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TECHNICAL SOLAR PHOTOVOLTAIC POTENTIAL OF SCALED PARKING LOT CANOPIES: A CASE STUDY OF WALMART U.S.A.

Potencial técnico fotovoltaico solar utilizando toldos grandes lotes de estacionamento: um estudo de caso da walmart em USA.

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Abstract: Solar photovoltaic (PV) technology can provide sustainable power for the growing global population in cities, but it demands considerable land area. This is a challenge for densely populated cities. However, the stranded assets of non-productive parking lots areas can be converted to solar farms with PV canopies, enabling sustainable electricity generation while preserving their function to park automobiles. This study provides a method for determining the technical and economic potential for converting a national scale retail company's parking lot area to a solar farm. First, the parking lot area for the company is determined and divided into zones based upon solar flux using virtual maps. Then the potential PV yield in each zone is calculated. A sensitivity analysis is performed on the price per unit power installed, solar energy production as a proxy for conversion efficiency, electricity rates and revenue earned per unit area. To demonstrate this method, analysis of Walmart Supercenters, USA is presented as a case study. The results show solar canopies for parking lot areas are a profitable as well a responsible step in most locations and there is significant potential for sustainable energy deployment in cities by other similar retailers using solar PV canopies.

Keywords: distributed generation; parking lot; photovoltaic; solar canopy

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Resumo: A tecnologia solar fotovoltaica (PV) pode fornecer energia sustentável para a crescente população global nas cidades, mas exige área de terra considerável. Este é um desafio para cidades densamente povoadas. No entanto, os ativos encalhados de áreas não produtivas de lotes de estacionamento podem ser convertidos em fazendas solares com coberturas fotovoltaicas, permitindo a geração sustentável de eletricidade, preservando sua função de estacionar automóveis. Este estudo fornece um método para determinar o potencial técnico e econômico para converter a área de estacionamento de uma empresa de varejo em escala nacional em uma fazenda solar. Primeiro, a área de estacionamento da empresa é determinada e dividida em zonas baseadas no fluxo solar usando mapas virtuais. Em seguida, calcula-se o rendimento potencial de PV em cada zona. Uma análise de sensibilidade é realizada sobre o preço por unidade de energia instalada, a produção de energia solar como um Proxy ou tentativa para avaliar a eficiência de conversão, as taxas de electricidade e as receitas obtidas por unidade de área. Para demonstrar este método, uma análise de supermercados Walmart nos Estados e utilizado como um estudo de caso. Os resultados mostram que telhados solares para áreas de estacionamento são rentáveis e representam uma inicativa responsável na maioria dos locais, e há um potencial significativo para a implantação de energia sustentável em cidades por outros varejistas semelhantes usando telhados solares fotovoltaicos.

Palvras-chave: Geração Distribuída; Estacionamentos; Energia Fotovoltaicas; Telhados Solares.

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INTRODUCTION

The global demographic has shifted from rural to urban, as the majority of humanity now choose to live in cities (Tacoli, et al., 2015; USDA, 2015). For example, the number of non-metro counties in United States, recording a population shift to metro areas reached a historic high of 1,310 between the periods of 2010-2014 (USDA, 2015). As the global environment and particularly the climate comes under increasing pressure from human activities (IPCC, 2013;Nyström, Folke, Moberg, 2000; Solomon et al. 2007; Kimani, 2014; Azevedo et al. 2015), there is a critical need to transition cities towards sustainability (IEA, 2009; NREL, 2015). One aspect of cities that needs more attention is that of land use (Nickerson, et al., 2011; Foley, et al., 2005) as areas within cities have expanded, creating sprawl with many negative consequences (Davis, et al., 2010; Squires, 2002). In the case of the United States, large portions of cities are occupied by expansive parking lot areas; with almost one third of the surface area of some major cities is made up of parking lots (Manville & Shoup, 2005; Ben-Joseph, 2012). Several previous studies have shown that large parking lot areas exceed actual population requirements (Hall, 2007;Ben-Joseph, 2012) resulting in substantial financial losses. In addition, the environmental damage caused by parking lots is well documented (Davis, et al., 2010; Wilson, 1995; Manville & Shoup, 2005) and thus, excess parking lot areas can be viewed as irresponsible utilization of land resources.

At the same time, cities are increasing their energy use, with the total global energy consumption projected to reach 34,454 TWh by 2035 (WNA, 2015). Greenhouse gas (GHG) emissions must be reduced to prevent dangerous global climate change (Moss, et al. 2010; IEA 2012; IPCC, 2013) and its negative externalities on cities such as: i) higher temperatures and heat waves that result in thousands of deaths from hyperthermia (Fouillet, et al., 2006; Dhainaut, et al., 2003; Poumadere, et al., 2003) in environments already experiencing heat island effects (Lo et al., 1997); ii) power outages (Vine, 2012) and the concomitant economic disruption; iii) rising sea levels which causes the low-lying coastal urban environments to submerge gradually (Frihy 2003; Moorhead and Brinson, 1995) while beaches and other amenities of the shorelines are erased with erosion (Frihy 2003; Moorhead and Brinson, 1995); iv) increased risk of flooding (Nicholls, et al., 1999) and saltwater intrusion, which can damage water supplies for cities (Bobba, 2002; Frihey,, 2003); v) strong storms, which cause more damage to coastal environments and increase the risk of floods (Desantis, 2007; Allen et al., 2010; Dale, et al., 2001; Carnicer, et al., 2011); and vi) increased risks from fire (Amiro, et al., 2001; Dale, et al., 2001; Flannigan et al., 2009). In addition, although cities are not primarily agricultural, climate changes threaten drastic changes in soil composition (Kirschbaum, 1995) and crop failures (D'Amato and Cecchi, 2008; ICES/CIESM, 2010;Adams, et al., 1990; Parry, et al., 2004) that aggravate global hunger including residents of cities (Parry et al., 2004; Schmidhuber and Tubeillo, 2007; Parry et al., 2005). These negative externalities have been shown to be due to human activities with the confidence level of 95% (primarily combustion of fossil fuels, which are the dominant cause of global warming from 1951 onward) (IPCC, 2013). To mitigate these negative consequences while maintaining an energy-intensive standard of living, this power will need to be supplied by renewable energy sources (El-Fadel, et al., 2003; Granovskii, et al., 2007; Sims, 2004; Tsoutsos, 2008). The most promising technology for a sustainable future is solar photovoltaic (PV) conversion of sunlight to electricity (Pearce, 2002).

Rapid growth in solar PV global production capacity (Masson, et al., 2015), improvements in the solar energy conversion efficiency (NREL, 2015), and improved financing mechanisms (Alafita & Pearce, 2014) have all resulted in a radical decline in the price of solar electricity (Branker et al., 2011). Thus PV represents an economical method of providing for a growing fraction of society's electrical needs.

However, to produce thousands of TWhs with solar electricity will involve the use of considerable land area (Ong, et al., 2013), which in part can be met with aggressive building integrated PV and rooftop PV (Wiginton, et al., 2010; Nguyen and Pearce, 2013; Nguyen, et al., 2012; Duke, et al., 2005; Hoffmann, 2006) it will not be enough, particularly in densely populated cities (NREL, 2013). To meet all demands, while avoiding the costs and negative externalities associated with conventional grid expansion (Fouillet, et al., 2006; Vine, 2012; Klinenberg, 2008), stranded assets of non-productive parking lot areas could be converted to solar farms with PV canopies, enabling sustainable energy production while preserving their function to park automobiles.

This study provides a method for determining the technical and economic potential for converting a nationally scaled retail company's parking lot area to a solar energy farm comprised of PV canopies. First, the parking lot area for the company is determined and divided into zones based upon solar flux using virtual maps and geographic information systems (GIS). Then the potential PV yield in each zone is calculated. A sensitivity analysis is performed on the i) price per unit power installed including a differential cost of solar canopies to account for snow loading in relevant regions ($/ W), ii) solar energy production as a proxy for conversion efficiency (kWh/acre), iii) electricity rates ($/kWh) and iv) revenue earned per unit area ($/acre). To demonstrate this method, a case study is used to investigate the economic effect of installing solar canopies in Walmart Supercenters, USA. The results are presented and discussed to determine the potential for this method of sustainable energy deployment in cities by other similar retailers.

MATERIALS AND METHODS

1. Parking Lot Solar Farm Conversion Economic Decision Algorithm

The flow chart of the parking lot solar farm conversion economic decision algorithm is shown in Figure 1.

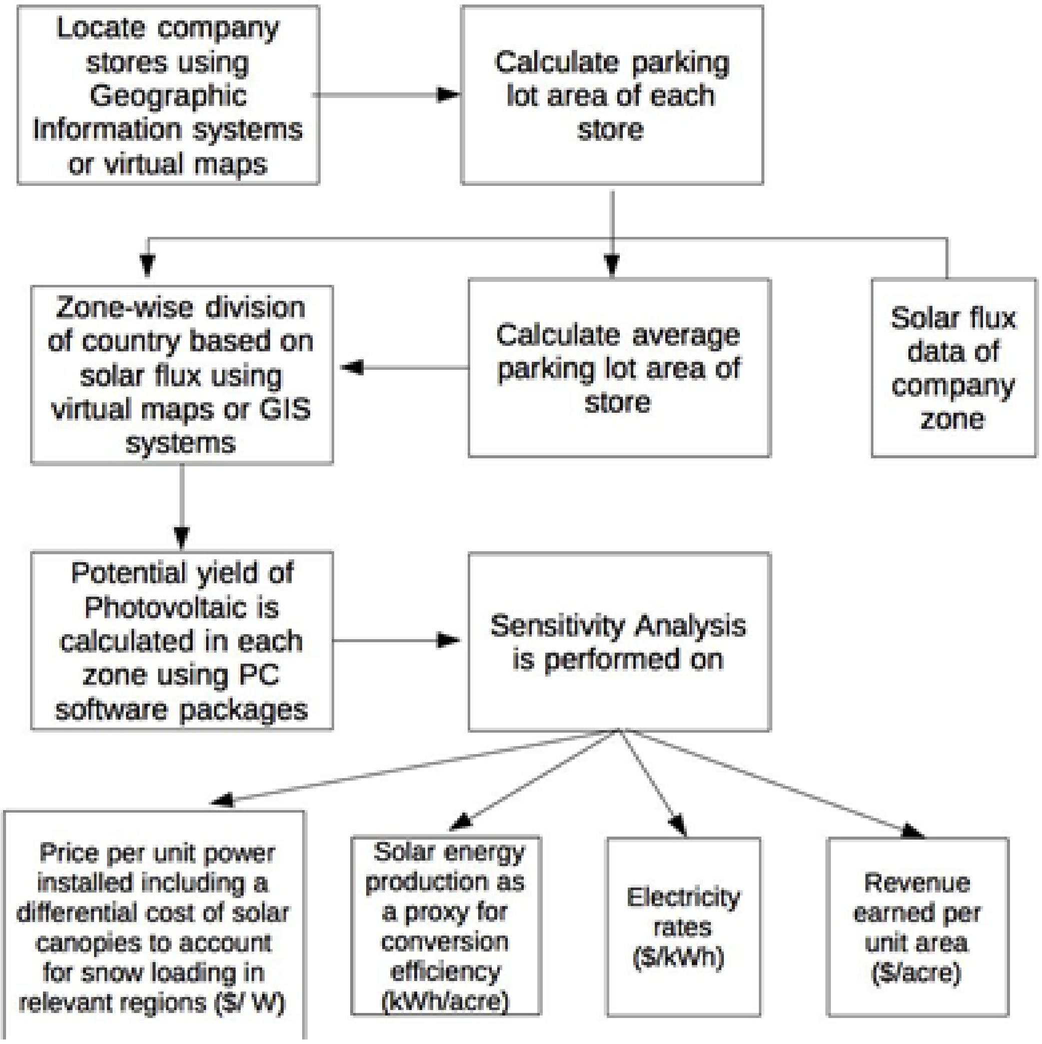
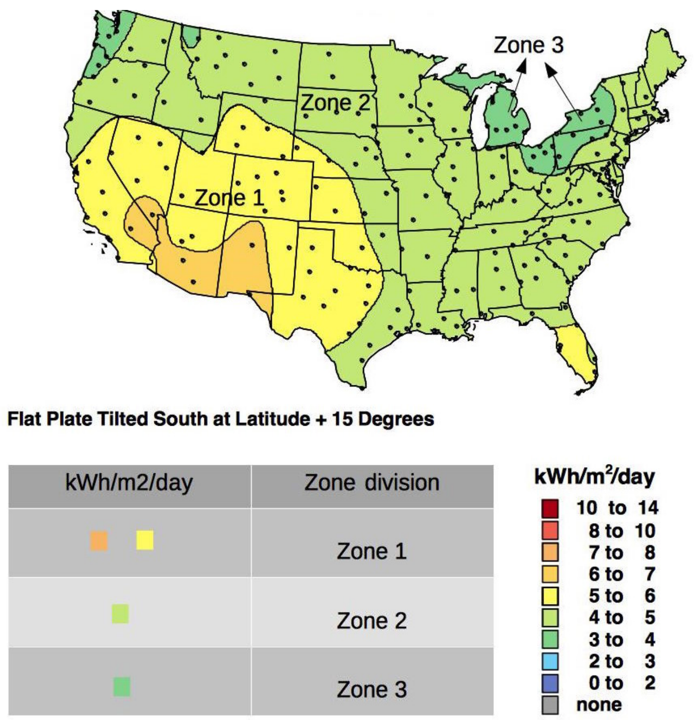


Figure 1. Flow chart of Parking Lot Solar Farm Conversion Economic Decision Algorithm

First, the parking lot area for the company is determined and divided into zones based on solar flux using Google Earth Pro (v 7.1.5.1557). In order to obtain a rough first approximation on potential PV yield, the U.S. is divided into three zones (South, East and North) according to the solar flux shown in Figure 2.



kWh/m2/day	Zone division
🟧 🟨	Zone 1
🟩	Zone 2
🟩	Zone 3

Figure 2. Map of U.S. divided up into three zones of approximately the same solar flux in each zone.

The United States map along with the solar flux zone-wise is obtained from National Renewable Energy Laboratory U.S Solar Radiation Resource maps (NREL, 2016). It should be noted here, that this is division is rough and meant to be a first approximation for decision makers if a more detailed GIS analysis is needed. This analysis could take the form of using an adaption of roof quantification methods with Arc GIS and Feature Analyst (Wiginton, et al., 2010) or the open source GRASS and r.sun (Nguyen and Pearce, 2010) or a store-by-store PV site assessment is warranted).

Next, sensitivity analysis is performed on the price per unit power installed including a differential cost of solar canopies to account for snow loading in relevant regions ($/ W). These values should range from $3.25/W to $1.00/W as a source for $3.25/W as the highest cost currently (Adelson, 2015) and the sensitivity reduced to follow historic learning curve trends in PV (Feldman, et al., 2014; International Renewable Energy Agency, 2015). Then the packing factor is determined using two example arrays representing aggressive and modest parking: 1) Belectric Solar Parking Canopy-EDEKA Krawczyk supermarket parking lot in Schwabach, Germany – 170 W/m2 (Solar Frontier, 2011; Olson, 2011) and Rutgers University, USA Solar Parking Lot – 65 W/m2 (Solaire, 2011). These packing factors are used to model a solar PV system for an area of the average parking lot for the store. For the case study, the average parking lot area for Walmart Supercenters was calculated using geospatial information from 23 Walmart locations throughout the United States and Canada. The average parking lot area was measured and a standard error was calculated from:

$$Standard\ Error = \frac{Standard\ Deviation\ (sample)}{\sqrt{Sample\ Size}} \qquad (1)$$

Two standard error were reported for the sample mean to approximate a 95% confidence interval of the mean. Then using representative solar flux values for the three regions using the locations of Arizona, Michigan, and New Jersey, Walmart Supercenters representing the three zones in the U.S., Solar Advisor Model (SAMv2015.1.30, 64 bit) is used to determine the energy output (MWh/year) for the two packing factors. Finally, electricity rates ($/kWh) and the profits earned per unit area (PPV) [$/acre/year] is calculated using equation 2, where E is the energy output [kWh/year], re is the rate of electricity [$/kWh], and LCOE is the levelized cost of electricity (Branker et al., 2011).

$$P_{PV} = E(r_e - LCOE) \qquad (2)$$

A sensitivity analysis is performed on the rates of 5, 10, 15 and 20 cents/kWh, which envelope the ranges in the standard rates of electricity, using three historical electrical rate escalations of 1) 0.3% (from 2010), 2% (2016 projected) and 5.7% (from 2008) (U.S. Energy Information Administration, 2015), representing the low, average, and high cases, respectively. The values for the PV LCOE parameters are lifetime of 25 years, operation and maintenance costs were set at 1.5% of initial investment cost and degradation rate was 0.5%/year (Branker et al., 2011). The indirect costs such as sales tax, land costs, engineering costs, grid connection costs were folded into the initial investment cost and were not considered independently in SAM. The tax and insurance rates, incentives, and salvage values were also not considered.

2. Case Study: Walmart Supercenters Stores Inc. USA

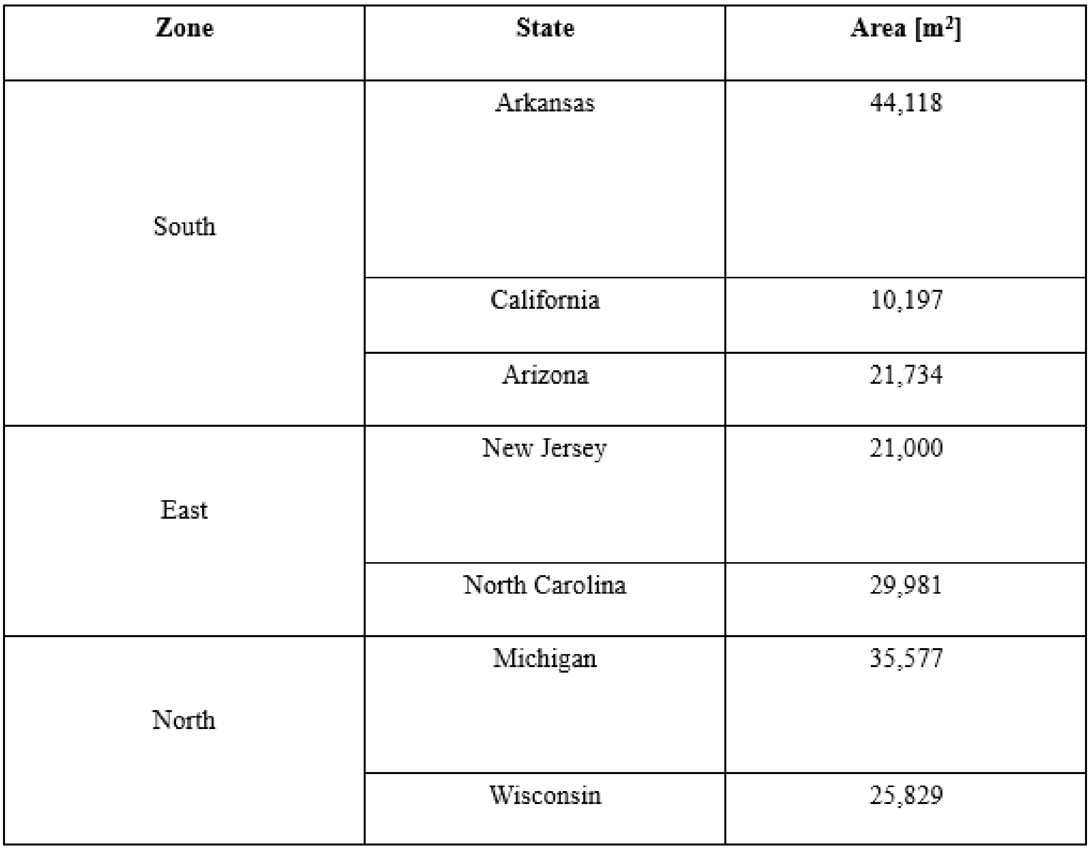
Walmart Stores, Inc., a popular American multinational retail corporation, had revenue of US$485.7 billion by the end of the fiscal year January 31, 2015 (Walmart, 2015). Walmart has over 5,200 retail stores in the U.S., with over 3,400 of them being Supercenters (Walmart, 2015). These Supercenters, designed to offer a one-stop shopping experience, occupy close to 182,000 square feet [16,908 m2] (Walmart Corporate, 2016) excluding their parking lots. Walmart has already made a commitment to improve sustainability (WSJ, 2013; Walmart Global Responsibility Report, 2013) and has installed close to 105MW of rooftop solar (Weissmann, 2014; Walmart Sustainability Report, 2014). Rooftop PV, however, is inadequate to meet even an individual Walmart's electricity needs, let alone make a positive contribution to a city's sustainability by exporting renewable energy. For this level of solar electric conversion, more surface area is needed. This case study uses the algorithm detailed above to determine the potential of the U.S. Walmart solar farm on their Super Center parking lot area.

RESULTS

1. Walmart Supercenter USA Land Area

The average size of Walmart Supercenter in three solar flux zones in the U.S. are displayed in Table 1. Walmart Supercenters were used as they have consistency in their parking lot area size, while normal Walmart retail stores showed a greater variation in parking lot size.

Table 1: Average parking lot area of Walmart Supercenters in United States



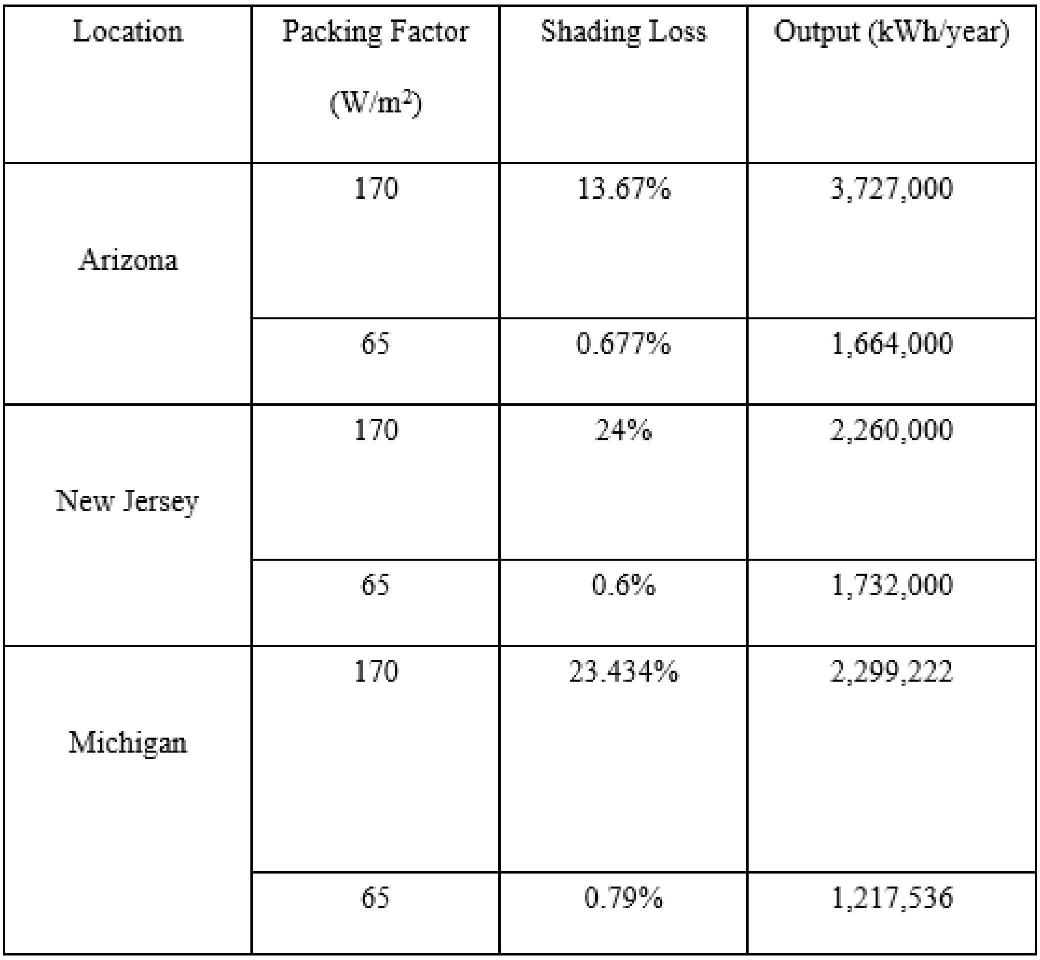
Zone	State	Area [m^2]
South	Arkansas	44,118
	California	10,197
	Arizona	21,734
East	New Jersey	21,000
	North Carolina	29,981
North	Michigan	35,577
	Wisconsin	25,829

Following equation (1) and the data from Table 1, the average parking lot area of North American Walmart stores was calculated to be 20,777 ± 5,047 m2.

WALMART'S USA SOLAR PHOTOVOLTAIC PARKING LOT CANOPY VALUE OVER 25 YEARS OF LAND USE

For this case study, locations of Arizona, Michigan and New Jersey are taken to encompass the high and low regions of solar flux. Table 2 summarizes the values used in SAM and the resulting energy and shading loss outputs, which are then used as inputs into the economic model described below. It should be noted that the packing factor is the peak rated power per unit roof area, which is determined by the array geometry. As can be seen in Table 2, two array geometries are analyzed. For simulation purposes, the Azimuth was taken to be due south and the tilt to be 200. The latter value, although not optimal from an energy yield per installed unit power perspective is necessary to allow canopy geometries (i.e. larger tilt angles reduce the packing factor and demand additional mechanical reinforcement and the associated expenses).

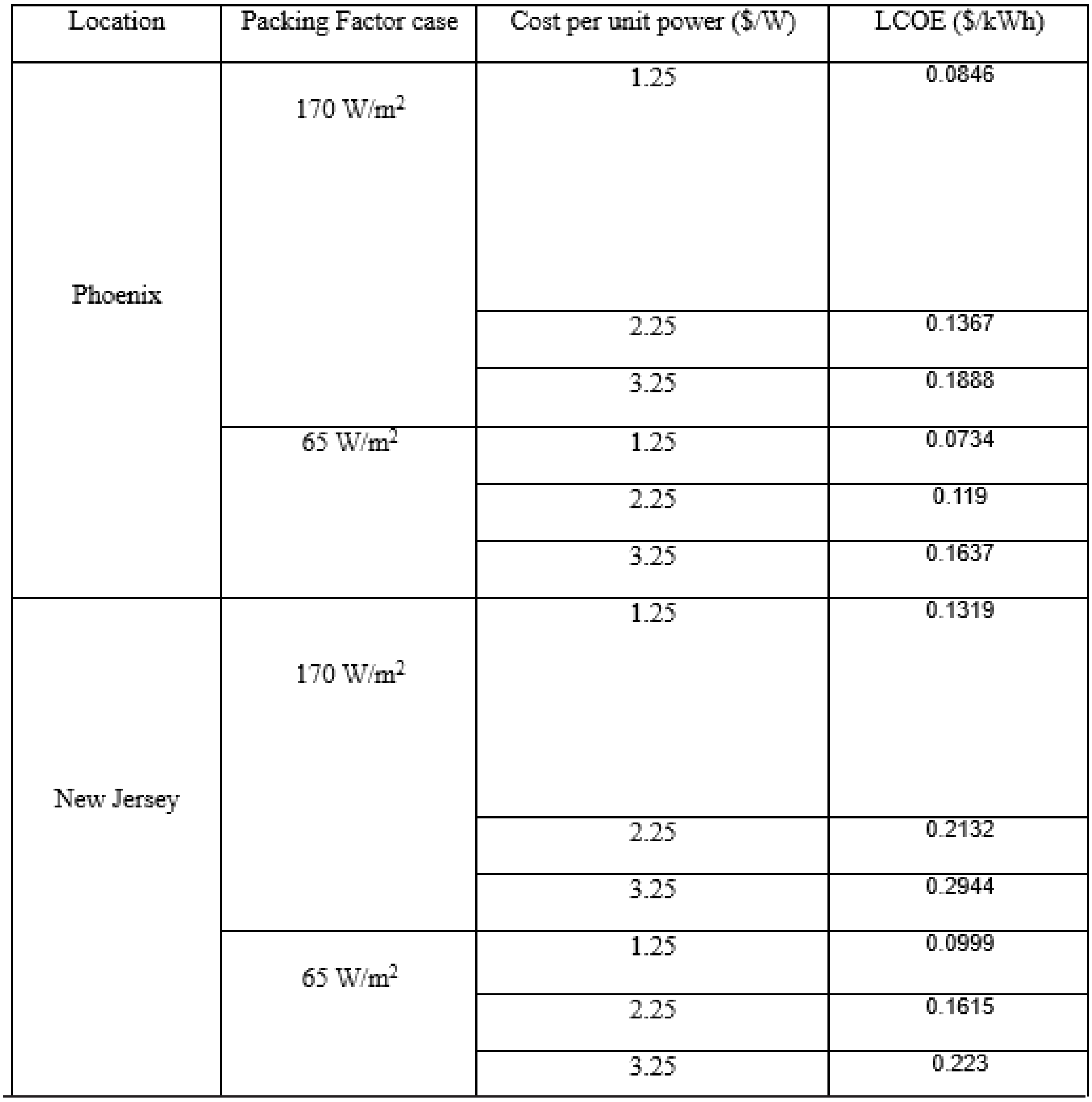
Table 2: Shading loss and annual electrical output for the two packing factor cases for an area of 21,000m2



Location	Packing Factor (W/m^2)	Shading Loss	Output (kWh/year)
Arizona	170	13.67%	3,727,000
	65	0.677%	1,664,000
New Jersey	170	24%	2,260,000
	65	0.6%	1,732,000
Michigan	170	23.434%	2,299,222
	65	0.79%	1,217,536

Table 3 summarizes the LCOE values obtained from SAM for the ranges of cost per unit power.

Table 3: LCOE values for case study location



Location	Packing Factor case	Cost per unit power ($/W)	LCOE ($/kWh)
Phoenix	170 W/m^2	1.25	0.0846
		2.25	0.1367
		3.25	0.1888
	65 W/m^2	1.25	0.0734
		2.25	0.119
		3.25	0.1637
New Jersey	170 W/m^2	1.25	0.1319
		2.25	0.2132
		3.25	0.2944
	65 W/m^2	1.25	0.0999
		2.25	0.1615
		3.25	0.223

Michigan	170 W/m^2	1.25	0.1313
		2.25	0.2121
		3.25	0.293
	65 W/m2	1.25	0.1006
		2.25	0.1626
		3.25	0.2245

For each location, two packing factor cases are considered to envelop the aggressive and modest PV system. Figures 3 and 4 show PV profits for Arizona enveloping the two packing factor cases. Similarly, Figures 5 and 6 cover New Jersey packing factor cases and Figures 7 and 8 cover Michigan cases.

Figure 3: Profits earned from PV canopies for the case 1 packing factor of 170W/acre in Phoenix, Arizona USA using equation 1 for $1.25-3.25/Wp cost per unit power

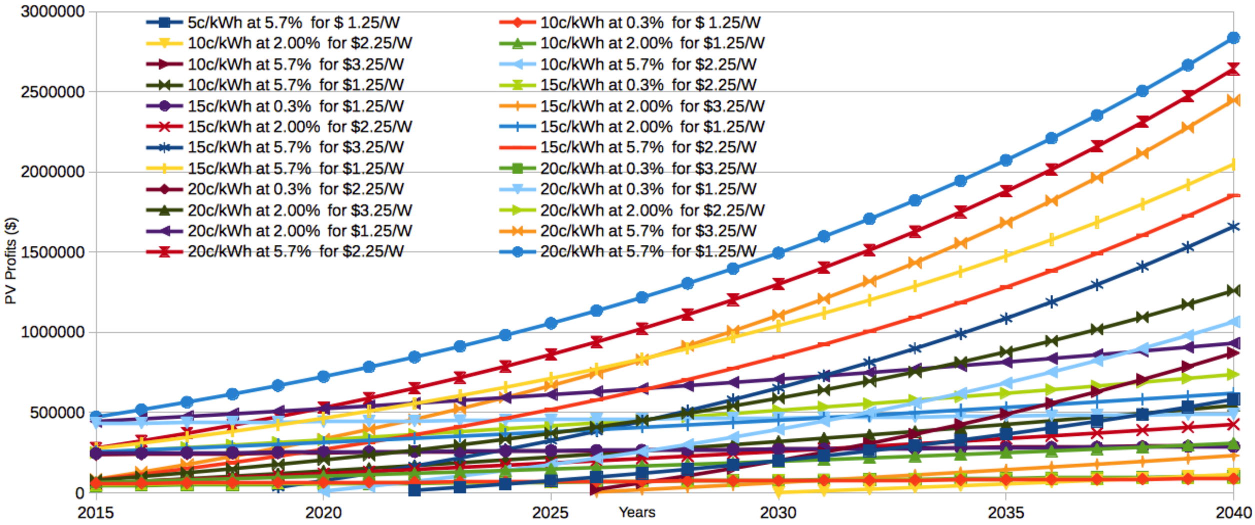


Figure 4: Profits earned from PV canopies for the case 2 packing factor of 65W/acre in Phoenix, Arizona USA using equation 1 for $1.25-3.25/Wp cost per unit power

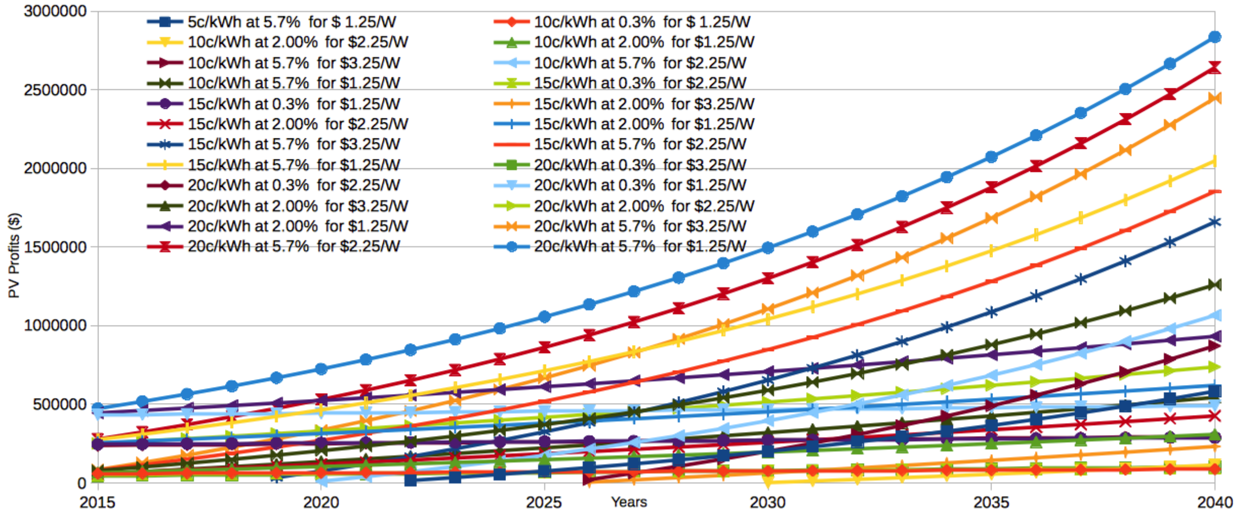


Figure 5: Profits earned from PV canopies for the case 1 packing factor of 170W/acre in Rutgers, New Jersey USA using equation 1 for $1.25-3.25/Wp cost per unit power

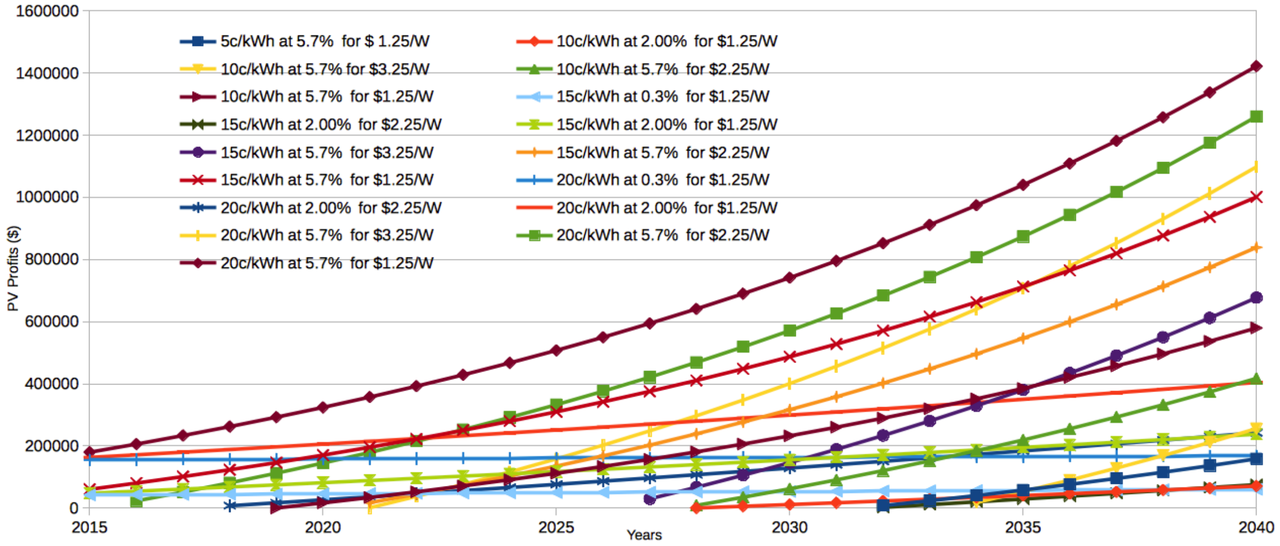


Figure 6: Profits earned from PV canopies for the case 2 packing factor of 65W/acre in Rutgers, New Jersey USA using equation 1 for $1.25-3.25/Wp cost per unit power

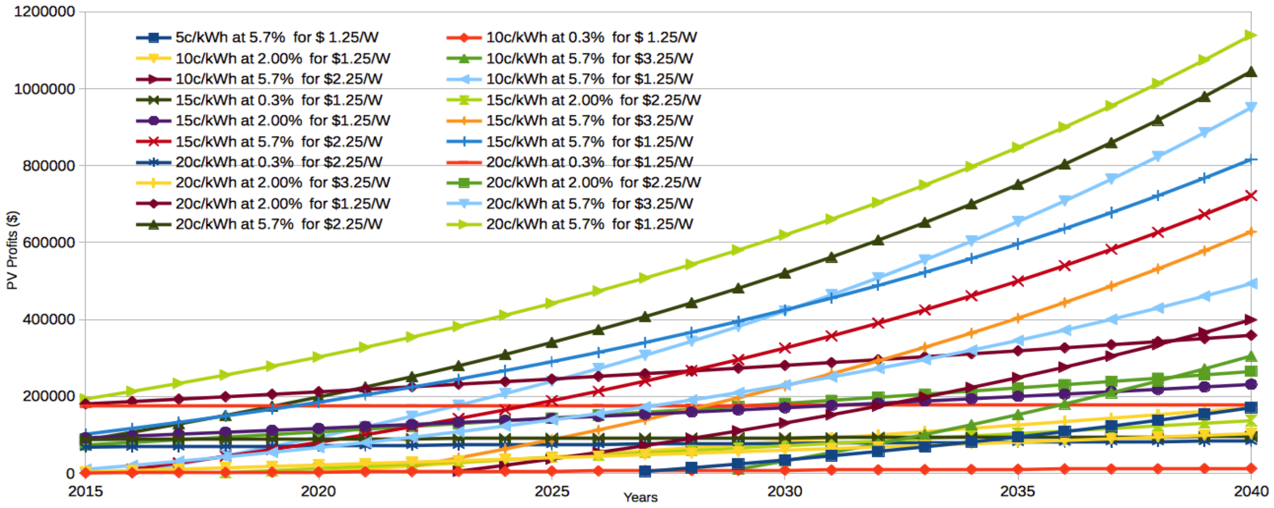


Figure 7: Profits earned from PV canopies for the case 1 packing factor of 170W/acre in Traverse City, Michigan USA using equation 1 for $1.25-3.25/Wp cost per unit power

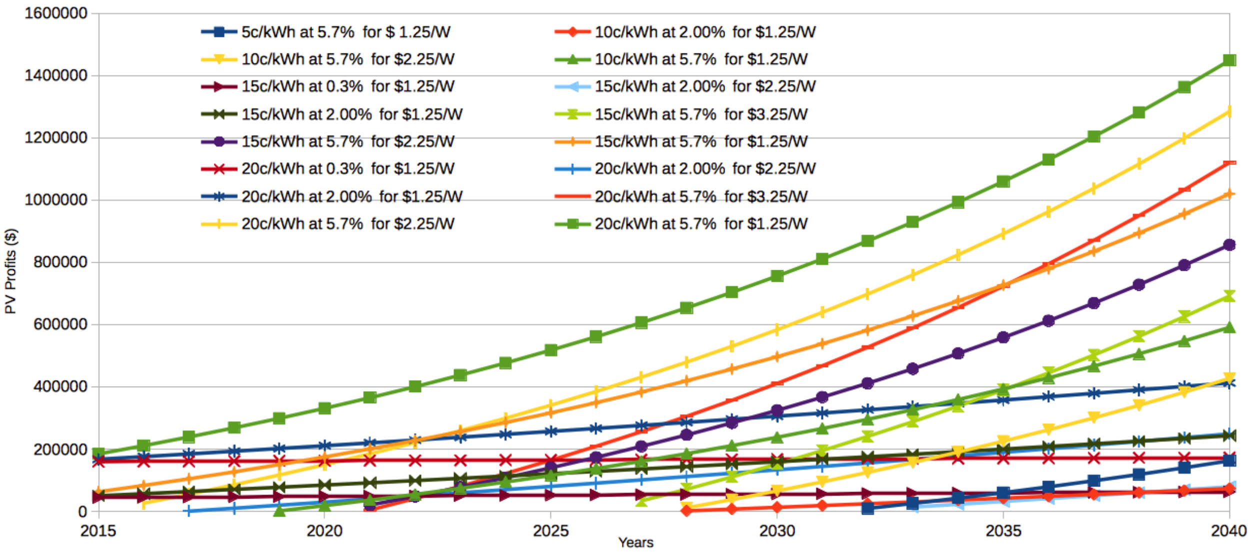
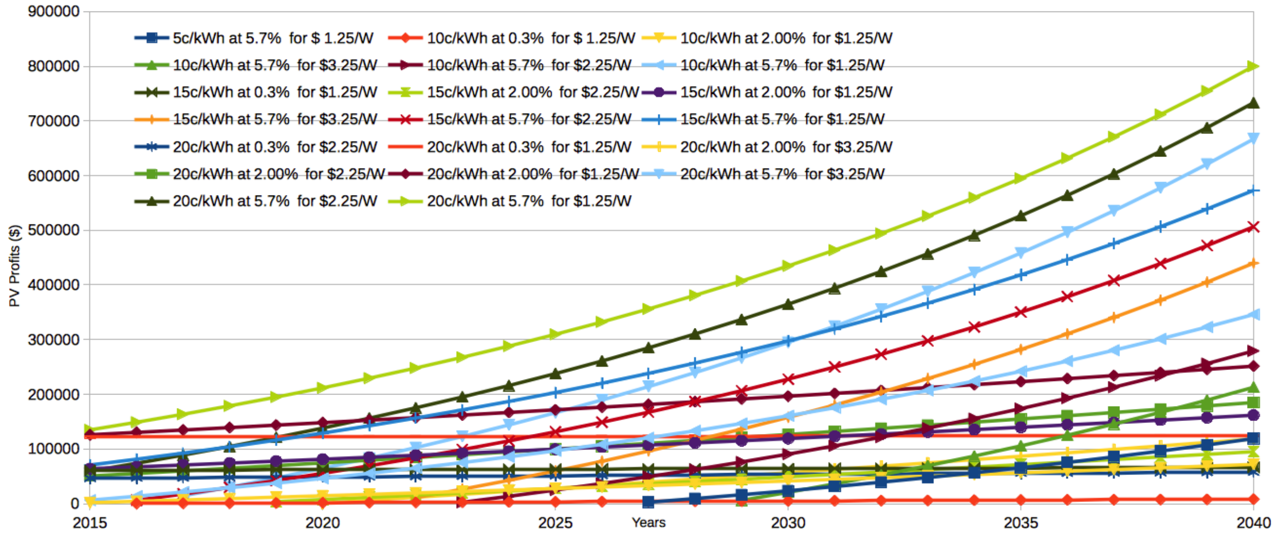


Figure 8: Profits earned from PV canopies for the case 2 packing factor of 65W/acre in Traverse City, Michigan USA using equation 1 for $1.25-3.25/Wp cost per unit power



As shown in Figure 3 for Arizona (170W/m2), even at a low selling electricity rate of 5 cents/kWh (increasing 5.7% annually), there is the potential for PV profits from the year 2023 at $1.25/W installation rate. On the other hand for the same installation rate, a high electricity rate of 20 cents/kWh escalating at 5.7% per year there is a potential of making 3 million dollars of PV profits over the span of 25 years. Arizona, with a packing factor case of 65W/m2 (Figure 4), shows the same potential for PV profits as the previous case, but overall profits are restricted to a maximum of 11 million dollars when sold at 20 cents/kWh increasing 5.7% annually.

New Jersey is a geographical area representing low solar flux and snow effects. Compared with Arizona, New Jersey would be expected to show less PV profits. Even with a packing factor case of 170W/m2, Walmart sees profits only from the year 2033 when sold at 5cents/kWh at 5.7% for $1.25/W and 2028 for 10cents/kWh at 2% for $ 1.25/W (Figure 5). The total profits earned for a best case scenario of 20cents/kWh at 5.7% for $ 1.25/W is close to $14 million over 25 years.

Michigan, which represents the areas of USA with the least solar flux and maximum snow effect, shows even less PV profit potential (Figure 7). For 170W/m2, similar to New Jersey, profits can be seen only from 2033 for a low of 5cents/kWh at 5.7% at $1.25/W. It presents the same profits of $14 million for the best-case scenario of 20cents/kWh at 5.7% increase over a span of 25 years. It should be noted that the current retail rate of electricity in many norther Michigan areas is already well over 20cents/kWh. When a low packing factor of 65W/m2 is considered, the overall profits for the same best case scenario is just about eight hundred thousand dollars over 25 years, the lowest of all case studies (Figure 8).

DISCUSSION

As clearly seen from Figures 3-8 above, solar canopies for Walmart Supercenters parking lot areas prove to be economical as well a responsible step in reducing global footprint. In areas like Phoenix, which represent Zone 1 of the United States with maximum solar flux, profits can be earned at installation rates of $1.25/W sold at low rates of $0.05/kWh increasing 5.7% annually. With utility scaled systems already installed today for less than $1.00/W (Solar Energy Industries Association, 2014) PV can be profitably installed. Areas such as New Jersey and Michigan, which get comparatively less solar flux as well as more snow, profits can be earned from as low as $0.10/kWh increasing 2% annually at installation rates of $1.25/W. With average costs of industrial rates of electricity in New Jersey and Michigan to be at 11 and 7 cents/kWh respectively, and projected to increase at 4% annually (U.S EIA, 2015), the potential to make PV profits is high. Houghton, Michigan, which has been used in case study and represents the area with least solar flux, with the electricity rates already averaging at $0.18/kWh with an average of 4% increase per year (U.S EIA, 2015), shows a profit potential of $14 million and $800,000 over the span of 25 years assuming an area of 21,000 m2 (Figures 7 & 8). Compared to this, areas such as Arizona (and others such as California, Florida, and Texas), which receive more solar flux, have a tremendous potential to make PV profits from these the substantial surface area devoted to parking lots.

The rapid decreasing installation costs of PV (Feldman et al. 2014; 54. IRENA 2012; Solar Energy Industries Association, 2014) as well as the government incentives offered for installing PV systems in most regions of the United States (Goodrich, James & Woodhouse, 2012; Davidson, James, Margolis, Fu, and Feldman, 2014) has built a very strong case for solar parking lot canopies with substantial acreages. With some regions in the United States already averaging electricity prices of 18-23 cents/kWh (e.g. Connecticut; Alaska) (U.S. EIA, 2015) PV canopies may already make financial sense if power-purchasing agreements can be arranged.

Walmart was selected as a case study retailer because it has already institutionalized profitable store-located PV systems (MacDonald, 2007; 2007b; Roselund, 2015). However, Walmart is far from alone for being well positioned to take advantage of the profitable opportunity that PV deployment on retail locations provides as many other big-box retailers such as Kohl’s, Costco, Staples, Target, and IKEA are already covering their rooftops with PV (IKEA, 2014; Feldman and Margolis, 2014; SEIA, 2014). Walmart is ahead of the pack in that they have already started considering expansion of this technology to parking lots.

The inherent limitations of this study include variations in parking lot areas using the approximations available data. Future work could include generating more accurate results using open source GIS systems or acquiring store by store area information via personal communication with the respective companies. Finally, future work could build upon this study to analyze state/government incentives while calculating LCOE, use of different types of PV systems (e.g. low concentration (Andrews, et al., 2015) and tracking systems (de Simón-Martín, et al., 2014).

CONCLUSIONS

With a substantial acreage of parking lot areas in cities both under utilized and in the case of large retailers such as Walmart, providing no direct income, the results of this study indicate it may be beneficial to cover these parking areas with solar photovoltaic canopies. The resultant renewable energy can be sold to grid operators or to microgrids and nearby residential areas at a fixed rate. This would not only prove to be financially viable for large retailers, but could also reduce their global ecological footprint by efficiently utilizing large land resources. This study reveals that even at modest rates of electricity and installation rates, PV profits from solar canopies are high, particularly in locations with high solar irradiation. With the ever-increasing need of cities for clean renewable power, solar canopies for parking lot areas for these companies would be financially and socially responsible.

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