Preprint: Aishwarya S. Mundada, Emily W. Prehoda, Joshua M. Pearce. U.S. market for solar photovoltaic plug-and-play systems. *Renewable Energy*. DOI:10.1016/j.renene.2016.11.034

U.S. Market for Solar Photovoltaic Plug-and-Play Systems

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Highlights

- Plug and play solar photovoltaic (PV) can be installed by an average prosumer
- This study estimates potential new market for such plug and play PV in U.S.
- Results show plug and play PV would create 57 GW of demand in U.S.
- This is a new market for PV of $14.3 billion – $71.7 billion
- Could generate ~108,417 thousand MWh/ year and save $13 billion/year

Abstract

Plug and play solar photovoltaic (PV) systems are affordable, easy to install and portable grid-tied solar electric systems, which can be purchased and installed by an average prosumer (producing consumer). The combination of recent technical/safety analysis and trends in other advanced industrialized nations, indicate that U.S. electrical regulations may allow plug and play solar in the future. Such a shift in regulations could radically alter the current PV market. This study provides an estimate of this new U.S. market for plug and play PV systems if such regulations are updated by investigating personal financial decision making for Americans. The potential savings for the prosumer are mapped for the U.S. over a range of scenarios. The results show the total potential U.S. market of over 57 GW, which represents an opportunity for sales for retailers from $14.3–$71.7 billion depending on the capital cost of plug and play solar systems ($0.25-$1.25/W). These systems would generate ~108,417,000 MWh/year, which is 4 times the electricity generated from U.S. solar in 2015. This distributed solar energy would provide prosumers approximately $13 billion/year in cost savings, which would be expected to increase by about 3% per year over the year lifetime of the systems.

Keywords: electricity market; distributed generation; levelized cost of electricity; photovoltaic; plug and play solar; prosumer

Nomenclature

AC-Alternate Current
BNEF- Bloomberg New Energy Finance
BOS-Balance of System
C_g - Electricity cost on grid ($/kWh)
d- Degradation rate (%/year)
DOE- Department of Energy
E- total potential electricity generated from appropriate plug and play PV systems in the US (kWh)
ECD- Esource Customer Direct
EIA- U.S. Energy Information Administration
EURAC- European Academy of Bozen/Bolzano
E_{pv} - Electricity generated by AC PV module (kWh)
GTM- Greentech Media Company
h- U.S. average Household size (%)
h_s - appropriately oriented households in a state
I- Installation cost of the plug and play solar photovoltaic system
IEA- International Energy Agency
IEEE- Instititute of Electrical and Electronics Engineering.
IFC- Internation Finance Corporation
IRENA- International Renewable Energy Agency
LCOE- Levelized cost of Electricity ($/kWh)
M- Total U.S. Market value for plug and play solar PV system (W)
NMCH- National Multi-Family Housing Council
NREL- National Renewable Energy Laboratory
NSJC- National Solar Job Census
O- Total amount of power of plug and play PV that can be installed by households that owns their homes/apartments (W)
O_o - Orientation in the class of housing for owners (%)
O_R - Orientation in the class of housing for renters (%)
OMB- Office of Management and Budget
p- Households that can install plus and play solar PV system
P_o – Total population that own their housing (%)
P_R - Total population that rent their housing (%)
P_S - Solar PV system size (kW)
P_{cf} - Capacity factor of the solar PV (%)
PV- Photovolatic
R- Total amount of power of plug and play PV that can be installed by households that rent their homes/apartments (W)
r- Discount rate (%)

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S_H – Percentage shading (%)
SEIA- Solar Energy Industries Association.
SPS- Solar Power Station
T- Life time of the technology (years)
Treasury- U.S. Department of Treasury
u_s – solar flux per unit area per day for a state (kWh/m^2/day or 1 sun hours)
WNA- World Nuclear Association
Z- Size of the system (kW)

1. Introduction

In the United States there is widespread support for solar energy from all political groups (Shahan, 2012; Riffkin, 2015; SEIA, 2015). Historically, the enormous potential of solar photovoltaic (PV) (Pearce, 2002) has only been held back from extensive use (and even dominance in the electrical generation market) by economics (Wilkins, 2002; Beck & Martinot, 2004; Pietruszko, 2006; IFC, 2007; Branker, Shackles, & Pearce, 2011; Alafita & Pearce, 2014). However, solar PV module costs have declined sharply (SEIA&GTM Q2, 2012; SEIA&GTM Q3, 2015) resulting in sustained and rapid growth of the solar PV market (SEIA&GTM, 2015; IRENA, 2015; SEIA&GTM-Q3, 2015). For example, solar PV module prices have declined by 75% between 2009 and 2014 (IRENA, 2015) and overall residential scale PV systems costs declined by 45% since 2010 (IRENA, 2015; SEIA&GTM, 2015). This resulted in cumulative 41 GWdc of U.S. solar PV installations from 2007 to 2016, of which 41% were residential (SEIA&GTM, 2015).

As the cost of fossil fuels increases due to reduced conventional sources (Payne, Dutzik & Figdor, 2009; IEA, 2014; WNA, 2016) and greenhouse gas emission liability increases (Short et.al., 2013; Cooper& Rosin, 2014; Heidari & Pearce, 2016), the demand for PV installations will continue to increase, resulting in further declines in PV manufacturing costs, which will continue to drive more demand (McDonald & Schrattenholzer, 2001; Van der Zwaan & Rabl, 2003; Watanab, Nagamatsu & Griffy-Brown, 2003; Nemet, 2006; Candelise, Winskel, & Gross, 2013 Parkinson, 2014; Zhang et al., 2014; Barbose, et al., 2015; Rubin, et al., 2015; WNA, 2016). Reductions in solar PV module costs reduces the levelized cost of electricity (LCOE) of solar (Branker, Pathak & Pearce, 2011; Parkinson, 2014) and helps expand the solar PV markets to achieve or surpass grid parity (Christian & Gerlach, 2013). Many economically beneficial PV markets already exist. The cost of electricity generated by small-distributed on-grid PV systems is comparable with the conventional electricity rates in various locations (Branker, Pathak & Pearce, 2011; Stefan and Yorston, 2013).

Despite the popularity of solar energy technology and ability to achieve positive economic returns, solar PV contributes only 0.54% to the total electricity generation in U.S. as of April 2015 (EIA, 2015a; EIA, 2015b). Primary barriers for rapid growth of solar PV among the general population include the lack of initial capital and inappropriate financing mechanisms (Wilkins, 2002; Beck & Martinot, 2004; Pietruszko, 2006; IFC, 2007; Branker, Shackles, & Pearce, 2011; Alafita & Pearce, 2014). While the U.S. is a wealthy country, with a total net worth of $84.9 trillion in June 2015, (Poppick, 2015), the top

20% of the population possesses 89% of the wealth (of which top 1% owns 35% of the wealth) (Wolff, 2012). The median net worth of U.S. households is only $81,400 (Lubin, 2013). Thus, obtaining a solar PV system capable of providing all electrical consumption is relatively expensive for the average American homeowner (Wilkins, 2002; Pietruszko, 2006; ECD, 2008).

One method to overcome this challenge is to allow installation of "plug and play" solar PV systems for residential purpose and small-commercial use (Mundada, Nilsiam & Pearce, 2016). Plug and play PV systems are affordable, easy to install, and portable grid-tied solar PV systems, which can be purchased and installed by an average prosumer (producing consumer). A prosumer can buy such a pre-configured and pre-certified grid-tied AC module (consisting of PV modules, microinverters, and wires) and can install it by plugging it into a household outlet to produce solar electricity. This can be accomplished using commonly available tools and without assistance of a trained licensed technician or concomitant overhead and soft costs. Additionally, plug and play solar systems are portable, allowing easy transport for people who relocate to own solar. The United Kingdom (Kennect 2012; SPS 2015), Switzerland, Netherlands and the Czech Republic (Movellan, 2014) currently permit and install plug and play solar without any technical issues. A recent technical review of plug and play solar indicated that it is technically viable and safe for U.S. adoption as well (Mundada, Nilsiam & Pearce, 2016).

Based on technical analysis and the trends in other advanced industrialized nations, expanding U.S. electrical regulations to allow/or include plug and play solar is viable. Such a shift in regulations could radically alter the current PV market. This study provides an estimate on a potential new market for plug and play PV systems in the U.S. if such regulations are updated. This is accomplished by investigating personal financial decision making for Americans using plug and play solar PV as an investment. First, the LCOE calculation is made for all the States in the U.S. based on solar flux using a sensitivity analysis on the cost of a system. Next, the current residential retail electricity rate is determined for the entire U.S. The potential savings for the prosumer are then mapped for the U.S. over a range of scenarios and escalation rates. Finally, demographic data is correlated with the GIS date to extract the total market in the U.S. These results are presented and discussed.

2. Methodology

LCOE can be determined by summing up all the costs incurred for the generation of electricity by a PV-based technology in a time span divided by the total energy generated by the technology during that time span (Branker, et al., 2011 ;Mundada, Shah & Pearce, 2016). LCOE is expressed in $/kWh, which can be compared directly to residential electric rates. There has been various methods to determine LCOE of solar PV technologies (Short, Packey, & Holt, 1995; Cambell, 2008; Grana, 2010; Velosa III, 2010; Darling, et al., 2011), however, this analysis will use the simplified version of the comprehensive review of LCOE by Branker et al. (2011). The LCOE of a plug and play solar PV depends on the following inputs:

1. Capital cost of the AC PV module (I)
2. Discount rate (r)
3. Degradation rate (d)
4. Electricity generated by AC PV module (E_{pv})
5. Life time of the technology (T), which is normally taken as the warranty life.

The LCOE from plug and play PV, C_{pnp}, is thus determine by:

$$C_{pnp} = \frac{I}{\sum_{n=1}^{T} \frac{\left(\frac{8760 hrs}{years}\right) * P_s * P_{cf} * (1-d)^n}{(1+r)^n}} \qquad \frac{\$}{kWh} \qquad (1)$$

where P_S is the solar PV system size (kW) and P_{cf} is the capacity factor of the solar PV (%), which is the ratio of full sun hours (defined as 1000W/m^2) to 24 hours in a day. The electricity generated by the plug and play solar PV module is location dependent, relying directly on the capacity factor of the solar PV module, and the solar flux (kWhr/m^2/day) of the region. The solar flux available in the United States ranges from 3 kWhr/m^2/day to 9 kWhr/m^2/day (NREL, 2007).

The savings, S, which prosumers can obtain from installing a plug and play PV system is given by:

$$S = C_g - C_{pnp} \qquad [\$/kWh] \qquad (2)$$

where C_g is the cost of electricity on the grid in [$/kWh]. Any positive S, indicates a positive return for the prosumer.

In this study a sensitivity analysis is run on the three primary variables in the LCOE calculation: 1) the capital cost of the AC PV module is varied from $0.25/W to $1.25/W, 2) the discount rate is analyzed at 1% and 7%, and 3) capacity factor is varied from 13% to 28%. The justification for this sensitivity and the values of the other core variables are explained below.

2.1 Theory and calculations for determining LCOE of plug and play solar PV microinverter system

2.1.1 Capital cost of the AC Solar PV module

A solar plug and play PV module consists of solar PV module, microinverter, mounting materials, and electric cables. As homeowners can install the systems themselves, the installation cost of the plug and play solar PV module includes only the capital cost of the hardware, which is dominated by the AC PV module (plug and play solar can be made up of a PV module and a microinverter or an AC PV module that integrates the microinverter into the module). Other factors that normally accompany PV installations such as labor costs, electrical BOS costs, structural BOS costs, engineering & permitting, inspection, and interconnection cost are excluded. This represents a substantial savings as labor cost and BOS of a solar PV system adds up to more than 50% of the system cost (Barbose, Darghouth, & Wiser, 2010) and is increasing as a percentage as PV module prices have declined. It should be pointed out here, that because of this, the plug and play PV systems reverse the trend observed in the rest of the PV industry: the larger the system the smaller the cost per unit power no longer holds. Reports show, since 1998, the overall installation cost of solar PV system is declining on average by 6%-8% every year in all the sectors (residential, commercial and utility scale) (Feldman, et al., 2014). From 2012-2013 the solar PV market realized a decline of 12% in the installation cost of solar PV system of <10kW (Feldman, et al., 2014). The solar PV module cost decreased sharply from

$1.85/W in 2010 to $0.65/W in 2013 (BNEF, 2013; SEIA&GTM, 2014). Additionally there has been noticeable decline in the inverter cost of 6% (i.e. $0.42/W to $0.25/W from 2010-2013) (BNEF, 2013; Davidson, et. al., 2014). In year Q1-2014 to Q1-2015 the solar module cost around $0.64/W to $0.75/W and the inverter cost around $0.23/W to $0.34/W (SEIA-&GTM- Q1, 2015). In addition, capital costs for PV modules drop below $0.50/W when purchased in bulk from wholesalers. For example: Sunvia solar modules currently cost $0.45/W (Sunvia, 2016). Thus, for determining the LCOE the capital cost of the AC solar PV module is considered to be $1.00/W. For sensitivity analysis the capital cost of the AC PV module is varied from $0.25/W to $1.25/W, representing near and medium term potential costs to prosumers.

2.1.2 Degradation rate

The degradation in performance of solar PV module is an important variable for predicting lifetime output and is influenced by chemical and material processes such as weathering, oxidation, corrosion and thermal stress (Jordan & Kurtz, 2012). Researchers conducted standardized tests to determine a degradation rate of solar PV modules (Osterwald et.al., 2002; Pinge et al., 2010; Jiang, Lu, & Sun 2011) and the degradation rates for amorphous silicon PV is 0.5-1.0%/year, for crystalline silicon it is 0.1-0.5%, for polycrystalline silicon PV it is 0.1-1.0% and for cadmium telluride 0.1-0.5%/year (Osterwald et.al., 2002; Jordan et.al., 2011; Belluardo, Ingenhoven, & Moser, 2013). A median degradation rate for solar PV module is 0.5%/year (Jordan and Kurtz, 2012) and thus the degradation rate considered for determining LCOE in this case is 0.5%/year following Branker et al. (2011).

2.1.3 Life span of the Plug-and-Play PV System

The lifespan of solar PV module is beyond 25 years (Czanderna & Jorgensen, 1999; Realini, 2003; Dunlop, Halton, & Ossenbrink, 2005; Skoczek, Sample, & Dunlop, 2009; Holladay, 2010). Although a lifespan of 30 years or more is expected for a solar PV module (Harrabin, 2009), the financial lifespan is normally taken as the warranty period, which is 20-25 years (Wohlgemuth, 2003; Brearley, 2009). In addition, a service life-time of over 25 years is expected for certified, microinverters available on the market (Nahi, 2009). The life-time of plug and play solar PV system depends on the life-time of the PV and microinverter, thus, the life span, T, of the system is considered to be 25 years. Table 1 summarizes the commercially available microinveretes on the U.S. market and their warranty period.

Table 1. Microinverters available on the U.S. market with their lifespan warranty period and certified standards.

Company [Source]	Warranty Period (Years)	Product	Safety Standard Compliance	Grid Connection Compliance
Chilicon Power	25	CP-250 Micro-inverter	UL1741. CSA C22.2 NO. 107.1	IEEE 1547

Solar Panel Plus	25	MI-250-240A Micro-inverter	UL 1741 CSA C22.2 No. 107.1	IEEE 1547
Enphase	25	M215 Micro-inverter	UL1741. CAN/CSA-C22.2 NO. 0-M91, 0.4-04, and 107.1-01	IEEE 1547
Enphase	25	M250 Micro-inverter	UL1741. CAN/CSA-C22.2 NO. 0-M91, 0.4-04, and 107.1-01	IEEE 1547
Enphase	25	C250 Micro-inverter	UL1741. CAN/CSA-C22.2 NO. 0-M91, 0.4-04, and 107.1-01	IEEE 1547
Enphase	25	S230 Micro-inverter	UL1741. CAN/CSA-C22.2 NO. 0-M91, 0.4-04, and 107.1-01	IEEE 1547
Enphase	25	S280 Microinveter	UL1741. CAN/CSA-C22.2 NO. 0-M91, 0.4-04, and 107.1-01	IEEE 1547
Siemens	25	SMIINV215R60XX Microinverter	UL1741, CAN/CSA-C22.2 NO. 0-M91, 0.4-04, and 107.1-01	IEEE 1547

2.1.4 Capacity factor

Capacity factor is the total energy a technology can produce in a duration of time compared to that of the total energy it could have generated to its full capacity. The capacity factor of solar PV module is a function of the solar irradiation at the location, the orientation of the solar PV module, the performance (or efficiency) of the solar PV module, the electrical efficiency of the system (Campbell et al., 2009; Hossein et al., 2012; NREL, 2013). For the case studies in this paper the capacity factor is varied from 13.08% (IL, Chicago, average sun hours/day 3.14 hrs/day) to 28.2% (NM, Albuquerque, average sun hours/day 6.77 hrs/day) (SolarDirect, 2016; Alternate Energy sources, 2016) depending on the solar irradiation (3 kWhr/m^2/day to 9 kWhr/m^2/day) (NREL, 2007) received at different states in U.S.

2.1.5 Discount rate

Discount rates are used to determine the discounted cash flows, which takes into account time value for money and risk or uncertainty involved in the future cash flows. The U.S. Department of

Energy (DOE) establishes technologically feasible energy efficiency standards for many appliances used daily in American households (i.e. microwaves, clothes dryers, and air conditioners). To determine if the investments in reduced electrical consumption are economically justified, the DOE performed a sensitivity analysis on consumer purchase of energy by varying the discount rate from 3% and 7% (OMB, 1992). These values were chosen by the OMB based on the following logic: On the low end, the OMB recommends using a "social rate of time preference" of approximately 3 percent, which approximates average saving rates using the real rate of return on long-term government debt, such as 10-year Treasury notes (OMB 2003, 33), and thus can act as a proxy of how consumers value future consumption against current consumption. On the high end, a 7% discount rate is appropriates the marginal pretax rate of return on an average investment in the stock market (OMB 1992, 9). Both of these values can be viewed as overly conservative. First, on the low-end the daily long term-real treasury rate for more than 10 years for 2015 was around 1% (Treasury, 2016). On the high end, 7%, may be the average rate of return on the stock market before taxes, but both energy efficiency and solar generated offsets of electricity consumption for consumers can be viewed as after tax savings. For high income households this number decreases significantly, but for the lowest income households 7% can be seen as the maximum valid discount rate. Thus, in this study 1% and 7% will be used in the sensitivity analysis.

It should be noted that discount rates are often points of contention in the literature. Various studies have attempted to determine "implicit consumer discount rates" based on purchasing preferences using appliances and finding large variances and in some cases extremely high (triple digit) discount rates (Ruderman et al., 1987; Hausman, 1979; Dermot, 1980; Frederick et al., 2002; Harrison et al., 2005; Andersen et al., 2006; Newell & Siikamäki, 2015). It has been well established that discount rates for consumers varies according to income, race, education (Newell & Siikamäki, 2015). For example, as the education of consumers increases the discount rates they use for decision-making decreases (Newell & Siikamäki, 2015). It has been pointed out that observed discount rates are so high because of lack of information and inability to adequately understand available information related to energy consumption (Frederick et al., 2002). Stated simply, un-educated or poorly educated consumers make irrational economic decisions. Unfortunately, some older studies such as (Hausman, 1979) have erroneously argued that low discount rates should only be used for efficiency standards for high-income households and are not suitable for low or median-income households that have implicit discount rates that are much higher. Sadly, even some modern authors have been confused and argued for government policy for low and median-income households to use implicit discount rates (e.g. 27% to 102%) (Miller, 2015). Such policy recommendations are simply incorrect and if adopted would perpetuate ignorant economic errors commonly observed in American middle and lower class. No low- or median-income household, for example, has standard legal low-risk investment opportunities available to them to reach triple digit returns. Yet as many studies have shown they pass up energy efficiency investments as if they do. Considerations for economic education will be presented in the discussion, but for the present case studies in this paper the discount rates considered is 1% and 7%.

2.2 GIS Analysis

A shapefile of the United States was obtained from the ArcGIS database (Fitzpatrick, 2012). The electricity rate of each state was obtained from the U.S. Energy Administration database (EIA 2016).

Savings for each state were calculated utilizing a 1% and 7% discounted LCOE at $1.25/W capital cost. Average electricity rate for each state was subtracted from this value. Average savings across the United States were transcribed to a map utilizing ArcMap version 10.3.1.

2.3 U.S. Market Analysis

To estimate total market for plug and play, several assumptions and factors that affect solar plug and play market size are included. The average family will require a 1kW plug and play installation to satisfy electrical needs. There are about 117,259,427 U.S. households and approximately, 37% of U.S. households (43,267,432) are renter occupied (h_r) and 63% (73,991,995) are owner occupied (h_o) (NMHC, 2014). As the number of occupants within a household is correlated with varying electrical consumption (Kavousian, 2013), it is expected that larger households will consume greater amounts of electricity. However, for the maximum plug and play PV system size considered here (1kW), even the smallest households (e.g. 1 person) are expected to have a demand above what can be provided by the PV system alone. This, thus, does not affect the potential market for plug and play solar.

It is assumed that the average U.S. utility rates will remain static or rise, allowing for the market penetration of plug and play solar determined in this study to be considered a base. This is a conservative assumption as the real electricity price escalation for the residential market has historically increased (e.g. on average 3.6% p.a. in the years 2000 to 2006 in the U.S. (EIA, 2016)). In addition, it is assumed that the median U.S. household incomes will remain at roughly $52,250 (Noss, 2014) indicating that the economic situation that favors plug and play over larger-scale residential PV remains intact.

Factors such as orientation, shading, and neighborhood configurations will affect customers who can optimally utilize plug and play solar technology. Homes or rented units oriented in a direction other than south, southwest, or southeast will affect solar plug and play performance and should be accounted for in calculations (Hachem et al 2013). For single family homes the size of the plug and play systems remove restrictions on orientation as it could be located on the southernmost facing facade. However, for those that rent, a fraction of 50% is used for appropriate orientation. This assumes a random orientation of the rentals with roughly half facing south in some capacity. Previous conservative estimation for unshaded roof in cities was taken as 30% for all locations (Wigington, et al., 2010) as shading due to trees, multiple facades on the home, or proximity to other residences can reduce PV performance (Norton et al., 2011). In this study because the prosumer would have the option to move the relatively small footprint (1kW is only 3 to 4 modules) of the plug and play solar to unshaded rooftop, porches, or yard locations this study assumes the unshaded percent is doubled to 60%. These factors and assumptions are considered when determining the total U.S. market, M, value for plug and play solar given by:

$$M = O+R \qquad [W] \tag{3}$$

Where O is the total power [W] of plug and play PV that can be installed by households that own their homes and is given by:

$$O = h_o*p*Z*s_h*o_o \qquad [W] \tag{4}$$

and R is the total number of power [W] of plug and play PV that can be installed by households that rent their homes/apartments and is given by:

$R = h_r*p*Z*s_h*o_r$ [W] (5)

Where p is the percent of U.S. households that can economically and technically install a plug and play PV system, Z is the size of that system based on power in W, s_h is the percent of unshaded residences and o_o and o_r is the appropriately oriented in that class of housing for owners and renters, respectively.

The average U.S. household size in 2015 was 2.54 (U.S. Census, 2015a). This value was used to estimate the number of households in each state given the state populations (U.S. Census, 2015b).

The potential energy generated from plug and play solar in the U.S. is then given by:

$E = \Sigma_{states} (h_s*Z*u_s*365 \text{ days/year}*s_h)$ (kWh) (6)

Where h_s is the appropriately oriented households in the state, which assumed the same ratio of renters and owners nationally resulting in a value of 0.8155), and u_s is the kWh/m^2/day (1 sun hours) for the state from Table 2.

3. Results

A case study is performed for residential sectors in all the states with average solar hours and average electricity rate as represented in Table 2.

Table 2: The average 1 sun (1000W/m^2) solar hours and the average electricity rates during Dec. 2015 for residential sector in United States (EIA, Dec 2015; Solar Direct, 2016; Alternate Energy Source, 2016):

States	Average sun hours (hrs/day)	Average Electricity rate (cents/kWh)
Connecticut	4.30	19.43
Maine	4.19	15.52
Massachusetts	3.79	19.60
New Hampshire	4.60	18.00
Rhode Island	4.23	19.88
Vermont	4.40	17.17
New Jersey	4.21	15.54
New York	3.16	17.53

Pennsylvania	3.28	14.12
Illinois	3.14	11.81
Indiana	4.21	11.11
Michigan	4.00	14.58
Ohio	3.94	12.61
Wisconsin	4.295	13.83
Iowa	4.40	10.61
Kansas	4.57	12.29
Minnesota	4.53	11.77
Nebraska	4.79	9.68
North Dakota	5.01	8.84
South Dakota	5.23	10.27
Missouri	3.78	10.39
Delaware	4.00	13.45
District of Columbia	4.23	13.34
Florida	4.99	11.49
Georgia	4.74	10.22
Maryland	4.47	14.67
North Carolina	4.71	10.96
South Carolina	5.06	12.05
Virginia	4.31	10.98
West Virginia	3.65	10.43
Alabama	4.23	11.23
Kentucky	4.94	10.34
Mississippi	4.44	11.16
Tennessee	4.37	10.40
Arkansas	4.69	9.51
Louisiana	4.63	8.70
Oklahoma	4.99	9.00
Texas	4.92	11.33
Arizona	6.36	10.75

Colorado	4.87	11.44
Idaho	4.70	9.64
Montana	3.99	10.42
Nevada	5.98	12.41
New Mexico	6.77	11.36
Utah	5.26	10.56
Wyoming	6.06	10.57
California	4.77	17.3
Oregon	3.72	10.39
Washington	3.57	9.19
Alaska	3.55	19.6
Hawaii	6.02	26.86

Using equation 1 and the input data discussed above, the LCOE was calculated for plug and play PV systems in each state. Figure 1 shows the effects of varying the capital cost of plug and play solar PV module, varying solar irradiation received, which consequently affects the capacity factor in the U.S. states on the LCOE of the solar plug and play solar PV system. The LCOE of the system is determined at different discount rates of 1%, and 7% and for a life span of 25 years with 0.5%/year degradation rate. The capital cost of the plug and play solar PV module is varying from $0.25-1.25/W. The states chosen in the graphs were representative of the principal solar flux viewed in the continental U.S.

Figure 1 A is for Michigan, which falls in the region that receives a minimum solar irradiation ranging between 4.00 - 4.50 kWhr/m^2/day with a minimum capacity factor of 16.7%. Figure 1 B shows New Jersey, which has between 4.50 – 5.00 kWhr/m^2/day with a minimum capacity factor of 17.5%. Figure 1 C represents South Carolina which falls in the region which receives 5.00- 5.50 kWhr/m^2/day with a minimum capacity factor of 21.1%. Figure 1 D shows data for Nevada, which falls in the region which receive solar irradiation ranging from 5.50 – 6.00 kWhr/m^2/day with a minimum capacity factor of 24.9%. Figure 1 E represents Wyoming, which falls in the region with 6.00 - 6.50 kWhr/m^2/day with a minimum capacity factor of 25.3%. Figure 1 F represents Arizona with solar irradiation above 6.50 kWhr/m^2/day with a minimum capacity factor of 26.5%. It can be observed from the Figure 1 A-F that the capital cost of the system is directly proportional to the LCOE and dominates the electricity costs. For example, in Figure 1 A the LCOE of the system with 1% discount rate and capital cost $0.25/W is $0.006/kWh whereas for capital cost $1.25/W is $0.028/kWh.

The discount rate of the system affects the LCOE of the system to a great extent. It can be observed from Figure 1 A-F that as the discount rate of the system increases the LCOE of the system increases with capital cost and life span maintained constant. For example from Figure 1 D the discount rate of the system increases from 1% to 7% the LCOE of the system also increases from $0.004/kWh to $0.008/kWh at $0.25/W and life span of 25 years.

Preprint: Aishwarya S. Mundada, Emily W. Prehoda, Joshua M. Pearce. U.S. market for solar photovoltaic plug-and-play systems. *Renewable Energy*. DOI:10.1016/j.renene.2016.11.034

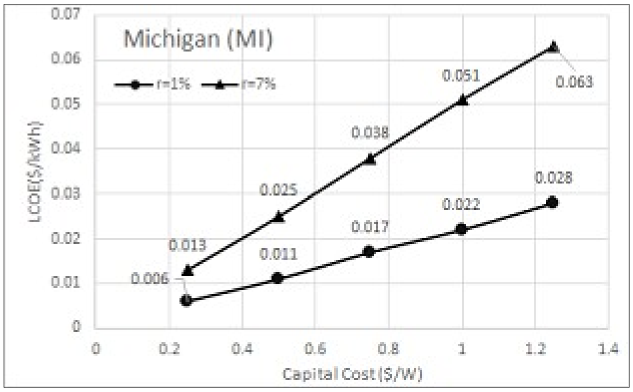

Figure 1 A-Michigan

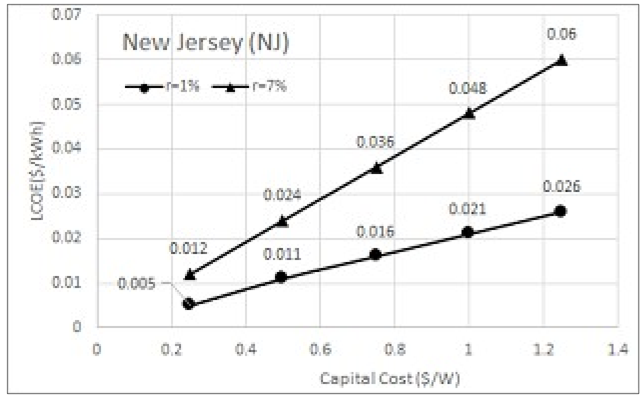

Figure 1 B- New Jersey

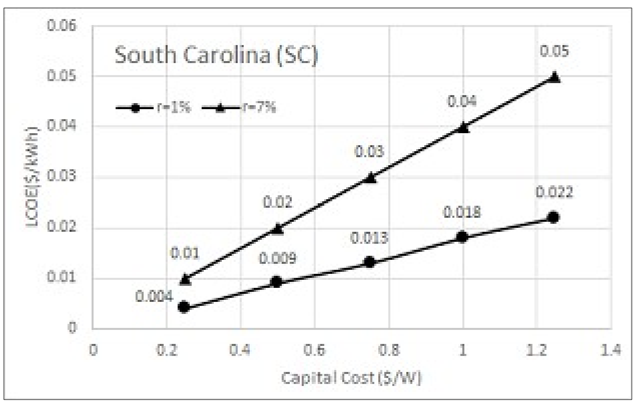

Figure 1 C-South Carolina

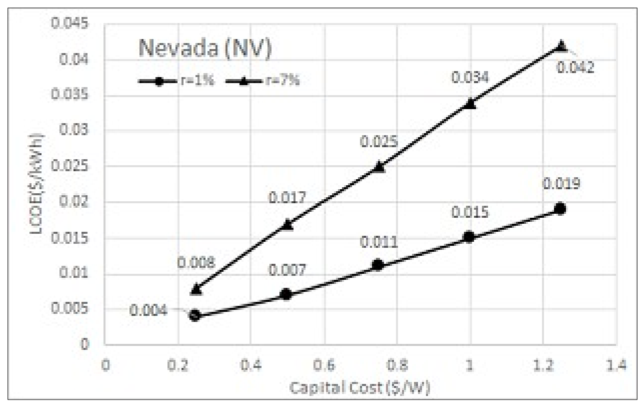

Figure 1 D- Nevada

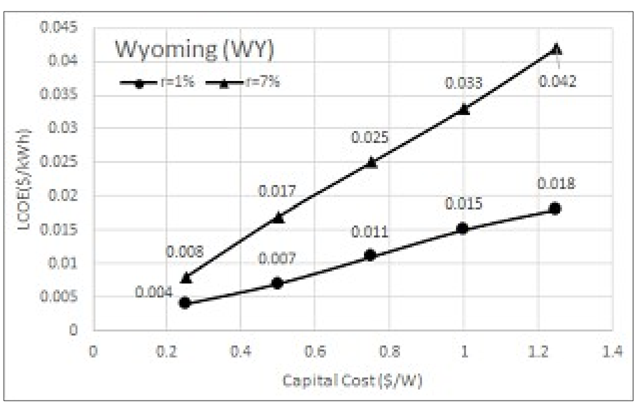

Figure 1 E-Wyoming

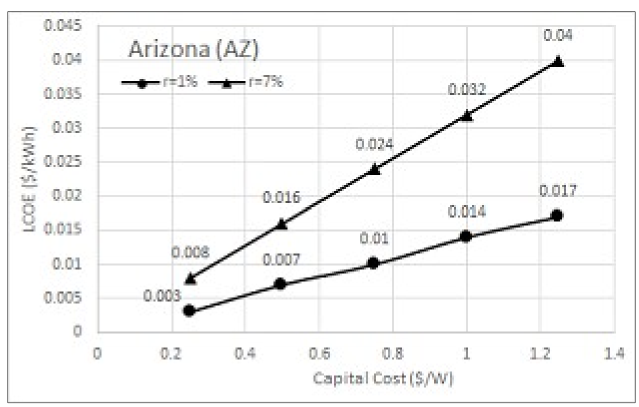

Figure 1 F- Arizona

Figure 1 A-F: LCOE of the plug and play solar PV systems at discount rates 1% and 7% for varying capital cost of the system ($0.25/W to $1.25/W) and varying capacity factor depending on geographical locations (16.7% to 25.3%). The life span of the system is 25 years with 0.5%/year degradation rate.

It can be seen from Figure 1 that the capital cost of the plug and play solar PV system affect the LCOE of the system by a significant amount. Even a small change in the value of capital cost was having a considerable amount of impact of the LCOE of the system. It can be observed that for all the states that as the capital cost of the system was reducing the LCOE of the system was decreasing. It can also be observed from the Figure 1 that discount rate also has a considerable amount of impact on the LCOE of the system. It can be observed that the LCOE of the system increases with increase in discount rate (1%-7%) for the system with same capital cost.

Figure 2 shows a geographic representation of the savings gained by installing such a plug and play PV system in all the states of the U.S., which depends on the LCOE of the solar plug and play solar PV system and current electricity rates for the residential sector for each state (equation 2). The LCOE of the system is determined at different discount rates of 1% and 7% and for a life span of 25 years with 0.5%/year degradation rate and where the capital cost of the system is considered to be $1.25/W.

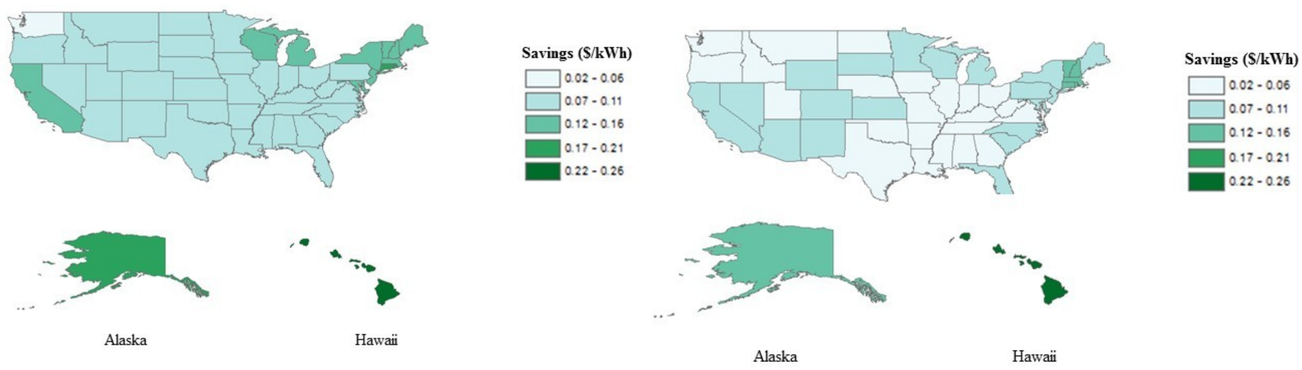

Figure 2 Prosumer savings obtained by installing the solar plug and play system at A) 1% and B) 7% discount rate respectively. Assumptions- the capital cost of the system is considered as $1.25/W and life span of the system is 25years with 0.5%/year degradation rate and current electricity rates for residential sector.

In Figure 2 the United States is divided into 5 regions depending upon the ranges of savings in which the state falls. From the Figure 2A it can be observed that the prosumer has a considerable amount of savings after installing such a system of 1kW even though the escalation rate of the electricity cost is considered to be 0% and capital cost of the system is considered to be at its maximum $1.25/W. The largest potential savings can be found in states such as Alaska, Hawaii, and variable states in the northeast region, with a range between $0.17-$0.26/kWh. The lowest potential savings, with a range of $0.02-$0.06/kWh can be found in states such as Washington. Total savings range from $0.02-$0.26/kWh.

Also from the Figure 2B it can be observed that the prosumer has a considerable amount of savings after installing such a system of 1kW even though the escalation rate of the electricity cost is considered to be 0% and capital cost of the system is considered to be at its maximum $1.25/W. Comparing Figure 2 A with B it can be observed that the prosumer savings for maximum number of states reduces with increase in the discount rate. For example the savings obtained by installing such a system in Utah (UT) with discount rate 1% lies in that range $0.07/W to $0.11/W and with discount rate 7% lies in the range $0.02/W to $0.06/W. Also the savings obtained by installing such a system in Alaska (AK) with discount rate 1% lies in that range $0.17/W to $0.21/W and with discount rate 7% lies in the range $0.22/W to $0.26/W. Again, the largest potential savings can be found in states such as Alaska, Hawaii, and variable states in the northeast region and across the U.S., with a range between $0.12-$0.26/kWh. The lowest potential savings, with a range of $0.02-$0.05/kWh can be found in states such as Washington, Oregon, Louisiana, Arkansas, Missouri, Ohio, West Virginia. Total savings range from $0.02-$0.26/kWh.

It is striking that the BOS savings made possible by plug and play PV systems enable economic savings for essentially the entire U.S. Thus Z in equation 4 and 5 becomes 1. Applying the conservative estimates to the market for households of renters and owners amounts to about 13GW and 44GW, respectively. Following equation 3 this results in a total potential U.S. market for plug and play PV systems of over 57 GW. Moreover, the total U.S. market for plug and play solar systems ranges from $14.3 billion – $71.7 billion depending on the capital cost of plug and play solar systems ($0.25-$1.25/W).

Following equation 6, these plug and play PV systems would generate approximately 108,417 thousand MWh per year, which is roughly 4 times the electricity generated from solar in the U.S. in 2015 (EIA, 2015). With the average cost of electricity in the U.S being about $0.12/kWh this represents roughly $13 billion/year in electricity cost savings for prosumers.

4. Discussion

A straightforward methodology for calculation of LCOE of plug and play solar PV systems and the savings prosumers would accrue from installation has been presented to determine the economic viability of such a system. The results from applying this methodology indicate that plug and play solar PV systems are profitable for prosumers if installed in any state in the U.S. The results from Figure 1 provide a quantitative view of the effects on the LCOE with changes in various input factors like capital cost, discount rate and capacity factor. The results from Figure 2 provide an overview understanding of prosumer savings that can be obtained after installing such a system.

The installation of such a system for residential sector irrespective of the geographical location in United States gives considerable amount of prosumer savings. From Figure 2 it can been seen that there is considerable amount of savings obtained by prosumer for both the discount rates (1% and 7%) with maximum capital cost and 0% escalation rate of the electricity cost for all the states in United States. It can also be observed that the savings are high with less discount rate (1%) as compared to the one with higher discount rates (7%).

The results of both the LCOE of the system (Figure 1) and the prosumer savings obtained by installing the system (Figure 2) provide decision makers with clear guides for the economic benefits of installation of plug and play solar photovoltaic systems. The lower LCOE costs and a considerable amount of prosumer savings obtained by installing the plug and play solar PV systems offers support to preliminary analysis that indicate a bright future for installation of plug and play solar PV system at residential or small commercial business levels.

4.1 U.S. Market and Employment

According to SEIA report on U.S. market analysis on solar PV installation the residential solar installation has increased by 66% from year 2014-2015 and is able to cross 2 GW in 2015 of residential solar PV installation (SEIA-Q4, 2015). The U.S. market analysis conducted in this paper shows homeowners or renters can install plug and play solar systems, ultimately expanding the potential market. Installation of such a system of just 1kW per residence can raise the residential solar installation on the U.S. market to over 57GW. Thus, the total residential solar installation in U.S. could be expanded by a factor of more than 28 if plug and play solar PV is legalized.

According to NSJC solar industry employment has grown by 123% in the years Dec 2009- Dec 2015, resulting in nearly 115,000 domestic living-wage jobs from solar (2015). Moreover, the total solar industry employment was around 208,859 in Nov 2015 showing an increase of 20.2% from Nov 2014-2015 (NSJC, 2015). Solar employment is sub divided into various components out of which manufacturing, sales and distribution, installation, and project development constitutes 80% of the total employment. Overall the solar installation was around 1GW in year 2010 which raised to 7.43GW installation in year 2015 (740% increase), whereas solar employment has increased approximately from manufacturing (20,000 from 30,000 or 50%), sales and distribution (10,000 to 25,000 or 150%), installation (40,000 to 120,000 or 300%), and project development (15,000 to 25,000 or <50%) (NSJC, 2015). The relatively small employment percentage increases for manufacturing and project development are due to importing of PV components and standardization of installs, respectively. For plug and play solar PV only the jobs associated with manufacturing and sales and distribution are expected to increase with plug and play installations. The largest increase would be expected in sales and distribution as companies previously unassociated with the PV market (e.g. both brick and mortar retail stores like Wal-Mart and online retailers like Amazon) have the potential to acquire significant profits from the shares of a new market that is estimated to be between \$14.3 billion – \$71.7 billion.

4.2. Limitations and Future Work

This study had several limitations. For the LCOE calculations performed for each state in this paper the minimum solar flux data for that state was taken into consideration, which results in the conservative maximum estimated LCOE for the state. Thus the savings for particular prosumers in a given state from this analysis may be greatly underestimated as the solar flux in some states varies considerably. For example, Arcata, CA average solar flux yearly is 3.93 kWhr/m^2/day whereas for Santa Maria, CA average solar flux yearly is 5.2 kWhr/m^2/day. Similarly the representative costs of the electricity for each state may also create a source of error as these values range widely for different utilities within a state. Future work is needed to do a more granular investigation of both the solar flux and the utility rates, although results presented here and the conclusion drawn from them are overall representative. A more granular approach could assist vendors target the most lucrative areas of the country with plug and play PV first. Additionally, shading varies for each house affecting the total energy generation. The assumptions used here again were conservative, but the error associated with the unshaded residences could be quantified using established techniques for the entire U.S. (Nguyen and Pearce, 2012; Nguyen et al., 2012; Liang, et al., 2014). Thus, a far better estimation could be made if such a system is to be installed for a particular house at a particular place. In addition, this approach could be extended to other markets using readily available solar flux data (Zhang et al., 2013; Amillo et al., 2014).

Following previous work (Pearce, et al., 2009) that enables straight forward conversion of investments in energy conservation measures to return on investment (ROI)s using the savings per year and the lifetime of the device, plug and play PV in all locations in the U.S. currently demonstrates positive returns as shown in the positive S values shown in this study throughout the country. For example, all in inflation adjusted values, the before tax internal rate of return of companies is about 10%, which is reduced to 7% from corporate income taxes, and reduced further to about 4% after investors pay capital gains taxes (Newell & Pizer, 2001). If the individual is in credit card debt, the opportunity cost of investment would be closer to 15%. However, an example is illustrative. If a household in Michigan is considered having purchased a plug and play PV system at the highest rate ($1.25/W, which amounts to $1,250 for a 1 kW system). With a conservative estimate of four 1 sun hours per day on average the system will create 1460kWh/year, which is worth over $292/year for those living in the upper peninsula of Michigan. A simply payback results in the system paying for itself comfortably under 5 years and creating a high double digit return that would challenge even those residents with substantial credit card debt as a sound investment.

However, as introduced in the discount rate section, low and middle income U.S. households do not have a rate of time preference over 100%, yet it appears that they do in energy efficiency studies because they simply make uniformed purchasing decisions. The fact that consumers make such uneconomic choices clearly points to a significant need for consumer education (Willis, 2008; Lusardi, 2008; Pearce, et al., 2009; Hasting, Madrian & Skimmyhorn; 2013). In regards to this issue for plug-and-play solar PV, it is apparent that the large market estimated in this study is only possible with an education campaign targeted at consumers to understand the rates of return for such systems so they could compare them to their other investment options.

5. Conclusions

A new method to calculate the LCOE and potential savings for prosumers of a plug and play solar photovolatic system was presented. A sensitivity analysis of such a system on the capital cost of the system, the discount rates and the capacity factor depending on the geographical location for each state in U.S. was carried out. The results show that for available costs, plug and play PV systems are economic throughout the U.S. already. If plug and PV is legalized in the U.S. the results show the total potential U.S. market is over 57 GW, which represents an opportunity for sales for retailers of a new product from $14.3 billion – $71.7 billion. Such a mass deployment of distributed PV systems would generate over 100,000 thousand MWh per year, which is roughly four times the electricity generated from solar in the U.S. in 2015. This distributed solar energy would provide prosumers approximately $13 billion/year in electricity cost savings, which would be expected to increase by about 3% per year for the 20 year lifetime of the plug and play PV systems.

Acknowledgments

The authors would like to acknowledge support from the Conway Fellowship.

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