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TECHNICAL SOLAR PHOTOVOLTAIC POTENTIAL OF LARGE SCALE PARKING LOT CANOPIES

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TECHNICAL SOLAR PHOTOVOLTAIC POTENTIAL OF LARGE SCALE PARKING LOT CANOPIES

By

Ram Krishnan

A REPORT

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In Electrical Engineering

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Table of Contents

Abstract

Solar photovoltaic (PV) technology can provide sustainable power for the growing global population, 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 report 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.

1. Introduction

1.1 Solar Photovoltaics: A basic overview

Solar Photovoltaic is the principle of converting sunlight into electricity. This principle, first described in 1839 by a French physicist Edmond Becquerel, demonstrates the properties of certain materials to generate electricity when exposed to sunlight. These materials, primarily semiconductor devices, generate free electrons when exposed to the photons composed in the sunlight (NREL, 1995).

PV systems make use of the direct and diffuse radiations from the sun, also termed as global irradiance. These PV systems, having the capability of working as grid-tied as well as stand-alone systems, can satisfy capacities ranging from 1W to gigawatts (IEA, 2014). The PV modules, having a guaranteed lifetime of 25 years, have efficiencies as high as 22% (SolarCity, 2015). With high efficiencies and decreasing investment costs, taking into consideration solar energy which is the most abundant energy resource on earth, Solar Photovoltaic technology shows to be a very promising source of renewable clean energy.

1.2 Potential for Solar Parking Lot Canopies

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 anthropogenic sources (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 consumed 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, these 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.

2. Materials and Methods

2.1 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.

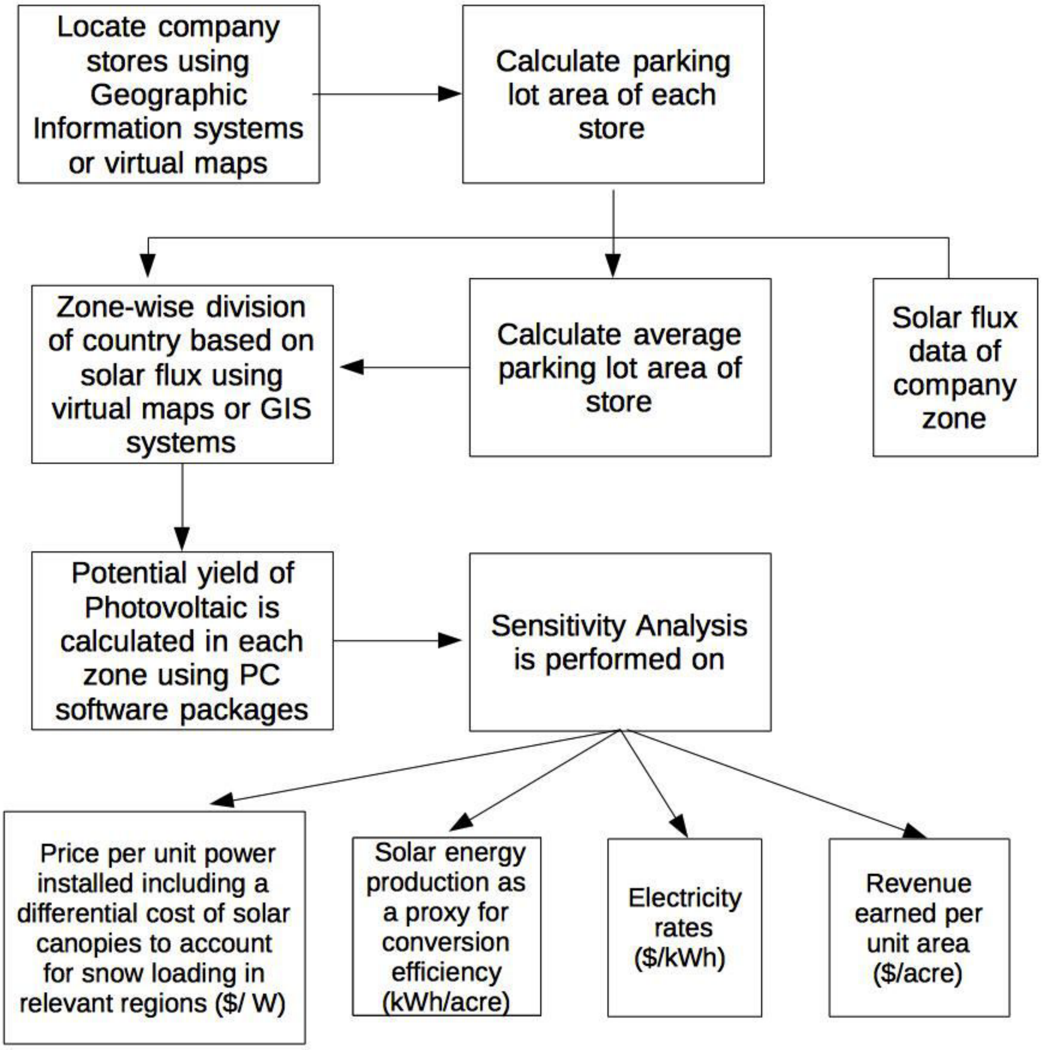

Figure1. Flow chart of Parking Lot Solar Farm Conversion Economic Decision Algorithm

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.

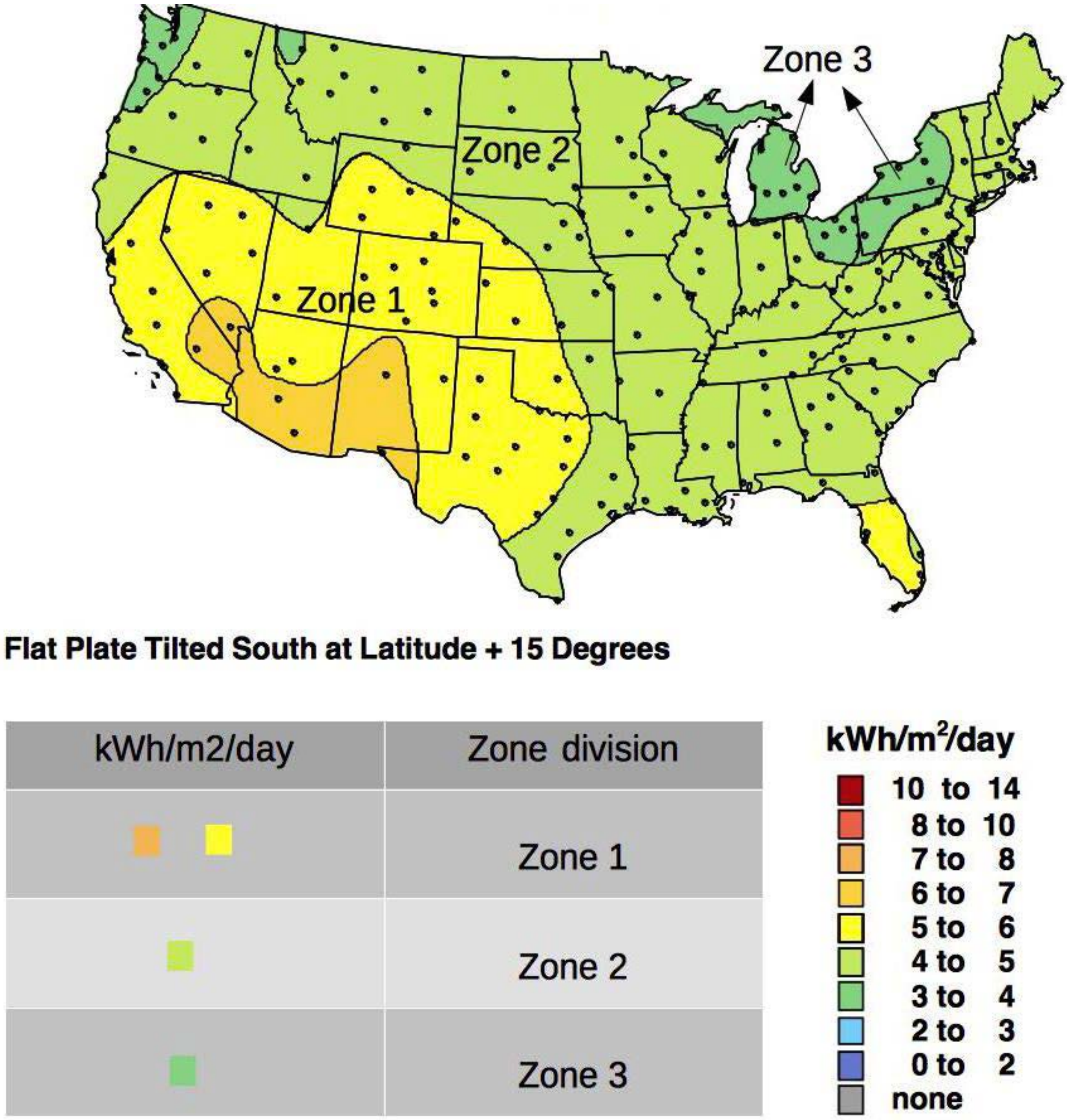

Figure 2. Map of U.S. divided up into three zones of approximately the same solar flux in each zone

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:

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

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], r_e is the rate of electricity [$/kWh], and LCOE is the levelized cost of electricity (Branker et al., 2011).

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

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 levelized cost of electricity (LCOE) produced by the PV followed the calculation from Branker et al:

$$LCOE = \frac{\sum_{t=0}^{T} \frac{I_t + O_t + M_t + F_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{E_t}{(1+r)^t}} = \frac{\sum_{t=0}^{T} \frac{I_t + O_t + M_t + F_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{S_t(1-d)^t}{(1+r)^t}} \quad (3)$$

Where:

T=Life of the project (years)

t= year t

E_t=Energy produced for t[$]
I_t=Initial investment/cost of the system including construction, installation, etc. [$]
M_t=Maintenance costs for t [$]
O_t=Operation costs for t [$]
F_t=Interest expenditures for t [$]
S_t= Rated energy o/p per year. [kWh/year]
1-d= Degradation factor
r = discount rate.

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, and 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.

2.2 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.

3. Results

3.1 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 m_2.

3.2 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.

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

For simulation purposes, the Azimuth was taken to be 0^0 and the tilt to be 20^0.

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.

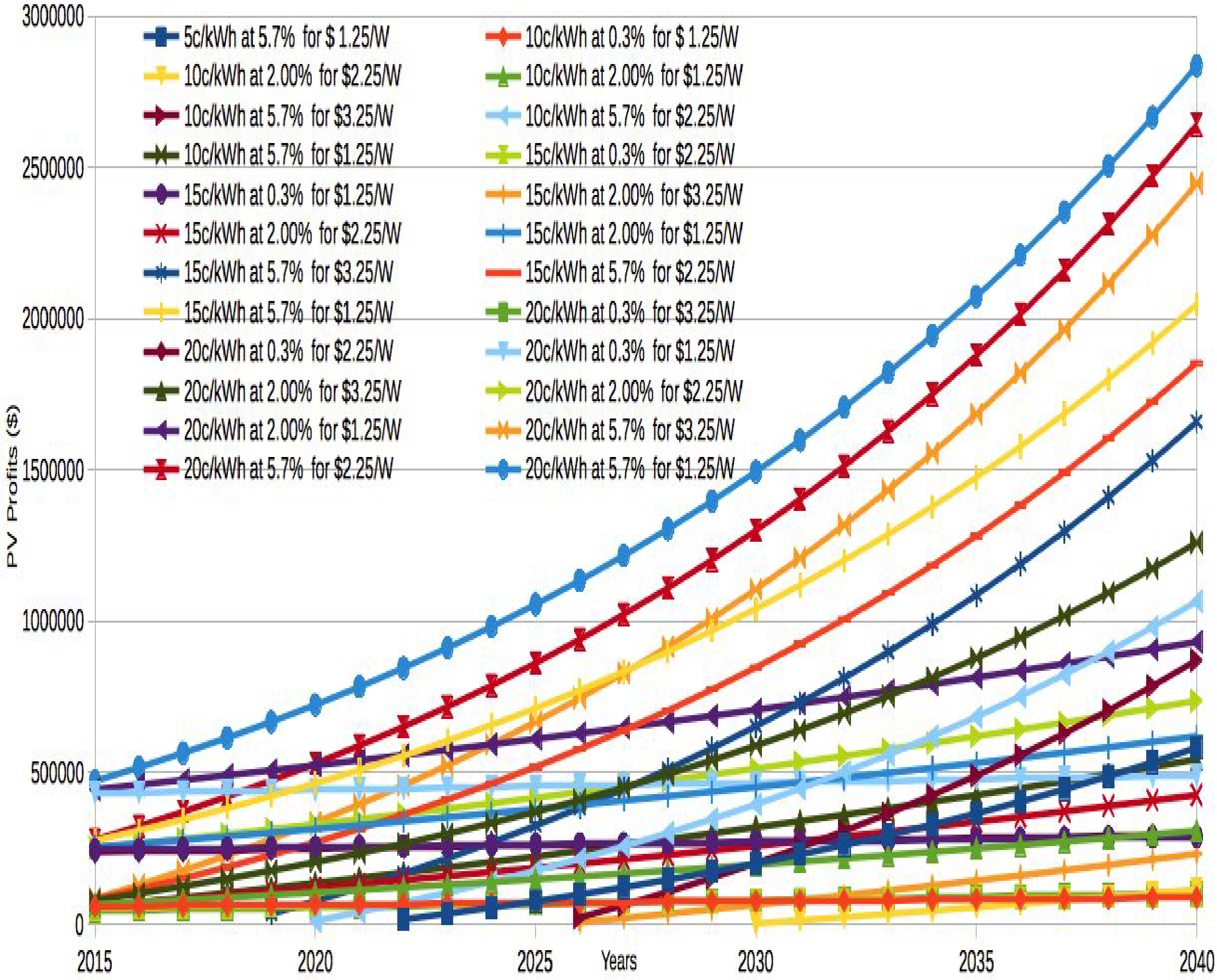

Figure 3: Profits earned from PV canopies for the case 1 packing factor of 170W/acre in Phoenix, Arizona USA using equation 1 for $1.25-3.25/Wp cost per unit power

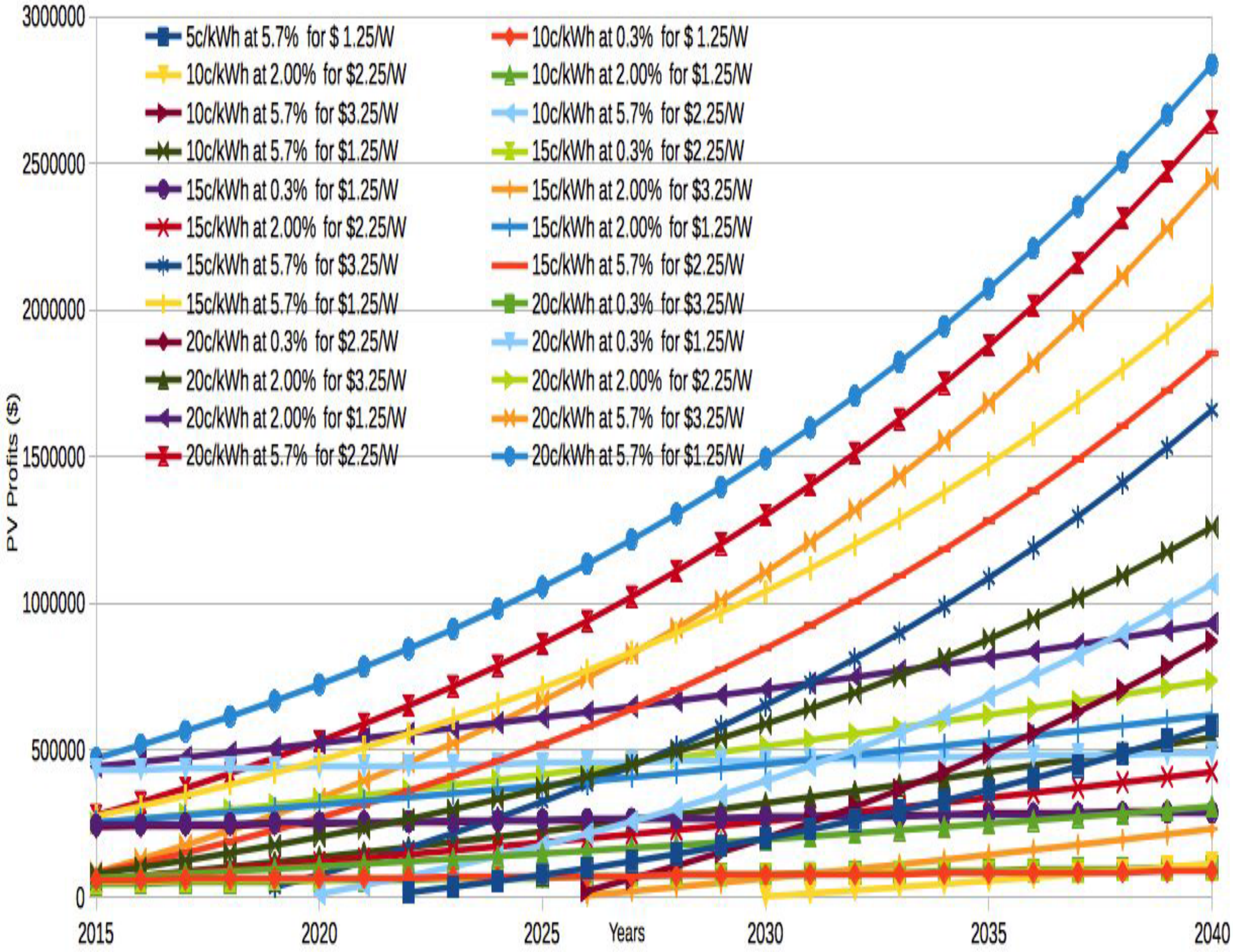

Figure 4: Profits earned from PV canopies for the case 2 packing factor of 65W/acre in Phoenix, Arizona USA using equation 1 for $1.25-3.25/Wp cost per unit power

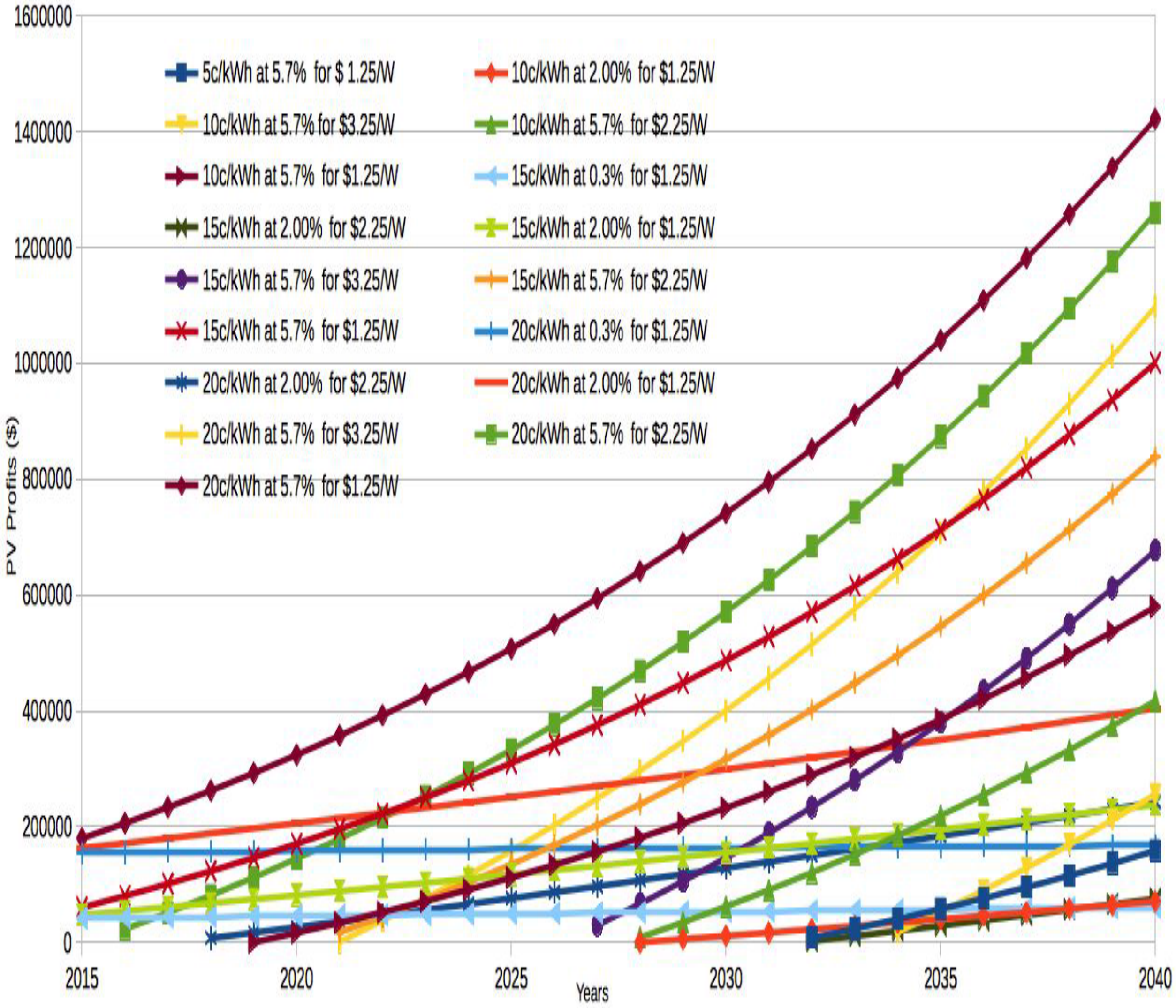

Figure 5: Profits earned from PV canopies for the case 1 packing factor of 170W/acre in Rutgers, New Jersey USA using equation 1 for $1.25-3.25/Wp cost per unit power

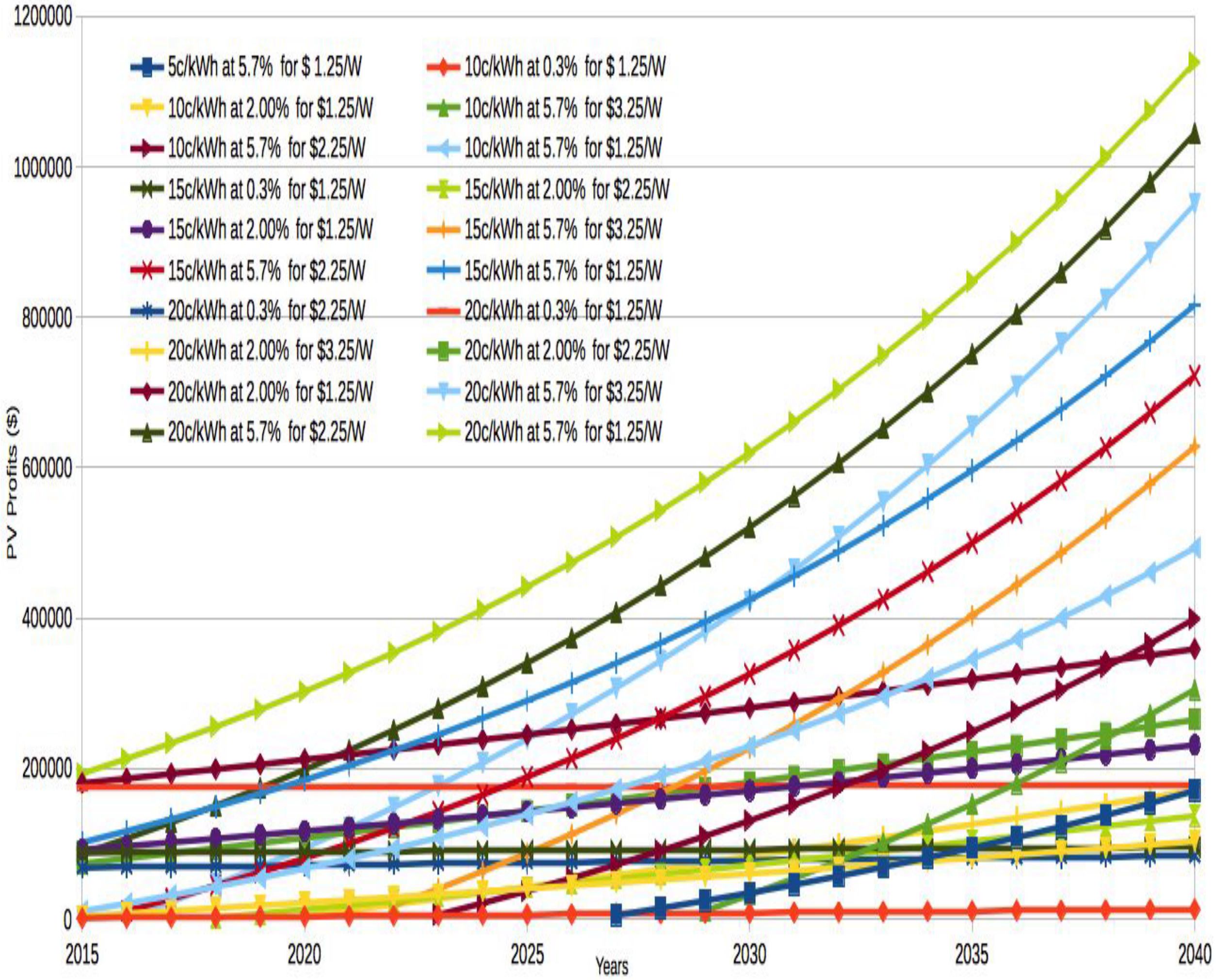

Figure 6: Profits earned from PV canopies for the case 2 packing factor of 65W/acre in Rutgers, New Jersey USA using equation 1 for $1.25-3.25/Wp cost per unit power

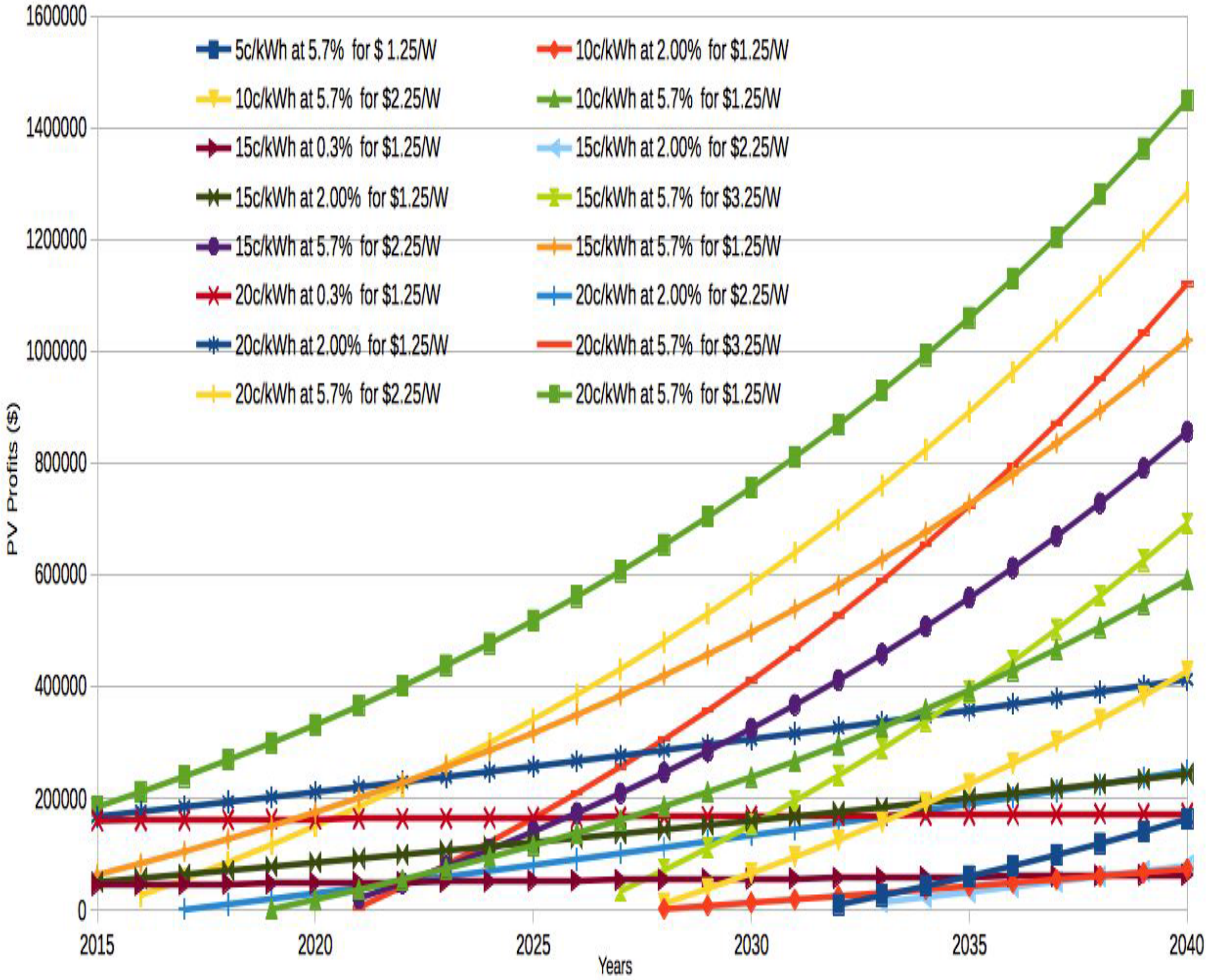

Figure 7: Profits earned from PV canopies for the case 1 packing factor of 170W/acre in Traverse City, Michigan USA using equation 1 for $1.25-3.25/Wp cost per unit power

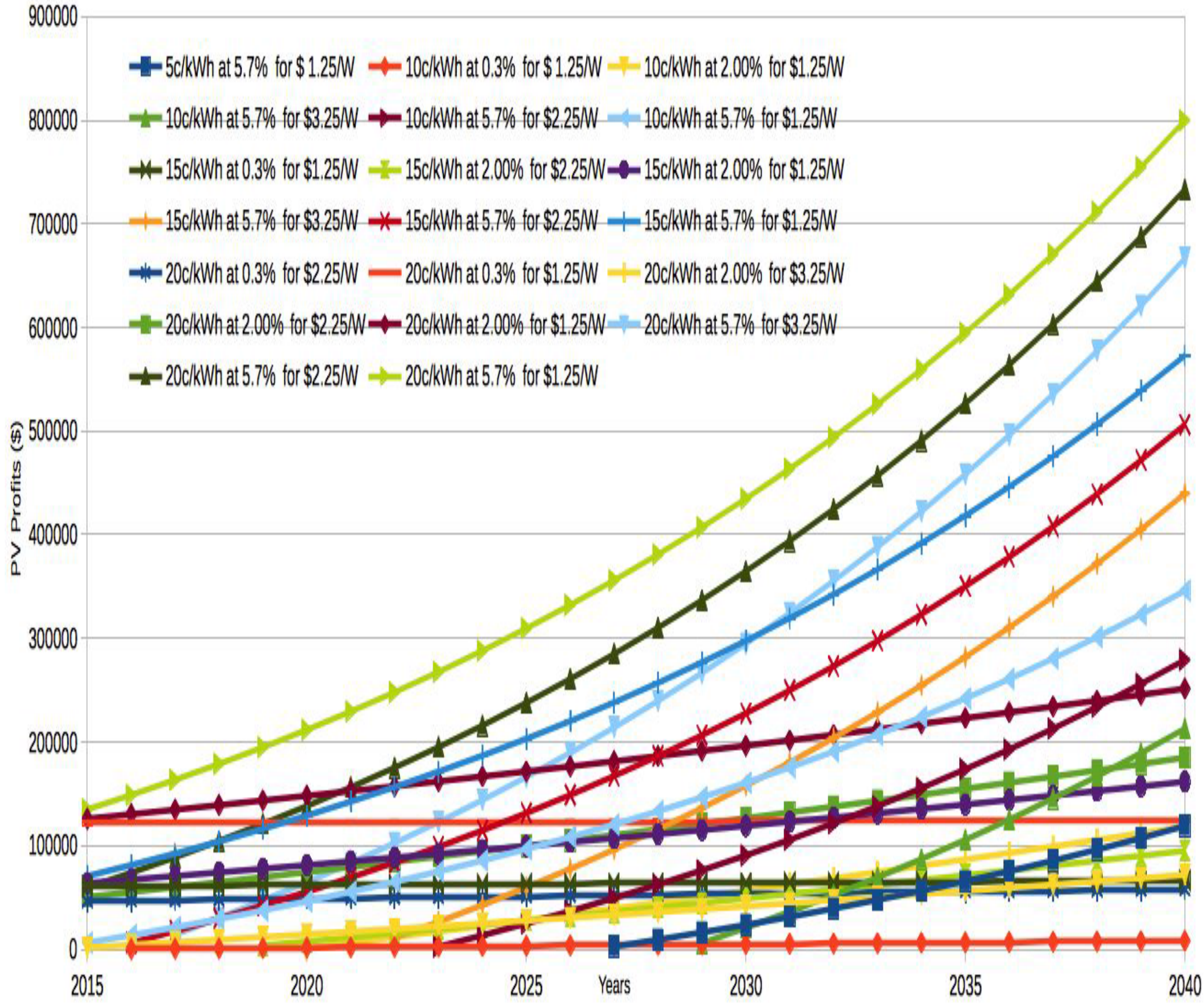

Figure 8: Profits earned from PV canopies for the case 2 packing factor of 65W/acre in Traverse City, Michigan USA using equation 1 for $1.25-3.25/Wp cost per unit power

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).

4. 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).

5. Conclusion

With a substantial acreage of parking lot areas in cities both underutilized 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.

6. References

Acknowledgements

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Aznar, Day, Doris, Mathur, and Donohoo-Vallett, "City-Level Energy Decision Making: Data Use in Energy Planning, Implementation, and Evaluation in US Cities," National Renewable Energy Laboratory (NREL), Golden, CO (United States), 2015.

Adams, Rosenzweig, Peart, Ritchie, McCarl, Glyer, Curry, Jones, Boote & Hartwell Allen Jr, 1990
Alan Goodrich, Ted James and Michael Woodhouse, “Residential, Commercial and Utility Scale Photovoltaic (PV) System Prices in the United States: Current Drivers and Cost- Reduction Opportunities” National Renewable Energy Laboratory, Golden, CO, Tech. Rep. NREL/TP-6A20-53347, February 2012.

Allen CD, Macalady AK, Chenchouni H, Bachelet D, McDowell N, Vennetier M, Kitzberger T, Rigling A, Breshears DD, Hogg EH, Gonzalez P, Fensham R, Zhang Z, Castro J, Demidova N, Lim JH, Allard G, Running SW, Semerci A, Cobb N. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management,vol. 259, no. 4. 2010; 660–684.

Amiro BD, Stocks BJ, Alexander ME, Flannigan MD, Wotton B.M. Fire, climate change, carbon and fuel management in the Canadian boreal forest. International Journal of Wildland Fire 10. 2001; 405–413.

Andrews, R.W., Pollard, A., Pearce, J.M., 2015. Photovoltaic System Performance Enhancement with Nontracking Planar Concentrators: Experimental Results and Bidirectional Reflectance function (BDRF)-Based Modeling, *IEEE Journal of Photovoltaics* 5(6), pp.1626-1635

Azevedo Ligia B., van Zelm Rosalie, Leuven Rob S.E.W., Hendriks A. Jan, Huijbregts Mark A.J “Combined ecological risks of nitrogen and phosphorus in European freshwaters, Environmental Pollution” Volume 200, May 2015, Pages 85-92, ISSN 0269-7491, http://dx.doi.org/10.1016/j.envpol. 2015.02.011.

Bill Adelson 2015. Personal communication with Bill Adelson, Director Western Operations, Solaire by SUNPOWER; November 2015.

Ben-Joseph, E. ReThinking a Lot: The Design and Culture of Parking. 2012.

Bobba AG. Numerical modelling of salt-water intrusion due to human activities and sea-level change in the Godavari Delta, India. Hydrological Sciences Journal, vol. 47, no. sup1. 2002; S67–S80.

Branker, K., Pathak, M.J.M. and Pearce, J.M., 2011. A review of solar photovoltaic levelized cost of electricity. *Renewable and Sustainable Energy Reviews*, *15*(9), pp.4470-4482.

Carnicer J, Coll M, Ninyerola M, Pons X, Sanchez G, Penuelas J. Widespread crown condition decline, food web disruption, and amplified tree mortality with increased climate change-type drought. Proceedings of the National Academy of Sciences, vol. 108, no. 4. 2011; 1474–1478.

D’Amato G, Cecchi L. Effects of climate change on environmental factors in respiratory allergic diseases. Clinical & Experimental Allergy, vol. 38, no. 8. 2008; 1264–1274.

Dale VH, Joyce LA, Mcnulty S, Neilson RP, Ayres MP, Flannigan MD, Hanson PJ, Irland LC, Lugo AE, Peterson CJ, Simberloff D, Swanson FJ, Stocks BJ, Michael Wotton B. Climate Change and Forest Disturbances. BioScience, vol. 51, no. 9. 2001; 723.

Davidson, C., T. L. James, R. M. Margolis, R. Fu, and D. J. Feldman, US Residential Photovoltaic (PV) Systems Prices, Q4 2013 Benchmarks: Cash Purchase, Fair Market Value, and Prepaid Lease Transaction Prices. National Renewable Energy Laboratory, 2014.

Davis, Pijanowski, Robinson & Engel, B. (2010). The environmental and economic costs of sprawling parking lots in the United States. *Land Use Policy*, *27*(2), 255-261.

Davis, Pijanowski, Robinson, and Engel, "The environmental and economic costs of sprawling parking lots in the United States," Land Use Policy, vol. 27, no. 2, pp. 255–261, Apr. 2010.

de Simón-Martín, M., Alonso-Tristán, C., & Díez-Mediavilla, M. (2014). Performance Indicators for Sun-Tracking Systems: A Case Study in Spain. Energy and Power Engineering, 6(09), 292.

Desantis LG, Bhotika S, Williams K, Putz FE. Sea-level rise and drought interactions accelerate forest decline on the Gulf Coast of Florida, USA. Global Change Biology, vol. 13, no. 11. 2007; 2349–2360.

Dhainaut JF, Claessens YE, Ginsburg C, Riou B. Unprecedented heat-related deaths during the 2003 heat wave in Paris: consequences on emergency departments. Critical Care, vol. 8, no. 1. 2003

Duke R, Williams R, and Payne A, "Accelerating residential PV expansion: demand analysis for competitive electricity markets," Energy Policy, vol. 33, no. 15, pp. 1912–1929, Oct. 2005.

EIA, Independent Statistics & Analysis U.S Energy Information Administration "Short-term energy outlook", March 10, 2015.

El-Fadel M, Chedid R, Zeinati M, Hmaidan. Mitigating energy-related GHG emissions through renewable energy. Renewable Energy, vol. 28, no. 8. 2003; 1257–1276.

Feldman D, Margolis R. To Own or Lease Solar: Understanding Commercial Retailers' Decisions to Use Alternative Financing Models. National Renewable Energy Laboratory, Golden, Colorado. 2014 Dec 1.

Feldman, David, Galen Barbose,Robert Margolis,Ted James, Samantha Weaver, Naïm Darghouth, Ran Fu, Carolyn Davidson, Sam Booth and Ryan Wiser "Historical, Recent, and Near Term Projections 2014 Edition", Sunshot U.S. Department of Energy, September 2014.

Flannigan M, Stocks B, Turetsky M, Wotton M. Impacts of climate change on fire activity and fire management in the circumboreal forest. Global Change Biology, vol. 15, no. 3. 2009; 549–560.

Foley, DeFries, Asner, Barford, Bonan, Carpenter, Chapin, Coe, Daily, Gibbs, Helkowski, Holloway, Howard, Kucharik, Monfreda, Patz, Prentice, Ramankutty, and Snyder Science 22 July 2005: 309(5734), 570-574. [DOI:10.1126/science.1111772]

Fouillet A, Rey G, Laurent F, Pavillon G, Bellec S, Guihenneuc-Jouyaux C, Clavel J, Jougla E, Hémon D. Excess mortality related to the August 2003 heat wave in France. International Archives of Occupational and Environmental Health, vol. 80, no. 1. 2006; 16–24.

Frihy OE. The Nile delta-Alexandria coast: vulnerability to sea-level rise, consequences and adaptation. Mitigation and Adaptation Strategies for Global Change, vol. 8, no. 2. 2003; 115–138.

Granovskii M, Dincer I, Rosen M. Greenhouse gas emissions reduction by use of wind and solar energies for hydrogen and electricity production: Economic factors. International Journal of Hydrogen Energy, vol. 32, no. 8. 2007; 927–931.

Hall, Kammen, Landis, Morris, Nemet, and Shoup, “ACCESS Magazine Spring 2007,” ACCESS Magazine, vol. 1, no. 30, 2007.

IKEA. (2014). IKEA US Renewable Energy Commitment Included In President Obama Announcement of Commitments and Executive Actions to Advance Solar Deployment and Energy Efficiency.
IKEA Corporate News, May 8, 2014:
http://www.ikea.com/us/en/about_ikea/newsitem/President_Obama_renewable_energy.

International Energy Agency “Cities, Town and Renewable Energy”, December 2009.

International Energy Agency “World Energy Outlook 2012 Executive Summary”

International Renewable Energy Agency “Renewable Power Generation Costs in 2014”, January 2015

IPCC Fifth Assessment Report. (2013) Available at < http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml> (Accessed on 29 September 2014).

IRENA “Renewable Energy Technologies: Cost Analysis Series Solar Photovoltaics” Volume 1, Issue 4/5, June 2012.

Joint ICES/CIESM Workshop to Compare Zooplankton Ecology and Methodologies between the Mediterranean and the North Atlantic (WKZEM), Ed., Proceedings of the Joint ICES/CIESM Workshop to Compare Zooplankton Ecology and Methodologies between the Mediterranean and the North Atlantic (WKZEM). Copenhagen, Denmark: ICES, International Council for the Exploration of the Sea, 2010.

Kibria “Trace/heavy Metals and Its Impact on Environment, Biodiversity and Human Health- A Short Review” DOI: 10.13140/RG.2.1.3102.2568, September 26, 2015.

Kimani N G and others, “Environmental pollution and impacts on public health: implications of the Dandora Munipal Dumping site in Nairobi, Kenya: Report Summary,” 2014.

Kirschbaum, The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic C storage, Soil Biology and Biochemistry, Volume 27, Issue 6, June 1995, Pages 753-760, ISSN 0038-0717, http://dx.doi.org/10.1016/0038-0717(94)00242

Klinenberg E. “Are You Ready for the Next Disaster?” New York Times Magazine, 2008.

Lo, C.P., Quattrochi, D.A. and Luvall, J.C., 1997. Application of high-resolution thermal infrared remote sensing and GIS to assess the urban heat island effect. *International Journal of Remote Sensing*, *18*(2), pp.287-304.

MacDonald M. The Wal-Mart Experience: Part One. ASHRAE Journal. 2007 Sep 1;49(9):14.

MacDonald M. The Wal-Mart Experience: Part two. ASHRAE Journal. 2007 Oct 1;49(10):22.

Manville and Shoup, “Parking, people, and cities,” Journal of Urban Planning and Development, vol. 131, no. 4, pp. 233–245, 2005.

Masson Gaëtan (iCARES consulting), Orlandi Sinead, Rekinger Manoel, European Photovoltaic Industry Association "Global Market outlook for Photovoltaics from 2014-2018"; 2014.

Melius, Margolis, and Ong "Estimating Rooftop Suitability for PV: A Review of Methods, Patents and Validation Techniques" December 2013.

Miranda "Rutgers Board of Governors Approves 32-Acre Solar Canopy Project" Rutgers Today. http://news.rutgers.edu/news-releases/2011/04/rutgers-board-of-gov-20110405#.VkbDq6JDm6Q; November 2015.

Moorhead KK, Brinson MM. Response of Wetlands to Rising Sea Level in the Lower Coastal Plain of North Carolina. Ecological Applications, vol. 5, no. 1. 1995; 261.

Moss R.H, Edmonds J.A, Hibbard K. A, Manning M.R, Rose S.K, van Vuuren D.P, Carter T.R, Emori S, Kainuma M, Kram T, Meehl G.A, Mitchell J.F.B, Nakicenovic N, Riahi K, Smith S.J, Stouffer R.J, Thomson A.M, Weyant J.P, and Wilbanks T.J, "The next generation of scenarios for Climate change research and assessment," *Nature*, vol. 463, no. 7282, pp. 747–756, Feb. 2010.

National Renewable Energy Laboratory Solar Flux Atlas. 2016. http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/atlas/

Nguyen H.T.and J.M. Pearce, "Estimating Potential Photovoltaic Yield with r.sun and the Open Source Geographical Resources Analysis Support System" *Solar Energy* 84, pp. 831-843, 2010.

Nicholls RJ, Hoozemans FM, Marchand M. Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. Global Environmental Change, vol. 9. 1999; S69–S87.

Nickerson, Ebel, Borchers, and Carriazo, *Major uses of land in the United States, 2007*. US Department of Agriculture, Economic Research Service, 2011.

NREL. Research Cell Efficiency Records. 2015. http://www.nrel.gov/ncpv/images/efficiency_chart.jpg

Nyström Magnus, Folke Carl, Moberg Fredrik, Coral reef disturbance and resilience in a human dominated environment, Trends in Ecology & Evolution, Volume 15, Issue 10, 1 October 2000, Pages 413-417, ISSN 0169-5347, http://dx.doi.org/10.1016/S0169-5347 (00)01948-0.

Ong, S., Campbell, C., Denholm, P., Margolis, R. and Heath, G., 2013. Land-use requirements for solar power plants in the United States. *Golden, CO: National Renewable Energy Laboratory*.

Ong, S. C. Campbell, P. Denholm, R. Margolis, and G. Heath, "Land-use requirements for solar power plants in the United States," Retrieved December, vol. 10, p. 2014, 2013.

Parmesan and Yohe, "A globally coherent fingerprint of climate change impacts across natural systems," *Nature*, vol. 421, no. 6918, pp. 37–42, Jan. 2003.

Parry M, Rosenzweig C, Livermore M. Climate change, global food supply and risk of hunger. Philosophical Transactions of the Royal Society B: Biological Sciences. 2005;360(1463), 2125-2138.

Parry ML, Rosenzweig C, Iglesias A, Livermore M, Fischer, G. Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global Environmental Change. 2004; 14(1), 53-67.

Parry, Rosenzweig, Iglesias, M Livermore, G Fischer, Effects of climate change on global food production under SRES emissions and socio-economic scenarios, Global Environmental Change, Volume 14, Issue 1, April 2004, Pages 53-67, ISSN 0959-3780 http://dx.doi.org/10.1016/j.gloenvcha. 2003.10.008.

Poumadère M, Mays C, Le Mer S, Blong R. The 2003 Heat Wave in France: Dangerous Climate Change Here and Now: The 2003 Heat Wave in France. Risk Analysis, vol. 25, no. 6. 2005; 1483–1494.

Roselund, C. Walmart to install up to 400 more solar PV systems over the next four years. PV Magazine.http://www.pv-magazine.com/news/details/beitrag/walmart-to-install-up-to-400-moresolar-pv-systems-over-the-next-four-years

Schmidhuber J, Tubiello FN. Global food security under climate change. Proceedings of the NationalAcademy of Sciences. 2007; 104(50), 19703-19708.

SEIA. Solar Means Business 2014. Top U.S. Commercial Solar Users. 2014. Solar Energy Industries Association, Washington DC. Sims RH. Renewable energy: a response to climate change. Solar Energy, vol. 76, no. 1–3. 2004; 9–17.

Solaire by SUNPOWER "Solar Canopies portfolio" http://solairegeneration.com/project/rutgersuniversity/;November 2015

Solar Energy Industries Association "Solar Industry Data" 2014

Solar Frontier "Solar Frontier and BELECTRIC Complete First CIS Supermarket Car Park Project" November 2015. http://www.solar-frontier.com/eng/news/2011/C002124.html

Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt K B, Tignor M, and Miller H L, "The physical science basis," *Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change*, pp. 235–337, 2007.

Squires 2002. Urban sprawl causes, consequences & policy responses. The Urban Institute Press, Washington, DC.

Syanne Olson "Solar Frontier, Belectric complete 340kW installation at German supermarket parking lot", PVTECH magazine, Novemeber 2015; http://www.pvtech.org/news/solar_frontier_belectric_complete_340kw_installation_at_german_supermarket

Tacoli, McGranahan Gordon and Satterthwaite "Urbanisation, rural-urban migration and urban poverty", March 2015.

Tsoutsos T, Papadopoulou E, Katsiri A, Papadopoulos AM. Supporting schemes for renewable energy sources and their impact on reducing the emissions of greenhouse gases in Greece. Renewable and Sustainable Energy Reviews, vol. 12, no. 7. 2008; 1767–1788.
United States Department of Agriculture "http://www.ers.usda.gov/topics/rural-economy-population/population-migration.aspx"

United States Department of Agriculture “http://www.ers.usda.gov/topics/rural-economy-population/ population-migration/recent-population-change.aspx”

van der Voet, United Nations Environment Programme, and Working Group on the Global Metal Flows, *Environmental risks and challenges of anthropogenic metals flows and cycles. Report 3 Report 3*. 2013.

Vine E. Adaptation of California’s electricity sector to climate change. Climatic Change, vol. 111, no. 1. 2012; 75–99.

Vine E. Adaptation of California’s electricity sector to climate change. Climatic Change, vol. 111, no. 1. 2012; 75–99.

Wal-Mart Stores Inc. “2013 Global Responsibility Report”, 2013.

Wal-Mart Stores Inc. “Walmart Sustainability Journey”, 2013.

Wal-Mart Stores Inc. “Walmart Sustainability report”, November 2014.

Walmart website: http://corporate.walmart.com/our-story/our-business

Walmart website: http://corporate.walmart.com/our-story/our-locations#/united-states

Weismann “Walmart Is Killing the Rest of Corporate America in Solar Power Adoption”, SLATE, October 2014.

Wiginton, L.K., H. T. Nguyen, J.M. Pearce, “Quantifying rooftop solar photovoltaic potential for regional renewable energy policy”, *Computers, Environment and Urban Systems* 34, (2010) pp. 345-357.

Wilson, 1995. Suburban parking requirements: a tacit policy for automobile use and sprawl. Journal of the American Planning Association 61, 29–42

World Nuclear Association “World Energy Needs and Nuclear Power”, 2015. http://www.world-nuclear. Org/info/Current-and-Future-Generation/World-Energy-Needs-and-Nuclear-Power

SolarCity “SolarCity Unveils World’s Most Efficient Rooftop Solar Panel, To Be Made in America”: http://www.solarcity.com/newsroom/press/solarcity-unveils-world%E2%80%99s-most-efficient-rooftop-solar-panel-be-made-america; October 2, 2015.

National Renewable Energy Laboratory “Photovoltaic Fundamentals” 1995.

Appendix A

SAM Simulation file system parameters

Case 1 packing factor: 170W/m^2

Modules	
SunPower SPR-210-BLK-U	
Cell material	Mono-c-Si
Module area	1.2 m²
Module capacity	215.2 DC Watts
Quantity	16,584
Total capacity	3.6 DC MW
Total area	20,630 m²

Inverters	
SMA America: SB4000US 240V	
Unit capacity	4 AC kW
Input voltage	250 - 480 VDC DC V
Quantity	811
Total capacity	3.2 AC MW
DC to AC Capacity Ratio	1.10
AC losses (%)	1.0

Array	
Strings	2,073
Modules per string	8
String voltage (DC V)	328.0
Tilt (deg from horizontal)	20
Azimuth (deg E of N)	0
Tracking	fixed
Backtracking	-
Rotation limit (deg)	-
Shading	no
Soiling	yes
DC losses (%)	4.4

Case 2 packing factor: 65W/m^2

Modules	
SunPower SPR-210-BLK-U	
Cell material	Mono-c-Si
Module area	1.2 m²
Module capacity	215.2 DC Watts
Quantity	6,336
Total capacity	1.4 DC MW
Total area	7,881 m²

Inverters	
SMA America: SB4000US 240V	
Unit capacity	4 AC kW
Input voltage	250 - 480 VDC DC V
Quantity	310
Total capacity	1.2 AC MW
DC to AC Capacity Ratio	1.10
AC losses (%)	1.0

Array	
Strings	792
Modules per string	8
String voltage (DC V)	328.0
Tilt (deg from horizontal)	20
Azimuth (deg E of N)	180
Tracking	fixed
Backtracking	-
Rotation limit (deg)	-
Shading	no
Soiling	yes
DC losses (%)	4.4