



U.S. market for solar photovoltaic plug-and-play systems



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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.

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1. Introduction

In the United States there is widespread support for solar energy from all political groups [1–3]. Historically, the enormous potential of solar photovoltaic (PV) [4] has only been held back from extensive use (and even dominance in the electrical generation market) by economics [5–10]. However, solar PV module costs have declined sharply [11,12] resulting in sustained and rapid growth of the solar PV market [13,11,14]. For example, solar PV module prices have declined by 75% between 2009 and 2014 [15] and overall residential scale PV systems costs declined by 45% since 2010 [15,13]. This resulted in cumulative 41 GWdc of U.S. solar PV installations from 2007 to 2016, of which 41% were residential [13].

As the cost of fossil fuels increases due to reduced conventional sources [16–18] and greenhouse gas emission liability increases [19–21], the demand for PV installations will continue to increase, resulting in further declines in PV manufacturing costs, which will continue to drive more demand [22–29,18,30]. Reductions in solar PV module costs reduces the levelized cost of electricity (LCOE) of

solar [31,26] and helps expand the solar PV markets to achieve or surpass grid parity [32]. 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 [31,33].

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 [34,35]. Primary barriers for rapid growth of solar PV among the general population include the lack of initial capital and inappropriate financing mechanisms [5–10]. While the U.S. is a wealthy country, with a total net worth of \$84.9 trillion in June 2015 [36], the top 20% of the population possesses 89% of the wealth (of which top 1% owns 35% of the wealth) [37]. The median net worth of U.S. households is only \$81,400 [38]. Thus, obtaining a solar PV system capable of providing all electrical consumption is relatively expensive for the average American homeowner [39,9,10].

One method to overcome this challenge is to allow installation of “plug and play” solar PV systems for residential purpose and small-commercial use [40]. 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-

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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	Institute of Electrical and Electronics Engineering
IFC	International 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	Photovoltaic
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 (%)
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)

certified grid-tied AC module (consisting of PV modules, micro-inverters, 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 [41,42], Switzerland, Netherlands and the Czech Republic [43] 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 [40].

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 data 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 [7,44]. 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 [45–49], however, this analysis will use the simplified version of the comprehensive review of LCOE by Branker et al. [3,7]. 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:

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

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 1000 W/m²) to 24 h 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/m²/day) of the region. The solar flux available in the United States ranges from 3 kW h/m²/day to 9 kW h/m²/day [50].

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

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