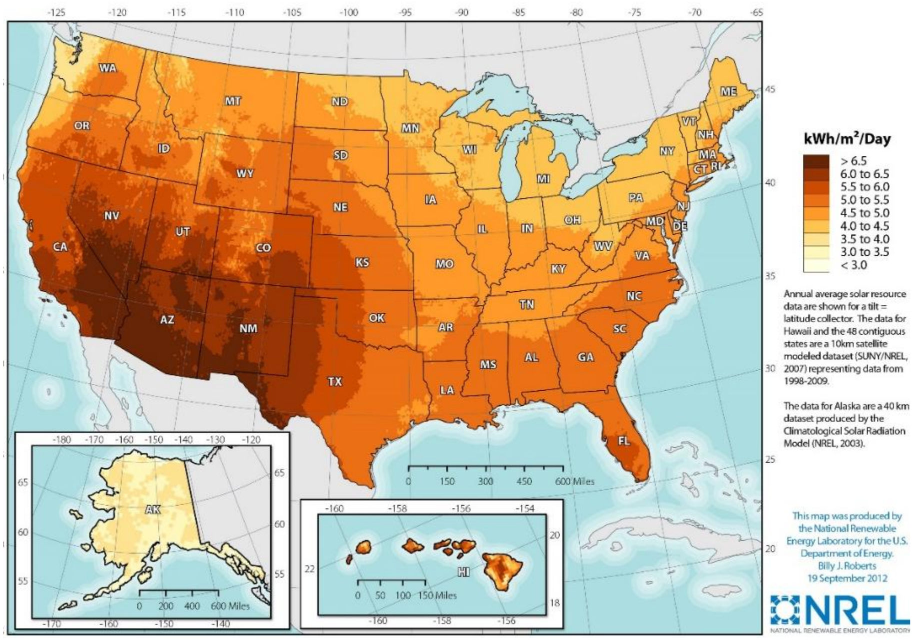

Figure 1. Photovoltaic solar resource of the United States [23].

Table 1. Representative city and solar availability for five selected states.

State	Representative city	Maximum solar availability ($kWh/m^2/Day$)	Average solar availability ($kWh/m^2/Day$)
Florida	Miami	6.0	5.5
Georgia	Atlanta	5.5	5.0
Hawaii	Honolulu	6.5	5.0
Nevada	Las. Vegas	6.5	5.75
Vermont	Montpelier	4.5	4.25

3. Incentive Analysis

3.1. Payback period estimation

In order to determine the simple payback period of a PV system, the cost of installing a PV system and the annual savings earned from the PV system should be known. In this paper, the focus is on the capital cost of a PV system, since it constitutes a large portion of the total cost of the PV system. For a commercial building, the cost for a medium-scale PV system ($Cost_{PV}$) in the U.S. averaged 2.25 $/W [24], and this value is used in this study to estimate the simple payback period. The capital cost of a PV system is calculated as:

$$Cost_c = Cost_{PV} \cdot Cap \tag{7}$$

where Cap represents the capacity of the PV system.

The annual savings are calculated as:

$$\mathrm{AS} = E_{PV} \cdot Cost_e \tag{8}$$

where E_{PV} is the annual useable electricity energy generated by the PV system. $Cost_e$ is the cost of electricity (from the grid). Table 2 shows the electricity price used in the simulation for each location.

Table 2. Electricity prices used in the simulation for each location [25].

State	$Cost_e$ ($/kWh)
Florida	0.0965
Georgia	0.0975
Hawaii	0.2692
Nevada	0.0925
Vermont	0.1451

Then the simple payback period can be estimated as:

$$\mathrm{PB} = Cost_c \,/\, AS \tag{9}$$

If the incentive is taken into the consideration, then the payback period is:

$$PB_i = (Cost_c - In_1) / \left(AS + In_2\right) \tag{10}$$

where PB_i is the simple payback period with incentive policies, and In_1 and In_2 are the incentives on the installation costs (e.g., rebates and tax incentives) and the utility rates (e.g., performance-based incentives), respectively. The incentives on the installation costs (In_1) help diminish the total capital cost while the incentives on the utility rates (In_2) increase the annual savings from the operation.

3.2. Existing incentive structures

In many cases, governments and local utility companies have incentive programs to encourage the use of renewable energy technologies, including PV. This section includes several examples from local utilities in the United States. In this study, two main incentive categories are considered: installation cost incentives and utility rate incentives. The incentives on the installation costs include rebates and tax credits based on the capacity of PV systems in watts and the incentives on the utility rates include performance-based incentives based on the electricity generation and usage from PV systems. Several incentive policies practiced in the U.S. are discussed in this section and compared and analyzed for effectiveness.

3.2.1. Federal incentive

The solar Investment Tax Credit (ITC) is an important federal policy which aims at promoting the development of solar energy in the US. A tax credit allows a person or company to receive a dollar-for-dollar reduction in their income taxes. The ITC is calculated according to the amount of investment in solar systems. The ITC for both the residential and commercial applications are equal to 30 percent of the investment in solar systems [26].

3.2.2. Florida power and light

Florida Power and Light (FPL) has a net metering program that allows customers to connect approved renewable energy systems (including PV arrays) to the grid. This system allows such customers to reduce their electricity bills as well as sell any excess electricity to FPL [27]. FPL also has a solar rebate program for residential and commercial customers who install PV arrays. Commercial customers can earn a rebate of up to $ 50,000 per location [28].

3.2.3. Georgia power

In 2012, Georgia Power, a local utility owned by Southern Company, initiated a plan called the Georgia Power Advanced Solar Initiative (GPASI) [29]. The goal of GPASI is to drive economic growth in the solar industry in Georgia, as well as to encourage development of renewable energy technologies as a whole, without negatively impacting prices or reliability for customers. Georgia Power has developed two programs to help meet that goal: (1) a net metering system to encourage customers to sell distributed solar energy to the utility from small- and medium-scale projects; and (2) an auction scheme to allow solar developers to bring large-scale PV arrays to market.

In addition to GPASI, Georgia Power also provides residents a buyback program which pays a higher price than net metering for electricity generated by solar panels. This buyback program is available to both residential and commercial customers. Electricity generated by photovoltaic systems is purchased back by Georgia Power at a rate of $ 0.17/kWh, for any power capacity up to 5 MW, as opposed to the buyback rate at a retail price (0.0975 $/kWh in Georgia) for typical net metering [30].

3.2.4. Hawaiian electric

Hawaiian Electric Company currently utilizes a feed-in tariff (FIT) program to promote renewable energy technologies. The Hawaii Public Utilities Commission has established three tiers for renewable energy technologies based on the type of technology, the capacity, and the island on which the project is located [31]. The tiers for PV on Oahu are presented in Table 3.

Table 3. Hawaii public utilities commission tiers.

Tier	Project Size
1	0–20 kW
2	Greater than 20 kW and up to and including 500 kW
3	Greater than Tier 2 maximums and up to and including the lesser of 5 MW

The energy payments are determined based on the tier, and therefore capacity, as shown in Table 4.

Table 4. Hawaiian electric PV payment rates.

Tier	FIT Energy Payment Rate ($/kWh)
1	0.218
2	0.189
3	0.197

According to the capacities investigated in this research, Tier 2 and 3 are selected for corresponding situations.

3.2.5. Nevada energy

Nevada Energy offers an incentive program called "RenewableGenerations" [32]. Under this package, solar PV systems with capacities up to and including 25 kW receive an up-front incentive (UFI, dollars per watt), and systems with capacities higher than 25 kW receive a performance-based incentive (PBI, dollars per kilowatt hour). In the current investigation, only PBI is considered because the PV capacities (will be shown in Section 4 and 5) are all larger than 25 kW. The current structure of solar PV incentive rates under the "RenewableGenerations" program is presented in Table 5.

Table 5. Nevada energy PV incentive rates.

Category	PBI ($/kWh)
Public, low-income, non-profit	0.0317
Residential, commercial, industrial	0.0159

Nevada Energy also provides a rebate program for small businesses and public buildings using solar applications. Eligible customers (up to 1 MW) could get paid $ 1.35/W for their solar energy systems with a maximum of $ 310,000 for public facilities; $ 67,500 for small business buildings; and $ 155,000 for schools [33].

3.2.6. Green mountain power

In Vermont, Green Mountain Power has an incentive program called "GMP Solar" for customers who generate electricity from solar arrays [34]. "GMP Solar" is a net metering program. In the event customers generate more energy than they use, customers are compensated for the excess energy according to Vermont state law. Systems with capacities of up to 500 kW are eligible for the net metering program. For those systems eligible for the net metering, an additional benefit of $ 0.043/kWh for the gross generation from solar sources is also available [35].

3.2.7. Summary of existing incentive structures

Table 6 presents a summary of the incentive benefits available in each examined region for commercial buildings. In the Table 6, the column PBI includes not only the PBI incentive in Nevada, but also all the other incentives which pay the customers according to the amount of electricity (kilowatt hours) for their PV system, including the buyback program in Georgia, the FIT program in Hawaii, and the GMP solar program in Vermont.

Table 6. Incentive summary for each location.

	PBI ($/kWh)	Net Metering	Others
Federal Incentive	N/A	N	Tax credit (equal to 30% of investment)
Florida Power and Light (FL)	N/A	Y	Rebate ($ 50,000)
Georgia Power (GA)	0.17 (up to 5 MW)	Y (if no PBI)	N/A
Hawaiian Electric (HI)	0.189; 0.197 (based on capacity)	N	N/A
Nevada Energy (NE)	0.0317; 0.0159 (based on building type)	N	Rebate ($ 1.35/W)
Green Mountain Power (VT)	0.043 (up to 500 kW)	Y(up to 500 kW)	N/A

4. Building Model Description

There are 16 commercial reference building models which are developed by the U.S. Department of Energy (DOE) and represent nearly 70% of the commercial buildings in the U.S [36,37]. With EnergyPlus simulation software, these reference buildings could provide complete descriptions for whole building energy analysis. In this paper, four types of buildings are selected: hospital, large office, large hotel, and secondary school.

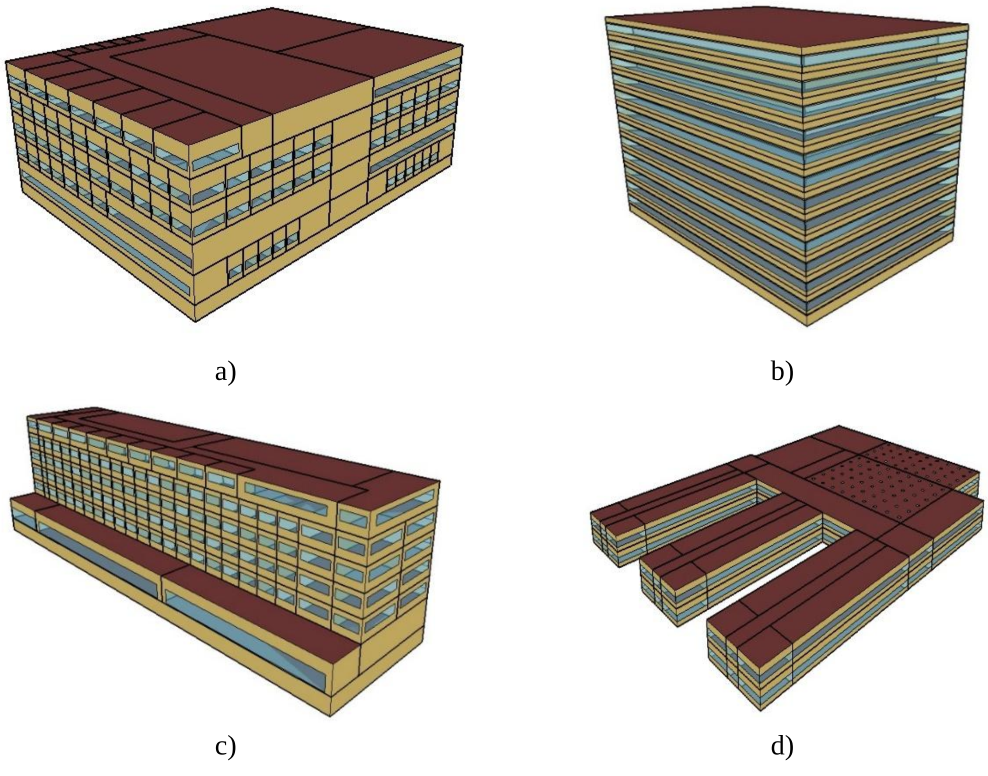

Figure 2. Drawings of the four types of buildings. a) hospital; b) large office; c) large hotel; d) secondary school.

Figure 2 shows the constructional drawings of the four types of buildings [38], respectively. The characteristics of each building type are listed in Table 7.

Table 7. Types and characteristics of the chosen reference buildings.

Building type	Floor area (ft^2)	Number of floors
Hospital	241,351	5
Large office	498,588	12
Large hotel	122,120	6
Secondary school	210,887	2

These four building types were chosen because the electrical energy consumptions in those buildings are relatively large compared to other DOE's commercial reference building models, so that the existing PV incentives can be effectively evaluated with the consideration of its capacity limit in some states' incentive policies. In addition, the feasibility of PV systems in different types of buildings can be effectively demonstrated using those four building types because each building has unique electric load profiles.

In this paper, the hourly electric energy consumptions, e_{con}, for each building in different locations are obtained by simulating those reference building models in EnergyPlus software. Then the PV models are run in the Mathcad software to simulate the hourly electricity generation, e_{gen}, of the PV system. The hourly difference between onsite electric energy consumption and generation can be estimated as:

$$\Delta e = e_{gen} - e_{con} \tag{11}$$

When $\Delta e > 0$, part of the electricity generated by the PV is not used by the building, thus is wasted if not considering any incentives (e.g., net metering or feed-in-tariff). A larger Δe value implies that more electricity would be wasted. When $\Delta e < 0$, excess electricity needs be imported from the grid to meet the electricity demand of the building. A larger magnitude negative Δe value means that more electricity would be imported. Figure 3 shows the hourly electricity consumption, generation and difference in an arbitrary day for a building. Furthermore, the annual positive difference (PD) and negative difference (ND) can be determined by summing positive Δe and negative Δe for the entire simulation period, respectively, as shown Eqs. (12) and (13).

$$PD = \sum_{i=1}^{8760} \Delta e_i \quad \text{if} \quad \Delta e_i > 0 \tag{12}$$

$$ND = \sum_{i=1}^{8760} \Delta e_i \quad \text{if} \quad \Delta e_i < 0 \tag{13}$$

Then the PD and ND can be normalized by its PV capacity using Eqs. (14) and (15) and the normalized PD and ND values are shown in Table 8.

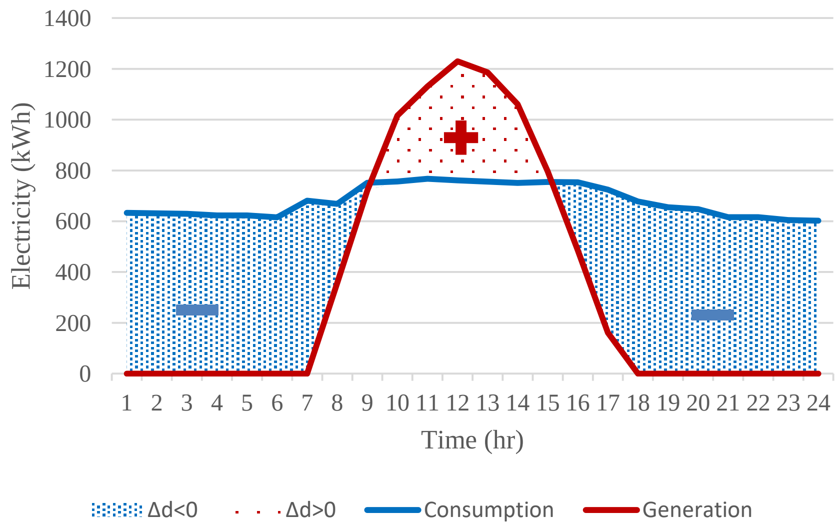

Figure 3. Hourly electricity consumption, generation and the difference in an arbitrary day.

Table 8. Annual total difference between hourly electricity generation and consumption normalized by its PV capacity (MWh/kW).

	Hospital		Large office		Large hotel		Secondary school	
	$\overline{PD}$	$\overline{ND}$	$\overline{PD}$	$\overline{ND}$	$\overline{PD}$	$\overline{ND}$	$\overline{PD}$	$\overline{ND}$
Florida	0.053	–4.047	0.181	–2.591	0.268	–3.400	0.437	–1.474
Georgia	0.086	–3.407	0.244	–2.157	0.395	–2.933	0.605	–1.019
Hawaii	0.080	–3.397	0.218	–2.281	0.352	–3.148	0.512	–1.262
Nevada	0.244	–2.803	0.486	–1.751	0.634	–2.702	0.902	–0.935
Vermont	0.095	–3.234	0.255	–2.018	0.327	–2.752	0.566	–0.927

$$\overline{PD} = \frac{PD}{Cap} \tag{14}$$

$$\overline{ND} = \frac{ND}{Cap} \tag{15}$$

$\overline{PD}$ indicates the excess electricity generated onsite per kilowatt capacity and $\overline{ND}$ shows the electricity imported from the grid per kilowatt capacity. By normalizing the PD and ND, the influence of PV capacity on the annual difference can be estimated. This information will be useful when the simple payback periods with/without any incentives for various buildings are compared in subsequent discussions for Figure 5.

Table 9 indicates the peak electricity load for four kinds of buildings in all locations. This information will be used to decide the capacity of PV array for each kind of building in subsequent discussions for Figure 5.

Table 9. Peak electricity load for each kind of building in all locations [Unit: kW].

	Hospital	Large office	Large hotel	Secondary school
Florida	1341	1689	434	1228
Georgia	1262	1553	426	1101
Hawaii	1218	1565	417	1108
Nevada	1188	1478	476	1202
Vermont	1182	1497	404	938

Figure 4 shows the monthly electric load for the four kinds of reference buildings in all five locations. It can be seen from Figure 4 that the electric load for the hospital and large office buildings are much higher than that for the large hotel and secondary school buildings. For each building type, the electric load in Florida and Hawaii are higher than that in other states during most times of the year due to larger air conditioning requirement, and the electric load in Vermont is the least among five locations.

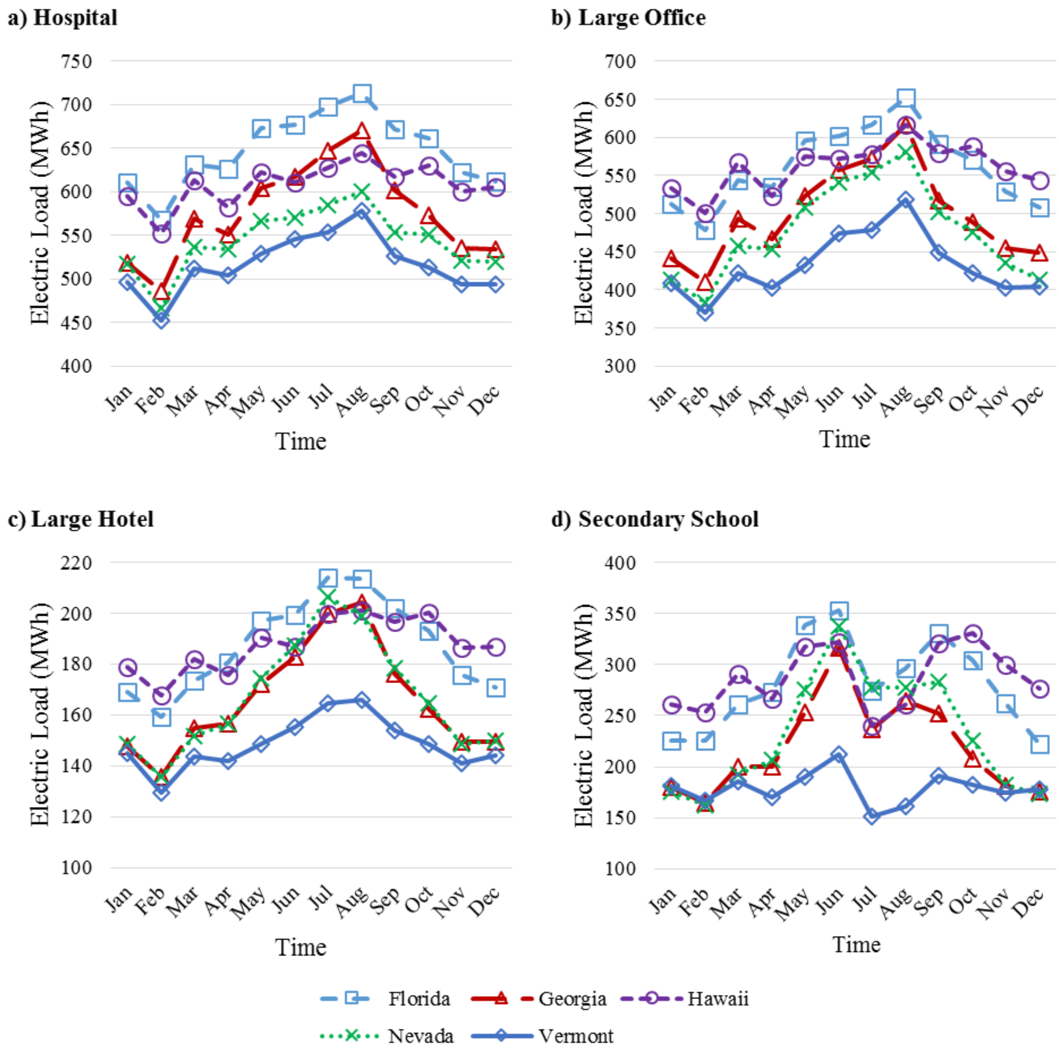

Figure 4. Monthly electric load for the reference buildings in all locations. a) hospital; b) large office; c) large hotel; d) secondary school.

5. Results and Discussion

In this section, the results of simple payback periods for each building type in all locations are compared with each other. Then the parameter study is conducted in order to reveal the influence of each parameter on the payback period of a PV system. Note that all incentives listed in Table 6 are used for the calculation of the payback period with incentive in each figure unless specifically mentioned otherwise.

5.1. Payback period analysis

Figure 5 shows the results of payback period analysis with and without the existing incentive policies in each location for four different buildings including hospital, large office, large hotel, and secondary school. In this part, the capacity of the PV array is selected based on the maximum electricity load of each building type. The selected capacities are 1400 kW, 1700 kW, 480 kW, and 1300 kW for the hospital, large office, large hotel, and secondary school, respectively. For each building type, the payback period of a PV system is calculated based on the local incentive policies (as described in Section 3.2) and then compared to the case without considering incentives. The findings from the simulation results shown in Figure 5 are discussed in detail below:

- In all locations, the PV system for hospital building possesses the shortest payback period before incentive policies are taken into consideration, while the PV system for secondary school has the longest payback period. As can be seen from Table 8, the hospital building in each location processes the lowest normalized positive difference ($\overline{PD}$), which means the waste of the generated electricity is the lowest among all building types when the incentive policies are not taken into consideration. This explains well why the hospital has the shortest payback period without incentives. Table 8 also shows that $\overline{PD}$ becomes larger in the order of hospital, large office, large hotel and secondary school although the order magnitude of their PV capacities do not follow this order. With this observation, one can explain why the payback period becomes bigger in the order of hospital, large office, large hotel and secondary school in Figure 5.
- When the incentive policies are adopted, the payback period can be significantly reduced in most locations and building types. The payback periods for all building types in most locations become less than 10 years after the incentives are applied. Considering the expected lifespan of the PV modules in the market is between 20 and 30 years [1], reducing the payback period below 10 years with the incentives in each selected state can effectively promote the PV installations in their states. However, the level of reduction can vary depending on the location and building type (i.e., the reduction in the payback period varies approximately from 2 to 11 years). Interestingly, one can also observe from Figure 5 that the level of payback period reduction decreases in the order of secondary school, large hotel, large office and hospital when the incentives are considered in the calculation. This is the exact opposite trend compared to that without the incentives mentioned above. It means that the larger $\overline{PD}$ would result the larger reduction of payback period because those buildings have more excess electricity would benefit more from the PBI and net metering policies.
- It is important to mention here that the incentive policy from Green Mountain Power in Vermont (i.e., a PBI of 0.043 $/kWh and net metering) is only for the system under 500 kW. Thus, among the four building types, only the PV system for a large hotel is eligible for the incentive policy from Green Mountain Power. That is why the payback period with incentive for large hotel in

Vermont is much shorter than that for other building types in Vermont.

- Notably, for all building types, the payback periods in Hawaii are quite attractive (all below 5 years) even without including the incentive policy. This is due to the influence of the solar availability and electricity cost. From Table 1 and Table 2, it can be seen that Hawaii possesses high solar availability and high electricity cost. Higher solar availability means that the PV system can generate more electricity under the same conditions, and higher electricity cost means that more money can be saved when using the electricity generated from PV instead of grid electricity. As a comparison, Nevada also has the same or even higher solar availability, but much lower electricity cost compared to Hawaii; thus, the payback period in Nevada is much higher than that in Hawaii. Similarly, even though the solar availability in Vermont is lower than that in Florida and Georgia, the payback period without incentive of PV system in Vermont is still better than that in Florida and Georgia (except for the case of secondary school) due to much higher electricity cost in Vermont compared to that in Florida and Georgia. The exception for the secondary school can be explained in such a way that the negative normalized difference for secondary school is smaller than that for other building types, which reduces the influence of electricity cost on the payback period because a smaller normalized negative difference means less electricity is imported from the grid. The above mentioned analysis shows that, while electricity cost is certainly not the only factor impacting PV locational performance, it definitely provides a substantial impact on PV cost performance.

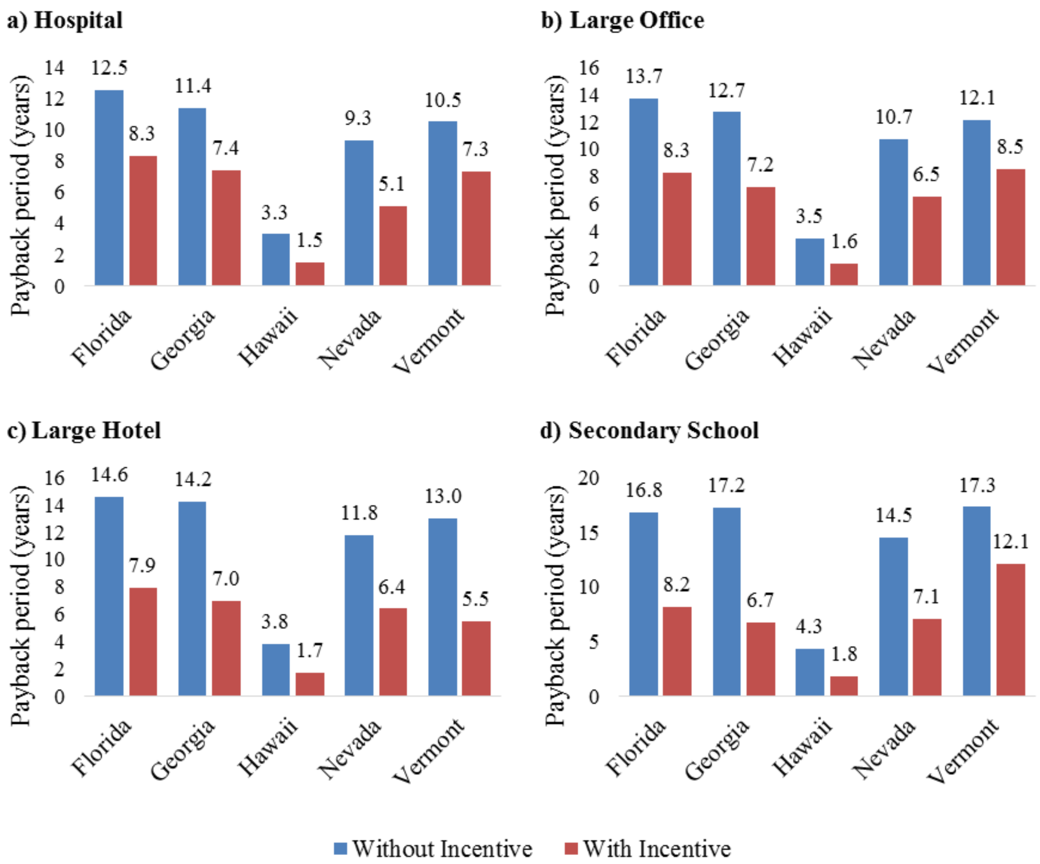

Figure 5. Results of payback period analysis for four kinds of buildings. a) hospital; b) large office; c) large hotel; d) secondary school.

5.2. Parametric analysis

In addition to the two factors solar availability and electricity cost (which have been discussed before), there are several other factors that can influence the payback period of a PV system: capacity of the PV system, capital cost of PV, sell back electricity rate, and PBI rate. It can be seen from Figure 5 that the trends of the variation of the payback period with the locations among different building types are similar. For this reason, the hospital building is taken as a representative building type to perform a parametric analysis to illustrate the impact on the payback period by each factor (capacity of PV system, capital cost of PV, sell back electricity rate and PBI rate) in the following paragraphs. In this parametric analysis, it is assumed that the baseline scenarios include the existing incentive policies for each location (e.g., a PBI rate is reflected in the payback results for Hawaii in the baseline scenario to evaluate the impact of the aforementioned factors).

The influence of each parameter on the payback period is analyzed and presented in the following paragraphs, and Figure 6 to Figure 9 show the results of the parameter study. Figure 6 illustrates the influence of the capacity of PV system on the payback period for hospital buildings for the locations of Florida, Georgia, Hawaii, Nevada, and Vermont. As the capacity of PV system varies from 400 kW to 2000 kW, the payback periods with/without incentives are compared to each other. As shown in the figure, the payback period without incentive increases with the increase of the PV capacity for all locations. For the payback periods without incentives in all locations, 1200 kW is an inflection point. When the capacity is smaller than 1200 kW, the payback period increases slowly with the change of PV capacity. However, when the capacity exceeds 1200 kW, the payback period increases quickly with the change of PV capacity. This is because the maximum electricity load in all locations is around 1200 kW (see Table 9). When the PV capacity is larger than the maximum electricity load, the PV system generates more electricity than the building consumes, so without any incentives (i.e., buy-back policies), the excess electricity is wasted. However, when net metering or PBI incentives are included, the excess electricity serves to diminish the payback period. Among the five locations, the payback periods are more sensitive to the variation of the PV capacity in Nevada and Vermont than in other locations, while the influence of the PV capacity is not significant in Hawaii, nor is it significant in Florida and Georgia when incentive polices are taken into consideration. This is due to the high PBI (i.e., feed-in tariff rate) in Hawaii and Georgia, as well as the net metering policy in Florida. For those locations that do not provide either a high PBI or a net metering policy, the users need to be aware that choosing an appropriate size is critical to achieve a desired payback period, while the policy makers may consider this as an opportunity to promote the PV systems in their states by implementing either a PBI or a net metering policy. As shown in Figure 5d–e, the payback period can vary from 2 to 6 years in Nevada and from 5 to 8 years in Vermont as the PV capacity increase from 400 kW to 1200 kW.

Figure 7 shows the variation trend of PV system payback period for hospital buildings when the capital cost of PV system changes from 0.5 $/W to 5 $/W. In this case, the capacity of the PV system is set to a value of 1400 kW, which is based on the maximum electrical load of the hospital buildings among the five locations. As can be seen in the figure, the payback period increases linearly with the increase of capital cost of PV in all five locations, no matter whether the incentive is taken into consideration or not.

The slope of the line in the figure indicates how deeply the payback period is influenced by the capital cost of PV. For example, when the cost of PV changes from 0.5 to 5 $/W, the payback period without incentive varies from 2 years to almost 30 years in Florida, while it only varies from 2 years to nearly 10 years in Hawaii. Furthermore, from the figure, the conclusion can be drawn that if the capital cost goes down in the future (now the average price is about 2.25 $/W), the payback period of a PV system will be more attractive. The results shown in this figure are useful for both PV users and policy makers. On one hand, the potential PV users can estimate the payback periods of PV systems with the capital cost of PV in their locations and then determine whether it is worthwhile to install a PV system. On the other hand, the policy makers can consider providing an UFI and determine incentive rate based on the capital cost of PV in their locations. Taking Florida as an example, if a UFI of 1 $/W is given, the equal effect is the capital cost of PV system reduces from 2.25 $/W to 1.25 $/W, and then the payback period reduces from 12 to 7 years (without the existing incentives) and from 8 to 5 years (with the existing incentives).

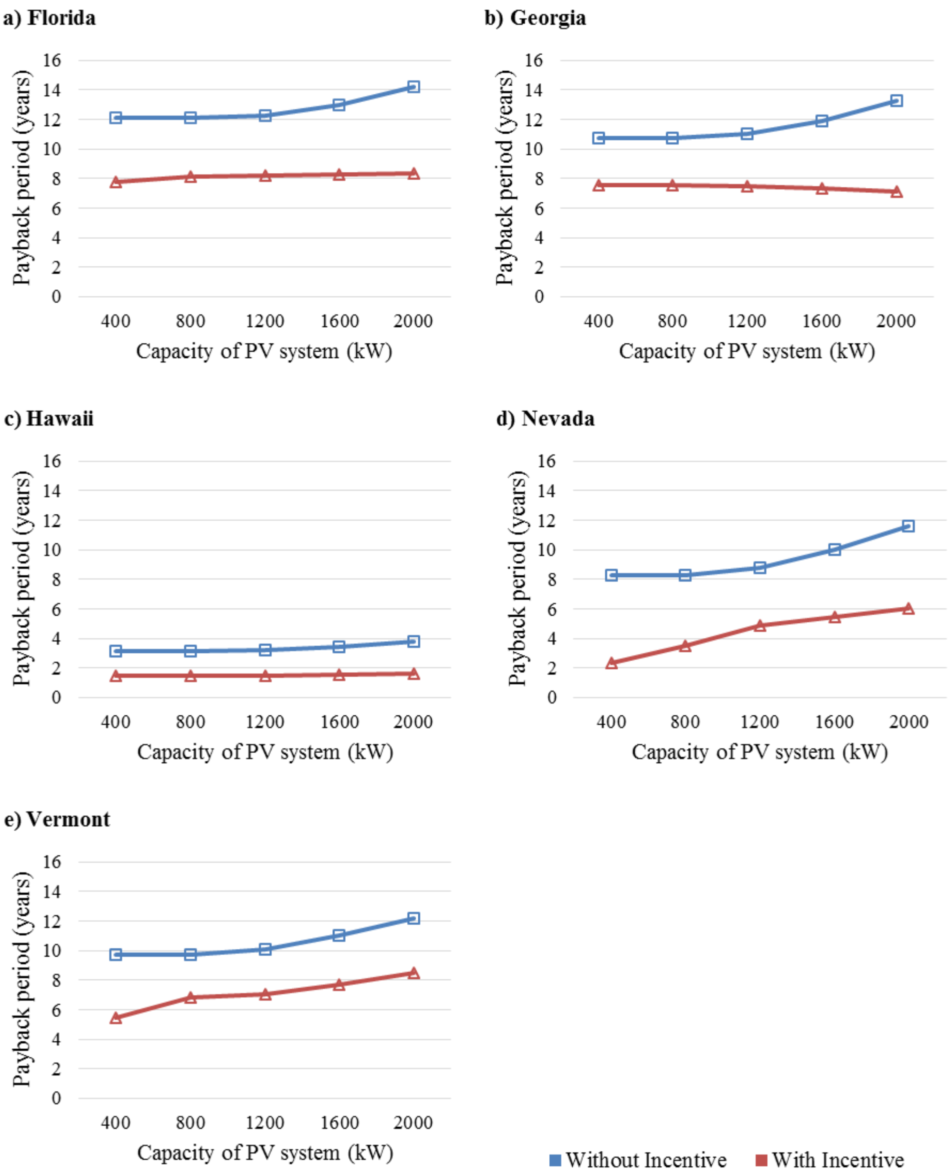

Figure 6. Influence of the PV capacity on the payback period for hospital buildings. a) Florida; b) Georgia; c) Hawaii; d) Nevada; e) Vermont.

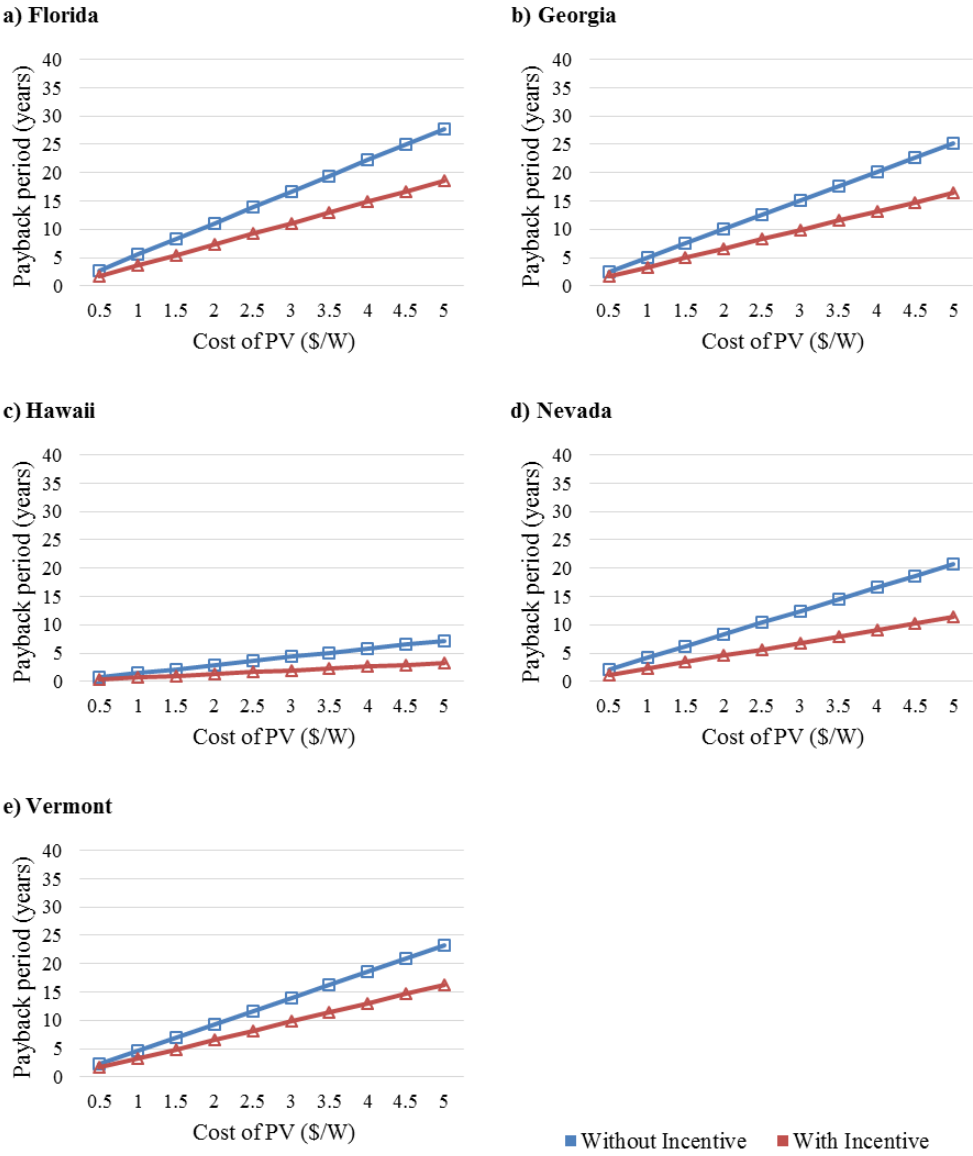

Figure 7. Influence of the capital cost of PV on the payback period for hospital buildings. a) Florida; b) Georgia; c) Hawaii; d) Nevada; e) Vermont.

The influence of the sell back ratio on the payback period for hospital buildings is illustrated in Figure 8. In this part, when calculating the payback period with incentive, the net metering incentive will not be applied directly, but instead assumes that the PV users in all the five locations can sell excess electricity back to a utility company. The sell back price is given out by defining a new parameter, sell back ratio. Namely, the sell back ratio indicates the ratio of the sell back rate of electricity to the local purchase rate charged by the utility company. In this case, the variation range of the sell back ratio is from 0.1 to 1, with an interval of 0.1. When the sell back ratio equals to 1, it means that net metering is available for the PV system. The capacities of PV systems are set to 1400 kW and 2000 kW. The reason why a 2000 kW capacity is added here is to supply enough excess electricity generation to adequately analyze the influence of the net metering on the payback period. Apparently, the payback period without incentive remains a constant value for a specific location and capacity. Also, in the same location, the payback period of the PV system with a capacity of 2000 kW is larger than that of the PV system with a capacity of 1400 kW. When the incentive policies are applied, the payback period decreases with the increase of the sell back ratio, which is especially significant for the cases with 2000 kW capacity. This is because at the capacity of 2000 kW, the PV system generates much more excess electricity to sell back than the case at the capacity of 1400 kW; thus, the influence of the sell back ratio on the payback period is more significant. Notably, when the sell back ratio equals to 1, i.e., net metering is adopted, the 2000 kW capacity PV system has almost the same payback period as the 1400 kW PV system. This indicates that the users need to be aware that they need to carefully size their PV systems based on their maximum electricity demand in their buildings when there are no policies to sell excess electricity back to a utility company in their locations.

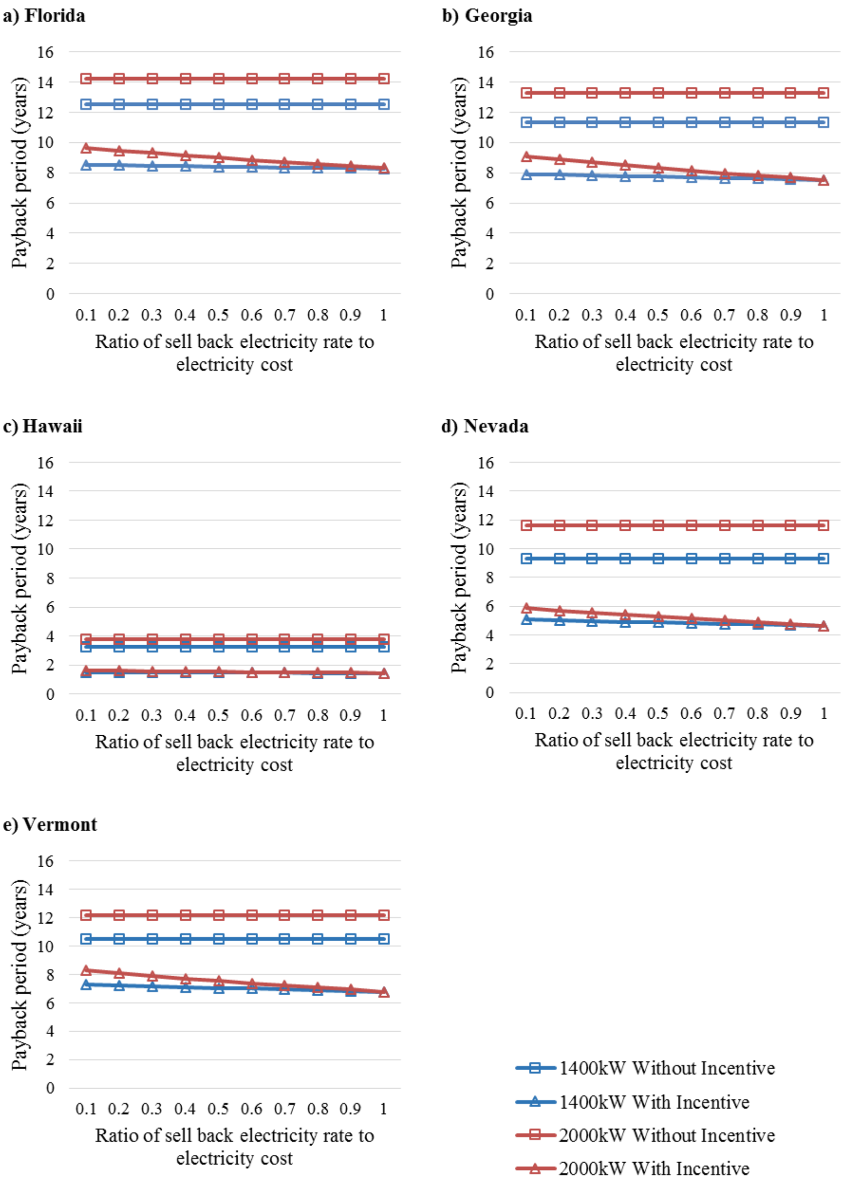

Figure 8. Influence of the sell back ratio on the payback period for hospital buildings. a) Florida; b) Georgia; c) Hawaii; d) Nevada; e) Vermont.

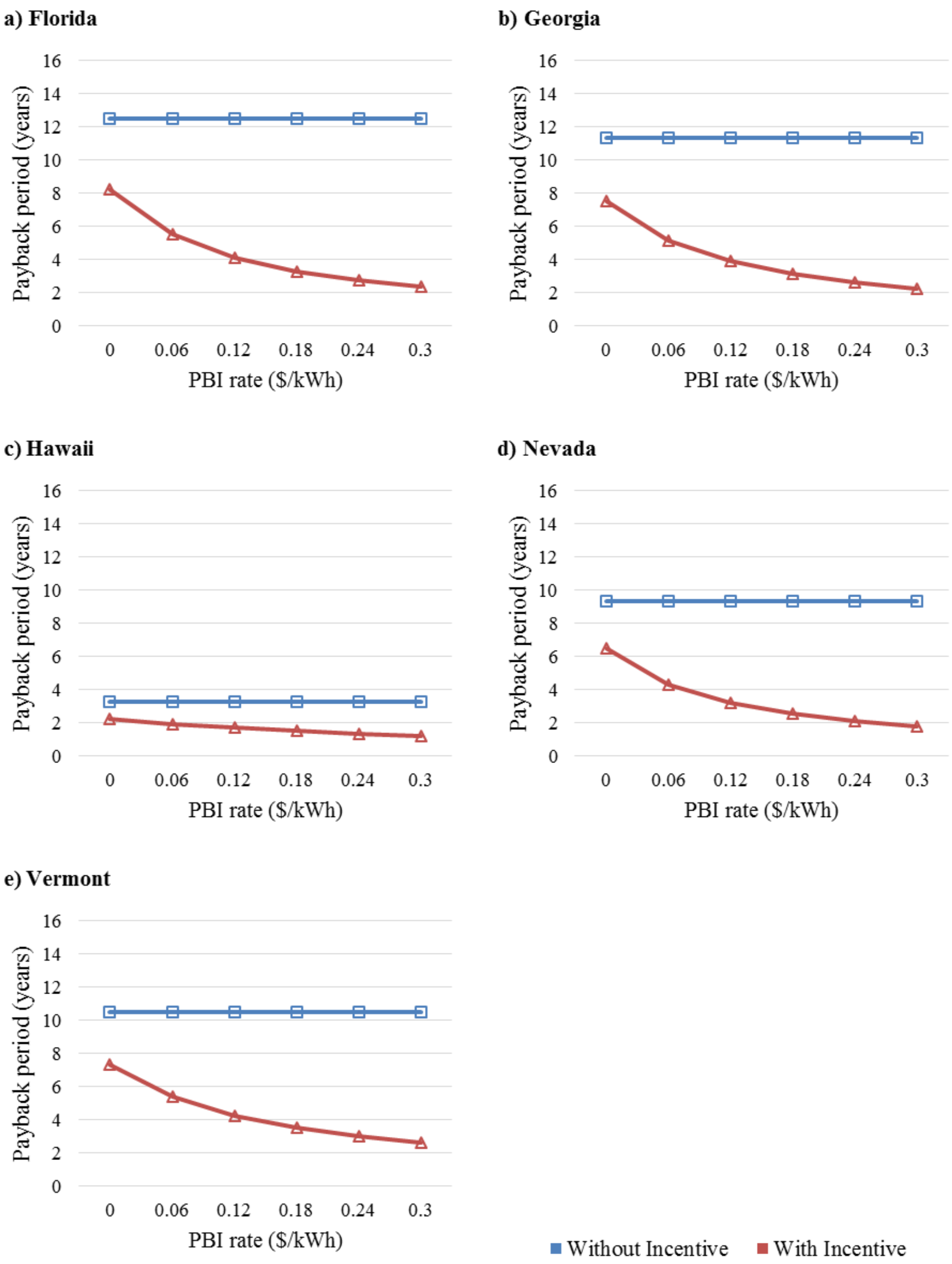

Figure 9. Influence of the PBI rate on the payback period for hospital buildings. a) Florida; b) Georgia; c) Hawaii; d) Nevada; e) Vermont.

Figure 9 shows the influence of the PBI rate on the payback period for hospital buildings. In this case, the capacity of PV system is set to 1400 kW for all locations. When calculating the payback period with incentive, instead of using existing PBI rate for each location, it is assumed that in all the locations, the PV customers are eligible for a PBI of which the rate ranges from 0–0.3 $/kWh. Additionally, the other incentives summarized in Section 3.2.7 are still available with the exception of the existing PBI. Note that, in this part, customers are assumed to be paid for the amount of the electricity generated by their PV systems, no matter whether they use the electricity only in their properties or export it to the grid. Just like the variation trend shown in Figure 8, the payback period without incentive here remains a constant value for a specific location. However, the payback period decreases as a decay curve with the increasing PBI rate when the incentive is taken into consideration. In all locations, increasing the PBI is an effective way to improve the payback period of PV system. It is important to mention here that the payback period in Hawaii does not reduce drastically because it already has a low payback period even without regarding to incentive. With these results, the policy makers can effectively determine a PBI rate in a particular location to promote the PV systems.

6. Conclusion and Policy Implications

In this paper, four types of buildings (hospitals, large offices, large hotels, and secondary schools) located in five different states, which each have their own incentives, are selected and analyzed for the PV incentives. Then the simple payback period for the PV systems in different locations is calculated according to the local incentive policies. This payback period is then compared to the one without regard for incentive policies. In this way, the existing incentive policies employed by utility companies in each city are analyzed and critiqued. Finally, a parametric analysis is conducted in order to find out the influence of the variation that each parameter has on the performance of the PV system. Through the analysis, the following conclusions are drawn:

(1) For most locations and building types, the analysis results show that the individual existing incentive policy can reduce the payback period effectively below 10 years. However, the effectiveness of each existing incentive policy can vary depending on the location and building type.

(2) In each location, larger surplus electricity generated onsite indicates that more electricity is wasted when incentives are not taken into consideration. Thus, the payback period would become longer, and the potential to reduce the payback period would become higher when considering incentives such as PBI and net metering policies.

(3) As expected, the solar availability and electricity cost are key factors which affect the payback period significantly. For larger solar availability, more electricity can be generated by the PV system under the same condition, while larger electricity cost values lead to more cost savings when using a PV system to generate electricity, instead of purchasing electricity from the grid.

(4) For those locations that do not provide either a high PBI or a net metering policy, the users need to be aware that choosing an appropriate size of the PV system is critical to achieve a desired payback period.

(5) The payback period increases linearly with the increase of capital cost of PV in all five locations, no matter whether the incentive is taken into consideration or not. The slope of variation line shows how deeply the payback period is influenced by the capital cost of PV for each location.

(6) When the sell back ratio equals to 1, i.e., net metering is available, it can reduce the impact of the PV capacity on the payback period. This means that the PV users could install a larger capacity PV system without sacrificing the payback period.

(7) The analysis results indicate that the level of UFI and PBI need to be carefully selected considering all the parameters discussed in this paper, i.e., location (solar availability), building type (electric load profile), PV capacity, local electricity cost, and local PV capital cost, when designing those incentive policies.

Acknowledgments

The work presented herein was financially supported by the Bagley College of Engineering and the Department of Mechanical Engineering at Mississippi State University (MSU).

Conflict of Interest

All authors declare no conflicts of interest in this paper.

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