# Rooftop Solar and the Utilities Death Spiral[i]:

**A system dynamics analysis of the potential effects of rooftop solar diffusion on the electricity rates and $CO_2$ emissions of the U.S. electricity supply sector**

by
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## Abstract

U.S. electric utilities are concerned by the recent exponential growth in rooftop solar installations among their customers. They fear that if their customers continue to adopt such self generation technologies and buy less electricity from the utility, then the utility will no longer make enough sales to achieve 'cost recovery' from these customers. Utilities argue that, in order to compensate for this, they will have to increase their electricity rates, and that these rate rises will in turn make self-generation technologies such as rooftop solar even more attractive. Such a situation results in a vicious loop, popularly known as the death spiral, whereby rooftop solar adoption results in rate increases, which in turn leads to more rooftop solar adoption. These rate rises would also be a social problem, as low-income families are statistically the least likely to install rooftop solar, and thus the most likely to suffer these rate rises the most. This study uses a system dynamics model to first analyze the validity of this 'death spiral' hypothesis in the context of residential rooftop solar and, secondly, to evaluate the policy of rooftop solar subsidies, based on their effects on (i) utility rates and (ii) reduction of $CO_2$ emissions. Simulations reveal that the effect of rooftop solar on both utility rates and $CO_2$ prevention is highly dependent on whether or not utilities claim/buy Renewable Energy Certificates for these privately owned rooftop solar systems, as part of meeting their Renewable Energy Portfolio. As a case study, the model uses data from the Salt River Project, a public owned utility based in Arizona.

*Key words: rooftop solar, electric utility rates, utilities death spiral, $CO_2$emissions, rooftop solar subsidies, renewable energy certificates, system dynamics.*

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[i] This paper is based on a thesis that was submitted for the European Master in System Dynamics. To see this thesis and the accompanying model (in iThink software), please contact the main author at comeehan@tcd.ie.

# 1. Introduction and Background

## How much residential rooftop solar is there in the U.S.?

In 2014, capacity in solar technology accounted for 1.13% of the U.S.'s total electric generating capacity, and supplied .4% of the electricity consumed in that year in the U.S.[1]. Roughly half of this solar generation came from customer-sited PV systems [2], or what will be referred to as 'rooftop solar systems', which are PV systems owned/rented by utility customers, and which are usually installed on the rooftop of the home or business of that customer.

Although rooftop solar still only accounts for a small amount of current generation in the U.S., it is expected that its presence will become stronger and stronger over the years to come. For example, in the reference case of U.S. Energy Information Administration's (EIA's) Annual Energy Outlook 2014, it is projected that roughly 11% of all electricity generation capacity additions between 2013 and 2040 will be in Solar PV systems [3]. It is also projected that 60% of these PV systems will be rooftop solar systems, from both residential and commercial utility customers [3]. In this paper the focus will be on residential rooftop solar only, and so will exclude focus on the effects of commercial scale rooftop solar. If we assume that residential rooftop solar accounts for roughly half of rooftop solar capacity, then we can say that it is projected to account for roughly 3.3% of capacity additions between 2013 and 2040.

## What is the Utilities Death Spiral?

The exponential growth in rooftop solar can be seen as great news for reducing the electricity supply industry's $CO_2$ emissions, and thus its effect on global warming. However it has also been causing U.S. electric utilities to become increasingly alarmed, and for the following reason: when customers install their own solar panels, they buy significantly less electricity from the utility. Utilities in regulated markets have argued that, when this happens, they no longer achieve 'cost recovery' from those customers, i.e. they no longer achieve sufficient revenues from that customer in order to meet the costs of serving them (most of which are fixed) [4]. In order to compensate for these lost revenues and regain cost recovery, utilities say that they will have to increase their electricity rates (i.e. the prices that they charge their customers per kWh of electricity used). This increase in the price of electricity from the grid will in turn make self-generation technologies such as rooftop solar even more attractive. As such, U.S. utilities could become caught in a vicious loop, popularly known as the 'death spiral', whereby the reduced demand resulting from rooftop solar leads to an increase in rates, which in turn leads to more uptake of rooftop solar (or other self-generation/energy saving technologies), more reduced demand, a further increase in rates, and so on. The end result, some say, is that it is the poorest customers who are likely to suffer these rate rises the most, as they are the least likely to be able to install rooftop solar [5]. This is because they are the most likely to live in rented accommodation, for example, or because they cannot afford the upfront costs of solar panels. The idea that rooftop solar diffusion causes rate rises can be known as the 'cross subsidization hypothesis', as it essentially says that non-solar customers will have to pay higher rates in order to compensate (i.e. subsidize) for the lost revenues that the utilities experience from their rooftop solar customers.

An additional problem is that if utilities' revenues continue to decrease despite rate increases, then this may pose a threat to their ability to maintain important infrastructure such as the grid and dispatchable generation capacities, both of which are still used by all customers when the sun is not shining. The effects of rooftop solar on security of supply will not be directly examined in this paper, but the utility's lost profits as a result of rooftop solar diffusion will be discussed, and this can be used as a proxy for this security of supply issue.

In order to counteract the lost revenues that may result from rooftop solar diffusion, several U.S. electric utilities have recently proposed/ imposed either a special rate plan or a special charge for their rooftop solar customers [4,6,7]. For example, both SRP and Arizona Public Service Company (APS) (Arizona's largest electric utilities) have proposed changes in the rate plans of their rooftop solar customers that would add roughly $50 to the monthly bill of a typical rooftop solar customer [8]. SRP's board of directors approved this proposal, but allowed all existing solar customers to be grandfathered from these changes for 20 years [9]. In response to this policy, Solar City (one of the leading rooftop solar installations companies in the U.S.) has recently filed a lawsuit against SRP, stating that it was engaging in 'anti-competitive behaviour' [10].

APS' regulator, the Arizona Corporation Commission, partially rejected APS's proposal and instead allowed an average increase of just $5 a month for their solar customers [6,11]. However, APS has recently made another proposal to increase this charge to $21 a month, the results of which are pending [6]. Such proposals are likely to become more common in other parts of the country as rooftop solar spreads.

In addition to fighting for special rate plans for their solar customers, many utilities and their representatives have also called for an end to the subsidy of net metering, which they say overvalues the electricity that utilities are forced to 'buy' from the their rooftop solar customers [12–15]. They also argue that the two way flow of electricity that net metering is based on incurs some extra costs for the utility, as the grid was originally designed for a one-way flow [16,17]. The end result is increased costs and thus reduced profits for the utility, which they argue will result in them having to charge higher rates, meaning that there will be some cross subsidization of solar customers by non-solar customers.

## How exactly could rooftop solar diffusion affect utility rates?

Most U.S. electric utilities operate in a regulated market, and so their rates are determined under the principle of 'cost recovery', rather than by spot markets, as they would be a deregulated market. Cost recovery essentially means that a utility will be regulated to charge a rate that will gather them sufficient revenue in order to (i) continue meeting the costs of providing service to the customers in their service area, whilst (ii) making a reasonable rate of return for its investors [18,19].

Thus the way in which such a rate is determined by utilities (i.e. a rate that will achieve cost recovery) can be roughly represented by the following simple equation [19]:

Cost of providing service to customers*Reasonable rate of return for investors ($) / Expected demand from customers (kWhs) = a price ($) per kWh

As such we can see that in SRP's context (as well as the context of most regulated utilities), when the expected demand for a utility's electricity falls (as a result of rooftop solar diffusion, for example) and costs remain the same or do not decline sufficiently, then utilities will have to (or at least will be allowed to, by their own regulators or board of directors) charge higher rates in order to maintain 'cost recovery'. This is because the utility's costs will have to be spread over fewer kWh sales. This can be seen in the equation shown, as we see that the bottom of the fraction will become smaller from the reduced demand (resulting from rooftop solar use), and if the top of the fraction does not reduce sufficiently, then a higher price per kWh will be chosen.

Part of the reason that reduced demand will result in lost profits is due to utilities' rate structures. Most U.S. utilities have rate structures that are designed to collect the bulk of revenue through volumetric charges[ii], whilst the majority of their costs are fixed [11,18,20]. As such utilities argue that a significant drop in demand from rooftop solar customers could result in some of the utility's fixed costs being under recovered [4,11,18,21]. This has also been argued in academic studies [20].

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[ii] This is in order to protect low-income and low-usage customers, and to encourage energy conservation by high consumption customers [17,57]

## What evidence has there been to suggest that rooftop solar diffusion has affected or will affect utility rates?

To this author's knowledge one of the clearest pieces of evidence suggesting that rooftop solar diffusion has already affected at least one U.S. electric utility's rates can be seen in APS' 'lost fixed cost recovery' charge. This charge is designed to recover 'a portion of unrecovered fixed costs resulting from energy efficiency and distributed generation programs' [22], the latter of which includes rooftop solar. The charge applies only to residential and small business customers because large commercial and industrial customers have rate structures that already include the recovery of fixed costs [22]. Currently, this charge will increase the monthly bills of these customers by 1.46% [22,23]. Given that this charge reflects both distributed generation *and* energy efficiency programs, and given that it currently increases the monthly bills of some customers by just 1.46% in one of the most solar-penetrated markets in the U.S., it seems fair to say that distributed generation alone is not currently causing any significant increases in the monthly bills of non-solar customers. However this may change under scenarios of higher rooftop solar penetration.

Indeed, evidence in markets with much higher levels of distributed energy penetration, such as the Australian and particularly German market, has shown that distributed generation resources could have a significant effect on the price of electricity. In these markets, policies such as net metering as well as heavy subsidies to renewables and demand-side management have been said to be causing big problems for the traditional utilities there [14,24–27]. RWE, Germany's second largest utility, has been saying since 2013 that its declining profits and forced shutdown/mothballing of capacity has been in large part caused by the reduced demand brought about by intermittent subsidized renewables such as rooftop solar [28]. In 2013, RWE announced that it will take 3100 MWs of capacity offline in Germany and the Netherlands and will also dispose of 1200 MWs of German coal-fired capacity to which it has contractual usage rights [29]. Taking this dispatchable capacity offline could have serious repercussions for Germany's ability to meet future demand[iii]. The fears of not being able to meet demand on cloudy, windless days has spurred the German government to consider starting a capacity market that would subsidize unprofitable power plants, thus allowing them to stay open and provide power when renewables can't [30].

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[iii] However one should note that Germany's current market is in a state of oversupply, and so their reserve margin may remain sufficient for the time being, at least until all nuclear capacity is forcibly turned off in 2022 [58].

These subsidies, as well as the direct subsidies for solar customers, are gathered through additions to utilities' rates [31]. As such, one could speculate that the high level of rooftop solar diffusion in Germany could be part of the reason for the country having some of the highest electricity rates in Europe [32]. Indeed in 2013, over half of the capacity in Germany's two largest renewable sources of energy, wind and solar, was owned by individuals, farmers and industry actors, whilst just 5% was owned by big utilities and 7% by regional/municipal utilities [33]. Thus it is clear that whilst distributed customer-owned generation has been a major factor in the success of Germany's energy transition, it has also been a major recipient of the renewable subsidies that have been gathered from increased electricity prices there.

## Does rooftop solar negatively affect any other stakeholders, apart from utilities?

Yes – if rooftop solar does increase rates, then it is the poorest members of society that are most likely to feel the effects of this the most. This is because low-income households are statistically the least likely to install rooftop solar, as can be seen in Figure 1 below.

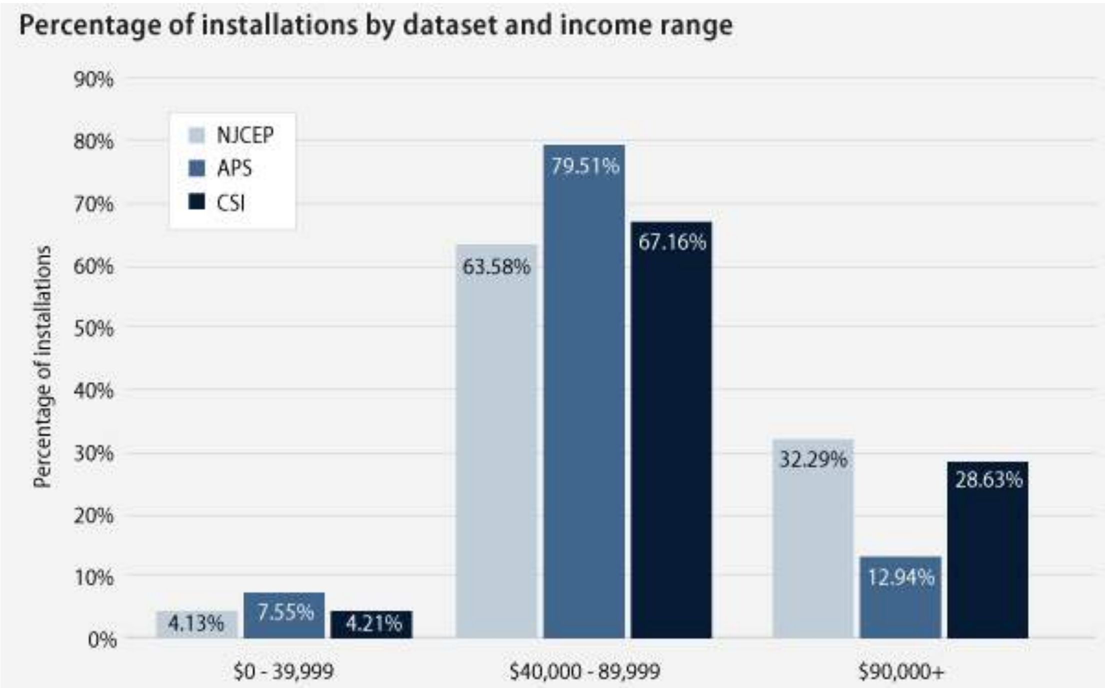


**Figure 1 - Rooftop solar installations in zip code areas with different average incomes[iv], as revealed in reference [5]**

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[iv] Data limitations of this graph should be noted as it uses 'median income data at the ZIP-code level from the U.S. Census Bureau because actual income data for each installation are not publicly available. There is an inherent amount of uncertainty in using median income data as

All members of society, ratepayers or not, could also be affected by rooftop solar diffusion if it begins to cause problems for security of supply. This is because an increasing reduction in utility revenues could make it difficult (in a regulated market) or unattractive (in a deregulated market) for them to maintain essential infrastructure such as the grid and dispatchable generation technologies, both of which will almost certainly be needed in the coming decades (given that storage options for renewable energies remain uneconomic at a large scale for the time being).

## What are the perceived benefits of rooftop solar, and who benefits from it the most?

The most obvious benefit of rooftop solar is that its output generally displaces that of fossil fuel plants, and thus reduces the $CO_2$ emissions[v] arising from these plants [34]. This benefits the planet at large. As already stated, in 2013 over half of the capacity in Germany's two largest renewable sources of energy (wind and solar) was owned by individuals, farmers and industry actors, whilst just 5% was owned by big utilities and 7% by regional/municipal utilities [33]. As such it is clear that distributed customer-owned generation has been a major factor in Germany's highly successful renewable energy transition, and thus a major contributor to the fight against climate change.

Rooftop solar can also be said to have the following benefits for other stakeholders:

- It benefits those who install it, as they often achieve a positive return on their investment.
- It benefits the economy by creating jobs [35].
- It increases security of supply in the face of downed power lines [35].
- It creates a sense of environmental action amongst citizens, as well as a sense of freedom in choosing how their energy is produced.
- It increases competition in a previously monopolised market, which could (all else equal) benefit all ratepayers eventually.

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proxies for real income data, as actual incomes associated with each installation could be higher or lower than the median income' [5]

[v] It should also be noted that energy is used in the production of PV systems, and that this energy use causes some $CO_2$ emissions. However the overall effect of producing a PV system is that it prevents far more $CO_2$ emissions than it creates, with between 87 and 97% of the energy produced by a PV system having no effect on pollution, greenhouse gases, and depletion of resources [59].

- It helps utilities to avoid some costs, such as fuel costs. As will be discussed later in the model description, these avoided costs could potentially outweigh lost revenues in some scenarios.

Overall then it is clear that the growth of rooftop solar is clearly seen from many perspectives, some of which are positive and some of which are negative. A useful review of these perspectives is provided below, in the form of a first person statement that may represent the viewpoint of each stakeholder:

- **Most Utilities**: '*Rooftop solar will kill our profits!*' (via reduced revenues)
- **Some Utilities**: '*Time to change our business model!*' (by providing distributed generation resources)
- **Rooftop solar installers/customers**: '*Utilities are trying to kill us, their only competition!*' (via the special rate plan for solar customers)
- **Non-solar customers**: '*We are subsidizing the solar customers!*' (via the addition in rates made necessary by rooftop solar)
- **Environmentalists**: '*How many $CO_2$ emissions does rooftop solar diffusion prevent*?' (via replacement of output from fossil fuel plants)

## What is the focus of this paper?

This study uses a system dynamics model to first analyse the validity of the 'death spiral' and 'cross subsidization' hypotheses as they apply in the context of residential rooftop solar. In light of this, the model is then used to evaluate three policies concerning rooftop solar – (i) rooftop solar subsidies, (ii) special rate plans/charges for rooftop solar customers, and (iii) the utility's use/non-use of the Renewable Energy Certificates (RECs)[vi] arising from their customers' rooftop solar systems, as part of the utility's Renewable Portfolio Standard (RPS)[vii]. These policies are evaluated based on their effects on (i) utility rates and (ii) prevention of $CO_2$ emissions. Utility rates can be considered a social issue for policymakers, whilst $CO_2$ emissions represent the environmental aspect at play.

The study makes a contribution to the existing literature surrounding rooftop solar in the U.S. by adding to the literature on the death spiral. It will also have a contribution to rooftop solar diffusion studies, by including the effects of the

[vi] An REC is a tradable right to claim the environmental and other attributes associated with 1 megawatt-hour of renewable electricity from a specific generation facility.' [60].

[vii] An RPS is a sometimes legally enforceable requirement for electric utilities to meet a certain percentage of their customers' demand through renewable generation sources, by a certain year. While RPS requirements differ across states, there are generally three ways that electricity suppliers can comply with the RPS:
1. Owning a renewable energy facility and its output generation.
2. Purchasing Renewable Energy Certificates (RECs).
3. Purchasing electricity from a renewable facility inclusive of all renewable attributes. [60].

feedback loops that exist between rooftop solar diffusion and utility rates. To my knowledge, the effects of these feedback loops have been lacking in all but one other study looking at rooftop solar diffusion, and this study focused on an Australian electricity market [36].

The paper will also make a contribution by focusing specifically on how the existence and use of RECs is a major factor in determining the effects of rooftop solar (and its subsidies) on both utility rates and prevention of $CO_2$ emissions.

# 3. The Model

The purpose of the model is to determine the effects of rooftop solar diffusion on (i) SRP's rates for residential customers, and (ii) prevention of $CO_2$emissions arising from electricity production in SRP's service area. The model will also represent rooftop solar diffusion among SRP's customers. However the main focus will be on electricity rates and prevention of $CO_2$emissions.

The model is essentially composed of two parts. The first part (seen in Figure 2) represents the three main reinforcing feedback loops that drive rooftop solar diffusion. One of these reinforcing feedback loops (R1) represents the 'death spiral' hypothesis as it relates to residential rooftop solar. It shows how the lost revenues resulting from this rooftop solar diffusion causes an increase in SRP's residential rates, which in turn causes greater rooftop solar diffusion among residential customers.

The second part of the model (presented from Figure 4 up to Figure 7) represents (some of) the avoided costs that SRP benefits from as a result of rooftop solar diffusion, and how these, all else equal, will reduce SRP's rates and thus discourage the diffusion of rooftop solar. In this model we look only at the avoided variable costs and avoided generation capacity investment costs made possible by rooftop solar. The effects of rooftop solar diffusion on the utility's grid costs are ignored in this model. This is because it seems that there does not yet exist a proper method of analysis for quantifying the change in grid costs attributable to rooftop solar diffusion [37].

The model will be presented through causal loop diagrams (CLDs), followed by discussion of the most important feedback loops in each CLD.

**How does the model represent the effect of rooftop solar on utilities rates, and the problem of the death spiral?**

Below we see a CLD of the three main reinforcing feedback loops that affect rooftop solar diffusion. R is used to denote reinforcing loops in these CLDs, whilst B will be used to denote balancing loops. Additionally, the term 'Utility' has been used in place of SRP so that a more generically applicable understanding can be achieved by these CLDs.

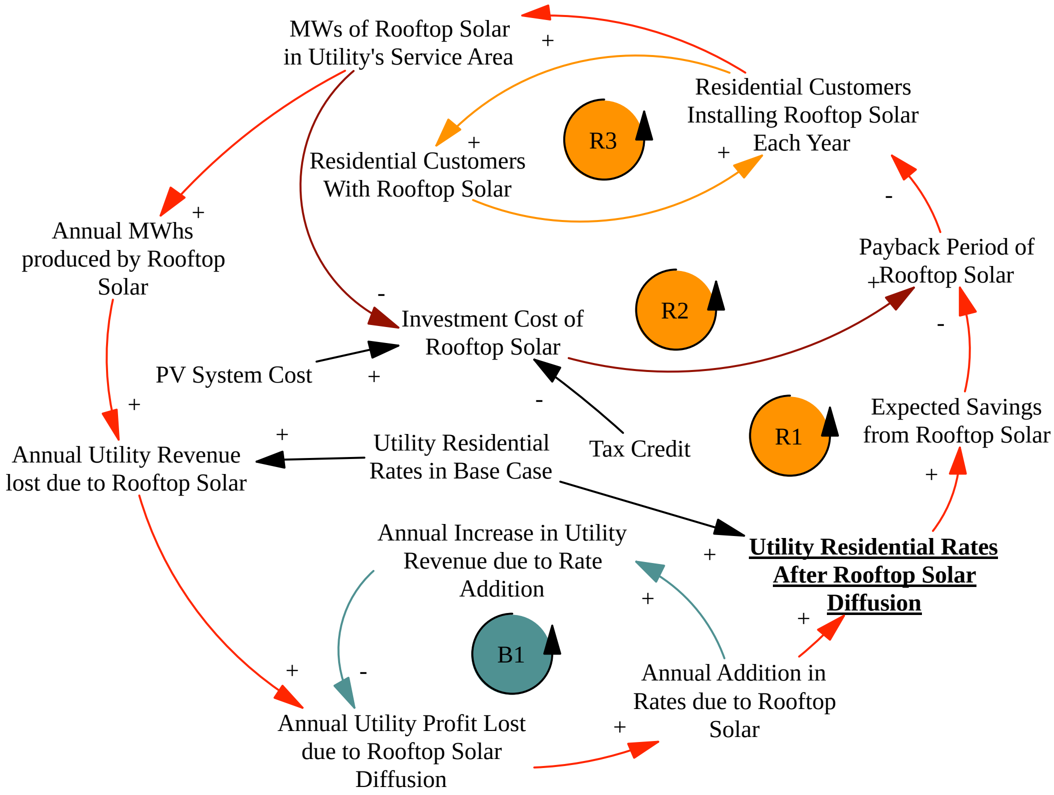


**Figure 2 - CLD representing the feedback loops driving rooftop solar diffusion, and the resulting effects on the utility's rates.**

**Loop R1 (outer red loop):** This loop represents the death spiral hypothesis. For every SRP residential customers that installs a rooftop solar system, SRP lose some revenues. This is because rooftop solar panels installed by residential customers produces a certain number of MWhs per year (quite a lot in sunny Arizona) and these MWhs replace those MWhs that the rooftop solar customer would have bought from SRP. As such, SRP make less sales of its product and its revenues are reduced.

In the CLD we see that the 'annual revenue lost…' will increase the 'annual profit lost…', which in turn increases SRP's rates. This represents the fact that the rates that SRP charges are determined under the principle of 'cost recovery', which has already been explained on page 4. This essentially means that any lost profits for SRP will result in them charging higher rates.

Finally, we note that a raise in SRP's rates will increase the expected savings that potential rooftop solar adopters would expect to make from their investment. This in turn will reduce the expected payback period[viii] of their investment, which will therefore increase the number of residential customers installing rooftop solar each year.

**Loop B1:** This loop has the opposite effect of the R1 loop. It represents the fact that the addition in rates due to rooftop solar will result in some increased revenues for SRP (all else equal). This in turn will decrease their profits lost due to rooftop solar, which will reduce the addition in rates needed in the next year.

**Loop R2:** This reinforcing loop represents the fact that provision of rooftop solar is a relatively young industry. As such, it is likely to experience some increases in efficiency as it gains more experience. The model also represents the 30% tax credit that was introduced in 2006 and which has been extended until 2016 [38]. This policy gives residential customers who buy a distributed PV system (amongst other technologies) a tax credit that is equal to 30% of the final price paid for the module (i.e. including system and installation costs). Whether or not this tax credit is renewed in 2016 remains to be seen, and as such it can be treated as a policy variable in the model.

**Loop R3:** This loop represents the 'word-of-mouth' effect that is often found in models representing the diffusion of a new technology [39–41]. The word of mouth effect in regards to rooftop solar diffusion in particular has also been validated through survey evidence [42]. This effect essentially says that as more and more people adopt a certain technology, their friends, family and neighbours will become more aware of the technology and so will become more likely to adopt it themselves. This further increases the stock of adopters, and so further increases the word-of-mouth effect. Such a phenomenon has been found to be a driver of the exponential growth often experienced by young technologies [40].

### How does the model represent the avoided costs that utilities can benefit from as a result of rooftop solar?

The CLD below represents the avoided generation capacity costs that SRP can benefit from as a result of rooftop solar diffusion.

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[viii] The payback period means the number of years that it will take for the money saved via the rooftop solar system to exceed the cost of the investment in that system. So if the rooftop solar system is expected to save you on average $200 a year, and the investment cost was $2000, then the expected payback period of that system would be 10 years. This metric has been shown to be the one most commonly used by prospective rooftop solar adopters[61,62].

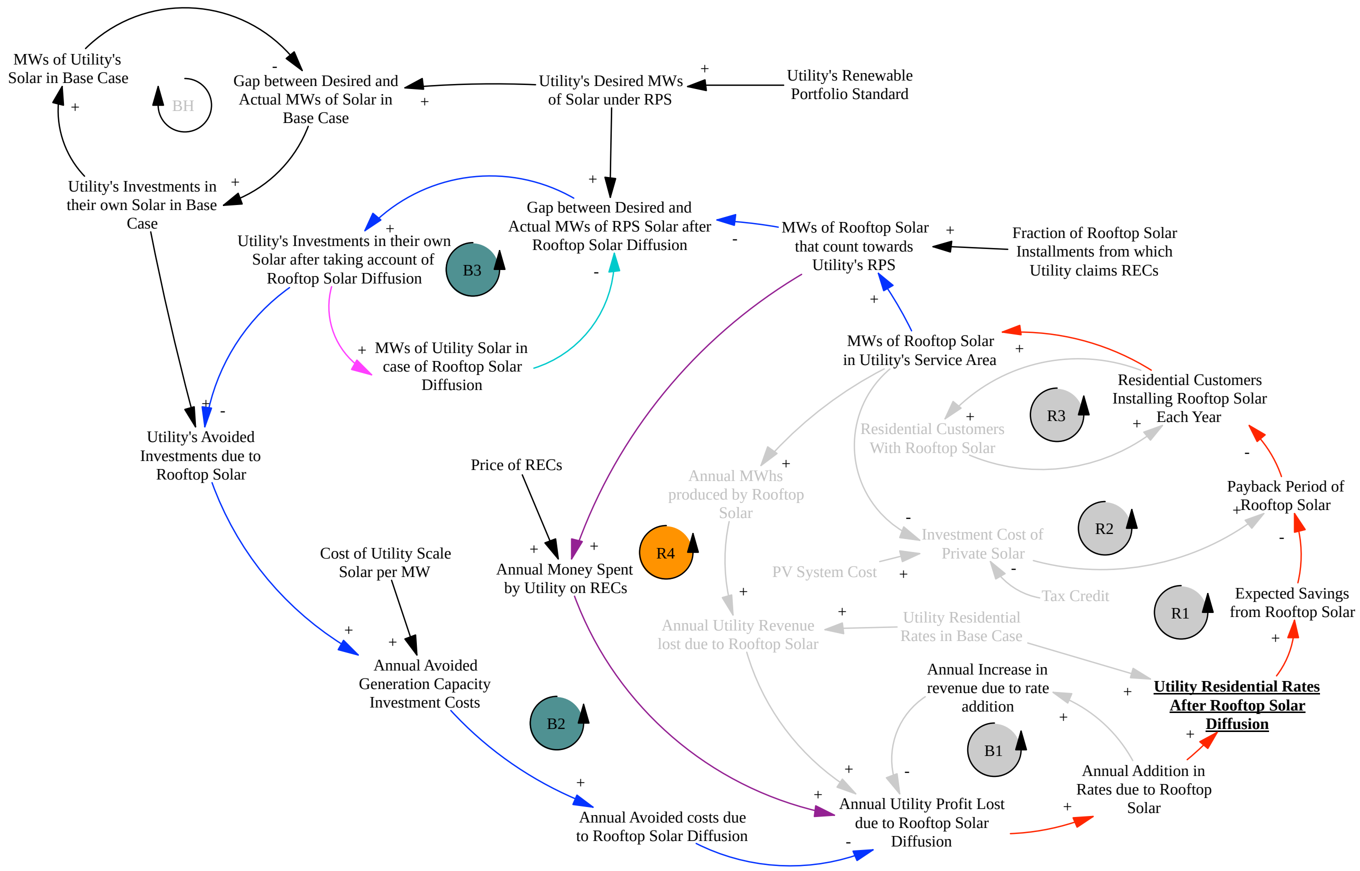


**Figure 3 - CLD representing the utility's avoided generation capacity costs.**

The most important of these loops are:

**Loop B2 (Blue to Red Loop):** This loop represents the avoided generation capacity investment costs that the utility can benefit from due to rooftop solar (see assumption 1 in Appendix A). This loop is based on the idea that SRP, like most utilities, operates with a Renewable energy Portfolio Standard (RPS), and that part of this RPS can be met through the use of Renewable Energy Certificates (see assumption 2 in Appendix A). Thus the model assumes that SRP can enter into a contract with their rooftop solar customers in order to claim the RECs from their systems. Claiming these RECs would allow the utility to balance its investments in its own solar which would otherwise be necessary to meet their RPS. These annual avoided generation capacity costs then reduce the 'Annual Profit Lost due to Rooftop Solar', which in turn reduces SRP's rates. This eventually reduces the number of customers installing rooftop solar each year, which, to close the loop, slows down the growth of the 'MWs of Rooftop Solar in Utility Service Area'. The meaning of this loop is essentially that, all else equal, rooftop solar diffusion will allow SRP to avoid some generation capacity investment costs, which in turn should (a) reduce SRP's rates and thus (b) cause less solar diffusion. This means that rooftop solar diffusion is caught in a balancing loop.

**Loop BH:** To determine how many investments in their own solar have been avoided, we need to know what investments SRP would have made each year *if there was no* rooftop *solar diffusion* (note that this is a hypothetical situation, and so for this reason this loop has been termed BH, to alert the reader to the fact that it does not refer to any actual loop that exists in the system[ix]). The purpose of this loop is to help us determine the 'Utility's Avoided MW Investments due to Rooftop Solar', by seeing the difference between the utility's annual investments in the case of no rooftop solar diffusion (called the Base Case) and their annual investments in their own solar '…after taking account of Rooftop Solar Diffusion' (in the RS Case). Note that if the utility does not claim or buy any RECs from their customer's rooftop solar systems, then the difference between their base case investments and their investments after taking account of solar will be zero, and so SRP will not avoid any capacity investment costs.

**Loop R4 (Red to Purple Loop):** This reinforcing loop represents the fact that the RECs from rooftop solar systems belong to the system owner (i.e. the SRP solar customer) and so for SRP to claim these RECs it would have to buy them (see assumption 6 in Appendix A). This in turn would reduce its profit, which would eventually cause an increase in rates, greater rooftop solar diffusion, a greater stock of MWs from which SRP buys RECs, and so, to close the loop, a greater number of RECs for which SRP pays. Note that this reinforcing loop acts in exact opposition to the B1 loop, which allows SRP to avoid costs based on the stock of rooftop solar systems.

[ix] This hypothetical loop is necessary in this model because we are not modelling all of SRP's capacity investments and their associated costs. If we were, then we would be able to determine the avoided costs due to rooftop solar by first simulating a scenario of no rooftop solar diffusion, looking at the investment costs, and then simulating a scenario with rooftop solar diffusion, and seeing the extent to which the investment costs have been reduced. Such simulation results are not possible in this smaller model, unless we use this hypothetical loop.

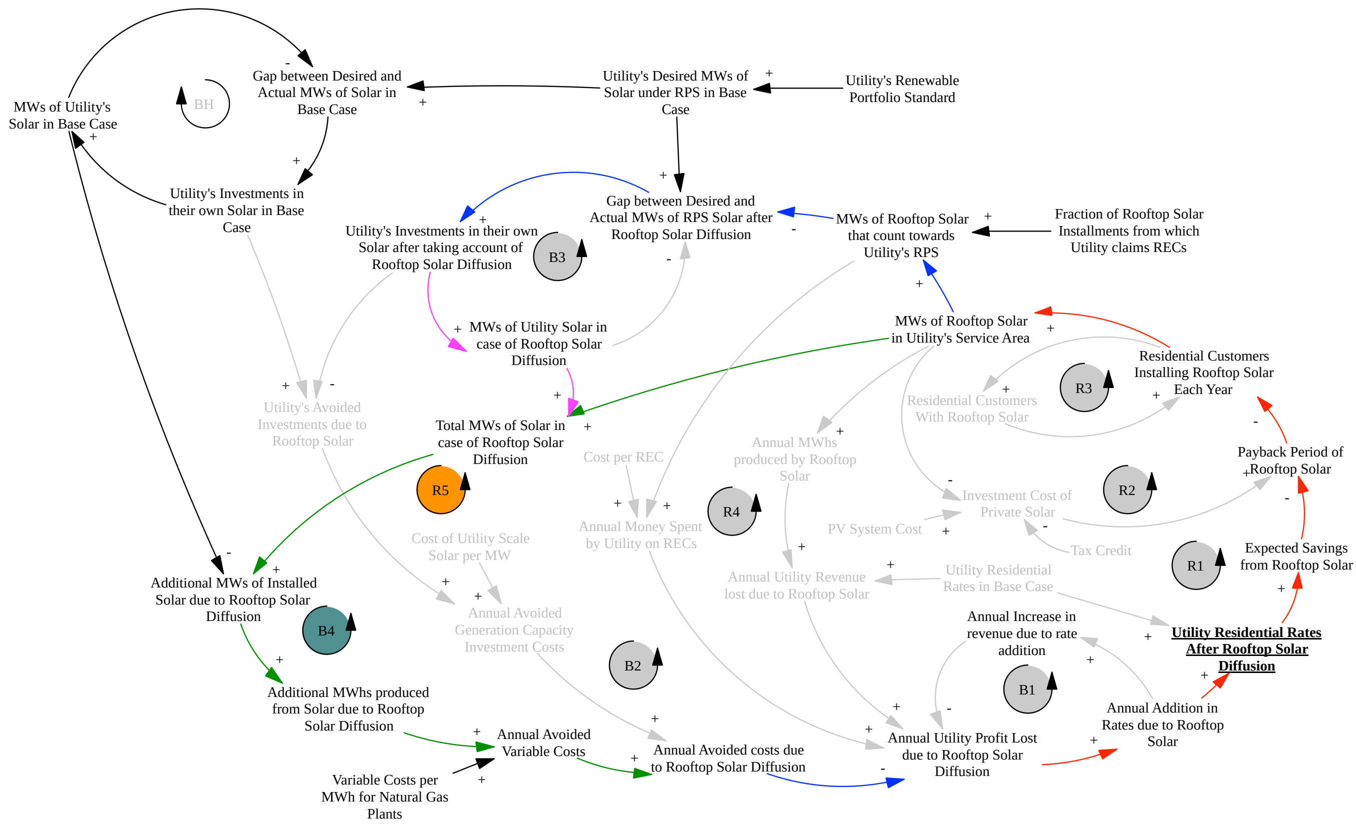


**Figure 4 - CLD representing the avoided variable costs made possible by rooftop solar**

**Loop B4 (Red to Green Loop):** This balancing loop represents SRP's avoided variable costs due to rooftop solar diffusion. We assume that all solar generation technology allows for avoided variable costs that would arise from natural gas plant generation[x] (see assumption 11 in Appendix A). This loop essentially says that every MW of rooftop solar increases the difference between the MWs of solar that are present in SRP's service area in the RS case (i.e. in the case of rooftop solar diffusion), and the MWs of solar that would be present in the Base Case. These 'additional' MWs in turn increases the additional MWhs produced by solar in SRP's service area. These MWhs in turn displace natural gas plant use, resulting in some avoided variable costs for SRP. Once again these avoided variable costs reduce the profit lost due to rooftop solar, which reduces rates, reduces rooftop solar diffusion, and so finally, to close the loop, slows the growth of rooftop solar in SRP's service area.

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[x] Around 87% of these natural gas plant variable costs are fuel costs, whilst the remaining 13% is split between operation and maintenance costs [63]

### How does the model represent rooftop solar's effect on $CO_2$ emissions?

As seen in Figure 5 below, the model uses the variable of the 'Additional MWhs produced from Solar due to Rooftop Solar Diffusion' to determine not only the variable costs avoided due to rooftop solar, but also the additional $CO_2$ emissions prevented by rooftop solar. These additional MWhs displace production from natural gas plant generation, and so for every additional MWh produced in the rooftop solar diffusion case, we can say that a certain amount of $CO_2$emissions (determined by the '$CO_2$ Emissions per MWh produced by Natural Gas Plants') were prevented due to rooftop solar difusion.

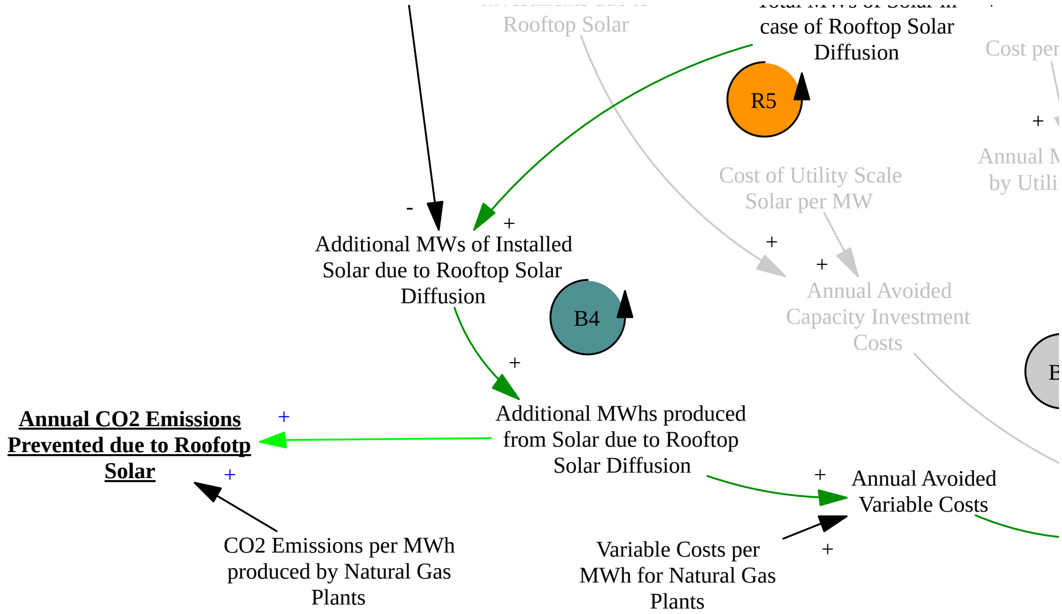


**Figure 5 - CLD showing how the model represents the CO2 emissions prevented by rooftop solar.**

Note that the dynamics determining $CO_2$emissions are the same as those determining the avoided variable costs. As such, the additional $CO_2$ emissions prevented by rooftop solar diffusion is highly dependent on the 'Fraction of Rooftop Solar Installments from which Utility claims RECs'. If the utility *does* claim these RECs, then it *will* balance its investments in its own solar. This means that the total stock of solar in SRP's service area will be smaller, leading to less $CO_2$ emissions prevented from natural gas plant generation. Converesely, if SRP receives less/none of these RECs, then it will balance less/not balance its investments in its own solar. This leads to a higher stock of total solar, and thus greater $CO_2$ emissions prevented. However it also means that the utility will not benefit from any avoided generation capacity investment costs, which means that their lost profits and thus addition in rates will be higher. This is the main insight of this CLD – there is a tradeoff between preventing more $CO_2$ emissions and preventing increases in rates.

Below in Figure 6 we see the CLD in its entirety. Note the addition of the 'Special Charge for Solar Customers', which reflects the recent mandatory price plan that SRP introduced for its distributed generation customers.

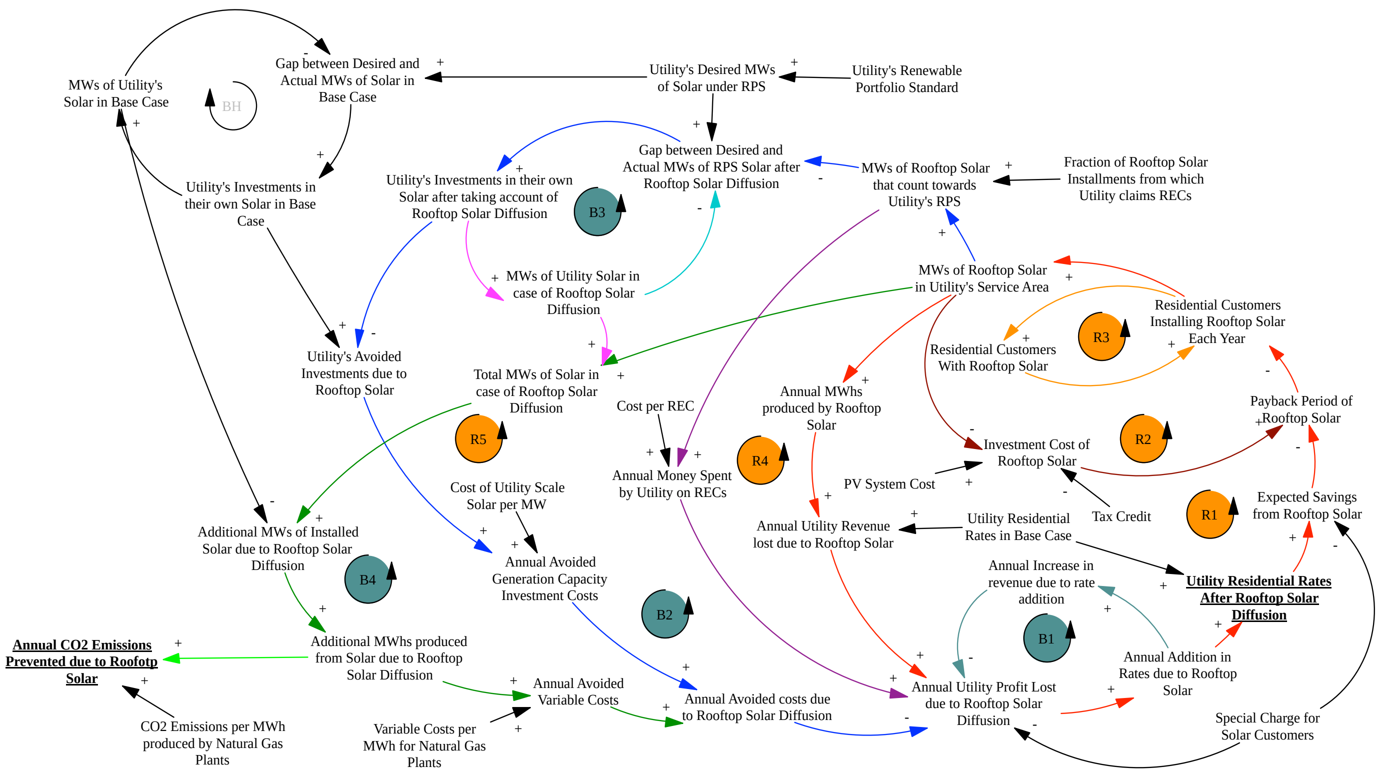


**Figure 6 - Whole CLD**

To see the assumptions upon which the model is based, please see Appendix A. This appendix also gives a list of the issues that are within and outside of the model's boundary.

# 4. Model Behaviour and Policy Analysis

## What results does the model produce in Scenario 1?

In analysing the behaviour of this model, we will use a reference case scenario referred to as Scenario 1. Note that this scenario is different to the Base Case, which refers to the scenario of no rooftop solar diffusion. Instead, Scenario 1 analyses the effects of rooftop solar diffusion, under the following conditions: (i) SRP receive no RECs for their customers' rooftop solar systems, (ii) the tax credit will not be renewed after it expires in 2016, and (iii) SRP's new rate plan and its effect on rooftop solar's payback period and savings will *not* be included in this scenario. This last condition will not be included (even though it has already been introduced by SRP) in Scenario 1 so that it can be more easily evaluated in the policy analysis section.

The model's validity was determined under the guidelines laid out by Barlas & Kanar (1999), and the model was shown to satisfy the recommended tests.[xi]

In this scenario, the model produces the following diffusion of rooftop solar, with rooftop solar adopters presented as a fraction of all of SRP's residential customers.


Figure 7 - Scenario 1 run for rooftop solar diffusion

Note that the growth of this stock is exponential. This is due to the falling PV prices, the increasing Base Case rates, as well as the effects of the model's five reinforcing feedback loops. We see that in 2016 there is a slight decrease in the exponential growth path of rooftop solar adopters. This is because the residential renewable energy tax credit expired for rooftop solar systems in this year, thus increasing their payback periods and reducing their rate of adoption. Nonetheless, by the end of 2030 the model projects that in this scenario 21% of SRP's residential customers will have installed rooftop solar.

## How are SRP's rates affected by the rooftop solar diffusion in Scenario 1?

In this Scenario 1, rooftop solar diffusion has the following effect on SRP's rates (all prices show are in 2012 U.S. dollars):

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[xi] to see these tests, please email the main author at comeehan@tcd.ie

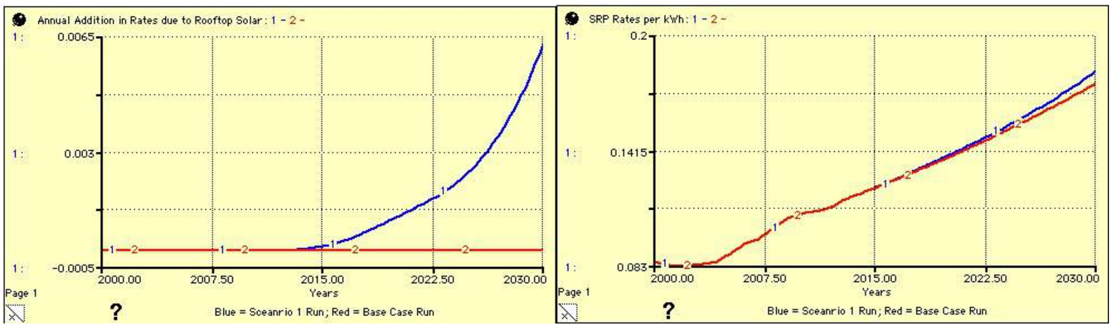

**Figure 8 - Effect of rooftop solar on SRP's rates in Scenario 1**

The Base Case rates (the red run) have been shown alongside the actual rates so that the reader can get an idea of the magnitude of the addition in rates.
By the end of the simulation period, SRP’s rates are $.0147 higher than they would be if there had been no rooftop solar diffusion. This is an increase of 8.3% from the Base Case rate. The increase in rates seen here is caused directly by SRP’ profit lost as a result of rooftop solar. This happens because the lost revenues due to rooftop solar are greater than the costs avoided due to rooftop solar. This happens in Scenario 1 because SRP receive/claim no RECs. This means that their avoided costs come solely from avoided variable costs, as in this scenario they cannot avoid any generation capacity investment costs. Thus the avoided costs are less than the lost revenues, resulting in lost profits for SRP, which in turn causes them to make additions to their normal rates. These lost profits accumulate to $933,371,580 profits lost by the end of 2030. Throughout the simulation period these lost profits translate into additions to their Base Case rates. Such a result validates the cross-subsidization hypothesis, at least in the context of Scenario 1. It also serves as a proxy for security of supply issues, as the significant lost revenues experienced by SRP would likely result in their investors being less willing/able to invest in new infrastructure.

### Does the model validate the death spiral hypothesis in Scenario 1?

The death spiral essentially says that rooftop solar diffusion will be significantly reinforced due to its effect on the utility’s rates. Thus to properly test this hypothesis, we need to determine how much the increase in rates due to rooftop solar actually affects the diffusion of rooftop solar. This can be done by comparing simulation results for the Scenario 1 diffusion with the diffusion when the death spiral loop (R1) is cut. This loop can be cut by multiplying the ‘addition in rates due to rooftop solar’ variable by zero. The results are displayed below:


**Figure 9 - effect of the death spiral loop on rooftop solar diffusion**

We see that the feedback effect between rooftop solar diffusion and increased utility rates does indeed result in greater rooftop solar diffusion. However, the result may not be dramatic enough to warrant the term 'death spiral'. If rooftop solar did not result in any addition in rates (i.e. the Blue run), then the model projects that there would still be 223,242 rooftop solar adopters in SRP's service area by the end of 2030, which is roughly 19% of the expected residential customers for that year, compared to 21% in Scenario 1 (where rate additions were accounted for).

In comparison to this, simulation results showed that the rate at which rooftop solar's installed cost declines seems to be a more important factor in determining rooftop solar's diffusion (and the resulting effect on SRP's rates).

### How does rooftop solar affect $CO_2$ emissions in Scenario 1?

As seen in Figure 10, rooftop solar diffusion in Scenario 1 results in an additional 5.73 million metric tons of $CO_2$ emissions prevented by the end of the simulation period.

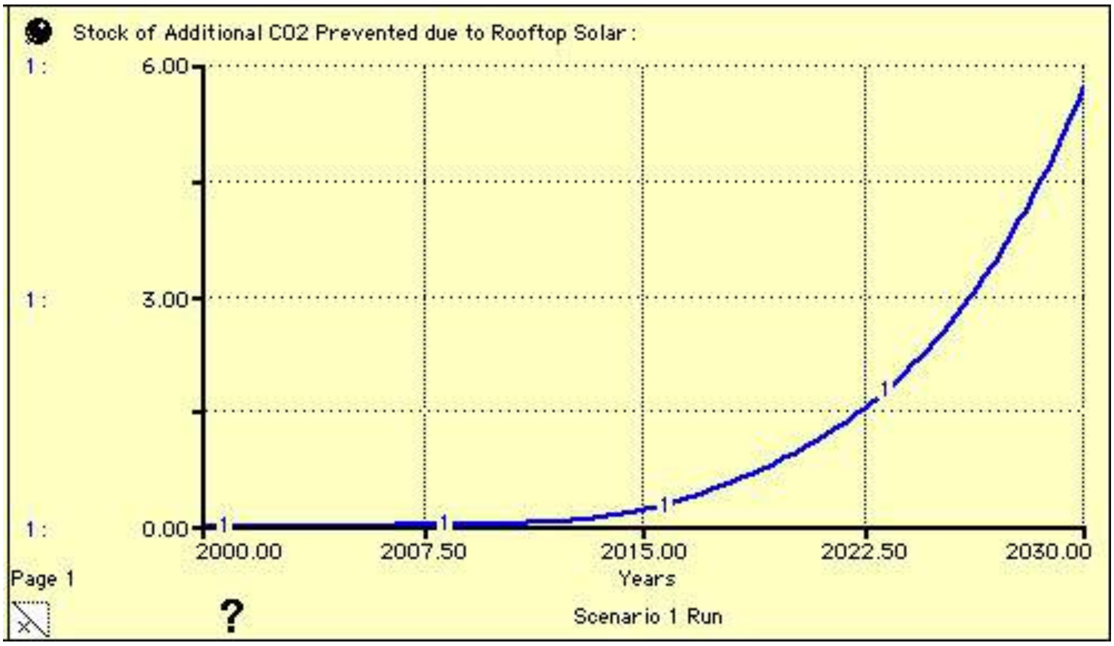

Figure 10 - CO2 emissions prevented due to rooftop solar in Scenario 1 (Units in Million Tons of CO2)

Note that these avoided $CO_2$ emissions are dependent on two things in the model – (i) the diffusion of rooftop solar, and (ii) the fraction of rooftop solar systems from which SRP claim RECs.

That concludes our discussion of the model behaviour in Scenario 1. We can now use the model to evaluate different policy options by analysing the results of changing different policy parameters in the model.

## Which are the policy variables in the system, i.e. which variables can be directly controlled by policy makers?

Most of the model's inputs are more or less outside of the control of any policy maker. For example, neither the demand for SRP's electricity nor the global price of PV systems are directly determinable through SRP's or the government's policies. However there are three parameters which are directly determinable by the system's policy makers. The ones most easily controlled by SRP are:

- The fraction of rooftop solar systems from which SRP claims/buys RECs.
- The annual increase in rooftop solar customers' bills due to the new rate plan.

The main policy variable that can be controlled by the U.S. government is:

- The tax credit for residential solar systems after 2016[xii].

Readers should note that the U.S. government could also have influence over how RECs are used, via RPS requirements/restrictions. Furthermore, in most contexts the U.S. government could also have influence over the policy of a special rate plan for solar customers. This is because most U.S. electric utilities are regulated, meaning that new rate plans could only be proposed by the utility and then accepted or rejected by the state commission that regulates them. In the context of this study, however, SRP is a publicly owned utility and so it essentially regulates itself, via its publicly elected board of directors.

In this section we will analyse how varying the three policy parameters above will affect SRP's rates and its $CO_2$ emissions.

### How does changing the fraction of RECs claimed by SRP affect their rates?

In Scenario 1, described on page 16, SRP claimed none of the RECs from their customers' rooftop solar systems. We will now analyse what happens if SRP claims *all* of the RECs from their customers' rooftop solar systems. In one run (Run 3 of Figure 11), we see what happens if SRP claim these RECs for free. In reality, however, SRP is likely to have to pay their customers for these RECs. As such we also analyse what happens if they have to pay a price of $100[xiii] (Run 4) per REC (i.e. per MWh of output from their customers' rooftop solar systems). These scenarios will be compared against Scenario 1 runs, so that the effects of these policy parameters can be seen. Additionally, the Base Case (i.e. the case of no rooftop solar diffusion) scenario will also be presented, so that the magnitude of the effect of rooftop solar can be seen.

In the Base Case run, there is no rooftop solar diffusion and thus no addition in rates due to rooftop solar (see Figure 11). As already discussed, Scenario 1 results in an increase in rates of 8.3% by the 2030. In the 'all RECs for free' (Run 3) case, there is initially a *decrease* in rates. This is because the RECs allow SRP to forego investments in their own solar capacity each year. Avoiding the cost of these investments means that rooftop solar diffusion actually results in *more* 'costs avoided due to rooftop solar' than 'revenues lost due to rooftop solar'. This results in an initial decrease in rates, because SRP's Board of Directors should

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[xii] Other subsidies such as net metering could also be controlled by the government, but for the sake of simplification the model does not represent these subsidies. The effects of such subsidies would essentially be the same as the tax credit anyway – they would reduce the payback period of rooftop solar, and thus stimulate greater diffusion.

[xiii] One study has noted that the price of RECs for solar has ranged between $45 and $250[52].

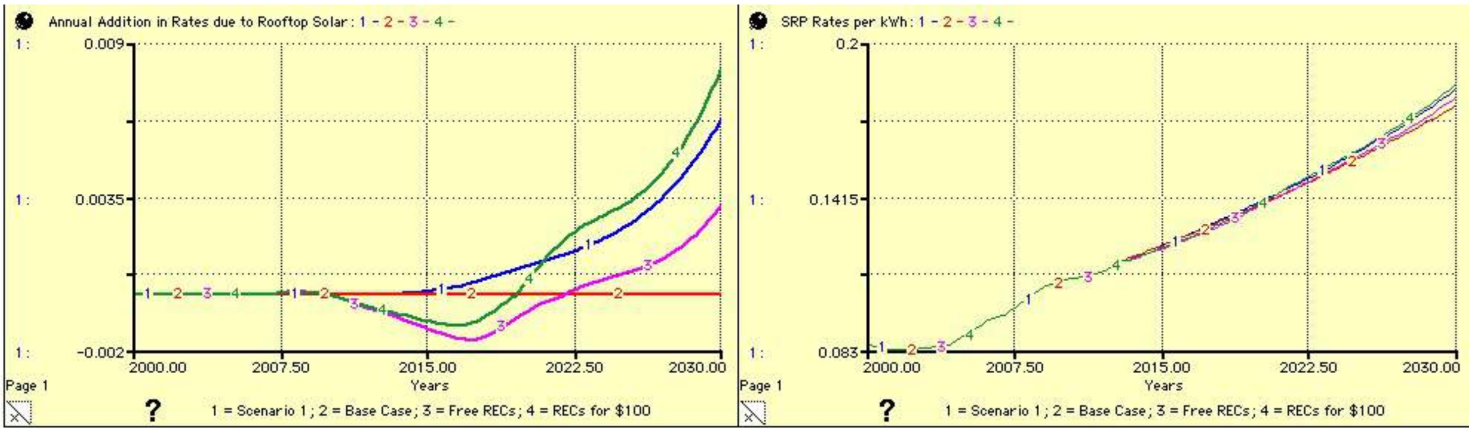


**Figure 11 - effect of claiming RECs policy on the addition in rates due to rooftop solar**

recognize the fact that SRP should now be able to afford lower rates whilst still maintaining cost recovery. However, as seen in the results above, this decrease in rates is only temporary. This is because the main part of these avoided costs come from the 'annual generation capacity investment costs avoided due to rooftop solar', which is based on a flow – the annual rooftop solar installations. On the other hand, the annual lost revenues are directly determined by a stock – the MWs of rooftop solar in SRP's service area. Initially, the effect of this flow outweighs the effect of the stock. However, as the MWs of rooftop solar installed accumulate over time, their effect eventually begins to outweigh the effects of the flow (of avoided investments). In Run 3, this happens at year 2020.

In the 'all RECs for $100' scenario (Run 4), similar behaviour is seen. However the initial decrease in rates is less because SRP's costs will be increased $100 for every REC bought. Furthermore, the eventual increase in rates is greater, for the same reason.

## How does changing the fraction of RECs claimed by SRP affect the $CO_2$ emissions prevented?

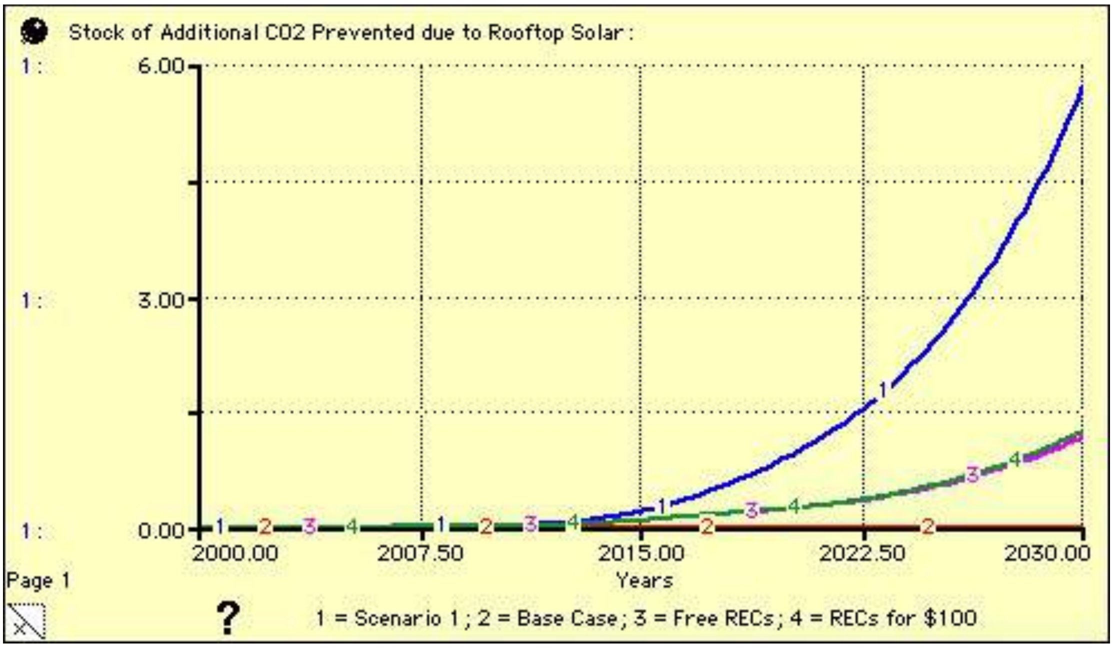


**Figure 12 - Effect of REC policy on CO2 emissions prevented due to rooftop solar**

In Figure 12 we see that Scenario 1 results in the most $CO_2$ emissions being prevented. This is because SRP does not balance its investments in its own solar in this case. When SRP does receive the RECs, then they will balance their investments in their own solar, meaning less solar is present, and less emissions are saved, as seen in Run 3 and Run 4 above. In other words, in this scenario every MW of rooftop solar installed will result in SRP eventually investing in 1 less MW of their own solar.

Nonetheless, the simulations reveal that some additional emissions are still saved. This is because SRP reduce their investments *after a delay in perceiving rooftop solar installations.* This delay is seen in the model when rooftop solar installations flow into the stock of 'MWs of solar from which SRP claim RECs'. The flow is not accumulated into this stock until after 1 time-step, which in this model is one year. This delay means that SRP will not balance its investments immediately, which means that every rooftop solar installation will not result in balanced investments *until 1 year after the installation.* This means that more MWs of solar will come online quicker than it would otherwise have been (if there had been no rooftop solar diffusion), which in turn prevents $CO_2$ emissions that would otherwise not have been prevented. In other words, rooftop solar diffusion allows SRP to achieve its RPS goals quicker than it was planning to, and thus helps to prevent more $CO_2$ emissions. However, it should be noted that if SRP began to make projections about rooftop solar diffusion and to rely on receiving a certain number of RECs from these future systems, then they may balance their investments earlier, meaning that rooftop solar diffusion would result in even less/no extra $CO_2$ emissions prevented.

### How does SRP's new rate plan affect their rates?

As discussed in the introduction, SRP has recently introduced a special rate plan for their solar customers, which is expected to increase the monthly bills of their average distributed generation customer (such as rooftop solar owners) by $50 [18,44]. However, existing rooftop solar customers have been grandfathered for 20 years [18,44]. In the model this affects both diffusion of rooftop solar (by lowering the expected savings of rooftop solar) and SRP's profits lost as a result of rooftop solar (by decreasing SRP's profits lost for every MW of rooftop solar installed after 2015). Figure 13 below shows comparisons between the Scenario 1 run with a run of the same conditions, except that the effects of the new rate plan have been introduced (this is the pink run). The Base Case run has also been included, so that the magnitude of the effect of rooftop solar can be easily seen.

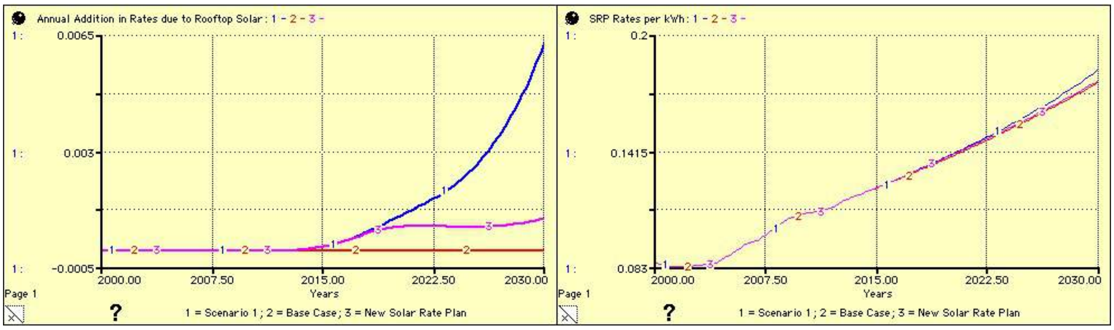

Figure 13 - effect of SRP's new rate plan on addition in rates due to rooftop solar

Here we see that the introduction of this rate plan allows for a much smaller addition in rates due to rooftop solar. However, it is interesting that according to these simulation results, SRP would still have to have additions in rates even after introducing this rate plan.

## How does SRP's new rate plan affect rooftop solar diffusion and $CO_2$ emissions?

The left hand graph below compares the rooftop solar diffusion in Scenario 1 with the diffusion in the scenario in which the effects of SRP's new rate plan are included. Without the introduction of the fee, 21% of SRP's customers are projected to install rooftop solar by the end of 2030. With the introduction of the fee, the diffusion slows down from 2015 onwards such that only 5% of their customers have installed rooftop solar by the end of 2030. This is because SRP's new rate plan will decrease the expected savings from rooftop solar, as well as decrease the addition in rates due to rooftop solar. Both of these effects will (all else equal) increase the expected payback period of solar, which will slow its diffusion.

The right hand graph below shows how the introduction of the new rate plan could affect the $CO_2$ emissions prevented due to rooftop solar. We see that there are less $CO_2$ emissions prevented because there is less rooftop solar diffusion.

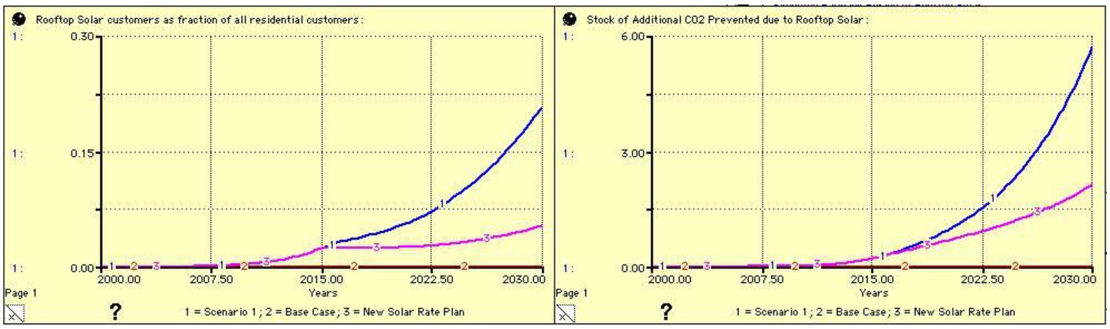

Figure 14 - effect of SRP's rate plan on rooftop solar diffusion and CO2 emissions prevented

## How does changing the tax credit affect SRP's rates?

The residential renewable energy tax credit grants homeowners who install rooftop solar systems (and other micro renewable generation technologies) a tax credit worth 30% of the installed cost of their system. This tax credit is due to run out in 2016, and there is much debate about whether or not it should and will be renewed for rooftop solar systems [45]. In Scenario 1, the tax credit was not renewed. In this policy analysis section, we will see what happens when the tax credit is maintained at 30% from 2016 on.

The graph below compares the Scenario 1 run with a run of the same conditions, except that the tax credit is maintained after 2016. The Base Case run has also been included, so that the magnitude of the addition in rates can be easily seen.

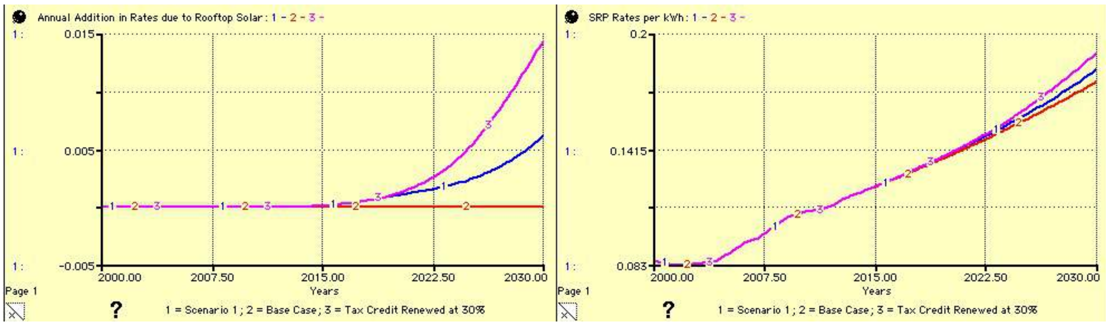

**Figure 15 - the effect of renewing the tax credit on the addition in rates due to rooftop solar**

The graph below then shows how renewing the tax credit will affect rooftop solar diffusion and the resulting $CO_2$ emissions prevented by this diffusion.

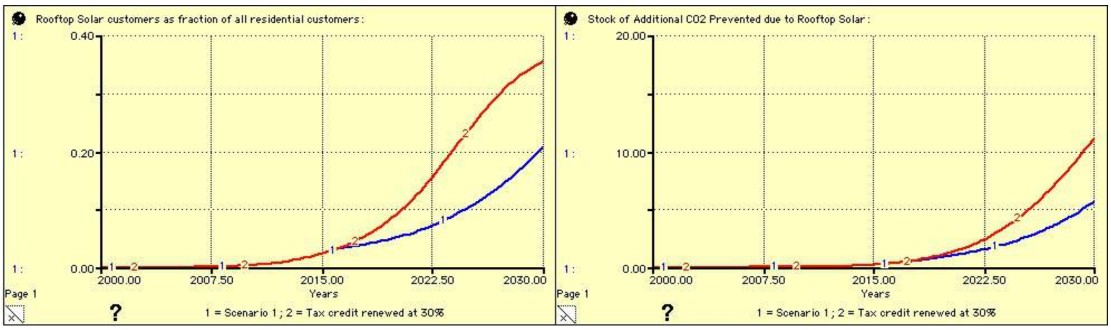

**Figure 16 - the effects of renewing the tax credit on the CO2 emissions prevented due to rooftop solar.**

In Scenario 1, when the tax credit is not renewed, the model projects that 21% of SRP's customers will have installed rooftop solar by the end of 2030. When the tax credit *is* renewed at 30%, 36% of SRP's customers are projected to have installed rooftop solar. However the financial costs of this tax credit should also be taken into account. The model's side calculations reveal that in Scenario 1, the government foregoes $200,492,685 in tax credits for residential rooftop solar installers by the end of 2030. When this tax credit is renewed at 30% in 2016, the model projects that the government will forego $1,923,640,729 by the end of 2030. Such costs should be taken into account when analysing the effectiveness of renewing the tax credit.

To conclude, this section of the paper has reviewed the effects of changing three policy parameters – (i) the fraction of rooftop solar systems from which SRP claims RECs, (ii) the introduction of a special rate plan for SRP's rooftop solar customers, and (iii) the non-renewal of the tax credit after it runs out in 2016. The effects of changing these policy parameters can be summarized in the following table:

| Policy | Effect on rooftop solar diffusion | Effect on SRP's rates | Effect on $CO_2$ emissions prevented |
|---|---|---|---|
| **Claim all RECs (in RECs free scenario)** | Minimal | Initially allows for reductions from Base Case rate, followed by additions from 2020 on | Results in less $CO_2$ emissions being prevented, due to SRP balancing their investments |
| **Claim all RECs (when RECs are $100)** | Minimal | Initially allows for small reductions from Base Case rate, followed by larger additions from 2022 on | Results in less $CO_2$ emissions being prevented, due to SRP balancing their investments |
| **Introduce special solar rate plan** | Greatly reduces diffusion | Allows for almost no rate additions to be needed | Results in much less CO2 prevented |
| **Renew tax credit after 2016** | Greatly increases diffusion | Exacerbates rate additions | Increases CO2 emissions prevented |

Having reviewed the effects of changes in the model's main policy parameters, we can now turn to look at the limitations of this study, and the recommendations for further work on this topic. Discussion of the implications of this policy analysis will be saved for the concluding remarks.

# 4. Conclusions and Recommendations for Further Work

## What are the main limitations of this study?

With limited time and availability of data, there were several limitations to this study. The most notable limitations were as follows:

- There was no focus on the effect of solar storage technology, which could affect SRP's avoided costs and thus their rate additions.
- Didn't include SRP's costs and other factors determining the way their rates are formed.
- Didn't include commercial scale rooftop solar.
- Didn't include the benefits/costs of rooftop solar to the grid.
- Didn't include the effect that higher rates may have on SRP's customers' energy efficiency, which results in another vicious loop of reduced demand, reduced revenues, higher rates, and thus again reduced demand.
- Doesn't go into detail about customer rates – the difference between onpeak and offpeak rates in time-of-use rate plans. Also the effects of decoupling, which in one study was shown to help prevent lost revenues[2].
- Didn't include the savings experienced by rooftop solar owners

I would say that lack of inclusion of the effects of rooftop solar on the utility's grid costs is the biggest limitation to this study, as this variable could have a significant effect on SRP's profits, which in turn would have significant effects on the validity of the cross subsidization and death spiral hypotheses.

## What are my recommendations for further work on this topic?

The growth of rooftop solar and the resulting concerns of utilities are quite recent affairs. Although there have been several studies already conducted on these topics [34,36,46,47], there is much work that remains to be done. My recommendations for this future work are as follows:

- Include the effects of rooftop solar in relation to microgrid formation
- Include the effect of rooftop solar on grid costs – not yet known whether this will increase or decrease grid costs overall. Could depend on where in the gird the rooftop solar systems are installed
- Include greater accuracy in the word of mouth diffusion part of the model.
- Include effects of how a more centrally planned diffusion process (as could be done by utilities, for example) could bring about greater net benefits. For example, west facing panels may be better at meeting peak

demand than south facing panels, although south facing panels produce more kWhs. As such, some incentives for west facing panels may be necessary. Additionally, certain locations in the grid will benefit from the reduced load resulting from rooftop solar more than others.

- Include effect of distributed generation on security of supply [48].
- Include greater accuracy of avoided variable costs – does rooftop solar also allow for avoided operation and maintenance costs, or only for avoided fuel costs?

## What is my main recommendation for further work on this subject?

The use and price of RECs had a significant effect on model behaviour in this study, yet I was unable to find clear literature on how the RECs resulting from rooftop solar systems are being used by SRP. As such, I feel that this is the most important issue for further research on this topic.

## What is the main insight of the thesis?

The main insight arising form this thesis is that, based on the assumptions made in the model, if SRP does *not* claim or buy any RECs from their customers' rooftop solar systems, then rooftop solar is shown to reduce their revenues more than it reduces their costs, in both the long term and the short term. This means that SRP would likely raise rates in compensation (or will at least have higher-than-otherwise rates), thus validating the cross subsidization hypothesis.

The model also shows that this increase in rates would encourage greater rooftop solar diffusion, thus validating the death spiral hypothesis. However, this feedback effect between rooftop solar diffusion and utility rates is quite minimal in the model, and does not have as much of an effect as does falling global PV prices. This conclusion is consistent with another system dynamics study looking at the death spiral in an Australian market [36]. Thus it seems that falling PV prices are likely to be the main driver behind rooftop solar diffusion. Finally, in this 'no RECs received' scenario, rooftop solar diffusion will have a considerable effect on $CO_2$ emissions, preventing 5.73 million emissions by the end of 2030.

However, in the policy analysis section it is revealed that if SRP *does* claim/buy all the RECs from its customers' rooftop solar systems, then they may (depending on the price paid for these RECs) be able to *temporarily* avoid more costs than lose revenues. This is because the RECs allow the utility to avoid investments in its own renewable generation capacity, which it would otherwise have had to make in order to meet its RPS. If the utility really can temporarily avoid more costs than lose revenues as a result of rooftop solar, then both the 'death spiral' and ‘cross subsidization’ hypotheses could be *partially* rejected, because rooftop solar diffusion should result in *temporarily* lower-than-otherwise rates.

However, there is a trade-off occurring in this scenario – if installation of rooftop solar systems allows utilities to invest less in their own renewable generation capacity, then rooftop solar diffusion will no longer have the effect of increasing the stock of solar present in the utility’s service area. In other words, if an SRP customer were to install a 4kW rooftop solar system, and if that allowed SRP to avoid 4kWs of investment in their own solar, then the action of the SRP customer would have very little effect on the prevention of $CO_2$ emissions. However, it will also mean that the customer’s rooftop solar system will *not* increase SRP’s rates, or will at least increase them by less than in if the RECs were not claimed.

### What conclusions could utility managers draw from these simulation results?

From a utility’s perspective, the main finding would be that the problem of lost revenues as a result of rooftop solar diffusion could be most effectively tackled by claiming the RECs from their customers’ rooftop solar systems. If these RECs are sufficiently cheap, then they could help the utility to at least temporarily reduce/overcome the impact of lost revenues resulting from rooftop solar, by way of allowing the utility to avoid investments in their own solar capacity. Additionally, the simulations have shown that introduction of SRP’s new rate plan (which will increase the monthly bills of a typical rooftop solar customer by $50) would solve the problem of rate additions almost entirely, but may still result in some lost profits for the utility.

### What conclusions could government policy makers draw from these simulation results?

From a government/social perspective, there are three main questions addressed in this study. The first question concerns how the Renewable Energy Certificates arising from residential rooftop solar systems should be regulated. The government faces a trade-off situation here – if they allow/encourage/force the utility to claim the RECs arising from rooftop solar systems, then this *may* (depending on the price of the RECs) result in less additions in rates due to rooftop solar, which avoids the social problem of cross-subsidization. However, this policy will also result in the utility investing less in its own solar, which means less $CO_2$ emissions prevented, and thus less help in achieving the U.S.’s carbon emissions targets.

The second question for the government concerns the allowance of special rate plans for utilities' rooftop solar customers. The government's acceptance or rejection of such rate plan proposals should be informed by the use and price of RECs. If no RECs are being received by the utility, then rate increases will occur, which is socially problematic from the government's point of view. In such a scenario, the special rate plans seem justified. On the other hand, if the RECs of rooftop solar systems *are* being claimed by the utility and at a sufficiently low price, then an increase in the monthly bills of rooftop solar customers would be unnecessary. This is because the avoided costs are almost as large as the revenues lost in this scenario. For example, in the 'all RECs for free' scenario, introducing SRP's new special rate plan (which increases the monthly bills of an average solar customers by $50) would result in SRP temporarily making an overall profit as a result of rooftop solar diffusion, because they avoid many costs and also achieve higher revenue from the new rate plan. Nonetheless, even in this scenario, the utility's avoided costs are eventually outweighed by the lost revenues caused by the growing stock of rooftop solar systems.

Perhaps the main problem with these special rate plans is that they may have a negative effect on rooftop solar diffusion. For example, simulations show that if the tax credit is not renewed, and if SRP's new rate plan for solar customers was introduced, then the model projects that rooftop solar installations would drop to zero for all of 2016. Although installations would pick up again from 2017 onwards, as global PV costs continue to decline, the overall stock of rooftop solar would be reduced significantly (from 1090 MWs in 2030 in Scenario 1, to 282 MWs in this scenario).

In addition to discouraging rooftop solar diffusion, SRP's proposed rate plan could have another downside – it seeks to guarantee cost recovery by charging higher fixed costs and proportionately lower variable costs (particularly at off-peak times) [18]. These lower variable costs (i.e. the price per kWh used) could discourage energy efficiency, which would have a negative environmental effect. It could also have a disproportionately negative effect on low-usage rooftop solar households (many of whom may be lower income households), as the increased fixed costs would increase bills more noticeably.

The third and last question for the government concerns the renewal of the tax credit after 2016. State policy makers may wonder if this tax credit could be more effectively used elsewhere. If utilities are claiming the RECs of rooftop solar systems, and if this causes utilities to balance investments in their own solar, then it begs the question – is rooftop solar the most efficient way for a utility to meet its RPS, and should the government be subsidising this way of achieving the RPSs? One argument *against* the renewal of the tax credit would be that this tax credit does not promote the most efficient and socially equitable way of achieving utilities' RPSs. The tax credit policy is not socially equitable because most of the credits go to middle and higher income households [5], and because rooftop solar results in higher rates in almost all of the scenarios studied in the model. Additionally, rooftop solar may not be the most efficient way of achieving an RPS – one study has shown that utility scale solar has been between 30 and 40% cheaper than residential scale solar, per installed MW [46]. Thus, one may argue that state subsidies would be more efficiently used if they were solely directed at larger scale solar projects. This is because, firstly, it would avoid the cross-subsidization problem. Secondly, it may still encourage solar diffusion by allowing the government to set higher RPS standards (and thus prevent more $CO_2$ emissions), seeing as the utility is now receiving more help to achieve its goal (after the tax credit 'budget' has been redirected from residential to utility scale solar) and is doing so with the benefits of economies of scale (because the RPS is being achieved through large scale solar rather than small scale rooftop solar).

However, the above arguments against the renewal of the tax credit for rooftop solar ignore two things. Firstly, they do not consider the potential benefits to the grid that distributed generation sources may bring. Such benefits have been ignored in this study, due to a lack of clear frameworks for calculating them [37]. Secondly, these arguments ignore the fact that the diffusion of distributed generation resources is based on customer choice, which may be the most effective way of bringing about greater diffusion of renewables. Indeed, looking at Germany, one of the most successful countries in terms of diffusion of renewables, it is interesting to note that in 2013 over half of the capacity in their two largest renewable sources of energy (wind and solar) was owned by individuals, farmers and industry actors, whilst just 5% was owned by big utilities and 7% by regional/municipal utilities [33]. Thus it is clear that distributed customer-owned generation, driven by the power of customer choice and government subsidies, has been a major factor in Germany's highly successful renewable energy transition. Following from this, environmentalists may argue that the government should focus more on stimulating the demand for renewables from a grass-roots basis, i.e. via the choices of individual households and small-scale businesses. Indeed, it could be argued that large-scale industry actors such as utilities cannot be relied on to make the investments necessary to combat climate change.

### Is there a better way to diffuse solar power?

All of the policy options discussed above have some trade-offs between rate increases and $CO_2$ emissions prevented. Thus it is natural to ask, is there any policy that could avoid such trade-offs? There may be. From my perspective, the best way to diffuse solar technology would be to encourage/subsidize community scale solar projects. Such projects already exist, and are usually offered by utilities. The utility's customers may participate in the solar project by 'contributing either an up-front or ongoing payment to support a solar project. In exchange, customers receive a payment or credit on their electric bills that is proportional to 1) their contribution and 2) how much electricity the solar project produces' (Page 8, from reference [49]).

There are five reasons for which I feel that this is the best way to diffuse solar technology. Firstly, it allows all electric customers (regardless of whether they live in a home or an apartment) an equal opportunity to avail of solar energy. This would alleviate the cross-subsidization problem. Secondly, the utility should be able to benefit from any profits to be made from such projects, which should allow them to charge lower rates. Thirdly, these medium/large solar projects will benefit from economies of scale and reduced administration costs, keeping the costs per MW installed lower, thus making solar energy more competitive with fossil fuel based energy. Fourthly, if the solar plants can be located close to the point of consumption, then this will reduce load losses on the grid. It will also not require grid updates to accommodate a two-way flow of electricity, seeing as the electricity would only flow from the plant to the point of consumption. Lastly, this way of encouraging diffusion of solar still relies on the powerful force of consumer choice, which in the context of Germany appears to have been a major force in the success of their transition to renewable energies.

# References


1. U.S. Energy Information Administration. What is U.S. electricity generation by energy source? (2015). at <http://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3>

2. Wiser, R., Capper, P. & Darghouth, N. Financial Impacts of Net-Metered PV on Utilities and Ratepayers: A Scoping Study of Two Prototypical U.S. Utilities. (2014). at <http://emp.lbl.gov/sites/all/files/LBNL PV Business Models Report_no report number (Sept 25 revision).pdf>

3. U.S. Energy Information Administration. EIA projects modest needs for new electric generation capacity. (2014). at <http://www.eia.gov/todayinenergy/detail.cfm?id=17131>

4. Salt River Project. Proposed Adjustments To SRP's Standard Electric Price Plans Effective With Tthe April 2015 Billing Cycle. (2014). at <http://www.srpnet.com/prices/priceprocess/pdfx/BlueBook.pdf>

5. Hernandez, M. Solar Power to the People: The Rise of Rooftop Solar Among the Middle Class | Center for American Progress. (2013). at <https://www.americanprogress.org/issues/green/report/2013/10/21/76013/solar-power-to-the-people-the-rise-of-rooftop-solar-among-the-middle-class/>

6. Randazzo, R. APS asks to raise solar fees. (2015). at <http://www.azcentral.com/story/money/business/2015/04/02/aps-asks-raise-solar-fees/70848750/>

7. Uhlenhuth, K. Kansas utility targets solar customers for higher rate. (2015). at <http://midwestenergynews.com/2015/03/24/kansas-utility-targets-solar-customers-for-higher-rate/>

8. Randazzo, R. Arizona regulators: APS to ask for higher solar fees. (2015). at <http://www.azcentral.com/story/money/business/2015/03/13/regulators-expect-aps-ask-higher-solar-fees/70283120/>

9. Randazzo, R. SRP board OKs rate hike, new fees for solar customers. (2015). at <http://www.azcentral.com/story/money/business/2015/02/26/srp-board-oks-rate-hike-new-fees-solar-customers/24086473/>

10. Solar City. Our response to anti-competitive behavior in Arizona. (2015). at <http://blog.solarcity.com/our-response-to-anti-competitive-behavior-in-arizona>

11. Chamerlain, J. & Lyons, T. Review of Proposed Adjustments to Salt River Project's Standard Electric Price Plans. (2014). at <http://www.srpnet.com/prices/priceprocess/pdfx/Review.pdf>

12. Maassel, M. Current net metering system is unfair. (2015). at <http://www.indystar.com/story/opinion/readers/2015/01/25/current-net-metering-system-unfair/22317479/>

13. Burt, H. Helen Burt: Net Energy Metering for solar power users unfair to other PG&E customers - San Jose Mercury News. (2013). at <http://www.mercurynews.com/ci_22475617/helen-burt-net-energy-metering-solar-power-users>

14. Kind, P. Disruptive Challenges: Financial Implications and Strategic Responses to a Changing Retail Electric Business. *Edison Electr. Inst.* (2013).

15. Wood, L. *Getting Solar Pricing Right*. (2014). at <http://www.edisonfoundation.net/iei/Documents/IEI_TheEdge_Sept-Oct2014.pdf>

16. J. Bank, B. Mather, J. Keller, and M. C. High Penetration Photovoltaic Case Study Report. *National Renewable Energy Laboratory* (2013). at <http://www.nrel.gov/docs/fy13osti/54742.pdf>

17. Blackburn, G., Magee, C. & Rai, V. Solar Valuation and the Modern Utility's Expansion into Distributed Generation. *Electr. J.* **27,** 18–32 (2014).

18. NERA Economic Consulting. Review of Salt River Project's Proposed Residential Customer Generation Price Plan. (2014). at <http://www.srpnet.com/prices/priceprocess/pdfx/NERAReview.pdf>

19. Lazar, J. *Electricity Regulation in the US: A Guide*. (2011). at <http://books.google.co.uk/books/about/Electricity_Regulation_in_the_US.html?id=pAEkygAACAAJ&pgis=1>

20. Massachusets Institute of Technology. *The Future of the Electric Grid. Electrical Engineering* (2011). doi:ISBN 978-0-9828008-6-7

21. Arizona Public Service. E-Docket of Application of Arizona Public Service Company For Approval of Net Metering Cost Shift Solution. (2013). at <http://images.edocket.azcc.gov/docketpdf/0000146792.pdf>

22. Arizona Public Service. APS - Adjustors. (2015). at <https://www.aps.com/en/business/accountservices/serviceplans/Pages/adjustors.aspx>

23. Arizona Corporation Commission. Arizona Public Service Company - Application for Approval of Annual Lost Fixed Cost Recovery Mechanism Adjustment. (2013). at <http://images.edocket.azcc.gov/docketpdf/0000142150.pdf>

24. McCracken, R. Energy Economist: tough times for European utilities may have a lesson for the US « The Barrel Blog. (2013). at <http://blogs.platts.com/2013/11/22/ee-nov13/>

25. Conrad, R. S. Electric Utilities: The American Way vs Germany and Australia | Conrad's Utility Investor. (2014). at <https://conradsutilityinvestor.com/electric-utilities-the-american-way-vs-germany-and-australia/>

26. Lacey, S. This Is What the Utility Death Spiral Looks Like : Greentech Media. (2014). at <http://www.greentechmedia.com/articles/read/this-is-what-the-utility-death-spiral-looks-like>

27. Pearson, M. The 'Utility Death Spiral'? | WHEB. (2014). at <http://www.whebgroup.com/the-utility-death-spiral/>

28. RWE. RWE Statement 2013. *Statement on rwe.com* (2013). at <http://www.rwe.com/web/cms/en/110504/rwe/investor-relations/news/news-ad-hoc-statements/?pmid=4009732>

29. Bryant, C. Solar energy boom takes shine off RWE. *FT.com* (2013). at <http://www.ft.com/intl/cms/s/0/91afaaf0-04a3-11e3-9e71-00144feab7de.html#axzz3ZTXvFxM8>

30. Schlandt, J. Germany mulls support for fossil fuel power plants. (2014). at <http://www.cleanenergywire.org/dossiers/power-market-and-energy-transition>

31. Frondel, M., Ritter, N., Schmidt, C. M. & Vance, C. Economic impacts from the promotion of renewable energy technologies: The German experience. *Energy Policy* **38,** 4048–4056 (2010).

32. Eurostat. Energy price statistics. (2015). at <http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_price_statistics#Electricity_prices_for_household_consumers>

33. Morris, C. Half of Germany's 63,000 Megawatts of Renewable Energy is Locally Owned | Institute for Local Self-Reliance. *energytransiiton.de* (2013). at <http://ilsr.org/germanys-63000-megawatts-renewable-energy-locally-owned/>

34. National Renewable Energy Laboratory. *The Western Wind and Solar Integration Study Phase 2: Executive Summary*. (2013). at <http://www.nrel.gov/docs/fy13osti/58798.pdf>

35. Hansen, L. & Lacy, V. A review of solar pv benefit & cost studies. 1–59 (2013).

36. Grace, W. Exploring the Death Spiral - A system dynamics model of the South West Interconnected System. *AUDRC Laboratory* (2014). at <http://www.audrc.org/wp-content/uploads/2014/11/141121_LAB_grace.pdf>

37. Wood, L. Getting Solar Pricing Right. (2014). at <http://www.edisonfoundation.net/iei/Documents/IEI_TheEdge_Sept-Oct2014.pdf>

38. Database of State Incentives for Renewables & Efficiency. Residential Renewable Energy Tax Credit. (2015). at <http://programs.dsireusa.org/system/program/detail/1235>

39. Palmer, J., Sorda, G. & Madlener, R. *Modeling the Diffusion of Residential Photovoltaic Systems in Italy: An Agent-based Simulation*. (2013). at <http://poseidon01.ssrn.com/delivery.php?ID=391084087124086004073108110118072119041027020035083029074065024002112117093005005101106062010057062109039083004001005104081087025060001076032090086124076089005030031042053083121116069009001083109027126001009065 11>

40. Bass, F. M. A New Product Growth for Model Consumer Durables. *Manage. Sci.* **15,** 215–227 (1969).

41. Radomes, A. A. & Arango, S. Renewable energy technology diffusion: an analysis of photovoltaic-system support schemes in Medellín, Colombia. *J. Clean. Prod.* **92,** (2015).

42. Schelly, C. Residential solar electricity adoption: What motivates, and what matters? A case study of early adopters. *Energy Res. Soc. Sci.* **2,** 183–191 (2014).

43. Barlas, Y. & Kanar, K. Structure-oriented Behavior Tests in Model Validation. in (1999). at <http://www.systemdynamics.org/conferences/1999/PAPERS/PLEN8.PDF>

44. Salt River Project. Standard Electric Price Plans - SRP report for 2015 Billing Cycle. (2015). at <http://www.srpnet.com/prices/priceprocess/pdfx/April2015RatebookPUBLISHED.pdf>

45. Koss, G. Boom puts spotlight on renewing solar tax break. (2015). at <http://www.jsonline.com/business/boom-puts-spotlight-on-renewing-solar-tax-break-b99483521z1-300407951.html>

46. Feldman, D. *et al. Photovoltaic System Pricing Trends: Historical, Recent, and Near-Term Projections 2013 Edition*. (2013). at <http://www.nrel.gov/docs/fy13osti/60207.pdf>

47. Bebic, J. *Power System Planning: Emerging Practices Suitable for Evaluating the Impact of High-Penetration Photovoltaics*. (2008). at <http://www.nrel.gov/docs/fy08osti/42297.pdf>

48. Evans, A. & James, T. Impact of Solar Generation upon Arizona's Energy (Electricity) Security. (2011). at <http://seidmaninstitute.com/wp-content/uploads/2011/12/Electricity_Security_1111draft.pdf>

49. U.S. Department of Energy Efficiency and Renewable Energy. A Guide to Community Solar - Utility, Private, and Non-profit Project Development. (2010). at <http://www.nrel.gov/docs/fy11osti/49930.pdf>

50. Sullivan, P., Eurek, K. & Margolis, R. Advanced Methods for Incorporating Solar Energy Technologies into Electric Sector Capacity-expansion Models: Literature Review and Analysis. (2014). at <http://www.nrel.gov/docs/fy14osti/61185.pdf>

51. Salt River Project. SRP: Renewable Energy. (2015). at <http://www.srpnet.com/environment/renewable.aspx>

52. National Renewable Energy Laboratory. *Emerging Markets for Renewable Energy Certificates: Opportunities and Challenges*. (2005). at <http://apps3.eere.energy.gov/greenpower/resources/pdfs/37388.pdf>

53. U.S. Energy Information Administration. Arizona State Energy Profile. (2015). at <http://www.eia.gov/state/print.cfm?sid=AZ>

54. U.S. Energy Information Administration. Electric Sales, Revenue, and Average Price. (2015). at <http://www.eia.gov/electricity/sales_revenue_price/>

55. National Renewable Energy Laboratory. Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics. (2012). at <http://www.nrel.gov/docs/fy13osti/56487.pdf>

56. Palmer, J., Sorda, G. & Madlener, R. Modeling the Diffusion of Residential Photovoltaic Systems in Italy: An Agent-based Simulation. (2013). at <https://www.rwth-aachen.de/global/show_document.asp?id=aaaaaaaaaagvwak>

57. Rocky Mountain Institute. Net energy metering, zero net energy and the distributed energy resource future. *RMI* (2012). at <http://www.rmi.org/Content/Files/RMI_PGE_NEM_ZNE_DER_Adapting_Utility_Business_Models_for_the_21st__Century.pdf.pdf>

58. Morris, C. Reality check: massive overcapacity on German power market. (2014). at <http://energytransition.de/2014/04/reality-check-massive-overcapacity-on-german-power-market/>

59. National Renewable Energy Laboratory. What is the energy payback for PV? (2004). at <http://www.nrel.gov/docs/fy04osti/35489.pdf>

60. United States Environmental Protection Agency. Renewable Portfolio Standards. (2014). at <http://www.epa.gov/agstar/tools/funding/renewable.html>

61. Drury, E., Denholm, P. & Margolis, R. Modeling the U . S . Rooftop Photovoltaics Market. in *National Solar Conference 2010, 17-22 May 2010, Phoenix, USA* (2010).

62. Rai, V. & Sigrin, B. Economics of Individual Decision-Making: Buy vs. Lease Differences in the Adoption of Residential Solar. (2012). at <http://www.usaee.org/usaee2012/submissions/OnlineProceedings/120907, Economics of Decision-Making in Residential PV, Rai & Sigrin, USAEE, Nov-12.pdf>

63. U.S. Energy Information Administration. Average Power Plant Operating Expenses for Major U.S. Investor-Owned Electric Utilities. (2014). at <http://www.eia.gov/electricity/annual/html/epa_08_04.html>

# Appendix A – Model Assumptions and Model Boundaries

## What assumptions does the model make?

System dynamics models are highly aggregated and highly simplified representations of reality. As such they are often built upon many assumptions. Such assumptions can be necessary/justifiable based on either (i) the need for simplicity and/or (ii) the lack of available data. The list below describes and justifies the assumptions upon which the model of this study were based:

1. Regarding avoided generation capacity investments; I assume that rooftop solar can only allow SRP to forego investments in its own solar, and not in any of its other types of generation technologies. This assumption is based on the fact that, for reasons of security of supply, it is said to be difficult to determine the extent to which presence of solar capacity can allow utilities to reduce their investments in dispatchable generation technologies such a natural gas or coal plants [50]. This is because the sun may not be shining at the times of peak demand, and so in order to ensure that such demands could be met at all times, utilities would require the same/a similar size stock of dispatchable technologies as they would if there was no solar capacity. Thus for simplicity we assume that rooftop solar can only allow utilities to avoid investments in their own solar, and not in their dispatchable generation technologies.

2. I assume that the only way in which rooftop solar can allow SRP to forego investments in its own solar is if it receives renewable energy certificates for the output of some/all of the privately owned systems.

3. SRP's RPS (which as a public utility is not legally binding) is to meet 20% of its expected demand in 2020 by renewable resources [51]. The goal beyond 2020 has not been stated yet but in the model I make a simple assumption that the goal will be increased to meeting 40% of the demand by renewables by 2030. I assume that SRP wishes to produce half of this renewably generated electricity through solar technology. Thus I assume that the goal for 2020 will be to meet 10% of demand through solar, and by 2030 it will be to meet 20% of demand through solar technology. Changing these assumptions has little effect on the important model variables.

4. I also assume that SRP plan to meet these goals for the years 2020 and 2030 via a number of goals for each year, and that the goals for each year will increase exponentially or linearly (depending on the scenario set by the model user). The justification for this is that solar prices are falling rapidly, and so I presume that SRP will want to make increasing investments as time passes, rather than making the most investments at the beginning of the simulation period, when solar prices are highest.

5. I assume that this goal of meeting a certain percentage of expected demand (i.e. a certain number of MWhs) through solar technology translates into a certain desired level of MWs of solar, in order to be able to produce the necessary MWhs.

6. I assume, for the sake of simplicity, that the only way that SRP can claim RECs from its customers' rooftop solar systems is by buying them. It has also been said that utilities may also claim the RECs from such a system if they provided an incentive for the customer to install the system [52]. This possibility has been ignored in the model because its effect is essentially the same as the utility buying these RECs (i.e. instead of buying the REC, the utility gives an incentive).

7. I assume that in SRP's RPS, it is responsible to meet a certain percentage of total customer demand *minus* the demand that comes from rooftop solar systems from which SRP are *not* claiming RECs. This assumption seems reasonable, seeing as the demand met by such rooftop systems does not come from SRP's generation. However if SRP does claim the RECs from the output of some of these systems, then it can be assumed that this will increase the total MWhs of demand for which they are responsible, seeing as the output of such systems could be considered as SRP's own generation in some sense.

8. I assume that when SRP obtains RECs from rooftop solar, it does so by entering into a contract with the rooftop solar owner. The model also assumes that this contract will last the whole lifetime of the rooftop solar system, and that the price paid for these RECs is not fixed but can vary year to year (depending on the price of RECs set by the model user).

9. I assume that SRP will make their investments in their own solar generation technology with lump sums paid over 1 year.

10. I assume the costs avoided due to rooftop solar increase linearly with greater rooftop solar penetration of the market. Other studies have shown that as the presence of distributed solar resources increases in a market, the costs avoided on behalf of these solar resources does not increase proportionately, but disproportionately [2]. In other words, rooftop solar brings results less and less costs avoided per MW as its presence in the market grows. However, for the sake of simplicity in the model, this dynamic has been ignored.

11. Regarding avoided variable costs, I assume that rooftop solar output allows for avoided variable costs that would have arisen from natural gas plant use only. This is justified by the fact that solar energy usually only displaces use of Natural Gas plants, and not of other generation technologies [34]. This is because Natural Gas plants have the ability to quickly ramp up and down their output, and so can more easily be used in conjunction with the intermittent output of solar than it can with the less agile output of Coal or Nuclear plants. Additionally, in Arizona peak demand happens at the sunniest times of day (largely due to air conditioning use) [53], and at peak times such as these Natural Gas plants are being used to meet the quick spike in demand. Thus because this peak demand happens at the sunniest times of day, when solar output is greatest, I can increase the confidence in our assumption that solar output generally replaces Natural Gas plant output. As such, any increase in solar energy will likely decrease the use of natural gas plants only, and not of the other kinds of plants, such as Coal or Nuclear.

12. I assume that the addition in rates due to rooftop solar diffusion will be calculated by dividing 'SRP's profit lost' by the expected annual kWhs of demand from residential customers. That these lost profits are made up for from residential customers only is not a certainty but a necessary assumption based on lack of information on how exactly SRP's lost profit from rooftop solar diffusion would affect their rates. However, according to APS, Arizona's largest utility, all residential and small business customers are subject to a 'lost fixed cost recovery' charge, which is partly determined by lost profits due to rooftop solar diffusion [22]. APS note that large commercial and industrial customers have current rate structures which already include the recovery of fixed costs, and so are exempt of this charge [22]. Thus I take this to mean that the lost profits (or gains made) due to rooftop in the case of SRP will also be spread over the demand of the residential/small-business sector only.

13. Information on the exact number of residential customers that SRP has could not be found. However data on the fraction of demand that comes from residential customers in the state of Arizona as a whole could be found [54], and this was used to estimate the fraction of demand that came from SRP's residential customers.

14. The lifetime of rooftop solar systems is assumed to be 25 years. Some studies estimate this lifetime to be 30 years [55], whilst others use an estimate of 20 years [56]. As such, the average value of these studies was used.

## What are the Model's boundaries?

Just as every map has an edge, every model must have a boundary. The table below can be used to describe the boundary of this model. It lists the variables in the model which are endogenous (i.e. determined by other variables within the model) and exogenous (i.e. determined by data taken from the perimeter of the model boundary). Issues that are excluded/ignored by the model (outside of the boundary) are also listed.

| Endogenous | Exogenous | Excluded |
|---|---|---|
| -SRP customers installing rooftop solar<br><br>-Annual SRP revenues lost due to rooftop solar<br><br>-SRP profits lost due to rooftop solar<br><br>-Addition in SRP's rates due to rooftop solar<br><br>-Expected savings from rooftop solar<br><br>-Overall perceived installed cost per MW of rooftop solar (affected by the stock of rooftop solar in SRP's service area)<br><br>-SRP's own stock of solar after the effects of rooftop solar | -SRP's Base Case Rates<br><br>-Overall electricity demand in SRP's service area (including demand that was/will be met by rooftop solar)<br><br>-Expected annual MWhs produced per MW of solar in Arizona<br><br>-Growth rate of Arizona's electric customers<br><br>-Time to install rooftop solar<br><br>-Adoption from WOM fraction<br><br>-Contact rate (between solar adopters and non-adopters) | -Change in SRP's grid costs and load losses due to rooftop solar<br><br>-Effect of battery storage technology on rooftop solar's diffusion and effect on SRP profits<br><br>-Effect of time-of-use plans on SRP's profits lost due to rooftop solar<br><br>-Effects of rooftop solar on the economy in general (jobs created)<br><br>-Effects of SRP's lost profits on its ROE[xiv] and shareholder earnings[xv]<br><br>-Effects of SRP's lost profits on the rating of their bonds |

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[xiv] Note that if ROE goes down due to SRP's lost profits, SRP's investors may deem their investment more risky and thus demand a higher return. This in turn will have a negative effect on SRP's profits, resulting in another vicious loop between lost profits and demands for higher return from investors. This loop is ignored in the model.

[xv] In one study, shareholder earnings is said to be more affected by rooftop solar diffusion than both return on equity and utility rates. This is because of 'deferred capital expenditures that would otherwise generate earnings for shareholders' (page ix of reference [2]).

| | | |
|---|---|---|
| -Annual SRP capacity investment costs avoided due to rooftop solar<br><br>-Annual SRP variable costs avoided due to SRP solar<br><br>-$CO_2$ emissions prevented due to rooftop solar | -Average MWs installed per rooftop solar adopter<br><br>-Historical and projected cost per MW of installed residential solar<br><br>-Historical and projected cost per MW of utility scale solar.<br><br>-Years between rooftop solar installation and receiving contract for RECs<br><br>-Price of RECs to claim 1MWh worth of solar output<br><br>-SRP's solar renewable portfolio standard for each year<br><br>-Variable costs per MWh of natural gas plant use<br><br>-Million tons of $CO_2$ emissions per MWh of natural gas plant generation | -Effects of addition in rates on social inequality among SRP's customers<br><br>-Effects of rooftop solar policies on SRP's public relations<br><br>-How rooftop solar diffusion could be affected by a shortage of supply for PV systems and/or rooftop solar installation companies. |