Using Sensitivity and Scenario Analysis to Examine the Costs and Benefits of Solar to Duke Energy Carolinas

by

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Executive Summary

The issue of compensation for solar energy is a hotly debated national issue, with numerous solar cost/benefit studies commissioned in recent years. This project builds on existing studies by identifying a feasible range of values for the various benefits and costs that can be attributed to solar power. This range of values is then applied to 15-year (2015-2029) solar power projections from Duke Energy Carolina's (DEC) 2014 Integrated Resource Plan to provide a net present value (NPV) of solar power to DEC.

This paper begins by giving context to the solar debate in North Carolina. While in many states there is much controversy around net metering, in North Carolina the more relevant topic is the Avoided Cost rate. Net metering is how distributed generation (DG) customers (i.e., homes and businesses with solar panels on their roofs) are compensated, and Avoided Costs are how utility-scale customers (i.e., solar farms of 20,000+ panels) are compensated. In North Carolina, over 90% of the solar is utility-scale.

The background data for this study comes primarily from three sources: 1) a prior study by Crossborder Energy examining the benefits and costs of solar for North Carolina, 2) a solar integration study for North Carolina carried out by Pacific Northwest National Laboratory, and 3) the 2014 Avoided Cost proceedings from the North Carolina Utilities Commission (NCUC). From these sources, the relevant benefits and costs of solar are identified, as well as a feasible range for the values ($/MWh) for each benefit and cost.

This study deviates from previous studies by using scenario and sensitivity analysis to account for future uncertainty. Since the benefits and costs of solar are controversial, three different scenarios are created, each incorporating different benefit and cost values from the identified feasible range.

Scenario 1 ("All Benefits, All Costs Scenario") incorporates all the benefits and costs of solar. Scenario 2 ("Status Quo Scenario") only incorporates the benefits and costs that are currently approved (or soon to be approved) by the NCUC. Scenario 3 ("2020 Scenario") models a future outcome. It uses the values from Scenario 2, but adds on an Environmental Benefit of solar starting in 2020, when the compliance period for the Environmental Protection Agency's Clean Power Plan begins. Scenario 3 also factors in an Integration Cost for solar to account for grid costs associated with maintaining reliability given higher penetration of solar resources.

In addition to scenario analysis, sensitivity analyses are performed on four key model inputs that are subject to uncertainty. These inputs are the energy output from a solar panel, the proportion of solar that is utility-scale vs. DG, the proportion of DG that is residential vs. commercial, and the discount rate used by DEC. The energy output from a solar panel can vary considerably depending on where it is in the state. The future solar mix in North Carolina could change depending on the policy landscape. Finally, the DEC's discount rate changes from rate case to rate case.

Scenario 1 has a NPV of $164M, Scenario 2 has a NPV of -$188M, and Scenario 3 has a NPV of $41M.

The results of the sensitivity analyses for Scenarios 1 and 3 show that for every 100 kWh per kW capacity increase in energy output, the NPV increase by \$10.7M and \$2.7M, respectively. For Scenario 2, a 100kWh increase in energy output per kW actually results in a \$12.3M decrease in NPV. These counterintuitive results are explained by the fact that both costs and benefits in the model are based on production. If the costs of solar are higher than the benefits of solar, increased production is actually detrimental for DEC since they are paying the costs on a per kWh basis and receiving benefits on a per kWh basis.

Every 1% increase in discount rate results in approximately a 7% decrease, 7% increase, and 8% decrease in NPV for Scenarios 1, 2, and 3, respectively. The sensitivity analyses on the solar mix reveals that changes in proportion of utility-scale vs. DG solar have a much greater impact on NPV than changes in the proportion of residential DG vs. commercial DG. This is due to the low amount of DG solar in the state (~6%). For Scenario 1, the percentage of DG in the state can reach 81.7% before overall NPV is negative. For Scenario 3, the point where NPV becomes negative is 27.6%. These results can be attributed to the fact that DG solar is more expensive to DEC than utility-scale solar.

This paper concludes with the following points/recommendations:

- Scenario 2 shows that the Status Quo is a net negative NPV for solar energy to DEC. However, Scenarios 1 and 3 show that when you factor in additional benefits and costs of solar, the NPV becomes positive. These findings highlight the need for the NCUC to recognize all the benefits and costs of solar, which the commission has already acknowledged in its recent Order Setting Avoided Cost Parameters (12/31/14).
- In addition to recognizing the additional benefits and costs of solar, the NCUC should open up proceedings to put values on the benefits and costs of solar. This is already being piloted in Minnesota and in the city of Austin, TX. These proceedings should have transparent calculations so that stakeholders can see the methodology underlying the values.
- Nationally, solar energy is a flourishing job market. Increasing solar energy in North Carolina could give a boost to the state's economy. By not properly compensating solar developers with a rate that incorporates all the benefits and costs of solar, we run the risk of losing these developers and their associated jobs to neighboring states.

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Introduction

Overview

North Carolina currently boasts 722 MW of installed solar PV, of which over 70% has been installed since 2013 (SEIA, 2014). With this increase, North Carolina is now ranked 4th in the nation for installed solar capacity, behind California, Arizona, and New Jersey. The growth in solar can be attributed mostly to two factors: favorable policies in North Carolina and the declining cost of solar infrastructure. This paper will examine solar policies in North Carolina.

The approach this paper takes in examining solar policies for North Carolina is to focus on utility commission rules that pertain to how solar power producers are compensated. These rules are the Avoided Cost rates paid to utility-scale solar power producers, and net metering rates paid to residential and small commercial rooftop solar customers. This paper explores whether these rates are appropriately compensating solar energy after considering all its benefits and costs. Because there is uncertainty around how to value the benefits and costs of solar, this paper incorporates both scenario and sensitivity analyses to previously documented values (Crossborder Energy, 2013; Pacific Northwest National Laboratory, 2014; North Carolina Utilities Commission, 2014).

The scope of this paper is limited to the service territory of Duke Energy Carolinas (DEC), shown in Figure 1. There are two other major investor-owned electric utilities (IOUs) in North Carolina: Duke Energy Progress (DEP) and Dominion North Carolina Power (DNCP) (North Carolina Utilities Commission, 2015). While both of these utilities also deal with policy issues related to solar compensation for North Carolina customers, DEC serves the most customers (Carolina Country Magazine, 2013), and thus was the focus for this analysis.

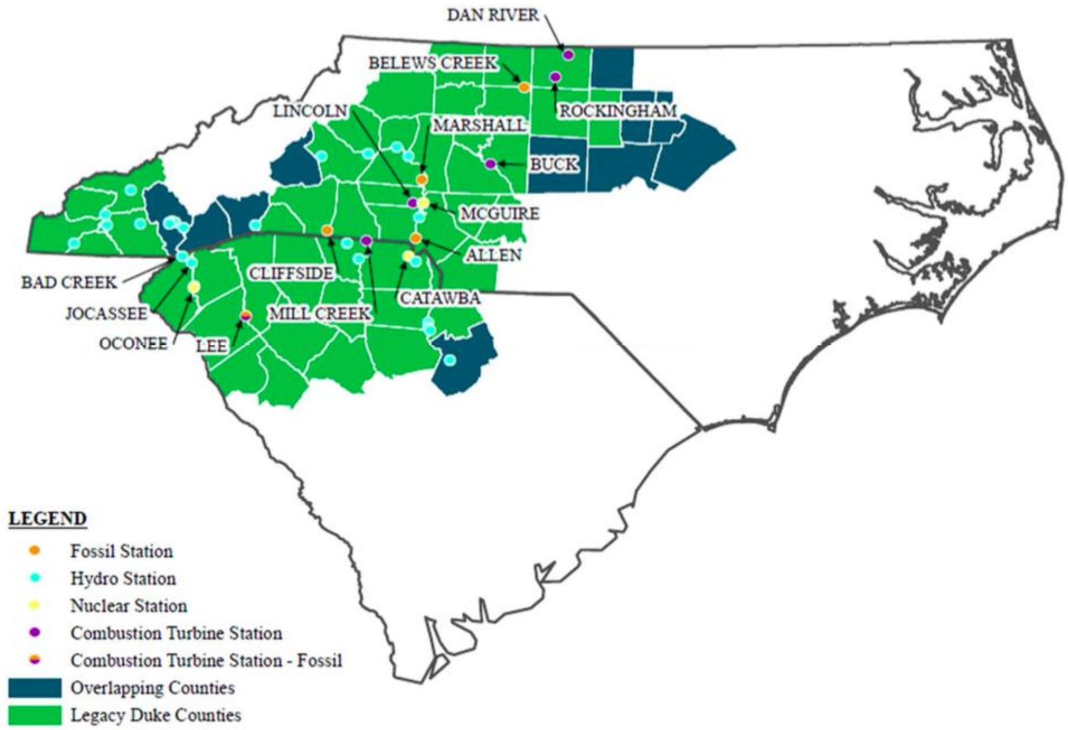

Figure 1. DEC's Service Territory ***Source: Duke Energy Carolinas (DEC), 2014***

Solar Power in North Carolina

In 2007, when the North Carolina Legislature passed Senate Bill 3 (SB3), it became the 25th state to enact a Renewable Portfolio Standard (RPS) (NCSEA, 2012). Under the state's Renewable Energy and Energy Efficiency Portfolio Standard (REPS), IOUs in North Carolina are required to supply a percentage of retail electricity sales from clean energy (see Table 1). This requirement is a major reason for the burgeoning solar industry in North Carolina. While the REPS requirement can be met through a number of avenues (including energy efficiency), it does contain a separate "solar carve out." This solar carve out requires that a percentage of the REPS be met from solar photovoltaic (PV) or solar hot water technologies.

	2015	2016	2017	2018	2019	2020	2021 - 2029
SB3 REPS Requirement	6.00%	6.00%	6.00%	10.00%	10.00%	10.00%	12.50%
Solar Carve Out	0.14%	0.14%	0.14%	0.20%	0.20%	0.20%	0.20%

Table 1. NC REPS Requirement, 2015-2029 ***Source: Duke Energy Carolinas (DEC), 2014***

Before delving too much further into solar in North Carolina, we should examine the characteristics of solar in the state.

North Carolina's Solar Mix

The solar mix in North Carolina is quite different from the solar mix in other states. While in other states, much of the new solar capacity has come about as a result of homes and small commercial businesses installing solar on their rooftops, in North Carolina the majority of the solar has come about as a result of utility-scale solar farms (SEIA, 2014). For the purposes of this paper, we will define rooftop solar systems on homes (<20 kW) and small businesses (<250 kW) as distributed generation, or DG. Utility-scale solar will be defined as solar arrays that are on large parcels of land that are in the range of 2 MW – 5 MW. In email correspondence with the

North Carolina Utilities Commission, public staff member Jay Lucas stated that the solar currently online in Duke Energy Carolinas' service territory "is mostly utility scale (2 MW_{AC} or greater). I estimate that fewer than 30 MW is distributed, mostly constructed by residential customers." (Jay Lucas, personal communication, February 25, 2015). To understand the reasons why solar in North Carolina is mostly utility-scale, we need to dig a little further into some of the regulatory and policy issues surrounding solar. A big catalyst for the large build-out of utility-scale solar in North Carolina is the Public Utilities Regulatory Policies Act (PURPA).

Policy Background for Utility-Scale Solar in NC: PURPA

In 1978, PURPA was passed as part of the National Energy Act. The catalyst for PURPA was the series of energy crises that affected the United States and other industrialized nations during the 1970s. In response to an inconsistent oil supply and rising oil costs from Middle East suppliers, the Carter Administration made it a priority to lead the US towards energy independence. PURPA attempted to achieve this by: 1) promoting energy conservation/energy efficiency, and 2) encouraging domestic energy production from generators other than those owned by electric utilities. One of the strategies to spur domestic energy production was to require utilities to purchase power from "qualifying facilities" (QFs), so long as the cost of that power was less than the utilities "Avoided Costs" from having to producing their own power or purchase power from another supplier. On top of requiring utilities to purchase power from QFs, PURPA required utilities to both provide back-up power to and interconnect with QFs (Electric Power Supply Association, 2015).

The Federal Energy Regulatory Commission (FERC) divides QFs into two categories: small power production facilities, and cogeneration facilities (Federal Energy Regulatory Commission, 2012). The small power production facilities are defined as having a capacity of 80 MW or less and being powered primarily by one of the following: hydro, wind, solar, biomass, waste, or geothermal.

For utilities that are subject to state jurisdiction (i.e., DEC, DEP, DNCP), FERC has delegated implementation of the rules on how to compensate QFs to the state regulatory authorities. In North Carolina, the rules are determined in biennial Avoided Cost proceedings.

Policy Background for Utility-Scale Solar in NC – NCUC's Avoided Cost Proceedings

Every two years, the NCUC holds Avoided Cost proceedings where it considers opinions of various stakeholders interested in the Avoided Cost rates. Avoided Cost rates are defined as the marginal cost for the utility to produce one more unit of power (Independent Energy Producers Association, 2015). As mentioned in the previous section, utilities are required to pay this rate to QFs. In North Carolina, QFs are defined more strictly than how FERC defines QFs. Before 1985, the size limit for QFs in North Carolina was 80 MW (North Carolina Utilities Commission, 2015, p. 11), which aligns with FERC's definition of a QF. At this time, the NCUC thought it prudent to incentivize renewable energy developers, who were new to the energy industry and lacked the bargaining power to negotiate with large utilities. By making them eligible for QF status, the NCUC allowed these larger developers to apply for a "standard offer" contract, thus entitling them to contracts based on the Avoided Cost rate and negating the need for negotiating contracts with the utility. As renewable energy developers began to gain some footing and increase bargaining, the NCUC lowered the size cap to 5 MW (North Carolina Utilities Commission, 1984). The 5 MW limit is still applicable today, though there have been recent requests by North Carolina utilities to lower it to 100 kW (Henderson, 2014).

Due to the continued growth of solar in North Carolina, the 2014 Avoided Cost proceedings were especially controversial. Solar developers and renewable energy advocates pushed to expand the definition of a QF, thus making "standard offer" contracts applicable to a wider range of utility-scale solar projects. Additionally, solar advocates sought longer contracts, which would guarantee cash flows for an extended period of time and make financing of solar projects more attractive. The North Carolina utilities, in contrast, are pushing to narrow the definition of QFs so that they can enter into more "negotiated contracts" with solar project developers. By negotiating contracts, the utilities could potentially pay lower rates for solar energy than they do with "standard contracts." Additionally, the utilities are seeking shorter contracts in order to not lock themselves into rates that may be less attractive in ten or fifteen years.

The 2014 Order Setting Avoided Cost Input Parameters (North Carolina Utilities Commission, 2014) was arguably a victory for solar advocates. The NCUC upheld the 5 MW limit for QFs (but did not raise it to 10 MW), declared that utilities continue to offer standard contracts up to 15 years (but did not increase the term to 20 years), and recognized the avoided fuel hedging benefits of solar. The Order also stated that there are various costs and/or benefits associated with increased renewables in the utilities' energy mix, and that these costs/benefits should be examined in a more comprehensive solar integration study. These second part of this paper attempts to delve further into some of the applicable costs and benefits of solar to DEC, and uses both scenario and sensitivity analyses to account for uncertainty in these values.

Policy Background for Rooftop Solar in NC – Net Metering

Net metering makes solar financially viable for residential and small commercial customers in North Carolina. Net metering is an energy policy whereby customers who generate their own electricity using solar panels or other renewable technologies can transfer that energy back onto the electricity grid, offsetting their own electricity costs. Currently, over 40 states have net metering policies (SEIA, 2013). The policies in states vary significantly, including differences in individual system capacity limit, aggregate system capacity limit, eligible customer types, eligible system types, treatment of net excess generation, payment for net excess generation, and ownership of renewable energy certificates (RECs) associated with customer generation (DSIRE, 2012). RECs are the property rights to the environmental, social, and other nonpower qualities of renewable energy generation (Environmental Protection Agency, 2014). One REC is generated for every 1 Megawatt-hour (MWh) of electricity placed on the grid, and REC markets exist in certain regions of the United States.

The policies for net metering in North Carolina are summarized in Table 2 below.

Applicable Utilities	IOUs
System Capacity Limit	20 kW (residential); 1 MW (non-residential)
Aggregate Capacity Limit	None
Payment for Net Excess Generation	Credited to customer's next bill at retail rate; surrendered to utility at beginning of summer billing season (May 31st)
REC ownership	Utilities own RECs

Table 2. Summary details of North Carolina's net metering policy ***Source: NC Clean Energy Technology Center, 2014***

North Carolina homeowners and businesses with rooftop solar currently get compensated at the retail rate (10.65 ¢/kwh, as of November 2014) for electricity they supply to the grid. However, recently there has been debate over this rate. In a January 2014 meeting with reporters from the Charlotte Observer, Duke Energy Chief Executive Officer Lynn Good announced that Duke Energy would propose a rate change to the North Carolina Public Utilities Commission (Energy & Policy Institute, 2014). This change would reduce the rate Duke Energy pays to residential solar customers from the retail rate to the avoided cost rate (between 5¢/kWh-7¢/kWh). The utility claims that rooftop solar customers are not properly paying for the transmission and distribution infrastructure that they use when the sun is not shining and they must use grid electricity.

Declining cost of solar infrastructure

On top of a favorable policy environment, another reason for the growth of solar in North Carolina is the declining cost of solar systems. In 2010, the U.S. Department of Energy started the SunShot Initiative to help make solar energy fully cost-competitive with traditional energy sources by 2020 (U.S. Department of Energy, 2015). The initiative's goal is to reduce the cost of solar energy to $0.06 per kilowatt-hour (kWh) by 2020. According to the Sunshot Initiative website, solar energy costs are currently about 60% of the way to the goal as the price of utility-scale PV systems have dropped to $0.11/kWh from 2011 prices of $0.21/kWh. Two big reasons for the declining cost of solar systems are the increased supply of solar panels and the reduction in the cost of the raw materials required to build the panels (Kincer, 2014).

Solar Costs and Benefits

While there's no disputing the growth of solar, the question of how much and how fast solar should continue to grow remains unanswered. There are a number of benefits to more solar power, but there are also a number of complications. As solar has grown in other states, various cost-benefit analyses have been undertaken to try and assess whether more solar power is warranted or not (Crossborder Energy, 2013; Crossborder Energy, 2013; Xcel Energy Services, 2013). In September 2013, the Rocky Mountain Institute (RMI) published a meta-analysis that outlines the salient points of the various cost/benefit studies, and provides recommendations for future cost/benefit studies (Rocky Mountain Institute, 2013).

Table 3 shows some of the benefits and costs cited in the RMI meta-analysis, as well as their associated values.

While different studies phrase the benefits and costs in different ways, there are many commonalities across them. Arguably the most important benefit of solar is that it does not contribute to global warming. However, this benefit does not distinguish solar from other renewable energy sources. One of the major advantages of solar power over other renewable energy sources is its ability to interconnect to distribution systems. This feature allows solar power's location to be optimized, such that it can reduce grid congestion (Rocky Mountain Institute, 2014). Another benefit of solar's locational flexibility is its ability to increase grid resiliency. During major system outages, distributed solar could provide power to critical facilities, such as hospitals, shelters, and wastewater treatment facilities (NREL, 2014).

BENEFITS ($/MWh)			
	LOW	**HIGH**	**MID**
Energy	$25.00	$105.00	$65.00
System Losses	$1.00	$25.00	$13.00
Generation Capacity	$10.00	$110.00	$60.00
Transmission & Distribution Capacity	$2.00	$85.00	$43.50
Grid Support Services	$1.00	$10.00	$5.50
Fuel Price Hedge	$3.00	$32.00	$17.50
Market Price Response	$8.00	$45.00	$26.50
Security Risk	$8.00	$21.00	$14.50
Carbon	$5.00	$22.00	$13.50
Criteria Pollutants	$10.00	$22.00	$16.00
General Environmental	$1.00	$39.00	$20.00
Social	$10.00	$41.00	$25.50
Total	$84.00	$557.00	$320.50
COSTS ($/MWh)			
	LOW	**HIGH**	**MID**
Photovoltaic Technology	$290.00	$350.00	$320.00
Grid Support Services	$1.00	$1.00	$1.00
Solar Penetration Cost	$1.00	$140.00	$70.50
Total	$292.00	$491.00	$391.50

Table 3. Solar Benefits and Costs from RMI Meta-Analysis *Source: Rocky Mountain Institute, 2013*

Studies Assessing Solar in North Carolina

Two studies regarding solar in North Carolina were used as a basis for the research.

Crossborder Study

The Crossborder study was commissioned by the North Carolina Sustainable Energy Association (NCSEA) in order to try and value some of the less obvious benefits of solar. The NCSEA asked Crossborder to replicate the solar cost/benefit methodology they had previously performed in Arizona (Crossborder Energy, 2013). The study looks at the benefits and costs of solar for both utility-scale and DG solar projects, for each of the major North Carolina utilities: DEC, DEP, and DNCP.

The Crossborder study relies on data from the IRPs, avoided costs proceedings, and general rate cases of the North Carolina utilities. To a certain extent, the study also uses data from the regional gas and electric markets in which the utilities operate. The report aims to use publicly available data and transparent calculations so that the methodology is clear.

Because the solar benefits and costs from the Crossborder study were the same benefits and costs used in this paper's analysis, it is necessary to provide insight into the rationale that Crossborder used in calculating their values for the benefits and costs of solar (Tables 4 & 5).

Benefit	Rationale
Avoided Energy	By purchasing energy from utility-scale solar developers or DG customers, utilities avoid having to produce their own energy or buy wholesale energy from another power producer. The marginal resource to be displaced by solar power is gas-fired power generation, and these costs are reflected by DEC's avoided cost rates. The Crossborder study applies a 14% premium to DEC's avoided cost rates in order to account for the time-varying value of solar energy (solar produces significant power during the mid-afternoon hours of peak demand).
Avoided Capacity Value (Utility-Scale)	By purchasing power from utility-scale solar developers or DG customers, utilities defer costs resulting from having to build new power plants and/or procure additional capacity. These Avoided Capacity rates are based on the annualized fixed costs of a new combustion turbine (the "peaker" method), but the methodology is confidential. Though the Avoided Capacity rates themselves are publically available, the Crossborder study attempts to verify them using publicly available data on combustion turbine costs. Through this, Crossborder obtains a higher value for Avoided Capacity than what DEC uses.
Avoided Capacity Value (DG)	The Crossborder study states that behind-the-meter DG, unlike utility-scale solar, reduces the utility's peak demand (net load is reduced). Therefore, DG also reduces the utility's capacity requirement to meet reserve margins, which in North Carolina is 15%. As a result, DG capacity is given a 15% premium over utility-scale capacity.
Hedging Value	The Crossborder study cites that, in 2011-2012, a North Carolina utility incurred costs of \$121M in above-market costs by hedging its gas purchases. These costs effectively increased the price of each MMBtu consumed by \$0.74, resulting in a cost increase of \$0.08/kWh, or \$8/MWh.
Avoided Transmission Costs Value	Both DG and utility-scale solar are generally interconnected with distribution systems, thus reducing use of transmission lines. Reduced use equates to avoided costs both from less wear and tear, and from less maintenance. The Crossborder study estimates this value by calculating marginal transmission capacity costs using the NERA regression method. This method is used by many utilities to estimate their marginal T&D capacity costs.
Avoided Distribution Costs Value (DG only)	The Crossborder study states that DG can reduce peak loads on distribution circuits, reducing the need to upgrade the circuit when it is approaching capacity. In order to estimate values for Avoided Distribution, the Crossborder study relied on a previous study done by the consulting firm E3 for the California Public Utilities Commission. The E3 study based its calculations on marginal distribution costs, and the correlation between solar output and distribution substation peaks.
Environmental Value	The Crossborder study bases this value largely on CO_2 emission costs cited in DEC's IRP. Costs for abating criteria pollutants are thought to already be included in DEC's avoided cost modeling.
Avoided Renewables (DG)	Crossborder estimates the cost of a REC using a range of data, including a North Carolina municipal utility's previous purchase of RECs, DEC and

	DEP REPS compliance filings, and cost premiums from N.C. utilities' green pricing programs. Their final estimated cost of a REC is \$0.01 to \$0.02 cents per kWh, or \$10 to \$20 per MWh. DG reduces the utility's sales, thus lowering the future REPS obligation by the solar output times the applicable REPS percentage (average of 9.6% from 2013-2027). Since the vast majority of DG customers surrender their REC's to the utility, the value of DG to helping the utility meeting its REPS requirement is the value of a REC plus a 9.6% premium.
Avoided Renewables (Utility-Scale)	Since it is assumed that utility-scale solar purchases will include the transfer of RECs, Crossborder's estimated market cost of a REC (\$10-20 per MWh) is the value of utility-scale solar in helping the utility to meet its REPS requirement.

Table 4. Solar Benefits Cited in Crossborder Study ***Source: Crossborder Energy, 2013***

Cost	Rationale
PPA Price (Utility-scale only)	The Crossborder study uses a Lawrence Berkeley National Lab (LBNL) survey of installed costs of utility-scale solar PV as a basis for estimating its costs PPA costs for utility-scale solar in North Carolina. However, since the LBNL study is focused mostly on solar in the western U.S., the Crossborder study adjusts the PPA costs up by 25% to account for the fact that capacity factors in the western U.S. are 20% higher than those in North Carolina. This results in a cost estimate of \$70-\$90 per MWh.
Integration Costs (Utility-scale and DG)	The Crossborder study relies on figures published in studies by Arizona Public Service and Xcel Energy to assume a solar integration cost of \$3 per MWh.
Lost Revenue – Residential (DG only)	Costs based on retail rate credits provided to solar customers through net metering. DEC's residential rate is largely a single rate with some seasonal variation and a fixed monthly charge.
Lost Revenue – Commercial (DG only)	Costs based on retail rate credits provided to solar customers through net metering. DEC's commercial rate is generally a declining block structure rate.

Table 5. Solar Costs Cited in Crossborder Study ***Source: Crossborder Energy, 2013***

The Crossborder study concludes that if North Carolina were to add 400MW of utility-scale solar and 100MW of solar DG, the result would be a \$26M net benefit to ratepayers.

The exact solar benefit and cost values used by the Crossborder Study can be found in Appendix A.

PNNL Study

The PNNL study (Pacific Northwest National Laboratory, 2014) was commissioned by Duke Energy to examine the technical barriers and associated costs posed by the increased penetration of solar, an intermittent resource. A PV penetration range of 2-20% of peak load was chosen. The study found that, though the Duke Energy system was able to maintain reliability standards with a 20% peak load solar penetration, reserve requirements increased, driving up costs. The increased abundance of solar would lead to integration costs ranging from $1.43-$9.82 per MWh, scaling up with higher penetration. Effects of solar on Duke Energy's T&D system were also examined, but those results fall outside the scope of this paper's analysis.

Data & Analysis

Model Overview

The analysis uses an Excel-based model to estimate the costs and benefits of solar to Duke Energy Carolinas. There are three primary sets of data input into the model: 1) Solar benefit/cost values from literature; 2) Model assumptions; and 3) DEC's solar projections from its 2014 IRP (Duke Energy Carolinas (DEC), 2014). Using these inputs, the model produces a net present value (NPV) for the value of the Benefits minus Costs for the years of DEC's planning period, 2015-2029. Appendix B outlines the specific calculations used to calculate the dollar amounts for each benefit and cost. Additionally, Appendix C provides the cash flows for each benefit and cost for each year from 2015-2029. Figure 2 below shows a model schematic.

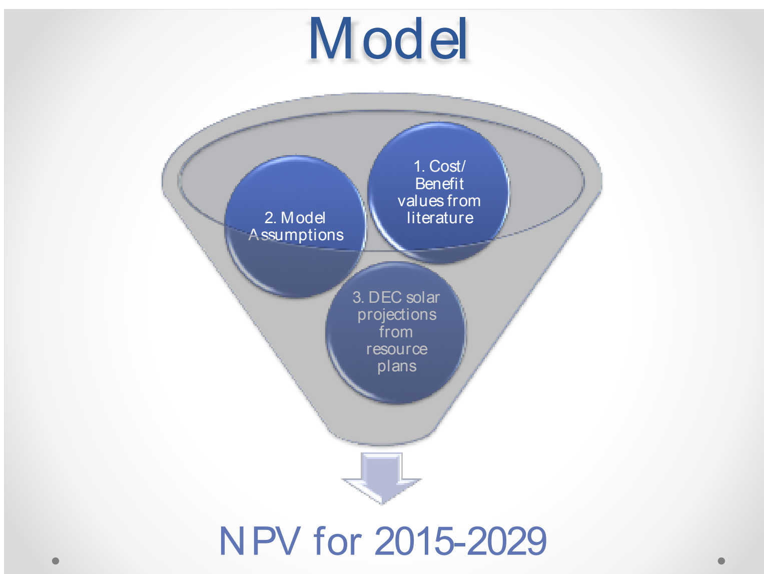

Figure 2. Model Schematic

Input # 1: Solar benefit/cost values from literature

The first input into the model were values for the benefits and costs of solar based on previous studies (Crossborder Energy, 2013; Pacific Northwest National Laboratory, 2014) and DEC's current Avoided Cost rates (Duke Energy Carolinas, 2014). Tables 6 and 7 below outline the benefits and costs, respectively, that were incorporated into the analysis for this project. The tables show a Low, High, and Mid value. The Low and High values are explained in the tables, and the Mid values for all the benefits and costs are the midpoint between the Low and High values.

BENEFITS ($/MWh)				
	Low	High	Mid	Explanation
Avoided Energy	$50.20	$57.00	$53.60	Low is the weighted average of DEC's Avoided Cost Rates; High is the low value in the Crossborder study range
Avoided Capacity Value (DG)	$9.46	$36.76	$23.11	Both Low and High are 15% higher than the Utility-Scale Avoided Capacity rates
Avoided Capacity Value (Utility-Scale)	$8.23	$31.96	$20.10	Low is the weighted average of DEC's Avoided Capacity Rates; High is the high value used in the Crossborder study range
Hedging Value	$0.00	$8.00	$4.00	Low is zero value, High is the value used in Crossborder study
Avoided Transmission Costs Value	$0.00	$10.00	$5.00	Low is low value from Crossborder study range; High is high value from Crossborder study range
Avoided Distribution Costs Value (DG only)	$2.00	$5.00	$3.50	Low is low value from Crossborder study range; High is high value from Crossborder study range
Environmental Value	$4.00	$22.00	$13.00	Low is low value from Crossborder study range; High is high value from Crossborder study range
Avoided Renewables (DG)	$0.96	$22.00	$11.48	Low is low value from Crossborder study range; High is high value from Crossborder study range
Avoided Renewables (Utility-Scale)	$10.00	$20.00	$15.00	Low is low value from Crossborder study range; High is high value from Crossborder study range
Total Benefits (Utility-Scale)	$72.43	$148.96	$110.70	Sum of above values applicable to Utility-Scale
Total Benefits (DG)	$66.62	$160.76	$133.79	Sum of above values applicable to DG

Table 6. Range of Benefit Values Used in Model

COSTS ($/MWh)				
Utility-Scale Costs				
	Low	High	Mid	Explanation
PPA Price	$70.00	$90.00	$80.00	Low is low value from Crossborder study range; High is high value from Crossborder study range
Integration	$1.43	$9.82	$5.63	Low is low value from the PNNL study; High is high value from the PNNL study
Total Costs: Utility-Scale	$71.43	$99.82	$85.63	Sum of above values
DG Costs				
	Low	High	Mid	Explanation
Lost Revenues - Residential	$98.00	$107.00	$102.50	Low is low value from Crossborder study range; High is high value from Crossborder study range
Lost Revenues - Commercial	$77.00	$84.00	$80.50	Low is low value from Crossborder study range; High is high value from Crossborder study range
Integration	$1.43	$9.82	$5.63	Low is low value from the PNNL study; High is high value from the PNNL study
Total Costs - DG Residential	$99.43	$116.82	$108.13	Sum of above values applicable to DG Residential
Total Costs - DG Commercial	$78.43	$93.82	$86.13	Sum of above values applicable to DG Commercial

Table 7. Range of Cost Values Used in Model

These benefits and costs were cited in numerous solar cost/benefit studies that have been performed in other states (Crossborder Energy, 2013; Xcel Energy Services, 2013). Additionally, the most recent Order from the NCUC setting Avoided Cost input parameters mentioned a number of the benefits and costs listed in the tables (North Carolina Utilities Commission, 2014). Specifically, the Order states that including a hedging benefit is appropriate (the amount and time frame are still to be determined). The Order also states that including a value for environmental benefit is not yet appropriate as carbon costs are still highly uncertain, and including solar integration costs are premature pending further studies. However, that fact that these costs and benefits are now being mentioned in Avoided Cost proceeding conversations indicates that their inclusion in further Avoided Cost rates is a real possibility.

The Crossborder study's values were used as the basis for many of the values incorporated into the model for this paper's analysis. The rationale behind Crossborder's chosen values are detailed in the Introduction. There was not sufficient time and resources to take a deep dive into the assumptions behind Crossborder's values, however the study is widely cited in articles and reports, and provides a good starting point for this analysis

In a few cases, Crossborder's values were either not used or were modified. For example, for the Avoided Energy and Avoided Capacity rates, values from the 2014 DEC Avoided Cost tariffs were substituted in to get a value for the Low end of the range. This was done because Crossborder's rates for Avoided Energy and Avoided Capacity rates seemed to be on the high end, and it seemed prudent to use the rates directly from DEC's tariffs in the model as the Low boundary.

For the Avoided Capacity–DG rates, Crossborder set them 15% higher than the Avoided Capacity–Utility-Scale rates. This is due to the fact that DG sits behind the meter and thus reduces the need for DEC to meet its 15% reserve margin.

For the Avoided Hedging Value rates, the value for the low end of the range was set at zero since the Crossborder study only specified one value rather than a range of values.

Finally, the Integration Cost values from the PNNL study were substituted for Crossborder's Integration Cost values since the PNNL study provided a much more robust methodology.

Input # 2: Model Assumptions

The primary assumptions used in the model, as well as their sources, are shown in Table 8 below. The top four assumptions regarding NC's solar mix were based on email correspondence with the NCUC, as detailed in the Introduction section of this report (Jay Lucas, personal communication, February 25, 2015).

DEC's discount rate was found in their 2013 General Rate Case (North Carolina Utilties Commission, 2013).

The energy (kWh) from $1kW_{AC}$ of solar panel assumption was from the Crossborder study.

Input	Value	Source
% of solar that is utility-scale	93.75%	North Carolina Utility Commission (NCUC) email correspondence
% of solar that is DG	6.25%	
% of DG that is residential	80%	
% of DG that is commercial	20%	
DEC discount rate	7.88%	(North Carolina Utilties Commission, 2013)
Energy (kWh) from $1kW_{AC}$	1524	(Crossborder Energy, 2013)

Table 8. Model Assumptions

Input # 3: DEC's Solar Projections from 2014 IRP

The third input into the model was solar projections from DEC's 2014 IRP. The calculations to determine the amount of energy (MWh) produced from both utility-scale solar and DG solar are outlined in the Appendix B.

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Amount Interconnected (MW_{AC})	480	554	572	597	719	869	1009	1139	1265	1381	1498	1605	1702	1754	1681

Table 9. Amount of Solar Projected to be on DEC's System ***Source: Duke Energy Carolinas (DEC), 2014***

Model Scenarios

There is disagreement between solar advocates and utilities about which of solar's benefits and costs should be incorporated into ratemaking. Also, there is debate about the monetary value for each of the benefits and costs. Because of this, the analysis in this paper created three scenarios in which to calculate NPVs. These scenarios are outlined in Table 10 below. The benefit and cost values incorporated into the scenarios are outlined in Table 11 below.

Scenario Descriptions	
Scenario 1	**"All Benefit/All Cost Scenario":** Scenario replicates Crossborder Energy's 2013 study, with slight variations/updates. The avoided energy and avoided capacity values from the Crossborder study were substituted with rates that are currently paid to qualifying facilities by DEC, since the premiums that the Crossborder study applies to these rates did not seem adequately justified. Additionally, the integration cost used by Crossborder was updated with values from PNNL's 2013 Solar Integration Study.
Scenario 2	**"Status Quo Scenario":** Scenario uses values deemed appropriate by the North Carolina Utilities Commission. Specifically, this scenario uses a weighted average of the on-peak and off-peak energy credits and capacity credits paid to qualifying facilities by Duke Energy Carolinas, as specified by their Avoided Cost rate schedule. Values for other solar benefits (i.e., avoided T&D costs, environmental value, etc.) are not included as the Commission considers these benefits to already be encompassed by the energy and capacity credits paid to QFs by DEC. However, a hedging value is included as the Commission recognized the hedging benefits of renewables generation in the most recent Avoided Cost proceedings.
Scenario 3	**"2020 Scenario":** Scenario attempts to model a most likely future outcome. Midpoint values for energy and capacity benefits are used since it is likely that, moving forward, more solar benefits will be recognized. Other regions (Minnesota & Austin, TX) have already begun to recognize and assign value to these benefits. Additionally, an Environmental Value is included starting in 2020, when the compliance period for the EPA's Clean Power Plan will begin. The plan will impose limits (and therefore associated costs) on carbon emissions, thus giving value to the carbon-free generation from solar power. Additionally, this scenario includes an integration cost for solar. The Commission mentions integration costs several times in the most recent Avoided Cost proceedings (North Carolina Utilities Commission, 2014), indicating that its inclusion could be forthcoming. The recent solar integration study by PNNL (commissioned by Duke Energy) calculated an integration cost range of \$1.42 - \$9.82 per MW as more solar comes on the grid. The scenario starts off with a low integration cost in 2015, which then ramps up to the high value starting in 2021 when solar capacity is projected to eclipse 1000 MW.

Table 10. Model Scenario Descriptions

	Scenario 1	Scenario 2	Scenario 3
BENEFITS			
Avoided Energy	Low	Low	Mid
Avoided Generation Capacity (DG)	Low	Low	Mid
Avoided Generation Capacity (Wholesale)	Low	Low	Mid
Hedging Value	High	High	High
Avoided Transmission Costs	Mid	n/a	n/a
Avoided Distribution Costs (DG only)	Mid	n/a	n/a
Environmental Value	Mid	n/a	Mid, starting 2020
Avoided Renewables (DG)	Mid	n/a	n/a
Avoided Renewables (Wholesale)	Mid	n/a	n/a
COSTS			
Capital and O&M/PPA (Wholesale)	Mid	Mid	Mid
Lost Revenues - Residential (DG)	Mid	Mid	Mid
Lost Revenues - Commercial (DG)	Mid	Mid	Mid
Integration (DG and Wholesale)	Mid	n/a	Low, High starting 2021

Table 11. Benefit and Cost Values Incorporated into Three Scenarios

Model Sensitivity Analysis

In addition to the Scenario Analyses, Sensitivity Analyses were performed on key model inputs to account for future uncertainty. For example, as a default, it was assumed that 1 kW_{AC} of solar produces 1524 kWh of energy per year (Crossborder Energy, 2013). However, this value can vary depending on a number of factors, including age of the panel, axial tilt, and geographic location. The model therefore allows for sensitivity analyses on this input.

In terms of the type of solar in North Carolina, the model defaults to a mix of 93.75% utility scale solar, and 6.25% DG (roof-top) solar. Of the DG solar, the default is 80% residential, 20% commercial. As mentioned in the Introduction, all of these inputs are based on rough estimates from email conversations with NCUC staff (Lucas, 2015). Because of the uncertainty of these inputs, the model allows for sensitivity analysis of these parameters as well.

Finally, sensitivity analyses were run on the discount rate allowed to Duke Energy Carolinas as this value can change between rate cases. The default value used in the model is 7.88%, the current rate of return allowed to DEC in the most recent general rate case (North Carolina Utilties Commission, 2013)

The values that were used in sensitivity analysis for the four inputs mentioned above are listed in Table 12 below.

Model Input	Sensitivity Analysis Values
Energy output from 1 kW_{AC}	1024, 1124, 1224, 1324, 1424, **1524**, 1624
% of solar that is distributed (DG)	0%, **6.25%**, 10%, 15%, 25%, 50%, 100%
% of DG solar that is residential	0%, 5%, 10%, 25%, 50%, **80%**, 100%
DEC discount rate	5.88%, 6.88%, **7.88%**, 8.88%, 9.88%, 10.88%, 11.88%

Table 12. Sensitivity Analysis Values (Default values shown in bold)

Results

Scenario NPVs

NPVs are calculated from 2015 – 2029, the planning horizon for Duke Energy Carolina's most recent IRP. Scenario 1 ("All Benefits/All Costs"), which replicates the Crossborder study with some slight modifications, yields a NPV of $163,947,528 during the planning period. Scenario 2 ("Status Quo"), which incorporates values currently accepted by the NCUC, returns a NPV of -$188,098,972. Scenario 3 ("2020 Scenario), which attempts to model a possible future outcome, gives a NPV of $41,404,070. Year-by-year results for the cost and benefit cash flows for all three scenarios can be found in Appendix C.

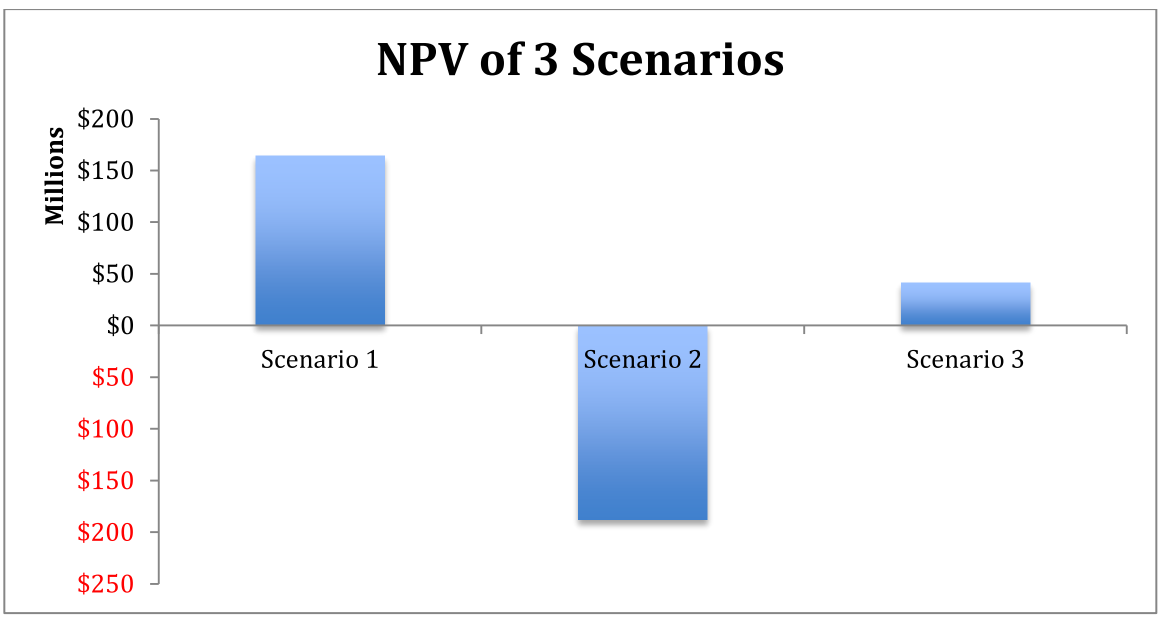

Figure 3. NPVs of Three Scenarios

Scenario 1 Sensitivity Analysis - Results

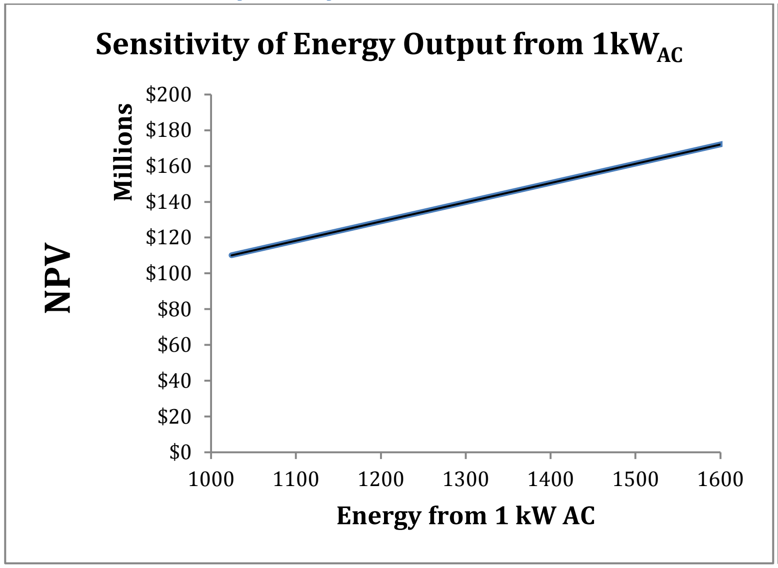

Figure 4. Scenario 1 Sensitivity Analysis - PV Panel Energy Output

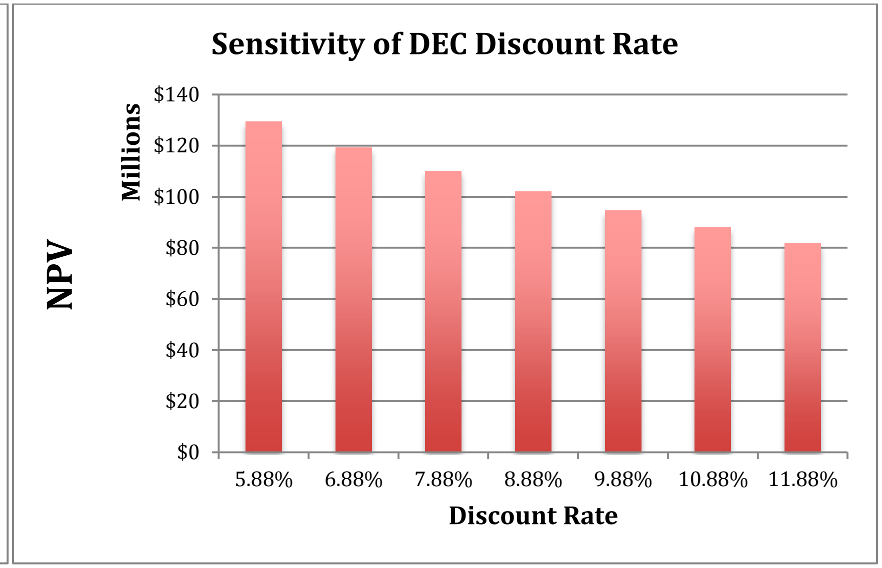

Figure 5. Scenario 1 Sensitivity Analysis – DEC Discount Rate

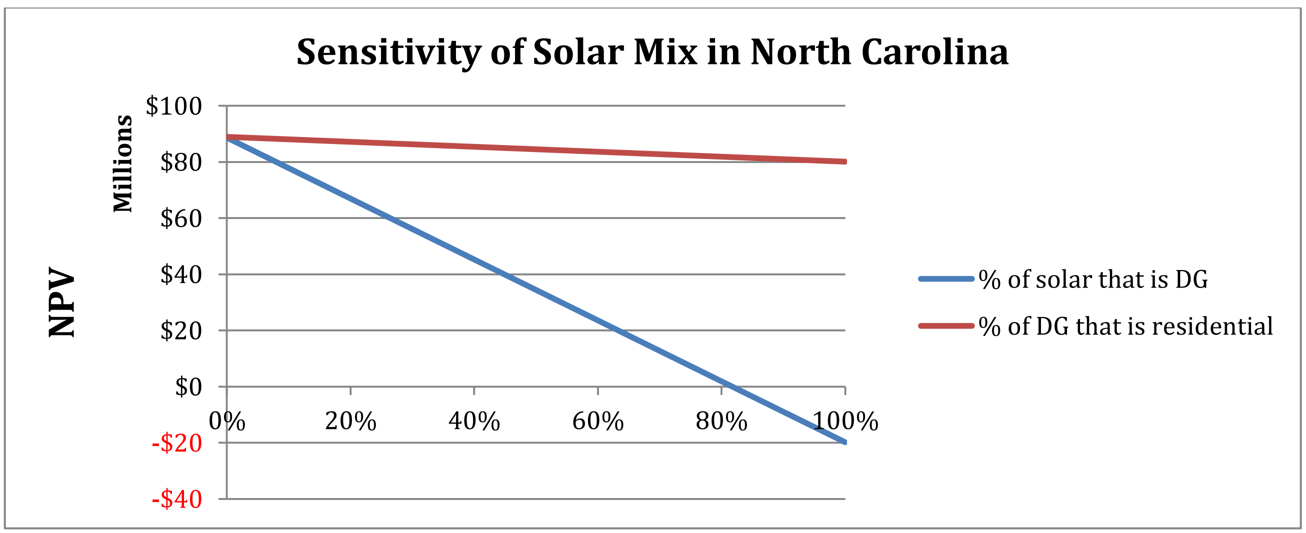

Figure 6. Scenario 1 Sensitivity Analysis - NC Solar Mix

Figures 4 - 6 show the results for the sensitivity analyses performed on Scenario 1's model inputs.

For Scenario 1, the NPV was positive regardless of the energy output from 1kW of solar power. At the low end of the sensitivity analysis (1024 kWh/kW) the NPV was $110M, while at the high end (1624 kWh/kW) the NPV was $175M. Every 100kWh increase in energy output per kW resulted in a $10.7M increase in NPV, scaling linearly.

Figure 3 shows that NPV drops as DEC's discount rate increases. At the lowest discount rate used (5.88%) the NPV was $193M, while at the highest discount rate (11.88%) the NPV was $122M. In the range specified, a 1% increase in discount rate resulted in a 7-8% drop in NPV.

Figure 4 shows the NPVs of solar for DEC given a range of: 1) the percentage of solar that is distributed, and 2) the percentage of distributed solar that is residential. The NPV when DEC's solar is 100% utility-scale was $177M, while the NPV when the solar is 100% distributed (given a default of 80% of DG being residential) was -$39M. The break-even point for the proportion of solar that is DG is 81.7%, above which having more solar be distributed would yield a negative NPV.

Given a default of 93.75% of utility-scale solar (6.75% DG), the NPV of 0% of the DG being residential was $178M, while the NPV of 100% of the DG being residential was $160M. NPV was much less affected by a change in the proportion of residential DG vs. commercial DG than in a change to the proportion of utility-scale vs. distributed generation.

Scenario 2 Sensitivity Analysis – Results

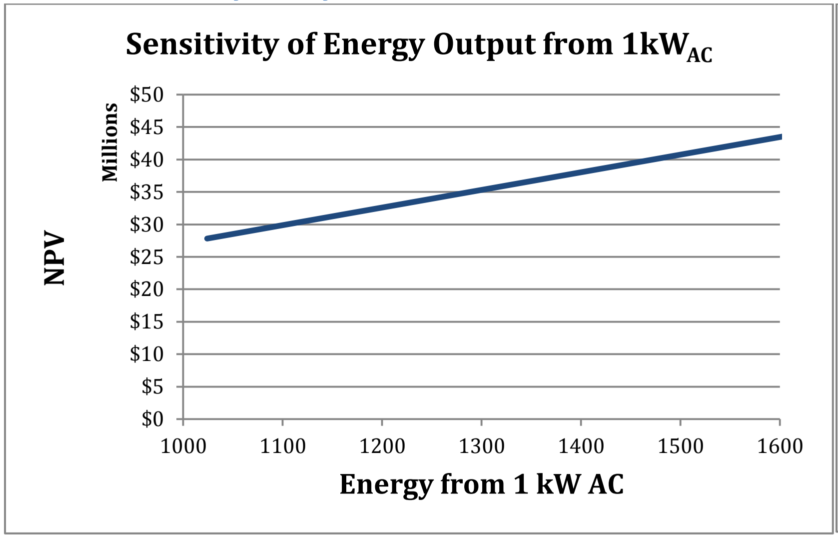

Figure 7. Scenario 2 Sensitivity Analysis – PV Panel Energy Output

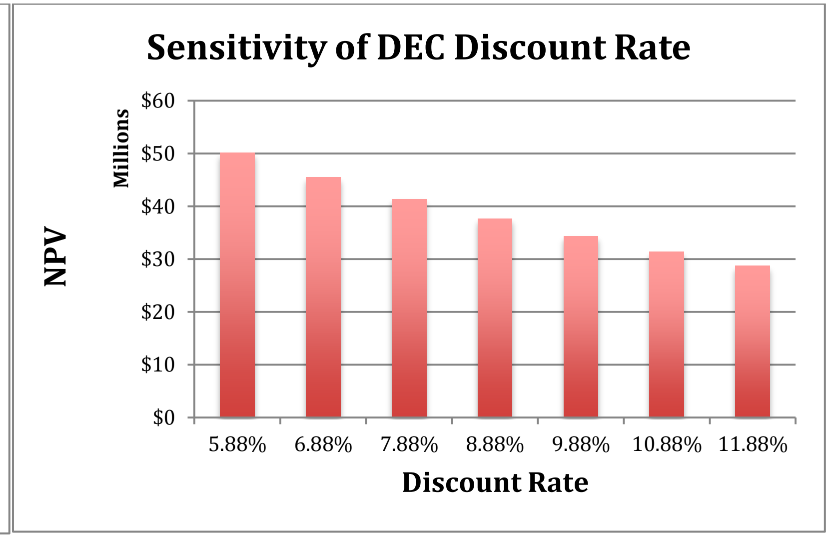

Figure 8. Scenario 2 Sensitivity Analysis - DEC Discount Rate

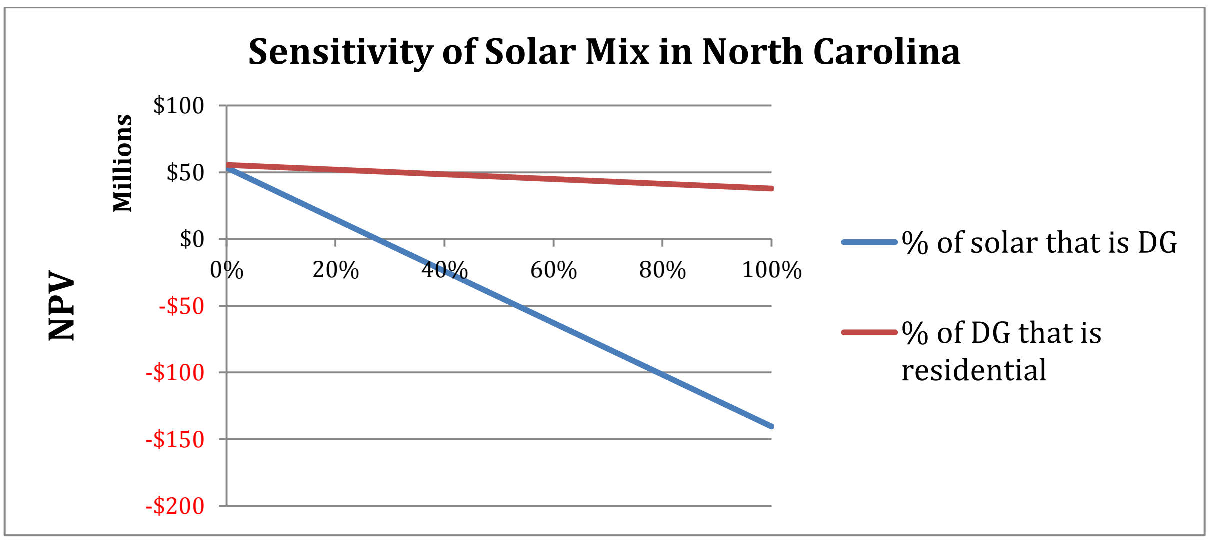

Figure 9. Scenario 2 Sensitivity Analysis - NC Solar Mix

Figures 7 - 9 show the results for the sensitivity analyses performed on Scenario 3's model inputs.

For Scenario 2, the NPV was negative regardless of how much energy 1kW of solar power produced. At the low end of the sensitivity analysis (1024 kWh/kW) the NPV was -$126M, while at the high end (1624 kWh/kW) the NPV was -$200M. Every 100kWh increase in energy output per kW actually resulted in a $12.3M <u>decrease</u> in NPV, scaling linearly. These counterintuitive results can be explained by the fact that both costs and benefits in the model are based on production. If the costs of solar are higher than the benefits of solar, increased production is actually detrimental for DEC since they are paying the costs on a per kWh basis and receiving benefits on a per kWh basis.

Figure 6 shows that NPV improves as DEC's discount rate increases. At the lowest discount rate used (5.88%) the NPV was -$221M, while at the highest discount rate (11.88%) the NPV was -$139M. In the range specified, a 1% increase in discount rate resulted in a 7% to 8% increase in NPV.

Figure 4 shows that NPV for Scenario 2 is negative regardless of the DEC's solar mix. The NPV when DEC's solar is 100% utility-scale was -$391M, while the NPV when the solar is 100% distributed was -$174M.

Given the default of 93.75% of solar being utility-scale (6.75% DG), the NPV of 0% of the DG being residential was -$174M, while the NPV of 100% of the DG being residential was -$191M. Similar to Scenario 1, the NPV was much less affected by a change in the proportion of residential DG vs. commercial DG than in a change to the proportion of utility-scale vs. distributed generation.

Scenario 3 Sensitivity Analysis – Results

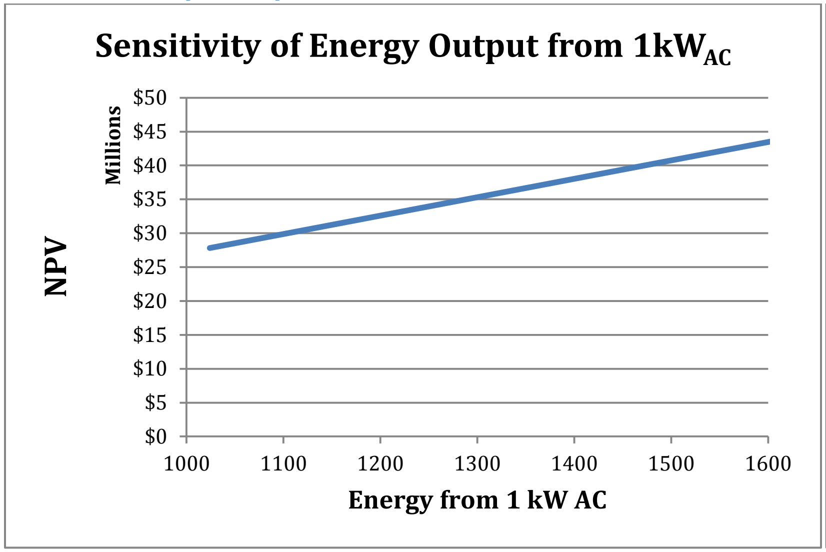

Figure 10. Scenario 3 Sensitivity Analysis – PV Panel Energy Output

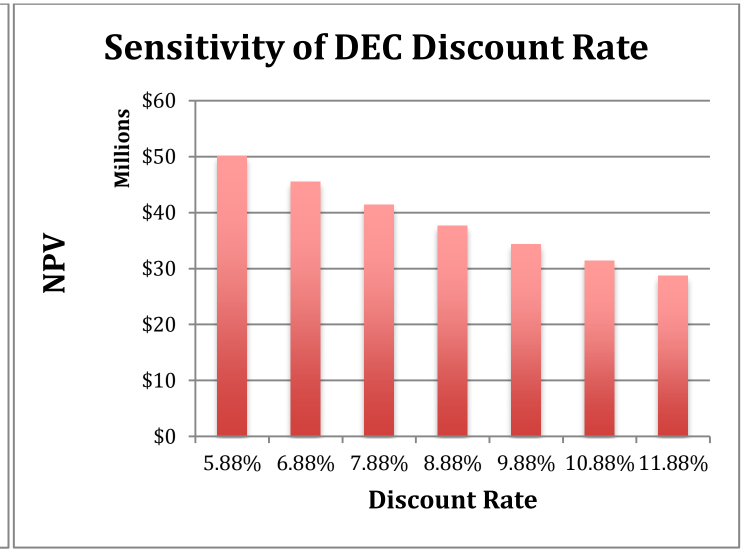

Figure 11. Scenario 3 Sensitivity Analysis - DEC Discount Rate

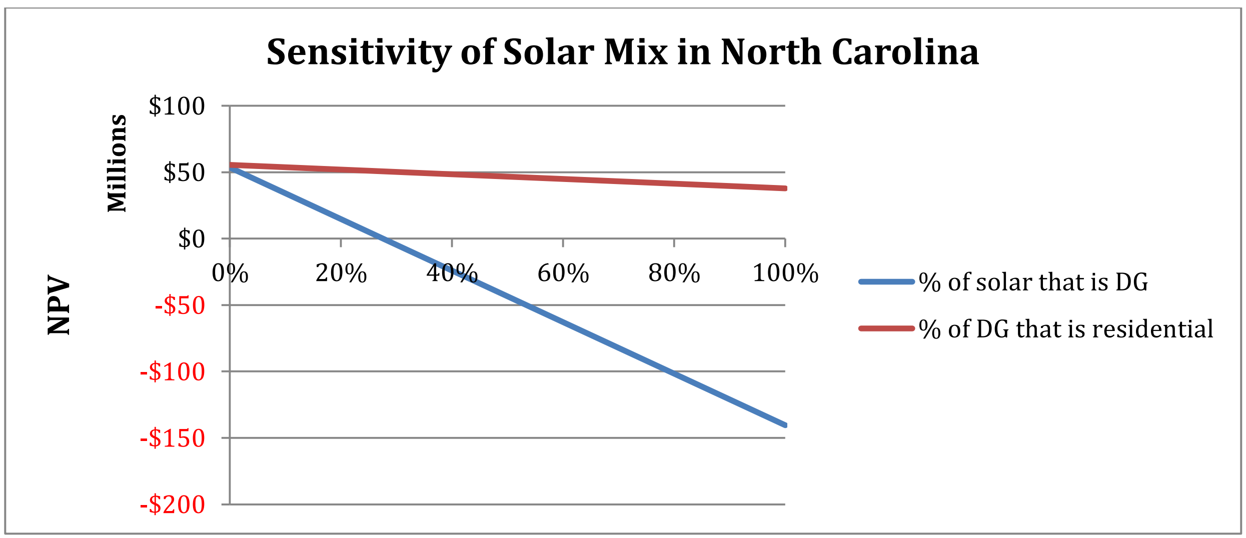

Figure 12. Scenario 3 Sensitivity Analysis - NC Solar Mix

Figures 10 - 12 show the results for the sensitivity analyses performed on Scenario 3's model inputs.

Similar to Scenario 1, Scenario 3's NPV was positive regardless of the energy output from 1kW of solar power. At the low end of the sensitivity analysis (1024 kWh/kW) the NPV was $28M, while at the high end (1624 kWh/kW) the NPV was $44M. Every 100kWh increase in energy output per kW resulted in a $2.7M increase in NPV, scaling linearly.

Figure 9 shows that NPV drops as DEC's discount rate increases. At the lowest discount rate used (5.88%) the NPV was $50M, while at the highest discount rate (11.88%) the NPV was $29M. In the range specified, a 1% increase in discount rate resulted in an 8% to 9% drop in NPV.

Figure 10 shows the NPVs of solar for DEC given a range of: 1) the percentage of solar that is distributed, and 2) the percentage of distributed solar that is residential. The NPV when DEC's solar is 100% utility-scale was $53M, while the NPV when the solar is 100% distributed (given a default of 80% of DG being residential) was -$140M. The break-even point for the proportion of solar that is DG is 27.6%, above which having more solar be distributed would yield a negative NPV.

Given a default of 93.75% of solar being utility-scale (6.75% DG), the NPV of 0% of the DG being residential was $56M, while the NPV of 100% of the DG being residential was $38M. NPV was much less affected by a change in the proportion of residential DG vs. commercial DG than in a change to the proportion of utility-scale vs. distributed.

Discussion and Conclusion

Comparing the NPVs of the three scenarios yields some interesting observations. First, as shown by the negative NPV of Scenario 2, it is clear that current NCUC-approved avoided energy/avoided capacity rates do not do enough to incentivize DEC to pursue more distributed and/or utility-scale solar energy. However, the question of whether or not the NCUC is valuing solar energy appropriately remains unanswered. Given that the REPS requirement includes a solar carve out, it is mandatory that North Carolina utilities procure a certain amount of their generation portfolio from solar resources, regardless of whether or not the incentives are aligned correctly. However, until a more comprehensive valuation study of solar is completed for the state, it likely that solar may not be growing at the rate that is optimal.

The positive NPVs of Scenarios 1 and 3 show that, when additional benefits of solar are monetized and factored into value calculations, the benefits of solar outweigh the costs. This finding is corroborated by the RMI study (Rocky Mountain Institute, 2013). In the fourteen studies that the RMI analysis profiled, twelve of the studies showed the benefits of solar outweighing the costs. The NCUC has already recognized the need for more detailed integration studies, and has requested that these studies be carried out as solar penetration becomes more pervasive (North Carolina Utilities Commission, 2014).

A logical solution to the controversy surrounding solar in North Carolina is for the NCUC to follow the leads of the state of Minnesota and city of Austin, TX in enacting a Value-of-Solar Tariff (VOST) (Clean Power Research, 2014; Clean Power Research, 2006). A VOST is a rate design that assigns a value to each benefit of solar, and then compensates customers with solar installations commensurate with the sum of those benefits. Currently in Minnesota and Austin, the VOST is being used to compensate DG customers as an alternative to net metering. While this same strategy could alleviate conflict surrounding solar DG compensation in North Carolina, a bigger issue is how to compensate utility-scale solar customers. Considering the solar landscape in North Carolina (>90% utility-scale solar), this is arguably the question that solar advocates should be asking.

The most recent Avoided Cost proceedings revolved mostly around the length of PPA contracts, and whether utility-scale developers should be given the standard contract offer or the negotiated contract offer. However, there is still a lot of uncertainty about how the Avoided Cost rates are calculated in the first place. NCUC staff state that Avoided Cost rates already encompass avoided T&D costs, and that perhaps these costs are too high since DEC still has the obligation to serve when the sun is not shining (North Carolina Utilities Commission, 2015). However, it is impossible for outside stakeholders to check these assumptions given that the Avoided Cost calculations are confidential. The same holds true for other benefits that may already incorporated into Avoided Cost calculations. For this reason, many of the current solar benefit/cost studies argue for greater transparency around Avoided Cost calculations (Rocky Mountain Institute, 2013; Crossborder Energy, 2013).

In addition to greater transparency, it also makes sense for different energy resources to be paid different Avoided Cost rates since each resource offers its own benefits and costs. For example, utility-scale solar is easier to site closer to distribution networks than wind farms. Biomass energy plants that combust swine and poultry waste may offer benefits from avoided water pollution or avoided costs from less agricultural wastes. Duke Energy states that it spent $20M on cleanup efforts from the Dan River coal ash spill (Duke Energy, 2014). NC WARN points out that solar (and potentially other energy sources) have near-zero water usage, zero waste storage costs, and zero risk of fuel cost increases (Kennedy, 2012). The NCUC has already begun to address this issue with Finding of Fact # 10 in its 2014 Order Setting Avoided Cost Inputs (North Carolina Utilities Commission, 2014):

> "Integration of solar resources into a utility's generation mix, depending in part upon their location, may result in costs and/or benefits, many of which may be appropriate for inclusion in a utility's avoided cost calculations. Thus, it is appropriate for the costs and benefits attributed to solar integration as such integration becomes more pervasive to be more fully evaluated in detailed integration studies."

It is imperative that the NCUC make the methodologies from these studies transparent so that all stakeholders can provide input.

While Duke Energy recently made a $500M investment into solar power for North Carolina, the investment came with mixed reviews from the solar community (Trabish, 2014). Opponents claim that, according to its long-range plans, this investment is the only step Duke Energy plans to move forward with solar in the next 15 years. Ultimately, as long as North Carolina remains a fully-regulated state for electricity, it will be up to the NCUC to determine solar growth in the state. While there is already an REPS requirement in the state, the solar carve-out is low at 0.2% (Duke Energy Carolinas (DEC), 2014). This number is relatively small compared to other states (Zientara, 2014). One way the NCUC could increase solar power in the state would be to increase the carve-out.

If North Carolina does not reevaluate how it compensates solar power producers, we run the risk of stifling a growing job market. Solar is one of the fastest growing sectors of the US economy (Kennedy, 2012). Additionally, neighboring states like South Carolina and Georgia are beginning to enter the solar market. We could very well lose solar developers to these states if our policies do not encourage the market to grow.

Limitations

There are some limitations to the analysis performed in this paper. First and foremost is the uncertainty around the values used for the benefits and costs of solar. Tables 13 & 14 show a comparison between the solar benefit and cost values used in this study, and the values stated in the RMI study. The values used in this study are not just within the ranges stated in the RMI study, but generally much lower. While this observation gives some validity to the values used for this analysis, in actuality the values are very specific to the utility. Compounding the difficulty to estimating the values is that many of the methodologies used by the utility are confidential or rely on confidential data.

	RMI Meta-analysis Range	My Range
Energy	\$25.00 - \$105.00	\$50.20 - \$57.00
System Losses	\$1.00 - \$25.00	n/a
Generation Capacity	\$10.00 - \$110.00	\$8.23 - \$36.76
T&D Capacity	\$2.00 - \$85.00	\$2.00 - \$15.00
Grid Support Services	\$1.00 - \$10.00	n/a
Fuel Price Hedge	\$3.00 - \$32.00	\$0.00 - \$8.00
Market Price Response	\$8.00 - \$45.00	n/a
Security Risk	\$8.00 - \$21.00	n/a
Carbon	\$5.00 - \$22.00	\$4.00 - \$22.00
Criteria Pollutants	\$10.00 - \$22.00	
General Environmental	\$1.00 - \$39.00	
Social	\$10.00 - \$41.00	n/a

Table 13. Comparison of Solar Benefit Values Between RMI Study and Internal Analysis

	RMI Meta-analysis Range	My Range
PV Technology	\$290.00 - \$350.00	n/a
Grid Support Services	\$1.00 - \$1.00	\$1.43 - \$9.82
Solar Penetration Cost	\$1.00 - \$140.00	n/a

Table 14. Comparison of Solar Cost Values Between RMI Study (RMI, 2013) and Internal Analysis

A second limitation in the study is the uncertainty around the solar mix in North Carolina. In email correspondence with the NCUC (North Carolina Utilities Commission, 2015), public staff stated that the first report from DEC, DEP, and DNCP on interconnected facilities is due in Spring 2015. This report should add clarity to exactly how much of the solar in DEC's system is utility-scale vs. DG. The Excel model used for this analysis allows for these inputs to be easily changed.

Another limitation to this study is that it only encompasses a portion of North Carolina ratepayers. Due to the limited time allowed to complete this project, it was impractical to scour the commission documents of the two other major North Carolina utilities. However, since the federal/state incentives and policy landscape do not vary by utility, it is likely that their situations are similar to DEC's. Additionally, DEP is a subsidiary of Duke Energy and thus likely faces similar rules to DEC regarding Avoided Cost calculations and net metering rates.

A final limitation to this study is that it does not fully account for the effects of more solar on DEC's system. While integration costs attempt to put a monetary value of having more intermittent resources on the system, the true technical impacts of more solar on the grid are still unknown.

Acknowledgements

I would like to thank my advisor, Dr. Timothy L. Johnson, for his valuable and timely feedback, and for providing a schedule of deadlines that helped break this undertaking into bite-size pieces. Many thanks to the public staff at the NCUC, specifically Kennie Ellis, Jack Floyd, and Jay Lucas, for their guidance in navigating the labyrinth of utility commission documents. I benefitted greatly from conversations with Justin LaRoche from Duke Energy and Nancy LaPlaca from NC WARN when I initially started researching the topic. They provided excellent background on some of the key issues surrounding solar in North Carolina. I also need to acknowledge R. Thomas Beach and Patrick G. McGuide, whom I never spoke with but who authored the Crossborder study which served as a great jumping off point for my analysis. Finally, I would like to thank the Nicholas School of the Environment for providing the resources to get me interested in the topic in the first place.

Appendix

Appendix A. Solar Benefit and Cost Values Used in the Crossborder Study

BENEFITS	
Avoided Energy	\$57 - \$65
Avoided Generation Capacity (DG)	\$22 - \$37
Avoided Generation Capacity (Utility-Scale)	\$19 - \$32
Hedging Value	\$8
Avoided Transmission Costs	\$0 - \$10
Avoided Distribution Costs (DG only)	\$2 - \$5
Environmental Value	\$4 - \$22
Avoided Renewables (DG)	\$1 - \$22
Avoided Renewables (Wholesale)	\$10 - \$20
COSTS	
PPA (Utility-Scale)	\$70 - \$90
Lost Revenues - Residential (DG)	\$98 - \$107
Lost Revenues - Commercial (DG)	\$80 - \$87
Integration (DG and Wholesale)	\$3

Appendix B. Model Calculation Methodology

Energy Production Inputs	
Model Input	**Calculation Method**
Total Solar Energy Produced	MW_{AC} Nameplate in System from IRP x 8760 hrs x Capacity Factor (17.4%)
Utility-Scale Energy Produced	Total Solar Energy Produced (MWh) x % of solar that is utility-scale (Default of 93.75%)
Residential DG Energy Produced	Total Solar Energy Produced (MWh) x % of solar that is DG (6.25%) x % of DG that is Residential (Default of 80%)
Commercial DG Energy Produced	Total Solar Energy Produced (MWh) x % of solar that is DG (6.25%) x % of DG that is Commercial (Default of 20%)
Total DG Produced	Residential DG Energy Produced (MWh) + Commercial DG Energy Produced (MWh)

Benefits	
Model Input	**Calculation Method**
Avoided Energy Value	Total Solar Energy Produced (MWh) x Avoided Energy Value ($/MWh)
Avoided Capacity Value	[Utility-Scale Energy Produced (MWh) x Avoided Capacity Value (Util. Scale)] + [Total DG Produced (MWh) x Avoided Capacity Value (DG)]
Hedging Value	Total Solar Energy Produced (MWh) x Avoided Hedging Value ($/MWh)
Avoided Transmission Value	Total Solar Energy Produced (MWh) x Avoided Transmission Value ($/MWh)
Avoided Distribution Value (DG only)	Total DG Produced (MWh) x Avoided Distribution Value ($/MWh)
Environmental Value	Total Solar Energy Produced (MWh) x Avoided Environmental Costs Value ($/MWh)
Avoided Renewables	[Utility-Scale Energy Produced (MWh) x Avoided Renewables Value (Util. Scale)] + [Total DG Produced (MWh) x Avoided Renewables Value (DG)]
Total Benefits	Σ (All Benefit Values)

Costs	
Model Input	**Calculation Method**
PPA Costs (Utility-Scale)	Utility-Scale Energy Produced (MWh) x PPA Price ($/MWh)
Lost Revenues (Residential)	Residential DG Energy Produced (MWh) x Lost Revenues for Residential ($/MWh)
Lost Revenues (Commercial)	Commercial DG Energy Produced (MWh) x Lost Revenues for Commercial ($/MWh)
Integration Costs	Total Solar Energy Produced (MWh) x Integrations Costs ($/MWh)
Total Costs	Σ (All Cost Values)

Appendix C-1. Scenario 1 Cash Flows and Results

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Solar DEC Base Case Nameplate (MWac)	480	554	572	597	719	869	1,009	1,139	1,265	1,381	1,498	1,605	1,702	1,754	1,681
Solar energy produced (MWh)	731,635	844,429	871,865	909,971	1,095,929	1,324,565	1,537,958	1,736,109	1,928,164	2,104,975	2,283,312	2,446,405	2,594,256	2,673,517	2,562,247
Utility Scale Energy Produced (MWh)	685,908	791,652	817,374	853,098	1,027,433	1,241,779	1,441,836	1,627,603	1,807,653	1,973,414	2,140,605	2,293,505	2,432,115	2,506,422	2,402,107
Residential DG Energy Produced (MWh)	36,582	42,221	43,593	45,499	54,796	66,228	76,898	86,805	96,408	105,249	114,166	122,320	129,713	133,676	128,112
Commercial DG Energy Produced (MWh)	9,145	10,555	10,898	11,375	13,699	16,557	19,224	21,701	24,102	26,312	28,541	30,580	32,428	33,419	32,028
Total DG Produced (MWh)	45,727	52,777	54,492	56,873	68,496	82,785	96,122	108,507	120,510	131,561	142,707	152,900	162,141	167,095	160,140
Avoided Energy Value	$36,729,139	$42,391,548	$43,768,891	$45,681,867	$55,017,190	$66,495,046	$77,207,712	$87,155,187	$96,796,586	$105,672,795	$114,625,523	$122,813,060	$130,235,407	$134,214,397	$128,628,507
Avoided Capacity Value	$6,075,481	$7,012,118	$7,239,948	$7,556,380	$9,100,564	$10,999,152	$12,771,168	$14,416,611	$16,011,424	$17,479,666	$18,960,564	$20,314,890	$21,542,644	$22,200,821	$21,276,841
Hedging Value	$5,853,082	$6,755,432	$6,974,922	$7,279,770	$8,767,428	$10,596,516	$12,303,665	$13,888,875	$15,425,309	$16,839,804	$18,266,492	$19,571,242	$20,754,052	$21,388,136	$20,497,980
Avoided Transmission Value	$3,658,176	$4,222,145	$4,359,326	$4,549,856	$5,479,643	$6,622,823	$7,689,791	$8,680,547	$9,640,818	$10,524,877	$11,416,558	$12,232,026	$12,971,282	$13,367,585	$12,811,237
Avoided Distribution Value (DG only)	$160,045	$184,719	$190,721	$199,056	$239,734	$289,748	$336,428	$379,774	$421,786	$460,463	$499,474	$535,151	$567,494	$584,832	$560,492
Environmental Value	$9,511,258	$10,977,576	$11,334,249	$11,829,627	$14,247,071	$17,219,339	$19,993,456	$22,569,422	$25,066,127	$27,364,681	$29,683,050	$31,803,268	$33,725,334	$34,755,720	$33,309,217
Avoided Renewables (DG)	$524,948	$605,878	$625,563	$652,904	$786,329	$950,375	$1,103,485	$1,245,658	$1,383,457	$1,510,320	$1,638,276	$1,755,296	$1,861,379	$1,918,248	$1,838,413
Avoided Renewables (Wholesale)	$10,288,620	$11,874,782	$12,260,606	$12,796,471	$15,411,495	$18,626,689	$21,627,537	$24,414,038	$27,114,801	$29,601,217	$32,109,068	$34,402,573	$36,481,732	$37,596,332	$36,031,605
Total Benefits	$72,800,749	$84,024,198	$86,754,226	$90,545,932	$109,049,456	$131,799,690	$153,033,242	$172,750,111	$191,860,308	$209,453,822	$227,199,005	$243,427,505	$258,139,323	$266,026,071	$254,954,290
PPA Costs (Wholesale)	$54,872,640	$63,332,172	$65,389,896	$68,247,846	$82,194,642	$99,342,342	$115,346,862	$130,208,202	$144,612,270	$157,873,158	$171,248,364	$183,480,390	$194,569,236	$200,513,772	$192,168,558
Lost Revenues (Residential)	$3,749,630	$4,327,698	$4,468,310	$4,663,603	$5,616,634	$6,788,393	$7,882,036	$8,897,560	$9,881,838	$10,787,999	$11,701,972	$12,537,827	$13,295,564	$13,701,774	$13,131,518
Lost Revenues (Commercial)	$736,208	$849,707	$877,314	$915,659	$1,102,778	$1,332,843	$1,547,570	$1,746,960	$1,940,215	$2,118,132	$2,297,582	$2,461,695	$2,610,471	$2,690,226	$2,578,261
Integration Costs	$4,115,448	$4,749,913	$4,904,242	$5,118,588	$6,164,598	$7,450,676	$8,651,015	$9,765,615	$10,845,920	$11,840,487	$12,843,627	$13,761,029	$14,592,693	$15,038,533	$14,412,642
Total Costs	$63,473,926	$73,259,490	$75,639,762	$78,945,696	$95,078,652	$114,914,254	$133,427,483	$150,618,338	$167,280,243	$182,619,776	$198,091,545	$212,240,941	$225,067,964	$231,944,306	$222,290,979
Benefits - Costs	$9,326,823	$10,764,708	$11,114,464	$11,600,236	$13,970,803	$16,885,436	$19,605,759	$22,131,773	$24,580,064	$26,834,047	$29,107,460	$31,186,564	$33,071,359	$34,081,765	$32,663,311

NPV = $163,947,528

Appendix C-2. Scenario 2 Cash Flows and Results

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Solar DEC Base Case Nameplate (MWac)	480	554	572	597	719	869	1,009	1,139	1,265	1,381	1,498	1,605	1,702	1,754	1,681
Solar energy produced (MWh)	731,635	844,429	871,865	909,971	1,095,929	1,324,565	1,537,958	1,736,109	1,928,164	2,104,975	2,283,312	2,446,405	2,594,256	2,673,517	2,562,247
Utility Scale Energy Produced (MWh)	685,908	791,652	817,374	853,098	1,027,433	1,241,779	1,441,836	1,627,603	1,807,653	1,973,414	2,140,605	2,293,505	2,432,115	2,506,422	2,402,107
Residential DG Energy Produced (MWh)	36,582	42,221	43,593	45,499	54,796	66,228	76,898	86,805	96,408	105,249	114,166	122,320	129,713	133,676	128,112
Commercial DG Energy Produced (MWh)	9,145	10,555	10,898	11,375	13,699	16,557	19,224	21,701	24,102	26,312	28,541	30,580	32,428	33,419	32,028
Total DG Produced (MWh)	45,727	52,777	54,492	56,873	68,496	82,785	96,122	108,507	120,510	131,561	142,707	152,900	162,141	167,095	160,140
Avoided Energy Value	$36,729,139	$42,391,548	$43,768,891	$45,681,867	$55,017,190	$66,495,046	$77,207,712	$87,155,187	$96,796,586	$105,672,795	$114,625,523	$122,813,060	$130,235,407	$134,214,397	$128,628,507
Avoided Capacity Value	$6,075,481	$7,012,118	$7,239,948	$7,556,380	$9,100,564	$10,999,152	$12,771,168	$14,416,611	$16,011,424	$17,479,666	$18,960,564	$20,314,890	$21,542,644	$22,200,821	$21,276,841
Hedging Value	$5,853,082	$6,755,432	$6,974,922	$7,279,770	$8,767,428	$10,596,516	$12,303,665	$13,888,875	$15,425,309	$16,839,804	$18,266,492	$19,571,242	$20,754,052	$21,388,136	$20,497,980
Avoided Transmission Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Avoided Distribution Value (DG only)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Environmental Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Avoided Renewables (DG)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Avoided Renewables (Wholesale)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Benefits	$48,657,702	$56,159,098	$57,983,762	$60,518,017	$72,885,183	$88,090,715	$102,282,545	$115,460,672	$128,233,319	$139,992,264	$151,852,579	$162,699,192	$172,532,102	$177,803,353	$170,403,328
PPA Costs (Wholesale)	$54,872,640	$63,332,172	$65,389,896	$68,247,846	$82,194,642	$99,342,342	$115,346,862	$130,208,202	$144,612,270	$157,873,158	$171,248,364	$183,480,390	$194,569,236	$200,513,772	$192,168,558
Lost Revenues (Residential)	$3,749,630	$4,327,698	$4,468,310	$4,663,603	$5,616,634	$6,788,393	$7,882,036	$8,897,560	$9,881,838	$10,787,999	$11,701,972	$12,537,827	$13,295,564	$13,701,774	$13,131,518
Lost Revenues (Commercial)	$736,208	$849,707	$877,314	$915,659	$1,102,778	$1,332,843	$1,547,570	$1,746,960	$1,940,215	$2,118,132	$2,297,582	$2,461,695	$2,610,471	$2,690,226	$2,578,261
Integration Costs	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Costs	$59,358,478	$68,509,577	$70,735,520	$73,827,107	$88,914,054	$107,463,578	$124,776,468	$140,852,723	$156,434,323	$170,779,289	$185,247,918	$198,479,912	$210,475,271	$216,905,773	$207,878,338
Benefits - Costs	$10,700,776	$12,350,479	$12,751,758	$13,309,090	$16,028,871	$19,372,864	$22,493,923	$25,392,050	$28,201,004	$30,787,025	$33,395,339	$35,780,720	$37,943,169	$39,102,420	$37,475,010

NPV = -$188,098,972

Appendix C-3. Scenario 3 Cash Flows and Results

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Solar DEC Base Case Nameplate (MWac)	480	554	572	597	719	869	1,009	1,139	1,265	1,381	1,498	1,605	1,702	1,754	1,681
Solar energy produced (MWh)	731,635	844,429	871,865	909,971	1,095,929	1,324,565	1,537,958	1,736,109	1,928,164	2,104,975	2,283,312	2,446,405	2,594,256	2,673,517	2,562,247
Utility Scale Energy Produced (MWh)	685,908	791,652	817,374	853,098	1,027,433	1,241,779	1,441,836	1,627,603	1,807,653	1,973,414	2,140,605	2,293,505	2,432,115	2,506,422	2,402,107
Residential DG Energy Produced (MWh)	36,582	42,221	43,593	45,499	54,796	66,228	76,898	86,805	96,408	105,249	114,166	122,320	129,713	133,676	128,112
Commercial DG Energy Produced (MWh)	9,145	10,555	10,898	11,375	13,699	16,557	19,224	21,701	24,102	26,312	28,541	30,580	32,428	33,419	32,028
Total DG Produced (MWh)	45,727	52,777	54,492	56,873	68,496	82,785	96,122	108,507	120,510	131,561	142,707	152,900	162,141	167,095	160,140
Avoided Energy Value	$39,216,173	$45,262,000	$46,732,606	$48,775,115	$58,742,559	$70,997,613	$82,435,663	$93,056,710	$103,350,956	$112,828,197	$122,387,140	$131,129,078	$139,054,013	$143,302,432	$137,338,305
Avoided Capacity Value	$14,840,161	$17,128,019	$17,684,525	$18,457,450	$22,229,324	$26,866,874	$31,195,254	$35,214,464	$39,110,007	$42,696,379	$46,313,668	$49,621,787	$52,620,736	$54,228,420	$51,971,479
Hedging Value	$5,853,082	$6,755,432	$6,974,922	$7,279,770	$8,767,428	$10,596,516	$12,303,665	$13,888,875	$15,425,309	$16,839,804	$18,266,492	$19,571,242	$20,754,052	$21,388,136	$20,497,980
Avoided Transmission Value	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Avoided Distribution Value (DG only)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Environmental Value	$0	$0	$0	$0	$0	$17,219,339	$19,993,456	$22,569,422	$25,066,127	$27,364,681	$29,683,050	$31,803,268	$33,725,334	$34,755,720	$33,309,217
Avoided Renewables (DG)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Avoided Renewables (Wholesale)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Benefits	$59,909,415	$69,145,450	$71,392,053	$74,512,335	$89,739,311	$125,680,343	$145,928,039	$164,729,471	$182,952,398	$199,729,060	$216,650,349	$232,125,374	$246,154,135	$253,674,708	$243,116,981
PPA Costs (Wholesale)	$54,872,640	$63,332,172	$65,389,896	$68,247,846	$82,194,642	$99,342,342	$115,346,862	$130,208,202	$144,612,270	$157,873,158	$171,248,364	$183,480,390	$194,569,236	$200,513,772	$192,168,558
Lost Revenues (Residential)	$3,749,630	$4,327,698	$4,468,310	$4,663,603	$5,616,634	$6,788,393	$7,882,036	$8,897,560	$9,881,838	$10,787,999	$11,701,972	$12,537,827	$13,295,564	$13,701,774	$13,131,518
Lost Revenues (Commercial)	$736,208	$849,707	$877,314	$915,659	$1,102,778	$1,332,843	$1,547,570	$1,746,960	$1,940,215	$2,118,132	$2,297,582	$2,461,695	$2,610,471	$2,690,226	$2,578,261
Integration Costs	$1,046,238	$1,207,533	$1,246,767	$1,301,259	$1,567,178	$1,894,127	$15,102,749	$17,048,594	$18,934,567	$20,670,859	$22,422,119	$24,023,699	$25,475,599	$26,253,937	$25,161,270
Total Costs	$60,404,717	$69,717,110	$71,982,287	$75,128,366	$90,481,232	$109,357,706	$139,879,217	$157,901,316	$175,368,890	$191,450,147	$207,670,037	$222,503,611	$235,950,870	$243,159,709	$233,039,607
Benefits - Costs	$495,302	$571,661	$590,234	$616,031	$741,920	$16,322,637	$6,048,822	$6,828,155	$7,583,508	$8,278,913	$8,980,312	$9,621,763	$10,203,266	$10,514,999	$10,077,373

NPV	$41,404,070

Appendix D. List of Relevant Acronyms

Acronym	Name
DEC	Duke Energy Carolinas
DEP	Duke Energy Progress
DG	Distributed Generation
DNCP	Dominion North Carolina Power
FERC	Federal Energy Regulatory Commission
IOU	Investor-owned utility
IRP	Integrated Resource Plan
kW	Kilowatt
kWh	Kilowatt-hour
MW	Megawatt
MWh	Megawatt-hour
NCSEA	North Carolina Sustainable Energy Association
NCUC	North Carolina Utilities Commission
NPV	Net Present Value
PNNL	Pacific Northwest National Labs
PURPA	Public Utilities Regulatory Policies Act
PV	Photovoltaic
QF	Qualifying Facility
REC	Renewable Energy Certificate
REPS	Renewable Energy and Energy Efficiency Portfolio Standard
RMI	Rocky Mountain Institute
RPS	Renewable Portfolio Standard
T&D	Transmission and distribution
VOST	Value of Solar tariff

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