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The challenging economics of US residential grid defection

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ABSTRACT

Declining costs for solar photovoltaics (PV) and excitement about new technologies have led to speculation that self-sufficient PV/battery storage systems will soon become competitive with traditional electricity service. We compare a grid-tied residential solar system with an off-grid solar-plus-battery system at 1020 US locations, and calculate three effects of "grid defection" for each: the private net costs to the homeowner, the change in system generation costs, and change in system emissions. For the average US location, an off-grid solar system is almost double the price of grid-connected solar, is associated with higher system generation costs, and has no emissions benefit.

1. Background and literature review

Distributed, home-scale solar photovoltaic (PV) systems (also called "residential" or "rooftop" solar) have become increasingly popular in the United States. The US Department of Energy estimates that approximately 500,000 homes had rooftop solar systems in 2014 (US Energy Information Administration, 2014), and that this figure is expected to climb to several million by 2020 (US Department of Energy, 2012). These systems are being rapidly adopted, apparently because of state and federal subsidies, net metering policies, and costs that are competitive with consumer retail rates, which are higher than wholesale generation prices. In addition to grid-tied self-generation, consumers have the emerging option of "grid defection" where they purchase and install an energy storage system that enables them to self-supply reliable power and disconnect completely from the local utility. The critical technologies for residential grid defection – solar photovoltaics, batteries, and inverters – have all realized continual and significant price decreases in recent years (IRENA, 2014). At the same time, grid electricity prices in most regions of the world are expected to increase over time (Deutsche Bank, 2015). These two effects have led to an evolving discussion on "price parity" between on-grid and off-grid systems.

While off-grid solar PV/battery storage systems are generally predicted to economically supply electricity in developing countries with poor or non-existent grid access, much of the emphasis in industrialized countries has been on grid-connected distributed generation systems (Erge et al., 2001). In an effort to assess and determine the potential of solar PV electricity for EU member states, Suri et al. (2007) used regional solar irradiance data and a grid-connected PV system to determine the prospects for grid-tied solar in the EU. Dusonchet and Telaretti (2010) followed with an economic analysis of various support policies for grid-tied PV in western EU countries to assess the impact of various support mechanisms in different countries. Bernel-Augustin and Dufo-Lopez (2006) studied the profitability of grid connected solar PV systems in Spain while Celik (2006) conducted a techno-economic feasibility of roof-top solar PV in Turkey, concluding that grid-connected systems are an expensive proposition unless they make use of batteries for storage. Perez and Fondo (2014) analyzed PV competitiveness with electricity prices in seven countries including Germany, France, Italy, Spain, and Mexico. Their mathematical model assumes a grid-tied solar PV system to show that the main grid parity driver for solar PV systems in these countries is a decrease in PV prices. Eltawil and Zhao (2010) investigated the importance of grid connected PV systems and critically reviewed potential problems associated with high levels of penetration.

For off-grid systems, Stone et al. (2000) presented case studies of stand-alone solar PV projects used for rural electrification in India. In their book, Bhattacharyya and Palit (2014) discussed challenges of grid extension at remote locations in developing countries, which may worsen problems of energy shortfall and poor financial health of utilities. They maintain that stand-alone

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renewable systems can offer reliable power at a small scale. In a similar work, Chakarbarti and Chakarbarti (2002) conducted a feasibility study for stand-alone solar PV for an island in India to illustrate its socio-economic viability and the diseconomy faced by conventional power systems. Ravindra and Iyer (2014) identified the challenges of reliably matching supply with demand in developing countries and how locally installed off-grid systems could be the way forward. Others, like Guevara-Stone (2013), considered the potential of off-grid systems to leapfrog past grid extension in rural areas of developing countries. In their report, Schnitzer et al. (2014) used off-grid solar PV case studies from developing countries like India to draw their conclusion that the technical and financial inefficiencies of connecting remote areas to the grid limit its value. Kaundinya et al. (Siddiqui, 2015) conducted a techno-economic analysis of a stand-alone solar PV—hybrid system to illustrate its viability in developing countries with unreliable power.

Most of this body of work, however, focuses only on grid-connected or stand-alone systems in developing regions where the technology is competitive with utility extension. Few works provide a techno-economic-environmental comparison of the two for a developed country such as the US (Kaundinya et al., 2009). Moreover, research that contrasts grid defection with grid-tied residential solar PV is even more limited. The few comparative studies available show a large division of opinion on grid price-parity for solar PV systems in the developed world.

Some recent studies, including those from the Rocky Mountain Institute, have predicted that solar/battery systems will reach grid parity and defection will become an increasingly popular option and a threat to traditional utility models in the coming decades (Bronski et al., 2014). A study in Australia (Future-Grid-Forum-Partici, 2013) concludes that the rate of grid disconnection will continually increase such that almost one third of the customers could be expected to leave the grid by 2050. However, other recent work has shown that fully leaving the grid requires significant investment in solar PV and batteries that have a net present cost far higher than the money saved from disconnection (Khalilpour and Vassallo, 2015). An updated work (Bronski et al., 2015) by RMI softens the grid parity claim, concluding that the number of customers actually defecting from the grid to rely entirely on off-grid systems would be small. Instead, many customers may want to invest in less expensive and more reliable grid-tied systems that still benefit from grid resources well before going completely off-grid.

Several research studies caution that grid defection is expensive relative to the low costs of grid electricity in many developed regions and that staying connected to the grid remains beneficial (Khalilpour and Vassallo, 2015). Work by Brenner (2000) compares the costs of self-supplied electricity for solar and non-solar homes with/without access to the grid to conclude that solar PV may be the best alternate solution to grid connection, but only if grid connectivity becomes relatively expensive. Olson and Jones (2012) revisit the concept of grid parity for renewables. They describe parity as a moving target because the value of renewables in displacing conventional grid power with increasing penetration will diminish, thus limiting the ability of renewables to compete on cost alone. A study by the Electric Power Research Institute (EPRI, 2014) maintains that grid connection is necessary in order to fully capture the value of distributed renewables, and that leaving the grid with residential solar PV in the US could have cost 4–8 times more than if the same solar PV were grid-tied. In an independent analysis, Hoch and Harris (2014) quantify the significant benefits drawn by keeping rooftop PV systems grid connected in Australia to show that grid-defection would result in poorer financial outcomes for both consumers and utility providers.

With the recent announcement of Tesla's Powerwall home battery storage device (as well as the emergence of competitors), media discussions have frequently implied that homeowners can now cost effectively generate and store power from residential solar, making grid defection economically reasonable (Barnard, 2015; Bronski et al., 2014). However, a thorough comparative economic analysis of these alternative arrangements has not yet been performed. In this work, we use microgrid system modeling tools and marginal emissions estimates associated with grid operations to compare a grid-tied solar PV system to an off-grid solar/battery residential system. We estimate three important effects of grid defection: 1) the net cost or savings to the homeowner, 2) the change in total grid generation costs, and 3) the change in CO_2, NO_x, and SO_2 emissions from the grid. Our analysis is performed for both Tesla Powerwall batteries and traditional lead-acid batteries for 1020 US residential locations. This work goes beyond the existing literature in several respects. First, we perform an in-depth analysis of off-grid systems based on the Tesla Powerwall battery. Second, we examine locational effects at much higher resolution than earlier work, using more than a thousand locations rather than a few major cities. Third, we include two relevant social effects of grid defection: change in total generation costs and change in total system emissions.

Our results highlight that the economics of grid defection is a function of interrelated factors and not just the falling prices of residential solar PV/battery systems. Utility rate design and rebate policies, electricity prices, and residential adoption of solar PV are all important determinants of defection. We also conclude that utilities will respond to lower PV generation and energy storage costs by adopting these technologies, reducing the financial motivations for customers to defect from the grid. This is in contrast with the inaccurate assumption that price declines in solar PV are solely associated with residential customers and that utilities lack the capability or willingness to adopt and deploy these technologies. In fact, with superior financial and technical resources and advantages of scale relative to homeowners, a utility in any location experiencing grid defection should be able to compete favorably by offering a similar product/service at a slightly lower cost.

2. Data and methods

The decision to go off-grid can be divided into two elements: first, the decision to self-generate electricity by purchasing a residential solar photovoltaic (PV) system and, second, the decision to additionally purchase batteries (and possibly more solar panels) so that the home can disconnect completely from the grid. This work focuses on the latter decision and assumes that the home already has a rooftop solar system scaled to annual electricity consumption of the home. This approach is adopted for several reasons. First, we want to assess the grid defection decision in isolation from the decision to adopt residential solar. Second, grid-connected residential PV systems are gaining in popularity and these homes are likely candidates for grid defection. Third, this approach limits the need to precisely estimate capital costs of solar installations, which are complicated by time and location varying subsidy programs and policies. Finally, the economics and operation of a grid-tied residential solar system makes a good comparison case for an off-grid system because it achieves electricity neutrality (i.e. consumption = production, on average) but not electricity independence.

For each of the 1020 examined residential locations, we assume that the residence already has a solar PV system scaled so that the annual production of electricity from the system equals the annual consumption of electricity in the home (i.e. net electricity consumption is zero). We then compare this situation to one where the homeowner decides to take the home off-grid by purchasing the