Residential Distributed Generation Systems and the Traditional Utility Business Model: Is a Utility Death Spiral a Viable Threat?

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Contents

Abstract

The unknown costs of integrating rapidly growing distributed generation systems (DG) into an aging grid have once again thrust the idea of a utility death spiral into the limelight Using system dynamics modeling, we simulate a traditional regulated utility business model in Los Angeles, California, Sydney, Australia, and Boulder, Colorado (utility of the future? -> different business model) for residential electricity retail rates and investigate the impacts of declining photovoltaic (PV) and battery systems prices on a utility's ability to retain customers and therefore remain a viable business.

Our model indicates that a utility death spiral due to customers shifting from conventional electricity providers to distributed PV and off-grid PV is highly unlikely. A death spiral was indicated to occur only with combinations of extremely high values of adoption rates, consumer incentives, growth in utility costs, and nearly zero or negative required rates of return by customers using a net present value criteria. Alternative business models are also evaluated for their effectiveness in reducing the likelihood of a death spiral. (additional work to be done)

1 Background

A utility death spiral - in which customers switch to distributed technologies and/or efficiency improvements causing a steep decline in demand for power from traditional utilities - is not a new concept. After the oil embargo of 1973, rising fuel prices and efficiency measures cut into utility profits and raised fears of a death spiral [1]. However, these fears were found to be based on "unrealistic conditions" for the three primary stakeholders: utility managers' reaction to financial loss; customers' response to higher retail prices; and regulators' willingness to protect utilities [2].

More recently, concern over the possibility of a utility death spiral has found new legs in growing adoption of grid-connected distributed generation systems, especially solar photovoltaics (PV) [3, 4, 5]. Solar PV is growing faster than any other energy generation technology [6]. Though PV systems have not yet reached price parity with grid supplied electricity, installed PV costs are dropping rapidly [7]. For example, in June, 2015 the average retail price of electricity in Los Angeles County was \$0.21/kWh [8] (the national average was \$0.13/kWh [9]), and the levelized cost of electricity from a 5kW PV system was approximately \$0.30/kWh (see Appendix B). Furthermore, financial incentives such as net-metering make distributed generation (DG) systems more attractive to consumers while simultaneously reducing utility revenues [10]. Additionally, utility fixed costs are rising due to modernizing measures (such as smart-grid technologies), maintenance of aging transmission and distribution infrastructure, environmental regulations, and rising costs of fossil fuels [7, 11]. These factors combine to raise volume-based prices, which in turn encourage more customers to adopt DG systems and reduce their demand to save money. If these trends continue utilities in the US could lose from \$18 billion to \$48 billion per year over the next decade [12].

Today, a new threat to the traditional utility business model is emerging: energy storage combined with distributed generation raises the prospect of consumer grid defection [7]. Battery technology is an extremely active field of research (for example [13, 14, 15, 16]) and battery prices are expected to drop significantly in the near future [7, 17]. Combined, PV and battery systems could create disruptive competition for utilities [4].

While there is disagreement on the root cause of a potential death spiral, there is a consensus that utilities must adapt [18, 10, 4, 19, 1]. Raskin argues that by the time DG is a real threat to utilities a solution will have been found via the "regulatory compact", an unspoken relationship between utilities and regulators that allows utilities to attract investments that are necessary to maintain reliable service and meet regulatory requirements [10]. Many agree, including Raskin, that net-metering is an unfair and unsustainable subsidy for DG systems that will not be allowed to persist, which will reduce the risk of a death spiral [1, 19]. Graffy and Kihm argue that protecting utilities through regulation might not be able to sustain utilities through the disruptive competition created by a myriad of factors, including improving DG technologies, expanding renewable portfolio standards, morphing consumer preferences and practices, and innovative businesses providing more attractive options than utilities currently offer [4]. Felder and Athawale state that a death spiral will not be the result of disruptive competition, but rather rate design. They argue that the current volumetric rate design, which spreads the utility's cost equally across most customers (some large energy consumers may receive special negotiated rates), is not viable for recovering utility costs [1].

There is no doubt that utilities and regulators face a changing tide of consumers reducing electricity use and a growing public sentiment for reducing greenhouse gas emissions. If battery technology has a breakthrough that drastically drops costs and raises storage capacity before utilities are able to adapt then utilities in areas with high solar energy will certainly be faced with an existential crisis.

2 Scope

We view the utility death spiral as a positive feedback loop between rising retail prices and residential DG system adoption. The work outlined here simulates the traditional utility business model and forecasts the effects of residential DG adoption on the retail price of electricity, and vice-versa, out to 2050. As three example cases, we simulate residential Los Angeles County, California add Sydney, Boulder?. Our goal in creating this model was to determine what sort of scenarios could create a utility death spiral and in doing so determine if a death spiral is a real threat to utilities. We also investigate alternative business models that have been proposed in the literature for reducing the risk of a utility death spiral. (Perhaps this can be a special case for Boulder, which is working on a municipal utility - see conclusions

Los Angeles (LA) was chosen for this study for a combination of reasons. High retail prices (currently $\approx 40\%$ greater than the national average [9, 7], high solar potential [20], and the rapidly growing number of installed solar photovoltaic (PV)

(Figure 1) make LA a likely candidate for the death spiral. The only other US location that has higher retail prices than LA and a high solar potential is Hawaii. However, LA was selected over Hawaii because LA has more than twice the population of Hawaii and it is expected that results for a large, continental city will be more applicable to the rest of the US than results for an island population.

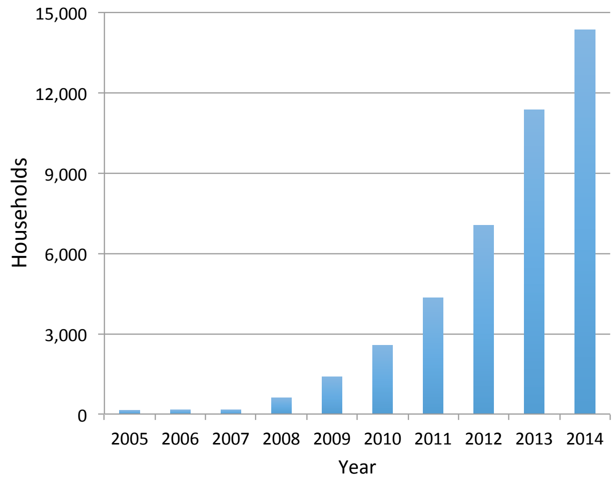


Figure 1: Cumulative households with PV systems in LA. Estimate constructed using data from [21, 22]. (See Appendix A.) revisit calibrating model to these values

Our analysis focuses on PV systems due to their rapidly declining costs and increasing availability. We have also included PV combined with battery systems. If retail prices continue to grow at the recent rate (≈ 3% over the last three years) in LA, price parity between the retail price of electricity and the levelized cost of energy (LCOE) of a typical 5kW PV system will occur as early as 2018 (Figure 2). For PV and battery systems (10kW of PV with 65kWh of battery) the LCOE of going off-grid will be the same as the retail price of electricity as early as 2037 [7].

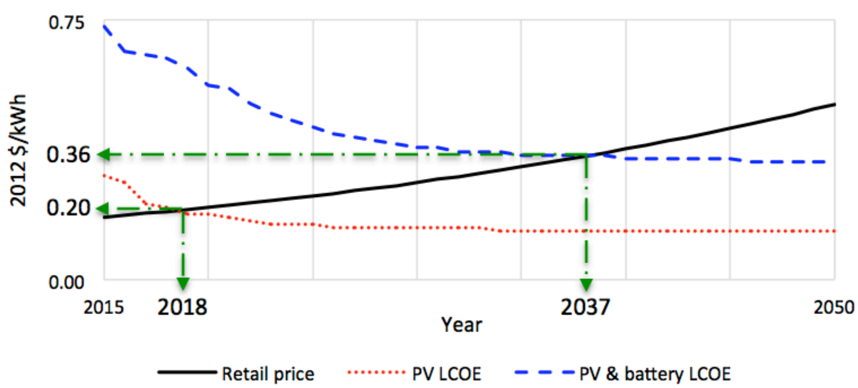


Figure 2: Price parity of PV and battery systems with retail electricity price assuming 3% growth rate [7]

3 Methods and model structure

Figure 3 provides a schematic diagram of the model. This figure illustrates the primary system dynamics captured in the model and the essential components of the utility death spiral. The heart of the model is the adoption of PV and battery systems among households, which is detailed in Section 3.1. The model includes three types of households: regular customers; customers with PV; and defectors or off-grid households with PV and battery systems. In addition to the one-way adoption flows, the model recreates the traditional utility business model, outlined in Section 3.2. The imbalance of the cost and revenue exchanges between the utility and customers with and without PV, also illustrated in Figure 3, are captured in formulating the retail price of electricity. Together, the three types of households and the retail price of electricity make up the primary outputs of the model.

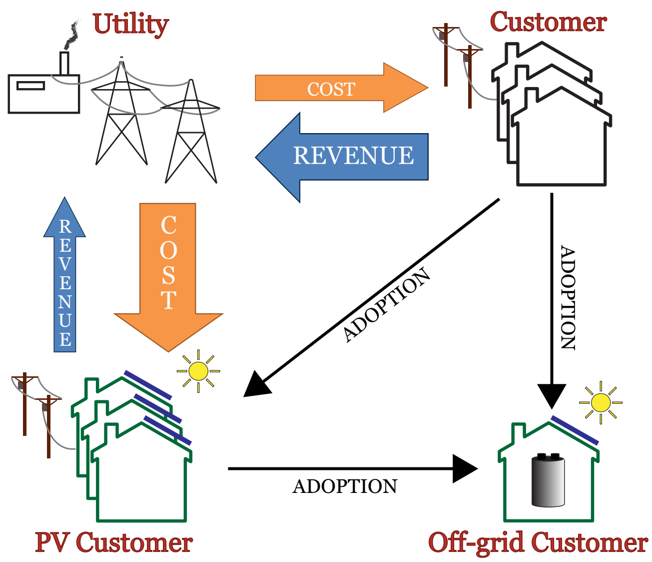


Figure 3: General model schematic diagram. [Figure inspired by [23]]

The model is formulated around two central questions: (i) how do consumers evaluate the adoption of PV and battery technologies, and (ii) how can we recreate the traditional utility business model while capturing the complicated component of how residential PV systems affect utility costs and therefore the retail price of electricity. We consider these questions in the following sections.

3.1 Adoption rates

The technology adoption flows are built with the Bass diffusion model [24]. Developed by Frank Bass, the Bass diffusion model consists of a differential equation that describes how new products are adopted in a population. The adoption rates are a function of both early adopters and late adopters, presented as innovation and imitation flows respectively [25]. Equation 3.1 shows a form of the Bass model for the adoption of a single technology, where $f(t)$ is the rate of change of the installed base fraction (units: time^{-1}), $F(t)$ is the installed base fraction (unit-less), which asymptotically approaches one from zero, p is the coefficient of innovation (unit-less), and q is the coefficient of imitation (unit-less). Figure 4 shows an example how that equation can be implemented in a model.

$$\frac{f(t)}{1-F(t)} = p + qF(t) \tag{3.1}$$

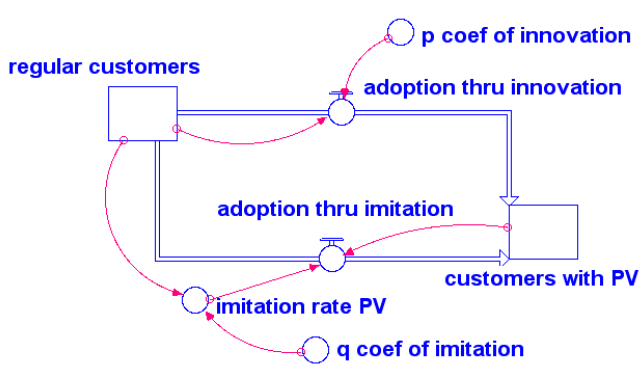


Figure 4: A simple Bass model in Stella®.

The model was constructed in Stella® [26], a system dynamics software that allows for rapidly creating and varying the parameters of differential equations via a graphical interface. As seen in Figure 4: state variables, or stocks, are represented by squares; exchange variables, or flows, are represented by double-line arrows with circular valves in their centers; and auxiliary variables are represented by circles. Single-line arrows allow definition of functional or graphical relationships between variables.

Figure 5 shows the more complicated adoption model used for the work herein. At the broad level, the model consists of three simple Bass diffusion models nested within each other (one for each "adoption" arrow in Figure 3). However, instead of constant coefficients of innovation and imitation, the adoption rates are determined using a financial evaluation.

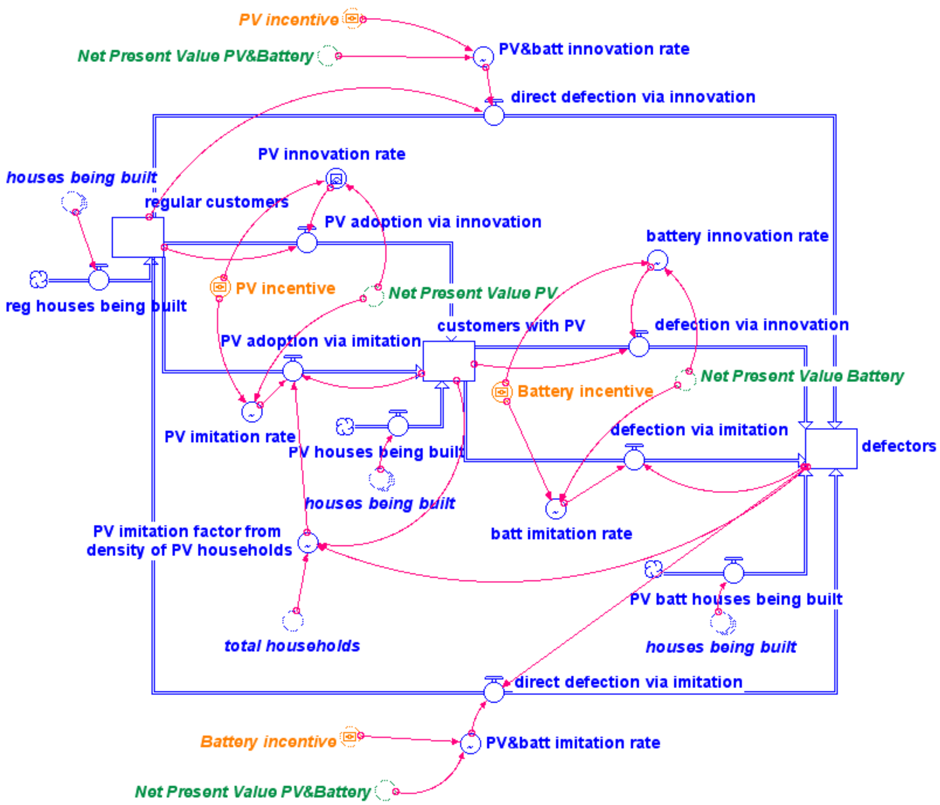


Figure 5: Bass diffusion flows from Stella® model. (The following components have been removed for clarity: flow rate scaling factors (set equal to one in baseline model); limit on the ratio of PV customers to regular customers; and drain slowing function.)

Each of the six adoption flow formulas are shown in Equations 3.2 - 3.7, where h is the number of households adopting the technology per year, k is a unit-less constant of proportionality (used for sensitivity analyses), R is graphical rate function (units: time^{-1}), N is number of households with the subscripts reg, PV, and def respectively represent regular households, PV households, and off-grid households, L is a graphical limit function (unit-less), and d is a graphical drain-slowing function (unit-less). The subscripts on h, k and R distinguish the six adoption flows, with PN for PV innovation, PM for PV imitation, BN for battery innovation, BM for battery imitation, DN for direct defection innovation, and DM for direct defection imitation. Lastly, ρ is a PV density factor that has no effect (equal to one) when there are no PV households, and effectively doubles the imitation flow rate (equal to two) when the number of homes with PV panels (including defectors) is equal to the number of regular households. (No density factor is used for battery system imitation since they are presumed to be installed indoors and therefore do not have the "keeping up with the Jones" effect that highly visible PV panels can affect.)

$$h_{PN} = k_{PN} * R_{PN} * N_{reg} * L * d \tag{3.2}$$

$$h_{PM} = k_{PM} * R_{PM} * N_{PV} * \rho * L * d \tag{3.3}$$

$$h_{BN} = k_{BN} * R_{BN} * N_{PV} * d \tag{3.4}$$

$$h_{BM} = k_{BM} * R_{BM} * N_{def} * d \tag{3.5}$$

$$h_{DN} = k_{DN} * R_{DN} * N_{reg} * L * d \tag{3.6}$$

$$h_{DM} = k_{DM} * R_{DM} * N_{def} * L * d \tag{3.7}$$

The innovation and imitation rates, represented by R, are defined as graphical functions of the net present value (NPV) of each technology. Figure 6 shows a portion of the model used to calculate the NPV. NPV represents the difference between the present value of cash inflows and cash outflows for the lifetime of a project, and is commonly used to assess the profitability of investing in a project. For example, the cash inflows of a PV system include the electricity produced by a PV system (valued at the current retail price) and the cash outflows include the cost of purchasing the system, or fixed capital investment (FCI) and operation and maintenance costs. Using forecasts from [7] we determined the FCIs for the installed price of PV systems and the price of batteries. The key assumptions in the NPV formulation were:

- investment is financed with 50% of debt
- debt interest rate is 5% throughout the 20-year lifetime of the system, with a 10-year term of loan
- required rate of return is 10%.
- annual operation and maintenance costs of the PV, battery, and PV-battery systems are \$60/kW, \$1.54/kWh (\$100), and \$70/kW respectively

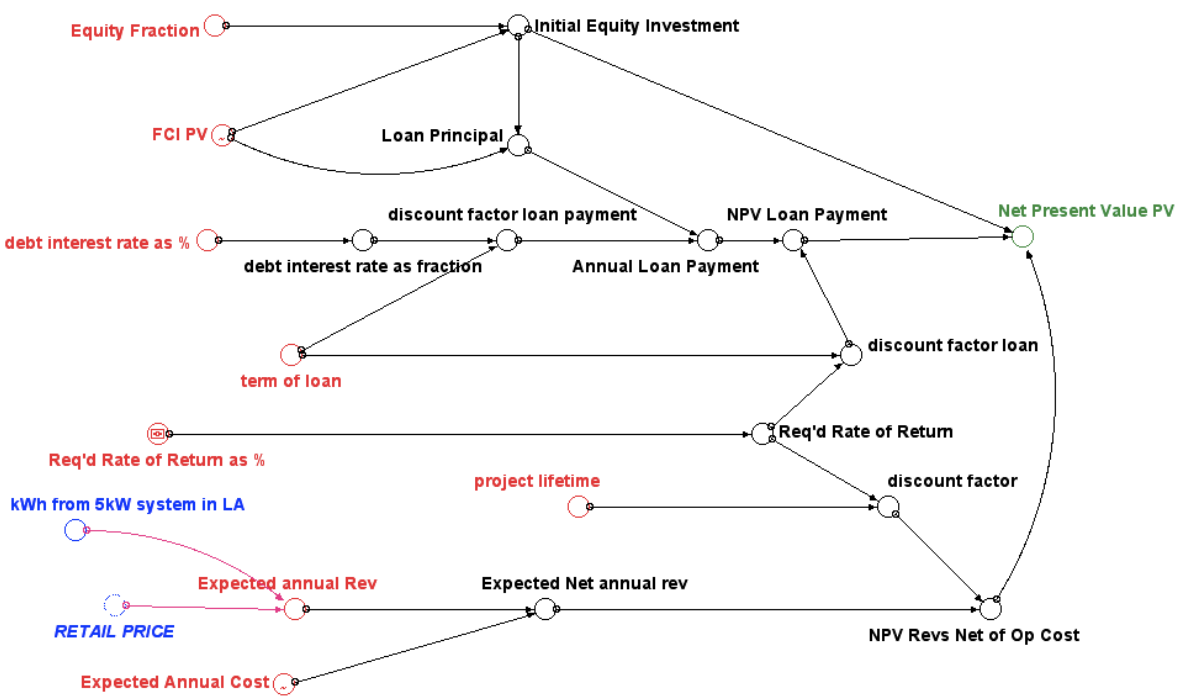


Figure 6: Net Present Value model for PV system.

For PV system innovators, data was available to estimate the actual adoption rate. The initial adoption rate of PV systems was set to the 2014 value in LA, or 0.5% of total homes per year (value determined from historical data, see Appendix A) and is assumed to grow linearly to 5% per year for NPV equal to $10,000.

For all the other innovation adoption rates we assumed an initial value of 0.1% of the potential base per year for a zero NPV (i.e. break even point). We did this under the assumption that innovators are willing to except a negative NPV to be the first in the neighborhood to have the latest technology. (In the case of renewable DG systems, innovators may also be willing to accept a negative NPV because they value reducing greenhouse gas emissions (GHGs), among other reasons.) These innovation rates grow linearly from the initial value of 0.1% to 0.5% (add rationale for using these upper and lower bounds) for NPV equal to $10,000.

The imitation rates are similar to the innovation rates, except they are set to zero when the NPV is equal to zero and they grow to 0.4% when the NPV reaches $10,000. This implies that imitators do not adopt the technology until it is financially beneficial based on the NPV evaluation.

The limit function, L, limits the number of households with PV systems. As the residential home rental fraction in California is approximately 46% with a growth rate of 1.85% every three years [27], the residential rental fraction in LA was assumed to be 50% on average from 2015 to 2050. Since renters have little financial incentive to install PV systems [28], they are eliminated from the adoption pool for PV systems. Therefore, the ceiling for the number of homes with PV systems as a fraction of the total households was set to 50%. This is achieved in the model using a graphical function that smoothly reduces the PV adoption and direct defection flows to zero as the fraction of households with PV to total households approaches one-half.

Lastly, we introduced a first-order drain-slowing function, d, for each adoption flow. The purpose of this function is to create more realistic (lower) adoption rates as the number of potential households approach zero. Once the number of potential households drops below a certain threshold, the drain-slowing function reduces the adoption rate using an 'S' curve. Through trial-and-error we found that a threshold of two million households produced a smooth transition to a zero adoption rate as the number of households approached zero. Without the drain-slowing function the adoption rates would be unrealistically high for small numbers of potential households.

Table 1 summarizes the model parameters described in this section and the following sections.

Table 1: Summary of model parameters. Values given for Los Angeles.

Parameter	Variable type	Initial Value	Source and/or assumption
regular households	state	3,361,031	[29]
households with PV	state	14,344	[21, 22], see Appendix A
off-grid households (defectors)	state	1	initialized to one
annual base demand per home	state	16,648 kWh	[30]
annual reduction in demand	auxiliary	0.5%	[31] conservative estimate
retail price	auxiliary	20.9 cents/kWh	[8] Jan., 2015 average in 2012 $ [32]
annual PV production	auxiliary	12,469 kWh	[20]
population growth rate	auxiliary	0.6%	[29] 2013-2014 value. Decays to 0.3% by 2050
Cost of PV and batteries	auxiliary	varies with time	[7] average of multiple forecasts
incremental fixed cost per new PV home	auxiliary	$190/kW to $270/kW	[33]
incremental fixed cost per new reg. home	auxiliary	?? 1/2 of PV??	none yet
wholesale price growth rate	auxiliary	1%	[34] Apr 2009 - Dec 2013 avgerage 0.8%
fraction of utility costs from generation	auxilliary	56%	[35] Used to calibrate initial wholesale price
net present value	auxilliary	n/a	see Section 3.1
adoption rates x6 (see Figure 5)	exchange	0.5% for PV innovators, 0.1% others	see Section 3.1
houses being built	exchange	$total\ households * population\ growth\ rate$	see Section 3.4

3.2 The traditional utility business model

The traditional utility business model consists of a volumetric rate design. The pricing structure is simply the utility's variable costs C_v plus fixed costs C_f, all divided by the total demand D, as shown in Equation 3.8. The variable costs are the same as generation costs, which are the number of customers multiplied by the cost of generating power (or purchasing generated power) times the amount of demand from each customer. The fixed costs consist primarily of transmission and distribution (see Figure 7).

$$\text{Retail Price } [\$/kWh] = \frac{C_v + C_f}{D} \tag{3.8}$$

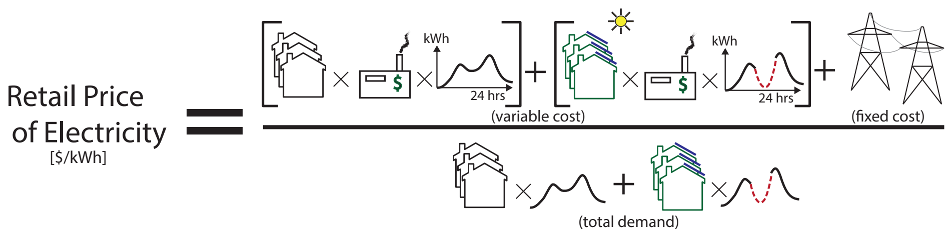


Figure 7: Retail price model summary

As Figure 8 demonstrates, the actual model is much more complicated than Equation 3.8 indicates. Due to their decreased demand for electricity, customers with PV produce lower revenues for utilities. Additionally, due to the variability that grid-connected PV systems introduce, PV customers can also create higher energy production costs than regular customers†. We captured these costs in the model by including the reduced demand of PV customers and an inflated wholesale price for meeting the energy needs of PV customers.

Reference [30] provided annual demand values for a baseline, single family house in LA. The baseline electricity demand is 16,648 kWh per year. To capture the improving efficiency of retail customers, lighting systems, and home appliances, the model includes a reduction in the baseline demand as a percentage of the total per year (baseline value of 0.5%).

Determining the demand of a PV household began with determining the energy produced by a 5kW grid connected PV system (standard size in southern California [37]). The PV panels' production capacity was determined using irradiance data from the most recent year with hourly data available (from LAX International Airport) [20]. The PV system produces 12,469 kWh per year.

A net metering model might assume that the demand from a PV customer would simply be the baseline demand minus the panel production capacity, or $\approx 4,000$ kWh per year. However, with hourly resolution data, we found that the actual demand of a PV customer (without batteries) would be 10,500 kWh per year. This is due to the imbalance in the timing of the panel production peak and the peak in demand in early evening. Interestingly, a PV customer in LA would be able to directly use roughly half of the electricity produced by their panels, and the other half would be placed in the grid ($\approx 6,300$ kWh).

To determine a realistic demand value for PV customers we chose to use estimates of the Effective Load Carrying Capability (ELCC) of grid connected PV systems [38]. ELCC is a measure of how effective a generation system is at reducing the demand on the grid without decreasing the grid's reliability in meeting demand. Here we use the percentage definition of ELCC. For example, a 1 MW rated power plant with a 50% ELCC effectively provides 0.5 MW to the grid. The ELCC of PV systems declines with increasing penetration of PV systems. Therefore, our model estimates a PV household's demand as:

$$PV_{demand} = Baseline_{demand} - ELCC\left(\text{as a function of } \frac{PV_{homes}}{total_{homes}}\right) * PV_{production} \tag{3.9}$$

We determined the wholesale price for electricity such that 56% of the retail price came from the utility's generation cost [35]. Figure 9 shows a breakdown of a utility bill in southern California. To simplify the model we assumed that all cost values, including wholesale price, implicitly include the utility's mark-up. This allowed for calibrating the initial cost values to produce the average retail price in Los Angeles in recent times of 21.6 cents/kWh [8]. The wholesale price calibration included the inflated wholesale price for PV customers. The added cost of electricity generation due to DG systems is an open question in the literature. However, from a survey of the few studies that exist on this topic we concluded that an additional 1 ¢/kWh was a reasonable starting point [23, 39, 40]. The wholesale price is assumed to grow 1% per year in the baseline model. A 1% growth rate is based on an average of the US annual average retail price from 2001 to 2014 [9].

†The extent and existence of the added cost of distributed generation for utilities is up for debate. Estimates are few and vary widely (see [23] for examples). [36] enumerates some these costs for energy generators, such as part-load penalty, min-gen penalty, and cycling cost, in a model

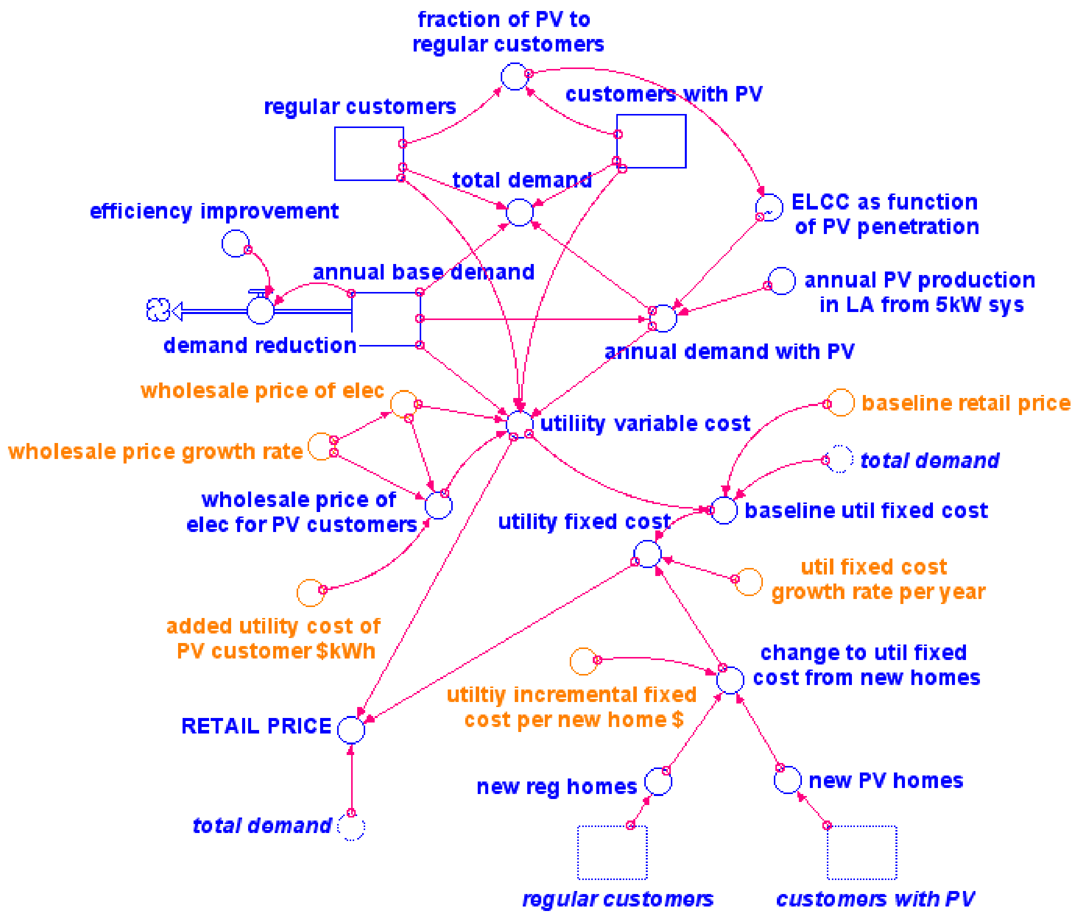


Figure 8: Retail price formulation via the traditional utility business model

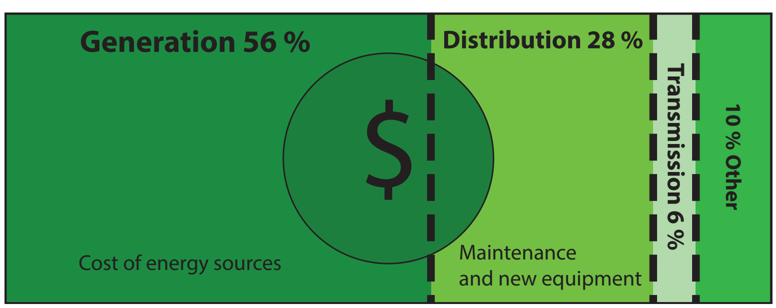


Figure 9: Breakdown of Southern California Edison Utility Bill [35]

The last pricing component is the utility's fixed cost. This was straightforward to determine given that we have an initial retail price. The baseline fixed cost is simply the initial retail price times the total initial demand minus the initial variable costs. The baseline fixed cost is allowed to change via two pathways: (i) population growth (see Section 3.4; and (ii) a growth rate, set to a small value for the baseline model (1% growth per year).

that indicates that in some cases curtailing intermittent generators can reduce utility costs.

3.3 Alternative business models

add three alternative business models given in conclusions

3.4 Population growth

In addition to the adoption flow of households, the model includes an influx of households via population growth (illustrated in Figure 5). The initial value of population growth is set to the value in 2014 (0.6% annual change from 2013 [29]), and then tapers off to half of the initial value in 2050 (assuming that LA will not grow indefinitely). Which type of house people choose to build is determined by the attractiveness of each type of house, formulated in a logit choice model [41]. The logit function, expressed in Equation 3.10, provides the probability P of a homebuilder choosing alternative i from the set of j choices with an attractiveness x.

$$P_i = \frac{e^{(k_i + Bx_i)}}{\Sigma_j \left(e^{(k_i + Bx_i)} \right)} \tag{3.10}$$

The coefficient B is simply a scaling factor.

We determined the relative attractiveness of a house using the cost of adding a PV or PV and battery system to a new home. Furthermore, given that the construction of many new houses will not be paid for by the same people that will pay the utility bill, we gave regular households an additional higher weighting than houses with DG systems. We achieved this weighting for regular households by doubling the unexplained utility factor, k, relative to households with DG.

As more homes are added to the system we assumed that the utility's fixed cost will increase. New neighborhoods will require extension of the existing transmission and distribution system, in addition to increasing the load placed on existing infrastructure. We modeled the added cost by adding a flat amount per household to the baseline fixed cost. As expected, reasonable estimates for the scale of this added cost have relatively small impact on the system behavior. Sensitivity analyses indicate that numbers on the order of \$10, \$100, or \$1,000 per household only slightly increase the retail price over time (1 ¢/kWh higher in 2050 for \$1,000 per household vs. \$100 per household). Given that any scale larger than \$1,000 per household is unreasonable, we set the baseline value to \$1,000 per household.

4 Results

The results from the theoretical model are summarized here. Results are best visualized in two graphs: the numbers of households in each category; and the retail price of electricity compared to the LCOE of the DG systems (see Appendix B).

4.1 Baseline model

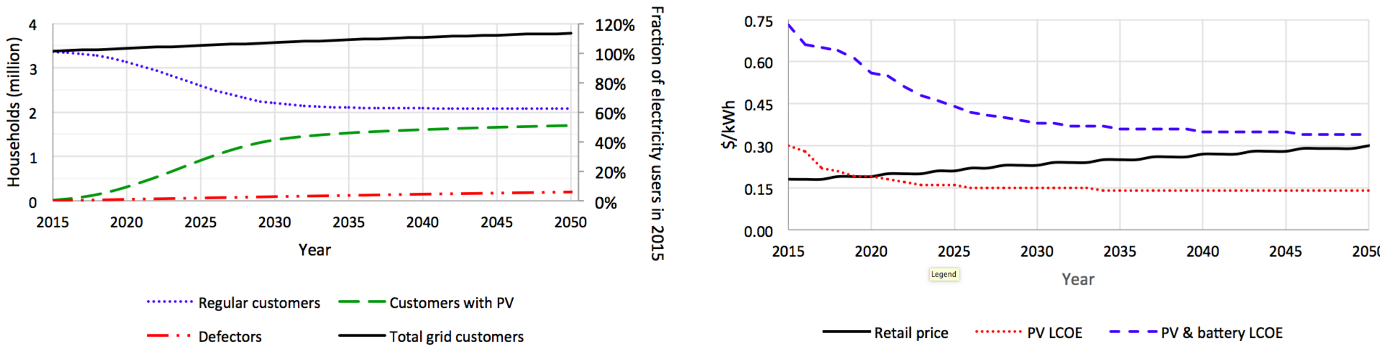
Our baseline model indicates that a death spiral is unlikely. From Figure 10 we see that the number of households with PV systems will grow significantly until 2030 and then taper off as the threshold of households for which a PV system is viable is reached. Also, the number of offgrid customers is insignificant compared to the number of grid-connected customers.

In considering if our model results are reasonable we compared our predicted value of the retail price with historical numbers and some forecasts. The real retail price of electricity in the US has grown by an annual average of 1% per year since 2001 [9]. However, in some areas, including California, the retail price of electricity has grown by nearly 3% per year for the last three years. Our baseline model predicts an annual growth rate of 1.9% to 2050. This seems reasonable given that forecasts range from 0.1% to 3% growth in retail prices [7] and that the US Energy Information Administration's *Annual Energy Outlook 2015* also forecasts a 1.9% growth rate in electricity retail prices for the Pacific Region out to 2040 [42].

add three alternative business models given in conclusions

4.2 Sensitivity analyses

Incorporate: results very sensitive to efficiency improvement, look at increased energy consumption as well - add inflow to baseline demand. Show top and bottom 5 effectors.



(a) Households as a function of time

(b) Retail price and LCOE as a function of time

Figure 10: Baseline model results

The model indicates that a death spiral can only be initiated by increasing a combination of baseline assumptions well beyond their initial values. Model results are relatively insensitive to changes in the individual components of adoption rates, retail price, and net present value. For example, increasing the adoption rates 10x the baseline values causes the PV and regular household curves to converge twice as fast and a much higher growth rate in off-grid homes (see Figure 11), but the retail price only increases slightly above the baseline forecast.

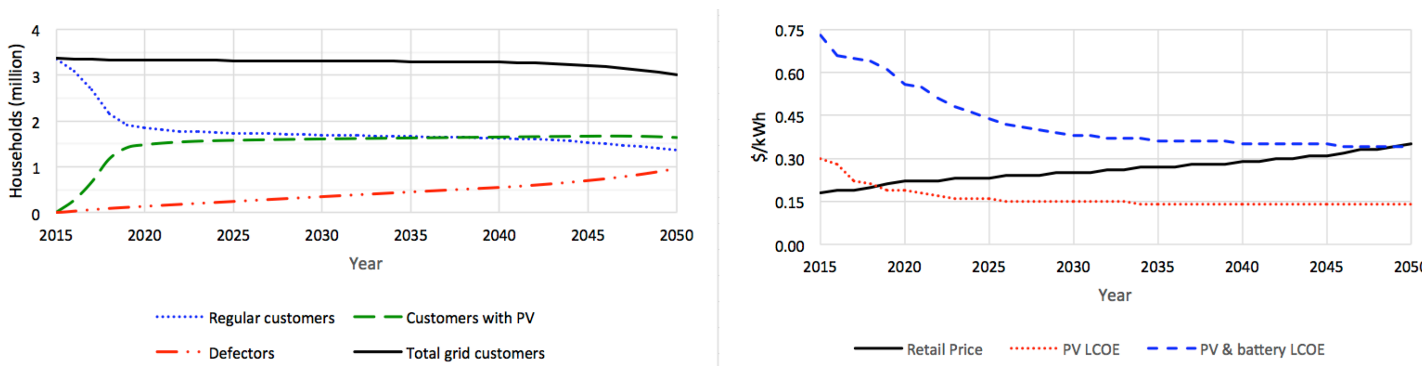


Figure 11: 10x adoption rates

Other factors, such as increasing the battery and PV incentives to $10,000 per year (introduced as additions to net present value) or increasing the cost to utilities from DG customers have even less impact than the inflated adoption rates.

In short, the only method to initiate a death spiral was to inflate a combination of factors to accelerate the flow of off-grid customers, such as unreasonably high battery incentives (>$10,000 per year) and 2x adoption rates) *combined with* a lower required rate of return (1%). Inflating retail prices by increasing the fixed cost and wholesale price growth rates to 5x has surprisingly little affect on customer flows even though retail prices grow much faster (Figure 12).

No limit on number of PV households

It is interesting to explore scenarios where the number of PV households is not limited to a fraction of the total households. In fact, with the recent advent of community and utility owned solar projects, the number of households powered by PV systems could be much greater than the number of households with PV systems installed locally on rooftops or mounted in yards.

Figure 13 shows model results with no limit on PV households and high values for the retail price structure. To produce these results the added utility cost from PV customer is set to 5 ¢/kWh, fixed cost and wholesale price growth rates are set to 4% per year, and the incremental cost of a new home to the utility is set to $10,000 per home. After 2036 we see that the utility rapidly loses customers as retail prices grow. Interestingly the retail price levels off towards 2050. This could indicate

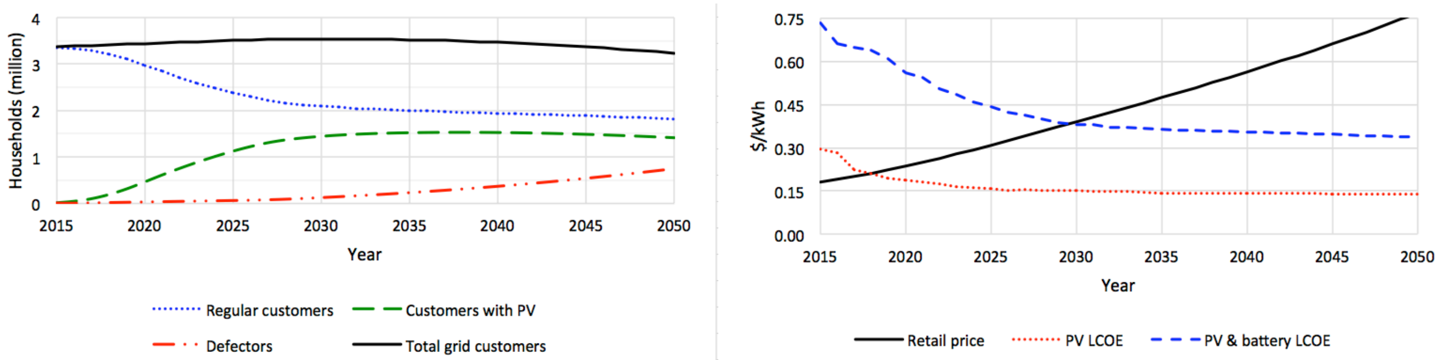


Figure 12: 5x fixed cost and wholesale price growth rates

that the utility might be able to sustain a lower number of customers without everyone shifting to off grid systems. However, given that it is hard enough to believe the forecasts 35 years from now we did not investigate model results beyond 2050.

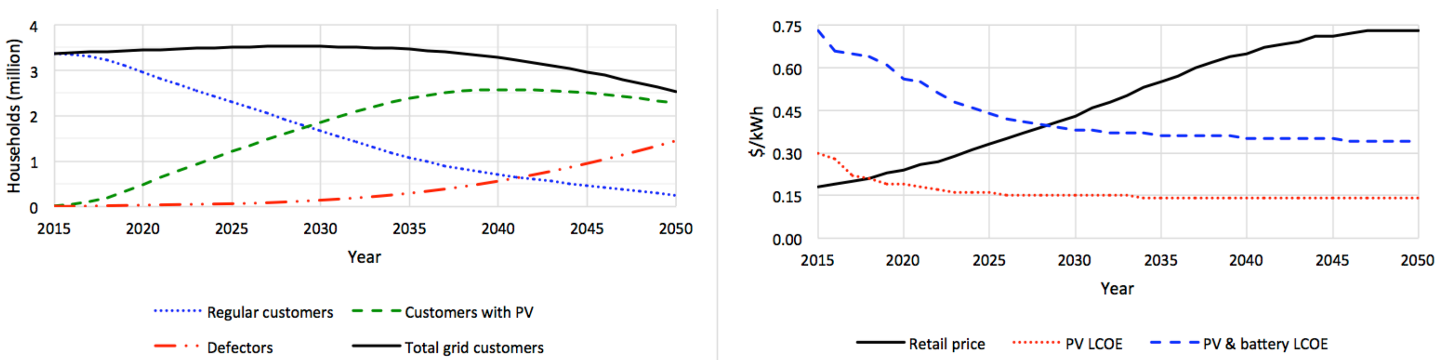


Figure 13: Results with no limit on PV households, extreme retail price model values

A customer scenario almost identical to the left-hand side of Figure 13 can also be created by setting the required rate of return for the NPV evaluations to 1% (baseline is 10%). In this scenario (not shown) the retail price curve does not cross the PV & battery LCOE curve until 2044. A lower required rate of return is likened to a system in which consumers are less concerned about making a profitable decision. One can imagine such a customer is willing to give up financial benefits in return for external factors such as lower greenhouse gas emissions, and for customers with battery systems, perhaps increased reliability compared to an aging and overburdened grid.

5 Conclusions

A utility death spiral due to solar photovoltaic and battery systems in Los Angeles is highly unlikely. Indeed, given that utilities are already adopting alternative business models a utility death spiral seems unlikely in the US. Three examples of alternative business models include [19]:

- demand charge - with smart meters utilities can charge customers with higher demand a higher rate (already occurring in California)
- compensate DG customers at a rate other than retail price for excess generation
- charge DG customers with a standby rate and compensate the customer for excess generation using the utility's avoided cost

However, examples abound of regulators rejecting or reducing utilities' attempts to recoup lost revenue by more directly tying their costs to customer rates and charges [4].

Predicting the future is fuzzy business and there are many unknowns on the horizon for utilities. The most likely solution to the unsustainable volumetric pricing method is separating fixed and variable costs when billing customers. For example, a utility could reward DG customers for providing peak power, reducing line congestion, and deferring infrastructure investments [1].

Utilities are regulated monopolies that are protected for the public good. They sometimes have conflicting interests of obtaining a satisfactory rate of return for investors while providing affordable, reliable electricity service. In the future, if distributed generation and storage technologies provide a more attractive option than grid power to consumers - while simultaneously achieving societal goals such as reducing greenhouse gas emissions - will it still be in the public's best interest to protect private utilities from extinction? An interesting experiment to this effect is occurring in Boulder, Colorado. The citizens of Boulder have voted to create a municipal utility if the current utility cannot meet their requirements for increased service and decreased environmental impact [43]. The city of Boulder is currently attempting to purchase the transmission and distribution infrastructure from the incumbent utility.

It is indeed a time of rapid change for the utility industry in the US. Though a death spiral may not be a viable threat to utilities, customers are rapidly becoming prosumers and more aware of where and how their electricity is produced. The Golden Age of utilities is at an end and it is certain that utilities must adapt to survive.

6 Acknowledgements

Steve is awesome!

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7 Appendix A: Historical PV data used to estimate initial adoption rate

convert this data to horizontal table and clean up

The numbers of households in LA with PV are estimated using two data sources:

California's Solar Cities 2012 report by Environment California Research & Policy Center provides solid numbers from 2009 (1388 homes with PV) and mid 2011 (4018 homes with PV)

This report also provided estimated growth rates: 10% from 2000 to 2006; and 40% growth per year forecasted after 2011

https://www.californiasolarstatistics.ca.gov/reports/monthly_stats/

With the following filters: time scale: years; data type: # of apps; Host customer sector: residential; Admin: SCE; Application status: Installed

We then estimated the percentage of SCE's applications in LA by using the numbers from the Solar Cities report

SCE = Southern California Edison

Year	SCE installed each year	SCE cumulative installations	cumulative PV installations in LA	estimates to compare	per year growth		
2000			85			3361031	initial number of reg customers
2001			94		10%		
2002			103		10%		
2003			113		10%		
2004			125		10%	10%	back forecast 10% from 2009
2005			137		10%	24%	percentage of LA of Cali's permits
2006			151		10%		
2007	706	706	166		10%		
2008	1870	2576	605		265%		
2009	3351	5927	1393	1388	130%		
2010	4994	10921	2566		84%		
2011	7531	18452	4336	4018 mid 2011	69%	26%	growth from 2013 to 2014
2012	11489	29941	7036		62%	2991	additional PV households in 2014
2013	18367	48308	11352		61%	0.09%	percent of total houesholds "switching" to PV in 2014
2014	12729	61037	14344	15893	26%	**0.5%**	**assuming 40% growth from 2013 (Solar Cities estimate)**

8 Appendix B: Forecasts for Levelized Cost of Electricity of PV and batteries