Energy Policy ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Customer-economics of residential photovoltaic systems (Part 1): The impact of high renewable energy penetrations on electricity bill savings with net metering

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HIGHLIGHTS

- We investigate the impact of high renewables on customer economics of solar.
- We model three types of residential retail electricity rates.
- Based on the rates, we calculate the bill savings from photovoltaic (PV) generation.
- High renewables penetration can lead to lower bill savings with time-varying rates.
- There is substantial uncertainty in the future bill savings from residential PV.

ARTICLE INFO

Article history:
Received 12 August 2013
Received in revised form
18 November 2013
Accepted 21 December 2013

Keywords:
Photovoltaics
Net metering
Electricity rate design

ABSTRACT

Residential photovoltaic (PV) systems in the US are often compensated at the customer's underlying retail electricity rate through net metering. Given the uncertainty in future retail rates and the inherent links between rates and the customer–economics of behind-the-meter PV, there is growing interest in understanding how potential changes in rates may impact the value of bill savings from PV. In this article, we first use a production cost and capacity expansion model to project California hourly wholesale electricity market prices under two potential electricity market scenarios, including a reference and a 33% renewables scenario. Second, based on the wholesale electricity market prices generated by the model, we develop retail rates (i.e., flat, time-of-use, and real-time pricing) for each future scenario based on standard retail rate design principles. Finally, based on these retail rates, the bill savings from PV is estimated for 226 California residential customers under two types of net metering, for each scenario. We find that high renewable penetrations can drive substantial changes in residential retail rates and that these changes, together with variations in retail rate structures and PV compensation mechanisms, interact to place substantial uncertainty on the future value of bill savings from residential PV.

Published by Elsevier Ltd.

1. Introduction

Customer-sited U.S. photovoltaic (PV) systems are often compensated at the customer's underlying retail electricity rate through net metering, which provides customers with PV bill credits for each unit of PV generation at the underlying retail rate, regardless of the temporal match between PV generation and customer load. Calculations of the customer economics of PV, meanwhile, often assume that retail rate structures and PV compensation mechanisms will not change and that retail electricity prices will increase (or remain constant) over time, thereby also increasing (or keeping constant) the value of bill savings from PV. This article investigates the impact of, and interactions among, three key sources of uncertainty in the future value of bill savings from customer-sited, residential PV: changes to electricity market conditions that affect retail electricity prices, changes to the retail rate structures available to residential PV customers, and shifts away from standard net-metering toward other PV compensation mechanisms. For example, higher penetrations of renewable energy could have a significant impact on the hourly profile of wholesale electricity prices. These changes could, in turn, impact retail electricity rates and the bill savings from residential PV, particularly if full net metering were no longer available or if residential retail rate

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0301-4215/$ - see front matter Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.enpol.2013.12.042

structures were to shift towards marginal-cost pricing[1] with higher temporal resolution (i.e., prices that change by day or hour) through time-of-use rates or real-time pricing. This is the first known study to evaluate these types of interactions, and is the first of a two-part series investigating these interactions. While this paper presents results using baseline assumptions, which include an energy-only market (allowing for very high wholesale prices) and retail rates that recover all costs through volumetric charges, the second paper will focus on two alternate sets of assumptions: wholesale markets with price cap and retail rates that recover fixed costs through customer charges.[2]

This article, which is based upon a more expansive analysis presented in Darghouth et al. (2013) and Darghouth (2013), builds on a body of literature that has approached different aspects of net metering, rate design, and renewable electricity generation. Electricity markets of the future may look very different from today's. Variations in the level of future renewable energy (RE) deployment could influence both the marginal cost of electricity supply and the hourly profile of wholesale electricity prices. These changes, in turn, will impact average retail electricity rates and the temporal profile of time-differentiated rates and thus the customer economics of behind-the-meter PV. Despite this, there have been few attempts to explore the impact of future electricity market changes on retail rates. A number of studies have, however, examined the impacts of renewable generation on hourly wholesale market price profiles (e.g., Lamont, 2008; Sáenz de Miera et al., 2008; Sensfuß et al., 2008; Green and Vasilakos, 2010; Jacobsen and Zvingilaite, 2010; Steggals et al., 2011; Woo et al., 2011; De Jonghe et al., 2012; Mills and Wiser, 2012; Weiss et al., 2012). Prior studies also have explored links between *current* retail rate levels and structures and the customer economics of behind-the-meter PV (e.g., Hoff and Margolis, 2004; Borenstein, 2005, 2007, 2008; Mills et al., 2008; Bright Power, Inc, Energywiz, Inc, The Association of Energy Affordability, 2009; E3, 2010a; Ong et al., 2010; Darghouth et al., 2011). In summary, the existing literature has not considered retail rate design and net metering concurrently with potential changes in wholesale price profiles associated with future electricity market scenarios. Our study is designed to fill that gap.

Our results are influenced by our underlying assumptions, and the conclusions are limited by the scope and structure of the analysis. First, we focus on the private value of bill savings to the residential PV owner, not the broader impacts on society or the electricity system.[3] Second, the analysis is based in part on potential California electricity market characteristics in 2030 but is not a forecast of this market. At the same time, although our results are intended to apply beyond California, some findings are closely linked to the electricity market characteristics assumed. Third, we use an economic investment and dispatch model developed in Mills and Wiser (2012) that simulates an energy-only market with no parallel capacity markets. Under this design, hourly electricity prices can climb to very high levels for a few hours during the year. The analysis results may be impacted heavily by prices during those few hours, and some findings could differ under other wholesale market designs (e.g., an energy market with a price cap combined with a parallel capacity market, to be considered in the second article of this two-part series). Finally, the analysis examines a limited set of electricity market scenarios, retail rate designs, PV compensation mechanisms, and PV array orientations. Exploring other assumptions in future analyses presented in the second paper of this series will be a valuable addition to the analysis presented here, such as examining the impact of residential retail rate structures with fixed customer charges.

2. Data, methods, and assumptions

The principal objective of our study is to characterize the sensitivity of the bill-savings value of behind-the-meter PV to increases in renewable energy penetration and the dependence of those sensitivities on retail rate structures and PV-compensation mechanisms. We first model the impacts of various electricity market scenarios on hourly wholesale market prices using a simplified production-cost and capacity-expansion model developed by Mills and Wiser (2012). We base a number of the assumptions used in this model on projections of the California electricity market in 2030 (see Section 2.1 and Darghouth et al. (2013)). Second, based on the hourly wholesale market prices calculated in the first step, and with other assumptions specified later, we create three potential future retail rates for each electricity market scenario: a flat (time-invariant) rate, a time-of-use (TOU) rate (which charges higher prices during peak periods and seasons), and a real-time pricing (RTP) rate (which can vary hourly depending on wholesale prices). The rate levels and structures are created by assuming full utility cost recovery, using standard rate design principles. Third, for each of 226 California residential customers for whom data on hourly metered load are available, we determine the value of bill savings from PV by calculating those customers' annual electricity bills with and without PV generation, for each retail rate type and electricity market scenario. We account for two PV-compensation methods: net metering and hourly netting, a partial form of net metering.

2.1. Electricity market scenarios

For the two scenarios analyzed, California gross retail load is assumed to grow at an average of 1.2%/year through 2030 (CPUC, 2010), to 340,975 GW h/yr, prior to deducting behind-the-meter generation, but retains a similar hourly load profile shape.[4] Residential load is assumed to account for 32% of total retail load—the average for 2007–2010 (CEC, 2012). All scenarios assume the same capacity of legacy generation (plants existing in 2010 but not reaching their technical lifetimes by 2030—see Mills and Wiser (2012)), which is complemented by new generation built to meet load and reserve requirements (this can differ for each scenario and is determined by the model described in Section 2.3). Distributed, behind-the-meter PV generation is assumed to be evenly distributed (on an energy basis) between residential and commercial sites for all scenarios. Although the PV generation profiles are assumed to be identical for residential and commercial sites, only the residential PV generation is considered for residential rate-making calculations.

Table 1 summarizes the scenarios. In the reference scenario, the renewable capacity is based on California's 2011 renewable electricity capacity and remains constant through 2030. This is meant to be a baseline, rather than a "most likely," scenario. The 33% RE mix scenario attains a high RE penetration through a mix of RE,

[1] Under marginal cost pricing, the end-user is charged a rate that is commensurate with the cost of generating and delivering an additional unit of electricity at that time.

[2] Increasingly, utilities are considering customer charges to recover fixed costs, which is the impetus for this additional analysis. The results from this paper will be used as a baseline with which to compare the impacts of the fixed costs analysis.

[3] For example, behind-the-meter PV may reduce transmission and distribution costs and losses. E3 (2010a), Barnes and Varnando (2010), and Weissman and Johnson (2012), describe potential social benefits of net metering.

[4] The year 2030 was chosen as sufficiently far in the future to enable high renewable penetrations while giving markets time to adapt to changes and reach equilibrium. The exact date should not impact conclusions significantly.