INFORMATION SHEET

PRESIDING: Commissioner Clodfelter, Presiding; Chair Mitchell; Commissioners Brown-Bland, Gray, Duffley, Hughes, and McKissick
PLACE: Via WebEx Videoconference
DATE: Tuesday, June 9, 2020
TIME: 1:15 p.m. – 1:19 p.m.
DOCKET NO.: E-7, Sub 1229
VOLUME NUMBER: 2
COMPANIES: Duke Energy Carolinas, LLC
DESCRIPTION: Application of Duke Energy Carolinas, LLC, for Approval of Renewable Energy and Energy Efficiency Portfolio Standard Cost Recovery Rider Pursuant to N.C.G.S. § 62-133.8 and NCUC Rule R8-67

APPEARANCES
See attached.

WITNESSES
See Attached.

EXHIBITS
See Attached.

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PLACE: WebEx Video Conference

DATE: Tuesday, June 9, 2020

TIME: 1:15 p.m. - 1:19 p.m.

DOCKET NO.: E-7, Sub 1229

BEFORE: Commissioner Daniel G. Clodfelter, Presiding

Chair Charlotte A. Mitchell

Commissioner ToNola D. Brown-Bland

Commissioner Lyons Gray

Commissioner Kimberly W. Duffley

Commissioner Jeffrey A. Hughes

Commissioner Floyd B. McKissick, Jr.

IN THE MATTER OF:

Application of Duke Energy Carolinas, LLC, for Approval of Renewable Energy and Energy Efficiency Portfolio Standard Cost Recovery Rider Pursuant to N.C.G.S. 62-133.8 and NCUC Rule R8-67.

VOLUME: 2

Noteworthy Reporting Services, LLC

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T A B L E O F C O N T E N T S

E X A M I N A T I O N S

E X H I B I T S

BEFORE THE NORTH CAROLINA UTILITIES COMMISSION

DOCKET NO. E-7, SUB 1229

In the Matter of: Application of Duke Energy Carolinas, LLC for Approval of Renewable Energy and Energy Efficiency Portfolio Standard (REPS) Compliance Report and Cost Recovery Rider Pursuant to N.C. Gen. Stat. § 62-133.8 and Commission Rule R8-67	))))))))	**APPLICATION FOR APPROVAL OF REPS COST RECOVERY RIDER AND 2019 REPS COMPLIANCE REPORT**

Duke Energy Carolinas, LLC ("DEC" or the "Company"), pursuant to N.C. Gen. Stat. § 62-133.8 and Rule R8-67 of the Rules and Regulations of the North Carolina Utilities Commission ("Commission"), hereby makes this Application (1) for approval of its 2019 Renewable Energy Portfolio Standard ("REPS") Compliance Report, and (2) to implement a monthly charge to recover the incremental costs associated with compliance with the REPS. In support of this Application, the Company respectfully shows the following:

1. The Company is a public utility operating in the states of North Carolina and South Carolina where it is engaged in the generation, transmission, distribution, and sale of electricity for compensation. Its general offices are located at 550 South Tryon Street, Charlotte, North Carolina, and its mailing address is DEC 45A, 550 South Tryon Street, Charlotte, North Carolina 28202.

2. The attorneys for the Company, to whom all communications and pleadings should be addressed, are:

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3. N.C. Gen. Stat. § 62-133.8 requires North Carolina's electric power suppliers to supply ten (10) percent of their North Carolina retail kilowatt hours ("kWh") sales from "renewable energy resources," as that term is defined by N.C. Gen. Stat. § 62-133.8(a)(8), for calendar year 2019. In addition, N.C. Gen. Stat. § 62-133.8(d) requires that the electric power suppliers supply 0.20 percent of their North Carolina retail kWh sales from solar photovoltaic or thermal solar resources in 2019. Further, N.C. Gen. Stat. § 62-133.8(e) and (f) require that the electric power suppliers also obtain their allocated share of the state-wide requirement of 0.20 percent of the total North Carolina retail kWh sold from swine waste resources and 900,000 megawatt hours ("MWh") of the total electric power sold to North Carolina retail customers from poultry waste resources, respectively, in 2019.[1]

4. N.C. Gen. Stat. § 62-133.8(h) provides that the electric public utilities shall be allowed to recover the incremental costs[2] associated with complying with N.C.

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[1] Both the Poultry Waste and Swine Waste Set-Aside Requirements established by N.C. Gen. Stat. § 62-133.8 have been modified by Commission order pursuant to N.C. Gen. Stat. § 62-133.8(i)(2), as discussed herein.

[2] "Incremental costs" include (1) all reasonable and prudent costs incurred by an electric utility to meet the solar and renewable generation requirements of the statute that are in excess of the utility's avoided costs, (2) costs associated with research that encourages the development of renewable energy, energy efficiency, or improved air quality provided those research costs do not exceed one million dollars ($1,000,000) per year, and (3) costs, including program costs, incurred to provide incentives to customers pursuant to N.C.Gen. Stat. § 62-155(f) (solar rebate program costs and incentives).

Gen. Stat. § 62-133.8 through an annual rider not to exceed the following per-account charges:

Customer Class	2008-2011	2012-2014	2015 and thereafter
Residential per account	$ 10.00	$ 12.00	$ 27.00
Commercial per account	$ 50.00	$ 150.00	$ 150.00
Industrial per account	$ 500.00	$ 1,000.00	$1,000.00

The statute provides that the Commission shall ensure that the incremental costs to be recovered from individual customers on a per-account basis are in the same proportion as the per-account annual charges for each customer class set out in the chart above.

5. Rule R8-67(c) requires the Commission to conduct an annual proceeding for each electric public utility to review the utility's costs to comply with N.C. Gen. Stat. § 62-133.8 and establish the electric public utility's annual rider to recover such costs in a timely manner. The Commission shall also establish an experience modification factor ("EMF") to collect the difference between the electric public utility's actual reasonable and prudent REPS costs incurred during the test period and the actual revenues realized during the test period. Rule R8-67(c) further provides that the Commission shall consider each electric public utility's REPS compliance report at the hearing provided for in Rule R8-67(e) and shall determine whether the electric public utility has complied with N.C. Gen. Stat. § 62-133.8(b), (d), (e) and (f).

6. According to Rules R8-67(c) and (e), the electric public utility is to file its application for recovery of its REPS costs, as well as its REPS compliance report, at the same time it files the information required by Rule R8-55, and the Commission is to conduct an annual rider hearing as soon as practicable after the hearing required by Rule R8-55.

7. Pursuant to the provisions of N.C. Gen. Stat. § 62-133.8 and Commission Rule R8-67(e), DEC requests the Commission to establish a rider to recover its reasonable and prudent forecasted REPS compliance costs to be incurred during the rate period. As provided in Rule R8-67(e), the Company requests to return to DEC's retail customers, through the EMF, $1,956,331of REPS costs incurred and other credits for the period beginning January 1, 2019 through December 31, 2019 ("EMF Period") and collect from DEC's retail customers $34,984,948 for REPS costs to be incurred during the rate period from September 1, 2020 through August 31, 2021 ("Billing Period"). The REPS rider and EMF will be in effect for the twelve-month period September 1, 2020 through August 31, 2021.

8. Pursuant to the provisions of N.C. Gen. Stat. § 62-133.8 and Rule R8-67, DEC requests Commission approval of the annual billing statements, including both the REPS monthly charge and the EMF monthly charge, for each customer class as follows:

Customer Class	**REPS Monthly Charge** (excl. regulatory fee)	**Monthly EMF** (excl. regulatory fee)	**Total REPS Monthly Charge** (excl. regulatory fee)	**Total REPS Monthly Charge** (incl. regulatory fee)
Residential	$ 0.79	$ (0.01)	$ 0.78	$ 0.78
General[3]	$ 3.99	$ (0.15)	$ 3.84	$ 3.84
Industrial	$16.67	$ 1.84	$18.51	$18.53

The calculation of these rates is set forth in Exhibit No. 4 of the direct testimony of Veronica I. Williams filed with this Application.

[3] Duke Energy Carolinas' General Service rate schedule generally covers the class of customers intended to be captured by the "Commercial" class included within N.C. Gen. Stat. § 62-133.8. The Company does not have a rate schedule for "Commercial" customers.

9. Further, pursuant to the provisions of N.C. Gen. Stat. § 62-133.8 and Commission Rule R8-67(c), the Company requests Commission approval of its 2019 REPS Compliance Report, attached as an exhibit to the direct testimony of Megan Jennings filed in support of this Application. As described by Ms. Jennings' testimony, and illustrated in DEC's 2019 REPS Compliance Report, the Company has complied with the requirements of N.C. Gen. Stat. § 62-133.8(b) and (d) for 2019. In its December 16, 2019 *Order Modifying the Swine and Poultry Waste Set-Aside Requirements and Providing Other Relief* and its February 13, 2020 *Errata Order,* in Docket No. E-100, Sub 113, the Commission lowered the 2019 Poultry Waste Set-Aside Requirement (N.C. Gen. Stat. § 62-133.8(f)) to 500,000 MWh and delayed by one year the scheduled increases in that requirement. The Commission also lowered the Swine Waste Set-Aside Requirement for DEC, Duke Energy Progress, LLC and Dominion Energy North Carolina to 0.04% of prior-year retail sales, delaying the scheduled increase to 0.07% of prior-year retail sales to begin in calendar year 2020-2021, and delaying future increases by one year.[4] The Company has complied with these modified Poultry Waste and Swine Waste Set-Aside Requirements.

[4] In its *Order Modifying the Poultry and Swine Waste Set-Aside and Granting Other Relief* issued in Docket No. E-100, Sub 113 (November 29, 2012), the Commission eliminated the Swine Waste Set-Aside Requirement for 2012 and delayed for one year the Poultry Waste Set-Aside Requirement. In its March 26, 2014, *Final Order Modifying the Poultry and Swine Waste Set-Aside Requirements and Providing Other Relief*, the Commission delayed the Swine and Poultry Waste Set-Aside Requirements for an additional year. In its November 13, 2014 *Order Modifying the Swine Waste Set-Aside Requirement and Providing Other Relief*, the Commission directed that Swine Waste Set-Aside Requirement remain at 0.07 percent for the years 2015-2016. Subsequently, in its December 1, 2015 *Order Modifying the Swine and Poultry Waste Set-Aside Requirements and Providing Other Relief*, the Commission directed that the Swine Waste Set-Aside Requirement for 2015 be delayed an additional year and that the 2015 Poultry Waste Set-Aside Requirement would be the same as the 2014 level. In its October 17, 2016 *Order Modifying the Swine and Poultry Waste Set-Aside Requirements and Providing Other Relief*, the Commission directed that the 2016 Swine Waste Set-Aside Requirement be delayed an additional year and that the 2016 Poultry Waste Set-

10. The information and data required to be filed under Commission Rule R8-67 is contained in the direct testimony and exhibits of Witnesses Jennings and Williams, which are being filed simultaneously with this Application and incorporated herein by reference.

WHEREFORE, the Company respectfully prays:

That consistent with this Application, the Commission approves the Company's 2019 REPS Compliance Report and allows the Company to implement the rate riders as set forth above.

Aside Requirement remain at the same level as the 2015 requirement and delayed by one year the scheduled increases in that requirement. In its October 16, 2017 *Order Modifying the Swine and Poultry Waste Set-Aside Requirements and Providing Other Relief*, in Docket No. E-100, Sub 113, the Commission directed that the 2017 Swine Waste Set-Aside Requirement be delayed an additional year and that the 2017 Poultry Waste Set-Aside Requirement (N.C. Gen. Stat. § 62-133.8(f)) remain at the same level as the 2016 requirement, which the Commission had previously approved at 170,000 MWh, and delayed by one year the scheduled increases in that requirement. In its October 8, 2018 *Order Modifying the Swine and Poultry Waste Set-Aside Requirements And Providing Other Relief* in Docket No. E-100, Sub 113, the Commission modified the 2018 Swine Waste Set-Aside Requirement for electric public utilities to 0.02% and delayed by one year the scheduled increases to the requirement. The Commission also modified the 2018 Poultry Waste Set-Aside Requirement to 300,000 MWh, and delayed by one year the scheduled increases in the requirement.

Respectfully submitted, this the 25th day of February, 2020.

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ATTORNEYS FOR DUKE ENERGY CAROLINAS, LLC

VERIFICATION

STATE OF NORTH CAROLINA)
) DOCKET NO. E-7, SUB 1229
COUNTY OF MECKLENBURG)

Veronica I. Williams, being first duly sworn, deposes and says:

That she is Rates and Regulatory Strategy Manager for Duke Energy Carolinas, LLC; that she has read the foregoing Application and knows the contents thereof; that the same is true except as to those matters stated on information and belief; and as to those matters, she believes them to be true.

Veronica I. Williams

Sworn to and subscribed before me
this the 24th day of February, 2020.

Notary Public Aloma M. Felder

My Commission Expires: July 21, 2020

ALOMA M. FELDER
NOTARY PUBLIC
CABARRUS COUNTY, N.C.

CERTIFICATE OF SERVICE

I certify that a copy of Duke Energy Carolinas, LLC's REPS Cost Recovery Rider and 2019 Compliance Report, in Docket No. E-7, Sub 1229, has been served by electronic mail, hand delivery, or by depositing a copy in the United States Mail, 1st Class Postage Prepaid, properly addressed to parties of record.

This the 25th day of February, 2020.

Robert W. Kaylor

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ATTORNEY FOR DUKE ENERGY CAROLINAS, LLC

CAPER

Center for Advanced Power Engineering Research
2017-2019 Research Project Report

Development and Demonstration of a 40kW Photovoltaic Synchronous Generator (PVSG)

Prepared by:

Dr. Alex Huang (PI), UT Austin

Dr. Ramtin Hadidi (Co-PI), Clemson University

Project Period:

Start Date: 4/1/2017

Completion Date: 10/31/2019

CAPER

Center for Advanced Power Engineering Research
2017-2019 Research Project Report

Table of Contents

1 Project Objectives

The project objective is to design and develop a 40 kW ultracapcitor energy storage system that works in parallel with commercial grid following PV inverters. The entire system behaves like a grid forming PV Synchronous Generator (PVSG). It is a significant step needed to make all PV systems to provide both Voltage and Frequency support to the grid.

2 Project Team and Tasks

UT Austin Team	
Role	**Name**
Faculty Advisor	Dr. Alex Huang
Graduate Students	Yizhe Xu (graduated), Xiangjun Quan(graduated) and Chengjing Li

Clemson Team	
Role	**Name**
Faculty Advisor	Dr. Ramtin Hadidi
Graduate Students	Puspal Hazra

3 Project Description and Outcomes

3.1 Background, Research Objectives and Major Accomplishments

As the renewable energy and distributed generation penetration increases in utility power grids, the traditional control approach for these resources needs a fundamental change in order to maintain overall grid stability. Traditionally, PV inverters are designed as a grid following current source, providing no ancillary services to maintain the grid stability. For very high PV penetration levels, PV power plants will replace traditional synchronous generator and they must also provide grid frequency support and regulation capability. This effectively requires a totally new generation of PV inverter technology.

Dr. Huang's team has previously developed a single phase PVSG, this work has been accomplished and one paper was published. See paper in "Integration of DC Microgrids as Virtual Synchronous Machines into the AC Grid," in *IEEE Transactions on Industrial Electronics*, vol. 64, no. 9, pp. 7455-7466, Sept. 2017.

In this CAPER project, a novel AC coupled solution that transforms an existing grid following PV system to a grid forming one without any hardware and software modification of the PV inverter is proposed and implemented. The resulting system, the Photovoltaic Synchronous Generator (PVSG), is achieved by an AC coupled supercapacitor-based energy storage system (ESS). The following major accomplishments have been made in CAPER project:

1- A 40 kW/480V ultra capacitor ESS is designed, developed, and tested.
2- Together with a commercial PV system, the 40 kW PVSG system is tested and demonstrated in October 2019 at UT Austin in 2019. Duke Energy, Austin Energy representatives participated in the demonstration.
3- In Feb 2020, the 40 KW PVSG system was also demonstrated to representatives from ERCOT
4- A novel control for the PVSG was developed with robust inertia and primary frequency response capability.
5- Following papers are published.

[1] X. Quan *et al*., "Novel Power Control of Voltage-Controlled Inverters for Grid Inertia Support," in 2019 IEEE Applied Power Electronics and Exposition (APEC), Anaheim, CA, USA, 2019, pp. 927-931.

[2] X. Quan *et al*., "Photovoltaic Synchronous Generator (PVSG): Architecture and Control Strategy for A Grid-Forming PV Energy System," in *IEEE Journal of Emerging and Selected Topics in Power Electronics*. doi: 10.1109/JESTPE.2019.2953178 is published.

[3] X. Quan, A. Q. Huang and H. Yu, "A Novel Order Reduced Synchronous Power Control for Grid-Forming Inverters," in IEEE Transactions on Industrial Electronics. doi: 10.1109/TIE.2019.2959485

[4] P. Hazra and R. Hadidi, "Inertial response enhancement of a microgrid using Photovoltaic Synchronous Generator," 2018 IEEE Electronic Power Grid (eGrid), Charleston, SC, Nov. 2018, pp. 1-4.

3.2 PVSG Description

The system diagram of the implemented three-phase PVSG is shown in Fig. 1. Fig. 2 displays the schematic illustration of the proposed PVSG whose equivalent circuit diagram is shown in Fig. 3.

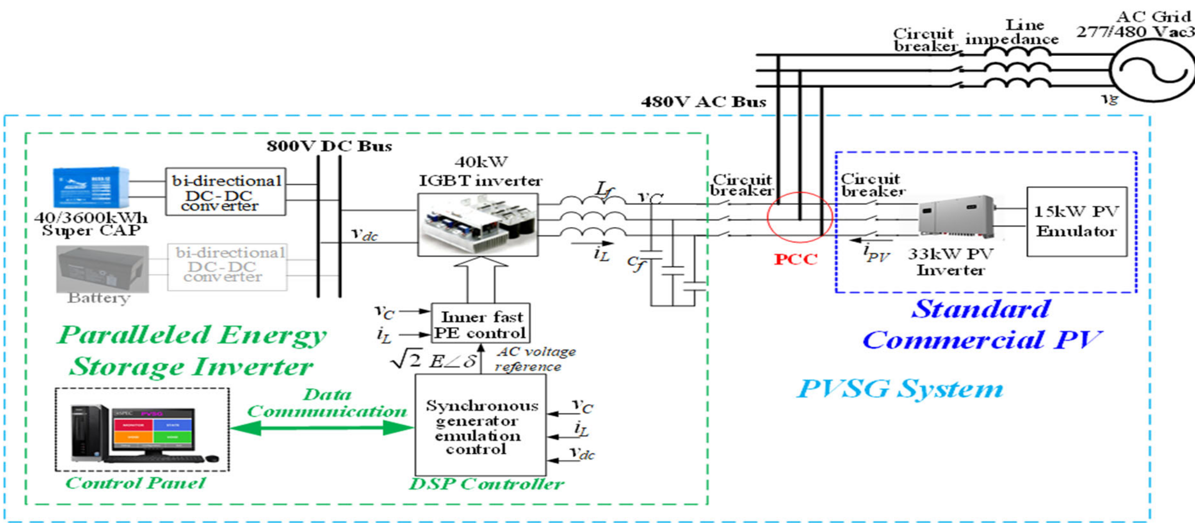

Fig. 1. System Diagram of the implemented three-phase PVSG system.

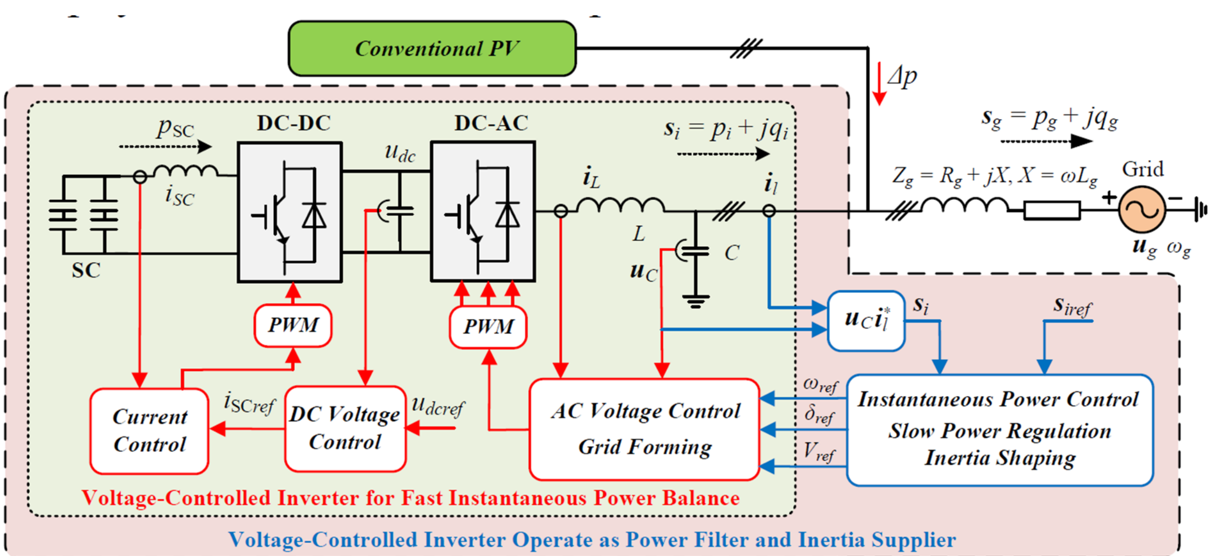

Fig. 2. Illustration of the proposed PVSG by paralleled grid-forming inverter.

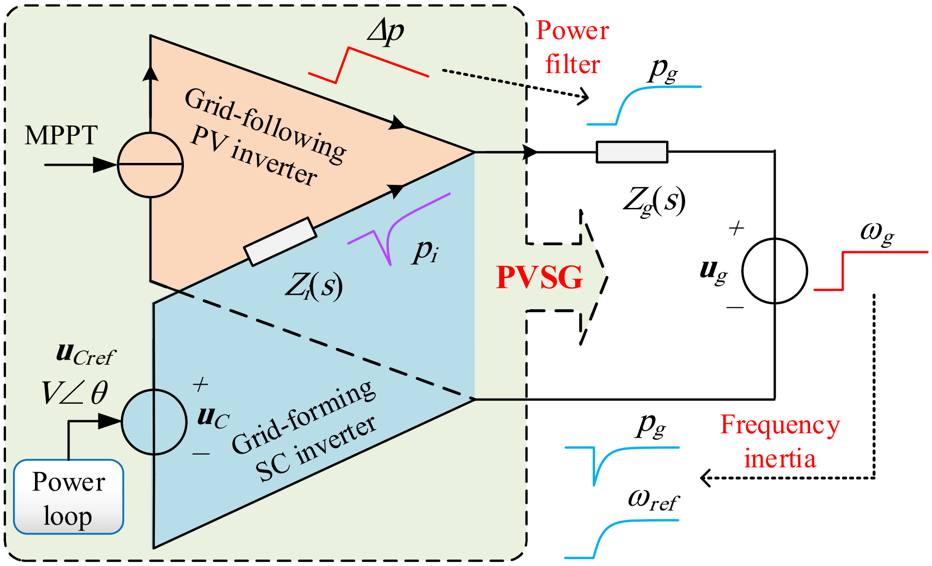

Fig. 3. Equivalent circuit diagram of the proposed PVSG and the functionality illustration of the power filter and frequency inertia.

The PVSG includes a grid following PV (and/or load) in parallel with a grid-forming inverter with SC on the DC side. The control of the PV is a standard grid-following MPPT controlled inverter system. PVSG controls are implemented in the SC inverter which can be further divided into two parts. The first one is the fundamental voltage and current control with fast dynamic response which achieves the automatic and fast response to the power intermittence and grid frequency variations, as shown by red parts in Fig. 2. The second part implements the slow power control to emulate the inertia hence achieving power filter and frequency inertia, as shown by the blue parts in Fig. 2. The proposed inertia solution includes frequency inertia and power filter as demonstrated in Fig. 3. These two functions are used to alleviate power demand of kinetic energy of SG in event of power and frequency variations. Therefore, they need a very fast and short time active power injection/absorbing to/from the grid when PV power or frequency changes suddenly. To this end, the response of the grid-forming inverter should be as fast as possible to avoid the requirement of step power from grid. As shown in Fig. 3, the conventional grid-following PV system achieves the MPPT control, while the added inverter operates as a voltage source whose amplitude and frequency are adjusted by the power loop. The proposed control diagram of the PVSG is illustrated in Fig. 4, for detailed design of AC-DC, DC-DC, and power flow controllers design please refer to [2]. TABLE I lists the system parameters and the experimental setup is displayed in Fig. 5.

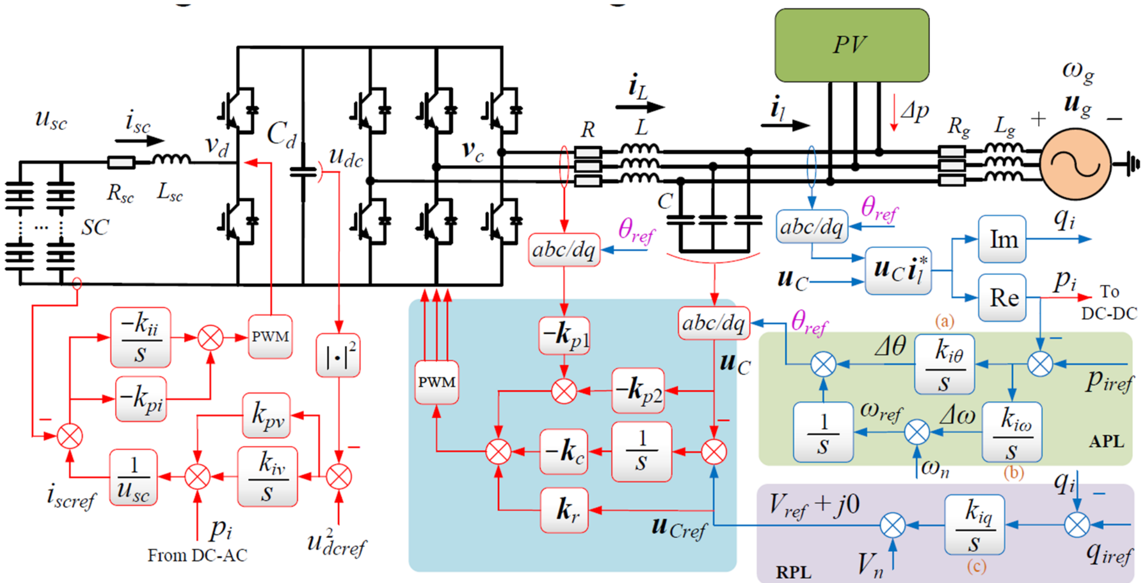

Fig. 4. Control of the proposed PVSG by paralleled grid-forming inverter.

Table 1. Circuit Parameters of the PVSG System

Parameter		Value
L	Inductance of AC filter	1 mH
C	Capacitance of ACfilter	54 µF
R	Inductor resistance	0.05 Ω
L_g	Grid-side inductance	1.5 mH
L_{sc}	SC-side inductance	1.8 mH
SC	Super capacitance	2 F
C_d	DC link capacitance	3300 µF
f_s	Switching frequency	16,000 Hz
	Voltage ph-ph RMS/ frequency	480 V / 60 Hz
	DC link voltage	830 V

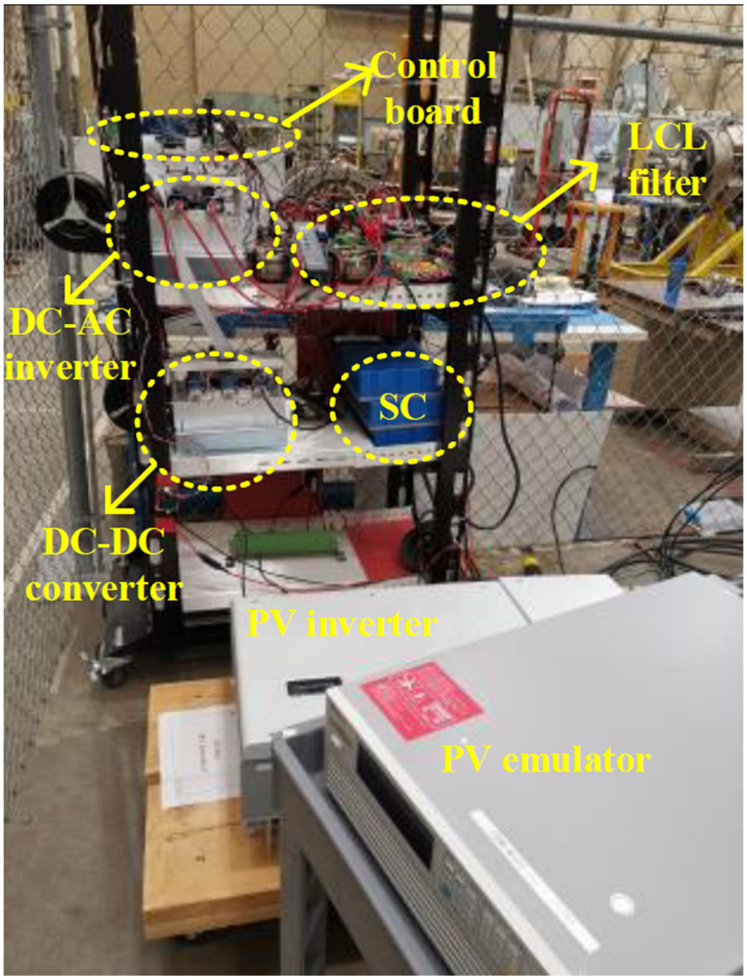

Fig. 5. Experiment setup.

3.3 Experimental Test Results

The experimental test results are shown in Fig. 6 and Fig. 7. In these tests, the PVSG system is connected to three-phase 480 V Austin Energy grid. In Fig. 6, it can be seen that by variation in the grid's frequency, shown in middle figure, the Super Capacitor (SC) system injects or absorbs active power, shown in top figure with red color, to provide inertia to the grid frequency. Also, this system is capable of reactive power compensation where the reactive power injected/absorbed by SC inverter is shown in top figure by green. In Fig. 7, it can be seen that by although a sudden change has happened in PV generation, the grid frequency is smoothed by the PVSG system.

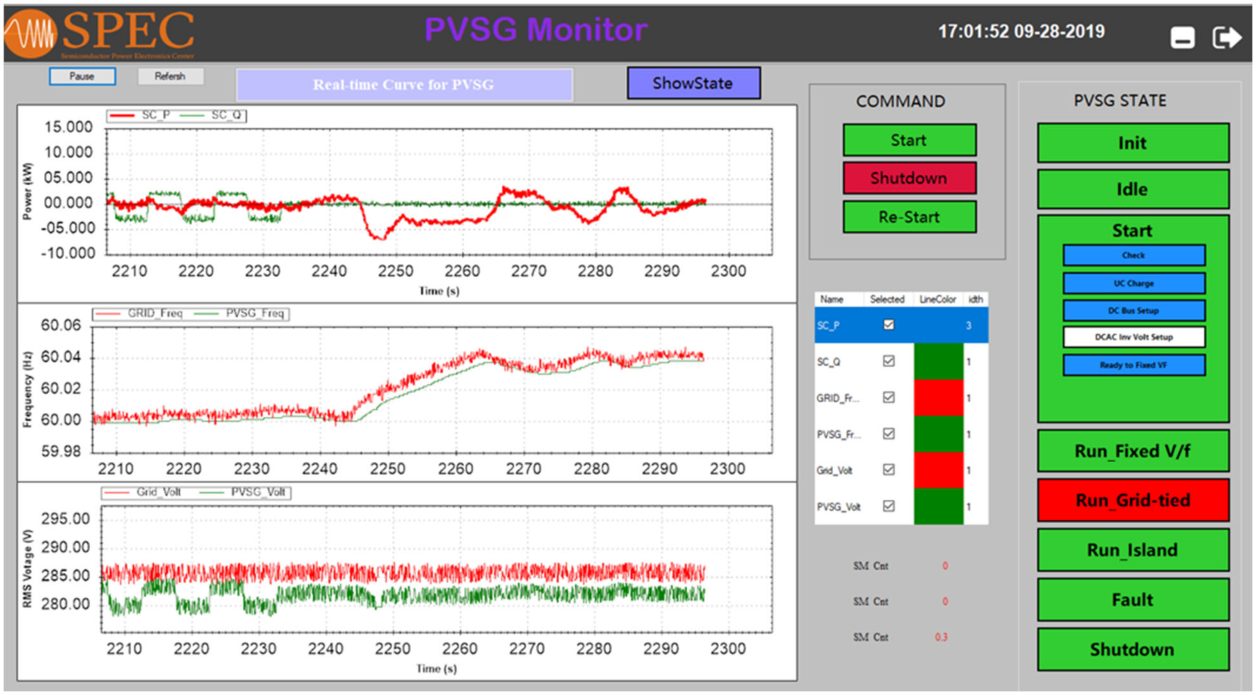

Fig. 6. Experimental test results shown by developed software.

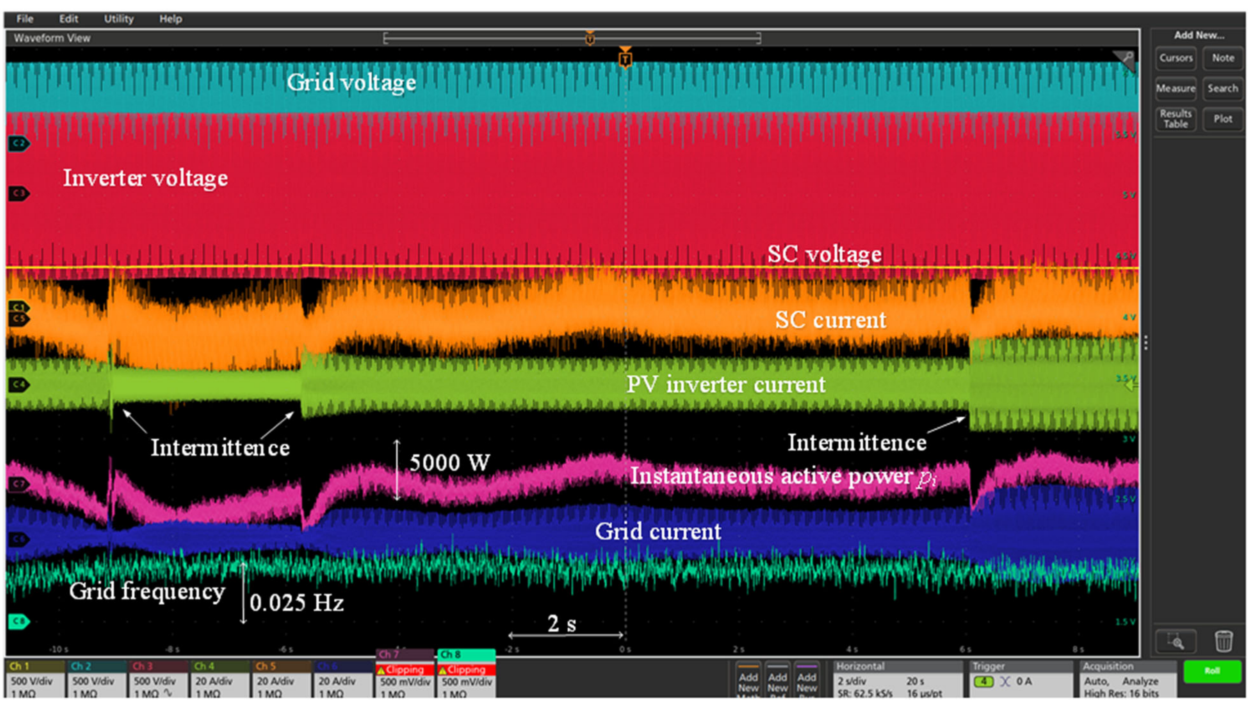

Fig. 7. Experimental results shown by oscilloscope.

3.4 System Studies with PVSG

The system study has been performed in two microgrid test systems to show the effectiveness of the PVSG solution. Fig. 8 shows the first system. The synchronous machine is rated at 52.5 kVA,460 V L-L RMS, 1800 RPM and PVSG unit is rated at 40 kVA.

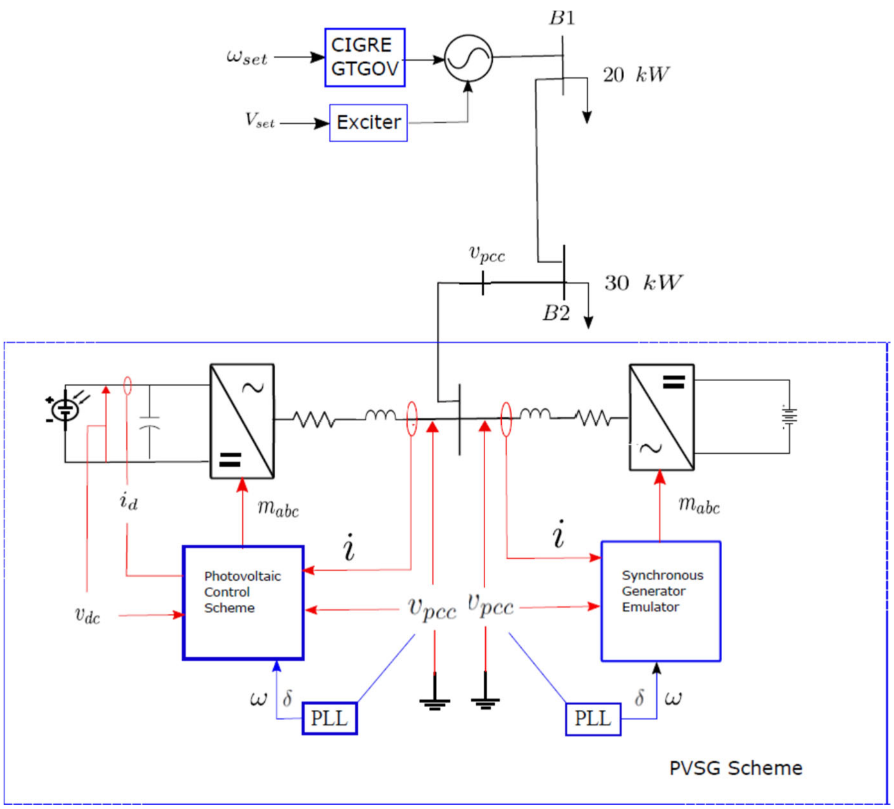

Fig. 8. Microgrid Test System for 40kVA PVSG system.

Figure 9 shows the response of PVSG units subject to power set point change in photovoltaic inverter from 0.4 p.u.to 0.3 p.u. at t=50s. This creates an under frequency disturbance. Figure 10 compares frequency deviation in a system with a PVSG unit and one without synchronous generator emulator part which clearly shows the improvement in frequency response. Figure 11 shows the frequency response of PVSG units subject to power set point change in photovoltaic inverter from0.4 p.u. to 0.5 p.u. at t=50s. This creates an under frequency disturbance. Figure 12 compares frequency deviation in a system with a PVSG unit and one without synchronous generator emulator part which clearly shows the improvement in frequency response. All plots are in per unit.

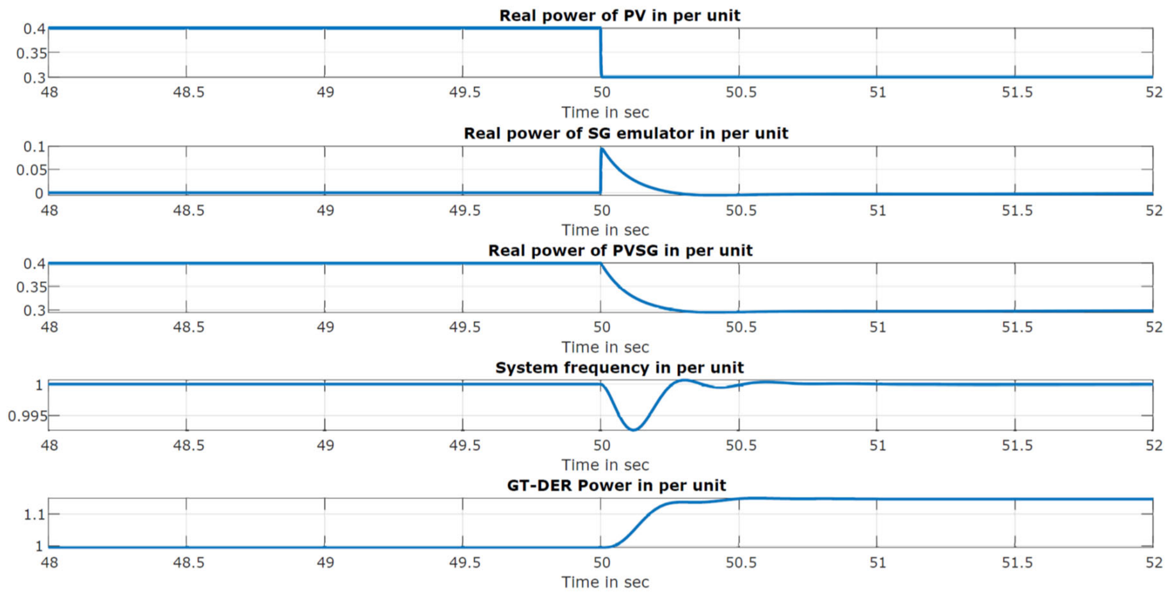

Fig. 9. Time-domain response of different components subject to power set point change in photovoltaic inverter from 0.4 p.u.to 0.3 p.u. at t=50s.

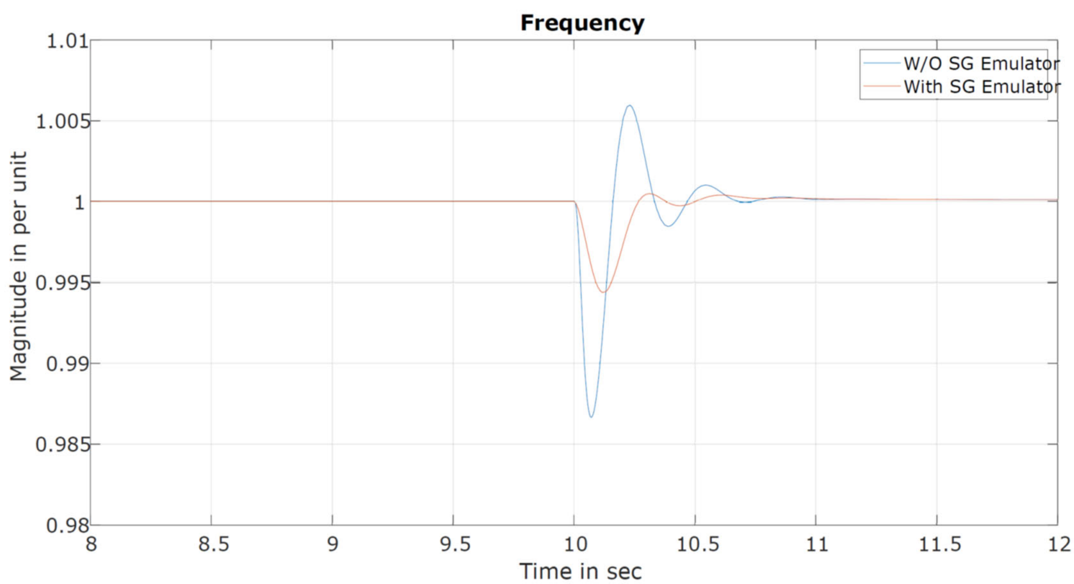

Fig. 10. Frequency comparison for a system with and without the synchronous generator emulator part.

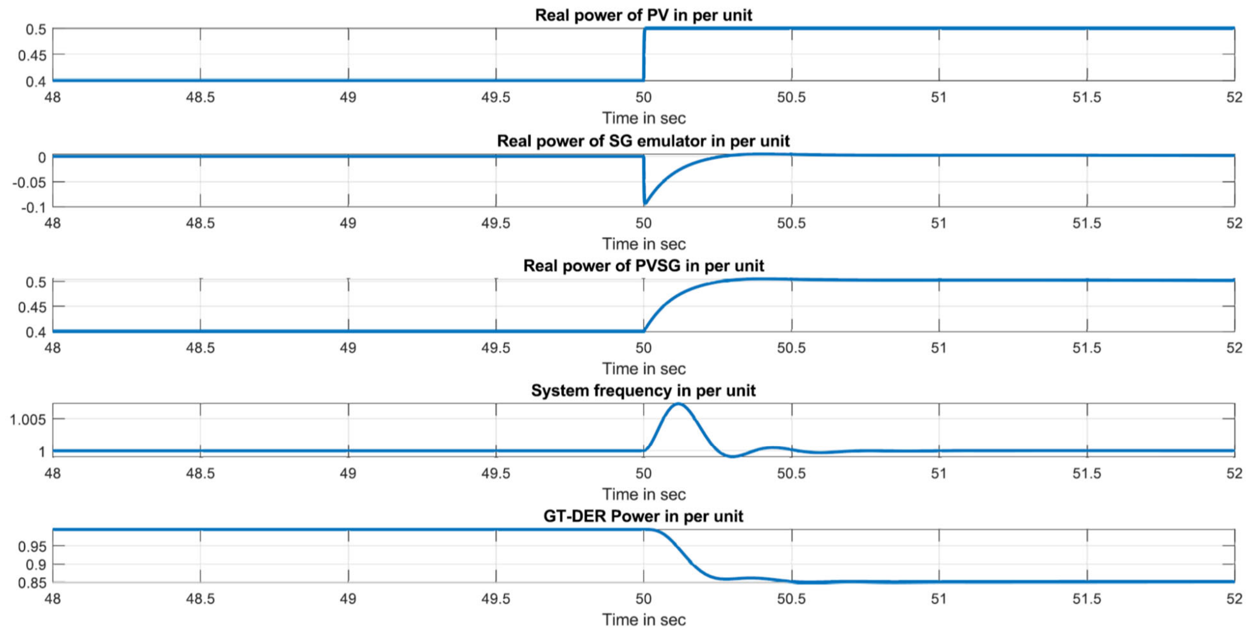

Fig. 11. Time-domain response of different components subject to power set point change in photovoltaic inverter from 0.4 p.u.to 0.5 p.u. at t=50s.

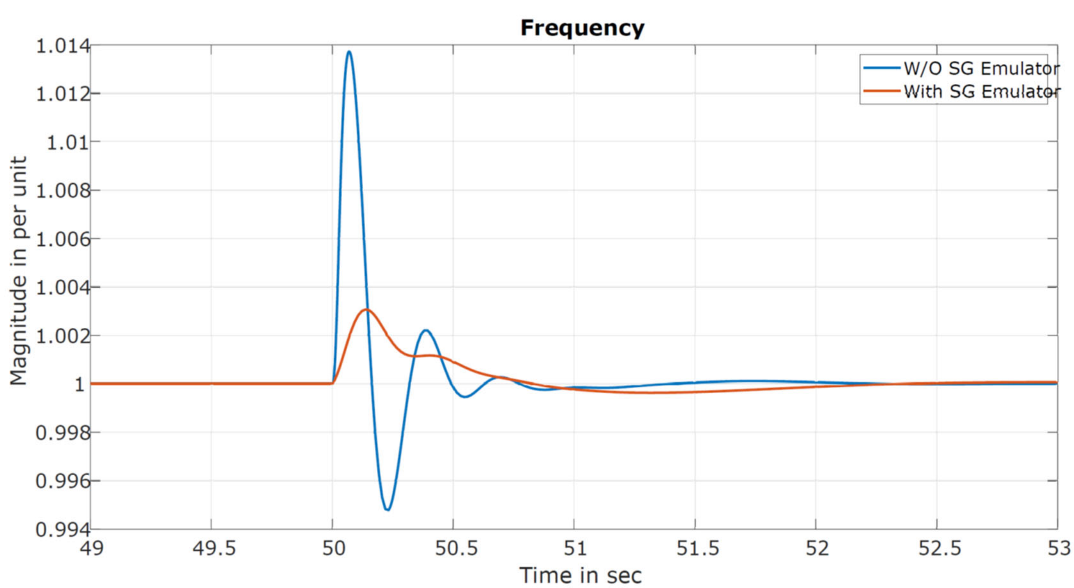

Fig. 12. Frequency comparison for a system with and without the synchronous generator emulator part.

A second test system is considered for studying the effect of larger PVSG unit on the system behavior and response. IEEE 13 node system is selected for the study as shown in Figure 13.

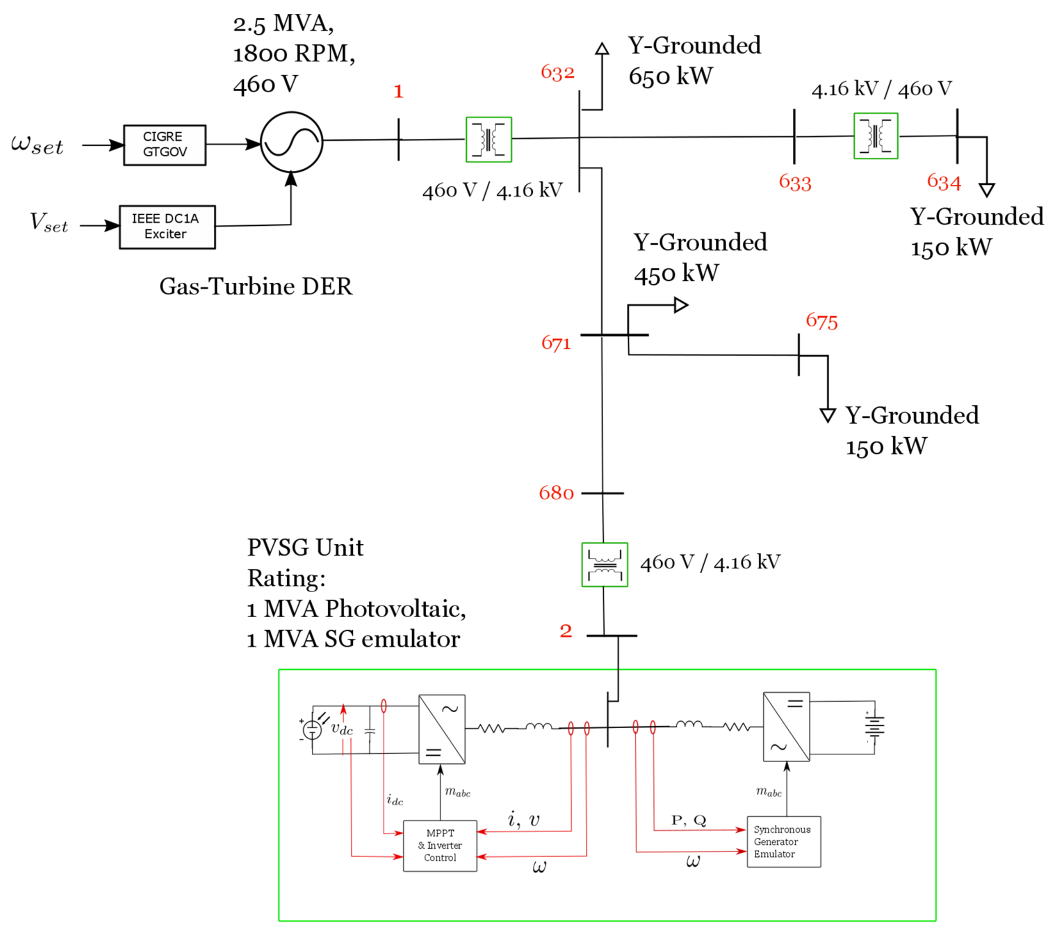

Fig. 13. Modified IEEE 13 node system for PVSG unit integration study.

The system frequency response to PV power reduction without SG emulator part in steps of 160kw until 640 kw are shown in Figure 14. The same step reduction in PV output is applied in a system with PVSG and the frequency responses are capture in Figure 15. It is clear from Figures 14 and 15 that frequency dip has been improve significantly for a system with PVSG. The real power output of PVSG unit and real power response of the gas turbine with PVSG unit are shown in Figures 16 and 17 due to this PV set point changes. Fig 16 shows smooth response of PVSG unit as a step change of PV inverter which results to better inertia support for the system.

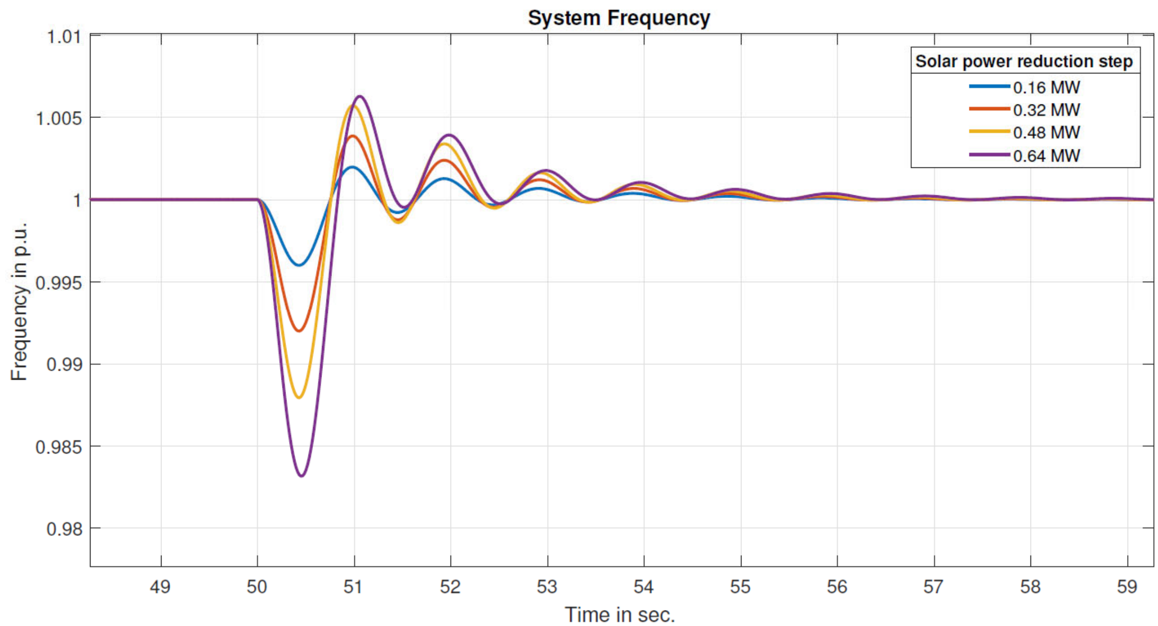

Fig. 14. Time-domain frequency response to step changes in PV inverter set-point with steps of 160 kW in the system without SG emulator.

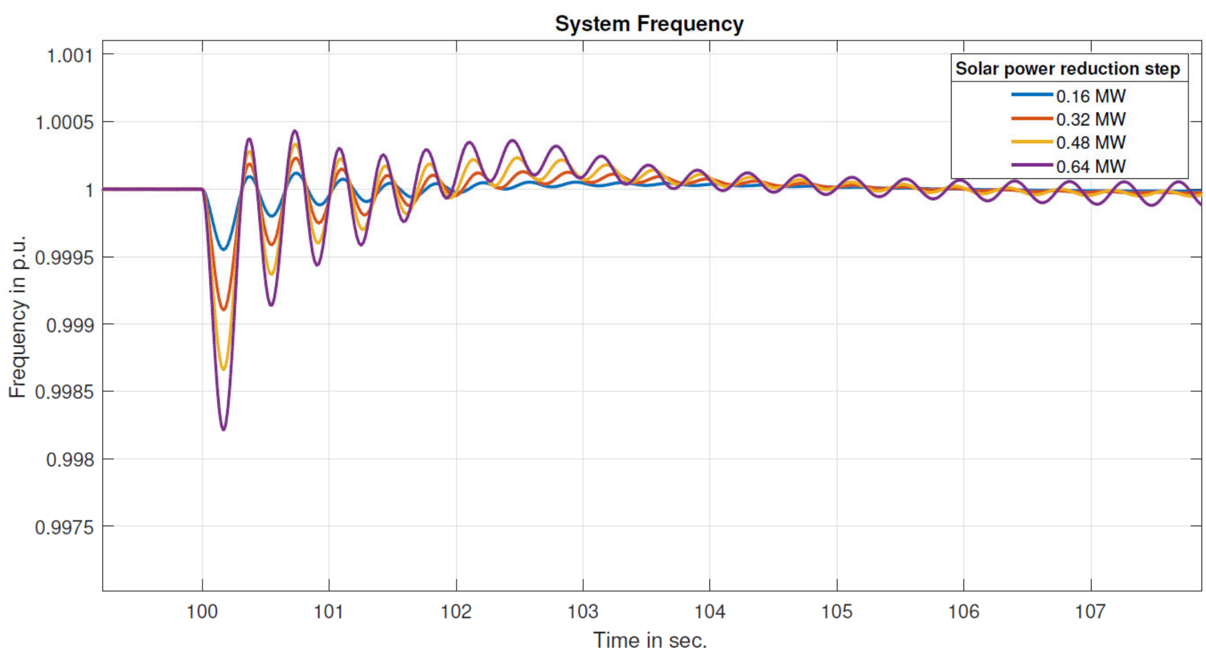

Fig. 15. Time-domain frequency response to step changes in PV inverter set-point with steps of 160 kW in the system with SG emulator.

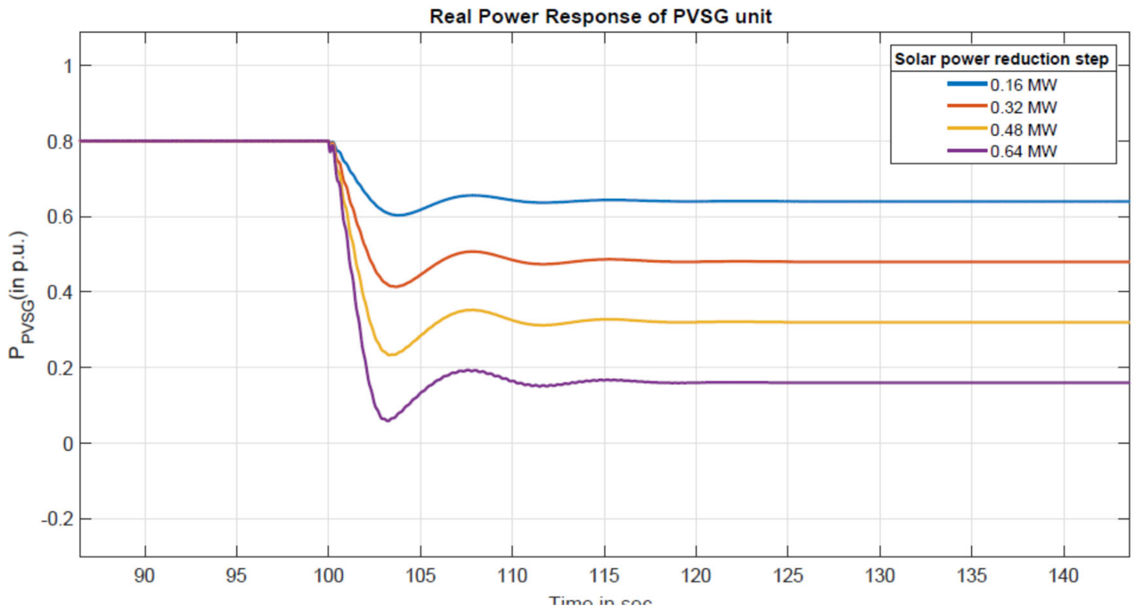

Fig. 16. Time-domain PVSG power response to step changes in PV inverter set-point with steps of 160 kW in the system with SG emulator.

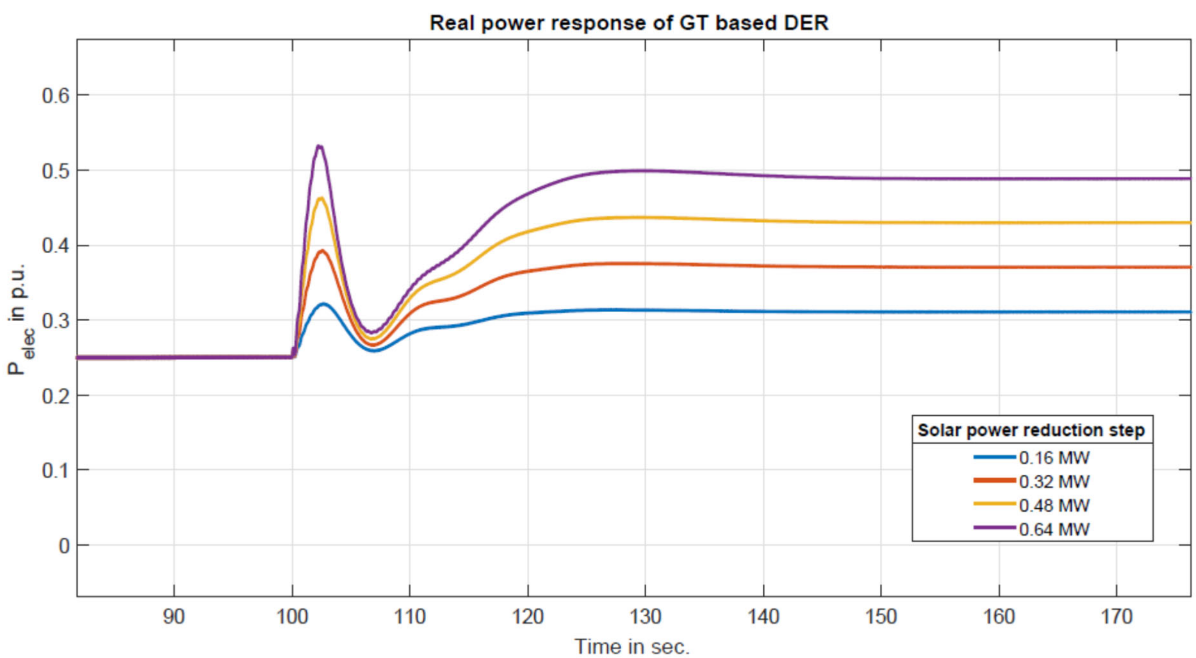

Fig. 17. Time-domain gas turbine power response to step changes in PV inverter set-point with steps of 160 kW in the system with SG emulator.

3.5 Technical Presentations and Live Demonstration

Several technical presentation and live demonstration of the PVSG system conducted for the researchers from academia, DOE, and industry at CAPER meetings and also in Semiconductor Power Electronics Center (SPEC), University of Texas at Austin, Austin, TX that are illustrated in the following figures.

Fig. 18. Project Progress presentation at Fall 2018 CAPER meeting in Charleston, November 15, 2018.

Fig. 19. Project Progress presentation at spring 2019 CAPER meeting in Raleigh on Mach 28, 2019.

Fig. 20. Project final presentation at Fall 2019 CAPER meeting in Charlotte on November 15, 2019.

Fig.21. Live PVSG Demonstration to Duke Energy, Austin Energy, and Clemson University on October 7, 2019.

Fig.22. PVSG Demonstration to DOE guests on November 7, 2019 and January 29, 2020.

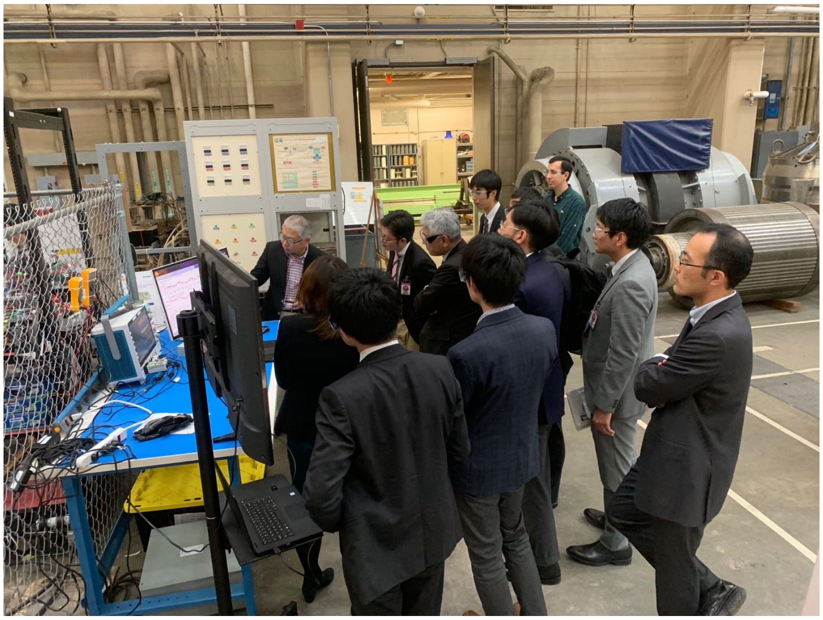

Fig.23. Demonstration to Japanese researchers from NEDO, TEPCO, Chubu Electric Power Company, Chugoku Electric Power Company, Kyushu Electric Power Company, Kansai Electric Power Company, Japan Electrical Manufacturers' Association and Mitsubishi Research Institute, Inc on November 18, 2019.

Fig.24. Live PVSG Demonstration to ERCOT and Austin Energy on February 4, 2020.

/A

Loyd Ray Farms, Inc.
Innovative Animal Waste Management System
Permit No. AWI990031
Permit Compliance Semi-Annual Report

January 1, 2019 – June 30, 2019 Semi-Annual Reporting Period

Submitted July 31, 2019

Submitted on Behalf of:
Loyd Ray Farms, Inc.
2049 Center Rd.
Boonville, NC 27011

This Annual Compliance Report provides an overview of the manner in which the subject facility, Loyd Ray Farms, has maintained compliance with the conditions of the Innovative Animal Waste Management System permit for the reporting period from January 1, 2019 through June 30, 2019. During this reporting period, the system was operated in accordance with the Innovative Swine Waste Treatment System and subject to the requirements thereof. Additionally, detailed site visits recording maintenance and repairs completed during the second half of 2018, from July 1 through December 31, 2018 are also included in this report.

In summary, From January 1, 2019 through June 30, 2019, although the processes that comprise the innovative swine waste treatment system were periodically fundamentally operational, and the electricity generation was capable for some of the reporting period, difficulties with the SCADA system after a power outage disrupted much of the data for this reporting period, much of which was unrecoverable. Overall, the system was less functional than the previous reporting period, as repairs on the digester pump and digester cover were necessary, but the monitoring team made every effort to keep things running as efficiently as possible in accordance with power generation, and from the perspectives of greenhouse gas emission reduction and environmental performance. The maintenance activities were a little more accelerated as the system is getting older, however the repairs made at the end of this period should keep the system functioning well for quite some time. Actual observation logs of system performance are exhibited in the operator log attached to this report. (Appendix A). In addition to addressing compliance with the conditions of the permit, the following summaries provide an overview of the system operations including graphs of systems performance, the Microturbine performance, and biogas levels (page 3). Sampling and reporting requirements per the Innovative Animal Waste Management System Permit No. AW1990031 can be found on (pages 30--32). For each requirement, this report records on-site monitoring that occurred, with a brief explanation for each farm site visit. The Operations Log data for January through March 15th is missing, as the data lost from the SCADA system and computer was unrecoverable, but starting with March 15th, it appears on (pages 19-27).

Also due to SCADA issues during the reporting period, it was impossible to estimate the uptime of the environmental treatment system, or microturbine output production. Downtime resulted from maintenance activities which are further described in the Operations Logs (Pages 19-27).

This report was completed on behalf of Loyd Ray Farms, Inc., by Cavanaugh & Associates, P.A., under the direction of the Duke Carbon Offsets Initiative (DCOI). Please contact Matthew Arsenault with any questions at 919-613-7466 (Matthew.Arsenault@duke.edu). A copy of this report will be provided to Loyd Ray Farms, Inc., and will be maintained on-site with the other permit compliance documentation.

Overview of System

The animal waste treatment system installed at Loyd Ray Farms is designed to meet the Environmental Performance Standards set forth by North Carolina law for new and expanded swine facilities through the use of nitrification/denitrification and further treatment. This report confirms on a semi-annual basis that the innovative waste management system is in compliance with NC Department of Environmental Quality and its divisions, to insure that the utilization of the anaerobic digester technology to turn raw animal waste into biogas for the purpose of reducing greenhouse gas emissions minimizes the overall environmental impact of the swine farm, and explains the occurrences of operations, and testing requirements over the six month period, to monitor the system, as it continues to produce renewable energy, generate carbon offsets, and reduce odor on the farm. The report is designed to not only show a synopsis of the maintenance activities on the farm, but also to supply the analysis of the system's performance and further describe the results of the monitoring and testing activities.

During this compliance period, ambient air analyses during the Spring and Summer months were accomplished on March 14, 2019 and June 13th, 2019, respectively, details of the monitoring events have been added to this report (pages 35-40). The air emissions from water surfaces were found to be in compliance and show that the system is performing according to expectations.

Overview of System Maintenance and Repairs

Maintenance and repairs completed during the second half of 2018, from July 1 through December 31, were included in the Semi-Annual report submitted to NCDENR DWR in January of 2019; and are hereby incorporated by reference. For the time period from January 1, 2019 through June 30, 2019, which is the period covered by this report, most processes that comprise the innovative swine waste treatment system were operational, however, as mentioned the system was less functional due to necessary repairs to the digester pump, digester cover and to the SCADA system. Unfortunately, because of the data system crash in April, we could not recover the data from January 1st through April 9th, so the graphs represent only the dates for which recorded data was available from the SCADA system. The same is true for the period of June 20th through June 27th due to an internet connectivity issue. The SCADA system started recording again on June 28th, the date of the repair.

Figure 1. below depicts the Microturbine Output in kilowatt hours (kWh) during the compliance period. Biogas flow is also monitored and recorded for the system. The biogas may only be disposed of through use by the microturbine and flare, controlled release through venting, or leaks from the system, which cannot be measured. The following graph illustrates the measured biogas usage for the system. During the months of January through April 9th, the zero-flow recorded is indicative of the disruption with the data acquisition system, which has rarely occurred during the entirety of the monitoring. The following chart normally depicts the same dataset for the duration of the reporting period, however, because we were experiencing difficulties with the SCADA system particularly from the beginning of January to April 9th, the results are perceived as no flow, however the system was under operation and working for much of that time period. The microturbine output was averaging about 50 per kilowatt hour for most of the monitoring period that was recorded, but again is missing the information from June 20th to June 27th.

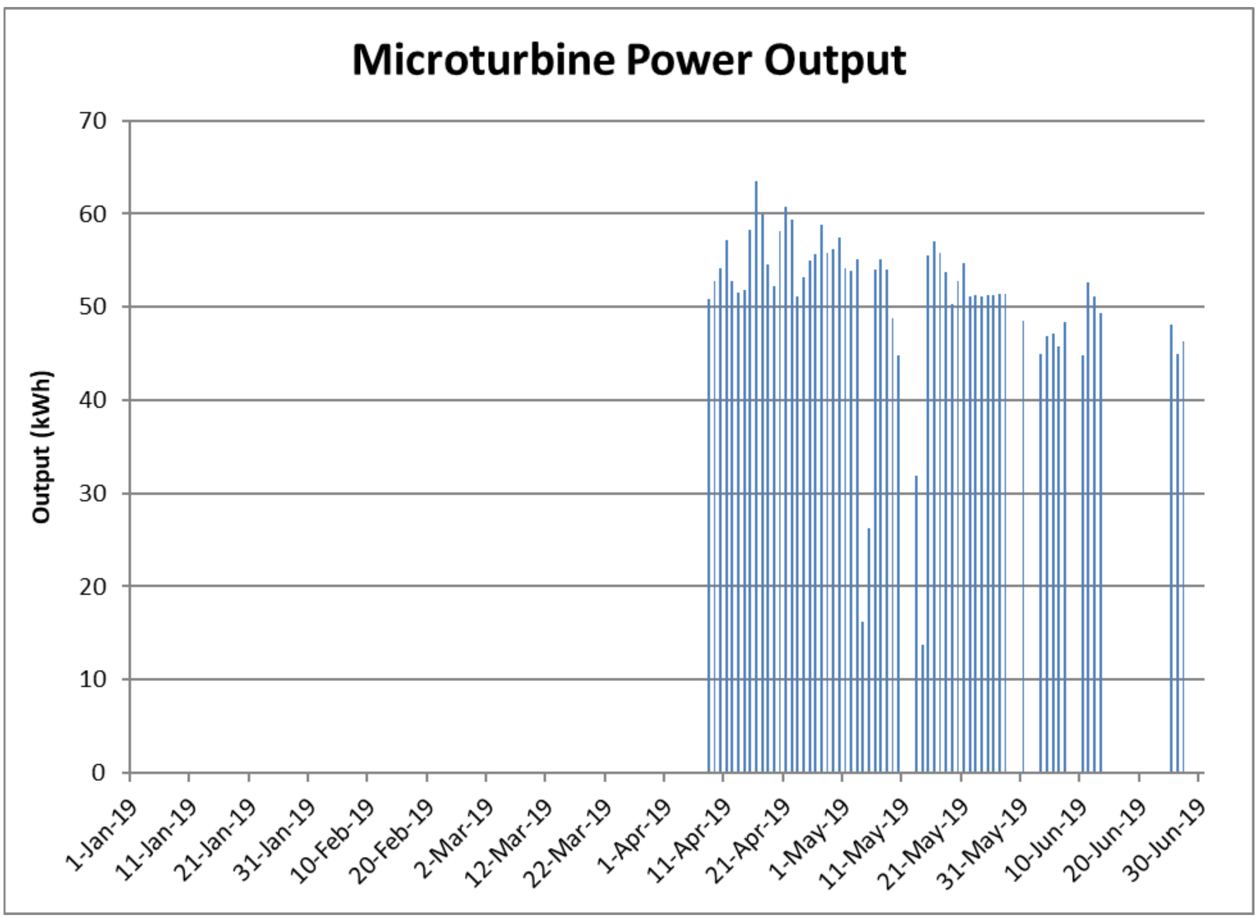

Figure 1. Microturbine Output in Kilowatt Hours (KWh) (January 1, 2019 -June 30, 2019)

Figure 2., *Measured Biogas Flow and Flare Usage*, which follows, depicts the dataset relative to the measured biogas flow and flare usage, which utilizes the same dataset for the duration of the compliance period. Similar to the Microturbine Output graph above, this graph also depicts the data loss for the months of January through April 9th and the period from June 20th through June 27th, of the reporting period. Once the required maintenance activities were accomplished, and the system returned to operational, the performance was normalized. The volume of gas is measured in standard cubic feet per minute (SCFM). Prior to May 1st, the system was averaging approximately 20 SCFM of biogas flow, which increased to an average of 23 SCFM in the months of May and June, with a few intermittent spikes on days of very high gas flow reaching to 30 SCFM or above.

The following graph illustrates the measured biogas usage for the system. Flare usage, as indicated by measured flow to the flare meter, for the reporting period may also be surmised from the graph. The flare was not operational from early April through June 30th due to a blockage in the flare's flame arrestor. It should be noted that days that indicate zero flow may also indicate a disruption with the data acquisition system, as described above. Microturbine flow is shown in red.

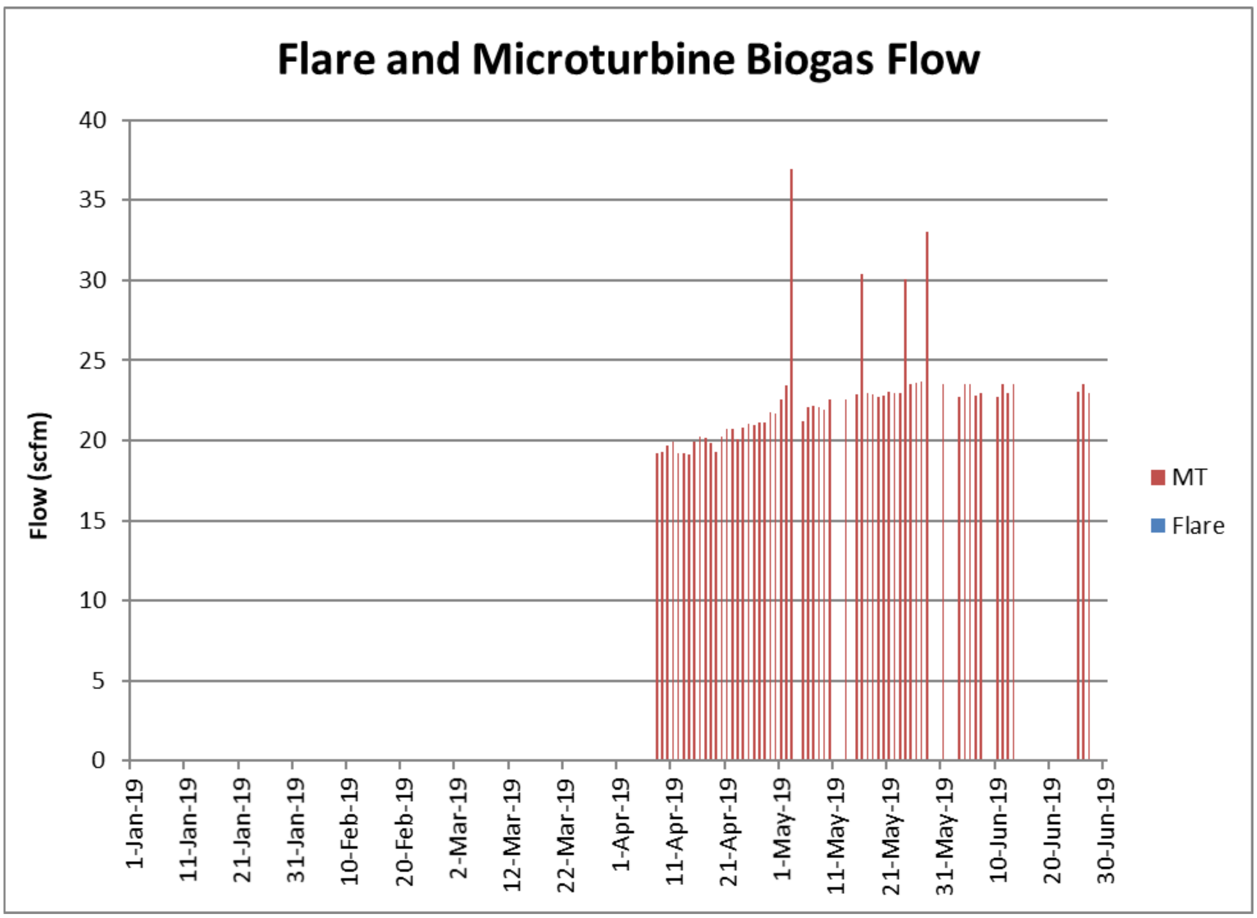

Figure 2. Measured Biogas Flow and Flare Usage (SCFM)

Environmental Treatment System

Figure 3. below, **Environmental Treatment System Uptime**, depicts the operation of the aeration system that performs the nitrification function for the monitoring period. The environmental treatment system was running for most of that period, although the inconsistent data makes it impossible to estimate an overall uptime. The data for the time period prior to April 9th was lost due to the SCADA issues. Just after April 9th, the data estimates the environmental treatment system reached its culmination point and was operating for almost 22 hours per day, but went down again in the start of May. The Loyd Ray Farms Inspection and Operation Log Sheets detail the activities which required repairs, which included repair of the digester pump, the breaker, and ordering new circuit boards for installation. Unfortunately, the SCADA issues were not resolved until the last few days of this monitoring period.

Figure 3., *Environmental Treatment System Uptime*, normally reflects the uptime for the compliance year (January 2019-June 30, 2019), but the percentage is hard to estimate due to the recording issues aforementioned in this report. Extraordinary circumstances caused the circuit board fans to cause systematic shutdowns, which required manual reboots, however, it could not continue running for long.

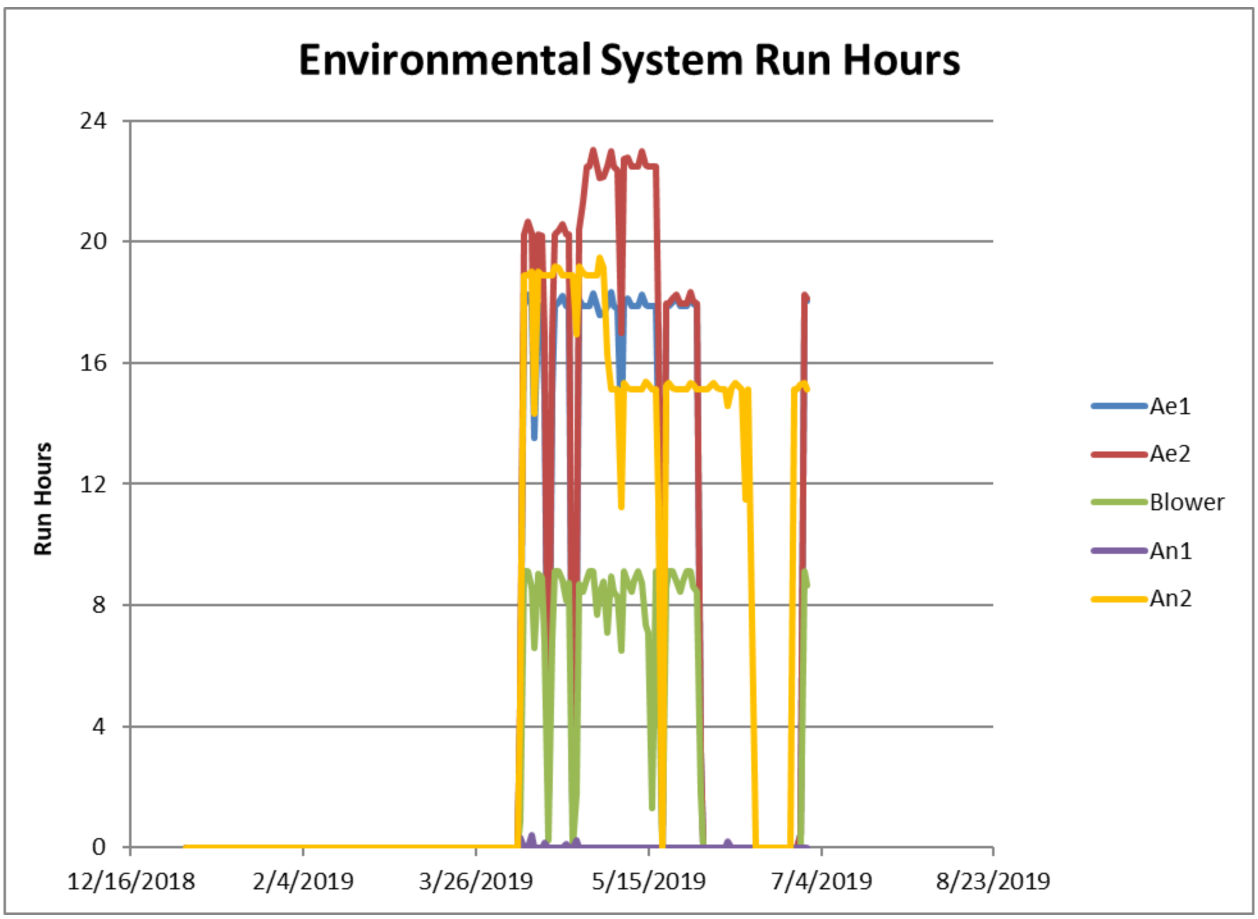

Figure 3. Environmental Treatment System Uptime (January 1, 2019 -June 30, 2019)

Figure 4., *Microturbine Run Hours*, normally reflects the uptime for the compliance period (January 2019-June 30, 2019), but the percentage is hard to estimate due to the recording issues aforementioned in this report.

The missing data from January through April 9th shows downtime. After April 10th, the monitoring indicates that the microturbine was running almost 24 hours daily, but was short-lived only until the start of May when problems arose with the digester pump, and the SCADA issues could not immediately be resolved.

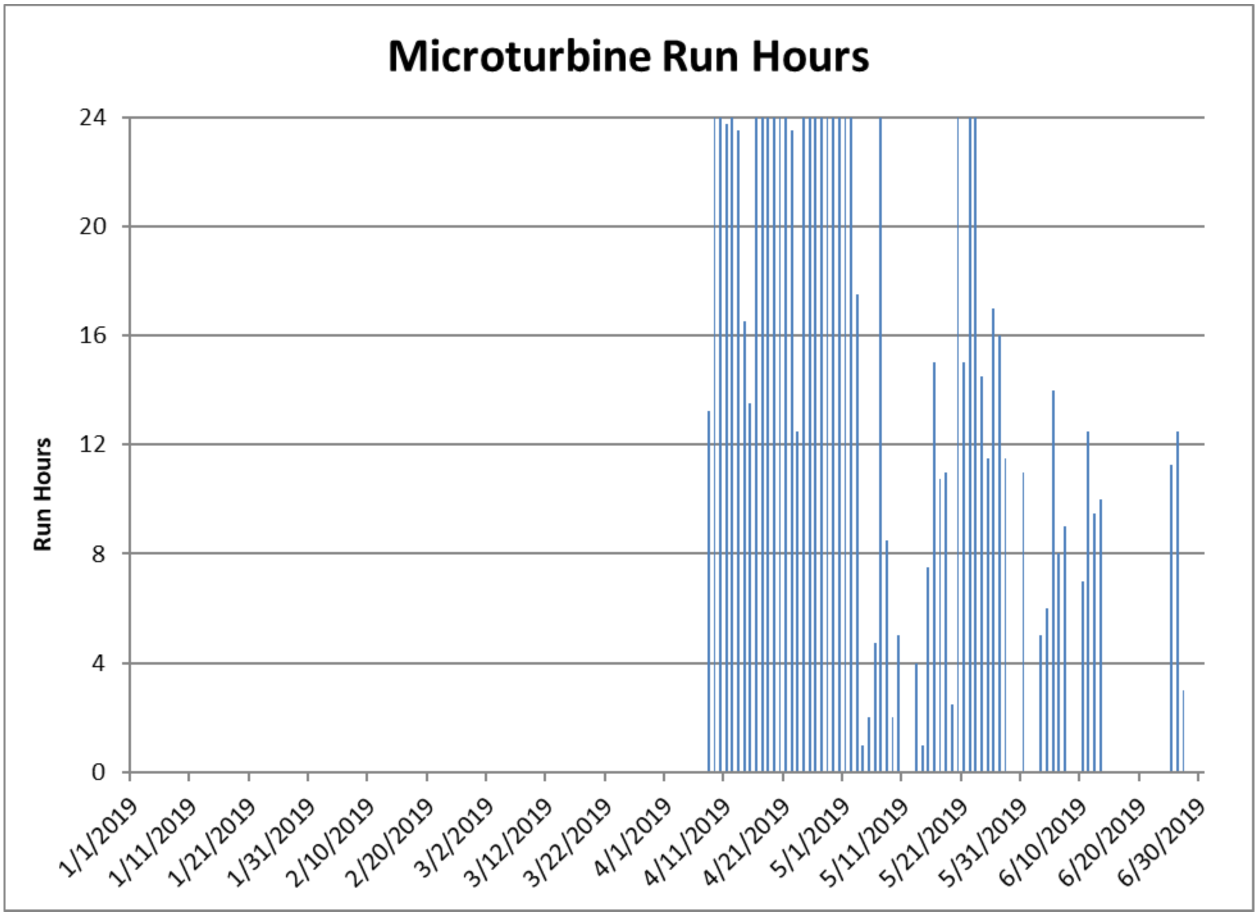

Figure 4. Microturbine Run Hours (January 1, 2019 -June 30, 2019)

Overview of System Maintenance and Repairs

Overall, the biogas system and the environmental treatment system operated in compliance with the requirements of the permit during the reporting period. We did, however, encounter some problems with transmission of the data due to weather-related occurrences which caused the Microturbine to fault, and precipitated frequent site visits to reboot the system. We also recorded some biogas conditioning skid downtime due to the hot weather. All maintenance which required troubleshooting by site visits or outside technical support appears in the log below, as maintained and recorded physically in the **Loyd Ray Farms Inspection and Operation Log Sheets**. In this six-month period we also experienced SCADA data acquisition system downtime, which impaired our ability to record all the data from the operating systems. During this time, monitoring was a little more labor-intensive for the Cavanaugh team who did their best to monitor the system in person, and log the activities in the report. While several efforts were made to repair the SCADA system, the SCADA repair, which required work on the circuit boards, was not fully accomplished until June 28th, at the end of this recording period. The electrical technician working on the circuit boards determined, in his opinion, that the turbine SCADA issues, which were initiated by storm damage, may be a result of an errata in the SCADA programming; likely a result of a loss of the SCADA computer hard drive and reinstallation of the software. Unfortunately, we were unable to recover a portion of the lost data, and thus, there is a gap in the Operation Log Sheets from January through March 15th.

In early April, the Cavanaugh monitoring team requested a necessary repair of the digester mixing pump. In anaerobic digester systems, the mixing pump is crucial for recirculating the sludge so it does not separate into layers, and keeps the sludge moving to prevent incomplete digestion, scum formations or settling of the feedstock composition into layers. It took some time to get the technician out to the farm but after diagnosing the problem, the technician explained that the mixing pump loses prime due to high sludge levels, and found that the rotating unit of the pump needed to be replaced. While the digester pump was not working properly it created pockets of gas all over that we were unable to vent, and it was more gas than the microturbine could burn. All replacement parts were identical parts of the existing pump, as were the filters that were replaced. Another purchase was a water removal cover pump to remove extra water on the cover, which again was the replacement of the same pump previously used.

Another major expense this year was the digester cover repair which was necessary because of storm damage. After a visit to do an analysis of what the work entailed, Plastic Fusion Fabricators submitted a price proposal estimating the cost of repairs, which were approved by Duke University and accomplished by Plastic Fusion Fabricators at the end of May.

The summary of the detailed operations log of on-site activities and monitoring for the period of January 1, 2019 through June 30, 2019 is presented as follows. The site was monitored by Kevin Harward and Marvin Cavanaugh in January 2019, by Marvin with backup from Steve Cavanaugh from February through May 30, 2019, and by Ben Cauthen and Steve Cavanaugh with coaching by Marvin Cavanaugh in June. The records below described the observances, and the presence of others who visited Loyd Ray Farms to do testing or repairs.

Date	Observation
7-2-2018	Monitored system remotely
7-25-2018	Site Visit to meet with Alex Gusnes of E-finity. We serviced the Microturbine (MT) and replaced air filter and the faulty fan we had been running. We found a faulty Rosemount meter which was registering incorrectly going to the MT. Also pumped surface water and did a site inspection.
7-27-2018	After remote monitoring, did a site visit. Pumped surface water and did a walk around site check. Turned flare on with 10 CMF going to flare.
7-30-2018	After remote monitoring, did site visit. Pumped surface water and performed site check. Flare off the balloon is getting low, as 5 of the 9 hog farms are empty. I installed a temporary

	cover for gas MH and dug a small ditch to help divert water away from the MH. Most operations automatic, with the exception of flush pumps by hand.
7-31-2018	Remote system monitoring during storms and heavy rainfall.
8-1-2018	Remote system monitoring, then site visit to inspect and review storm damage. After 6 inches of rain, worked all day with all entities to try and restore system back to normal operations. Monitored operations after storm damage trying to keep it running
8-2-2018	Remote system monitoring, then site visit to review storm damage. After 6 inches of rain, worked all day with all entities to try and restore system back to normal operations. Monitored operations after storm damage trying to keep operations running in stable mode.
8-3-2018	Monitored system remotely, checking to make sure post storm operations are normal.
8-6-2018	Monitored system remotely, then site visit to try and start the system. The gas balloon is growing, I started the flare, and pumped surface water and nursed the system to run. It failed twice due to heat, the outside temperature was in the 90's today.
8-7-2018	Monitored system remotely, then site visit to restart and monitor the operations. I shut the Flare off, as the balloon reach the level needed to shed rain. Pumped surface water and nursed the system to run. Communicated with reps at Unison and E-finity. A technician from E-finity is scheduled to be here on Thursday.
8-11-2018	Monitored system remotely, then site visit to do a restart after skid shut down because the MT would not start remotely. I ran a test and found that the MT failed to restart automatically after a skid shut down, so I started the flare. I will do a follow-up email with Nick at Unison.
8-13-2018	Site visit to do a restart of system with E-finity. We had a good start up, but now a skid warning for 33/342 reheat temp at 2:45 p.m. Will do a follow up email to Nick at Unison.
8-14-2018	Site visit to do a restart of system with E-finity. After the heat up at 2:45 p.m. yesterday, the skid was restarted, but the MT would not start, so I shut it down. I have restarted the skid today and will get E-finity to unblock the MT, and re-start it. Did a walk around inspected the system and started the auto pump for surface water.
8-16-2018	Monitored system remotely, Site inspection. Started the surface water pump. During the night, the Flare would not start. I turned on the mail at the MT, and it ran fine. I took influent, digester and effluent samples.
8-19-2018	Monitored system remotely, we had a shut-down today (Sunday). This was due to the outside temperature, after it cooled, I accomplished a successful restart of both the skid and the MT.

8-20-2018	Walk around inspection and site visit, operations are working normally.
8-21-2018	Monitoring system remotely, experienced a couple of shut downs, but was able to restart remotely.
8-22-2018	Monitoring system remotely, experienced a couple of shut downs, but was able to get back on line remotely.
8-23-2018	Site visit to meet with Matt Arsenault, Alex Gusner of Duke University, and Sarah Lanier (a student there). We took samples from the Lagoon Basin and Digester and also gas samples. I performed a site inspection and restarted the automatic pump and another non-automatic pump to handle surface water on the cover. System operations are normal.
8-27-2018	Site visit to do an On-site inspection, system and ground check. I worked on the camera with little success, system operating normally.
8-29-2018	After remote monitoring, did a site visit, tried to adjust the camera, system operations are running normally.
8-30-2018	System monitored remotely, then Site visit to do a system and ground check. Found the Unison system down. I tried to hard boot it, with no success. Unison is scheduled to be here on 9-10-2018, and I will call Unison to discuss.
9-5-2018	Remote monitoring this week.
9-10-2018	Site Visit. Met Marty Kass of Unison there to do service work. Flare is burning gravity gas. We found out we had no power. I called Salem Electric to do an emergency visit. They think the transformer is bad, and are checking on a source for a replacement one.
9-11-2018	We are still without power. Marty Kass of Unison, and Keith and Bryan from ProPump were on site, and I asked them to assess the no-electricity situation. They found the phase converter was bad, which showed like a bad transformer. They took down the two-phase converters and will ship them off to be rebuilt. They are also troubleshooting to change the flush pump from 3-phase to single phase, and are working to rebuild the IT. Marty Kass of Unison could not finish his service, and went to another job close by.
9-12-2018	ProPump returned with the converter rig for the flush pump and wired it inside the building to the pump with Kevin's help. We were able to get it back online and were able to flush.
9-13-2018	Flare is burning gravity gas. Kevin and Marvin worked to unclog the digester pump, but it is still clogged.
9-14-2018	Flare is burning gravity gas. Site visit to monitor operations and to prep for upcoming Tropical Storm Florence, which may be a hurricane.
9-15-2018	Monitored system remotely, flare is burning gravity gas.

9-15-2018	Monitored system remotely, then site visit to check system and water levels, flare is burning gravity gas.
9-16-2018	Remote monitoring, Flare is burning gravity gas, Site visit to check system and water levels.
9-17-2018	Remote monitoring, Flare is burning gravity gas
9-18-2018	After remote monitoring, went to Site to do a system and ground check. Found digester pump still clogged, tried to back flush system, but was not able to get valves open. The balloon is growing so I vented for one hour. The auto bilge pump failed, so I pumped surface water with two pumps for two hours.
9-22-2018	Remote monitoring, then site visit to check gas levels. Still flaring, but only had to vent once.
9-23-2018	Monitored system remotely, No Site visit today. System is still flaring, but not venting, only once.
9-24-2028	Monitored system remotely, No Site visit today. System is still flaring, but not venting, only once.
9-25-2018	Site visit to do a system and ground check, and found the digester pump still clogged, tried to backflush to see if I could unclog. I am still flaring but vented only once. The auto bilge pump failed so I pumped surface water with two pumps for the entire visit.
9-26-2018	Site visit to do a system and ground check, and found the digester pump still clogged, tried to backflush to see if I could unclog. I am still flaring but vented only once. The auto bilge pump failed so I pumped surface water with two pumps for the entire visit.
9-27-2018	Site visit to do a system and ground check, and found the digester pump still clogged, tried to backflush to see if I could break it free. I finally got the Digester pump to work, and plan to let it run all night to get it cleaned out. Still flaring the gas, vented only once. The auto bilge pump still failing, so I pumped surface water with two pumps for the entire visit.
9-28-2018	Site visit to do a system and ground check. Found the digester pump still working, so I moved it to the auto cycle. Pumped surface water during the site visit, vented at 2 ports for two hours.
10-1-2018	Site visit for system and ground check. Found digester pump still working, so I kept it on the auto cycle. Pumped surface water during the site visit.
10-2-2018	Site visit for a system and ground check. Operations are normal and the digester pump, remains on auto cycle. Pumped surface water. Conducted a tour of Duke University students and professors who came to observe operations.

10-3-2018	Site visit for a system and ground check. Digester pump still operating correctly, remains on auto cycle. Pumped excess surface water during the site visit.
10-4-2018	Monitored system remotely, no Site visit today.
10-5-2018	Site Visit to do a system and ground check and found our digester pump still working so I kept it on the auto cycle. Pumped surface water during site visit. Vented at two ports for 2 hours
10-6 & 10-7	Monitored system remotely without incidence.
10-8-2018	Site Visit to do a system and ground check and found digester pump still working so I kept it on the auto cycle. Pumped surface water during site visit. Met with Josh Amon to get the repaired Digester Pump installed. We worked on getting pumps unclogged, we are going to try to run as long as possible but not leave them unattended for a while, as sometimes they clog up and no fluid is being pumped.
10-9-2018	Site Visit for system and ground check, digester pump still working. Pumped surface water during site visit. I changed the timers and after the Digester pump restarted with a prime, I am going to try it through the evening.
10-10-2018	Site Visit to do a system and ground check and found our digester pump still working. Pumped surface water during site visit. I changed the timers and after the Digester pump restarted with a prime I am going to try it through another evening.
10-11-2018	Pumped surface water during site visit. I changed the timers and after the Digester pump restarted with a prime I am going to try it through another evening. Heavy rains from Michael with some flooding in the ditch. Mr. Bryant not happy with the ditch. Lost power for an hour or so all back running and seeing breaks in the clouds
10-9-2018	Site Visit for system and ground check, digester pump still working. Pumped surface water during site visit. I changed the timers and after the Digester pump restarted with a prime, I am going to try it through the evening.
10-10-2018	Site Visit to do a system and ground check and found our digester pump still working. Pumped surface water during site visit. I changed the timers and after the Digester pump restarted with a prime I am going to try it through another evening.
10-11-2018	Pumped surface water during site visit. I changed the timers and after the Digester pump restarted with a prime I am going to try it through another evening. Heavy rains from Michael with some flooding in the ditch. Mr. Bryant not happy with the ditch. Lost power for an hour or so all back running and seeing breaks in the clouds

10-12-2018	Pumped surface water during site visit. I changed the timers and after the Digester pump restarted with a prime I am going to try it through another evening. The Flare continues to run on gravity gas flow of 8-10 CFM I needed to vent today at two ports for 2.5 hours
10-14-2018	Monitored system remotely, particularly the flare.
10-15-2018	Site Visit to do a system and ground check and found our digester pump still working. Pumped surface water during site visit. The timers are working well with the restart of the Digester pumps. I am going to leave them as they are for now. The Flare continues to run on gravity gas flow of 8-10 CFM. No venting since Friday 10-12-2018.
10-17-2018	Pumped surface water during site visit. The timers are working well with the restart of the Digester pumps. I am going to leave them as they are for now. The Flare continues to run on gravity gas flow of 8-10 CFM. No venting since Friday 10-12-2018.
10-18-2018	Remote monitoring
10-19-2018	Pumped surface water during site visit. The timers are working well with the restart of the Digester pumps. I am going to leave them as they are for now. I worked on Drainage some. The Flare continues to run on gravity gas flow of 8-10 CFM. No venting since Friday 10-12-2018.
10-21-2018	The Flare continues to run on gravity gas flow of 8-10 CFM. No venting since Friday 10-12-2018.
10-22-2018	Site Visit to do a system and ground check and found our digester pump still working. Timers continue to work well, worked on drainage more. No venting since Friday 10-12-2018.
	Site Visit, no changes since yesterday.
10-24-2018	Site Visit, Pumped surface water during site visit. The timers are working well with the restart of the Digester pumps. The Flare continues to run on gravity gas flow of 8-10 CFM. No venting since Friday 10-12-2018.
10-25-2018	Site Visit, no change since yesterday.
10-26-2018	Site Visit needed to check system the team viewer was not working dependably we need to install cameras ASAP to save on visits. Timers still operating correctly to restart pumps. No venting since 10-12-2018.
10-28-2018	Monitored system remotely.
10-29-2018	The Flare continues to run on gravity gas flow of 8-10 CFM. No venting since Friday 10-12-2018. Technicians from ProPump were on site installing the Phase converters and setting up for the wiring changeover of Flush Pump from 1 Phase back to 3 Phase

10-30-2018	ProPump was on site installing the Phase converters and setting up for the wiring changeover of Flush Pump from 1 Phase back to 3 Phase, Kevin Harward joined us to assist. We put boat in Basin for the wiring change on the Flush Pump.
10-31-2018	Site visit, Kevin Harward came to the farm to install a power part on the Unison system. We attempted to start the system, but the chiller had a failure and would not start. We are trying to get help resolving the problem. ProPump will probably need to come back and help with the SCADA. Kevin and I moved the hose to push some of the digester sludge water to the Lagoon
11-1-2018	Site visit to accomplish a manual restart after an overnight failure, then working with folks from ProPump, trying to get SCADA to communicate with the Unison skid. The MT and skid were running again and no flare. Talked to ProPump via phone to set up for the SCADA repair.
11-3-2018	Steve Cavanaugh made a Site visit to start the conditioner. The MT failed after several tries it shut down.
11-4-2018	Site visit to start conditioner and MT. I found conditioner running but the MT not running and SCADA not recording properly. The MT failed after several tries it shut down. I then did a hard boot and it has been running since 11:05 AM. The MT is producing 59.6 output 54.9 on 18.3 CFM. I will monitor and keep records of output until SCADA can be fixed.
11-5-2018	Bryan from ProPump came to farm to work on SCADA, I was able to talk him through a restart. He had to drain the water from the gas pump on the south end of the skid and then the skid would start. I made a site visit to meet with Bryan. We were able to get the Skid and SCADA communicating and we are now running full bore. We have a lot of gas and I plan to stay as long as possible running both flare wide open; and the MT wide open burning about 50 CFM. I shut the Flare off at 4:30 PM
11-7-2018	I turned the flare off before I left on Monday and monitored remotely all-day Tuesday. Site visit today, the gas is still up, and the MT has been running since Monday.
11-8-2018	Site visit today, had a power blip that shut off team viewer, when I got to the site there were no alarms and the computer was back up the skid was just sitting there and not running, and the MT was in standby mode. Started the skid and when it was ready and sending to the MT; the MT would not start it was on, but not starting. I had to shut-off the breaker as before and when I turned it back on the MT started automatically. The gas volume is still up, and I will return tomorrow, and we may need to flare. Eight of the 9 hog houses are full of animals, loaded one out just now leaving the 8. The MT has been running since Monday,
11-9-2018	Site visit today, we have been running up until around 12:33PM we had a skid fault of high condensate at 741. I reset and restarted skid and the MT came on as it is supposed to at 2:00 PM. I started the flare to run while I am on site as the gas volume is still up. I did a walk around and up on the cover all is well. I installed a replacement fridge today. I received a new camera and will try and install it next week.

11-10-2018	Remote monitoring all day; we had three shutdowns and then late we had a MT fault. No site visit
11-11-2018	Site visit to restart the MT, as remote monitoring indicated a fault on the screen and the breaker had tripped. I had cut the skid off when the MT was in fault, so I restarted it, reset the breaker and opened the Flare valve. Everything restarted as it should have.
11-12-2018	Site visit to restart the MT I found a fault showing on the screen and the breaker had tripped. I had cut the skid off when the MT was in fault, so I restarted it, reset the breaker and opened the Flare valve. Everything restarted as it should have. This is the same as yesterday. I started the Gravity-flow Flare and it is running 10+ CFM, even though it does not seem to register on SCADA
11-13-2018	Remote monitoring, shutdown today, will do a site visit tomorrow.
11-14-2018	On Site Visit, I started the Gravity Flow Flare and it is running 10+ CFM even though it does not seem to register on SCADA and I am glad because we had a shut down on Tuesday.
11-15-2018	Site visit to restart system it refused to restart, but after 3 tries, I finally got the system restarted.
11-16-2018	Site Visit, due to shut-downs this week. I started the Gravity Flow Flare and it is running 10+ CFM even though it does not seem to register on SCADA and I am glad because we had a shut down on Tuesday and Wednesday and another during the evening on Thursday. Site visit to restart system and I found that the skid is not communicating with the SCADA and I am unable to start and stop or monitor skid data. I was able to re-start the skid and the flare continues to burn on gravity as above. The MT started as it should, and is running fine. I will monitor but if we shut down then it will be Sunday before I can manually restart. We need to burn all the gas that we can, the volume is high.
11-18-2018	During the evening on Thursday and again after site visit on Friday we had shut-downs. Monitored off and on Saturday, Flare burned at 10+CFM all the time. We need to burn all the gas that we can the volume is high. Site visit to try and restart system I had to do a hard boot of the Skid and the MT before I could get the System to run properly. When I did the hard boot on the Skid the communication with SCADA came back?? We are up and running again.
11-19-2018	Site visit to try and restart system Kevin restarted and was able to re-establish the communication Skid to SCADA by resetting at the panel several times. The MT started as it should at 12:52 PM. We started the flare through the conditioner and opened 2 vents at 1:45 PM. We had a shutdown at 3:16 PM and a quick restart. We shut the vents off at 3:45 venting for 2 hours. I cut the flare off coming through the Skid and restarted the Gravity Flow Flare and it is running 10+ CFM.

11-20-2018	Kevin and Marvin did a Site visit and took quarterly water samples. Had to reset the communications on the Unison panel as it shut down yesterday, acting like power is lost on the panel or something is going bad. Able to restart Skid and MT at 10:30a.m. Contacted Unison to let them know the issues hopefully get it fixed and or schedule a site visit soon. Think we have 2 bad level switches on the skid, they keep tripping-off and on, for 5- 30 seconds, once they are on for 30 seconds, the alarm is tripped, one is a high-level switch and is causing a shut down, again will let Unison know. We installed the new camera and set it up on team viewer. We did a walk around and up on top to check for leaks
11-21-2018	We did a site visit to restart same problem shutdown for condensate that is not there and faults out, so we cannot restart remotely but have to go to site to manually restart. Gravity Flare is burning at 10+ CFM
11-22-2018	Monitored system remotely most of week, trying to burn all the gas we can while the volume is high.
11-26-2018	Had to reset the communications on the Unison panel which shut down yesterday, acting like power is lost on the panel or something is going bad, was able to restart Skid and MT at 4:00PM. I emailed Unison to try to troubleshoot site issues and requested a site visit hopefully to get it fixed as soon as possible. Think we have 2 bad level switches on the skid, they keep tripping off. We did a site visit to restart, without success. The same problem occurred; shutdown for condensate that is not there, and the system short circuits, or faults out, disrupting the normal flow of the system, so we cannot restart remotely but must visit the site manually to restart. Gravity Flare is burning at 10+ CFM Started venting at two vents at 4:05 PM and closed them at 5:05 PM. By the time I got home at 8 it shut down.
11-27-2018	Monitored all during the night to see if flare was continuing to burn at 10 CFM. Site visit today to restart the system. I shut off the Gravity Flare at 11:00 AM and opened the valve and flared with gas through the skid at feed=28.4 and flow = 21.4 CFM. The skid is running with the fault light showing on SCADA, but the MT and skid are running full. Every shut down, or system failure, is requiring an on-site visit. At 2:00 PM I went back to Gravity Flare at 10+ CFM. The skid and MT have been running 4 hours. The red fault light is still showing on SCADA, but the system is running, and it will continue to fault out. We need to burn gas and make KWs. System shutdown at 3:10p.m. Flare continued to burn at 10+ CFM
11-28-2018	Monitored all during the night to see if flare was continuing to burn at 10 CFM. Site visit today to restart the system. I shut off the Gravity Flare at 2:38p.m. and opened the valve and flared with gas through the skid at feed=30.4 and flow = 25.4 CFM. The skid is running with the fault light showing on SCADA, but the MT and skid are running full. At 2:00p.m., I shut the system down and did a hard boot and this time the fault light on SCADA picture of the skid went off and the Unison screen started registering data. At 2:08 p.m., we are running full bore. Back to Gravity Flare at 10+ CFM. The skid and MT have been running 4 hours. The red fault light is still showing on SCADA, but the system is running, and after troubleshooting I discovered we need to burn gas and make KWs. System shutdown at 3:10p.m., re-fired at 4:10p.m., shutdown@5:27p.m., restart at 8:57-shutdown@11:57p.m. Flare continued to burn at 10+ CFM.

11-30 through 12-2-2018	Monitored all during the day and night to see if flare was continuing to burn at 10 CFM
12-3-2018	Monitored all during the night to see if flare was continuing to burn at 10 CFM. Site visit to restart system started at 11:45a.m. --Flared using skid at 24CFM 12:45p.m. until 3:50p.m. Reset gravity Flare at 10+ CFM for the night.
12-4-2018	Monitored during the night to see if flare was continuing to burn at 10 CFM. Site visit to meet with tech from Unison. Worked with Curt Schiesl of Unison to try to resolve the problem with the skid. I shut the flare off at 9:00a.m. He changed out switches and tried all kinds of things to keep it running. He had to order parts shipped overnight, and will continue troubleshooting tomorrow.
12-5-2018	Monitored system with Curt Schiesl, Field Service and Start-up Technician for Unison by computer and phone as he continued to try and fix the problem with the skid. He left for his home stating that he thought the problem was that the Phase converters were overheating. We had a shut down and panel fault as before.
12-6-2018	Site visit to restart the system and found we had a shutdown but no loss of power to panel, it just faulted as before. All I had to do to start the skid and MT running was to press the start button. I still do not have any data on skid panel screen, but we are running. We had a shutdown and showing no power to Unison panel. I did a hard boot to PC and after a short pause the Unison panel lit up with information, it ran for about 30 minutes and shutdown still showing power to the Unison panel. I restarted without any numbers and it is running; if and when we have a shutdown, it will have to be restarted by onsite visit. I started the Gravity Flare burning at 10+ CFM and plan for it to run until Monday regardless of what the Skid and/or the MT does.
12-11-2018	Site visit to restart the system and found we had a shutdown, but no loss of power to panel. The Gravity Flare has been burning at 10+ CFM continuously since I left on 12-06. I met with Norman and Bryan of ProPump and plan for it to run until Monday regardless of what the Skid and or the MT does.
12-12-2018	Site visit, met with ProPump and we continued to troubleshoot along with Doug from Unison.
12-13-2018	Site visit to restart the system and found we had a shutdown, but no loss of power to panel. The Gravity Flare has been burning at 10+ CFM continuously since I left on 12-06. Met with Bryan from ProPump and we continued to troubleshoot along with Doug from Unison. We added some new parts and it seemed to be fixed. Then in the evening we continued to have shut downs, Flare still running.
12-14-2018	The Gravity Flare has been burning at 10+ CFM continuously since I left on 12-06. Bryan from ProPump came to site and he installed a part and we were running. I monitored and sent text to Norman and Bryan of ProPump, and Doug from Unison. We added some new parts and it seemed to be fixed. Then in the evening we continued to have shut downs. Flare still

	running. I monitored all weekend during that time I lost communication due to a power Failure by Surry-Yadkin, Flare continued to burn.
12-17-2018	Site visit to restart the system and found we had a shutdown but no loss of power to panel. The Gravity Flare continued to burn all weekend. At 10.0+ CFM. I met with Bryan of ProPump and we spent the day troubleshooting system with concentration on Phase converter. With the help of a conventional fan we were able to cool Phase converter enough to run until we could get parts to repair. Started running at 10:50a.m. We shut the gravity flare off on the restart of the Skid and MT and ran the flare hard until 3:15 PM.
12-18-2018	Monitored system remotely by SCADA and Camera The system has been running from 11:00a.m. Monday without a shut down. Gravity Flare is off.
12-19-2018	Site visit to do a system check, the parts did not arrive, so after the inspection and repair of a small leak, I traveled home to return tomorrow. Gravity Flare is off.
12-20-2018	Site visit to do a system check. I met with Bryan of ProPump and he installed fans and circuit boards in Phase converter. We restarted system and we are up and running. The Gravity Flare is off.
12-21-2018	Site visit to do a system check. I met with Matt Arsenault of Duke U. We have been running solid since we replaced PC Fans yesterday. The Gravity Flare is off.
12-30-2018	Site visit to do a system inspection. The Gravity Flare is off. System was working but computer was down.
12-31-2018	Site visit to do a system check The Gravity Flare is off. System was working but computer was down again. Rebooted it again Checked and verified with Team Viewer home computer
	NOTE: The Data from 1-1-2019 through 3-14-2019 could not be recovered after the SCADA system shut down. We have restarted the log from the information available.
3-15-2019	Site visit for site inspection and monitoring water levels. We are still keeping the riser in the Basin to assist control of backflow from the Lagoon. I found that the computer was not working, as the hard drive is destroyed. I disconnected the unit and carried it to the Repair center. I am pumping surface water while I am on site.
3-17-2019	Site visit for site inspection and monitoring water levels. We are still keeping the riser in the Basin to assist control of backflow from the Lagoon. I installed the repaired computer with the new Hard Drive and tried to retrieve the data from backup but did not have the proper permissions. I am pumping surface water while I am on site

3-18-2019	Site visit for site inspection and monitoring water levels which are getting a little high, so I diverted some water to Lagoon. We are still keeping the riser in the Basin to assist control of backflow from the Lagoon. I tried the old LRF computer but it would not accomplish what I needed. I am pumping surface water while I am on site
3-20-2019	Site visit for site inspection and monitoring water levels which is so low, I have set the system to put all waste water into the Digester. We are still keeping the riser in the Basin to assist control of backflow from the Lagoon. The conditioner had shut down at 5:11 AM on 3-19-2019. On Site visit required as computer has crashed. I have called ProPump to get SCADA setup on the new Hard drive. I am pumping surface water while I am on site
3-22-2019	Site visit for site inspection and monitoring water levels we are low so I have set the system to put all waste water into the Digester. We are still keeping the riser in the Basin to assist control of backflow from the Lagoon. The conditioner has been running since our restart on March 20th. On site visits needed since computer crash. I have called ProPump to get SCADA setup on the new Hard drive. I am pumping surface water while I am on site. Ollie Frazier is scheduled to visit the farm on Tuesday the 26th to install data from BU. ProPump is scheduled to visit the farm on Thursday the 28th to install SCADA and tune up.
3-24-2019	Site visit for site inspection and monitoring water levels we are low, my observation was exactly the same as the visit on 3-22-2019.
	Ollie Frazier came to farm at 10:30 AM to work on restoring data back to computer. I conducted a site inspection and monitoring water levels we are low so I have set the system to put all waste water into the Digester. ProPump is scheduled to visit the farm on Thursday the 28th to install SCADA and tune up.
3-28-2019	Mike Nealy (of ProPump)visited the Farm at 8:30 AM to work on restoring data back to computer and to install SCADA and tune up. We could not get all the meters/gauges to show data on the computer but the camera is working and the power gauge is recording the power production which helps us to monitor remotely. I conducted a site inspection and monitoring water levels we are low so I have set the system to put all waste water into the Digester. We are still keeping the riser in the Basin to assist control of back flow from the Lagoon. The conditioner has been running since our restart on March 20th, but we shut down and did a restart today. I am pumping surface water while I am on site. I am still waiting on Josh Amon
4-2-2019	Marvin is working with Mike Nealy (of ProPump) to get SCADA working properly after the crash. The conditioner has been running since our restart on March 28th . We had to shut down and then restart on the 28th. I am pumping surface water while I am on site. I am still waiting on Josh Amon
4-5-2019	Marvin worked with Mike Nealy (of ProPump) to get SCADA working properly after the crash. I visited the Farm this afternoon to conduct a site inspection for monitoring water levels. We are low in the Basin so I have kept the system set to put all waste water into the Digester. We are still keeping the riser in the Basin to assist control of back flow from the Lagoon. The conditioner has been running since our restart on March 28th .We had to shut

	down and then restart on the 28th. I am pumping surface water while I am on site. I am still waiting on Josh Amon.

4-8-2019	Marvin visited the Farm today to conduct a site inspection for monitoring water levels. I worked with Mike Nealy (ProPump) remotely to get SCADA running properly after the crash. We have some data recorders running but not all. Mike pulled SCADA settings from the old DU computer and we picked up more meters that were working. We are needing to vent and run the gravity flare. We lost power causing a shutdown but when we booted back up the SCADA data was recording. The waste water levels are steady in the Basin, so I have kept the system set to put all wastewater into the Digester. We are still keeping the riser in the Basin to assist control of back flow from the Lagoon. The conditioner has been running since our restart on March 28th, except for a brief Power outage at 3:10PM. I am pumping surface water while I am on site. I am still waiting on Josh Amon for Digester pump repair.
4-11-2019	Tuesday and Wednesday I remotely monitored the system and worked with Mike and Gus trying to get data for reports, since we have been experiencing difficulties due to the crash. I visited the Farm today to conduct a site inspection for monitoring water levels. We needed to vent some today for 2 hours, as was the case Monday, we have been running the gravity flare since Monday, April 8th. It is only putting 7CFM but that helps to keep the balloon level at a good volume. The wastewater levels are steady in the Basin so I have kept the system set to put all wastewater into the Digester. We are still keeping the riser in the Basin to assist control of back flow from the Lagoon. The conditioner has been running since our restart on March 28th. I am pumping surface water while I am on site. I am still waiting on Josh Amon for Digester pump repair.
4-14-2019	Friday and Saturday Marvin remotely monitored the system and worked with Mike and Gus trying to get data for reports, we are experiencing difficulties due to the crash. I visited the Farm today to conduct a site inspection for monitoring water levels. We needed to vent some today for 2 hours as was the case Monday and Thursday, we have been running the gravity flare since Monday the 8th. It is only putting 7 CFM but that helps to keep the balloon level at a good volume. The wastewater levels are rising in the Basin so I opened Lagoon valve ½ way to send some waste to the Lagoon. We are still keeping the riser in the Basin to assist control of backflow from the Lagoon. The conditioner has been running since our restart on March 28th. With only two very short breaks due to storms not more than 20 minutes of down time. I am still waiting on Josh Amon for Digester pump repair.
4-15-2019	Site visit today to meet folks from Michigan State for Verification and Ollie (C&A) and Matt (Duke U) I remotely monitored the system during the night Sunday we had bad storms and lost connectivity with the MT. I rebooted this morning and we are running. The data is still not recording as it should. We are experiencing difficulties due to the crash. I visited the Farm today to conduct a site inspection for monitoring water levels. We needed to vent some today for 1 hour. We have been running the gravity flare since Monday the 8th. It is only putting 7 CFM but that helps to keep the balloon level at a good volume. Today I switched back to send everything going into the Digester. We are still keeping the riser in the Basin to assist control of backflow from the Lagoon. The conditioner has been running since our restart on March 28th. With only two very short breaks due to storms not more than 20

	minutes of down time, but this last time, we were down 9 hours. I am still waiting on Josh Amon for Digester Repair.
4-16-2019	Site visit to turn Basin pumps back on the water levels in the basin are low the back feed from the lagoon is off not flowing as before. The data is still not recording as it should. We are experiencing difficulties due to the crash. I visited the Farm today to conduct a site inspection for monitoring water levels. We needed to vent for 1 hour. We have been running the gravity flare since Monday the 8th. It is only putting 7 CFM but that helps to keep the balloon level at a good volume. All flush waste is going to the digester. We are still keeping the riser in the Basin to assist control of back flow from the Lagoon. The conditioner has been running since our restart on March 28th. With only two very short breaks due to storms not more than 20 minutes of down time and this last time down 9 hours. I am still waiting on Josh Amon for Digester pump repair.
4-20-2019	Marvin has been closely monitoring our site and system remotely by Team Viewer Wednesday until now. I made a Site visit to monitor system gas bubble is getting very high so I will vent for two hours to drop the level some to take care of the coming sunny day Sunday. The data is still not recording as it should. We are experiencing difficulties due to the crash. I conducted a site inspection for monitoring water levels. We have been running the gravity flare since Monday the 8th. It is only putting 7 CFM but that helps to keep the balloon level at a good volume. All flush waste is going to the digester. We are still keeping the riser in the Basin to assist control of back flow from the Lagoon. The conditioner has been running since our restart on March 28th. With only two very short breaks due to storms not more than 20 minutes of down time and this last time down 9 hours. I am still waiting on Josh Amon for Digester pump repair
4-22-2019	Marvin has been closely monitoring our Site and system remotely by Team Viewer Saturday until now. Site visit to monitor system gas bubble is getting very high, so I will vent for three hours to drop the level. We had too much on a sunny day Sunday and the cover pulled some on the North side next to the Lagoon. I have notified Mathew of Duke University and the Cavanaugh team. The data is still not recording as it should. We are experiencing difficulties due to the crash. I conducted a site inspection for monitoring water levels. We have been running the gravity flare since Monday the 8th. It is only putting 7 CFM but that helps to keep the balloon level at a good volume. All flush waste is now going to the Lagoon. We are still keeping the riser in the Basin to assist control of back flow from the Lagoon. Today I had to get the boat in the Basin to unclog the weep holes in the riser. The conditioner has been running since our restart on March 28th. With only two very short breaks due to storms not more than 20 minutes of down time and this last time down 9 hours. I am still waiting on Josh Amon for Digester pump repair.
4-23-2019	Marvin is monitoring the site remotely by Team Viewer off and on during the time that I am away. Site visit to monitor system and to lower the gas bubble for flushing out the cross over pipe from Digester to Basin. I will vent from 11:15 until 4:15 PM. The data is still not recording as it should. We are experiencing difficulties due to the crash. I conducted a site inspection for monitoring water levels. We have been running the gravity flare since Monday

	the 8th. It is only putting 7 CFM but that helps to keep the balloon level at a good volume. All flush waste is now going to the Lagoon. We were back in the boat today and with the help from LRF We removed top 2/3rds of the riser to help refill the basin for flushing. The MT faulted out around 8:00 PM and would not start remotely; I rebooted it this morning around 11:30 AM and have been running since. Larry Hice (of Plastic Fusion) called and is sending Al Corbet to assess the damage. I am still waiting on Josh Amon for Digester pump repair.
4-24-2019	After monitoring remote, did a Site visit to meet with Al Corbet (Plastic Fusion) to assess the damage. He took photos and measured the distances and did a complete walk around and will work up data and schedule a time for the repair. My visit today was also to monitor system and to lower the gas bubble for flushing out the crossover pipe from Digester to Basin. I will vent from 11:30 until 5:00 PM using 3 ports. The data is still not recording as it should. We are experiencing difficulties due to the crash. I conducted a site inspection for monitoring water levels. We have been running the gravity flare since Monday the 8th. It is only putting 7 CFM but that helps to keep the balloon level at a good volume. All flush waste is now going to the Lagoon. The MT has been running since the reboot on 4/23/19 at 11:00 AM. I am still waiting on Josh Amon for Digester pump repair. I worked on flushing the cross over pipe without any success.
4-25-2019	Remote monitoring then Site visit today to continue flushing the crossover pipe but the showers started so I disconnected the Pump and moved it inside. I will work on it next week. SCADA is still not recording as it should. We are experiencing difficulties due to the crash. I conducted a site inspection for monitoring water levels. The gravity flare is off. All flush waste is now going to the Lagoon. The MT has been running since the reboot on 4/23/19 at 11:00 AM. I was able to reach Josh Amon today and explained the situation with the Digester pump. He will try to get to us as soon as possible.
4-29-2019	Remote monitoring, then Site visit today to continue flushing the X over pipe . SCADA is still not recording as it should. We are experiencing difficulties due to the crash. I conducted a site inspection for monitoring water levels. The gravity flare is off. All flush waste is now going to the Lagoon. The MT has been running since the reboot on 4/23/19 at 11:00 AM. Today I met with Mr. Loyd Bryant to go over a letter about his permit he received. Plastic Fusion is scheduled to repair cover the end of this week. I am using the digester pump to move waste to the Lagoon by the way of the crossover pipe. I cannot vent anymore the gas is hung up in pockets and it is more than the MT can burn.
4-30-2019	Continued monitoring remotely by Team Viewer off and on during the day. Site visit today to continue to flush the crossover pipe using the surface water pump and the gas power trash pump. SCADA is still not recording as it should. We are experiencing difficulties due to the crash. I conducted a site inspection for monitoring water levels. The gravity flare is off. All flush waste is now going to the Lagoon. The MT has been running since the reboot on 4/23/19 at 11:00 AM. I was able to reach Josh Amon today and explained the situation with the Digester pump. He will try to get to us as soon as possible. Today I talked with Mr. Bryant to go over a letter about his insurance that he received. Plastic Fusion is scheduled to

	repair cover the end of this week. I am using the digester pump to move waste to the Lagoon. I was able to do a small amount of venting at the crossover, but elsewhere gas is blocked by the waste in the digester. We have pockets of gas all over but not able to vent and it is more than the MT can burn. I am pumping surface water off.
5-1-2019	Remote monitoring by Team Viewer, then site visit for monitoring water levels. I met the rental company who delivered equipment to repair damage and will bring a generator tomorrow. Plastic Fusion is scheduled to work on the cover repair tomorrow . I am using the digester pump to move waste to the Lagoon. I was able to do a small amount of venting at the X over but elsewhere gas is blocked by the waste in the digester. We have pockets of gas all over but not able to vent and it is more than the MT can burn. I am pumping surface water off
5-2-2019	Remote monitoring by Team Viewer, then site visit today to monitor water levels, and flush the Digester intake using the gas-powered trash pump. SCADA is still not recording as it should. I have reported it to Mike Nealy of ProPump. The rental company delivered the Generator to repair damage. Buddy with Plastic fusion came in this morning and the rest of the crew will be on site and are scheduled work on the cover repair tomorrow . I am using the digester pump to move waste to the Lagoon. I was able to do a small amount of venting at the X over but elsewhere gas is blocked by the waste in the digester. We have pockets of gas all over but not able to vent and it is more than the MT can burn. The MT shut down and I rebooted it.
5-3-2019	Remote monitoring then, I conducted a site inspection for monitoring water levels. The gravity flare is off. All flush waste is now going to the Lagoon. The MT has been running since the reboot on 4/23/19 at 11:00 AM. Buddy and the rest of the Plastic Fusion crew were here bright and early to do the repair. I am using the digester pump to move waste to the Lagoon. Buddy and crew finished up this evening and I was able to restart the MT. I am headed home and will monitor from home remotely.
5-4-2019	Remote monitoring then, Site visit today to reboot MT and get back online with production of KWs. SCADA is still not recording as it should. I have reported it to Mike Nealy of ProPump. We are experiencing difficulties due to the Computer crash. I conducted a site inspection for monitoring water levels. The gravity flare is off. All flush waste is now going to the Lagoon. The MT shut down yesterday and I rebooted it before leaving yesterday. I shut down during the evening since SCADA is not recording properly I am not sure of the time. I am still waiting on Josh Amon to repair the Digester pump. I have rebooted the MT and trimmed down the flow back to the lagoon. I am headed home and will monitor from home
5-5-2019	The MT shut down yesterday and I rebooted it before leaving yesterday. It shut down during the evening since SCADA is not recording properly I am not sure of the time. I am waiting on Josh Amon to repair the Digester pump. I have rebooted the MT and trimmed down the flow back to the lagoon. I am headed home and will monitor from home
5-6-2019	Remotely monitoring by Team Viewer off and on during the time that I am away. Site visit today to reboot MT and get back online with production of KWs. I found that the Phase Converter was down. SCADA is still not recording as it should. I have reported it to Mike

	Nealy of ProPump. I conducted a site inspection for monitoring water levels. The gravity flare is off. All flush waste is now going to the Lagoon. The MT shut down yesterday and I rebooted it before leaving. It shut down during the evening since SCADA is not recording properly I am not sure of the time. I am still waiting for Josh Amon to repair the Digester pump. I have rebooted the MT and trimmed down the flow back to the lagoon. I am headed home and will monitor from home
5-8-2019	Site visit today to reboot MT and get back online with production of KWs. I found that the breaker had tripped. I worked with Mike Nealy on Tuesday on the SCADA and we had it going but later that day we lost the graph, so SCADA is still not recording as it should, Mike is aware of the problem. I conducted a site inspection for monitoring water levels. The gravity flare is off. All flush waste is now going to the Lagoon. The MT shut down last night and I am rebooting now. I am waiting on Josh Amon to repair the Digester pump. I have rebooted the MT and trimmed down the flow back to the lagoon. I am headed home and will monitor from home.
5-10-2019	Site visit today to reboot MT and get back online with production of KWs. I found that the breaker had tripped. I worked Dean of LRF to reset breakers on Thursday but it would not keep running it continues to trip the Breaker, I reported to Mike Nealy on Wednesday that we are still having issues with the graph, so SCADA is still not recording as it should. I conducted a site inspection for monitoring water levels. The gravity flare is off. All flush waste is now going to the Lagoon. I am waiting on Josh Amon to repair the Digester pump. I have rebooted the MT and trimmed down the flow back to the lagoon. I am headed home and will monitor from home.
5-13-2019	Marvin conducted a site inspection for monitoring water levels. Gas is gaining on us, so I vented today, the gravity flare is off. All flush waste is now going to the Lagoon. I am waiting on Josh Amon to repair the Digester pump. We had a MT shutdown tripped breaker at 1:08 PM restart at 1:56 PM. I have rebooted the MT and trimmed down the flow back to the lagoon. I am headed home and will monitor from home
5-14-2019	Marvin conducted a site inspection for monitoring water levels. Gas is gaining on us so I vented today using one vent. The gravity flare is off. All flush waste is now going to the Lagoon. I am waiting on Josh Amon to repair the Digester pump. We had a MT shutdown tripped breaker at 1:08 PM restart at 1:56 PM yesterday, so I rebooted the MT and trimmed down the flow back to the lagoon. I am headed home and will monitor from home
5-15-2019	Site visit today to meet with Keith Owens of ProPump to troubleshoot our MT issue. We are installing a Fuse disconnect box and hopefully we can get it installed Wednesday, SCADA is still not recording as it should. I conducted a site inspection for monitoring water levels. Gas is gaining on us so I vented today using 1 vent. The gravity flare is off. All flush waste is now going to the Lagoon. I am waiting on Josh Amon to repair the Digester pump. We installed the disconnect Box and fired up the Chiller and conditioner. We fired the MT as soon as the temp got down. Started at 3:28pm and down at 3:44pm. Restart at 3:56pm, The Phase converter started tripping out. We found that the fans seem to be bad. We have two so Keith will install tomorrow while tonight we will use a window fan to cool. I will monitor all during the night.
5-16-2019	Site visit today to meet with Keith Owens of ProPump to install the repairs once install we still had to change out the breaker and ordered circuit boards for the PC. We installed a Fuse

	disconnect box and the circuit breaker, to attempt to fix the SCADA. I conducted a site inspection for monitoring water levels. Gas is gaining on us so I vented today using 1 vent. The gravity flare is off. All flush waste is now going to the Lagoon. We installed the two Fans also. We got it all running and headed for home I will monitor all during the night. I am waiting on Josh Amon to repair the Digester pump.
5-17 to 5-18-2019	Marvin has been closely monitoring our Site and system remotely by Team Viewer off and on during the time that I am away. Site visit today to restart the MT
5-19-2019	Site visit today to restart the MT and found the computer down. We had so much heat that the conditioner would not chill enough to keep running. I returned home and restarted in the PM after it cooled down.
5-20-2019	Site visit today to meet with Ollie Frazier and have him BU the system computer. We pumped waste to lagoon and updated him about what there is to do on a site visit. I had started the system in the cool of the day Sunday and it is still running.
5-21-2019	I continued to monitor the system and with the help of LRF staff was able to keep water level in check; the system does not like hot weather. I have had to reboot the system when the Conditioner shuts down due to heat
5-24-2019	Marvin has been closely monitoring our Site and system remotely by Team Viewer off and on during the time that I am away. I continued to monitor the system and with the help of LRF staff was able to keep water level in check the system does not like hot weather. I have had to reboot the system when the Conditioner shuts down due to heat. I restarted tonight after my stay in Baptist doing heart test at 11:34 PM in the cool of the evening
5-25-2019	Remote monitoring, I continued to monitor the system and with the help of LRF staff was able to keep water level in check the system does not like hot weather. I have had to reboot the system when the Conditioner shuts down due to heat. I restarted tonight in the cool of the evening at 10:46 pm, however it had shut down at 8:35 am.
5-30-2019	Ben Cauthen and Steve Cavanaugh were on site to try entering skid into a summer setting, I briefed Ben on the system by remote. At 12:40 AM on Friday I was able to start system and the MT
6/4/2019	Ben emailed Larry Hice (Plastic Fusion) regarding cover repair and payment. Larry Hice replied, "Yes we did complete the repair and left the cover functioning fine. The invoice was processed the end of last month and mailed to Cavanaugh. Total for the repair was $16,925.00."
6/4/2019	Ben called Josh Amon (Preferred Sources) regarding mixing pump repair. Josh said the mixing pumps have been discontinued so getting parts is difficult. The pumps sometimes lose prime due to high sludge levels. Ben will meet Josh on-site on June 7th at 7 am.
6/4/2019	Ben called Andrew. No answer. Ben will try again tomorrow.
6/6/2019	Ben emailed Jeff McGuire (ProPump) to explain the SCADA issues and request a quote for a service call by Mike Nealy. Also asked for a flame arrestor quote.

6/6/2019	Ben reached out to Kevin Harward regarding the sampling he was previously responsible for.
6/6/2019	Ben emailed Phil Rucker (Cooperative Extension) to describe the help that is needed at Loyd Ray. Phil will try to find a person who can fill the position.
6/7/2019	Ben met Preferred Sources (Josh Amon) at LRF to diagnose the mixing pump problem. The rotating unit needs to be replaced. Josh sent a quote for replacing the rotating unit ($6,130 + tax).
6/7/2019	Ben replaced the two blower filters with new filters. The new filters were already at LRF.
6/7/2019	Ben spoke with Kevin Harward regarding manure sampling. Ben needs to pick up sampling materials from R&A Labs then collect the samples.
6/10/2019	Ben called R&A Labs to confirm manure sampling procedure. Ben will pick up and return supplies to R&A Labs on June 25th to complete quarterly sampling.
6/10/2019	Ben ordered a utility pump for removing stormwater from the digester cover: WAYNE 57729-WYNP WAPC250 1/4 HP Automatic ON/OFF Water Removal Pool Cover Pump ($176.96).
6/23/2019	Ben purchased a check valve and fitting for the WAYNE stormwater pump ($47.76).
6/25/2019	Ben collected manure samples and delivered the samples to R&A Labs.
6/25/2019	Ben scheduled the Unison service work with Don Weeden. Unison will send a service tech to the farm the week of July 15th ($6,485). Ben sent Don pressure and temperature readings.
6/27/2019	Ben spoke with Keith Owens (ProPump). Bryan will repair the circuit boards on 6/28. The parts were ordered previously and arrived on 6/27.
6/28/2019	Bryan (ProPump) completed the circuit board repair. Ben spoke with Mike Nealy while at the farm. Mike stated that the lost data is not recoverable since the computer hard drive was lost. The turbine SCADA issues are a result of the SCADA programming.

As previously mentioned, the age of the system, normal wear and tear on the equipment required some failures such as the digester pump. The system was evaluated and a Corrective Maintenance List was made to facilitate the system operating in a cohesive manner, and to prevent failures in the future.

Cavanaugh & Associates has also created a spreadsheet of necessary repair needs which should be accomplished the Summer of 2019. While some of these items were able to be repaired on a temporary basis, the long-term repair solution would ideally fix the problem listed, and prolong the system life. Cavanaugh is working to secure pricing for the necessary repairs, if they did not occur before this report end, we have listed the date that the repair should be accomplished by. Although these repairs are not compliance issues, we are listing them here to inform the report, that we have some upcoming pending service items remaining from this report period. We will make every effort to keep the biogas and environmental system running as efficiently as possible and are hoping the repairs can be accomplished without interruption to the system.

Corrective Maintenance List

Item	Problem	Immediate Repair	Long-Term	Contact(s)	Action	Cost
1. Flare	Gas flow to the flare is almost totally blocked.	Remove flame arrestor to clean blockage then reinstall. May need to replace flame arrestor. ProPump just built a flare for Cavanaugh, so they can assist if needed.	Assess the flare's condition to determine if purchasing a new flare is warranted.	ProPump – Jeff McGuire; Cavanaugh	Cavanaugh remove flame arrestor, potentially with ProPump, to repair or replace. Complete or schedule repair by August 1, 2019.	
2. Chiller Unit	The chiller is cooling slowly and will not reach set point in high ambient temperatures.	Troubleshoot problem with Johnson Thermal. Replace compressor or resolve other issue.	Complete upkeep and preventative maintenance.	Johnson Thermal Systems	Cavanaugh to troubleshoot problem with JTS / schedule JTS for repair. Schedule repair by July 1, 2019.	$6,485 (Unison tech to service chiller and skid)
1. Digester Waste Inlet Pipe	Inlet pipe is blocked. Waste cannot be pumped into digester.	Remove blockage from the pipe, or more likely, remove sludge from the digester by using mixing pumps with firehose connection.	Monitor digester sludge level and prevent flushed manure and inorganic materials from creating blockages. Sludge should be removed every other year.	Andrew; Cavanaugh	Cavanaugh contact Andrew to schedule sludge removal. Cavanaugh pump sludge to lagoon. Complete as soon as lagoon capacity allows.	
2. Digester Mixing Pump	One digester mixing pump is not functioning.	Repair broken components in the mixing pump.	Complete preventative maintenance on both mixing pumps.	Preferred Sources – Josh Amon	Cavanaugh follow up with Josh about previously scheduled repair. Josh to complete repair when rotating unit arrives.	$6,130 + tax ($5,030 + tax for rotating unit; estimated 6 hours labor)
2. SCADA Malfunction	SCADA system is not recording data. There is a malfunction with the microturbine controls.	SCADA system is not recording data for the microturbine and the microturbine	Monitor SCADA system.	ProPump – Mike Neely	Cavanaugh contact ProPump to troubleshoot problem and schedule repair.	

		controls appear to be losing connection.			Complete repair by July 1, 2019.	
1. Pipe between Digester and Aeration Basin	Pipe between the digester and aeration basin may be blocked.	Remove blockage from the pipe, or more likely, remove sludge from the aeration basin by using aeration pumps and existing buried 4" line / valve back to manhole.	Prevent blockages by monitoring sludge level.	Cavanaugh	Cavanaugh to assess blockage after sludge removal / remove blockage if it still exists. Complete after sludge removal occurs.	
3. Control Panel Circuit Board	Burns were found behind a circuit board.	Replace circuit boards, possibly with used ones.	Monitor to prevent happening again.	ProPump – Keith Owens	Cavanaugh to follow up with Keith Owens about replacing circuit boards. Complete repair by July 1, 2019.	
3. Farm Flush Pumps	The aeration basin pump is being used to flush the barns. The water level in the aeration basin must be monitored and a valve to the lagoon must be manually turned to control the level.	Continue using aeration basin pump for flushing operations.	Install new pumps in the lagoon or find better management method for the water level in the aeration basin.	Loyd Bryant; Andrew	Cavanaugh to work with Loyd and Andrew to find a long-term flushing solution. Complete plan by August 1, 2019.	
1. Digester Cover	Digester cover pulled out of the trench.	Plastic Fusion has repaired the cover and grass has been reseeded.	Monitor gas level to ensure the cover does not pull out of the trench.	Plastic Fusion Fabricators	Cavanaugh to follow up with PFF to confirm the repair is complete and PFF has received payment. Estimate was	$16,925 for PFF and $915 for Wiles Grading and Landscaping. $17,840 total.

					$16,925 - $23,925.	
3. Blower Filter	Blower filter needs replacement.	Replace blower filter.	Replace blower filter at properly scheduled intervals.	Cavanaugh	Cavanaugh will replace blower filter. Complete by July 1, 2019.	$150 ($75 per filter)
3. SCADA Performance Data	Two months of performance data were not recorded or are not accessible.	Work with ProPump to locate data or correct cause of data loss.	Correct problem to ensure data loss does not occur again.	ProPump – Mike Neely; Cavanaugh	Cavanaugh will confirm data loss with Duke U and contact ProPump to attempt data recovery. Complete by July 1, 2019.	

The following table lists the compliance requirements as per the permit for the subject system, and the performance / compliance relative to each requirement:

	Description of Monitoring Requirement	Status	Result
1	Maintenance of adequate records by Permittee to track the amount of sludge/separated solids disposed.	N/A	No solids or sludge disposal occurred during the reporting period; with the exception that some sludge returned to the anaerobic digester for further breakdown in accordance with the Division approved Operations & Maintenance Plan.
2	Inspection of entire Innovative System waste collection, treatment, and storage structures and runoff control measures at a frequency to insure proper operation but at least monthly and after all storm events of greater than one (1) inch in 24 hours; Permittee maintenance of inspection log or summary including at least the date and time of inspection, observations made, and any maintenance, repairs, or corrective actions taken by Permittee.	☑	Inspections and observations conducted by representatives of Loyd Ray Farms, Inc., Cavanaugh & Associates, P.A., and DCOI. Observations recorded, and actions taken to adjust the operation of the System are recorded in log book kept onsite, and emailed in.
3	Maintenance of a log of all operational changes made to the Innovative System including at least the process parameter that was changed, date and time of the change, reason for the change, and all observations	☑	Log book entries, as described in item #2, above, maintained on site; copies attached to report (Appendix A)

	made both at the time of the change and subsequently as a result of the change by Permittee/ Permittee's designee.		
4	Representative Standard Soil Fertility Analysis to be conducted annually on each application site receiving animal waste.	☑	NCDA&CS Agronomic Division Report No. FY19-W005280, shows the results of the Predictive Home & Garden Soil Report for Loyd Ray Farms. The samples were compiled on 2/21/2019, and were completed on 3/05/2019, which are added to this report, they can also be accessed here: http://www.ncagr.gov/agronomi/
Wastewater Analysis			
5	Quarterly tests shall be conducted once within each of the following windows w/ at least sixty (60) days between any 2 sampling events. Water quality samples include analysis of copper, zinc, total suspended solids, pH, total nitrogen, TKN, NO2 + NO3, phosphorus, ammonia, and fecal coliform.		
	Quarter 3 (July 1 – September 30) *Data previously submitted with Semi-Annual Compliance Report*	☑	Sample Collected: 8/17/2018 Sample Analyzed: 9/18/2018 Results Reported: 9/18/2018 Results included in the attached report from Research & Analytical Laboratories, Inc. (Appendix B)
	Quarter 4 (October 1 – December 31) *Data previously submitted with Semi-Annual Compliance Report*	☑	Sample Collected: 11/20/2018 Sample Analyzed: 12/20/2018 Results Reported: 12/20/2018 Results included in the attached report from Research & Analytical Laboratories, Inc. (Appendix B) Retest of Fecal Coliform: Sample Collected: 1 /9/2019 Sample Analyzed: 1/11/2019 Sample Reported: 1/11/2019
	Quarter 1 (January 1 – March 30)	☑	Sample Collected: 2/15/2019 Sample Analyzed: 3/5/2019 Results Reported: 3/5/2019 Results included in the attached report from Research & Analytical Laboratories, Inc. (Appendix B)
	Quarter 2 (April 1 – June 30)	☑	Sample Collected: 6/25/2019 Sample Analyzed: 6/25/2019 Results Reported: 7/12/2019

Performed at a minimum of twice a year for the first two years to determine the calibration coefficient for the mass balance as described in the Monitoring Plan submitted March 17, 2010. Ambient air sampling shall be scheduled in summer and winter seasons.			
	Spring Season Ambient Air Sampling	☑	A Spring season ambient air sample taken on March 14, 2019 by Duke University is included in this report. Results included in the Explanation of Results and Sampling Methods.
	Waste Treatment and Storage System	☑	
	Barns	☑	
	Sprayfields	☐	*Not Measured*
	2nd Summer Season Ambient Air Sampling	☑	A second summer season ambient air sample taken on June 13, 2019. A winter analysis will be completed this fall, allowing a shift in sampling timing. Results included in the attached Explanation of Results and Sampling Methods.
	Waste Treatment System	☑	
	Barn Exhaust	☑	
	Sprayfields	☐	*Not Measured*
Odor Sampling			
6	Permittee shall monitor for odor compliance quarterly at both upwind and downwind locations on the property boundary. Permittee shall document monitoring locations on a site map, indicating prevailing wind direction, for each monitoring event.		
	Quarter 3 (July 1 – September 30) *Data previously submitted with Semi-Annual Compliance Report*	☑	Odor sampled June 26, 2018 Results included in the attached Explanation of Results and Sampling Methods.
	Quarter 4 (October 1 – December 31) *Data previously submitted with Semi-Annual Compliance Report*	☑	Odor sampled Results included in the attached Explanation of Results and Sampling Methods.
	Quarter 1 (January 1 – March 30)	☑	Odor sampled March 14th, 2019. Results included in below under Odor Emissions, and in the Explanation of Results and Sampling Methods.
	Quarter 2 (April 1 – June 30)	☑	Odor sampled June 13th, 2019. Results included in below under Odor Emissions, and in the Explanation of Results and Sampling Methods.
Record Keeping			

7	All records, including operation, maintenance, and repair records, shall be maintained on site and in chronological and legible form for a minimum of five (5) years by the Permittee; records shall be maintained on forms provided by or approved by the Division and shall be readily available for inspection.	☑	A copy of the report and all monitoring records are maintained in a binder in the System Control Building; the electronic form combines inspection and operations records on a single form, entitled "Loyd Ray Farms Inspection, Operations & Maintenance Log Sheet" which are being collected electronically, and submitted to the Regional Office via email.

EXPLANATION OF RESULTS AND SAMPLING METHODS

1. Amount of Sludge or Separated Solids Disposed
N/A. No disposal of sludge or separated solids was required from the Innovative System during the 7/1/2018 – 6/30/2019 reporting period. Some sludge was returned from the aeration basin to the anaerobic digester for further breakdown, as per usual and typical operations, in accordance with the division Operation and Maintenance Manual.

2. Log of System Inspections
See Operator Log Book, Appendix A. (digitally attached)

3. Log of Operational Changes to the Innovative System
See Operator Log Book, Appendix A. (digitally attached)

4. Results of Standard Soil Fertility Analysis
The Soil Fertility Analysis was conducted by LRF in 2018 which is included in Appendix C of this report. NCDA & CS Agronomic Division, analyze independent swine lagoon liquid samples in a Predictive Waste Report. The Loyd Ray Farms analysis on February 21, 2019 as stated in the reports completed on March 5, 2019. The actual test results and recommendations can be found in Appendix C.

Two separate reports, by NCDA & CS Agronomic Division, analyze independent soil samples which were taken at Loyd Ray Farms on October 22, 2018, as stated in the reports completed on November 1, 2018. The actual test results and recommendations for each sample can be found in Appendix C. The following tables are compiled to easily view the aggregated results.

Loyd Ray Farms Report No. FY19-SL009268

	Sample #	1A 01	1B 02	IC03	3A	3B	3C	9B
HM	Percent humic matter	0.41	0.41	0.41	0.41	0.36	0.42	0.51
W/V	Weight per volume	1.12	1.15	1.16	1.08	1.10	1.09	1.08
1	Cation exchange capacity	7.2	7.4	7.6	9.8	9.4	10.2	9.4
9	Manganese Index	165	167	172	119	120	140	232
Zn-1	Zinc Index	782	486	443	542	492	629	499

Cu-I	Copper Index	135	143	137	102	106	128	110
128	Sulfur Index	32	32	32	31	32	34	33
P-1	**Phosphorus Index**	**53**	**57**	**56**	**84**	**91**	**92**	**86**
K-1	**Potassium Index**	41	39	41	**474**	**50**	**363**	**345**
pH	**Acidity**	**6.4**	**7.2**	**7.2**	**7.2**	**7.2**	**7.0**	**6.7**

Loyd Ray Farms Report No. FY19-SL009269

	Sample #	**2**	**4**	**5**	**6**	**7**	**8**	**9A**	**9B**
HM	Percent humic matter	0.41	0.41	0.46	0.41	0.51	0.36	0.51	0.51
W/V	Weight per volume	1.07	1.08	1.10	1.04	1.07	1.02	1.07	1.10
CEC	Cation exchange capacity	10.7	10.7	12.1	11.2	9.9	11.4	9.0	8.8
Mn-I	Manganese Index	153	150	131	162	198	166	222	224
Zn-1	Zinc Index	616	608	1601	735	569	696	475	445
Cu-I	Copper Index	147	141	128	121	105	114	108	108
S-I	Sulfur Index	36	35	36	35	32	33	32	29
P-1	**Phosphorus Index**	**87**	**89**	**116**	**90**	**88**	**91**	**85**	**83**
K-1	**Potassium Index**	**535**	**539**	**643**	**574**	**595**	**618**	**334**	**351**
pH	**Acidity**	**7.1**	**7.1**	**7.2**	**7.2**	**7.3**	**7.3**	**6.8**	**6.8**

In almost all samples, the Phosphorus Index (P-I) and Potassium Index (K-I), were found to be *Above Optimum*. The range for *Optimum* is between 50 and 70, Sample 1B 02, and 1C 03 were a little below the *Optimum* range, but all others were very desirable. All of the samples in the 0269 group, in bold lettering above, exceeded those limits, and were *Above Optimum.* All of the samples in the 0268 group were at least at *Optimum* level, and many of which were in the *Above Optimum* range. The pH test for acidity results were higher than the 5.8 to 6.5 *Optimum* range, averaging about 7.1 on Report #FY19-SL009269. Similarly, the Sample # FY19-SL009268, was also in the *Optimum* range, averaging about 6.9.
The exact agronomist's comments and recommendations for fertilizer application can be found in the Actual Soil Reports See **Appendix C.**

5. Results of Water and Air Quality Sampling

a. Results of Waste Water Analysis
Water quality samples from the effluent were taken in each quarter, a synopsis of the results is found below. Samples were analyzed by Research Analytical Laboratories, Inc. in Kernersville. The 4th quarter sample of 2018, as well as 1st and 2nd quarters of 2019 resulted in higher fecal coliform counts than expected, and thus, additional samples were taken. While the re-sampling was done in July 2019, we have added it to the report for clarity. The following table compares the results of the water quality analysis of the final effluent from the Innovative System:

Parameter	8/17/2018	11/21/2018	2/21/2019	6/25/2019
TOT N	1080	972	2,230	720
TKN	1080	972	2,320	720
NO_2+NO_3	0.27	<.05	0.27	0.3333
TP	62.2	215	71	39.7
NH3-N	689	702	1,940	398
COPPER	0.088	0.334	0.801	0.105
ZINC	0.489	2.32	5.6	0.322
TS	848	1300	4,340	242
FECAL	1,400,000	33,000,000	1,100,000	10,000
pH	7.98	8.06	8.04	8.12

1. In 2018, The fecal coliform count for most of the sampling events exceeded the permit limit, and this has not been resolved. Almost all other constituent parameters as recorded above are decreasing since the beginning of the year, as indicated in the final effluent recordings in the chart above. The chart above describes the waste water analyses that is required to be conducted on a quarterly basis. These parameters are: total N, NH_3-N, NO_3-N/NO_2-N, total P, % solids, copper, zinc, pH and pathogens. Samples are to be taken from the digester and the effluent (leaving the aeration basin). All sampling was conducted:
    1. Sample ID: Effluent 1; Fecal Coliform – MPN = 1,400,000 MPN/100mL 8-17-2018
    2. Sample ID: Effluent 1; Fecal Coliform – MPN = 33,000,000 MPN/100mL 11-21-2018

2. Given the resampling produced fecal coliform counts that were quite high compared to the permit limit, an additional resampling event was conducted on January 9, 2019. Again, a composite sample was obtained of the effluent, split into three (3) sample bottles, then sent to the laboratory for analysis. The results are as follows:
    1. Sample ID: Effluent #1; Fecal Coliform – MPN = 40,0000 MPN/100mL
    2. Sample ID: Effluent #2; Fecal Coliform – MPN = 1,700,000 MPN/100mL
    3. Sample ID: Effluent #3; Fecal Coliform – MPN = 330,000 MPN/100mL

3. In 2019, the Fecal Coliform was again tested, and still exceeded the permit limits.
    1. Sample ID: Effluent #1; Fecal Coliform – MPN = 1,100,000 MPN/100mL
    2. Sample ID: Effluent #2; Fecal Coliform – MPN = 10,000 MPN/100mL

    According to the data presented, the fecal coliform levels are decreasing over time, but tend to be less during the hotter months, and highest over the coldest months of the year.

The results were much improved over the previous fecal coliform samples.

Ammonia Emissions

While precise ammonia emissions are hard to calculate, Odor was monitored by Duke University to comply with Section I.6.b.ii of the Swine Animal Waste Management Permit. Duke University's Dr. Marc Deshusses took Spring and Summer ambient Air Samples on March 14, 2019, and June 13, 2019, respectively, both results were found to be in compliance, and are further described below. Odor panelist rules were listed in the previous report and are not repeated here, but several measurements for wind speed and direction were taken to ensure that data were representative

Odor Sampling #1

Odor was monitored to comply with Section I.6.b.ii of the Swine Animal Waste Management Permit. One monitoring event was conducted on March 14, 2019.

Sampling took place at about noon. It was an overcast mild day (60° F) with moderate to strong wind (sustained 3.7 m/s with gusts at 4.5 m/s). Several measurements for wind speed and direction were taken. The predominant wind direction and sampling points for odor were selected as shown in Figure 5.

Odor was monitored by Marc Deshusses. Odor panelist rules were listed in an earlier report and are not repeated here. Odor was monitored using a Nasal Ranger (http://www.nasalranger.com/) field olfactometer, following the manufacturer recommended instructions.

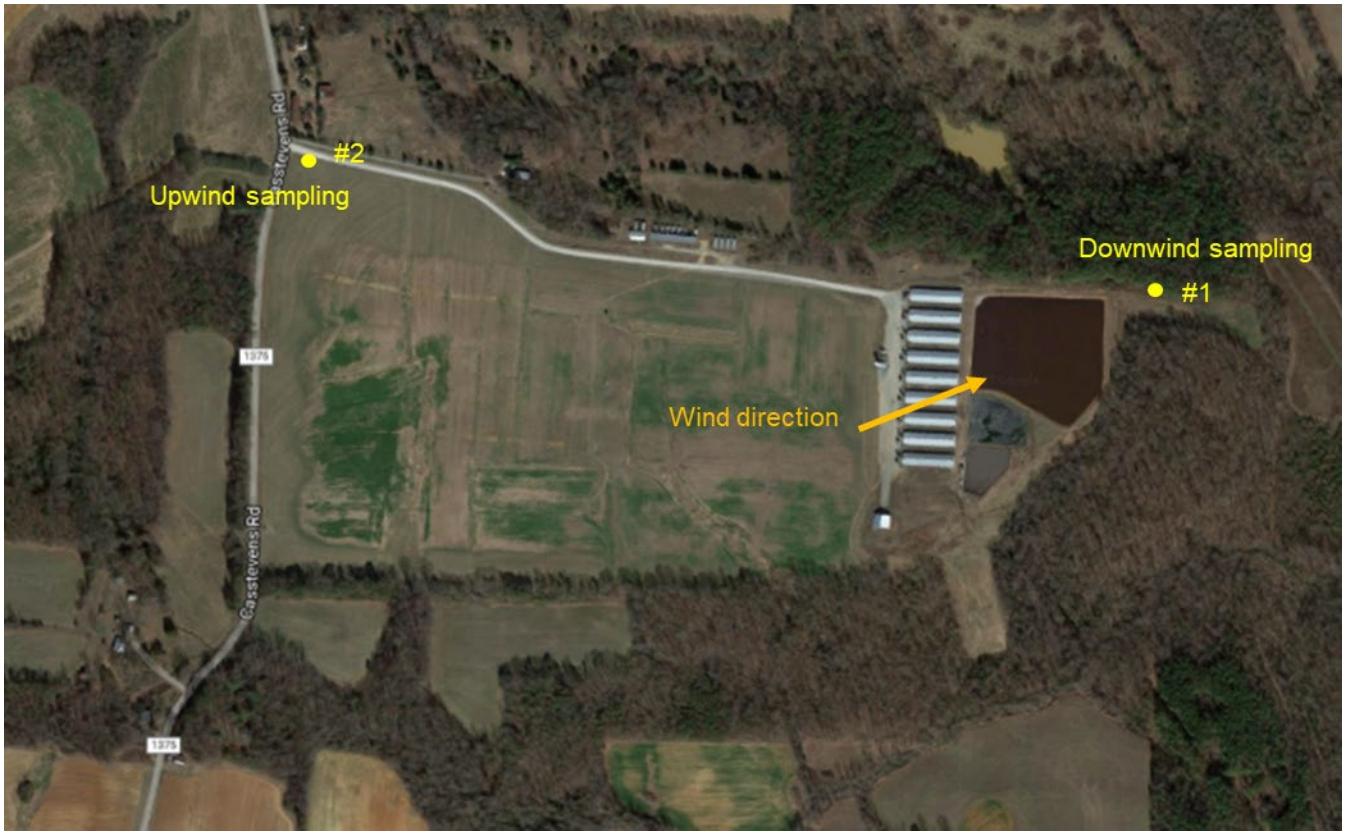

Figure 5. Aerial view of the facility and location of the monitoring points for odor for the March 14, 2019 sampling. The location was about 50 yards downwind of the little hunting hut. The arrows indicate the prevailing wind direction the day of the sampling.

<u>Sampling upwind</u>
Odor could not be detected at the 2 D/T level. This indicates that the odor level was lower than 2 D/T. Then the Nasal Ranger was taken off the nose and ambient air was sniffed and compared to odorless air from the Nasal Ranger. This was to determine whether a difference could be detected between ambient air and odorless air from the Nasal Ranger. No significant difference could be detected.

<u>Sampling downwind</u>
No odor could be detected at the 2 D/T level at location #1. This indicates that the odor level was lower than 2 D/T. Then the Nasal Ranger was taken off the nose and ambient air was sniffed and compared to odorless air from the Nasal Ranger. This was to determine whether a difference could be detected between ambient air and odorless air from the Nasal Ranger. There was a faint odor with sulfur notes possibly coming from the lagoon, but as mentioned before these odors were below the 2 D/T level.

These results indicate that odor levels complied with Section I.6.b.ii of the Swine Animal Waste Management Permit.

Odor Sampling #2

Odor was monitored to comply with Section I.6.b.ii of the Swine Animal Waste Management Permit. One monitoring event was conducted on June 13, 2019.

Sampling took place at about 9:15 am. It was a nice clear day, somewhat cool for the season (78° F) with very variable wind, from no wind to mild gusts of 2 m/s. Several measurements for wind speed and direction were taken. The average wind speed was 1.3 m/s, the predominant wind direction and sampling points for odor were selected as shown in Figure 6.

Odor was monitored by Marc Deshusses. Odor panelist rules were listed in the previous report and are not repeated here. Odor was monitored using a Nasal Ranger (http://www.nasalranger.com/) field olfactometer, following the manufacturer recommended instructions.

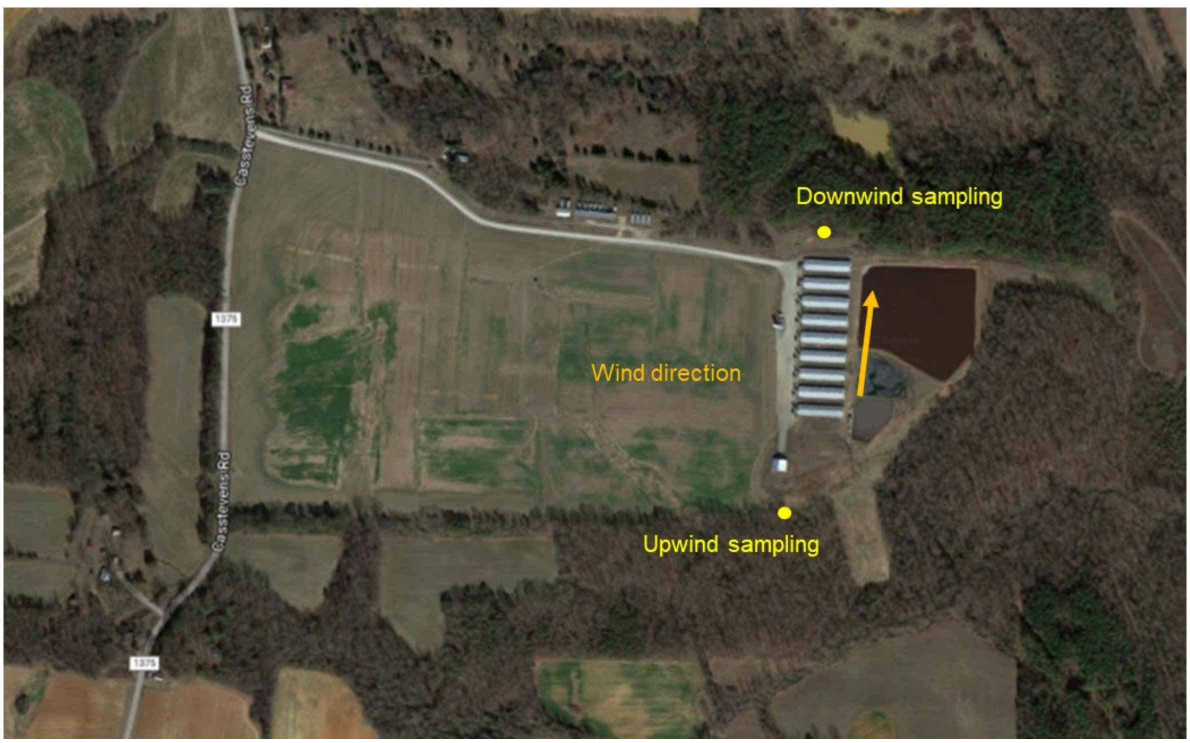

Figure 6. Aerial view of the facility and location of the monitoring points for odor for the June 26, 2018 sampling. The arrows indicate the prevailing wind direction the day of the sampling.

<u>Sampling upwind</u>

Odor could not be detected at the 2 D/T level. This indicates that the odor level was lower than 2 D/T. Then the Nasal Ranger was taken off the nose and ambient air was sniffed and compared to odorless air from the Nasal Ranger. This was to determine whether a difference could be detected between ambient air and odorless air from the Nasal Ranger. No significant difference could be detected.

Sampling downwind

No odor could be detected at the 2 D/T level at the downwind. This indicates that the odor level was lower than 2 D/T. Then the Nasal Ranger was taken off the nose and ambient air was sniffed and compared to odorless air from the Nasal Ranger. This was to determine whether a difference could be detected between ambient air and odorless air from the Nasal Ranger. There was a faint piggery/barn odor with notes of sulfur, but as mentioned before these odors were below the 2 D/T level.

These results indicate that odor levels complied with Section I.6.b.ii of the Swine Animal Waste Management Permit.

Emissions from Animal Waste Treatment and Storage System

Ammonia nitrogen emissions from the aeration basin and lagoon were quantified to determine if significant volatilization of NH_3-N occurred from this part of the waste management system. Emissions from the water surfaces were determined using a buoyant convective flux chamber (BCFC) which method was described in detail and illustrated with pictures in the February 15, 2012 report. Sampling took place on June 13, 2019 between 9:40 am and 11:30 am. It was a nice clear day, somewhat cool for the season (78° F) with very variable wind, from no wind to mild gusts of 2 m/s.

Results were as follows:

- Size of the chamber: 52.1 cm wide by 52.1 cm long and 2.5 cm in headspace height.
- Air sampling flow rate: 3 L/min
- **Average ammonia concentrations** in sweep air from the aeration basin while aeration was off: **45 ppm** (3 samples) or on average in mass concentration 0.026 g-N/m^3
- Ammonia concentrations in sweep air while aeration was on was not measured, earlier monitoring indicated that ammonia concentration in sweep air during aeration was slightly lower.

The total emission from the aeration basin can be calculated from the air sampling flow rate, the surface of the chamber and the surface area of the aeration basin. The latter surface is nominally 24,500 ft^2 (or 2277 m^2). Emission rate is calculated as follows:

NH_3 emission rate = NH_3 concentration × Sampling flow rate × Aeration basin area / Buoyant chamber area

After unit conversion, one obtains values of 38.5 g/h. This corresponds to a NH_3 emission rate of **6.47 kg NH_3-N/week.** This is a low value compared to the **allowable emissions of 106 kg NH_3-N/week** from the swine waste treatment and storage structures as specified in Section I.6.a.i of the Swine Animal Waste Management Permit.

Surface emission rate of NH_3 from the **lagoon** was determined following the same method. Average concentration of ammonia in the sweep air (with the same chamber and at the same flowrate of 3 L/min) was 57 ppm (2 samples). With the surface area of the lagoon (19,425 m^2), emission of NH_3 from the lagoon are estimated to be **69.92 kg NH_3-N/week**.

Results for the emissions from the aeration basin and the lagoon are summarized in the table below. Total ammonia (TAN) in the aeration basin and lagoon at the time of sampling is also reported for information. The concentrations of TAN were low; they reflect the fact that many of the barns were not populated with swine. Altogether, these numbers show the system is performing as expected.

	Aeration basin	**Lagoon**
Surface area	2277 m^2	4.8 acres = 19,425 m^2
TAN	345 mg-N/L	380 mg-N/L
Emission rate	6.47 kg NH_3-N/week	69.92 kg NH_3-N/week
Total emission (lagoon + aeration basin)	**76.39 kg NH_3-N/week**	

Thus, together lagoon and aeration basin contribute to the emission of **76.39 kg NH_3-N/week**. This is well below the allowable 106 kg NH_3-N/week.

Emissions from the Barns

Ammonia emissions from the barns were also determined on June 13, 2019. It should be noted that accurate determination of emissions from animal houses is a difficult exercise. This is because of the variable nature of the emission, the difficulty in accurately measuring air flow from the fans on the animal houses, and the fact that fan operation is automated, i.e., they are turned on and off automatically triggered by a thermostat. Thus, uncertainties on the numbers reported below exist and can be important.

Ammonia in the exhaust air from the barns was determined using Draeger tubes. Details on the concentrations and number of fans on at the time of sampling are shown in the table below. It should be noted that a majority of barns were empty, and that these barns did not have any fans on. Only three barns were populated and had ventilation fans on. The others were not measured.

Barn	NH_3 Concentration (ppm)	Small Fans working	Large Fans working
1		0	0
2	**4**	**0**	**2**
3		0	0
4		0	0
5		0	0
6	**4.1**	**1**	**2**
7	**5**	**1**	**2**
8		0	0
9		0	0

The total emission of ammonia can be estimated by multiplying the ammonia concentration in each of the barn's exhausts by the exhaust flowrate of that barn (33,000 cfm for large fans and 13,000 cfm for the small fans). At the time of sampling, total exhaust flow was 224,000 cfm and concentrations ranged from 4 to 5 ppm (see Table above). The calculated total weekly ammonia emissions from the barns was **159 kg NH_3-N/week.**

Adding the emission from the treatment system and the lagoon (**76.4 kg NH_3-N/week**) to the emissions from the barns (**159 kg NH_3-N/week**) amounts to a **total of 235.3 kg NH_3-N/week** from the swine farm**.** This is below the allowable value of 476 kg NH_3-N/week specified in Section I.6.a.iii of the Swine Animal Waste Management Permit.

This Semi-annual Compliance Report is compiled and respectfully submitted by:

William G. "Gus" Simmons, Jr., P.E.
Cavanaugh & Associates, P.A.
1-877-557-8923

Attachments:

Appendix A – PDF of Actual Operator log sheets
Appendix B – Sample Collection Dataset
Appendix C - Soil Report

Appendix A.

Operations and Maintenance Log – Digitally Attached

Appendix B.
Wastewater Sample Reports

(Digitally Attached)

Appendix C.

NCDA & CS Agronomic Division Soils Report

Loyd Ray Farms, Inc.
Innovative Animal Waste Management System
Permit No. AWI990031
Permit Compliance Semi-Annual Report

July 1, 2019 – December 31, 2019 Semi-Annual Reporting Period

Submitted January 31, 2020

Submitted on Behalf of:
Loyd Ray Farms, Inc.
2049 Center Rd.
Boonville, NC 27011

This Semi-Annual Compliance Report provides an overview of the manner in which the subject facility, Loyd Ray Farms, has maintained compliance with the conditions of the Innovative Animal Waste Management System permit for the reporting period from July 1, 2019 through December 31, 2019. During this reporting period, the system was operated in accordance with the Innovative Swine Waste Treatment System and subject to the requirements thereof.

Overview of System

The animal waste treatment system installed at Loyd Ray Farms is designed to meet the Environmental Performance Standards set forth by North Carolina law for new and expanded swine facilities through the use of nitrification/denitrification and further treatment. This report is provided to confirm, as applicable, on a semi-annual basis that the innovative waste management system is in compliance with NC Department of Environmental Quality and its divisions, to insure that the utilization of the anaerobic digester technology to turn raw animal waste into biogas for the purpose of reducing greenhouse gas emissions minimizes the overall environmental impact of the swine farm, and explains the occurrences of operations, and testing requirements over the six month period, to monitor the system, as it continues to produce renewable energy, generate carbon offsets, and reduce odor on the farm. The report is designed to not only show a synopsis of the maintenance activities on the farm, but also to supply the analysis of the system's performance and further describe the results of the monitoring and testing activities.

In addition to addressing compliance with the conditions of the permit, the following summaries provide an overview of the system operations including graphs of environmental system performance, microturbine performance, and biogas usage (pages 4-5), and lists all sampling and reporting requirements per the Innovative Animal Waste Management System Permit No. AW1990031 (pages 8-10). For each requirement, this report records on-site monitoring that occurred, with a brief explanation for each farm site visit (pages 6-8) for this reporting period. Additionally, detailed site visits recording maintenance and repairs completed during the second half of 2019, from July 1 through December 31, 2019 are also included in this report.

In summary, from July 1, 2019 through December 31, 2019, all processes that comprise the Innovative System were not fully operational, and electricity generation did not occur for the greater percentage of the reporting period. More intensive maintenance activities were required for some components, such as the anaerobic digester mixing pumps and the biogas conditioning skid, which is not abnormal for a system that has been operating for nearly ten years. Biogas production was lower than what is typically expected due to low hog populations throughout the summer, barn flushing system issues, and a blockage in the anaerobic digester manure collection piping (stemming from the barn flushing issues), which all led to lower manure supply to the digester. Various repairs were made to the system to continue operations as much as possible, and additional repairs are required to return the system to full operation. Those repairs include changing the digester mixing pumps' rotating unit and electric motor, replacing the biogas flare, and various repairs to the biogas conditioning skid. Quotes have been obtained for these repairs and are currently under review. Pending the decisions made regarding the costs and specified repairs, several system components may undergo repairs to bring the system back to expected operating conditions in the next reporting period. Additional observations of system performance are included below and exhibited in the operator logs attached to this report in Appendix A.

During this compliance period, ambient air analyses were accomplished on September 27, 2019, and December 31, 2019, details of the monitoring events have been added to this report (pages 12-16). The air emissions from water surfaces were found to comply and were lower than the permit allows and show that the system is performing according to expectations.

This report was completed on behalf of Loyd Ray Farms, Inc., by Cavanaugh & Associates, P.A., under the direction of the Duke Carbon Offsets Initiative (DCOI). Please contact Matthew Arsenault at 919-613-7466 (Matthew.Arsenault@duke.edu) with any questions. A copy of this report will be provided to Loyd Ray Farms, Inc., and will be maintained on-site with the other permit compliance documentation.

Environmental Treatment System

Figure 1, Environmental Treatment System Uptime, depicts the operation of the aeration system that performs the nitrification function and the anaerobic digester mixing pumps for the monitoring period. The environmental treatment system performed well throughout most of July, although low effluent supply to the aeration basin from the anaerobic digester caused system faults and operational issues during the remainder of the reporting period. The aeration basin mixing pumps eventually lost prime due to the low liquid level in the basin and were turned off in August to avoid continued faults and equipment damage. The liquid level in the basin can be restored to normal by removing the blockage from the anaerobic digester manure collection piping which will allow digester effluent to flow to the aeration basin. The liquid level was reduced because the farm uses recycle water from the aeration basin for barn flushing operations and no effluent was transferred from the digester to the basin. The blockage was not removed from the digester manure collection piping during the first half of the reporting period because the farm had low hog populations and flushing system issues. In addition, the biogas conditioning skid required repairs to the heat exchangers and chiller unit to ensure reliable operation. Those repairs were completed on July 16, 2019 and July 30, 2020. The farm resolved its flushing system issues in the latter half of the reporting period and the hog population was increased nearer to expected numbers. A quote has been obtained for removing the blockage and actions are expected to be taken in the next reporting period (January 1, 2020 through June 30, 2020) to resolve the issue.

One anaerobic digester mixing pump performed reliably for the beginning of the reporting period up to mid-September. The mixing pump experienced rotating unit failure in mid-September and was no longer able to function. The other mixing pump was repaired by Preferred Sources on August 16, 2020 by replacing the rotating unit. The pump was then identified to have a problem with the electric motor. Preferred Sources replaced the motor capacitors on September 19, 2020 which did not resolve the issue. It was then determined that the entire electric motor must be replaced. A quote has been received from Preferred Sources for replacing the rotating unit and electric motor and a decision on replacing the components is expected to be made in the next reporting period (January 1, 2020 through June 30, 2020). The environmental system operational issues are reflected in the graph depicting system uptime below.

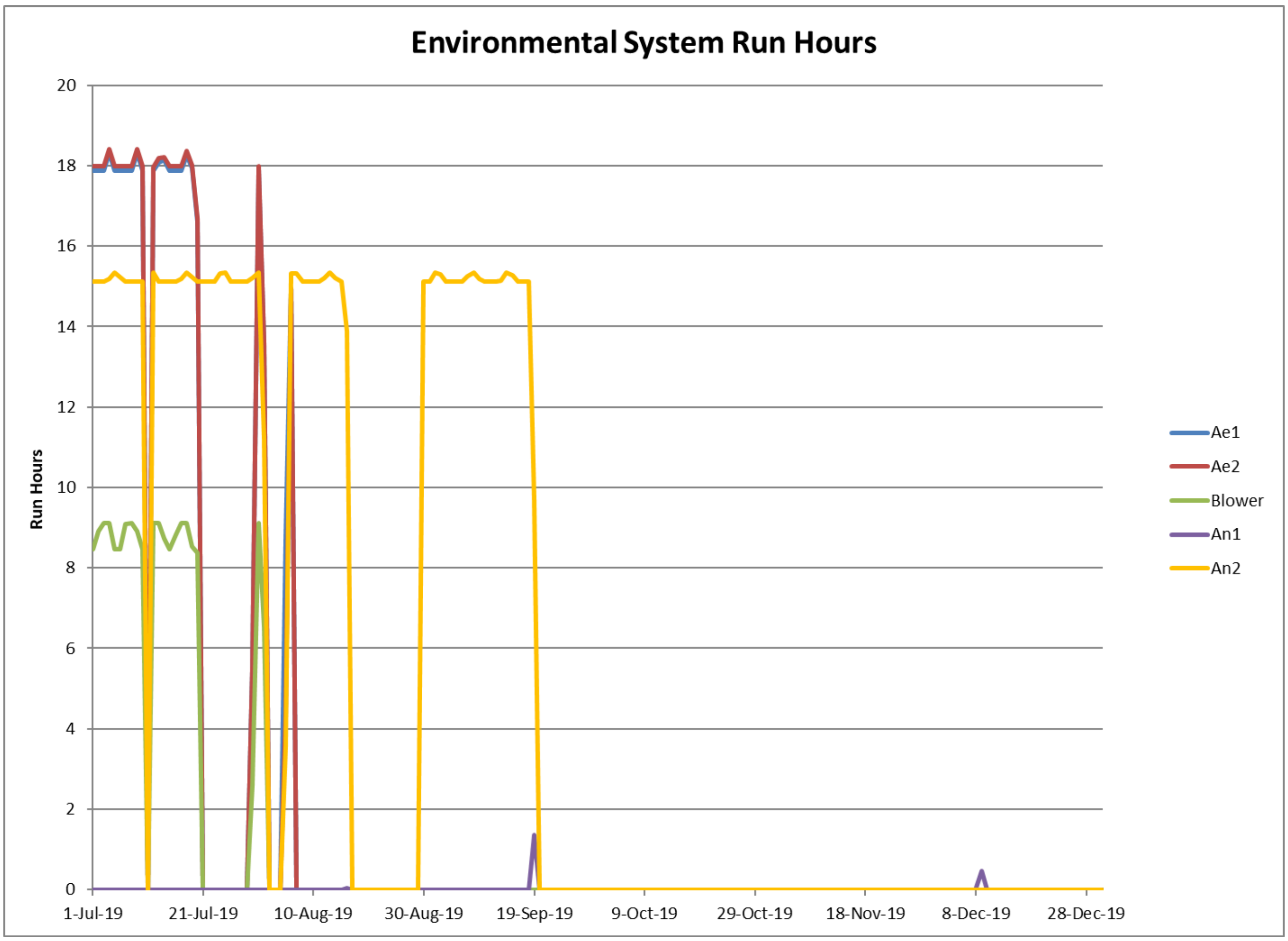

Figure 1. Environmental Treatment System Uptime (July 1, 2019 -December 31, 2019)

Biogas Production and Usage

Figure 2 below depicts the Microturbine Output in kilowatt hours (kWh) during the reporting period. Biogas may only be utilized through use by the microturbine and flare, controlled release through venting, or leaks from the system, which cannot be measured. Power was generated by the microturbine intermittently throughout July, August, and September when biogas quantities were sufficient for the microturbine to operate. The anaerobic digester did not produce sufficient volumes of biogas to supply the microturbine during October, November, and December so the microturbine was not operated. The digester did not perform to expectations due to low manure supply from the hog barns and a blockage in the digester manure collection piping. The microturbine performed reliably when operated, although, as stated and reflected in the graph below, low biogas volumes prevented it from operating for much of the reporting period.

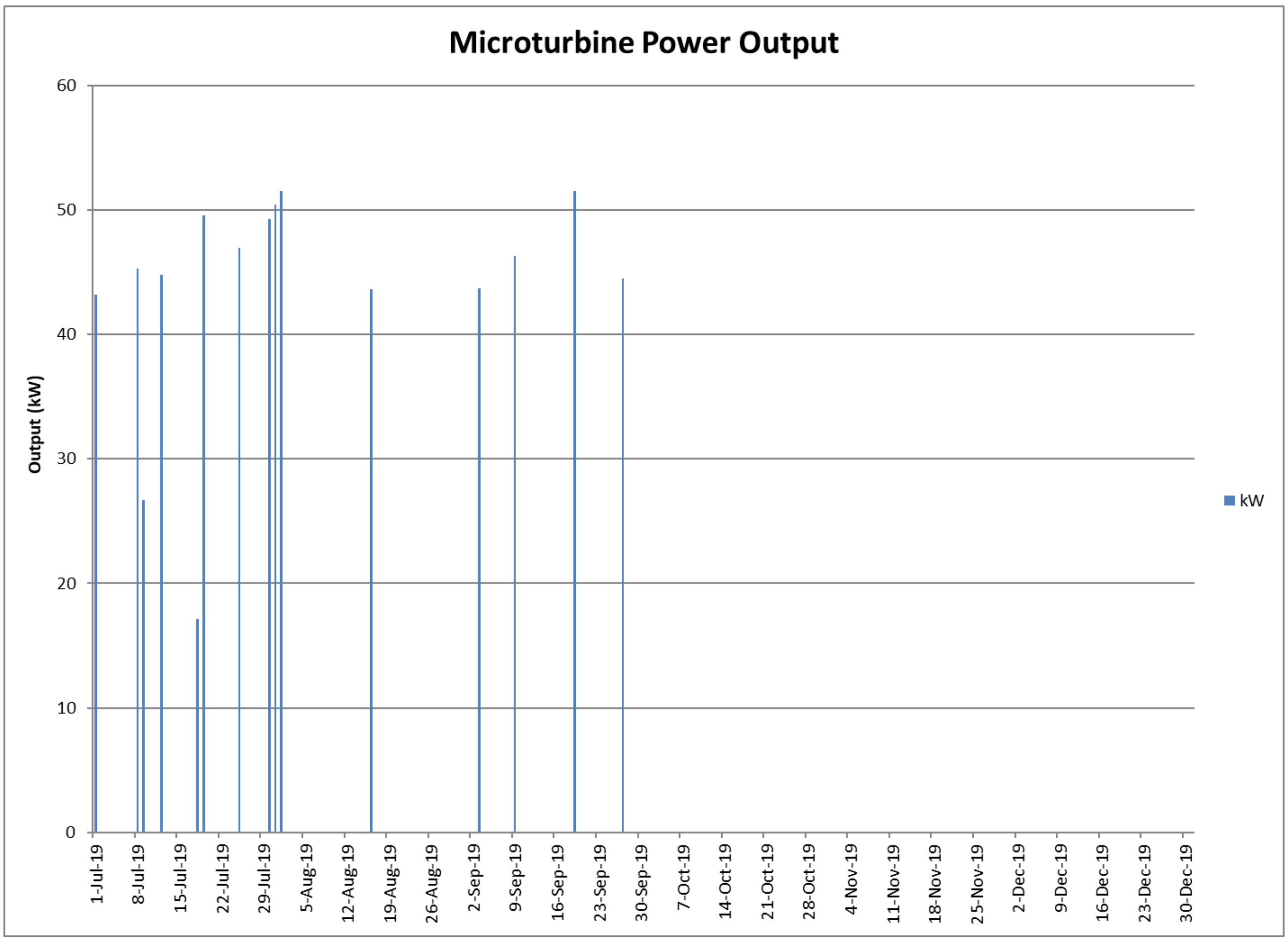

Figure 2. Microturbine Output (kW) (July 1, 2019 -December 31, 2019)

Figure 3, Measured Biogas Flow and Flare Use, depicts measured biogas usage in the microturbine and flare for the duration of the reporting period. As reflected above in the section describing microturbine output, the anaerobic digester did not produce projected biogas volumes due to manure supply issues. The biogas flare was not operated during the reporting period because a blockage in the flare's flame arrestor prevented biogas flow. The normal procedure for removing such a blockage from the flame arrestor is to disassemble the flare, remove the flame arrestor, replace or clean the flame arrestor, then reassemble the flare. Due to corrosion around the flare fittings, the flare cannot be disassembled and reassembled and needs to be completely replaced which represents a major capital expenditure. The flare will need to be replaced for continued long-term operation. A quote has been obtained for replacing the flare and is currently under review to determine if the flare should be replaced according to the quoted specifications or if another quote should be obtained. It is anticipated that a decision regarding the flare replacement will be made in the next reporting period (January 1, 2020 through June 30, 2020) and new flare equipment may be purchased pending the decision. There has not been a pressing need to replace the flare because the digester has not produced sufficient gas to supply the microturbine and flare and thus the flare has not been needed for biogas combustion. The lack of biogas usage in the flare is reflected in the graph below. The microturbine used biogas for power generation at various times throughout the reporting period as reflected in Figures 2 and 3. Again, due to manure supply issues and lack of biogas production in the digester, the biogas flow to the microturbine was much lower than is typically expected and has been historically reported.

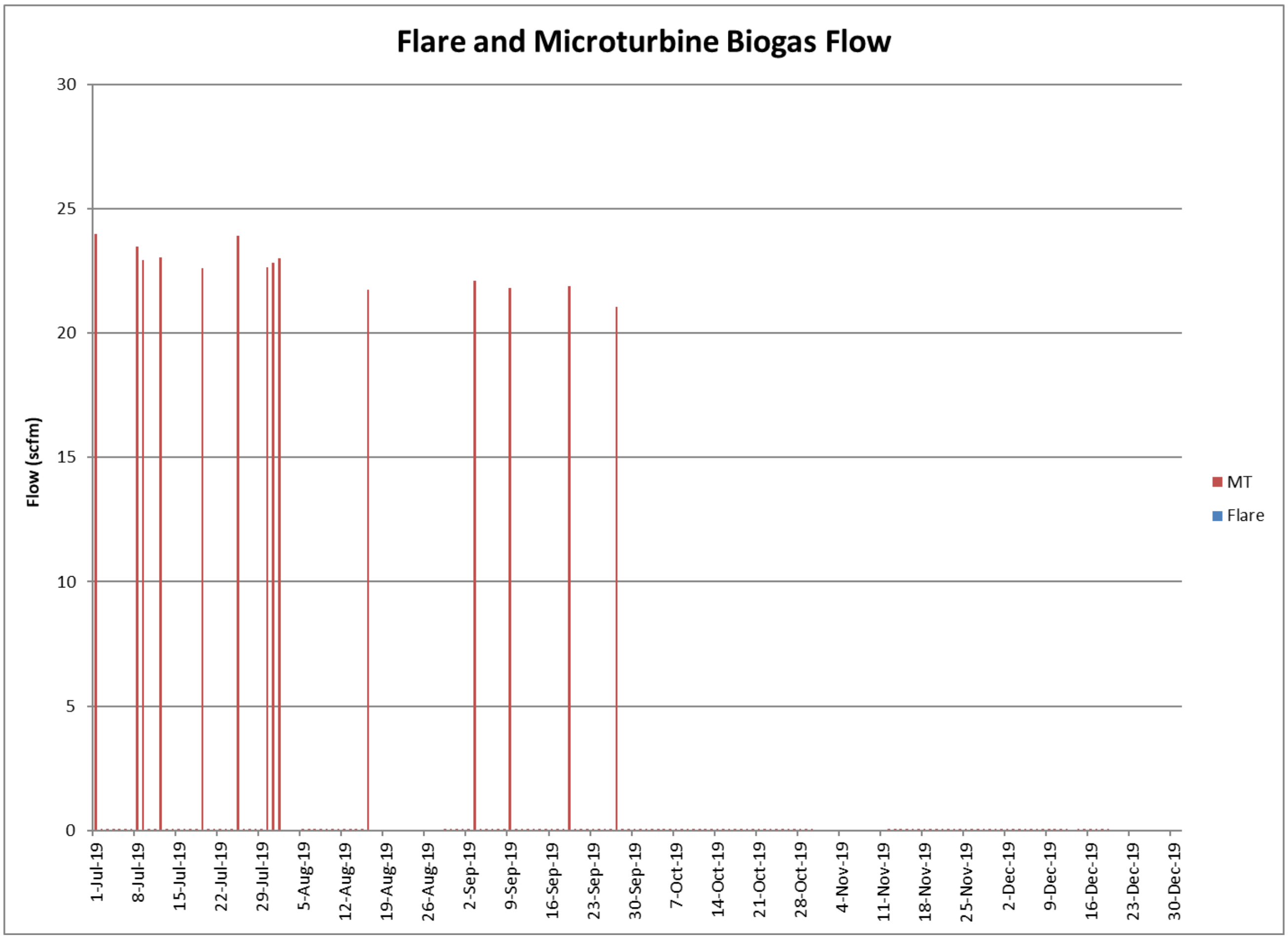

Figure 3. Measured Biogas Flow and Flare Use (July 1, 2019 -December 31, 2019)

Overview of System Maintenance and Repairs

Overall, the biogas system and the environmental treatment system remained under compliance but did not perform to expectations due to manure supply issues to the anaerobic digester. All maintenance exceptions appear in the log below, as maintained and recorded physically in the **Loyd Ray Farms Inspection and Operation**

Log Sheets. While remote monitoring occurs on a daily basis, those activities are not normally captured in the report. We will note here only occurrences which required a site visit to resolve, or how the technicians would troubleshoot any problems that arose. If a system alert precipitated a site visit, we have indicated how the monitoring team went about troubleshooting the problem, and logged the experience required to make the corrections. Oftentimes, Cavanaugh's team was able to resolve the issue, but if a representative from either Unison, the biogas skid provider, or another service technician, such as an electrician, was required for further assessment or repairs, we have also noted the dates of their presence, how they troubleshooted the problem, and if replacement, new or rebuilt parts were required. Please note that the system required more frequent service than usual as some of the components in the system, commissioned in 2011, are approaching their expected service life, however most of the service activities are viewed as normal operations and maintenance (O&M), and in all instances, no new system components were added to normal operations.

In summary, maintenance activities during this reporting period were completed to repair the anaerobic digester mixing pumps, the biogas conditioning skid and chiller unit, and the biogas piping, among other minor issues. Technicians from Preferred Sources assessed the digester mixing pump issues and made necessary repairs. A technician from Unison Solutions performed a service visit for the conditioning skid and a technician from Professional Air Systems performed a service visit for the chiller unit. The biogas piping repairs were coordinated by a technician from ProPump & Controls. The dates of these repairs are reflected in the operator logs and summary table below.

The summary of the detailed operations log of on-site activities and monitoring for the period of July 1, 2019 through December 31, 2019 is presented as follows:

Date	Observation
7-16-2019	Ben met Unison Solutions tech on site for biogas conditioning skid repairs. Also met ProPump & Controls tech on site to assess biogas flare repairs. Discovered small biogas leak in the condensate manhole near the building. Shut off gas flow to the manhole.
7-17-2019	Ben met Unison Solutions tech and ProPump and Controls tech on site for biogas leak repairs. Disassembled the manhole and repaired the leak by replacing the valve and collar. Repaired the manhole to original condition and opened the biogas valve. Biogas was no longer leaking.
7-30-2019	I met chiller tech from Professional Air Systems on site for chiller repairs. The tech did not identify any major issues but added refrigerant to the system to fill it. He replaced the chiller inlet and outlet glycol pressure gauges.
8-16-2019	Ben Cauthen met Preferred Sources at the farm to repair the rotating unit in anaerobic mixing pump 1. Preferred Sources completed the repair by approximately 9:30 AM. They then tested the pump and discovered the motor was drawing excessively high amperage. They tested the ohms of the starting components (capacitors) and didn't find an issue. One of the leads on a capacitor broke. Preferred Sources is going to order four new capacitors and replace the starting assembly. Mixing pump 1 is off until the capacitors are replaced.

	The aeration basin level is very low. The environmental system is turned off because the aerobic pumps lost prime due to the low liquid level. The farm used the basin liquid to flush hog houses without returning any liquid to the basin. The digester inlet must be reopened to allow waste to flow to the basin. The digester is producing very little gas due to the blocked inlet. Five of nine hog houses are filled with hogs.
8-29-2019	1. Digester Inlet Pipe a. I attempted to snake a piece of pipe into the inlet pipe today but couldn't get it to feed into the pipe. The manure in the manhole is very thick and is covering the pipe to the digester and the pipe to the lagoon. The 12" collection pipe is still visible as is the 4" forcemain from the aeration basin pumps. 2. Digester to Aeration Basin Pipe a. I'm not sure if this pipe is clogged but sludge may be blocking the inlet and outlet. 3. Conditioning Skid a. I could not get the conditioning skid to start today. The inlet heat exchanger discharge temp would not drop below 85°F. The operating range is 35 to 75°F. I'm not sure what the set point is for the skid to start. b. The temperature usually drops to at least 75°F even when it's very hot outside, and it isn't that hot today. The heat exchanger is cooling less now than it was before. The chiller appears to be running correctly and the glycol discharge pressure is correct. The chiller tech did not find anything wrong with the chiller except adding about 1 pound of freon. c. I haven't ran the skid in about 2 weeks. The inlet heat exchanger may have a blockage, which is what we suspected before. Maybe leaving the skid idle for a couple weeks somehow made the blockage worse. The Unison tech thought the chiller was the problem when he was here about a month ago and didn't attempt to repair the heat exchanger. 4. Flare a. I couldn't test the flare today since the skid wouldn't run. I didn't try to knock the flame arrestor with a pipe. 5. Digester Mixing Pumps a. Josh Amon is supposed to replace the capacitors in mixing pump 1 which will hopefully get it running. If not, the entire motor will need to be replaced. b. The rotating unit on mixing pump 2 sounds very rough. It should be replaced or rebuilt, although that's a $6,500 repair so I'm holding off for now. It's still functioning. 6. Environmental System a. The entire environmental system is turned off due to the very low aeration basin level. The pumps lost prime and are not functioning.
9-19-2019	Preferred Sources replaced the starting components in digester mixing pump 1. The pump pulled 22-27 amps after the capacitors were replaced. The pump is pulling above normal

	amperage meaning there is likely a more significant issue with the motor. I turned the pump off and will leave it off. Digester mixing pump 2 will not prime. We attempted to prime the pump with a hose and mixing pump 1, but neither approach worked. There is likely an issue with the rotating unit on the pump. Steve and I inspected the site and discussed decommissioning and the plan going forward. I completed Q3 manure sampling and returned the samples to R&A Labs.
9-27-2019	Performed a complete system check and operated the skid and turbine for several hours. Met Matt and Emma from Duke University and explained the system to them. Matt performed odor sampling for Q3.
10-23-2019	Met Yadtel tech to update router to match Yadtel's new specs. Efinity will need to replace the router to repair the internet. No internet is available now.
12-9-2019	Performed manure sampling to fulfill quarterly requirement. Met NCDEQ employees for inspection.
12-20-2019	Performed annual sludge survey to measure digester sludge accumulation. Repaired internet with Yadtel.

The following table lists the compliance requirements as per the permit for the subject system, and the performance / compliance relative to each requirement:

	Description of Monitoring Requirement	Status	Result
1	Maintenance of adequate records by Permittee to track the amount of sludge/separated solids disposed.	N/A	No solids or sludge disposal occurred during the reporting period.
2	Inspection of entire Innovative System waste collection, treatment, and storage structures and runoff control measures at a frequency to insure proper operation but at least monthly and after all storm events of greater than one (1) inch in 24 hours; Permittee maintenance of inspection log or summary including at least the date and time of inspection, observations made, and any maintenance, repairs, or corrective actions taken by Permittee.	☑	Inspections and observations conducted by representatives of Loyd Ray Farms, Inc., Cavanaugh & Associates, P.A., and DCOI. Observations recorded, and actions taken to adjust the operation of the System are recorded in log book kept onsite, and emailed in.
3	Maintenance of a log of all operational changes made to the Innovative System including at least the process parameter that was changed, date and time of the change, reason for the change, and all observations made both at the time of the change and	☑	Log book entries, as described in item #2, above, maintained on site; copies attached to report (Appendix A).

	subsequently as a result of the change by Permittee/ Permittee's designee.		
4	Representative Standard Soil Fertility Analysis to be conducted annually on each application site receiving animal waste.	☐	An NCDA&CS Agronomic Division Report showing results of the Predictive Home & Garden Soil Report for Loyd Ray Farms was not available for the compliance period. Predictive Waste Reports completed on 7/31/2019 and 11/13/2019 are attached to this report and can also be accessed here: http://www.ncagr.gov/agronomi/
Wastewater Analysis			
5	Quarterly tests shall be conducted once within each of the following windows w/ at least sixty (60) days between any 2 sampling events. Water quality samples include analysis of copper, zinc, total suspended solids, pH, total nitrogen, TKN, NO2 + NO3, phosphorus, ammonia, and fecal coliform.		
	Quarter 3 (July 1 – September 30)	☑	Sample Collected: 9/19/2019 Sample Analyzed: 9/19/2019 Results Reported: 10/2/2019 Results included in the attached report from Research & Analytical Laboratories, Inc. (Appendix B)
	Quarter 4 (October 1 – December 31)	☑	Sample Collected: 12/9/2019 Sample Analyzed: 12/9/2019 Results Reported: 1/13/2020 Results included in the attached report from Research & Analytical Laboratories, Inc. (Appendix B)
Ambient Air Sampling			
	Fall Season Ambient Air Sampling	☑	A fall season ambient air sample was taken on September 27, 2019. Results are included in the Explanation of Results and Sampling Methods.
	Waste Treatment and Storage System	☑	
	Barns	☑	
	Sprayfields	☐	
	Winter Season Ambient Air Sampling	☑	A second ambient air sample (winter analysis) was completed on December 31, 2019. Results are included in the Explanation of Results and Sampling Methods.
	Waste Treatment System	☑	

	Barn Exhaust	☑	
	Sprayfields	☐	
Odor Sampling			
6	Permittee shall monitor for odor compliance quarterly at both upwind and downwind locations on the property boundary. Permittee shall document monitoring locations on a site map, indicating prevailing wind direction, for each monitoring event.		
	Quarter 3 (July 1 – September 30)	☑	Odor sampled by Duke University on December 31, 2019. Results are included in the Explanation of Results and Sampling Methods.

EXPLANATION OF RESULTS AND SAMPLING METHODS

1. Amount of Sludge or Separated Solids Disposed and Measured
N/A. No disposal of sludge or separated solids was required from the Innovative System during the 7/1/2019-12/31/2019 reporting period.

Marvin Cavanaugh and Ben Cauthen of Cavanaugh & Associates, P.A. completed a sludge survey of the anaerobic digester on December 20, 2019. Sludge depth was measured from the two centermost digester vents at the locations depicted below. The depth at Location 1 was measured as 2’ and the depth at Location 2 was measured as 2’-6”.

Figure 4. Loyd Ray Farms anaerobic digester sludge survey locations from December 20, 2019.

2. Log of System Inspections
See Operator Log Book, Appendix A.

3. Log of Operational Changes to the Innovative System
See Operator Log Book, Appendix A.

4. Results of Standard Soil Fertility Analysis
There were no Soil Reports published by NCDA&CS Agronomic Division during the July 1, 2019 through December 31, 2019 compliance period. Soil samples were previously taken at Loyd Ray Farms on October 22, 2018 and the soil analysis results were included in the January 31, 2019 Semi-Annual Compliance Report. NCDA&CS Agronomic Division Predictive Waste Reports completed on 7/31/2019 and 11/13/2019 are attached to this report.

5. Results of Water and Air Quality Sampling

a. Results of Wastewater Analysis
Water quality samples were taken in each quarter and a synopsis of the results is found below and in Appendix B. Samples were analyzed by Research Analytical Laboratories, Inc. in Kernersville, NC. The following table compares the results of the water quality analysis of the final effluent from the Innovative System:

Parameter	9/19/2019	12/9/2019
TOT N	1630	852
TKN	1630	852
NO_2+NO_3	<0.05	0.757
TP	69.4	36.8
NH_3-N	852	436
COPPER	0.059	0.026
ZINC	0.224	0.086
TS	102	120
FECAL	<18	3
pH	8.59	8.44

The chart above describes the wastewater analyses that are required to be conducted on a quarterly basis. These parameters are total N, NH_3-N, NO_3-N/NO_2-N, total P, % solids, copper, zinc, pH and pathogens. Samples are to be taken from the raw manure, the digester, and the effluent (leaving the aeration basin).

b. **The Results of Air Sampling**

Duke University took Fall and Winter ambient Air Samples on September 27, 2019, and December 31, 2019, respectively, the results of which are described below.

Odor Sampling THIRD QUARTER

Odor was monitored to comply with Section I.6.b.ii of the Swine Animal Waste Management Permit. One monitoring event was conducted on September 27, 2019.

Sampling took place at about 11:40 am. It was slightly overcast day, temperature was 80° F with very variable wind 1.2 –2.5 m/s and average at about 2 m/s. The predominant wind direction and sampling points for odor were selected as shown in Figure 1.

Odor was monitored by Emma Fulop and Matthew Arsenault. Odor was monitored using a Nasal Ranger (http://www.nasalranger.com/) field olfactometer, following the manufacturer recommended instructions.

Figure 5. Aerial view of the facility and location of the monitoring points for odor for the September 27, 2019 sampling. The arrows indicate the prevailing wind direction the day of the sampling.

<u>Sampling upwind</u>
Odor could not be detected at the 2 D/T level. This indicates that the odor level was lower than 2 D/T. Then the Nasal Ranger was taken off the nose and ambient air was sniffed and compared to odorless air from the Nasal Ranger. This was to determine whether a difference could be detected between ambient air and odorless air from the Nasal Ranger. No significant difference could be detected.

<u>Sampling downwind</u>
No odor could be detected at the 2 D/T level at the downwind. This indicates that the odor level was lower than 2 D/T. However ambient air without Nasal Ranger had faint barn odors while still being below the 2 D/T level.

These results indicate that odor levels complied with Section I.6.b.ii of the Swine Animal Waste Management Permit.

Odor Sampling FOURTH QUARTER

Odor was monitored to comply with Section I.6.b.ii of the Swine Animal Waste Management Permit. One monitoring event was conducted on December 31, 2019.

Sampling took place at about 10:30 am. It was a nice cold (50° F) clear and windy day. The wind was strong with steady winds of 4 m/s and gusts of up to 10 m/s. Several measurements for wind speed and direction were taken. The average wind speed was about 6 m/s, the predominant wind direction and sampling points for odor were selected as shown in Figure 2.

Odor was monitored by Marc Deshusses. Odor panelist rules were listed in the previous report and are not repeated here. Odor was monitored using a Nasal Ranger (http://www.nasalranger.com/) field olfactometer, following the manufacturer recommended instructions.

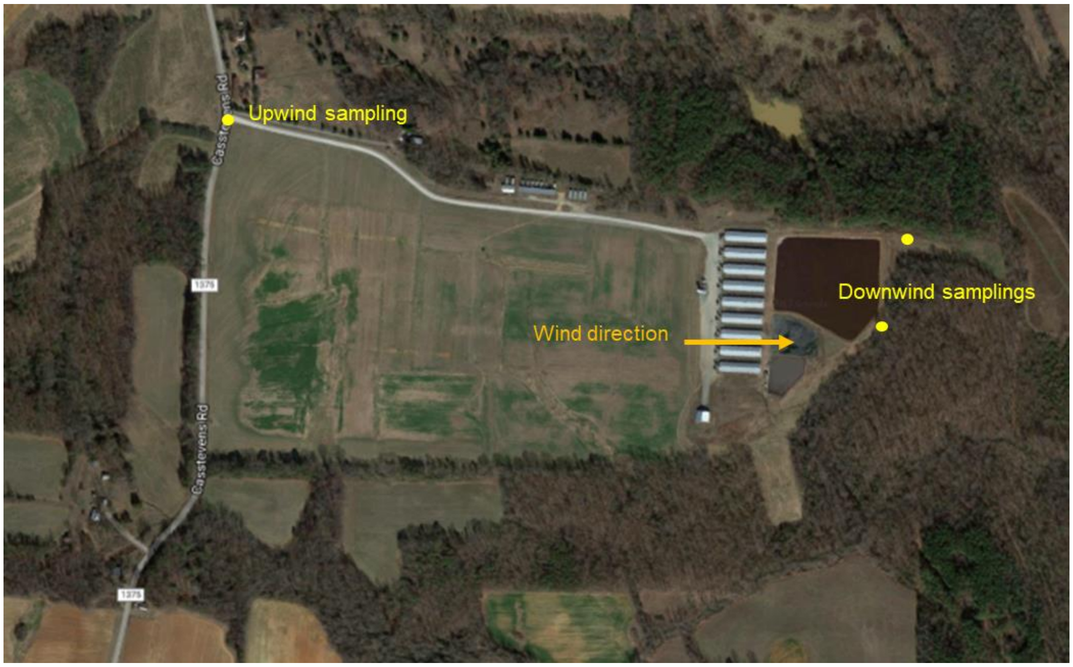

Figure 6. Aerial view of the facility and location of the monitoring points for odor for the December 31, 2019 sampling. The arrows indicate the prevailing wind direction the day of the sampling.

<u>Sampling upwind</u>
Odor could not be detected at the 2 D/T level. This indicates that the odor level was lower than 2 D/T. Then the Nasal Ranger was taken off the nose and ambient air was sniffed and compared to odorless air from the Nasal Ranger. This was to determine whether a difference could be detected between ambient air and odorless air from the Nasal Ranger. No significant difference could be detected.

<u>Sampling downwind</u>
Two sampling points were selected. Odor sensation without the olfactometer seemed variable probably because of the wind. No odor was consistently detected at the 2 D/T level at the downwind locations. This indicates that the odor level was lower than 2 D/T. Then the Nasal Ranger was taken off the nose and ambient air was sniffed and compared to odorless air from the Nasal Ranger. This was to determine whether a difference could be detected between ambient air and odorless air from the Nasal Ranger. There was a faint piggery/barn odor depending on wind gusts, but as mentioned before these odors were below the 2 D/T level.

These results indicate that odor levels complied with Section I.6.b.ii of the Swine Animal Waste Management Permit.

Emissions from Animal Waste Treatment and Storage System

Ammonia nitrogen emissions from the aeration basin and lagoon were quantified to determine if significant volatilization of NH_3-N occurred from this part of the waste management system. Emissions from the water surfaces were determined using a buoyant convective flux chamber (BCFC) which method was described in detail and illustrated with pictures in the February 15, 2012 report. Sampling took place on December 31, 2019. Sampling took place between 11 am and noon. It was a nice cold (50° F) clear and windy day. The wind was strong with steady winds of 4 m/s and gusts of up to 10 m/s. The average wind speed was about 6 m/s, Results were as follows:

- Size of the chamber: 52.1 cm wide by 52.1 cm long and 2.5 cm in headspace height.
- Air sampling flow rate: 2.9 L/min
- **Average ammonia concentrations** in sweep air from the aeration basin while aeration was off: **0.9 ppm** (2 samples) or on average in mass concentration 0.51 mg-N/m^3. We note here that this concentration is much lower than what was measured in earlier testing, possibly because of the lower use of the aeration basin.
- Ammonia concentrations in sweep air while aeration was on was not measured, earlier monitoring indicated that ammonia concentration in sweep air during aeration was slightly lower.

The total emission from the aeration basin can be calculated from the air sampling flow rate, the surface of the chamber and the surface area of the aeration basin. The latter surface is nominally 24,500 ft^2 (or 2277 m^2) but was reduced to 1600 m^2 for these calculations as the level of water in the aeration basin was low. Emission rate is calculated as follows:

NH_3 emission rate = NH_3 concentration × Sampling flow rate × Aeration basin area / Buoyant chamber area
After unit conversion, one obtains values of 0.52 g/h. This corresponds to a NH_3 emission rate of **0.088 kg NH_3-N/week.** This is a low value compared to the **allowable emissions of 106 kg NH_3-N/week** from the swine waste treatment and storage structures as specified in Section I.6.a.i of the Swine Animal Waste Management Permit. Surface emission rate of NH_3 from the **lagoon** was determined following the same method. Average concentration of ammonia in the sweep air (with the same chamber and at the same flowrate of 2.9 L/min) was 2.4 ppm (2 samples). With the surface area of the lagoon (19,425 m^2), emission of NH_3 from the lagoon are estimated to be **2.85 kg NH_3-N/week**.

Results for the emissions from the aeration basin and the lagoon are summarized in the table below. Total ammonia (TAN) in the aeration basin and lagoon at the time of sampling is also reported for information. The concentrations of TAN were low; they reflect the fact that many of the barns were not populated with swine. Altogether, these numbers show the system is performing as expected.

	Aeration basin	**Lagoon**
Surface area	1600 m^2	4.8 acres = 19,425 m^2
Emission rate	0.088 kg NH_3-N/week	2.85 kg NH_3-N/week
Total emission (lagoon + aeration basin)	**2.93 kg NH_3-N/week**	

Thus, together lagoon and aeration basin contribute to the emission of **2.93 kg NH_3-N/week**. This is well below the allowable 106 kg NH_3-N/week.

Emissions from the Barns

Ammonia emissions from the barns were also determined on December 31, 2019. It should be noted that accurate determination of emissions from animal houses is a difficult exercise. This is because of the variable nature of the emission, the difficulty in accurately measuring air flow from the fans on the animal houses, and the fact that fan operation is automated, i.e., they are turned on and off automatically triggered by a thermostat. Thus, uncertainties on the numbers reported below exist and can be important.

Ammonia in the exhaust air from the barns was determined using Draeger tubes. Details on the concentrations and number of fans on at the time of sampling are shown in the table below.

Barn	NH_3 Concentration (ppm)	Small Fans working	Large Fans working
1	7.5	1	1
2	8	1	1
3	ND	0	0
4	4	1	0
5	3.4	1	0
6	9	1	0
7	12.5	1	1
8	8.3	1	1
9	10	0	2

The total emission of ammonia can be estimated by multiplying the ammonia concentration in each of the barn's exhausts by the exhaust flowrate of that barn (33,000 cfm for large fans and 13,000 cfm for the small fans). At the time of sampling, total exhaust flow was 289,000 cfm and concentrations ranged from 4 to 12.5 ppm (see Table above). One barn is noted ND (not determined) because both fans were off. The calculated total weekly ammonia emissions from the barns was **411 kg NH_3-N/week.**

Adding the emission from the treatment system and the lagoon (**2.93 kg NH_3-N/week**) to the emissions from the barns (**411 kg NH_3-N/week**) amounts to a **total of 414 kg NH_3-N/week** from the swine farm**.** This is below the allowable value of 476 kg NH_3-N/week specified in Section I.6.a.iii of the Swine Animal Waste Management Permit.

Additional Observations

As noted above, there are several critical repairs required to return the Innovative System to full operation, including removing the blockage from the anaerobic digester manure collection piping, replacing components on both digester mixing pumps, and replacing the biogas flare. Those repairs would require significant spending and quotes have been received and are currently being reviewed. The Innovative System owner, Duke University, is currently determining the appropriate actions for the operation of the system going forward as the contract with Loyd Ray Farms to operate the system is nearing the end of its ten year term. Duke is reviewing the costs and benefits of continuing operation of the system long-term to determine appropriate repairs during 2020.

Loyd Ray Farms has maintained compliance with the conditions of the Innovative Animal Waste Management System permit since the blockage in the manure collection piping caused the farm to divert manure to the existing lagoon and resume operations as were done before the installation of the Innovative System.

This Semi-annual Compliance Report is compiled and respectfully submitted by:

Benjamin K Cauthen

Benjamin K. Cauthen, E.I.
Cavanaugh & Associates, P.A.
1-877-557-8923

Attachments:

Appendix A – PDF of Actual log sheets
Appendix B – Wastewater Sample Collection Dataset
Appendix C – Predictive Waste Reports

APPENDIX A – Operation and Log Sheets

LOYD RAY FARMS INSPECTION, OPERATIONS & MAINTENANCE LOG SHEET

IMPORTANT: AN INSPECTION, OPERATIONS & MAINTENANCE LOG SHOULD BE COMPLETED FOR EVERY SITE VISIT; PLEASE REVIEW PREVIOUS LOG ENTRY AND PROVIDE INFORMATION TO UPDATE OR RESOLVE ANY ON-GOING ISSUES NOTED (INCLUDING BUT NOT LIMITED TO MAINTENANCE, REPAIRS, OR CORRECTIVE ACTIONS).

Entry Made By: Ben Cauthen	**07-16-2019 Tuesday**	**Visit Start Time 8:00 AM**	**Visit Stop Time 2:30 PM**
Condition: Temperature	☐ Partly Cloudy ☐ Balmy **Sunny 85 °F**		
Precip Past 24 hours: 0.00 inches in gauge		**Wind: (mph): 0-2 mph**	

PURPOSE OF VISIT/ITEMS INSPECTED, OPERVATIONS

Ben met Unison Solutions tech on site for biogas conditioning skid repairs. Also met ProPump & Controls tech on site to assess biogas flare repairs. Discovered small biogas leak in the condensate manhole near the building. Shut off gas flow to the manhole.

ENVIRONMENTAL SYSTEM OBSERVATIONS:

Equipment Observed:	Operational Status
Fluidyne Aeration System, Including:	
Jet Motive Pumps	☒ Auto ☐ Hand On ☐ Off ☐ In Fault
Blower	☒ Auto ☐ Hand On ☐ Off ☐ In Fault:
CP-1 (Control Panel)	☒ Auto ☐ Hand On ☐ Off ☐ In Fault
Flush Pumps	☐ Auto ☒ Hand On ☐ Off ☐ In Fault
Digester Mixing Pumps	☒ Auto ☐ Hand On ☒ Off ☐ In Fault

CP-1 DATA & SET POINTS;

Cycles	Set Point	Current	Modified Set Pt	Notes
Static	60	60		
Anoxic	90	90		
Aerobic	180	180		
Blower	☐ Continuous ☒ Cycle			
Jet Motive Pumps	☐ Continuous ☒ Both ☐ Pump #1 ☐ Pump # 2			
Digester Pumps	☐ Continuous ☒ Both ☐ Sequential			

MOTOR DATA:

Aerobic	Run Time	Set Speed	Notes
Jet Motive Pump # 1		60Hz	
Jet Motive Pump # 2		60Hz	
Blower		30Hz	
Anaerobic			
Mixing Pump 4A		60 Hz	
Mixing Pump 4B		60 Hz	

BIOGAS & POWER SYSTEMS OBSERVATIONS:

Equipment Observed:	**Operational Status**				
Unison Gas Skid	Flow Rate	Total Flow	Comp. Press.	Outlet Press.	Gauge Press.
Fault? ☐ Yes ☒ No					
Microturbine	Speed	Exit Temp	Inlet Pressure	Inlet Temp	Power Out
Fault? ☐ Yes ☒ No					
Biogas System	BlueSens%	Flare On	Flare Flow	Total Flow	Flare Temp
		☐ Y ☒ N			

UNISON GAS CONDITIONING LOG

Pressure Data	**PIT 311** -5 to 10 inWC	**PIT 331** 88 to 110psig	**PIT 351** 88 to 110 psig	**Pressure Differential**	**Panel Door**	**HM 331** Hours	
Temperature Data	**TE 141** 32 to 45 F	**TE 311** 40 to 115 F	**TE 321** 35 to 75 F	**TE 331** 80 to 220 F	**TE 341** 33 to 45 F	**TE 342** 65 to 90 F	**TE 31** 35 to 115 F
Glycol Piping	**TI 141** 32 to 45 F	**PI 141** 35 to 52 psig	**FI 141** 2.5 to 3.5 gpm	**TI 142** 35 to 50 F	**PI 142** 33 to 50 psig	**TI 111** 38 to 52 F	**PI 111** 30 to 48 psig
Oil Piping	**PI 231** 90 to 110 psig	**TI 231** 178 to 215 F	**PI 232** 85 to 105 psig	**TI 232** 130 to 180 F	**PI 233** 80 to 100 psig	**TI 233** 168 to 185 F	**PI 234** 78 to 100psig
Gas Piping	**PIT 311** -10 to10inWC	**TI 311** 40 to 115 F	**TI 321** 35 to 75 F	**PDI 321** 0 to 6 inWC	**PI 331** 90 to 110 psig	**TI 331** 80 to 220 F	**PI 332** 90 to 110psig
Gas Piping	**TI 341** 80 to 220 F	**PI 341** 90 to 110 psig	**TI 342** 115 to 155 F	**PI 342** 90 to 110 psig	**TE 343** 33 to 45 F	**PI 343** 90 to 110 psig	
Gas Piping	**TI 351** 65 to 90 F	**PI 351** 88 to 15 psig	**Check Indicators**	**LI 721**	**LI 231**	**LI 741**	

PERSONNEL PRESENT:

Name	***Affiliation***	***Phone Number/Email***
Ben Cauthen	**Cavanaugh**	
Curt Schiesl	**Unison Solutions**	
Mark Roberts	**ProPump & Controls**	

LOYD RAY FARMS INSPECTION, OPERATIONS & MAINTENANCE LOG SHEET

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Entry Made By: Ben Cauthen	**07-17-2019 Wednesday**	**Visit Start Time 8:00 AM**	**Visit Stop Time 3:30 PM**
Condition: Temperature	☐ Partly Cloudy ☐ Balmy **Sunny 90 °F**		
Precip Past 24 hours: 0.00 inches in gauge		**Wind: (mph): 0 mph**	

PURPOSE OF VISIT/ITEMS INSPECTED, OPERVATIONS

Ben met Unison Solutions tech and ProPump and Controls tech on site for biogas leak repairs. Disassembled the manhole and repaired the leak by replacing the valve and collar. Repaired the manhole to original condition and opened the biogas valve. Biogas was no longer leaking.

ENVIRONMENTAL SYSTEM OBSERVATIONS:

Equipment Observed:	Operational Status
Fluidyne Aeration System, Including:	
Jet Motive Pumps	☒ Auto ☐ Hand On ☐ Off ☐ In Fault
Blower	☒ Auto ☐ Hand On ☐ Off ☐ In Fault:
CP-1 (Control Panel)	☒ Auto ☐ Hand On ☐ Off ☐ In Fault
Flush Pumps	☐ Auto ☒ Hand On ☐ Off ☐ In Fault
Digester Mixing Pumps	☒ Auto ☐ Hand On ☒ Off ☐ In Fault

CP-1 DATA & SET POINTS;

Cycles	Set Point	Current	Modified Set Pt	Notes
Static	60	60		
Anoxic	90	90		
Aerobic	180	180		
Blower	☐ Continuous ☒ Cycle			
Jet Motive Pumps	☐ Continuous ☒ Both ☐ Pump #1 ☐ Pump # 2			
Digester Pumps	☐ Continuous ☒ Both ☐ Sequential			

MOTOR DATA:

Aerobic	Run Time	Set Speed	Notes
Jet Motive Pump # 1		60Hz	
Jet Motive Pump # 2		60Hz	
Blower		30Hz	
Anaerobic			
Mixing Pump 4A		60 Hz	
Mixing Pump 4B		60 Hz	

BIOGAS & POWER SYSTEMS OBSERVATIONS:

Equipment Observed:	**Operational Status**				
Unison Gas Skid	Flow Rate	Total Flow	Comp. Press.	Outlet Press.	Gauge Press.
Fault? ☐ Yes ☒ No					
Microturbine	Speed	Exit Temp	Inlet Pressure	Inlet Temp	Power Out
Fault? ☐ Yes ☒ No					
Biogas System	BlueSens%	Flare On	Flare Flow	Total Flow	Flare Temp
		☐ Y ☒ N			

UNISON GAS CONDITIONING LOG

Pressure Data	**PIT 311** -5 to 10 inWC	**PIT 331** 88 to 110psig	**PIT 351** 88 to 110 psig	**Pressure Differential**	**Panel Door**	**HM 331** Hours	
Temperature Data	**TE 141** 32 to 45 F	**TE 311** 40 to 115 F	**TE 321** 35 to 75 F	**TE 331** 80 to 220 F	**TE 341** 33 to 45 F	**TE 342** 65 to 90 F	**TE 31** 35 to 115 F
Glycol Piping	**TI 141** 32 to 45 F	**PI 141** 35 to 52 psig	**FI 141** 2.5 to 3.5 gpm	**TI 142** 35 to 50 F	**PI 142** 33 to 50 psig	**TI 111** 38 to 52 F	**PI 111** 30 to 48 psig
Oil Piping	**PI 231** 90 to 110 psig	**TI 231** 178 to 215 F	**PI 232** 85 to 105 psig	**TI 232** 130 to 180 F	**PI 233** 80 to 100 psig	**TI 233** 168 to 185 F	**PI 234** 78 to 100psig
Gas Piping	**PIT 311** -10 to10inWC	**TI 311** 40 to 115 F	**TI 321** 35 to 75 F	**PDI 321** 0 to 6 inWC	**PI 331** 90 to 110 psig	**TI 331** 80 to 220 F	**PI 332** 90 to 110psig
Gas Piping	**TI 341** 80 to 220 F	**PI 341** 90 to 110 psig	**TI 342** 115 to 155 F	**PI 342** 90 to 110 psig	**TE 343** 33 to 45 F	**PI 343** 90 to 110 psig	
Gas Piping	**TI 351** 65 to 90 F	**PI 351** 88 to 15 psig	**Check Indicators**	**LI 721**	**LI 231**	**LI 741**	

PERSONNEL PRESENT:

Name	***Affiliation***	***Phone Number/Email***
Ben Cauthen	**Cavanaugh**	
Curt Schiesl	**Unison Solutions**	
Mark Roberts	**ProPump & Controls**	

LOYD RAY FARMS INSPECTION, OPERATIONS & MAINTENANCE LOG SHEET

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Entry Made By: Ben Cauthen	**07-30-2019 Tuesday**	**Visit Start Time 9:00 AM**	**Visit Stop Time 1:30 PM**
Condition: Temperature	☐ Partly Cloudy ☐ Balmy **Sunny 85 °F**		
Precip Past 24 hours: 0.00 inches in gauge		**Wind: (mph): 0 mph**	

PURPOSE OF VISIT/ITEMS INSPECTED, OPERVATIONS

I met chiller tech from Professional Air Systems on site for chiller repairs. The tech did not identify any major issues but added refrigerant to the system to fill it. He replaced the chiller inlet and outlet glycol pressure gauges.

ENVIRONMENTAL SYSTEM OBSERVATIONS:

Equipment Observed:	**Operational Status**
Fluidyne Aeration System, Including:	
Jet Motive Pumps	☒ Auto ☐ Hand On ☐ Off ☐ In Fault
Blower	☒ Auto ☐ Hand On ☐ Off ☐ In Fault:
CP-1 (Control Panel)	☒ Auto ☐ Hand On ☐ Off ☐ In Fault
Flush Pumps	☐ Auto ☒ Hand On ☐ Off ☐ In Fault
Digester Mixing Pumps	☒ Auto ☐ Hand On ☒ Off ☐ In Fault

CP-1 DATA & SET POINTS;

Cycles	**Set Point**	**Current**	**Modified Set Pt**	**Notes**
Static	**60**	**60**		
Anoxic	**90**	**90**		
Aerobic	**180**	**180**		
Blower	☐ Continuous ☒ Cycle			
Jet Motive Pumps	☐ Continuous ☒ Both ☐ Pump #1 ☐ Pump # 2			
Digester Pumps	☐ Continuous ☒ Both ☐ Sequential			

MOTOR DATA:

Aerobic	**Run Time**	**Set Speed**	**Notes**
Jet Motive Pump # 1		**60Hz**	
Jet Motive Pump # 2		**60Hz**	
Blower		**30Hz**	
Anaerobic			
Mixing Pump 4A		**60 Hz**	
Mixing Pump 4B		**60 Hz**	

BIOGAS & POWER SYSTEMS OBSERVATIONS:

Equipment Observed:	**Operational Status**				
Unison Gas Skid	Flow Rate	Total Flow	Comp. Press.	Outlet Press.	Gauge Press.
Fault? ☐ Yes ☒ No					
Microturbine	Speed	Exit Temp	Inlet Pressure	Inlet Temp	Power Out
Fault? ☐ Yes ☒ No					
Biogas System	BlueSens%	Flare On	Flare Flow	Total Flow	Flare Temp
		☐ Y ☒ N			

UNISON GAS CONDITIONING LOG

Pressure Data	**PIT 311** -5 to 10 inWC	**PIT 331** 88 to 110psig	**PIT 351** 88 to 110 psig	**Pressure Differential**	**Panel Door**	**HM 331** Hours	
Temperature Data	**TE 141** 32 to 45 F	**TE 311** 40 to 115 F	**TE 321** 35 to 75 F	**TE 331** 80 to 220 F	**TE 341** 33 to 45 F	**TE 342** 65 to 90 F	**TE 31** 35 to 115 F
Glycol Piping	**TI 141** 32 to 45 F	**PI 141** 35 to 52 psig	**FI 141** 2.5 to 3.5 gpm	**TI 142** 35 to 50 F	**PI 142** 33 to 50 psig	**TI 111** 38 to 52 F	**PI 111** 30 to 48 psig
Oil Piping	**PI 231** 90 to 110 psig	**TI 231** 178 to 215 F	**PI 232** 85 to 105 psig	**TI 232** 130 to 180 F	**PI 233** 80 to 100 psig	**TI 233** 168 to 185 F	**PI 234** 78 to 100psig
Gas Piping	**PIT 311** -10 to10inWC	**TI 311** 40 to 115 F	**TI 321** 35 to 75 F	**PDI 321** 0 to 6 inWC	**PI 331** 90 to 110 psig	**TI 331** 80 to 220 F	**PI 332** 90 to 110psig
Gas Piping	**TI 341** 80 to 220 F	**PI 341** 90 to 110 psig	**TI 342** 115 to 155 F	**PI 342** 90 to 110 psig	**TE 343** 33 to 45 F	**PI 343** 90 to 110 psig	
Gas Piping	**TI 351** 65 to 90 F	**PI 351** 88 to 15 psig	**Check Indicators**	**LI 721**	**LI 231**	**LI 741**	

PERSONNEL PRESENT:

Name	***Affiliation***	***Phone Number/Email***
Ben Cauthen	**Cavanaugh**	
Keith Simpson	**Professional Air Systems**	

LOYD RAY FARMS INSPECTION, OPERATIONS & MAINTENANCE LOG SHEET

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Entry Made By: Ben Cauthen	**08-16-2019 Friday**	**Visit Start Time 8:30 AM**	**Visit Stop Time 11:30 AM**
Condition: Temperature	☐ Partly Cloudy ☐ Balmy **Sunny 80 °F**		
Precip Past 24 hours: 0.00 inches in gauge		**Wind: (mph): 0-2 mph**	

PURPOSE OF VISIT/ITEMS INSPECTED, OPERVATIONS

Ben met Preferred Sources at the farm to repair the rotating unit in anaerobic mixing pump 1. Preferred Sources completed the repair by approximately 9:30 AM. They then tested the pump and discovered the motor was drawing excessively high amperage. They tested the ohms of the starting components (capacitors) and didn't find an issue. One of the leads on a capacitor broke. Preferred Sources is going to order four new capacitors and replace the starting assembly. Mixing pump 1 is off until the capacitors are replaced.

The aeration basin level is very low. The environmental system is turned off because the aerobic pumps lost prime due to the low liquid level. The farm used the basin liquid to flush hog houses without returning any liquid to the basin. The digester inlet must be reopened to allow waste to flow to the basin. The digester is producing very little gas due to the blocked inlet.

Five of nine hog houses are filled with hogs.

ENVIRONMENTAL SYSTEM OBSERVATIONS:

Equipment Observed:	**Operational Status**
Fluidyne Aeration System, Including:	
Jet Motive Pumps	☐ Auto ☐ Hand On ☒ Off ☐ In Fault
Blower	☐ Auto ☐ Hand On ☒ Off ☐ In Fault:
CP-1 (Control Panel)	☒ Auto ☐ Hand On ☐ Off ☐ In Fault
Flush Pumps	☐ Auto ☒ Hand On ☐ Off ☐ In Fault
Digester Mixing Pumps	☒ Auto ☐ Hand On ☒ Off ☐ In Fault

CP-1 DATA & SET POINTS;

Cycles	**Set Point**	**Current**	**Modified Set Pt**	**Notes**
Static	**60**	**60**		
Anoxic	**90**	**90**		
Aerobic	**180**	**180**		
Blower	☐ Continuous ☒ Cycle			
Jet Motive Pumps	☐ Continuous ☒ Both ☐ Pump #1 ☐ Pump # 2			
Digester Pumps	☐ Continuous ☒ Both ☐ Sequential			

MOTOR DATA:

Aerobic	**Run Time**	**Set Speed**	**Notes**

Jet Motive Pump # 1		**60Hz**	
Jet Motive Pump # 2		**60Hz**	
Blower		**30Hz**	
Anaerobic			
Mixing Pump 4A		**60 Hz**	
Mixing Pump 4B		**60 Hz**	

BIOGAS & POWER SYSTEMS OBSERVATIONS:

Equipment Observed:	**Operational Status**				
Unison Gas Skid	Flow Rate	Total Flow	Comp. Press.	Outlet Press.	Gauge Press.
Fault? ☐ Yes ☒ No	21.8 cfm	21.8 cfm	101.7 psi	99.6 psi	
Microturbine	Speed	Exit Temp	Inlet Pressure	Inlet Temp	Power Out
Fault? ☐ Yes ☒ No	95810 rpm	1175 F		94 F	43.4 kw
Biogas System	BlueSens%	Flare On	Flare Flow	Total Flow	Flare Temp
		☐ Y ☒ N			

UNISON GAS CONDITIONING LOG

Pressure Data	**PIT 311** -5 to 10 inWC -0.1	**PIT 331** 88 to 110psig 97.39	**PIT 351** 88 to 110 psig 91.8	**Pressure Differential** **2.0**	**Panel Door**	**HM 331** Hours 7060	
Temperature Data	**TE 141** 32 to 45 F 35.1	**TE 311** 40 to 115 F 83.1	**TE 321** 35 to 75 F 46.6	**TE 331** 80 to 220 F 186.5	**TE 341** 33 to 45 F 35.2	**TE 342** 65 to 90 F 88.3	**TE 31** 35 to 115 F
Glycol Piping	**TI 141** 32 to 45 F	**PI 141** 35 to 52 psig	**FI 141** 2.5 to 3.5 gpm	**TI 142** 35 to 50 F	**PI 142** 33 to 50 psig	**TI 111** 38 to 52 F	**PI 111** 30 to 48 psig
Oil Piping	**PI 231** 90 to 110 psig	**TI 231** 178 to 215 F	**PI 232** 85 to 105 psig	**TI 232** 130 to 180 F	**PI 233** 80 to 100 psig	**TI 233** 168 to 185 F	**PI 234** 78 to 100psig
Gas Piping	**PIT 311** -10 to10inWC	**TI 311** 40 to 115 F	**TI 321** 35 to 75 F	**PDI 321** 0 to 6 inWC	**PI 331** 90 to 110 psig	**TI 331** 80 to 220 F	**PI 332** 90 to 110psig
Gas Piping	**TI 341** 80 to 220 F	**PI 341** 90 to 110 psig	**TI 342** 115 to 155 F	**PI 342** 90 to 110 psig	**TE 343** 33 to 45 F	**PI 343** 90 to 110 psig	
Gas Piping	**TI 351** 65 to 90 F	**PI 351** 88 to 15 psig	**Check Indicators**	**LI 721**	**LI 231**	**LI 741**	

PERSONNEL PRESENT:

Name	***Affiliation***	***Phone Number/Email***
Ben Cauthen	**Cavanaugh**	
Josh Amon	**Preferred Sources**	
Brian Metot	**Preferred Sources**	

LOYD RAY FARMS INSPECTION, OPERATIONS & MAINTENANCE LOG SHEET

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Entry Made By: Ben Cauthen	**08-29-2019 Thursday**	**Visit Start Time 12:30 PM**	**Visit Stop Time 2:30 PM**
Condition: Temperature	☐ Partly Cloudy ☐ Balmy **Sunny 85 °F**		
Precip Past 24 hours: 0.00 inches in gauge		**Wind: (mph): 0-2 mph**	

PURPOSE OF VISIT/ITEMS INSPECTED, OPERVATIONS

1. Digester Inlet Pipe
   a. I attempted to snake a piece of pipe into the inlet pipe today but couldn't get it to feed into the pipe. The manure in the manhole is very thick and is covering the pipe to the digester and the pipe to the lagoon. The 12" collection pipe is still visible as is the 4" forcemain from the aeration basin pumps.
2. Digester to Aeration Basin Pipe
   a. I'm not sure if this pipe is clogged but sludge may be blocking the inlet and outlet.
3. Conditioning Skid
   a. I could not get the conditioning skid to start today. The inlet heat exchanger discharge temp would not drop below 85°F. The operating range is 35 to 75°F. I'm not sure what the set point is for the skid to start.
   b. The temperature usually drops to at least 75°F even when it's very hot outside, and it isn't that hot today. The heat exchanger is cooling less now than it was before. The chiller appears to be running correctly and the glycol discharge pressure is correct. The chiller tech did not find anything wrong with the chiller except adding about 1 pound of freon.
   c. I haven't ran the skid in about 2 weeks. The inlet heat exchanger may have a blockage, which is what we suspected before. Maybe leaving the skid idle for a couple weeks somehow made the blockage worse. The Unison tech thought the chiller was the problem when he was here about a month ago and didn't attempt to repair the heat exchanger.
4. Flare
   a. I couldn't test the flare today since the skid wouldn't run. I didn't try to knock the flame arrestor with a pipe.
5. Digester Mixing Pumps
   a. Josh Amon is supposed to replace the capacitors in mixing pump 1 which will hopefully get it running. If not, the entire motor will need to be replaced.
   b. The rotating unit on mixing pump 2 sounds very rough. It should be replaced or rebuilt, although that's a $6,500 repair so I'm holding off for now. It's still functioning.
6. Environmental System
   a. The entire environmental system is turned off due to the very low aeration basin level. The pumps lost prime and are not functioning.

ENVIRONMENTAL SYSTEM OBSERVATIONS:

Equipment Observed:	Operational Status
Fluidyne Aeration System, Including:	
Jet Motive Pumps	☐ Auto ☐ Hand On ☒ Off ☐ In Fault
Blower	☐ Auto ☐ Hand On ☒ Off ☐ In Fault:
CP-1 (Control Panel)	☒ Auto ☐ Hand On ☐ Off ☐ In Fault
Flush Pumps	☐ Auto ☒ Hand On ☐ Off ☐ In Fault
Digester Mixing Pumps	☒ Auto ☐ Hand On ☒ Off ☐ In Fault

CP-1 DATA & SET POINTS;

Cycles	Set Point	Current	Modified Set Pt	Notes
Static	**60**	**60**		
Anoxic	**90**	**90**		
Aerobic	**180**	**180**		
Blower	☐ Continuous ☒ Cycle			
Jet Motive Pumps	☐ Continuous ☒ Both ☐ Pump #1 ☐ Pump # 2			
Digester Pumps	☐ Continuous ☒ Both ☐ Sequential			

MOTOR DATA:

Aerobic	Run Time	Set Speed	Notes
Jet Motive Pump # 1		**60Hz**	
Jet Motive Pump # 2		**60Hz**	
Blower		**30Hz**	
Anaerobic			
Mixing Pump 4A		**60 Hz**	
Mixing Pump 4B		**60 Hz**	

BIOGAS & POWER SYSTEMS OBSERVATIONS:

Equipment Observed:	Operational Status				
Unison Gas Skid	Flow Rate	Total Flow	Comp. Press.	Outlet Press.	Gauge Press.
Fault? ☐ Yes ☒ No	0 cfm	0 cfm			
Microturbine	Speed	Exit Temp	Inlet Pressure	Inlet Temp	Power Out
Fault? ☐ Yes ☒ No					
Biogas System	BlueSens%	Flare On	Flare Flow	Total Flow	Flare Temp
		☐ Y ☒ N			

UNISON GAS CONDITIONING LOG

Pressure Data	**PIT 311** -5 to 10 inWC -0.1	**PIT 331** 88 to 110psig 97.39	**PIT 351** 88 to 110 psig 91.8	**Pressure Differential** **2.0**	**Panel Door**	**HM 331** Hours 7060	
Temperature Data	**TE 141** 32 to 45 F 35.1	**TE 311** 40 to 115 F 83.1	**TE 321** 35 to 75 F 46.6	**TE 331** 80 to 220 F 186.5	**TE 341** 33 to 45 F 35.2	**TE 342** 65 to 90 F 88.3	**TE 31** 35 to 115 F
Glycol Piping	**TI 141** 32 to 45 F	**PI 141** 35 to 52 psig	**FI 141** 2.5 to 3.5 gpm	**TI 142** 35 to 50 F	**PI 142** 33 to 50 psig	**TI 111** 38 to 52 F	**PI 111** 30 to 48 psig

Oil Piping	**PI 231** 90 to 110 psig	**TI 231** 178 to 215 F	**PI 232** 85 to 105 psig	**TI 232** 130 to 180 F	**PI 233** 80 to 100 psig	**TI 233** 168 to 185 F	**PI 234** 78 to 100psig
Gas Piping	**PIT 311** -10 to10inWC	**TI 311** 40 to 115 F	**TI 321** 35 to 75 F	**PDI 321** 0 to 6 inWC	**PI 331** 90 to 110 psig	**TI 331** 80 to 220 F	**PI 332** 90 to 110psig
Gas Piping	**TI 341** 80 to 220 F	**PI 341** 90 to 110 psig	**TI 342** 115 to 155 F	**PI 342** 90 to 110 psig	**TE 343** 33 to 45 F	**PI 343** 90 to 110 psig	
Gas Piping	**TI 351** 65 to 90 F	**PI 351** 88 to 15 psig	**Check Indicators**	**LI 721**	**LI 231**	**LI 741**	

PERSONNEL PRESENT:

Name	***Affiliation***	***Phone Number/Email***
Ben Cauthen	**Cavanaugh**	

LOYD RAY FARMS INSPECTION, OPERATIONS & MAINTENANCE LOG SHEET

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Entry Made By: Ben Cauthen	**09-19-2019 Thursday**	**Visit Start Time 9:00 AM**	**Visit Stop Time 1:00 PM**
Condition: Temperature	☐ Partly Cloudy ☐ Balmy **Intermittent Clouds 70 °F**		
Precip Past 24 hours: 0.00 inches in gauge		**Wind: (mph): 0 mph**	

PURPOSE OF VISIT/ITEMS INSPECTED, OPERVATIONS

Preferred Sources replaced the starting components in digester mixing pump 1. The pump pulled 22-27 amps after the capacitors were replaced. The pump is pulling above normal amperage meaning there is likely a more significant issue with the motor. I turned the pump off and will leave it off.

Digester mixing pump 2 will not prime. We attempted to prime the pump with a hose and mixing pump 1, but neither approach worked. There is likely an issue with the rotating unit on the pump.

Steve and I inspected the site and discussed decommissioning and the plan going forward.

I completed Q3 manure sampling and returned the samples to R&A Labs.

ENVIRONMENTAL SYSTEM OBSERVATIONS:

Equipment Observed:	**Operational Status**
Fluidyne Aeration System, Including:	
Jet Motive Pumps	☐ Auto ☐ Hand On ☒ Off ☐ In Fault
Blower	☐ Auto ☐ Hand On ☒ Off ☐ In Fault:
CP-1 (Control Panel)	☒ Auto ☐ Hand On ☐ Off ☐ In Fault
Flush Pumps	☐ Auto ☒ Hand On ☐ Off ☐ In Fault
Digester Mixing Pumps	☐ Auto ☐ Hand On ☒ Off ☐ In Fault

CP-1 DATA & SET POINTS;

Cycles	**Set Point**	**Current**	**Modified Set Pt**	**Notes**
Static	**60**	**60**		
Anoxic	**90**	**90**		
Aerobic	**180**	**180**		
Blower	☐ Continuous ☒ Cycle			
Jet Motive Pumps	☐ Continuous ☒ Both ☐ Pump #1 ☐ Pump # 2			
Digester Pumps	☐ Continuous ☒ Both ☐ Sequential			

MOTOR DATA:

Aerobic	**Run Time**	**Set Speed**	**Notes**
Jet Motive Pump # 1		**60 Hz**	
Jet Motive Pump # 2		**60 Hz**	

Blower		**30 Hz**	
Anaerobic			
Mixing Pump 4A		**60 Hz**	
Mixing Pump 4B		**60 Hz**	

BIOGAS & POWER SYSTEMS OBSERVATIONS:

Equipment Observed:	**Operational Status**				
Unison Gas Skid	Flow Rate	Total Flow	Comp. Press.	Outlet Press.	Gauge Press.
Fault? ☐ Yes ☒ No	22 cfm	22 cfm	102.3 psi	100.2 psi	
Microturbine	Speed	Exit Temp	Inlet Pressure	Inlet Temp	Power Out
Fault? ☐ Yes ☒ No	95866 rpm	1175 F		76 F	51.1 kW
Biogas System	BlueSens%	Flare On	Flare Flow	Total Flow	Flare Temp
		☐ Y ☒ N			

UNISON GAS CONDITIONING LOG

Pressure Data	**PIT 311** -5 to 10 inWC -0.2	**PIT 331** 88 to 110psig 102.3	**PIT 351** 88 to 110 psig	**Pressure Differential**	**Panel Door**	**HM 331** Hours	
Temperature Data	**TE 141** 32 to 45 F 34.8	**TE 311** 40 to 115 F 87.6	**TE 321** 35 to 75 F 41.1	**TE 331** 80 to 220 F 204.6	**TE 341** 33 to 45 F 36.1	**TE 342** 65 to 90 F 106.7	**TE 31** 35 to 115 F
Glycol Piping	**TI 141** 32 to 45 F	**PI 141** 35 to 52 psig	**FI 141** 2.5 to 3.5 gpm	**TI 142** 35 to 50 F	**PI 142** 33 to 50 psig	**TI 111** 38 to 52 F	**PI 111** 30 to 48 psig
Oil Piping	**PI 231** 90 to 110 psig	**TI 231** 178 to 215 F	**PI 232** 85 to 105 psig	**TI 232** 130 to 180 F	**PI 233** 80 to 100 psig	**TI 233** 168 to 185 F	**PI 234** 78 to 100psig
Gas Piping	**PIT 311** -10 to10inWC	**TI 311** 40 to 115 F	**TI 321** 35 to 75 F	**PDI 321** 0 to 6 inWC	**PI 331** 90 to 110 psig	**TI 331** 80 to 220 F	**PI 332** 90 to 110psig
Gas Piping	**TI 341** 80 to 220 F	**PI 341** 90 to 110 psig	**TI 342** 115 to 155 F	**PI 342** 90 to 110 psig	**TE 343** 33 to 45 F	**PI 343** 90 to 110 psig	
Gas Piping	**TI 351** 65 to 90 F	**PI 351** 88 to 15 psig 100	**Check Indicators**	**LI 721**	**LI 231**	**LI 741**	

PERSONNEL PRESENT:

Name	***Affiliation***	***Phone Number/Email***
Ben Cauthen	**Cavanaugh**	
Steve Cavanaugh	**Cavanaugh**	
Brian Metot	**Preferred Sources**	

LOYD RAY FARMS INSPECTION, OPERATIONS & MAINTENANCE LOG SHEET

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Entry Made By: Ben Cauthen	**09-27-2019 Friday**	**Visit Start Time 11:00 AM**	**Visit Stop Time 1:00 PM**
Condition: Temperature	☐ Partly Cloudy ☐ Balmy **Sunny 84 °F**		
Precip Past 24 hours: 0.00 inches in gauge		**Wind: (mph): 2-4 mph**	

PURPOSE OF VISIT/ITEMS INSPECTED, OPERVATIONS

Performed a complete system check and operated the skid and turbine for several hours. Met Matt and Emma from Duke University and explained the system to them. Matt performed odor sampling for Q3.

ENVIRONMENTAL SYSTEM OBSERVATIONS:

Equipment Observed:	**Operational Status**
Fluidyne Aeration System, Including:	
Jet Motive Pumps	☐ Auto ☐ Hand On ☒ Off ☐ In Fault
Blower	☐ Auto ☐ Hand On ☒ Off ☐ In Fault:
CP-1 (Control Panel)	☒ Auto ☐ Hand On ☐ Off ☐ In Fault
Flush Pumps	☐ Auto ☒ Hand On ☐ Off ☐ In Fault
Digester Mixing Pumps	☐ Auto ☐ Hand On ☒ Off ☐ In Fault

CP-1 DATA & SET POINTS;

Cycles	**Set Point**	**Current**	**Modified Set Pt**	**Notes**
Static	**60**	**60**		
Anoxic	**90**	**90**		
Aerobic	**180**	**180**		
Blower	☐ Continuous ☒ Cycle			
Jet Motive Pumps	☐ Continuous ☒ Both ☐ Pump #1 ☐ Pump # 2			
Digester Pumps	☐ Continuous ☒ Both ☐ Sequential			

MOTOR DATA:

Aerobic	**Run Time**	**Set Speed**	**Notes**
Jet Motive Pump # 1		**60 Hz**	
Jet Motive Pump # 2		**60 Hz**	

Blower		**30 Hz**	
Anaerobic			
Mixing Pump 4A		**60 Hz**	
Mixing Pump 4B		**60 Hz**	

BIOGAS & POWER SYSTEMS OBSERVATIONS:

Equipment Observed:	**Operational Status**				
Unison Gas Skid	Flow Rate	Total Flow	Comp. Press.	Outlet Press.	Gauge Press.
Fault? ☐ Yes ☒ No	20.8 cfm	20.8 cfm	101.6 psi	99.7 psi	
Microturbine	Speed	Exit Temp	Inlet Pressure	Inlet Temp	Power Out
Fault? ☐ Yes ☒ No	95964 rpm	1175 F		97 F	42.5 kW
Biogas System	BlueSens%	Flare On	Flare Flow	Total Flow	Flare Temp
		☐ Y ☒ N			

UNISON GAS CONDITIONING LOG

Pressure Data	**PIT 311** -5 to 10 inWC -0.2	**PIT 331** 88 to 110psig 101.7	**PIT 351** 88 to 110 psig	**Pressure Differential**	**Panel Door**	**HM 331** Hours	
Temperature Data	**TE 141** 32 to 45 F 41.6	**TE 311** 40 to 115 F 98.5	**TE 321** 35 to 75 F 47.8	**TE 331** 80 to 220 F 215.1	**TE 341** 33 to 45 F 43.8	**TE 342** 65 to 90 F 113.5	**TE 31** 35 to 115 F
Glycol Piping	**TI 141** 32 to 45 F	**PI 141** 35 to 52 psig	**FI 141** 2.5 to 3.5 gpm	**TI 142** 35 to 50 F	**PI 142** 33 to 50 psig	**TI 111** 38 to 52 F	**PI 111** 30 to 48 psig
Oil Piping	**PI 231** 90 to 110 psig	**TI 231** 178 to 215 F	**PI 232** 85 to 105 psig	**TI 232** 130 to 180 F	**PI 233** 80 to 100 psig	**TI 233** 168 to 185 F	**PI 234** 78 to 100psig
Gas Piping	**PIT 311** -10 to10inWC	**TI 311** 40 to 115 F	**TI 321** 35 to 75 F	**PDI 321** 0 to 6 inWC	**PI 331** 90 to 110 psig	**TI 331** 80 to 220 F	**PI 332** 90 to 110psig
Gas Piping	**TI 341** 80 to 220 F	**PI 341** 90 to 110 psig	**TI 342** 115 to 155 F	**PI 342** 90 to 110 psig	**TE 343** 33 to 45 F	**PI 343** 90 to 110 psig	
Gas Piping	**TI 351** 65 to 90 F	**PI 351** 88 to 15 psig 99.5	**Check Indicators**	**LI 721**	**LI 231**	**LI 741**	

PERSONNEL PRESENT:

Name	***Affiliation***	***Phone Number/Email***
Ben Cauthen	**Cavanaugh**	
Matt Arsenault	**Duke University**	
Emma Fulop	**Duke University**	

LOYD RAY FARMS INSPECTION, OPERATIONS & MAINTENANCE LOG SHEET

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Entry Made By: Ben Cauthen	10-23-2019 Wednesday	Visit Start Time 9:30 AM	Visit Stop Time 11:30 AM
Condition: Temperature	☐ Partly Cloudy ☐ Balmy **Sunny 60 °F**		
Precip Past 24 hours: 0.00 inches in gauge		Wind: (mph): 4 mph	

PURPOSE OF VISIT/ITEMS INSPECTED, OPERVATIONS

Met Yadtel tech to update router to match Yadtel's new specs. Efinity will need to replace the router to repair the internet. No internet is available now.

ENVIRONMENTAL SYSTEM OBSERVATIONS:

Equipment Observed:	Operational Status
Fluidyne Aeration System, Including:	
Jet Motive Pumps	☐ Auto ☐ Hand On ☒ Off ☐ In Fault
Blower	☐ Auto ☐ Hand On ☒ Off ☐ In Fault:
CP-1 (Control Panel)	☒ Auto ☐ Hand On ☐ Off ☐ In Fault
Flush Pumps	☐ Auto ☒ Hand On ☐ Off ☐ In Fault
Digester Mixing Pumps	☐ Auto ☐ Hand On ☒ Off ☐ In Fault

CP-1 DATA & SET POINTS;

Cycles	Set Point	Current	Modified Set Pt	Notes
Static	60	60		
Anoxic	90	90		
Aerobic	180	180		
Blower	☐ Continuous ☒ Cycle			
Jet Motive Pumps	☐ Continuous ☒ Both ☐ Pump #1 ☐ Pump # 2			
Digester Pumps	☐ Continuous ☒ Both ☐ Sequential			

MOTOR DATA:

Aerobic	Run Time	Set Speed	Notes
Jet Motive Pump # 1		60 Hz	
Jet Motive Pump # 2		60 Hz	

Blower		**30 Hz**	
Anaerobic			
Mixing Pump 4A		**60 Hz**	
Mixing Pump 4B		**60 Hz**	

BIOGAS & POWER SYSTEMS OBSERVATIONS:

Equipment Observed:	**Operational Status**				
Unison Gas Skid	Flow Rate	Total Flow	Comp. Press.	Outlet Press.	Gauge Press.
Fault? ☐ Yes ☒ No					
Microturbine	Speed	Exit Temp	Inlet Pressure	Inlet Temp	Power Out
Fault? ☐ Yes ☒ No					
Biogas System	BlueSens%	Flare On	Flare Flow	Total Flow	Flare Temp
		☐ Y ☒ N			

UNISON GAS CONDITIONING LOG

Pressure Data	**PIT 311** -5 to 10 inWC	**PIT 331** 88 to 110psig	**PIT 351** 88 to 110 psig	**Pressure Differential**	**Panel Door**	**HM 331** Hours	
Temperature Data	**TE 141** 32 to 45 F	**TE 311** 40 to 115 F	**TE 321** 35 to 75 F	**TE 331** 80 to 220 F	**TE 341** 33 to 45 F	**TE 342** 65 to 90 F	**TE 31** 35 to 115 F
Glycol Piping	**TI 141** 32 to 45 F	**PI 141** 35 to 52 psig	**FI 141** 2.5 to 3.5 gpm	**TI 142** 35 to 50 F	**PI 142** 33 to 50 psig	**TI 111** 38 to 52 F	**PI 111** 30 to 48 psig
Oil Piping	**PI 231** 90 to 110 psig	**TI 231** 178 to 215 F	**PI 232** 85 to 105 psig	**TI 232** 130 to 180 F	**PI 233** 80 to 100 psig	**TI 233** 168 to 185 F	**PI 234** 78 to 100psig
Gas Piping	**PIT 311** -10 to10inWC	**TI 311** 40 to 115 F	**TI 321** 35 to 75 F	**PDI 321** 0 to 6 inWC	**PI 331** 90 to 110 psig	**TI 331** 80 to 220 F	**PI 332** 90 to 110psig
Gas Piping	**TI 341** 80 to 220 F	**PI 341** 90 to 110 psig	**TI 342** 115 to 155 F	**PI 342** 90 to 110 psig	**TE 343** 33 to 45 F	**PI 343** 90 to 110 psig	
Gas Piping	**TI 351** 65 to 90 F	**PI 351** 88 to 15 psig	**Check Indicators**	**LI 721**	**LI 231**	**LI 741**	

PERSONNEL PRESENT:

Name	***Affiliation***	***Phone Number/Email***
Ben Cauthen	**Cavanaugh**	
Yadtel Tech	**Yadtel**	

LOYD RAY FARMS INSPECTION, OPERATIONS & MAINTENANCE LOG SHEET

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Entry Made By: Ben Cauthen	12-09-2019 Monday	Visit Start Time 9:30 AM	Visit Stop Time 1:30 PM
Condition: Temperature	☐ Partly Cloudy ☐ Balmy **Raining 50 °F**		
Precip Past 24 hours: inches in gauge		Wind: (mph): 0 mph	

PURPOSE OF VISIT/ITEMS INSPECTED, OPERVATIONS

Performed manure sampling to fulfill quarterly requirement. Met NCDEQ employees for inspection.

ENVIRONMENTAL SYSTEM OBSERVATIONS:

Equipment Observed:	Operational Status
Fluidyne Aeration System, Including:	
Jet Motive Pumps	☐ Auto ☐ Hand On ☒ Off ☐ In Fault
Blower	☐ Auto ☐ Hand On ☒ Off ☐ In Fault:
CP-1 (Control Panel)	☒ Auto ☐ Hand On ☐ Off ☐ In Fault
Flush Pumps	☐ Auto ☒ Hand On ☐ Off ☐ In Fault
Digester Mixing Pumps	☐ Auto ☐ Hand On ☒ Off ☐ In Fault

CP-1 DATA & SET POINTS;

Cycles	Set Point	Current	Modified Set Pt	Notes
Static	60	60		
Anoxic	90	90		
Aerobic	180	180		
Blower	☐ Continuous ☒ Cycle			
Jet Motive Pumps	☐ Continuous ☒ Both ☐ Pump #1 ☐ Pump # 2			
Digester Pumps	☐ Continuous ☒ Both ☐ Sequential			

MOTOR DATA:

Aerobic	Run Time	Set Speed	Notes
Jet Motive Pump # 1		60 Hz	
Jet Motive Pump # 2		60 Hz	

Blower		**30 Hz**	
Anaerobic			
Mixing Pump 4A		**60 Hz**	
Mixing Pump 4B		**60 Hz**	

BIOGAS & POWER SYSTEMS OBSERVATIONS:

Equipment Observed:	**Operational Status**				
Unison Gas Skid	Flow Rate	Total Flow	Comp. Press.	Outlet Press.	Gauge Press.
Fault? ☐ Yes ☒ No					
Microturbine	Speed	Exit Temp	Inlet Pressure	Inlet Temp	Power Out
Fault? ☐ Yes ☒ No					
Biogas System	BlueSens%	Flare On	Flare Flow	Total Flow	Flare Temp
		☐ Y ☒ N			

UNISON GAS CONDITIONING LOG

Pressure Data	**PIT 311** -5 to 10 inWC	**PIT 331** 88 to 110psig	**PIT 351** 88 to 110 psig	**Pressure Differential**	**Panel Door**	**HM 331** Hours	
Temperature Data	**TE 141** 32 to 45 F	**TE 311** 40 to 115 F	**TE 321** 35 to 75 F	**TE 331** 80 to 220 F	**TE 341** 33 to 45 F	**TE 342** 65 to 90 F	**TE 31** 35 to 115 F
Glycol Piping	**TI 141** 32 to 45 F	**PI 141** 35 to 52 psig	**FI 141** 2.5 to 3.5 gpm	**TI 142** 35 to 50 F	**PI 142** 33 to 50 psig	**TI 111** 38 to 52 F	**PI 111** 30 to 48 psig
Oil Piping	**PI 231** 90 to 110 psig	**TI 231** 178 to 215 F	**PI 232** 85 to 105 psig	**TI 232** 130 to 180 F	**PI 233** 80 to 100 psig	**TI 233** 168 to 185 F	**PI 234** 78 to 100psig
Gas Piping	**PIT 311** -10 to10inWC	**TI 311** 40 to 115 F	**TI 321** 35 to 75 F	**PDI 321** 0 to 6 inWC	**PI 331** 90 to 110 psig	**TI 331** 80 to 220 F	**PI 332** 90 to 110psig
Gas Piping	**TI 341** 80 to 220 F	**PI 341** 90 to 110 psig	**TI 342** 115 to 155 F	**PI 342** 90 to 110 psig	**TE 343** 33 to 45 F	**PI 343** 90 to 110 psig	
Gas Piping	**TI 351** 65 to 90 F	**PI 351** 88 to 15 psig	**Check Indicators**	**LI 721**	**LI 231**	**LI 741**	

PERSONNEL PRESENT:

Name	***Affiliation***	***Phone Number/Email***
Ben Cauthen	**Cavanaugh**	
Marvin Cavanaugh	**Cavanaugh**	

LOYD RAY FARMS INSPECTION, OPERATIONS & MAINTENANCE LOG SHEET

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Entry Made By: Ben Cauthen	**12-20-2019 Friday**	**Visit Start Time 10:10 AM**	**Visit Stop Time 2:30 PM**
Condition: Temperature	☐ Partly Cloudy ☐ Balmy **Sunny 40 °F**		
Precip Past 24 hours: 0 inches in gauge		**Wind: (mph): 4 mph**	

PURPOSE OF VISIT/ITEMS INSPECTED, OPERVATIONS

Performed annual sludge survey to measure digester sludge accumulation. Repaired internet with Yadtel.

ENVIRONMENTAL SYSTEM OBSERVATIONS:

Equipment Observed:	**Operational Status**
Fluidyne Aeration System, Including:	
Jet Motive Pumps	☐ Auto ☐ Hand On ☒ Off ☐ In Fault
Blower	☐ Auto ☐ Hand On ☒ Off ☐ In Fault:
CP-1 (Control Panel)	☒ Auto ☐ Hand On ☐ Off ☐ In Fault
Flush Pumps	☐ Auto ☒ Hand On ☐ Off ☐ In Fault
Digester Mixing Pumps	☐ Auto ☐ Hand On ☒ Off ☐ In Fault

CP-1 DATA & SET POINTS;

Cycles	**Set Point**	**Current**	**Modified Set Pt**	**Notes**
Static	**60**	**60**		
Anoxic	**90**	**90**		
Aerobic	**180**	**180**		
Blower	☐ Continuous ☒ Cycle			
Jet Motive Pumps	☐ Continuous ☒ Both ☐ Pump #1 ☐ Pump # 2			
Digester Pumps	☐ Continuous ☒ Both ☐ Sequential			

MOTOR DATA:

Aerobic	**Run Time**	**Set Speed**	**Notes**
Jet Motive Pump # 1		**60 Hz**	
Jet Motive Pump # 2		**60 Hz**	

Blower		**30 Hz**	
Anaerobic			
Mixing Pump 4A		**60 Hz**	
Mixing Pump 4B		**60 Hz**	

BIOGAS & POWER SYSTEMS OBSERVATIONS:

Equipment Observed:	**Operational Status**				
Unison Gas Skid	Flow Rate	Total Flow	Comp. Press.	Outlet Press.	Gauge Press.
Fault? ☐ Yes ☒ No					
Microturbine	Speed	Exit Temp	Inlet Pressure	Inlet Temp	Power Out
Fault? ☐ Yes ☒ No					
Biogas System	BlueSens%	Flare On	Flare Flow	Total Flow	Flare Temp
		☐ Y ☒ N			

UNISON GAS CONDITIONING LOG

Pressure Data	**PIT 311** -5 to 10 inWC	**PIT 331** 88 to 110psig	**PIT 351** 88 to 110 psig	**Pressure Differential**	**Panel Door**	**HM 331** Hours	
Temperature Data	**TE 141** 32 to 45 F	**TE 311** 40 to 115 F	**TE 321** 35 to 75 F	**TE 331** 80 to 220 F	**TE 341** 33 to 45 F	**TE 342** 65 to 90 F	**TE 31** 35 to 115 F
Glycol Piping	**TI 141** 32 to 45 F	**PI 141** 35 to 52 psig	**FI 141** 2.5 to 3.5 gpm	**TI 142** 35 to 50 F	**PI 142** 33 to 50 psig	**TI 111** 38 to 52 F	**PI 111** 30 to 48 psig
Oil Piping	**PI 231** 90 to 110 psig	**TI 231** 178 to 215 F	**PI 232** 85 to 105 psig	**TI 232** 130 to 180 F	**PI 233** 80 to 100 psig	**TI 233** 168 to 185 F	**PI 234** 78 to 100psig
Gas Piping	**PIT 311** -10 to10inWC	**TI 311** 40 to 115 F	**TI 321** 35 to 75 F	**PDI 321** 0 to 6 inWC	**PI 331** 90 to 110 psig	**TI 331** 80 to 220 F	**PI 332** 90 to 110psig
Gas Piping	**TI 341** 80 to 220 F	**PI 341** 90 to 110 psig	**TI 342** 115 to 155 F	**PI 342** 90 to 110 psig	**TE 343** 33 to 45 F	**PI 343** 90 to 110 psig	
Gas Piping	**TI 351** 65 to 90 F	**PI 351** 88 to 15 psig	**Check Indicators**	**LI 721**	**LI 231**	**LI 741**	

PERSONNEL PRESENT:

Name	***Affiliation***	***Phone Number/Email***
Ben Cauthen	**Cavanaugh**	
Marvin Cavanaugh	**Cavanaugh**	
Yadtel Service Tech	**Yadtel**	

APPENDIX B – Wastewater Sample Collection Dataset

Research & Analytical Laboratories, Inc.
PO Box 473
Kernersville, NC 27285
Phone 336.996.2841 Fax 336.996.0326
Email: info@randalabs.com

INVOICE
15766M

Date: October 04, 2019

Bill To:
Cavanaugh & Associates
PO Box 11197
Winston Salem, NC 27116

Attention: Accounts Payable

DESCRIPTION		AMOUNT
Project: LRF		
Samples collected: 09/19/19		
Analysis of three (3) samples for:		
Ammonia Nitrogen	**$20.00/sample**	$60.00
Copper, Total	**$20.00/sample**	$60.00
Fecal Coliform- MPN	**$50.00/sample**	$150.00
Nitrate + Nitrite	**$20.00/sample**	$60.00
PH	**$10.00/sample**	$30.00
Total Kjedjahl Nitrogen	**$20.00/sample**	$60.00
Total Phosphorous	**$20.00/sample**	$60.00
Total Suspended Solids	**$15.00/sample**	$45.00
Zinc, Total	**$20.00/sample**	$60.00
		$ 585.00

Make all checks payable to: **Research & Analytical Laboratories, Inc.**

TERMS: NET 30
"Past due invoices accrue interest at 1 1/2% interest per month until paid, should collection be required, customer agrees to pay all expenses incurred including attorney fees."

RESEARCH & ANALYTICAL LABORATORIES, INC.

Report of Analysis

10/2/2019

RESEARCH & ANALYTICAL LABS. SIDNEY L. CHAMPION DIRECTOR NC #34 NC #37701 CERTIFIED ANALYSIS

For: **Cavanaugh & Associates**
PO Box 11197
Winston-Salem, NC 27116

Attn: Lynda Hall

Client Sample ID: Influent
Site: Cavanaugh & Assoc

Lab Sample ID: **72291-01**
Collection Date: 9/19/2019 12:30

Parameter	Method	Result	Units	Rep Limit	Analyst	Analysis Date/Time
Ammonia Nitrogen	SM 4500 NH3 D-1997	1130	mg/L	0.1	FK	9/26/2019
Copper, Total	EPA 200.7	22.0	mg/L	0.005	JF	9/24/2019
Fecal Coliform - MPN	SM 9221 C E-2006	700000	MPN/100ml	2	BJ	9/19/2019 1625
Nitrate + Nitrite	SM 4500 NO3 E-2000	0.257	mg/L	0.05	DW	9/20/2019 1310
pH	SM 4500 H+B-2000	7.18	Std. Units		LP	9/20/2019 1347
Total Kjedjahl Nitrogen	SM 4500 N Org B (NH3 D-1997)	2100	mg/L	1	FK	9/23/2019
Total Nitrogen	Calc	2100	mg/L	1		
Total Phosphorous	SM 4500 P E-1999	265	mg/L	0.05	BJ	9/27/2019
Total Suspended Solids (TSS)	SM 2540 D-1997	14000	mg/L	5	AW	9/24/2019
Zinc, Total	EPA 200.7	22.8	mg/L	0.01	JF	9/24/2019

NA = not analyzed

Research & Analytical Laboratories, Inc.

Report of Analysis

10/2/2019

For: **Cavanaugh & Associates**
PO Box 11197
Winston-Salem, NC 27116

Attn: Lynda Hall

Client Sample ID: Digester **Lab Sample ID:** **72291-02**
Site: Cavanaugh & Assoc **Collection Date:** 9/19/2019 12:35

Parameter	Method	Result	Units	Rep Limit	Analyst	Analysis Date/Time	
Ammonia Nitrogen	SM 4500 NH3 D-1997	2160	mg/L	0.1	FK	9/26/2019	
Copper, Total	EPA 200.7	27.3	mg/L	0.005	JF	9/24/2019	
Fecal Coliform - MPN	SM 9221 C E-2006	<19.4	mpn/g TS	19.4	BJ	9/19/2019	1625
Nitrate + Nitrite	SM 4500 NO3 E-2000	0.339	mg/L	0.05	DW	9/20/2019	1310
pH	SM 4500 H+B-2000	7.49	Std. Units		LP	9/20/2019	1348
Total Kjedjahl Nitrogen	SM 4500 N Org B (NH3 D-1997)	3150	mg/L	1	FK	9/23/2019	
Total Nitrogen	Calc	3150	mg/L	1			
Total Phosphorous	SM 4500 P E-1999	2660	mg/L	0.05	BJ	9/27/2019	
Total Suspended Solids (TSS)	SM 2540 D-1997	83600	mg/L	5	AW	9/25/2019	
Zinc, Total	EPA 200.7	193	mg/L	0.01	JF	9/24/2019	

NA = not analyzed

Research & Analytical Laboratories, Inc.

Report of Analysis

10/2/2019

For: **Cavanaugh & Associates**
PO Box 11197
Winston-Salem, NC 27116

Attn: Lynda Hall

Client Sample ID: Effluent
Site: Cavanaugh & Assoc

Lab Sample ID: 72291-03
Collection Date: 9/19/2019 12:40

Parameter	Method	Result	Units	Rep Limit	Analyst	Analysis Date/Time
Ammonia Nitrogen	SM 4500 NH3 D-1997	852	mg/L	0.1	FK	9/26/2019
Copper, Total	EPA 200.7	0.059	mg/L	0.005	JF	9/24/2019
Fecal Coliform - MPN	SM 9221 C E-2006	<18	MPN/100ml	18	BJ	9/19/2019 1625
Nitrate + Nitrite	SM 4500 NO3 E-2000	<0.05	mg/L	0.05	DW	9/20/2019 1320
pH	SM 4500 H+B-2000	8.59	Std. Units		LP	9/20/2019 1352
Total Kjedjahl Nitrogen	SM 4500 N Org B (NH3 D-1997)	1630	mg/L	1	FK	9/23/2019
Total Nitrogen	Calc	1630	mg/L	1		
Total Phosphorous	SM 4500 P E-1999	69.4	mg/L	0.05	BJ	9/27/2019
Total Suspended Solids (TSS)	SM 2540 D-1997	102	mg/L	5	AW	9/24/2019
Zinc, Total	EPA 200.7	0.224	mg/L	0.01	JF	9/24/2019

NA = not analyzed

Jennings Exhibit No. 10
Docket No. E-7, Sub 1229

RESEARCH & ANALYTICAL LABORATORIES, INC.
Analytical / Process Consultations
Phone (336) 996-2841

CHAIN OF CUSTODY RECORD

COMPANY: Cavanaugh + Associates	JOB NO.
STREET ADDRESS: PO Box 11197	PROJECT: Loyd Ray Farm
CITY, STATE, ZIP: Winston Salem, NC 27116	SAMPLER NAME (PLEASE PRINT): Ben Cauthen
CONTACT: Lynda Hall — PHONE: 276-952-5205	SAMPLER SIGNATURE: [signature]

Container columns (WATER / WASTEWATER): 2L G (BNA, Herb. / Pest.); 2 40ml Vials (VOA) HCL; 250ml G (TOX); 250ml P (TOC) H_2SO_4; 1L P, G (BOD, TSS, Unpreserved, etc.); 1L G (Phenol, Oil & Grease) H_2SO_4; 1L P, G (COD, N, P) H_2SO_4; 1L P, G (Metals, Hardness) HNO_3; 1L P, G (CYANIDE) NaOH; Sterile P, G (Coliform); MISC.

SAMPLE NUMBER (LAB USE ONLY)	DATE	TIME	COMP	GRAB	TEMP °C	RES CL (mg/L)	CHLORINE REMOVED (Y or N)	SAMPLE MATRIX (S or W)	SAMPLE LOCATION / I.D.	NO. OF CONTAINERS	2L G	REQUESTED ANALYSIS
7229101	9-17-19	12:30							Influent (Raw)		(4)	TN
											↓	TKN
	↓										↓	NO_2+NO_3
02	↓	12:35							Digester		↓	Total Phosphorus
	↓										↓	NH3N
											↓	fecal-mpn
03		12:40							Effluent (AB)		↓	copper
												zinc
												TSS
												pH

RELINQUISHED BY	DATE/TIME	RECEIVED BY
/	|	
[signature]	9-19-19 14:15	[signature]

REMARKS: [illegible]

SAMPLE TEMPERATURE AT RECEIPT 3.0 °C

Research & Analytical Laboratories, Inc.
PO Box 473
Kernersville, NC 27285
Phone 336.996.2841 Fax 336.996.0326
Email: info@randalabs.com

INVOICE
15927M

January 13, 2020

Bill To:
Cavanaugh & Associates
PO Box 11197
Winston Salem, NC 27116

Attention: Accounts Payable

DESCRIPTION		AMOUNT	
Project: LRF			
Samples collected: 12/09/19			
Analysis of three (3) samples for:			
Ammonia Nitrogen	**$20.00/sample**	$	60.00
Copper, Total	**$20.00/sample**		60.00
Fecal Coliform- MPN	**$50.00/sample**		150.00
Nitrate + Nitrite	**$20.00/sample**		60.00
PH	**$10.00/sample**		30.00
Total Kjedjahl Nitrogen	**$20.00/sample**		60.00
Total Phosphorous	**$20.00/sample**		60.00
Total Suspended Solids	**$15.00/sample**		45.00
Zinc, Total	**$20.00/sample**		60.00
		$	**585.00**

Make all checks payable to: **Research & Analytical Laboratories, Inc.**

TERMS: NET 30
"Past due invoices accrue interest at 1 1/2% interest per month until paid, should collection be required, customer agrees to pay all expenses incurred including attorney fees."

RESEARCH & ANALYTICAL LABORATORIES, INC.

Report of Analysis

1/12/2020

RESEARCH & ANALYTICAL LABS. SIDNEY L. CHAMPION NC #34 NC #37701 DIRECTOR CERTIFIED ANALYSIS

For: **Cavanaugh & Associates**
PO Box 11197
Winston-Salem, NC 27116

Attn: Lynda Hall

Client Sample ID: Aerobic
Site: Cavanaugh & Assoc

Lab Sample ID: **75741-01**
Collection Date: 12/9/2019 9:30

Parameter	Method	Result	Units	Rep Limit	Analyst	Analysis Date/Time
Ammonia Nitrogen	SM 4500 NH3 D-1997	436	mg/L	0.1	FK	12/30/2019
Copper, Total	EPA 200.7	0.026	mg/L	0.005	SK	12/19/2019
Fecal Coliform - MPN	SM 9221 C E-2006	3	MPN/100ml	2	BJ	12/9/2019 1525
Nitrate + Nitrite	SM 4500 NO3 E-2000	0.757	mg/L	0.05	DW	12/10/2019 1550
pH	SM 4500 H+B-2000	8.44	Std. Units		LP	12/10/2019 1700
Total Kjedjahl Nitrogen	SM 4500 N Org B (NH3 D-1997)	852	mg/L	1	FK	12/30/2019
Total Nitrogen	Calc	852	mg/L	1		
Total Phosphorous	SM 4500 P E-1999	36.8	mg/L	0.05	BJ	12/27/2019
Total Suspended Solids (TSS)	SM 2540 D-1997	120	mg/L	5	AW	12/10/2019
Zinc, Total	EPA 200.7	0.086	mg/L	0.01	SK	12/19/2019

NA = not analyzed

Research & Analytical Laboratories, Inc.

Report of Analysis

1/12/2020

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RESEARCH & ANALYTICAL LABS. SIDNEY L. CHAMPION NC #34 NC #37701 DIRECTOR CERTIFIED ANALYSIS

Feb 25 2020

For: **Cavanaugh & Associates**
PO Box 11197
Winston-Salem, NC 27116

Attn: Lynda Hall

Client Sample ID: Digestor
Site: Cavanaugh & Assoc

Lab Sample ID: **75741-02**
Collection Date: 12/9/2019 9:30

Parameter	Method	Result	Units	Rep Limit	Analyst	Analysis Date/Time	
Ammonia Nitrogen	SM 4500 NH3 D-1997	2050	mg/L	0.1	FK	12/30/2019	
Copper, Total	EPA 200.7	17.7	mg/L	0.005	SK	12/19/2019	
Fecal Coliform - MPN	SM 9221 C E-2006	240	MPN/100ml	2	BJ	12/9/2019	1525
Nitrate + Nitrite	SM 4500 NO3 E-2000	<0.05	mg/L	0.05	DW	12/13/2019	1300
pH	SM 4500 H+B-2000	7.89	Std. Units		LP	12/10/2019	1703
Total Kjedjahl Nitrogen	SM 4500 N Org B (NH3 D-1997)	2450	mg/L	1	FK	12/30/2019	
Total Nitrogen	Calc	2450	mg/L	1			
Total Phosphorous	SM 4500 P E-1999	3670	mg/L	0.05	BJ	12/27/2019	
Total Suspended Solids (TSS)	SM 2540 D-1997	68000	mg/L	5	AW	12/11/2019	
Zinc, Total	EPA 200.7	164	mg/L	0.01	SK	12/19/2019	

NA = not analyzed

Research & Analytical Laboratories, Inc.

Report of Analysis

1/12/2020

For: **Cavanaugh & Associates**
PO Box 11197
Winston-Salem, NC 27116

Attn: Lynda Hall

RESEARCH & ANALYTICAL LABS. SIDNEY L. CHAMPION NC #34 NC #37701 DIRECTOR CERTIFIED ANALYSIS

Client Sample ID: Raw
Site: Cavanaugh & Assoc

Lab Sample ID: **75741-03**
Collection Date: 12/9/2019 9:30

Parameter	Method	Result	Units	Rep Limit	Analyst	Analysis Date/Time
Ammonia Nitrogen	SM 4500 NH3 D-1997	745	mg/L	0.1	FK	12/30/2019
Copper, Total	EPA 200.7	52.0	mg/L	0.005	SK	12/19/2019
Fecal Coliform - MPN	SM 9221 C E-2006	22000000	MPN/100ml	2	BJ	12/9/2019 1525
Nitrate + Nitrite	SM 4500 NO3 E-2000	<0.05	mg/L	0.05	DW	12/13/2019 1320
pH	SM 4500 H+B-2000	7.63	Std. Units		LP	12/10/2019 1704
Total Kjedjahl Nitrogen	SM 4500 N Org B (NH3 D-1997)	1050	mg/L	1	FK	12/30/2019
Total Nitrogen	Calc	1050	mg/L	1		
Total Phosphorous	SM 4500 P E-1999	162	mg/L	0.05	BJ	12/27/2019
Total Suspended Solids (TSS)	SM 2540 D-1997	3300	mg/L	5	AW	12/10/2019
Zinc, Total	EPA 200.7	44.1	mg/L	0.01	SK	12/19/2019

NA = not analyzed

Jennings Exhibit No. 10
Docket No. E-7, Sub 1229

RESEARCH & ANALYTICAL LABORATORIES, INC.
Analytical / Process Consultations
Phone (336) 996-2841

CHAIN OF CUSTODY RECORD

COMPANY: Cavanaugh + Associates	JOB NO.
STREET ADDRESS: PO Box 11197	PROJECT: Loyd Ray Farm
CITY, STATE, ZIP: Winston Salem, NC, 27116	SAMPLER NAME (PLEASE PRINT): Ben Cauthen
CONTACT: Lynda Hall PHONE: 877-557-8923	SAMPLER SIGNATURE: Ben Cauthen

WATER / WASTEWATER: 2L G (BNA, Herb. / Pest.); 2 40ml Vials (VOA) HCL; 250ml G (TOX); 250ml P (TOC) H_2SO_4; 1L P, G (BOD, TSS, Unpreserved, etc.); 1L G (Phenol, Oil & Grease) H_2SO_4; 1L P, G (COD, N, P) H_2SO_4; 1L P, G (Metals, Hardness) HNO_3; 1L P, G (CYANIDE) NaOH; Sterile P, G (Coliform)
MISC.

SAMPLE NUMBER (LAB USE ONLY)	DATE	TIME	COMP	GRAB	TEMP °C	RES Cl (mg/L)	CHLORINE REMOVED (Y or N)	SAMPLE MATRIX (S or W)	SAMPLE LOCATION / I.D.	NO. OF CONTAINERS	REQUESTED ANALYSIS
75741-01	12/4/19	9:30am							Aerobic	4	TN
	↓	↓									TKN
											NO2 + NO3
-02									Digestor	4	T-Phos
											NH-3-N
											fecal-mpn
-03									Raw	4	Copper
											Zinc
											TSS
											pH

RELINQUISHED BY	DATE/TIME	RECEIVED BY
Ben Cauthen	12/9 1:50	1355 S Yates
RELINQUISHED BY	DATE/TIME	RECEIVED BY

REMARKS:
on ice

SAMPLE TEMPERATURE AT RECEIPT 3.8 °C

APPENDIX C – NCDA&CS Agronomic Division Predictive Waste Reports (Source: www.ncagr.gov/agronomi/)

NCDA&CS Agronomic Division | Phone: (919) 733-2655 | Website: www.ncagr.gov/agronomi/ | **Report No.** FY20-W000712

Predictive

Waste Report

Links to Helpful Information

Farm: 2094

Sampled: 07/26/2019
Received: 07/29/2019
Completed: 07/31/2019

Client: Loyd Bryant
Loyd Ray Farms Inc
2049 Center Rd.
Boonville, NC 27011
Yadkin County

PALS #: 205223

Advisor:

PALS #:

OFFICIAL COPY

Feb 25 2020

Sample Information

ID: 001
Code: ALS
Description: Swine Lagoon Liq.
Grower Comments: swine waste water

Nutrient Measurements are given in units of parts per million (ppm), unless utherwise specifed.

Nitrogen (N)
Total N:
Total Kjeldahl N: 263
Inorganic:
NH_4-N
NO_3-N

P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
24.0	927	38.4	18.7	17.2	1.17	0.11	0.32	0.09	0.59	-

Other Results

C	Al	Na	Cl
-	0.54	249	-

SS (10^{-5} S/cm)	EC (mS/cm)	pH (Unitless)	BD (lb/yd³)	CCE (%)	ALE (1000 gal)	C:N (Unitless)	DM (%)
-	-	8.14	-	-	-	-	-

Estimate of Nutrients Available for First Year (lb/1000 gal)

Application Method:
Irrigation

N	P_2O_5	K_2O	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
1.10	0.46	9.28	0.32	0.16	0.14	0.01	0.00	0.00	0.00	0.01	-

Other Results (lb/1000 gal)

Al	Na	Cl
0.00	2.07	-

North Carolina
Tobacco Trust Fund Commission

Jennings Exhibit No. 10
Docket No. E-7, Sub 1229

Reprogramming of the laboratory-information-management system that makes this report possible is being funded through a grant from the North Carolina Tobacco Trust Fund Commission.

Thank you for using agronomic services to manage nutrients and safeguard environmental quality.
- Steve Troxler, Commissioner of Agriculture.

Understanding the Waste Report

Nutrient concentrations and other data on this report are provided so that waste materials can be applied at agronomic rates, thereby supplementing or reducing fertilizer application and preventing environmental contamination. In reading the **Laboratory Results** section, remember that materials with < 15% dry matter (generally liquids) are analyzed as received; all other wastes are dried first. Values in the **Estimate of Nutrients Available for First Crop** section are based on the type of waste and method of application you specify and reflects the fact that only 40-60% of the nitrogen becomes available within one year of application. The remainder *may or may not* ever become available.

ALE is Agricultural Lime Equivalence. The ALE indicates the amount of the waste material that provides a limiting effect equivalent to one ton of agricultural grade limestone.
BD is Bulk Density in lb/yd³.
CCE is Calcium Carbonate Equivalence and is used to determine ALE.
C:N ratio is the Carbon:Nitrogen ratio.

DM% is percent Dry Matter [for semi-solid and solid waste, this value facilitates conversion of dry-basis concentrations (ppm) back to wet-basis of original sample].
EC (Electrical Conductivity) measures salinity, or soluble salts (SS).
pH measures basicity/acidity.

Al = Aluminum	**Cu** = Copper	**NH4-N** = Ammonium -N
As = Arsenic	**Fe** = Iron	**Ni** = Nickel
B = Boron	**K** = Potassium	**NO3-N** = Nitrate -N
Ca = Calcium	**Mg** = Magnesium	**P** = Phosphorus
Cd = Cadmium	**Mn** = Manganese	**Pb** = Lead
Cl = Chloride	**Mo** = Molybdenum	**S** = Sulfur
Cr = Chromium	**N** = Nitrogen	**Se** = Selenium
	Na = Sodium	

meq/L = milliequivalent per liter; **mS** = millisiemens; **ppm** = parts per million or mg/L; **S** = siemens; **T** = trace (<0.005 lb/unit)

Additional information: www.ncagr.gov/agronomi/pdffiles/uwaste.pdf & www.ncagr.gov/agronomi/pdffiles/wasteguide.pdf

NCDA&CS Agronomic Division | Phone: (919) 733-2655 | Website: www.ncagr.gov/agronomi/ | Report No. FY20-W003012

OFFICIAL COPY

Feb 25 2020

Predictive

Waste Report

Links to Helpful Information

Client: Loyd Bryant
Loyd Ray Farms Inc
2049 Center Rd.
Boonville, NC 27011
Yadkin County

Advisor:

Sampled: Not Provided
Received: 11/08/2019
Completed: 11/13/2019

Farm: 2094

PALS #: 205223

PALS #:

Sample Information

ID: 001
Code: ALS
Description: Swine Lagoon Liq.
Grower Comments: Not Provided

Nutrient Measurements are given in units of parts per million (ppm), unless utherwise specifed.

Nitrogen (N)
Total N:
Total Kjeldahl N: 173
Inorganic:
NH_4-N
NO_3-N

P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
16.2	756	30.5	15.0	19.1	0.42	0.08	0.24	0.10	0.62	-

Other Results

C	Al	Na	Cl
-	0.23	210	-

SS (10^{-5} S/cm)	EC (mS/cm)	pH (Unitless)	BD (lb/yd³)	CCE (%)	ALE (1000 gal)	C:N (Unitless)	DM (%)
-	-	8.03	-	-	-	-	-

Estimate of Nutrients Available for First Year (lb/1000 gal)

Application Method: Irrigation

N	P_2O_5	K_2O	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
0.72	0.31	7.57	0.26	0.13	0.16	0.00	0.00	0.00	0.00	0.01	-

Other Results (lb/1000 gal)

Al	Na	Cl
0.00	1.75	-

North Carolina
Tobacco Trust Fund Commission

Jennings Exhibit No. 10
Docket No. E-7, Sub 1229

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BD is Bulk Density in lb/yd³.
CCE is Calcium Carbonate Equivalence and is used to determine ALE.
C:N ratio is the Carbon:Nitrogen ratio.

DM% is percent Dry Matter [for semi-solid and solid waste, this value facilitates conversion of dry-basis concentrations (ppm) back to wet-basis of original sample].
EC (Electrical Conductivity) measures salinity, or soluble salts (SS).
pH measures basicity/acidity.

Al	= Aluminum	**Cu**	= Copper	**NH_4-N**	= Ammonium -N
As	= Arsenic	**Fe**	= Iron	**Ni**	= Nickel
B	= Boron	**K**	= Potassium	**NO_3-N**	= Nitrate -N
Ca	= Calcium	**Mg**	= Magnesium	**P**	= Phosphorus
Cd	= Cadmium	**Mn**	= Manganese	**Pb**	= Lead
Cl	= Chloride	**Mo**	= Molybdenum	**S**	= Sulfur
Cr	= Chromium	**N**	= Nitrogen	**Se**	= Selenium
		Na	= Sodium		

meq/L = milliequivalent per liter; **mS** = millisiemens; **ppm** = parts per million or mg/L; **S** = siemens; **T** = trace (<0.005 lb/unit)

Additional information: www.ncagr.gov/agronomi/pdffiles/uwaste.pdf & www.ncagr.gov/agronomi/pdffiles/wasteguide.pdf

Carbon-Free Resource Integration Study

Reiko Matsuda-Dunn, Michael Emmanuel, Erol Chartan, Bri-Mathias Hodge, and Gregory Brinkman

National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5D00-74337
January 2020

Carbon-Free Resource Integration Study

Reiko Matsuda-Dunn, Michael Emmanuel, Erol Chartan, Bri-Mathias Hodge, and Gregory Brinkman

National Renewable Energy Laboratory

Suggested Citation
Matsuda-Dunn, Reiko, Michael Emmanuel, Erol Chartan, Bri-Mathias Hodge, and Gregory Brinkman. 2020. *Carbon-Free Resource Integration Study*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5D00-74337. https://www.nrel.gov/docs/fy20osti/74337.pdf.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5D00-74337
January 2020

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by Duke Energy. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

U.S. Department of Energy (DOE) reports produced after 1991 and a growing number of pre-1991 documents are available free via www.OSTI.gov.

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

List of Acronyms

DEC	Duke Energy Carolinas
DEP	Duke Energy Progress
NREL	National Renewable Energy Laboratory
PV	photovoltaic
WIND	Wind Integration National Dataset

Foreword

This report covers the results of a preliminary phase 1 analysis conducted by the National Renewable Energy Laboratory (NREL) with Duke Energy, who funded this work and whose expertise, specialist knowledge, and diligence has helped guide the process. This initial effort is a net load analysis which compares estimated hourly solar, wind, net load, and system minimum generation time series for different scenarios. It aims primarily to set up a baseline for more detailed modeling as part of a larger effort between Duke Energy and NREL expected to last multiple years. The full analysis will provide a broader insight into the costs, challenges, and opportunities of renewable energy integration in the Duke Energy service territory in the Carolinas. This report and the full analysis are not financial plans and are not intended to replace Duke Energy's integrated resource planning process. Rather, they examine the operational considerations of integrating additional carbon-free resources onto the Duke Energy Carolinas and Duke Energy Progress system.

Executive Summary

This report presents a net load analysis, geospatial analysis, and a web application for the Duke Energy Carbon-Free Resource Integration Study. In this collaborative engagement, the National Renewable Energy Laboratory (NREL) provides research support to Duke Energy to analyze the impacts of integrating significant amounts of new solar photovoltaic (PV) power into its service territory under a variety of scenarios. This analysis covers Duke Energy's territories in North Carolina and South Carolina, including two balancing authorities—Duke Energy Progress (DEP) and Duke Energy Carolinas (DEC)—with detailed assessments and discussions of the operations of the existing fleet, particularly nuclear generation, under high-penetration scenarios of solar PV. In addition to quantifying the solar potential, NREL is working with Duke Energy to identify possible opportunities for wind, storage, demand-side resources, and other technologies.

Scenario Analysis

This analysis looks at a variety of solar power penetration levels in Duke Energy's service territory in the Carolinas—compared to load and system-wide minimum generation levels—that best represent potential challenges and opportunities for renewable generation integration. An example of this includes an analysis of balancing solar and load for typical days during different seasons and extreme days, such as minimum and peak net load days. Net load is defined as the customer load less wind power and solar power generation. This analysis is performed by comparing estimated hourly solar, wind, net load, and system minimum generation time series for the different scenarios. The overall aim is to help Duke Energy understand initial estimates of possible curtailment, key periods of ramping, and load-following requirements. Further, this analysis captures net load impacts across different seasons and operational issues related to generation flexibility limit during periods of low load with high penetrations of solar energy.

Key Findings

Table ES-1 shows the results of the annual metrics, including annual percentage of load met by carbon-free generation, annual percentage of curtailed energy, annual hours of curtailment, and annual maximum instantaneous curtailment for all scenarios. For scenarios 1 through 11, both balancing authorities (DEC and DEP) are modeled as a single region, whereas Scenario 12 models DEP and DEC separately with an interconnection limit between them.

In scenarios 1 through 7, as solar energy penetration increases, the percentage of load met by carbon-free generation increases, until the flexibility limit is reached, when PV production must be curtailed, and additional solar power has a marginal impact. The average annual percentage of load met by carbon-free generation ranges from 60% to 77%, for these aforementioned scenarios, as shown in Table ES-1. As the PV penetration level increases, the marginal contribution to carbon-free generation suffers diminishing returns, due to the inability to shift the timing of PV generation to match the early and late hour net demand, especially from 20% through 35% PV energy penetration.

Table ES-1. Annual Metrics Evaluation for All Scenarios in the Net Load Analysis

Scenario	DEP and DEC Modeled as a Single Region or Separately	Definition	Annual Load Met by Carbon-Free Generation (%)	Annual Curtailed Renewable Energy (%)	Annual Hours of Curtailment	Annual Maximum Instantaneous Curtailment (MW)
1. Solar energy penetration 5%	Single region	4,109 MW, 5.5% of total solar is rooftop	60.4%	0%	6	530
2. Solar energy penetration 10%	Single region	8,219 MW, 5.5% of total solar is rooftop	65.5%	1%	179	3,323
3. Solar energy penetration 15%	Single region	12,328 MW, 5.5% of total solar is rooftop	69.7%	8%	882	6,618
4. Solar energy penetration 20%	Single region	16,438 MW, 5.5% of total solar is rooftop	72.5%	17%	1,506	10,003
5. Solar energy penetration 25%	Single region	20,547 MW, 5.5% of total solar is rooftop	74.4%	27%	2,016	13,504
6. Solar energy penetration 30%	Single region	24,656 MW, 5.5% of total solar is rooftop	75.6%	35%	2,355	17,207
7. Solar energy penetration 35%	Single region	28,766 MW, 5.5% of total solar is rooftop	76.5%	42%	2,587	20,909
8. Higher ratio of distributed to utility solar added to the system	Single region	Based on the 25% solar energy penetration scenario, 18.91% of PV is uncurtailable rooftop	74.4%	27%	2,017	13,548

Scenario	DEP and DEC Modeled as a Single Region or Separately	Definition	Annual Load Met by Carbon-Free Generation (%)	Annual Curtailed Renewable Energy (%)	Annual Hours of Curtailment	Annual Maximum Instantaneous Curtailment (MW)
9. Additional storage	Single region	Based on the 25% solar energy penetration scenario, addition of 1,000 MW of 4-hour storage, 1,000 MW of 6-hour storage, and 2,000 MW of 8-hour storage	77.1%	12%	1,239	11,073
10. Nuclear retirement	Single region	Based on the 25% solar energy penetration scenario, assume a 10% nuclear reduction	70.2%	22%	1,804	12,551
11. Additional wind energy at 5% penetration	Single region	Based on the 30% solar energy penetration scenario, an additional 5% wind energy penetration is added	79.4%	32%	2,486	17,486
12—DEC 5%	Separate regions	Based on scenarios 1–3 inclusive, DEP and DEC are analyzed separately with an interconnection limit between	70%	0%	5	246
12—DEC 10%	Separate regions		75%	1%	213	1,886
12—DEC 15%	Separate regions		80%	7%	912	3,418
12—DEP 5%	Separate regions		50%	0%	5	246
12—DEP 10%	Separate regions		54%	1%	205	1,600
12—DEP 15%	Separate regions		58%	10%	905	3,418

For scenarios 2 through 7 (solar energy penetration levels of 10% to 35% inclusive), analysis shows that the annual percentage curtailment ranges from 1% to 42% of total solar energy as PV penetration increases from 10% to 35%. The majority of the solar energy curtailment occurs during the spring and fall seasons, which are characterized with low load and high renewable energy production. Also, Scenario 7, which has a solar energy penetration level of 35% and models both balancing authorities as one region, experienced the highest maximum instantaneous curtailment and hours of curtailment: 20,909 MW and 2,587 hours, respectively.

The increased proportion of private solar PV analyzed in Scenario 8 does not materially affect the curtailment required. This does not infer that significant amount of rooftop will have no impact on system balancing. Given the assumptions of this study, with increasing penetration of rooftop solar from 5.5% of the total to 18.9% of the total, there is still sufficient curtailable solar to balance load and generation. Annual curtailment is 33% of utility solar and 27% of the total solar, which is the same as the baseline in Scenario 5.

The additional storage (26,000 MWh)[1] modeled in Scenario 9 results in a 3% increase in the amount of load met by carbon-free generation compared with the baseline in Scenario 5, which has 25% PV penetration. Also, the percentage of renewable energy curtailed decreases by 15%, whereas the 10% nuclear retirement scenario leads to a 4% decrease in the amount of load met by carbon-free generation and curtailed solar energy.

Further, the addition of 5% wind energy penetration to 30% solar energy in Scenario 11 results in a 2% increase in carbon-free energy production compared with the 35% solar energy penetration case. Also, the renewable energy curtailed decreases by 10% of the total renewable energy production. Thus, this shows that a balanced mix of renewable resources might reduce curtailment and the overall system cost compared to a similar penetration of PV-only generation

When DEC and DEP are modeled as individual balancing authorities with existing limited interconnection between them, Scenario 12 shows that DEP experiences a lower average percentage of load met by carbon-free generation, ranging from 50% to 58%, compared to DEC, which ranges from 70% to 80%. A production cost optimization would enable simulation of the interconnection and other transmission constraints in a more realistic manner.

Figure ES-1 (below) shows the annual contribution to carbon-free energy from all the scenarios considered in this study. The largest contribution resource to carbon-free energy is the nuclear power plant, followed by the increasing penetration of PV. Also, Figure ES-1 shows the impact of resource diversity with wind integration in the amount of carbon-free energy contribution with DEP and DEC modeled as a single balancing authority. Scenario 11, with 30% PV and 5% wind energy penetration, results in the highest contribution: 79%.

Another important metric used to assess the diminishing returns of increasing levels of variable generation resources added to the system is marginal curtailment.[2] As PV penetration levels increase, marginal curtailment increases more rapidly than total curtailment, as shown in Figure ES-2. This indicates that an increasing proportion of solar energy capacity will be curtailed as the system approaches high penetration levels of variable solar generation without adding sufficient system flexibility; however, solutions such as the addition of storage and wind power instead of additional solar power result in the marginal curtailment being reduced, as shown in Figure ES-2.

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[1] This study did not consider the value stacking of storage units (i.e., using storage for other ancillary services, such as frequency regulation, voltage support, spinning and nonspinning reserves); therefore, the load-shifting and flexibility benefit presented in this report cannot be used solely for the economic assessment of storage deployment in the grid.
[2] The marginal curtailment rate refers to the curtailment from an additional unit of variable generation capacity added to the system. For example, when increasing the variable generation penetration level from 10% to 15%, the marginal curtailment is the curtailment rate of the additional 5% of variable generation.

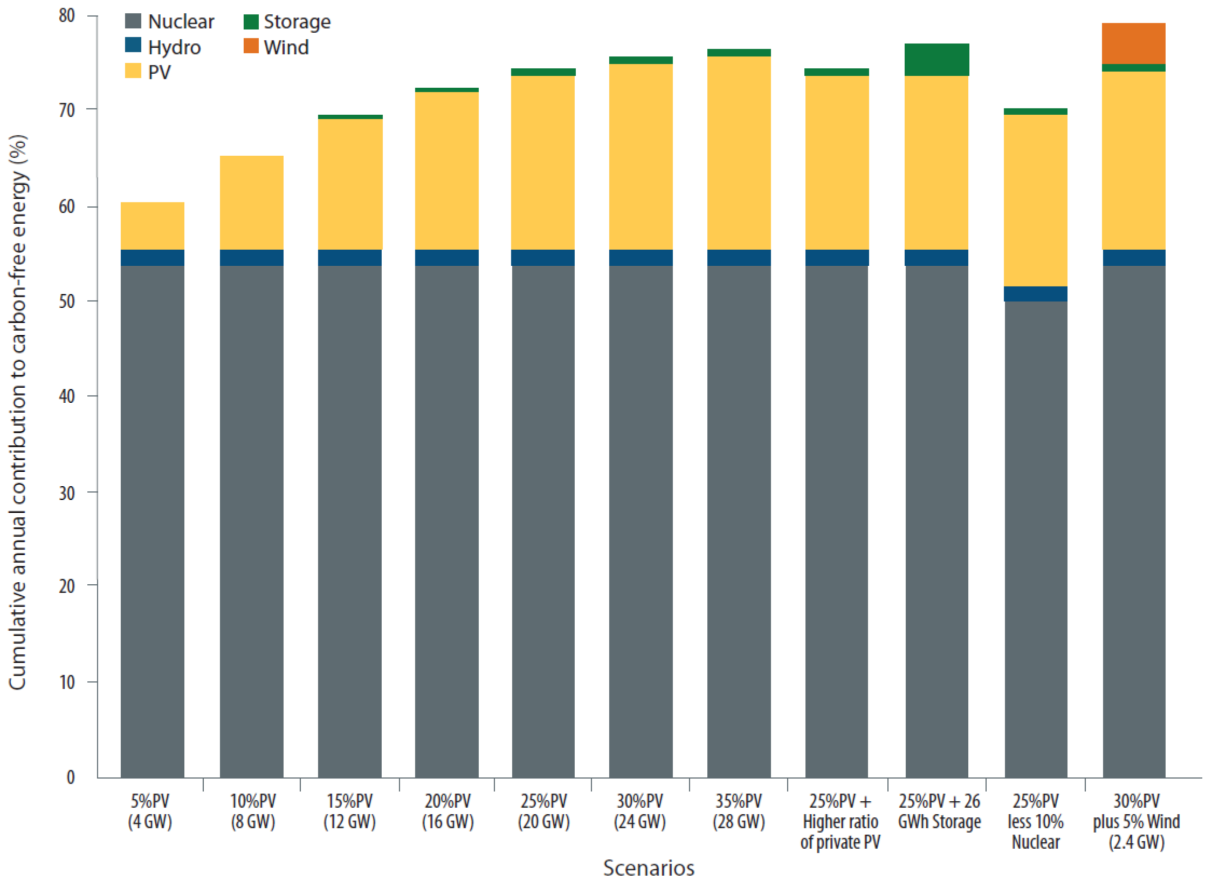

Figure ES-1. Percentage of annual carbon-free energy and contribution from each energy resource with increasing PV penetration, generation retirement, storage, and wind integration

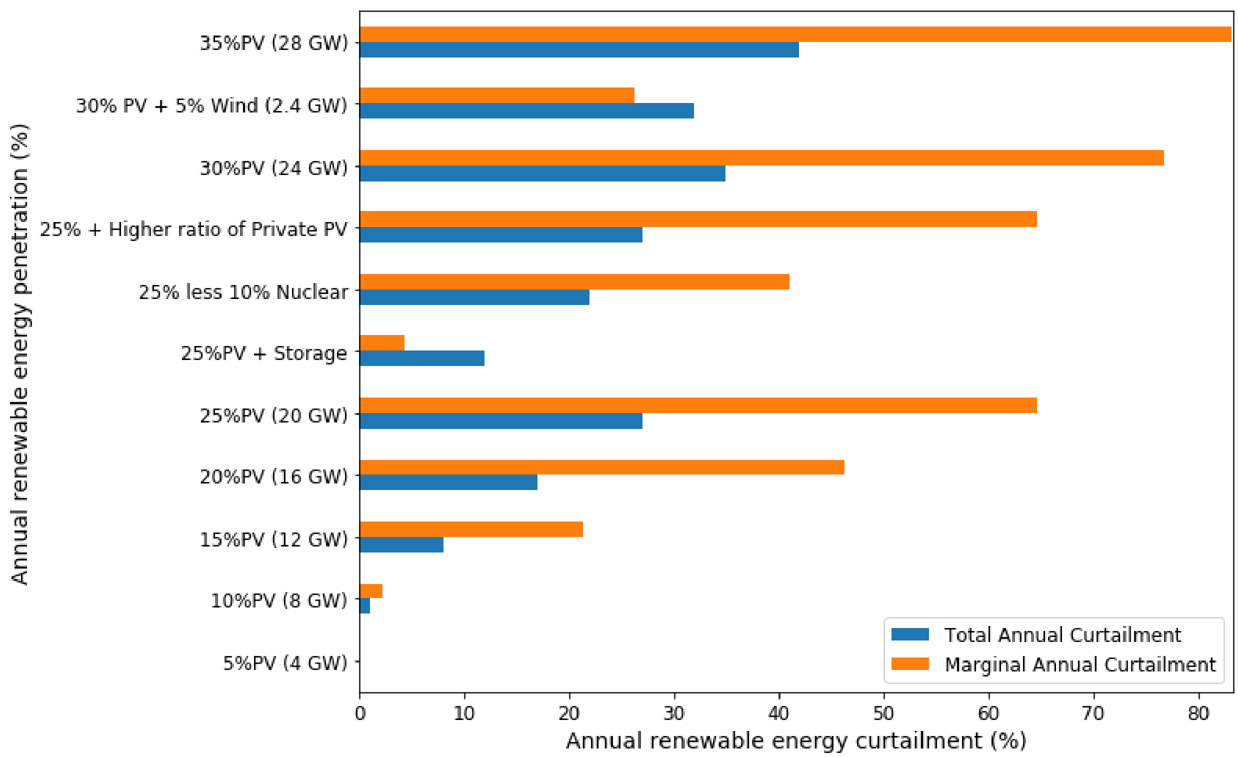

Figure ES-2. Marginal and total curtailment with increasing PV penetration, generation retirement, storage, and wind integration

Conclusions

The results and analysis of Phase 1 of the Carbon-Free Resource Integration Study presented in this report will help NREL and Duke Energy scope future work in this area to examine and address the identified grid integration challenges in greater technical detail. Further analysis with more advanced models—such as unit commitment and economic dispatch, capacity expansion planning, and dynamic analysis models—will be required to more fully assess system impacts with increasing variable generation penetration levels as well as flexibility opportunities to accommodate variable renewable energy sources to achieve the carbon-free goals of Duke Energy.

Table of Contents

List of Figures

List of Tables

1 Introduction

Duke Energy is one of the largest electric power holding companies in the United States. It has more than 30,000 distributed energy resource facilities, with a combined capacity of more than 3,700 MW operating across all Duke Energy jurisdictions. More than 90% of this capacity is in the Carolinas, where more than 16,000 distributed energy resource sites generate more than 3,200 MW on the transmission and distribution systems, making the Duke Carolinas a national leader for integrating utility-scale solar generation. Duke Energy continues to strengthen its commitment toward carbon-free electricity generation, and during the next several years the capacity of solar generation across Duke Energy is expected to at least double. The incentivization of commercial solar by Duke Energy coupled with the recently launched proposal for 6800 MW under the North Carolina House Bill 589, as well as plans to add 700 MW of solar facilities in Florida, continue to drive the rapid adoption of solar generation across Duke Energy's service territory (Duke Energy, 2018).

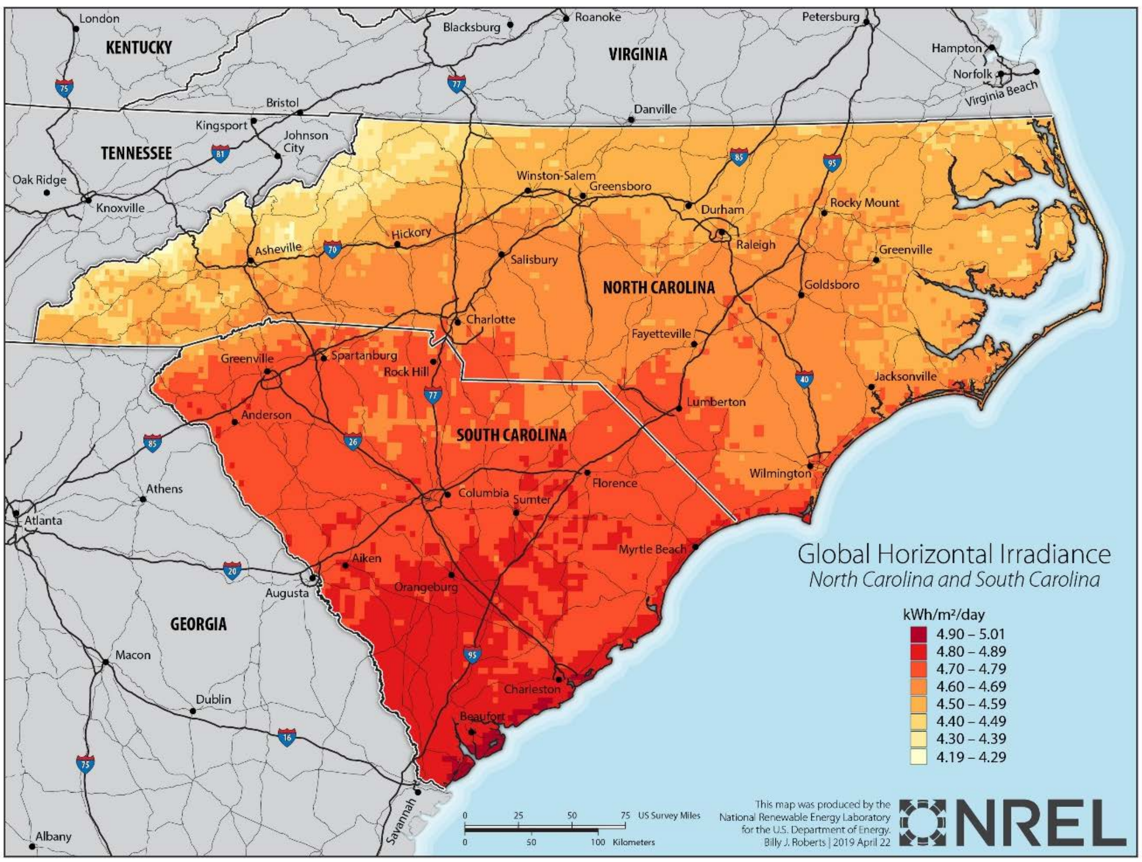

Figure 1. Solar energy resource in the Carolinas region

Duke Energy is seeking to analyze the impacts of integrating significant amounts of new carbon-free power sources into the Duke Energy power system under a variety of penetrations levels. This report focuses on investigating the addition of solar power along with understanding how the integration of variable generation sources, especially at high penetration levels, comes with potential challenges to reliable power system operations. The variability and uncertainty of renewable energy sources are two major constraints to integrating them into the power system. In power network operations, generation planners will always need to ensure that there is enough capacity to serve load at any given time. Characterizing variable generation resources in planning operations becomes a challenge because of their tendency to disrupt the balance of the generation portfolio. Consequently, thermal and hydro generators are operated differently to accommodate the variability and uncertainty of renewable electricity generators (Lew, 2013).

Additionally, the integration of variable and uncertain power generation from wind and solar units at high penetration levels introduces another pivotal variable: net load (normal load less wind power and solar power). This creates a new set of requirements for integrated and reliable power system planning operations. The net load variability has created a further need to evaluate system flexibility because of its impacts on system operating costs. The ability of the power system to integrate additional renewable resources is largely a function of its flexibility, which is chiefly driven by the ability of individual plants to change their output to serve these variations in net electricity consumption (Ela, 2014). The key to managing the variability and uncertainty of variable generation sources is to increase the system-wide flexibility in the power system (Mai, et al., 2012).

Duke Energy is committed to creating a carbon-free power system of the future. Currently, the large nuclear fleet contributes to load greatly as carbon-free generation. With the current cost of solar power, it makes sense to investigate increasing solar power capacity to meet higher carbon-free goals. This will likely increase the requirement for Duke's thermal generation sources to be flexible, which will be limited by their nuclear power plants, which typically run only at full output. A detailed understanding of power system flexibility characteristics has become critical because high levels of variable generation will have significant impacts on the operation of the traditional thermal generation fleet.

This report analyzes the net load and presents the impact of high penetration levels of variable generation on the operation of Duke Energy's power system given the flexibility limits set by a combination of the must-run units, hydro schedules, nuclear generators, and storage. These limits dictate curtailing excess solar power during times when there is a greater amount of solar photovoltaic (PV) generation than can be accommodated.

To contextualize subsequent discussions in this report, it is important to define variable generation penetration levels. One power-based definition considers the ratio of variable generation nameplate capacity to system peak load. The definition of penetration level by energy often estimates the amount of renewable energy (pre-curtailment) injected into the grid during a period of time and helps to quantify the amount of displaced fossil-fueled generation, fuel consumption savings, and avoided carbon emissions. The energy-based definition is useful when considering very large systems and long time frames, and it has been adopted in many renewable portfolio standards (Bebic, 2008). Therefore, the analysis presented in this report uses the energy-based definition of penetration level on an annual basis.

In scoping Phase 1 of this collaborative engagement, the National Renewable Energy Laboratory (NREL), in consultation with Duke Energy, designed the scenarios to be considered, as shown in Table 1. These scenarios are analyzed and documented in this report. Note that the penetration levels used in naming the scenarios are approximate numbers based on annual energy before curtailment.

Table 1. Scenarios for Net Load Analysis

Scenario	Definition
1. Solar energy penetration 5%	4,109 MW, 5.5% of total solar is rooftop
2. Solar energy penetration 10%	8,219 MW, 5.5% of total solar is rooftop
3. Solar energy penetration 15%	12,328 MW, 5.5% of total solar is rooftop
4. Solar energy penetration 20%	16,438 MW, 5.5% of total solar is rooftop
5. Solar energy penetration 25%	20,547 MW, 5.5% of total solar is rooftop
6. Solar energy penetration 30%	24,656 MW, 5.5% of total solar is rooftop
7. Solar energy penetration 35%	28,766 MW, 5.5% of total solar is rooftop
8. Higher ratio of distributed to utility solar added to the system	Based on the 25% solar energy penetration scenario, 18.91% of PV is uncurtailable rooftop
9. Additional storage	Based on the 25% solar energy penetration scenario, addition of 1,000 MW of 4-hour storage, 1,000 MW of 6-hour storage, and 2,000 MW of 8-hour storage
10. Nuclear retirement	Based on the 25% solar energy penetration scenario, assumes a 10% nuclear reduction
11. Additional wind energy penetration 5%	Based on the 30% solar energy penetration scenario, an additional 5% wind energy penetration is added
12. Scenarios 1–3 modeled with two balancing authorities	Based on scenarios 1–3 inclusive, DEP and DEC are analyzed separately with an interconnection limit between, defined in the appendix

This report examines the amount of renewable energy curtailment as well as the particular hours of curtailment for these scenarios. This report also presents an evaluation of the daily percentage of carbon-free generation from carbon-free plants.

Note that there are some limitations to the net load analysis presented in this report. This analysis does not include unit commitment and economic dispatch models; interconnection to neighbors; market models; system stability metrics such as voltage and/or frequency; or costs—all of which would be essential in recommending a pathway to the future.

2 Characterizing the Net Load

As power system planning continues to move toward adopting an integrated planning approach caused by increasing variable generation integration, it is now critical to begin characterizing the net load. The net load—defined here as the total customer demand minus the variable generation—gives the demand that must be met by traditional dispatchable generation. For this analysis, solar PV is considered to be non-dispatchable, though the utility solar power can be curtailed down. Therefore, its contribution to meeting reserve margins is quantified by how it changes the net load.

The net load analysis can be of interest for several reasons, including:

- At high penetration levels, variable generation can cause a significant shift in the timing of both the minimum and peak net load relative to the system or gross load, which can impact the system generation scheduling, cost of generation, and daily unit commitment and dispatch.
- During low-load conditions, which typically occur during the spring, high penetrations of variable generation can violate the system flexibility limit and result in significant integration issues. Consequently, during such periods renewable generation must be curtailed, which can adversely impact variable generation project economics or contractual arrangements with renewable generators.
- Net load analysis can be a useful tool in assessing power system flexibility in the presence of varying penetration levels of variable generation. Because increasing variable generation penetration levels can lead to increases in net load variability, and thus required thermal unit ramp rates and ramping ranges, the need for the power system to become more flexible increases. This scenario demands that conventional power plants would need to change their output more frequently than traditionally. Situations when the system flexibility requirements are not met could impact the reliable and economic operations of the grid. Impacts could include variable generation curtailment, reserve shortfalls, and potential frequency violations as a result of over- and undergeneration (Milligan, 2015)
- Outputs from net load analysis such as maximum renewable curtailment and the number of hours of curtailment are important metrics that can be used to evaluate system flexibility. Detailed flexibility evaluation, however, requires further analysis using different modeling methods, such as production cost modeling, capacity expansion planning, and dynamic stability analysis.

3 Scenario Analysis

This net load analysis covers the Duke Energy Carolinas (DEC) and Duke Energy Progress (DEP) balancing authorities, with 2019 hourly forecasted load data supplied by Duke Energy. Maintaining load and renewable resource coincident relationships is a primary consideration in net load analysis and assessing its impact on the system operational requirements, such as determining minimum generation levels (GE Energy, 2010). Spatial and temporal correlation of the load and variable generation sources are needed to accurately reflect the underlying weather patterns that drive both load and variable generation.

This report uses 2019 forecasted annual load and solar PV time-series profiles supplied by Duke Energy and based on the same weather period to ensure that the solar profiles are synchronized with the weather assumed in the load. For the net load analysis, thermal generation outside of nuclear, hydropower, and must-run units is considered to be entirely flexible—i.e., there are no constraints on minimum stable level, ramp rates, and outage rates. Rooftop solar is non-curtailable, utility solar is curtailable, and the must-run units are used for local voltage constraints. Table 8, in the appendix, shows a list of assumptions and definitions used for the net load analysis.

The generation flexibility limit consists of nuclear, hydropower units, and must-run units, offset by the hydropower pumped storage capacity (see Equation 1 in the appendix). Nuclear is assumed to run at 100% capacity for this analysis. From the data supplied by Duke Energy, note that the must-run units have hourly triggers and therefore could change intra-daily, whereas hydro schedules vary monthly. This explains why the generation flexibility limit line could change seasonally, and possibly daily, which is reflective of the inherent characteristics of the must-run units and hydro capacity considered in this analysis. The renewable energy curtailment per hour is the net load below the flexibility limit, which is calculated using Equation 2 in the appendix. The daily percentage of carbon-free generation includes solar power, wind power, hydropower, and nuclear (using storage), and it is calculated in Equation 3 in the appendix. The presented maximum up-ramp and down-ramp times are based on the ending times of each ramp.

An analysis of the average, minimum, and maximum net load days is performed to illustrate the varying impact of the net load variability across different seasons on key metrics, such as daily percentage of carbon-free generation, percentage of curtailed energy, maximum instantaneous curtailment, and hours of curtailment. The net load curves, as presented in this section, help capture the net load demand that the system must meet in real time for reliable operation of the grid.

3.1 Scenarios 1–7: 5%–35% Solar Energy Penetration

Seven different levels of solar energy penetration are explored, beginning with 5% penetration and increasing in 5% increments through 35% penetration. The solar output before curtailment is the 2019 PV time series provided by Duke Energy scaled to the specified percentage of the total load. The scalars used for each scenario are provided in Table 3 of the appendix and are calculated using Equation 4. Higher penetrations of solar power are expected to experience geographical smoothing, which the scalers do not account for and thus overestimate the variability. Ramp rates for all the scenarios are calculated as the difference between the net load at a given hour and the hour immediately prior.

Solar PV capacities for each level of solar penetration are shown in Table 2.

Table 2. PV Capacities for Penetration Levels Defined by Scenarios 1–7

PV penetration in terms of annual energy before curtailment (%)	5	10	15	20	25	30	35
PV capacity (MW)	4,109	8,219	12,328	16,438	20,547	24,656	28,766

Average daily values for load, generation flexibility limit, rooftop, and all PV plants are estimated across all seasons. Figure 2 shows these data for scenarios 1–7 in the spring season, which has the highest curtailment. Graphs for the three remaining seasons are available in the appendix. In low penetrations of PV, adding more PV increases the percentage of load met by carbon-free generation until the flexibility limit is reached, at which point curtailment increases and additional solar power has diminishing returns.

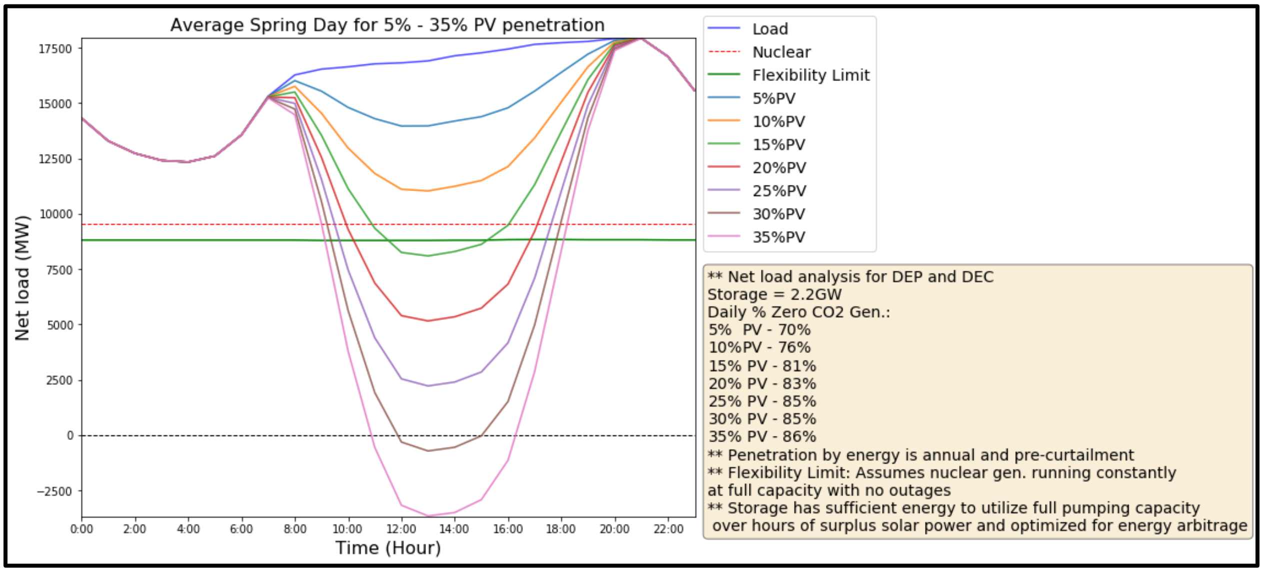

Figure 2. Average net load for all scenarios for spring

Annual average carbon-free generation ranges from 60% to 77% from the 5% PV penetration case to the 35% case, respectively. Seasonal values are shown in Table 3.

Table 3. Average Seasonal Percentage of Load Met by Carbon-Free Generation for Each Scenario

Scenario	Spring	Summer	Fall	Winter	Annual
1. Solar energy penetration 5%	69%	54%	65%	57%	60%
2. Solar energy penetration 10%	75%	59%	70%	61%	65%
3. Solar energy penetration 15%	80%	64%	74%	63%	70%
4. Solar energy penetration 20%	83%	68%	76%	65%	73%
5. Solar energy penetration 25%	84%	71%	78%	66%	74%
6. Solar energy penetration 30%	85%	73%	79%	67%	76%
7. Solar energy penetration 35%	86%	74%	80%	68%	77%
8. Increase proportion of distributed solar	84%	71%	78%	66%	74%
9. Additional storage	88%	73%	81%	68%	77%
10. Nuclear retirement	80%	67%	73%	62%	70%
11. Additional wind energy penetration 5%	90%	76%	83%	71%	79%
12. Two balancing authorities: DEC 5%	80%	61%	76%	66%	70%
12. Two balancing authorities: DEC 10%	87%	66%	82%	70%	75%
12. Two balancing authorities: DEC 15%	93%	71%	87%	73%	80%
12. Two balancing authorities: DEP 5%	56%	45%	53%	47%	50%
12. Two balancing authorities: DEP 10%	62%	50%	57%	50%	54%
12. Two balancing authorities: DEP 15%	65%	55%	60%	53%	58%

With the current flexibility limit, curtailment is necessary at PV penetration levels of 10% and more. Duke Energy will first experience significant curtailment at the 10% PV penetration level, at an annual average of 1.1%. Figure 3 shows a low net load day in spring, during which 20% curtailment will occur. With 10% PV energy, 65% of the annual load is met by carbon-free generation, indicating that in this case nearly 65% of energy from carbon-free sources could be achieved before any curtailment is needed. In Scenario 12, where DEP and DEC are modeled separately with a total PV penetration of 15%, DEC in spring achieves a carbon-free contribution of more than 100%. This is because we assume that existing storage can charge with energy that would otherwise be curtailed and then release the corresponding energy within the same day. This value suggests that this operation would result in a surplus of generation.

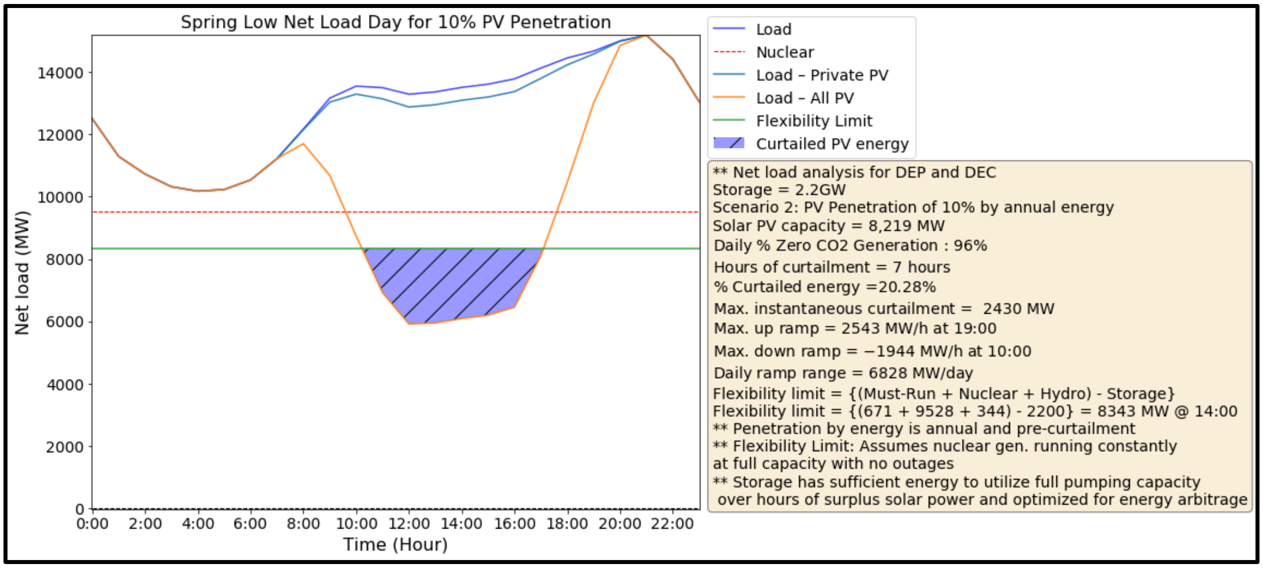

Figure 3. Minimum net load day for spring with 10% PV penetration

Annual percentage of curtailment ranges from 1.1% to 42% of total solar energy for scenarios 2–7. Seasonal and annual percentages of curtailment are shown in Table 4, and hours of curtailment are shown in Table 5. Seasonal maximum instantaneous curtailment is given in Table 13 in the appendix. Generally, the highest curtailment occurs in spring and the lowest in summer.

Table 4. Average Percentage Curtailed Energy

Scenario	Spring	Summer	Fall	Winter	Annual
1. Solar energy penetration 5%	0%	0%	0%	0%	0%
2. Solar energy penetration 10%	2%	0%	1%	2%	1%
3. Solar energy penetration 15%	12%	1%	10%	10%	8%
4. Solar energy penetration 20%	25%	4%	22%	22%	17%
5. Solar energy penetration 25%	36%	12%	32%	31%	27%
6. Solar energy penetration 30%	44%	21%	40%	39%	35%
7. Solar energy penetration 35%	50%	29%	46%	45%	42%
8. Increase proportion of distributed solar	36%	12%	32%	31%	27%
9. Additional storage	19%	2%	15%	14%	12%
10. Nuclear retirement	30%	8%	27%	26%	22%
11. Additional wind energy penetration 5%	40%	20%	36%	34%	32%
12. Two balancing authorities: DEC 5%	0%	0%	0%	0%	0%
12. Two balancing authorities: DEC 10%	2%	0%	1%	1%	1%
12. Two balancing authorities: DEC 15%	11%	1%	9%	10%	7%
12. Two balancing authorities: DEP 5%	0%	0%	0%	0%	0%
12. Two balancing authorities: DEP 10%	2%	0%	1%	1%	1%
12. Two balancing authorities: DEP 15%	15%	1%	13%	13%	10%

Table 5. Hours of Curtailment per Season

Scenario	Spring	Summer	Fall	Winter	Annual
1. Solar energy penetration 5%	0	0	0	6	6
2. Solar energy penetration 10%	76	0	45	58	179
3. Solar energy penetration 15%	351	36	275	220	882
4. Solar energy penetration 20%	533	216	403	354	1,506
5. Solar energy penetration 25%	636	458	494	428	2,016
6. Solar energy penetration 30%	707	598	562	488	2,355
7. Solar energy penetration 35%	752	700	610	525	2,587
8. Increase proportion of distributed solar	634	454	496	433	2,017
9. Additional storage	484	136	341	278	1,239
10. Nuclear retirement	593	363	457	391	1,804
11. Additional wind energy penetration 5%	746	650	584	506	2,486
12. Two balancing authorities: DEC 5%	0	0	0	5	5
12. Two balancing authorities: DEC 10%	91	2	54	66	213
12. Two balancing authorities: DEC 15%	358	53	278	223	912
12. Two balancing authorities: DEP 5%	0	0	0	5	5
12. Two balancing authorities: DEP 10%	90	1	51	63	205
12. Two balancing authorities: DEP 15%	361	45	282	217	905

In Duke Energy's current system, low load days are important because of the lack of flexible thermal generation that can be relied on to reduce power output, if needed. In the case of high solar power penetration, such as the 25% case shown in Figure 4, the minimum net load days are more important because the system becomes more sensitive to solar power forecasting errors and causes greater ramps and variability. In this case, the average curtailment for this season is 25%; however, this particular day shows a sunny low load day reaching 62.9% curtailment.

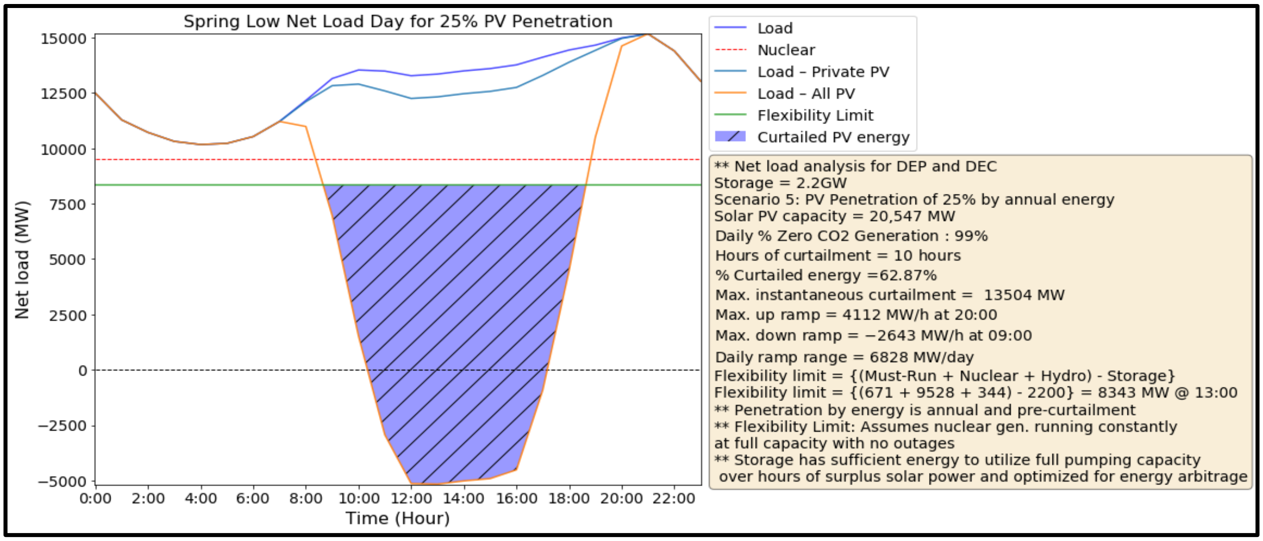

Figure 4. Minimum net load day for spring, the highest curtailment season, with 25% solar energy penetration

At higher loads, such as the peak load day of summer, which has 25% PV penetration, shown in Figure 5, flexible thermal generation needs to increase output, and therefore the system has a greater ability to reduce generation to be replaced with solar power during the day, and less curtailment is required. This is evident in Table 4, which shows that the curtailment during the summer is the minimum of all the values of seasonal curtailment across all scenarios.

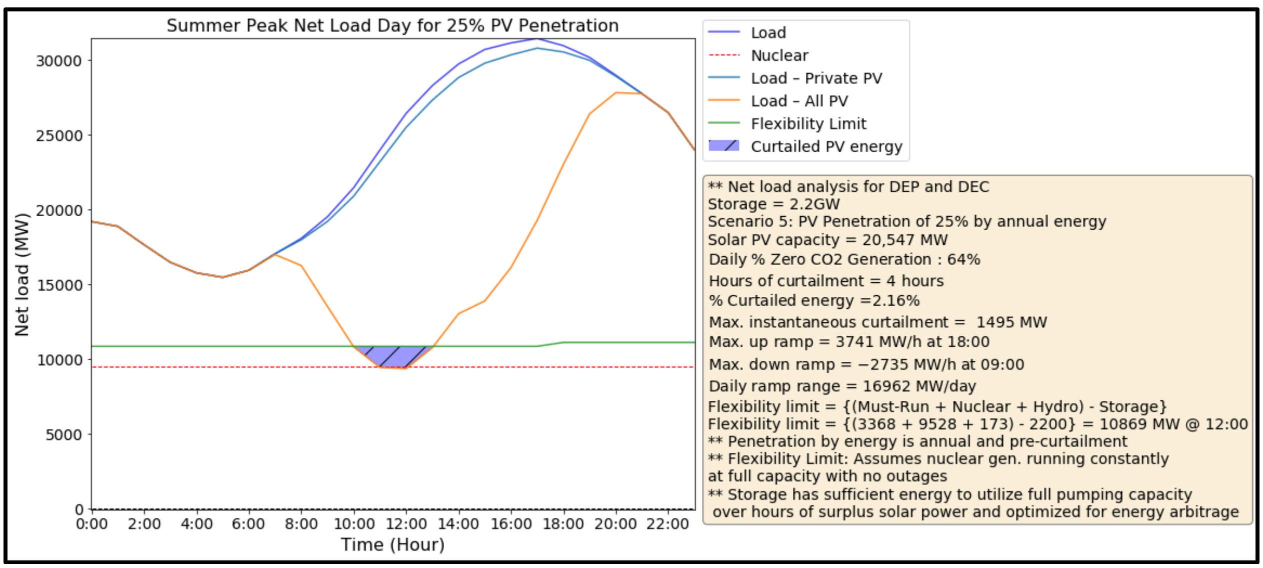

Figure 5. Max net load day for lowest curtailment season, summer, with 25% solar energy penetration

Marginal curtailment is defined as the percentage of the additional renewable energy that would be curtailed as the penetration level is increased by 5% of the load. The curtailment of each scenario is compared to that of the scenario with 5% less solar. Or, in the case of Scenario 11, which has 5% wind and 30% solar penetration, the curtailment is compared to that of Scenario 6, which has 30% solar. The marginal curtailment for all applicable scenarios is shown in Table 6.

Table 6. Percentage Marginal Curtailment

Scenario	% Marginal Curtailment
2. Solar energy penetration 10%	2.2%
3. Solar energy penetration 15%	21.4%
4. Solar energy penetration 20%	46.3%
5. Solar energy penetration 25%	64.6%
6. Solar energy penetration 30%	76.7%
7. Solar energy penetration 35%	83.2%
9. Additional storage	4.3%
10. Nuclear retirement	41.0%
11. Additional wind energy penetration 5%	26.3%
12. Two balancing authorities: 10% penetration	2.5%
12. Two balancing authorities: 15% penetration	22.9%

The load duration curve can also be a useful tool to illustrate the impact of variable generation penetration on the system peak and light loads. Load duration curves for the total system load and net load with 25% PV penetration are shown in Figure 6. The annual peak load is insignificantly reduced by the integration of solar PV because it occurs in winter before sunrise. During certain periods (1,947 hours), however, this penetration level reduces the annual minimum load to less than the minimum generation level set by the nuclear line. This implies that as PV penetration increases, solar PV will start to offset baseload generation or must be curtailed. This effect could vary based on the generation flexibility limit line imposed by the must-run units, hydro schedules, and energy storage systems.

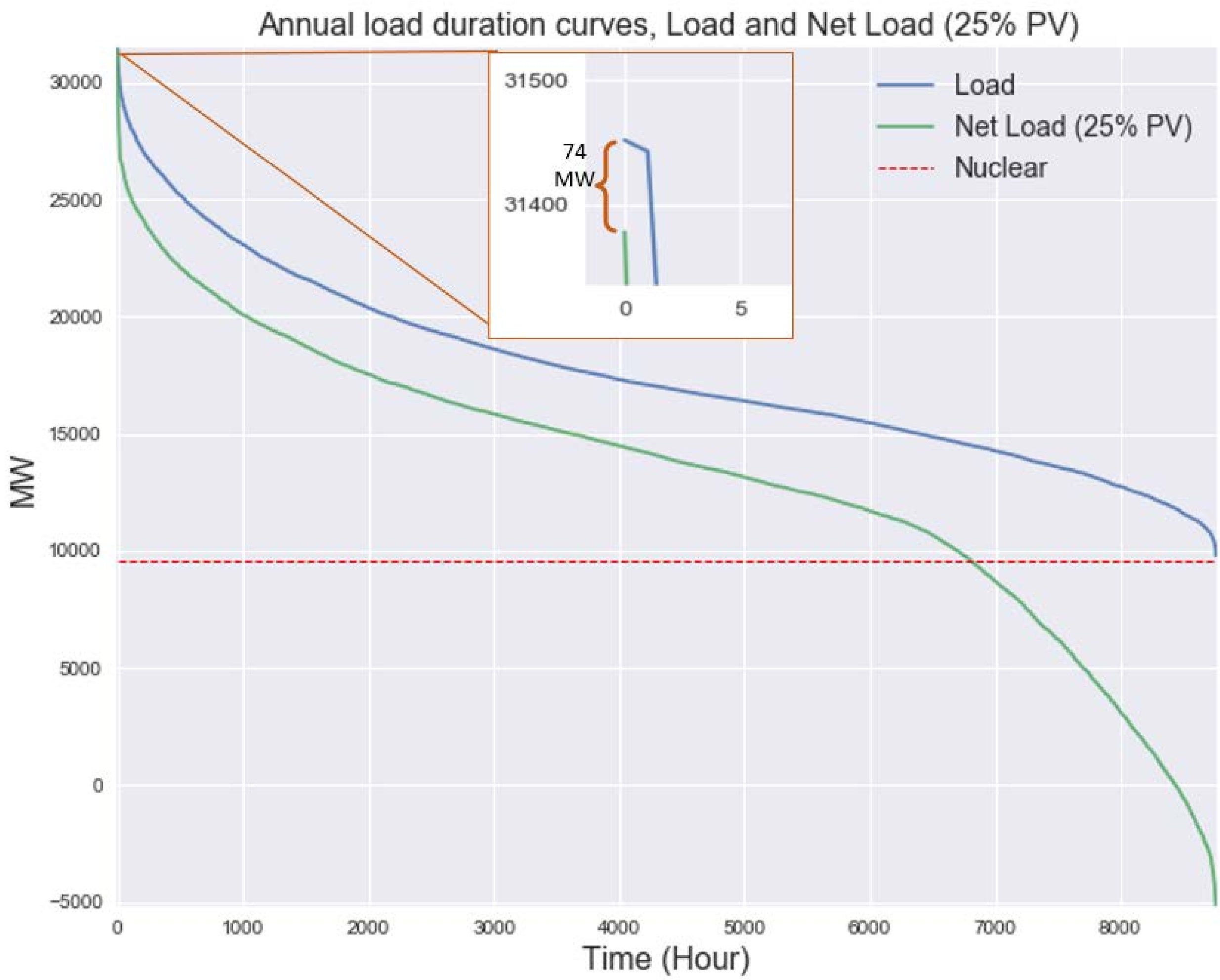

Figure 6. Annual load duration curves, load, and net load with 25% PV penetration

3.2 Scenario 8: Increased Proportion of Distributed Solar Energy

A portion of the PV generation, rooftop PV, is not curtailable by Duke Energy. Scenario 8 examines a relatively high solar penetration scenario of 25%, with the maximum expected proportion of the solar energy from rooftop solar. A model with such a large percentage of rooftop PV for the 25% solar power penetration by energy case will improve understanding of how the requirements for curtailment of additional PV might change with increased adoption of behind-the-meter solar PV. The PV time series provided by Duke includes separate profiles for rooftop and utility-scale solar energy, so the rooftop time series and utility time series are both scaled to forecast a higher proportion of rooftop solar generation. The scalars and equations used to calculate these profiles are shown in the appendix.

To capture an increase in rooftop PV by 2030, the maximum percentage of total solar PV that might be rooftop PV was assumed to be 18.91%. This percentage was obtained using the NREL-developed standard scenarios of the U.S. power sector tool,[3] which models 42 different scenarios to capture the impacts of fuel prices, demand growth, retirements, technology and financing costs, transmission and resource restrictions, and policy considerations on possible power system capacity expansion futures. The scenario predicting the largest ratio of rooftop solar to utility solar in the Carolinas in 2030 accounts for extended lifetimes of current generation facilities. This Extended Lifetimes Scenario assumes that coal power plant lifetimes are increased by 10 years, there are no retirements of underused coal power plants, and all nuclear power plants have 80-year lifetimes.

Using Scenario 5 (25% solar energy penetration) as a baseline, the effect of an increased proportion of distributed PV energy to utility PV energy is modeled. The PV time series corresponding to 25% solar penetration was scaled by the projected percentage of utility PV energy and the percentage of distributed PV energy to calculate the two projected time series.

The analysis assumes that rooftop PV cannot be curtailed, so an increase in the percentage of rooftop PV results in an increase in utility PV that must be curtailed. Comparing the results of Scenario 8 to Scenario 5 (25% PV penetration) shows that 33.2% of utility solar would be curtailed provided a maximum increase in the proportion of rooftop PV versus utility PV, whereas 28.5% of utility PV would be curtailed if this proportion remains unchanged from the assumptions used in scenarios 1–7.

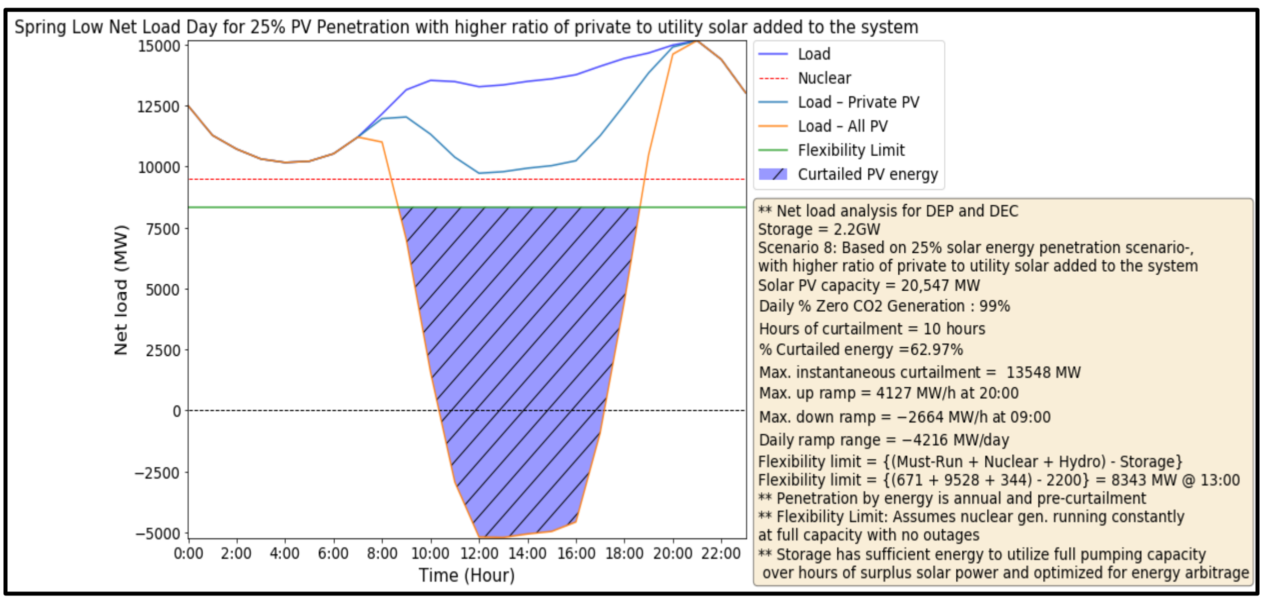

Figure 7. Minimum net load day with an increase in rooftop PV

As shown in Figure 7, even with a maximum increase in rooftop PV to 18.91%, the difference between load and solar as a result of rooftop generation never crosses the flexibility limit at 25% solar penetration.

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[3] https://openei.org/apps/reeds/#

3.3 Scenario 9: Additional Storage Capabilities

Scenario 9 captures the effect of an increase in storage with 25% solar energy penetration and demonstrates how this additional technology resource might reduce the curtailment required in a high solar penetration scenario. The hypothetical storage is charged entirely with surplus renewable energy sources and is assumed to discharge throughout the remainder of the day with a round-trip efficiency of 80%. The storage stores energy only during hours of surplus generation. In addition to the existing storage consisting of 2,200 MW of pumped storage hydropower, the additional storage modeled is 1,000 MW of 4-hour storage, 1,000 MW of 6-hour storage, and 2,000 MW of 8-hour storage. This is a total of 26,000 MWh of storage.

The storage is given a hierarchy of use preferences: for each modeled day, the 8-hour storage is used to capacity first, followed by the 6-hour storage, and finally the 4-hour storage is used. The generation flexibility limit line is then adjusted to incorporate the additional used storage, and curtailment is adjusted to fit the new flexibility limit.

The addition of such storage results in an improvement in the percentage of renewable energy curtailed from 26.9% (Scenario 5) to 14.8%. The greatest improvement is seen in the winter, during which time the curtailment decreases from 31.3% to 14%. The minimum net load day in the winter of Scenario 9 is shown in Figure 6, and that of Scenario 5 is shown in Figure 9.

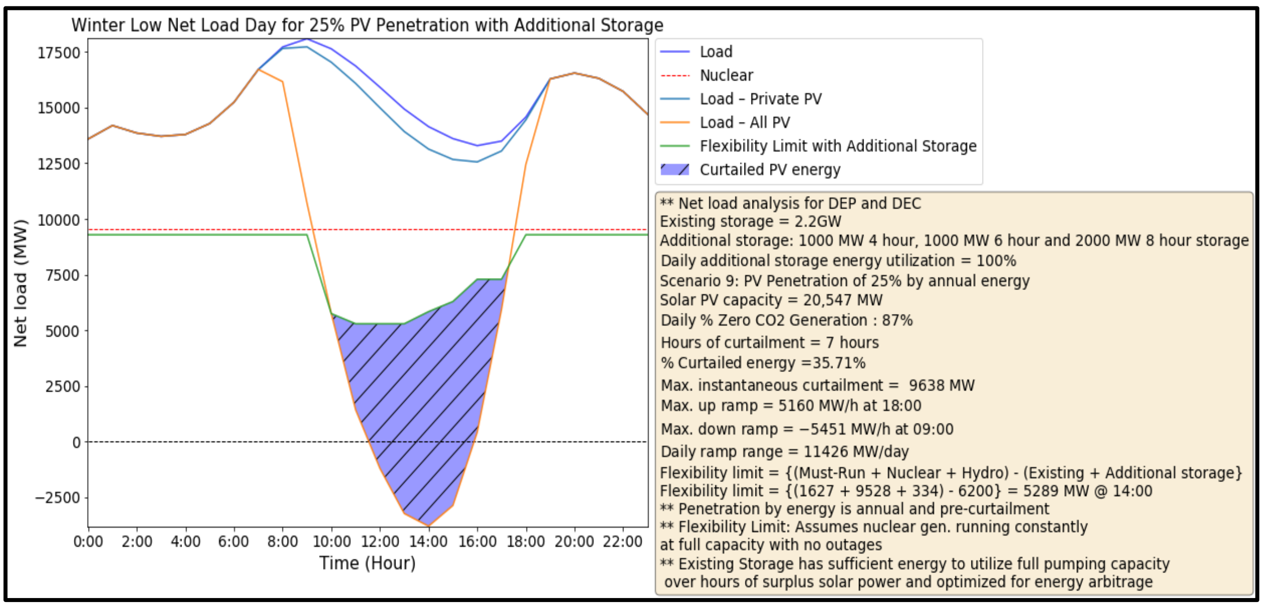


Figure 8. Minimum net load day in winter with additional storage

The additional storage modeled accounts for 7% of the load on this day. The annual contribution to this additional storage amounts to 3.7% of annual load.

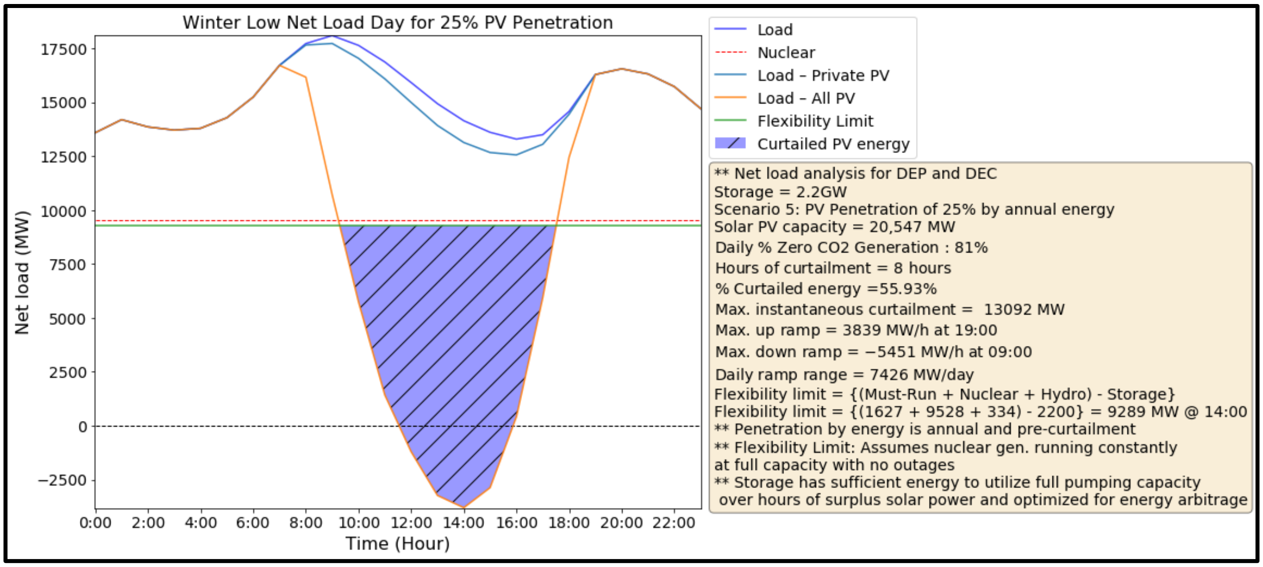


Figure 9. Minimum net load day in winter without additional storage

The smallest impact occurs in the summer, with an improvement from 11.8% curtailment to 2.3%. For this analysis, storage is assumed to be used exclusively for load-shifting. In reality, storage could also potentially provide ancillary services, such as regulation reserves, especially in the summer seasons, when the load-shifting requirement is minimal. Further, if transmission constraints were considered, the total contribution of storage to saving renewable energy curtailment could be higher.

In this model, energy storage devices are charging only during times of overgeneration. The additional storage modeled results in an annual average of 77% carbon-free energy, whereas the carbon-free percentage of Scenario 5 is 74%. The additional storage yields a greater percentage of the carbon-free energy resource than that of Scenario 7, the 35% solar energy penetration model (77%).

Further analysis should examine a unit commitment and economic dispatch model, which could help understand the most economical and effective storage solutions to meet the proposed extra flexibility here, including the potential to use controllable electric vehicle charging. Further, such detailed analysis would quantify the economic value and system stability benefits of the additional storage through such examples as additional capacity, enabling higher penetrations of low-cost solar power and providing ancillary services.

3.4 Scenario 10: Generation Retirement

The portion of energy from nuclear sources is unique in the Duke Energy Carolinas region, contributing to a large amount of carbon-free generation. For this analysis, the possibility of ramping down nuclear is excluded (see assumptions in Table 8). The flexibility of nuclear is limited, and therefore it impacts the amount of variable energy that must be curtailed, particularly at high penetrations of solar. As current nuclear generation facilities are retired, the generation flexibility limit could decrease, especially if the energy is replaced with flexible thermal sources, allowing for larger contributions from solar and wind energy resources. Scenario 10 looks at the required curtailment resulting from the retirement of 10% of the nuclear generation, again using 25% solar penetration. A new generation flexibility limit is calculated with the nuclear generation reduced to 90% to reflect the nuclear retirement. It is assumed that the generation is replaced with flexible thermal generation. The other components of the flexibility limit are the same as those used in scenarios 1–7, including inflexible hydropower units and must-run units, with additional flexibility provided by hydropower pumped storage.

This reduction in the nuclear generation of the system with 25% solar penetration reduces the necessary curtailment from 26.9% of total renewable energy to 22.2%. Despite greater quantities of carbon-free solar power contributing to load, however, the percentage of carbon-free energy is reduced from 74% to 70%, which is to be expected because nuclear energy is carbon-free and generates consistently throughout the day.

3.5 Scenario 11: Additional Wind Energy Penetration

Duke Energy will work toward the goal of carbon-free energy generation primarily by incorporating solar power because solar is a plentiful resource in the Carolinas regions (see Figure 1). As the penetration of solar power increases, however, the imbalance in the availability of solar during a day—with increased power during daylight hours and a complete lack of power otherwise—becomes more problematic. It is therefore beneficial to consider an additional renewable source that can generate at different times of the day, such as wind. Scenario 11 examines the incorporation of 5% of the annual load generated by wind energy in addition to 30% solar energy penetration. A map of the wind resource is shown in Figure 10.

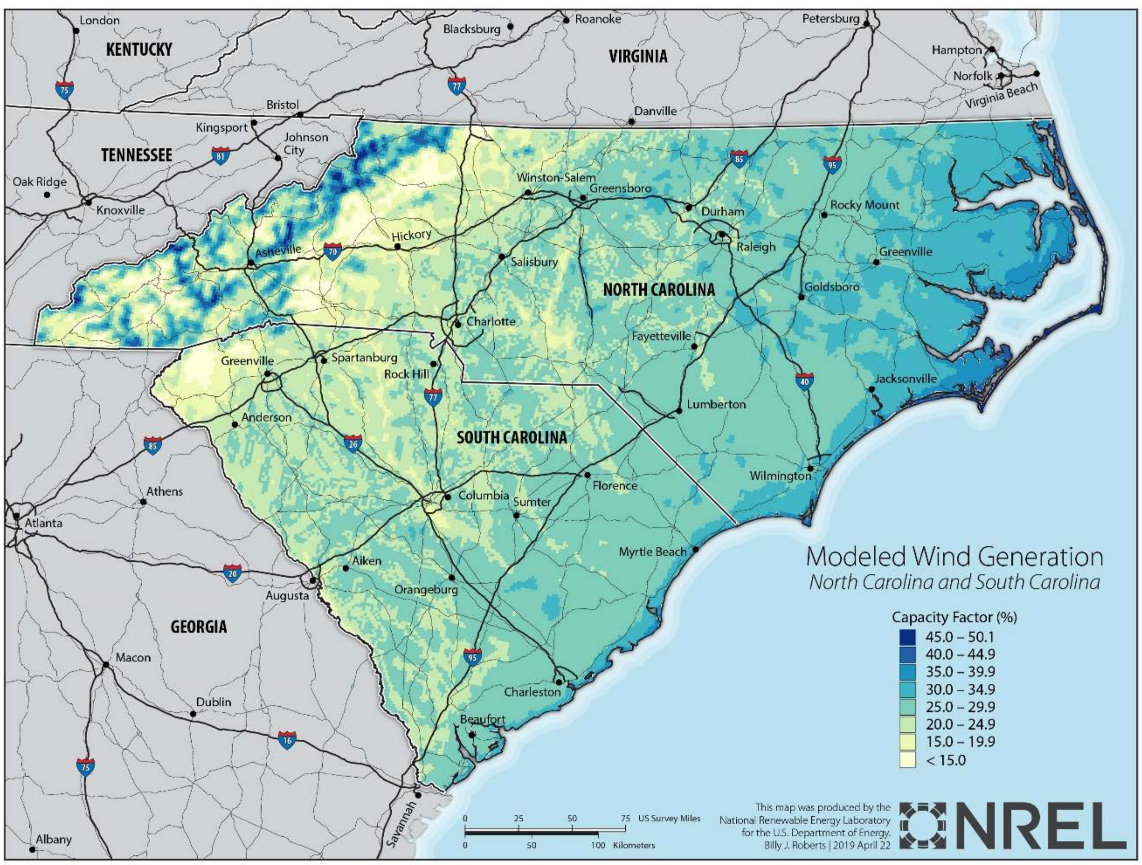


Figure 10. Wind capacity factors in the Carolinas

The wind time series is a simulated power output from NREL's Wind Integration National Dataset (WIND) Toolkit (Draxl, et al., 2015) based on the 2006 meteorological year. The 5% wind is calculated in a manner similar to the percentage of solar penetration levels (see Equation 5 in the appendix). The wind power profiles were taken from offshore profiles where the wind resource is high. Further, because the profiles are offshore, we assume that they are insignificantly correlated with load. The wind energy profile was scaled to match 5% of the load. The net load for this scenario is calculated as the remaining load after the contribution of the 5% wind and 30% solar penetration. The curtailment of wind and solar is proportional to the generation of wind and solar, respectively.

Building off of the 30% PV scenario (Scenario 6), there is an interesting comparison between adding another 5% of PV (to get 35% PV, Scenario 7)) or adding 5% wind (Scenario 11). Adding another 5% PV (to get to a total of 35% PV) leads to 83.2% of that additional 5% of solar being curtailed, while adding 5% wind (to 30% PV) requires only 26.3% of that additional wind to be curtailed. Looking at the total renewable curtailment of Scenario 11 compared to Scenario 7 (35% PV), adding wind improves the total renewable energy curtailment from 42% to 33.9%.

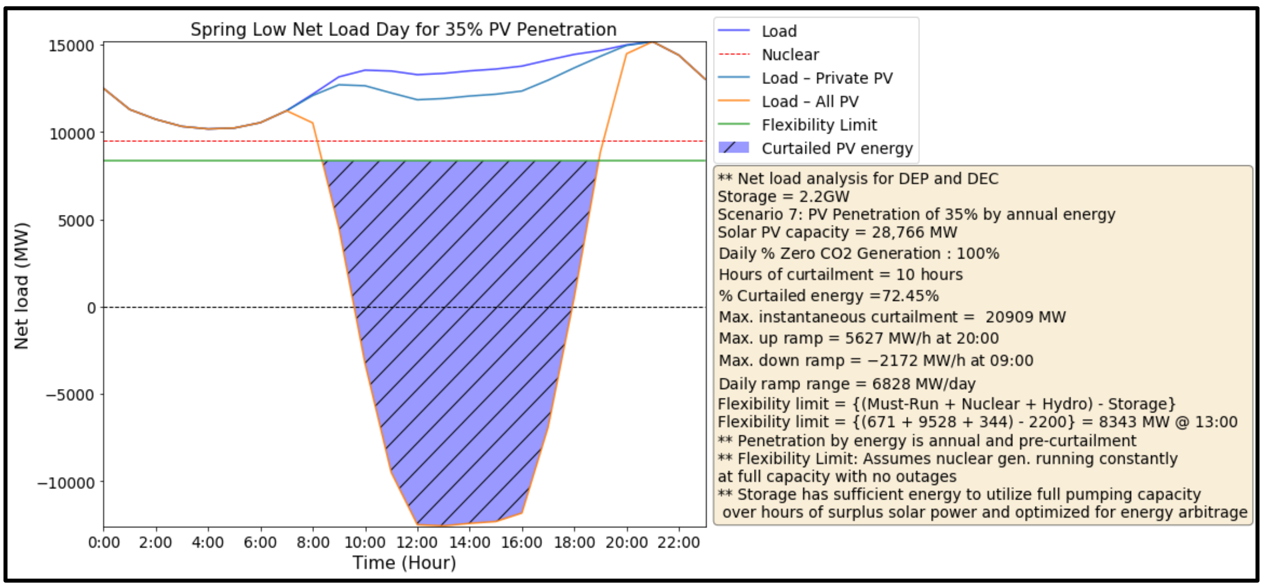


Figure 11. Minimum net load day in spring with 35% PV energy penetration

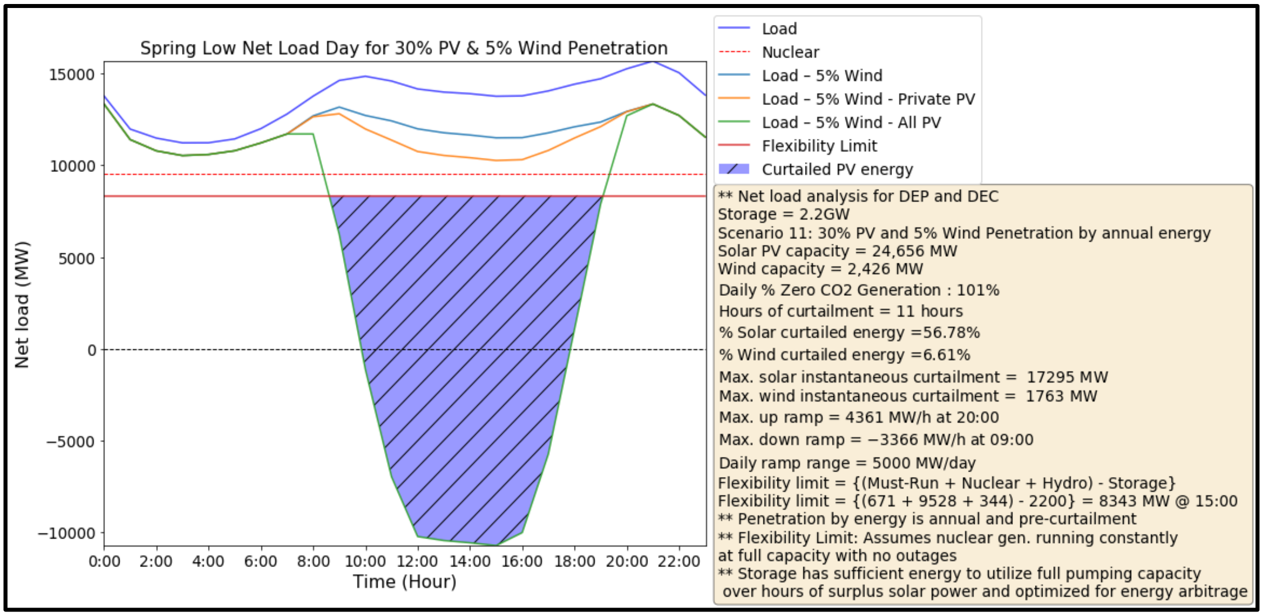


Figure 12. Minimum net load day in spring with 30% PV plus 5% wind energy penetration

And, since curtailment is reduced, that also means energy from carbon-free sources improves compared to Scenario 7. The average annual percentage of carbon-free energy in a 35% PV penetration scenario is 77%, whereas the percentage of carbon-free energy in a 30% PV, 5% wind penetration scenario is 79%, the greatest of all examined scenarios.

3.6 Scenario 12: DEC and DEP Modeled as Individual Balancing Authorities with a Limited Interconnection

All prior scenarios assume unlimited transfer capability in the Carolinas region. Scenario 12 separates DEC and DEP into separate regions with Duke Energy's existing transfer capability to observe the effect on the net load and curtailment given 5%, 10%, and 15% solar penetration levels by energy. The interconnection limit is provided by Duke Energy. It is directional and has different values for nighttime (0 h–7 h) and daytime (8 h–23 h). The separate loads are also provided by Duke Energy (all loads in prior analyses are the sum of these two loads). The generation totals of the must-run units for all prior scenarios are also calculated first for DEC and DEP and then summed, so the isolated values are used in Scenario 12. The generation flexibility limit is parsed between the two balancing authorities by separating must-run units, hydropower (see appendix for hydro assignments to DEC and DEP), nuclear (hourly generation values for DEC and DEP are provided by Duke Energy), and pumped storage (values also provided by Duke Energy). The equation for calculating each generation flexibility limit is the same as that used to calculate the generation flexibility limit for the total area (see Equation 1).

The interconnection is simulated to maintain the same difference between the net load and the flexibility limit of each balancing authority, provided that the transfer limit is not exceeded. This assumption of operating the interconnection to minimize the possibility of curtailment in high solar penetration scenarios was decided with Duke Energy. A production cost optimization would enable simulation of the interconnection and other transmission in a more realistic manner. If the difference between the net load of one balancing authority and its flexibility limit is less than that of the other, load is transferred until the difference is equal or the transfer limit in that direction, for that time of day, is met. This analysis uses 12 different equations to calculate 12 different scenarios resulting from variations in the calculations because of the sign and magnitude of the differences and the times of day (see appendix). The results of these 12 scenarios are then summed to produce a time series of load transfer, which is then used to calculate the net load of each balancing authority after the transfer. To calculate the transfer, load transfer to DEC is arbitrarily defined as negative, whereas load transfer to DEP is defined as positive. The resulting net loads of DEC and DEP are calculated with the transfer amount (see appendix).

The sum of the required solar power curtailment for both regions after the interconnection is modeled is greater than the curtailment that results when they are modeled as one balancing authority, or a region without transmission limitations. As shown in Table 7, an increase in transmission capabilities would support increased solar energy penetration. This benefit is minimal at low levels of PV penetration, but it increases at higher percentages.

Table 7. Comparison of Curtailment of the System Modeled With and Without Transmission Limitations

Percentage PV Penetration	Curtailment with Infinite Transmission (MWh)	Percentage Curtailment with Infinite Transmission	Curtailment with Limited Transmission (MWh)	Percentage Curtailment with Limited Transmission
5%	1,570	0.0%	1,361	0.0%
10%	172,444	1.1%	191,306	1.2%
15%	1,824,853	7.9%	1,928,162	8.3%

The minimization of curtailment with an increase in transmission capacity is illustrated when the minimum net load days to DEP and DEC, shown in Figure 13 and Figure 14, respectively, are compared to Figure 15. The first two figures of the separate balancing areas display 22% curtailed energy in DEP and 20% and DEC, whereas Figure 15 shows 20% curtailment on the minimum load day when DEP and DEC are modeled as one balancing area with unlimited transmission capabilities.

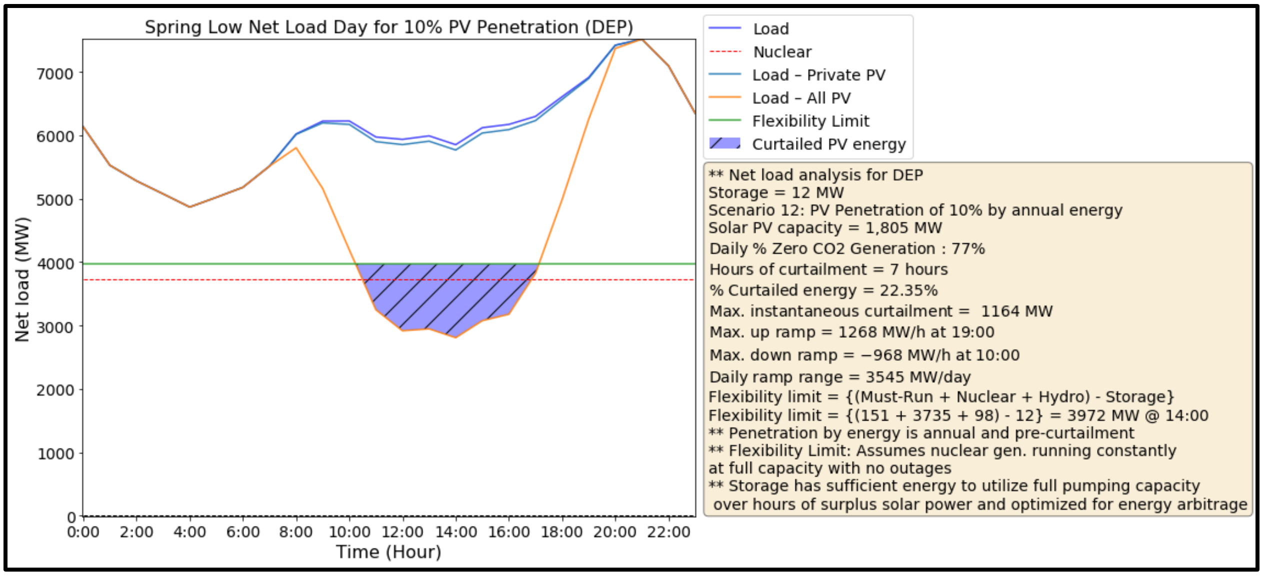


Figure 13. Low net load day for the DEP balancing authority with 10% PV penetration in spring

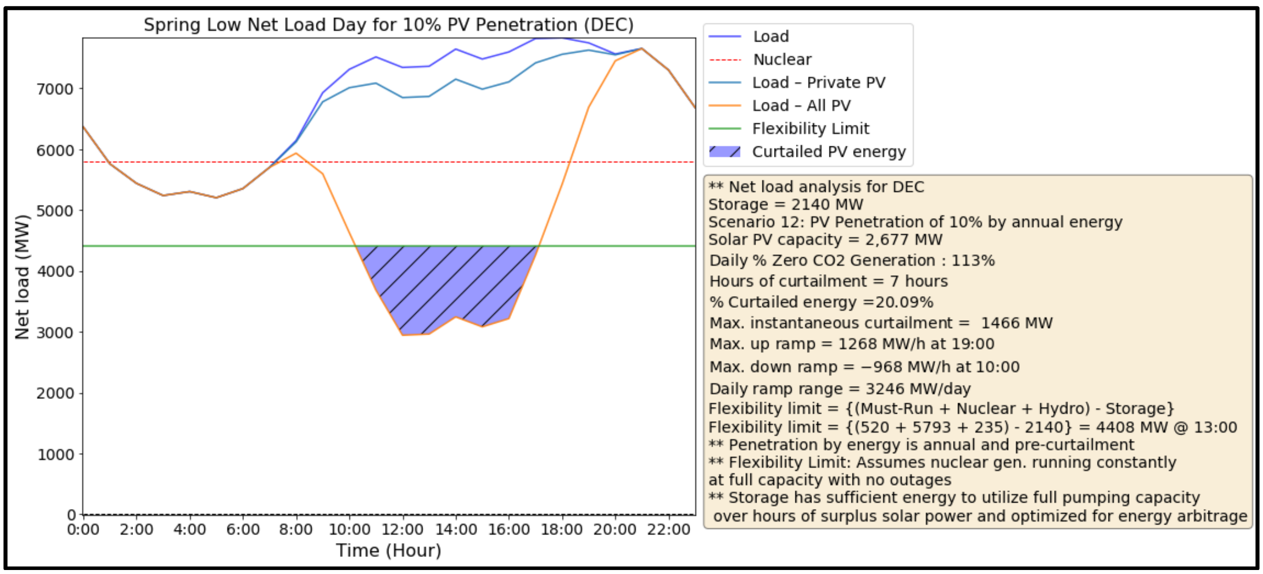


Figure 14. Low net load day for the DEC balancing authority with 10% PV penetration in spring

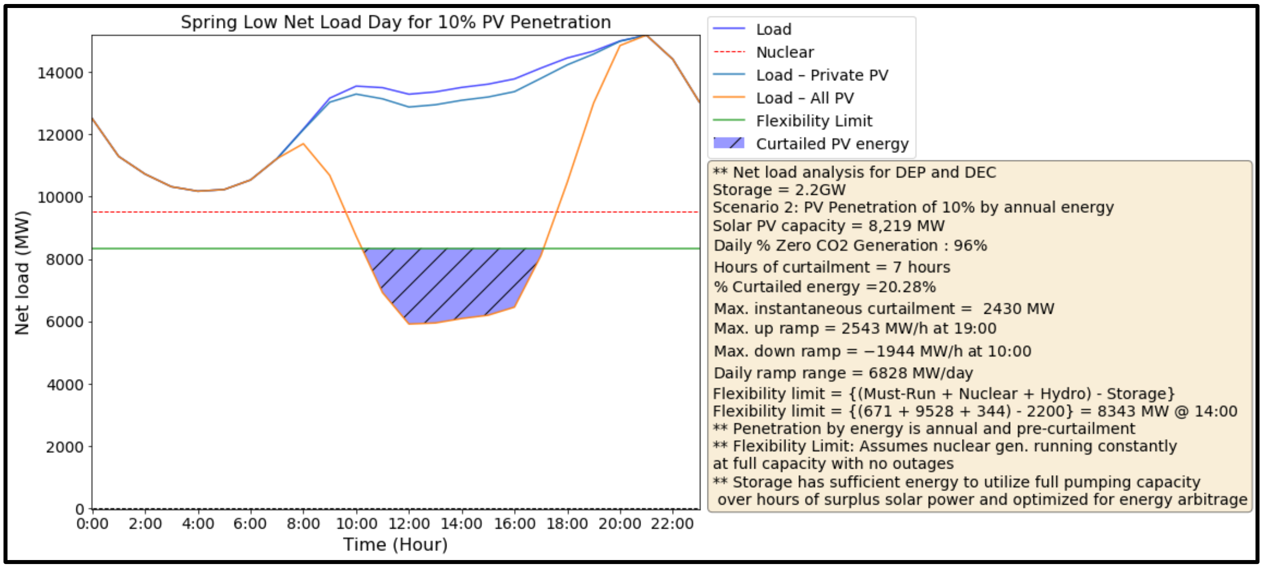


Figure 15. Low net load day with 10% PV penetration in spring when the Duke Carolinas territory is modeled with unlimited transmission capabilities

There is a difference in solar power output between the two balancing areas, such that DEP currently has roughly twice the solar capacity of DEC. The location of additional solar capacity will affect transmission constraints.

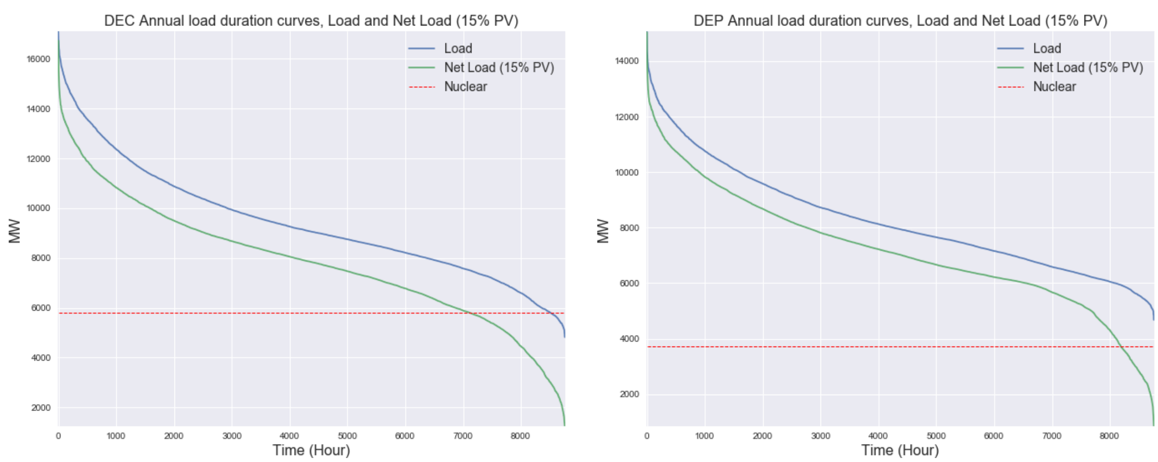


Figure 16. DEC and DEP load duration curves at 15% PV penetration

The load duration curves of the separate balancing authorities shown in Figure 16 show that at 15% PV energy penetration, there are 1,635 hours during which the net load dips below the nuclear generation limit in DEC and 577 hours in DEP, summing to 2,212 total hours. The load duration curve of the single balancing authority shown in Figure 17 shows an improvement, with 930 hours during which the net load is less than the nuclear limit.

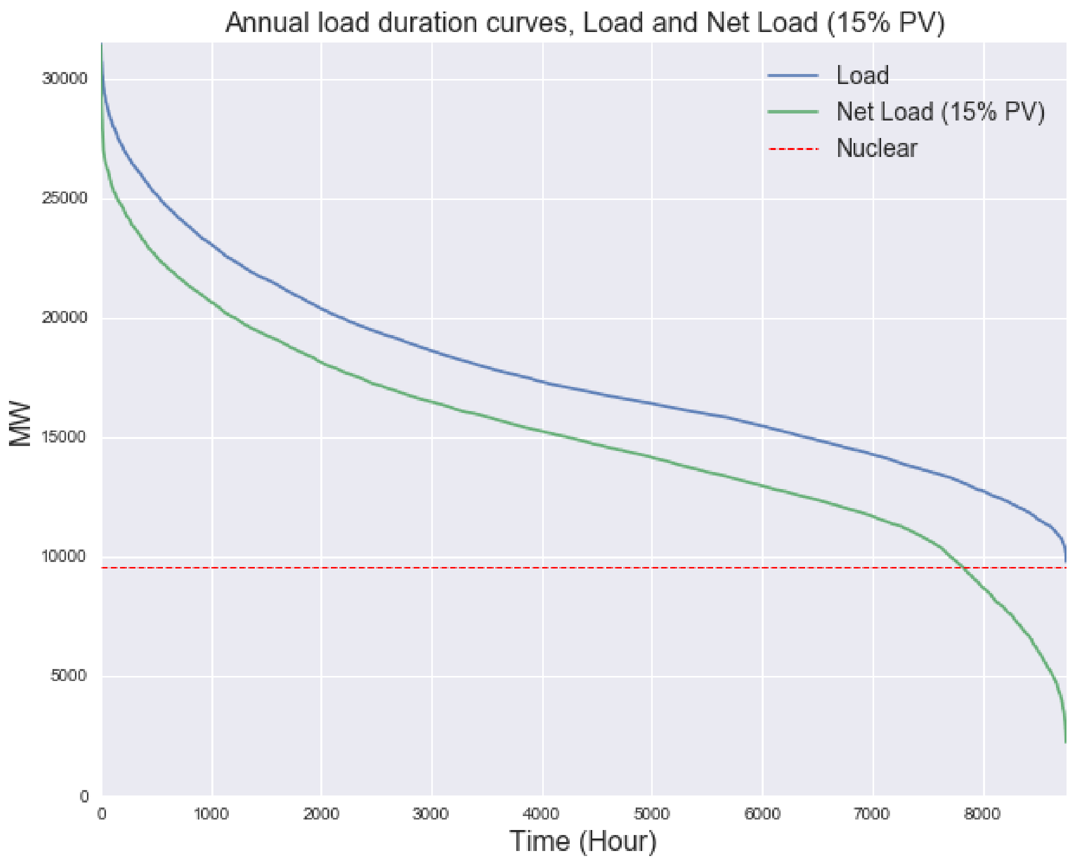


Figure 17. Load duration curve of the Duke Carolinas region modeled as one balancing area at 15% PV penetration

4 Geospatial Analysis

Several maps and an online application were created by the geospatial analysis team at NREL to visualize the solar and wind resources in the Duke Carolinas territory. The solar energy resource is characterized by global horizontal irradiance, and the wind energy resource is characterized by wind speed. Capacity factors were produced to visualize solar and wind generation, and exclusions[4] were made based on land categories and use type (see appendix for details). One such map is shown in Figure 18, which shows the capacity factors that are not in excluded areas of the region.

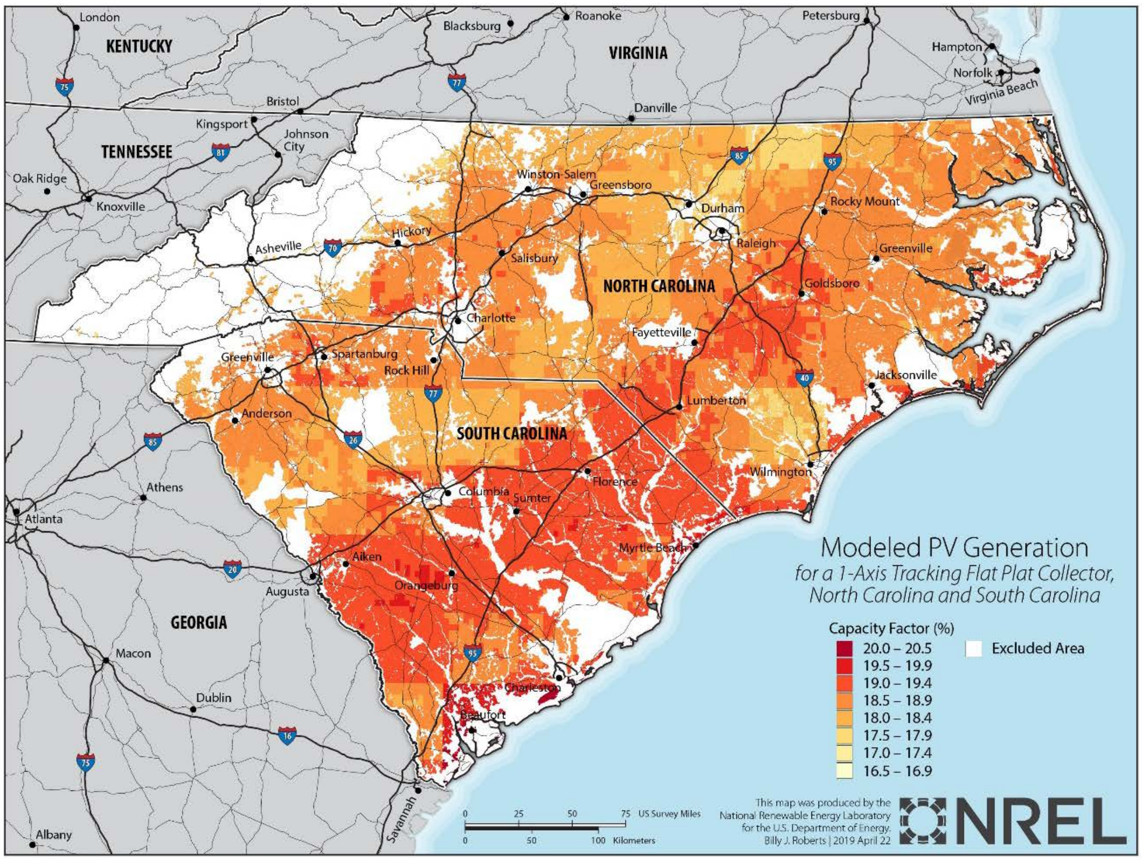


Figure 18. Multiyear mean capacity factors

The web application allows the user to examine these three layers of generation, energy resource, and exclusions for both wind and solar. The URL for the website is: https://maps.nrel.gov/duke. Note, please use Firefox, or Chrome for best results. The following layers are available on the web application:

- Solar exclusions: solar-categorized exclusions

[4] Exclusions include a slope >5%, urban areas, water and wetlands, parks and landmarks, national parks, and other environmentally or culturally sensitive areas.

- Solar generation: multiyear mean PV capacity factors using the listed PV system configurations
- Solar energy resource: Multiyear mean global horizontal irradiance
- Wind exclusions: wind-categorized exclusions. Both 100% exclusions and 50% exclusions are listed in this layer, depicting locations that are 100% excluded and other locations that are 50% excluded. The decision for 50% exclusions is based on assumptions used in Lopez (2012).
- Wind generation: multiyear mean wind capacity factors using the listed wind system configurations
- Wind energy resource: multiyear mean wind speed.

The web application allows the user to navigate geospatially and zoom in and out of areas of interest. Any combination of data layers can be displayed at once, including exclusions, generation, and energy resource for solar power and wind power. The legend tab enables the user to filter for ranges of data within each layer and control the transparency to maintain visual clarity, depending on the number of layers selected. This is shown in Figure 19. The query tab enables the user to intuitively retrieve the data being visualized by one of the four following options: the user can (1) select an individual point on the map, (2) query an entire region, (3) draw a custom shape of interest, and (4) filter based on specific attributes. The data behind this web app make it a useful tool to explore future development in the form of production cost models for the continued study of carbon-free resource integration.

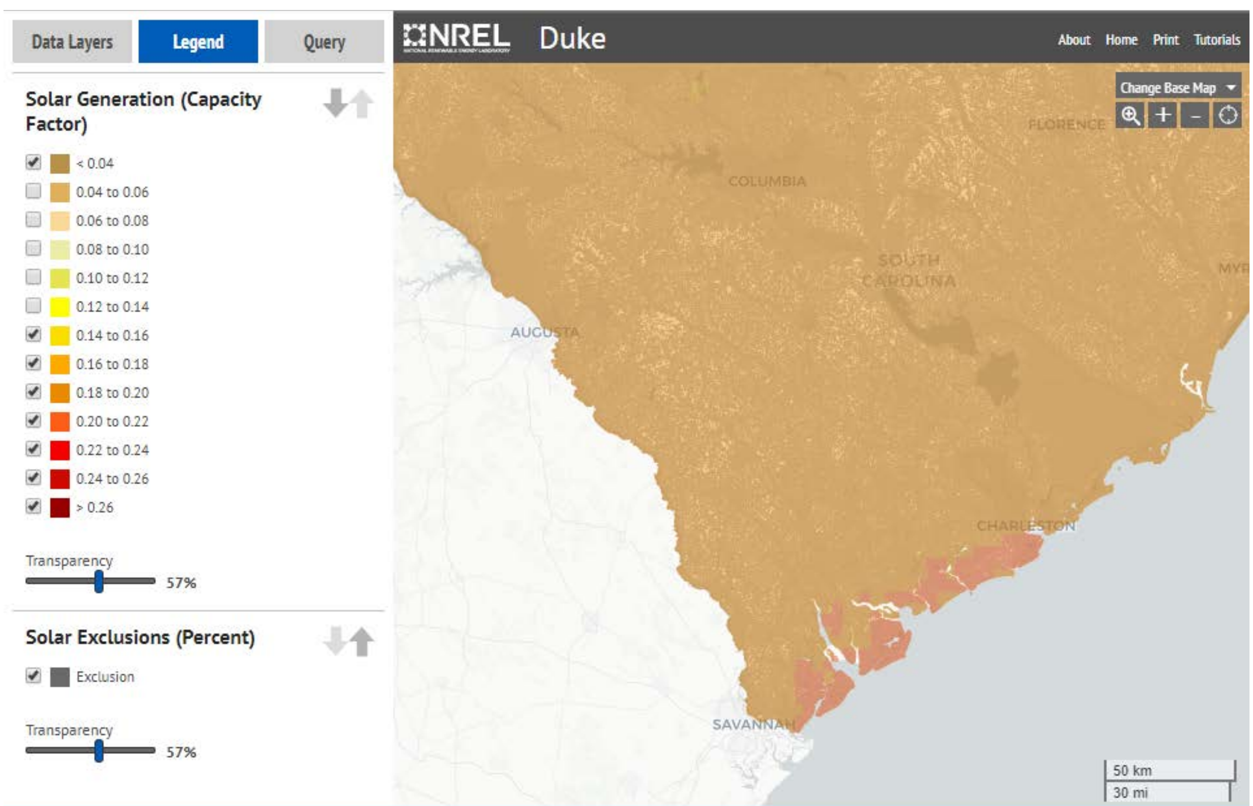


Figure 19. Screenshot of geospatial web application

5 Conclusion

Duke Energy endeavors to increase the proportion of load met by carbon-free generation. With high quantities of nuclear power currently providing carbon-free generation, and given their great solar irradiance resource, Duke Energy seeks to analyze the impact of integrating significant amounts of new solar power into its power system under a variety of penetration levels. This additional solar power will help reach carbon-free goals; however, with the high minimum generation level of existing nuclear power, this net load analysis concludes that curtailment of solar is likely to begin at 10% solar energy penetration. Thus, the net load analysis becomes an important initial step in realizing this goal while maintaining a reliable and economically viable grid.

This net load analysis shows:

- The greatest curtailment occurs during the spring, which is usually characterized by low load and an oversupply of solar PV power output during the middle of the day.
- The largest ramps remain in winter, through all solar PV penetrations, and for all seasons the ramps increase as solar PV penetration increases.
- The largest maximum instantaneous curtailment, percentage of curtailed energy, and duration of curtailment occur during the spring.
- The system experiences the largest percentage of daily carbon-free generation during the spring, which is the highest compared with other seasons.
- The net load analysis shows a significant reduction in the peak net load and a shift in the timing of the minimum and peak net load. This effect is most significant during the summer because of the time-coincident correlation between the demand and solar output. Thus, solar PV can significantly contribute capacity value to the system during the summer peak load; however, the shift in timing minimum and peak net loads can affect generator outage and maintenance scheduling, and this should be investigated further using unit commitment and economic dispatch models.
- Even at high solar penetration levels of 25%, with the highest anticipated level of rooftop solar, curtailment rights of utility solar is sufficient to avoid an imbalance of supply and load. This net load analysis shows that building wind power after high levels of solar power curtailment are reached and building storage are two solutions that can aid in increasing the share of carbon-free emission generation in Duke Energy's system.
- The analysis of scenarios 12 and 10 show that transmission constraints and nuclear retirement both work against the goal of meeting load with carbon-free generation.

A key constraint in accommodating additional variable generation penetration is the ramping ability of conventional generators, to change their output in response to the fluctuating renewables. For instance, during the spring minimum net load day shown in Figure 4, the traditional generator fleet is required to increase the output rapidly as the sun sets. For Duke Energy, because the nuclear fleet has a high minimum generation limit, increasing system flexibility with technologies that provide fast ramp rates and control over load should be examined to accommodate higher PV penetrations.

In addition, managing system flexibility requires serious operational adjustments coupled with a resource mix that can quickly respond to the balance of electricity demand and net load variability. The result of this study further reveals that exceeding 15% PV penetration could lead to serious integration issues, especially during the spring, which is characterized by low load and a possible frequent overgeneration scenario.

Further analysis with more advanced models—such as unit commitment and economic dispatch, capacity expansion planning, and dynamic analysis models—will be required to more fully assess system impacts with increasing variable generation penetration as well as flexibility opportunities for accommodating variable renewable energy sources with conventional generation.

References

Anthony Lopez, Billy Roberts, Donna Heimiller, Nate Blair, and Gian Porro. 2012. *U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis.* Golden : National Renewable Energy Laboratory, 2012.

Bebic, J. and Kroposki, B. 2008. *Power System Planning:Emerging Practices Suitable for Evaluating the Impact of High-Penetration Photovoltaics.* Golden, CO : National Renewable Energy Laboratory, NREL/SR-581-42297, 2008.

C. Draxl, B.-M. Hodge, and A. Clifton. 2015. *Overview and Meteorological Validation of the Wind Integration National Dataset Toolkit.* Golden : National Renewable Energy Laboratory, 2015.

Draxl, C., Hodge, B. and Clifton, A. 2015. *Overview and Meteorological Validation of the Wind Integration National Dataset Toolkit.* Golden : National Renewable Energy Laboratory, 2015.

Duke Energy. 2018. *Transforming the Future: Duke Energy 2018 Annual Report and Form 10-K.* Carolina : Duke Energy, 2018.

Ela, E., M. Milligan, A. Bloom, A. Botterud, A. Townsend, and T. Levin. 2014. *Evolution of Wholesale Electricity Market Design with Increasing Levels of Renewable Generation.* Golden, CO. : National Renewable Energy Laboratory, NREL/TP-5D00-61765, 2014.

GE Energy. 2010. *The Western Wind and Solar Integration Study Phase 1.* Schenectady, New York : GE Energy/No. AAM-8-77557-01, 2010.

Lew, Debra, Greg Brinkman, Eduardo Ibanez, Bri-Mathias Hodge, M. Hummon, A. Florita, and M. Heaney. 2013. *The Western Wind and Solar Integration Study Phase 2.* Golden, Colorado : National Renewable Energy Laboratory, NREL/TP-5500-55588, 2013.

Mai, T., et al. 2012. *Exploration of High-Penetration Renewable Electricity Futures. Vol. 1 of Renewable Electricity Futures Study.* Golden, CO : National Renewable Energy Laboratory, NREL/TP-6A20-52409-1, 2012.

Milligan, M., Frew, B., Zhou, E., and Arent, D. J. 2015. *Advancing System Flexibility for High Penetration Renewable.* Golden, CO. : National Renewable Energy Laboratory, NREL/TP-6A20-64864, 2015.

Sengupta, M., Xie, Y., Lopez, A., Habte, A., Maclaurin, G., & Shelby, J. (2018). The National Solar Radiation Data Base (NSRDB). *Renewable and Sustainable Energy Reviews*, *89*, 51–60. https://doi.org/10.1016/j.rser.2018.03.003

Appendix

A.1 Data Sources and Assumptions

In the context of data and files provided by Duke Energy, for both Duke Energy Progress and Duke Energy Corporation, the capacity factors from the "Third Party Non-Curtailable" sheet are multiplied by the rooftop solar capacity for 2019. The capacity factors from the "Utility Owned" tab are multiplied by the sum of the utility nameplate capacities. "Net Metered (Rooftop) Solar" is assumed to be rooftop solar PV, whereas "D-Tied Universal Solar" and "T-Tied Universal Solar" are assumed to be utility. Hydro schedules are from "Carolinas Hydro Schedules_Capacity and Energy_Confidential.xlsx."

Table 8. Assumptions and Definitions for the Net Load Analysis

Assumptions for Scenarios 1 - 7
Penetration by energy is annual and pre-curtailment.
Storage is 2.2 GW, which represents the existing pumped hydro storage capacity.
Storage has sufficient energy capacity to use full pumping capacity during hours of surplus solar power and is optimized for energy arbitrage.
The percentage of curtailed energy is estimated as a percentage of total PV output energy.
Must-run units are defined relative to the highest load within the last week because the majority of must-run units have a weeklong minimum up time.
Nuclear runs consistently at full capacity and has no outages.
No contingency reserve is added to the flexibility limit line.
Interconnections to neighboring regions are not considered

A.2 Equations for Scenario Analysis

The inflexibility generation limit line, Gen_{inflex}, is given as:

$$Gen_{inflex} = \left\{(\text{MustRun units} + \text{Nuclear capacity} + \text{Hydro units}) - \text{Storage}^{5}\right\} MW \quad (1)$$

Renewable energy curtailment is given as:

$$VG^{6}\, curtailment = \begin{cases} Gen_{inflex} - Net\ load, & Gen_{inflex} > Net\ load \\ 0, & Gen_{inflex} < Net\ load \end{cases} \quad (2)$$

Daily ratio of carbon-free generation is given as:

$$\sum_{n=1}^{24} \frac{(Nuclear_n + Hydro_n + 0.8 * Storage_n + VG\ precurtailment_n - VG\ curtailment_n)}{Total\ load_n} \quad (3)$$

Table 9. Scalars Used to Calculate PV Penetration

Scenario No.	Scalar
1	0.9642
2	1.9284
3	2.8926
4	3.8568
5	4.8210
6	5.7852
7	6.7494

The scalars to calculate the solar penetration required to meet the specified percentage of load were found with the following Equation:

$$\{(\text{Percent Penetration}) \cdot (AnnualLoad)/(AnnualPV)\} \quad (4)$$

[5] Storage represents the total pumped storage hydropower pumping capacity.
[6] *Variable generation* refers to solar and wind (where applicable) power plants.

The solar time-series was then multiplied by each scalar to produce the appropriate amount of annual solar to achieve the targeted penetration level for each Scenario. For example, to create the PV time-series for Scenario 1 with 5% solar penetration, the solar time-series was multiplied by 0.9642.

In Scenario 8 illustrates 25% solar energy penetration with 18.91% of solar due to rooftop solar generation. 18.91% of 25% of the load was calculated to find the amount of rooftop PV. A scalar to adjust the rooftop PV time-series was calculated similarly to the scalars used to calculate the time-series for Scenarios 1-7:

$$\{(\text{Percent Rooftop}) \cdot (25\% of AnnualLoad)/(AnnualRooftopPV)\} \tag{5}$$

The calculation for the remaining 89.09% of solar from utility is analogous:

$$\{(\text{Percent Utility}) \cdot (25\% of AnnualLoad)/(AnnualUtilityPV)\} \tag{6}$$

Additional storage in Scenario 9 is calculated according to the following rules:

If the curtailment is required, eight-hour storage is used to store as much of the curtailment required as possible, limited to 2000 MW inside of an hour. The maximum eight-hour storage over a 14-hour window is 2000 MW * 8 hours =16000 MWh, so any renewable generation beyond that must be stored by the six- or four-hour storage units. Next, the six-hour storage is used to store up to 1000 MW of excess energy in an hour, with the maximum storage over a 14-hour window of 6000 MWh. Finally, the four-hour storage is used to store up to 1000 MW of excess energy in an hour, with the maximum storage over a 14-hour window of 4000 MWh.

In Scenario 11, the wind time series is scaled by 0.6680 to match 5% of the total load, and is found with:

$$\{(0.05) \cdot (AnnualLoad)/(AnnualWind)\} \tag{7}$$

The wind time-series was then multiplied by 0.6680 to produce an annual generation equal to 5% of the load.

For Scenario 12, the location of hydropower units in each of the modelled BAs is as follows:

Table 10. Hydropower units corresponding to each region

DEC	DEP
Cowans Ford Hydro Keowee Hydro Lower Catawba Hydro Misc ROR Hydro Nantahala Hydro Upper Catawba Hydro	Blewett Hydro Marshall Hydro Tillery Hydro Walters Hydro

The Equations for calculating load transfer are listed in Table 11. "DEC" refers to the net load of DEC minus the flexibility limit of DEC, while "DEP" refers to the net load of DEP minus the flexibility limit of DEP.

Table 11. Equations to Calculate Load Transfer from DEC to DEP

<table>
<tr><th colspan="3">(Net Load –Flexibility Limit)</th><th rowspan="2">Time of Day</th><th rowspan="2">Equation</th></tr>
<tr><th>DEC</th><th>DEP</th><th>Comparison</th></tr>
<tr><td><0</td><td><0</td><td>|DEC|<|DEP|</td><td>8:00-23:00</td><td>If(|DEC-DEP|<1820):
If($DEP_{NetLoad}$ +|DEC-DEP|> $DEC_{NetLoad}$ -|DEC-DEP|):
Average(DEC,DEP)-Min(DEC,DEP)
Else: |DEC-DEP|
Else If($DEP_{NetLoad}$+1820> $DEC_{NetLoad}$-1820):
Average (DEC,DEP)-Min(DEC,DEP)
Else: 1820</td></tr>
<tr><td><0</td><td><0</td><td>|DEC|>|DEP|</td><td>8:00-23:00</td><td>If(|DEC-DEP|<1050):
If($DEC_{NetLoad}$ +|DEC-DEP|> $DEP_{NetLoad}$ -|DEC-DEP|):
-(Average(DEC,DEP)-Min(DEC,DEP))
Else: -|DEC-DEP|
Else If($DEC_{NetLoad}$+1050> $DEP_{NetLoad}$-1050):
-(Average (DEC,DEP)-Min(DEC,DEP))
Else: -1050</td></tr>
<tr><td><0</td><td>>0</td><td></td><td>8:00-23:00</td><td>If(|DEC-DEP|>1050):
If($DEC_{NetLoad}$+1050> $DEP_{NetLoad}$-1050):
-(Average(DEC,DEP)-Min(DEC,DEP))
Else: -1050
Else If($DEC_{NetLoad}$ +|DEC-DEP|> $DEP_{NetLoad}$ -|DEC-DEP|):
-(Average (DEC,DEP)-Min(DEC,DEP))
Else: -|DEC-DEP|</td></tr>
<tr><td>>0</td><td><0</td><td></td><td>8:00-23:00</td><td>If(|DEC-DEP|>1820):
If($DEC_{NetLoad}$+1820> $DEP_{NetLoad}$-18200):
Average(DEC,DEP)-Min(DEC,DEP)
Else: 1820
Else If($DEC_{NetLoad}$ +|DEC-DEP|> $DEP_{NetLoad}$ -|DEC-DEP|):
-(Average (DEC,DEP)-Min(DEC,DEP))
Else: |DEC-DEP|</td></tr>
<tr><td>>0</td><td>>0</td><td>|DEC|<|DEP|</td><td>8:00-23:00</td><td>If(|DEC-DEP|<1820):
If($DEP_{NetLoad}$ +|DEC-DEP|> $DEC_{NetLoad}$ -|DEC-DEP|):
-(Average(DEC,DEP)-Min(DEC,DEP))
Else:- |DEC-DEP|
Else If($DEP_{NetLoad}$+1820> $DEC_{NetLoad}$-1820):
-(Average (DEC,DEP)-Min(DEC,DEP))</td></tr>
</table>

<table>
<tr><th colspan="3">(Net Load –Flexibility Limit)</th><th rowspan="2">Time of Day</th><th rowspan="2">Equation</th></tr>
<tr><th>DEC</th><th>DEP</th><th>Comparison</th></tr>
<tr><td></td><td></td><td></td><td></td><td>Else: -1820</td></tr>
<tr><td>>0</td><td>>0</td><td>|DEC|>|DEP|</td><td>8:00-23:00</td><td>If(|DEC-DEP|<1050):
If($DEC_{NetLoad}$ +|DEC-DEP|> $DEP_{NetLoad}$ -|DEC-DEP|):
(Average(DEC,DEP)-Min(DEC,DEP))
Else: |DEC-DEP|
Else If($DEC_{NetLoad}$+1050> $DEP_{NetLoad}$-1050):
(Average (DEC,DEP)-Min(DEC,DEP))
Else: 1050</td></tr>
<tr><td><0</td><td><0</td><td>|DEC|<|DEP|</td><td>0:00-7:00</td><td>If(|DEC`-DEP|<2933):
If($DEP_{NetLoad}$ +|DEC-DEP|> $DEC_{NetLoad}$ -|DEC-DEP|):
Average(DEC,DEP)-Min(DEC,DEP)
Else: |DEC-DEP|
Else If($DEP_{NetLoad}$+2933> $DEC_{NetLoad}$-2933):
Average (DEC,DEP)-Min(DEC,DEP)
Else: 2933</td></tr>
<tr><td><0</td><td><0</td><td>|DEC|>|DEP|</td><td>0:00-7:00</td><td>If(|DEC-DEP|<1036):
If($DEC_{NetLoad}$ +|DEC-DEP|> $DEP_{NetLoad}$ -|DEC-DEP|):
-(Average(DEC,DEP)-Min(DEC,DEP))
Else: -|DEC-DEP|
Else If($DEC_{NetLoad}$+1036> $DEP_{NetLoad}$-1036):
-(Average (DEC,DEP)-Min(DEC,DEP))
Else: -1036</td></tr>
<tr><td><0</td><td>>0</td><td></td><td>0:00-7:00</td><td>If(|DEC-DEP|>1036):
If($DEC_{NetLoad}$+1036> $DEP_{NetLoad}$-1036):
-(Average(DEC,DEP)-Min(DEC,DEP))
Else: -1036
Else If($DEC_{NetLoad}$ +|DEC-DEP|> $DEP_{NetLoad}$ -|DEC-DEP|):
-(Average (DEC,DEP)-Min(DEC,DEP))
Else: -|DEC-DEP|</td></tr>
<tr><td>>0</td><td><0</td><td></td><td>0:00-7:00</td><td>If(|DEC-DEP|>2933):
If($DEC_{NetLoad}$+2933> $DEP_{NetLoad}$-2933):
Average(DEC,DEP)-Min(DEC,DEP)
Else: 2933
Else If($DEC_{NetLoad}$ +|DEC-DEP|> $DEP_{NetLoad}$ -|DEC-DEP|):
-(Average (DEC,DEP)-Min(DEC,DEP))
Else: |DEC-DEP|</td></tr>
<tr><td>>0</td><td>>0</td><td>|DEC|<|DEP|</td><td>0:00-7:00</td><td>If(|DEC-DEP|<2933):
If($DEP_{NetLoad}$ +|DEC-DEP|> $DEC_{NetLoad}$ -|DEC-DEP|):
-(Average(DEC,DEP)-Min(DEC,DEP))</td></tr>
</table>

(Net Load –Flexibility Limit)			Time of Day	Equation
DEC	DEP	Comparison		
				Else:- |DEC-DEP| *Else If*(DEP$_{NetLoad}$+2933> DEC$_{NetLoad}$-1820): -(*Average* (DEC,DEP)-*Min*(DEC,DEP)) *Else:* -2933
>0	>0	|DEC|>|DEP|	0:00-7:00	*If*(|DEC-DEP|<1036): *If*(DEC$_{NetLoad}$ +|DEC-DEP|> DEP$_{NetLoad}$ -|DEC-DEP|): (*Average*(DEC,DEP)-*Min*(DEC,DEP)) *Else:* |DEC-DEP| *Else If*(DEC$_{NetLoad}$+1036> DEP$_{NetLoad}$-1036): (*Average* (DEC,DEP)-*Min*(DEC,DEP)) *Else:* 1036

Equations 8 and 9 show how the net load of each BA is changed by the interconnection after the load transfer is calculated.

$$\{(\text{DEC Net Load Before}) - (\text{Load Transfer}) = (\text{DEC Net Load After})\} \quad (8)$$

$$\{(\text{DEP Net Load Before}) + (\text{Load Transfer}) = (\text{DEP Net Load After})\} \quad (9)$$

A.3 Seasonal Metrics

The dates of each season are defined in Table 12.

Table 12. Season definitions

	Start Date	End Date
Spring	3/1/2019	5/31/2019
Summer	6/1/2019	8/31/2019
Fall	9/1/2019	11/30/2019
Winter	12/1/2019	2/28/2019

Table 13. Maximum instantaneous curtailment of each season (MW)

Scenario	Spring	Summer	Fall	Winter
1	0	0	0	530
2	2430	0	2752	3233
3	6113	2913	5897	6618
4	9801	6106	9183	10003
5	13504	9299	12560	13389
6	17207	12542	16023	16774
7	20909	16143	19689	20271
8	13548	9248	12568	13452
9	11073	5769	9185	9842
10	12551	8346	11607	12436
11	17486	13326	16273	17084
12 – DEC 5%	0	0	0	246
12 – DEC 10%	1466	252	1390	1886
12 – DEC 15%	3116	1878	2958	3418
12 – DEP 5%	0	0	0	246
12 – DEP 10%	1234	117	1390	1600
12 – DEP 15%	3116	1630	2958	3418

Table 14. Maximum up ramp of each season (MW/h)

Scenario	Spring	Summer	Fall	Winter
1	2927	2355	3839	4039
2	3244	2272	3839	4384
3	4539	3294	4412	5341
4	5443	4316	5474	6609
5	5964	5338	5960	7252

Scenario	Spring	Summer	Fall	Winter
6	6277	6360	6813	8362
7	6583	6360	7508	9472
8	5924	5408	5986	7278
9	6873	5338	6717	7876
10	6564	5338	6489	7481
11	6179	5943	6757	8401
12 – DEC 5%	1724	1369	1900	2594
12 – DEC 10%	1722	1539	2093	2594
12 – DEC 15%	2306	2242	2988	3030
12 – DEP 5%	1502	1130	1941	2003
12 – DEP 10%	1629	1754	1941	2309
12 – DEP 15%	2266	2385	2102	3068

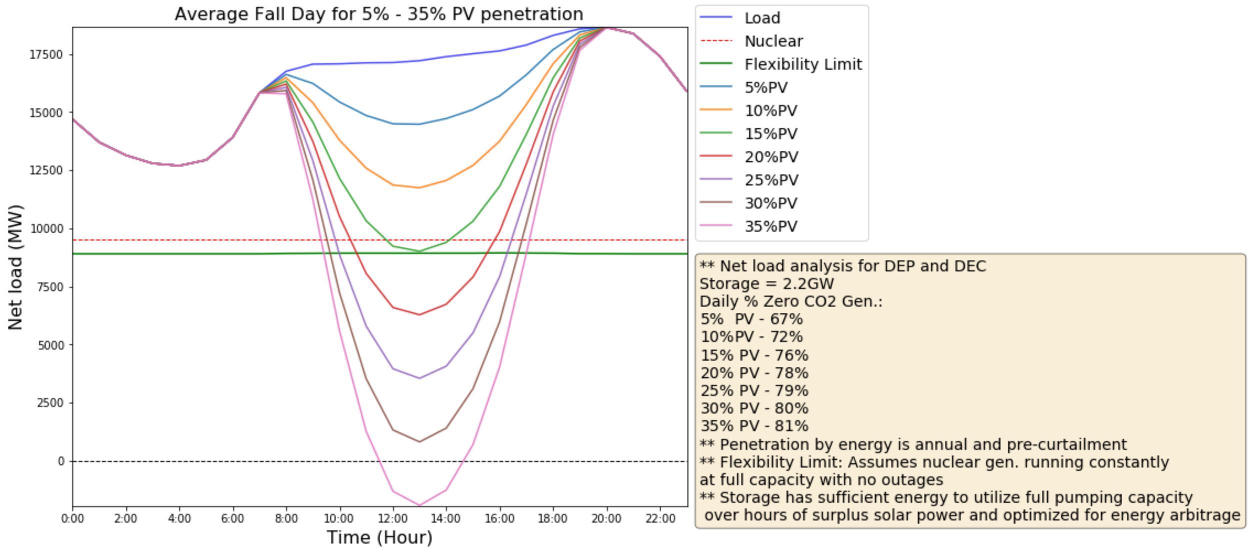
Table 15. Maximum down ramp of each season (MW/h)

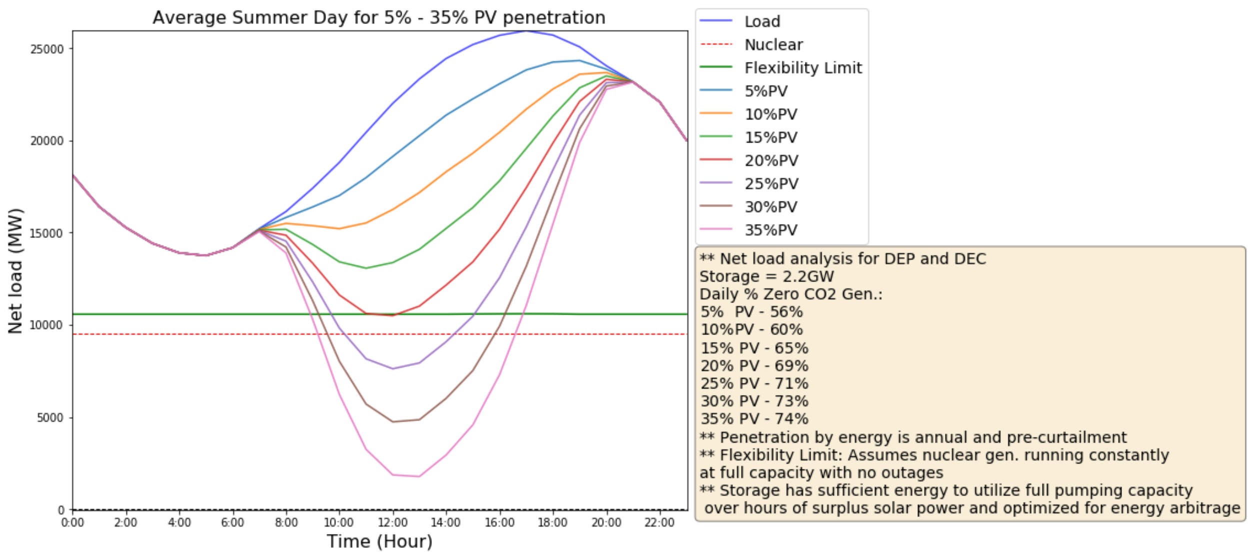
Scenario	Spring	Summer	Fall	Winter
1	-3080	-4090	-2830	-5873
2	-3406	-4090	-3403	-5873
3	-4712	-4090	-4354	-5873
4	-6069	-4090	-5658	-6699
5	-7427	-4090	-6964	-7894
6	-8784	-4406	-8270	-9090
7	-9869	-4482	-9577	-10286
8	-7419	-4090	-6951	-7906
9	-7427	-4090	-6964	-7894
10	-7427	-4090	-6964	-7894
11	-8673	-4461	-8427	-9555
12 – DEC 5%	-2047	-2313	-1480	-3122
12 – DEC 10%	-2047	-2313	-1865	-3122
12 – DEC 15%	-2413	-2313	-2621	-3320
12 – DEP 5%	-1390	-1874	-1660	-2750
12 – DEP 10%	-1707	-1874	-1714	-2750
12 – DEP 15%	-2349	-1874	-2519	-2750

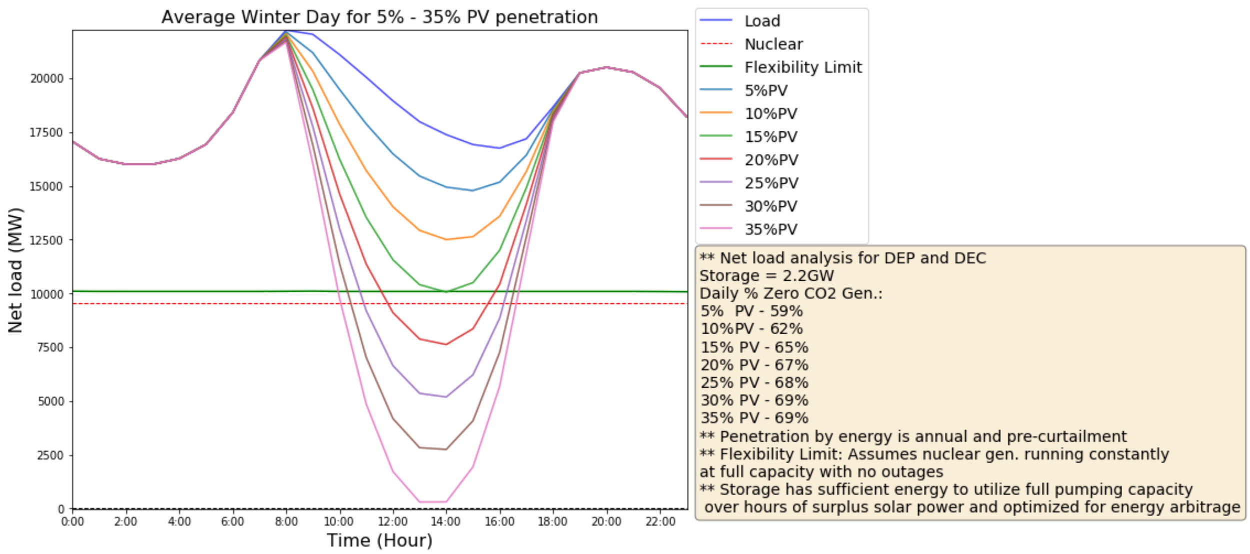
A.4 Additional Figures

Scenarios 1-7

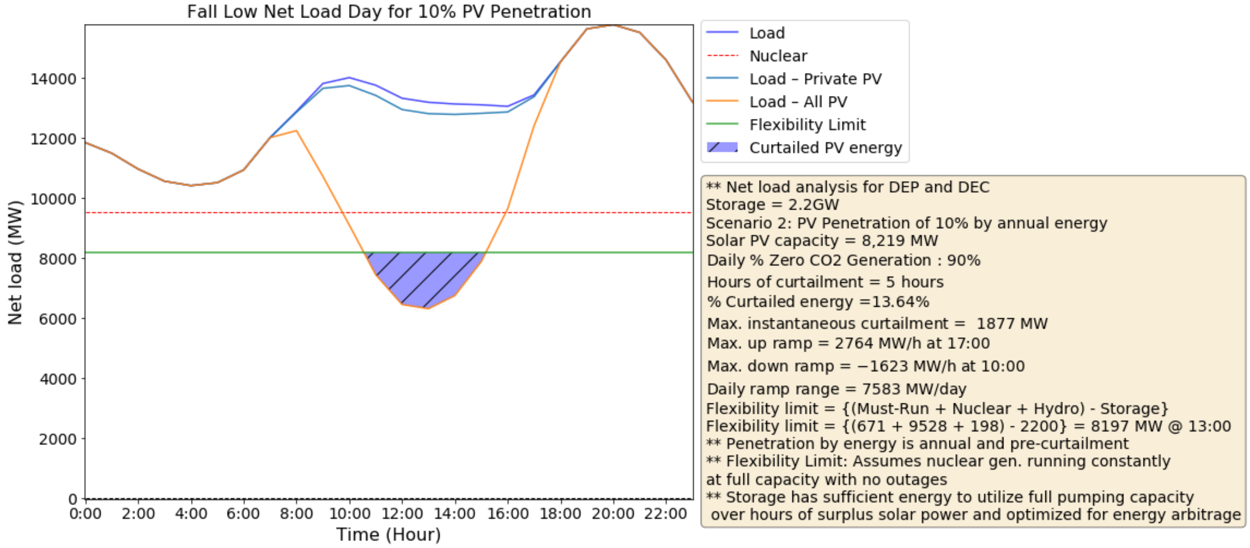
Seasonal Average for 5%-35% PV Penetration

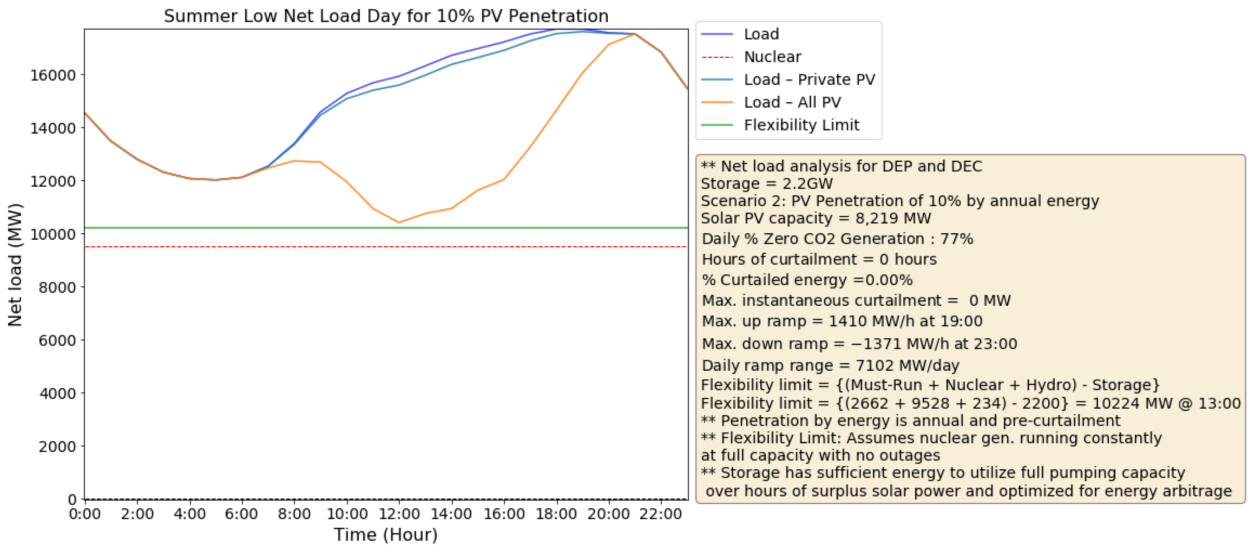


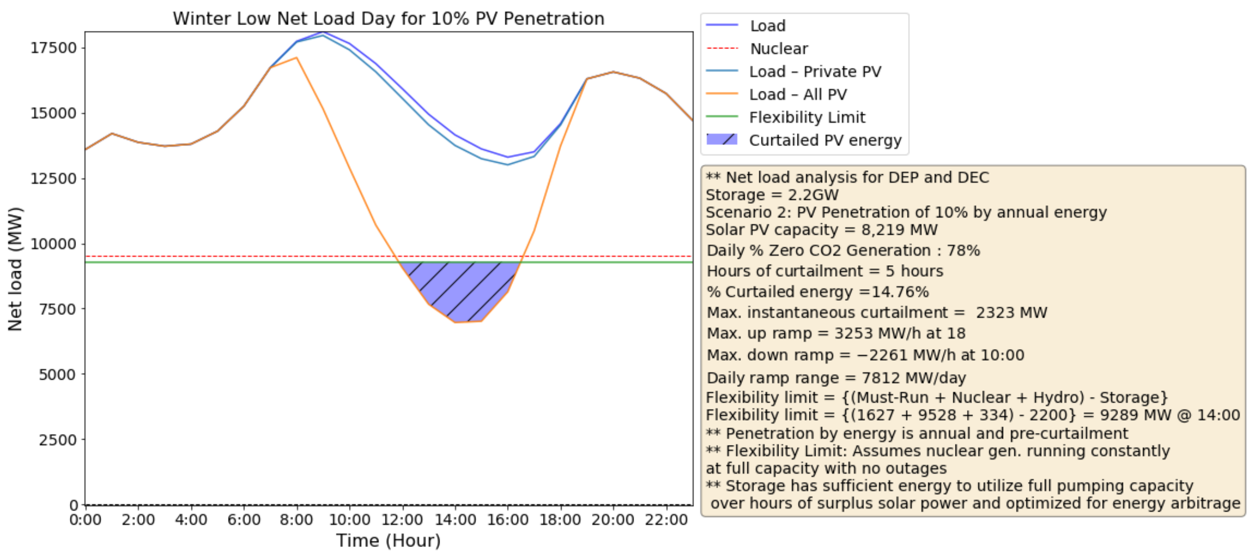



Average Winter Day for 5% - 35% PV penetration
Net load (MW)
Time (Hour)
0
2500
5000
7500
10000
12500
15000
17500
20000
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Load
Nuclear
Flexibility Limit
5%PV
10%PV
15%PV
20%PV
25%PV
30%PV
35%PV
** Net load analysis for DEP and DEC
Storage = 2.2GW
Daily % Zero CO2 Gen.:
5% PV - 59%
10%PV - 62%
15% PV - 65%
20% PV - 67%
25% PV - 68%
30% PV - 69%
35% PV - 69%
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

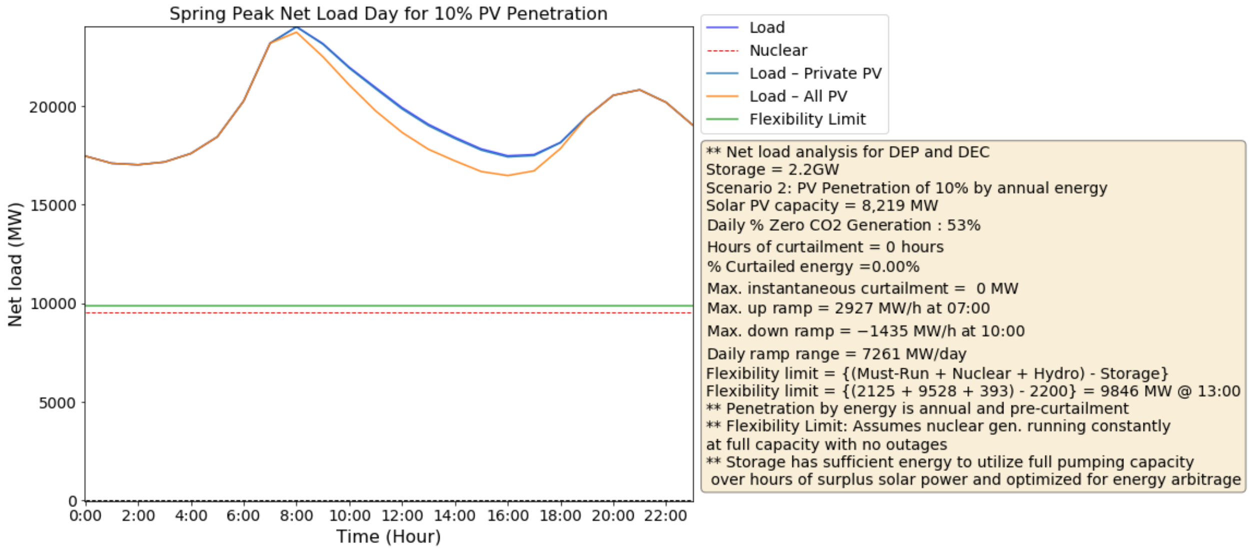
Seasonal Low Net Load Days: 10% PV Penetration

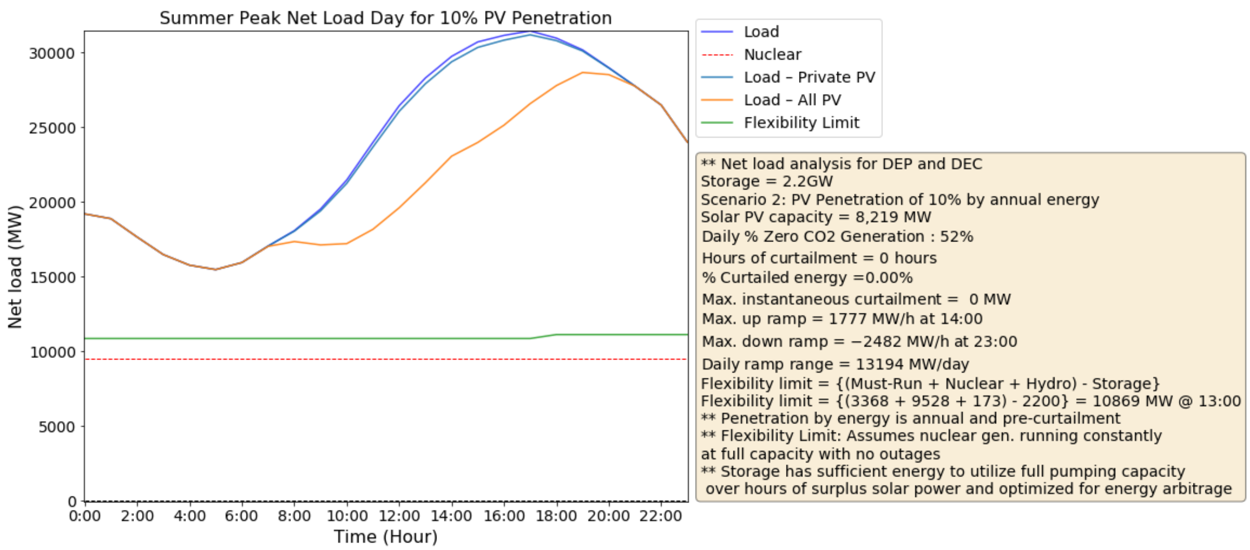


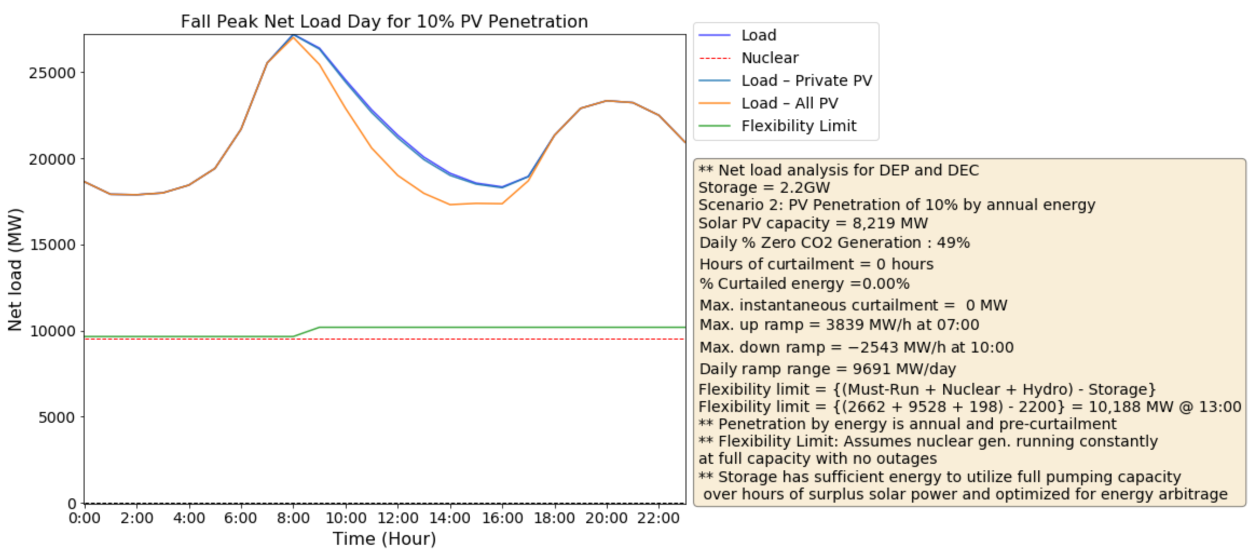


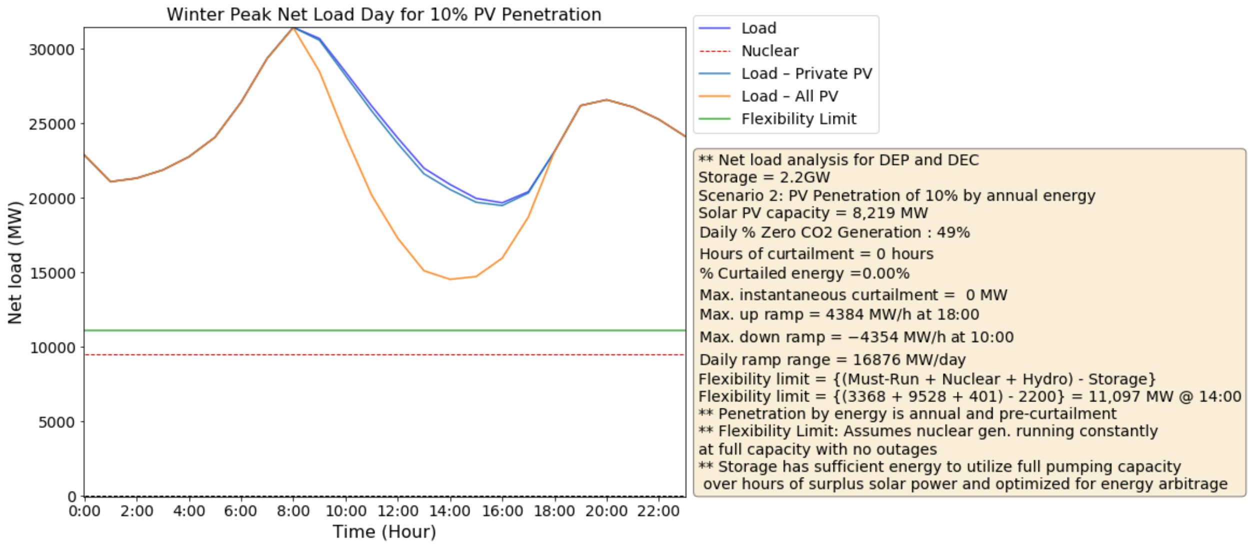


Seasonal Peak Net Load Days: 10% PV Penetration

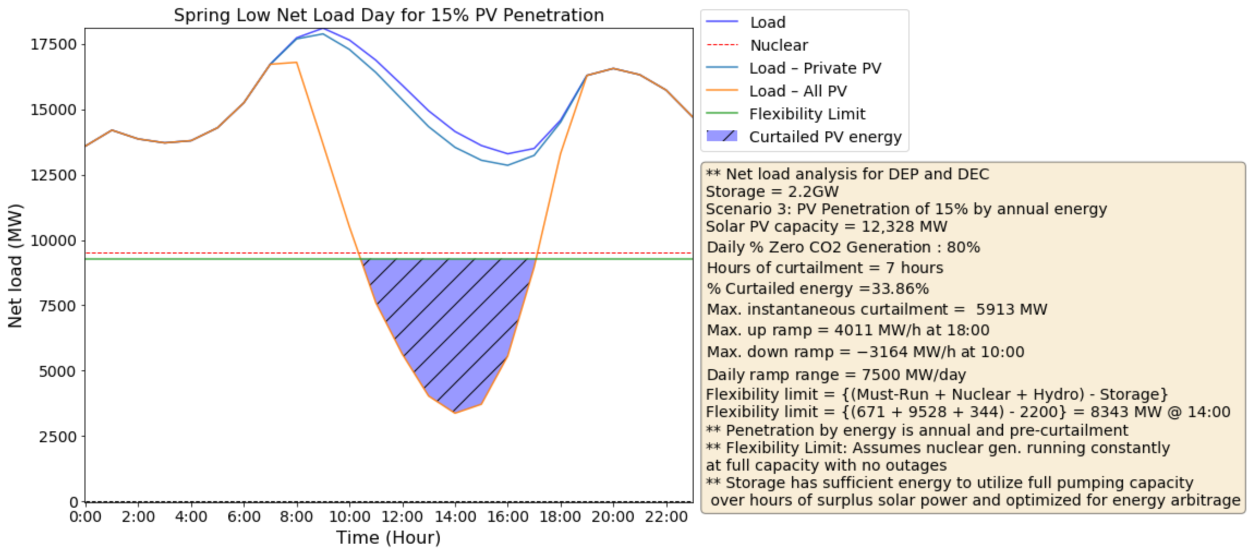


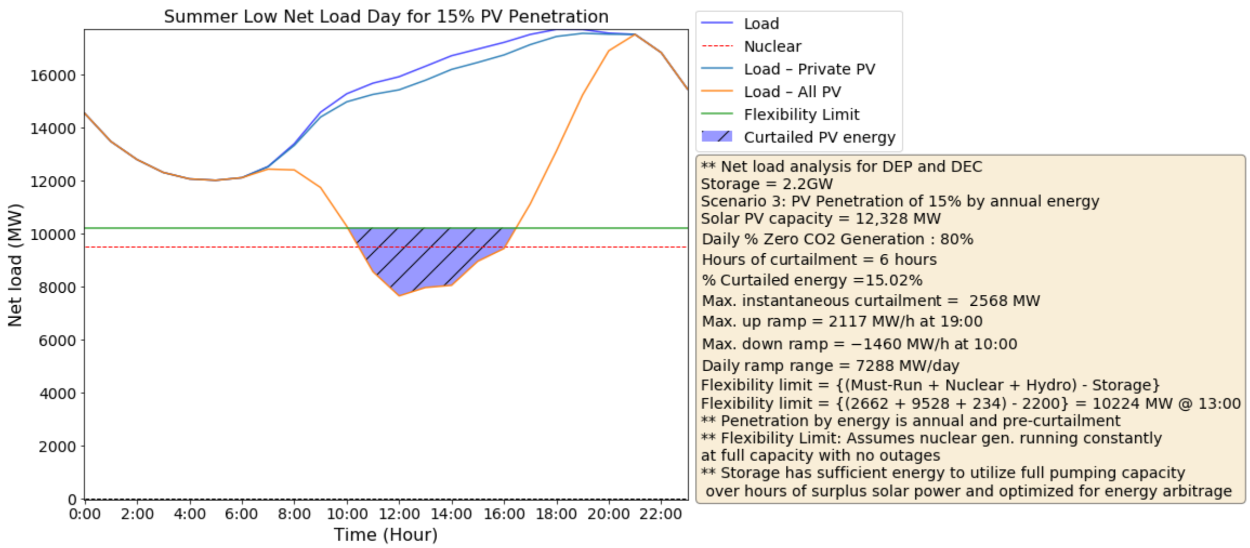


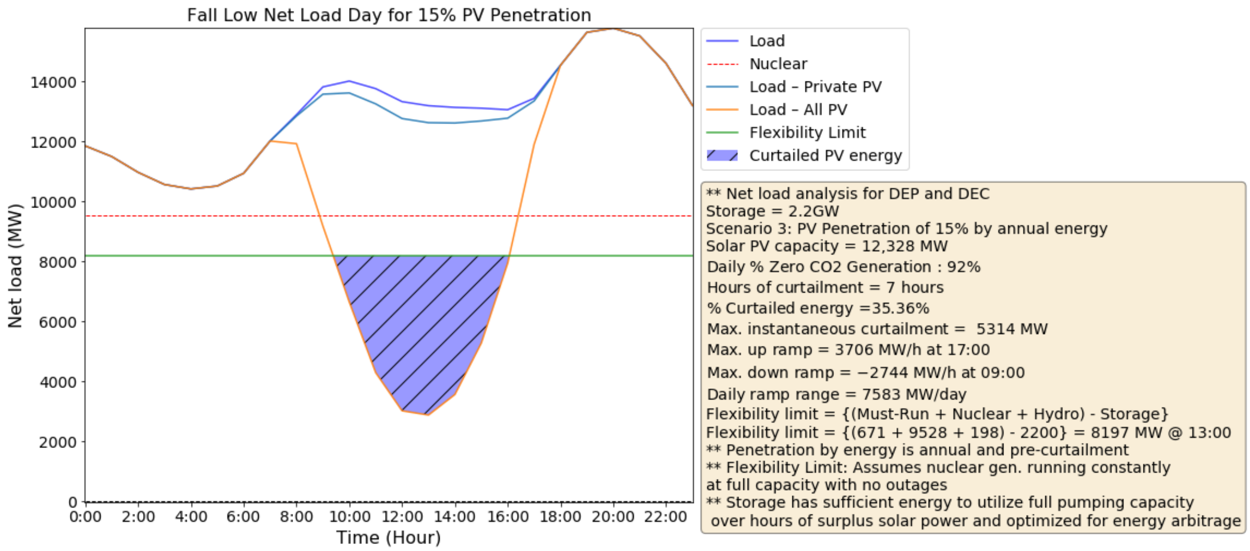


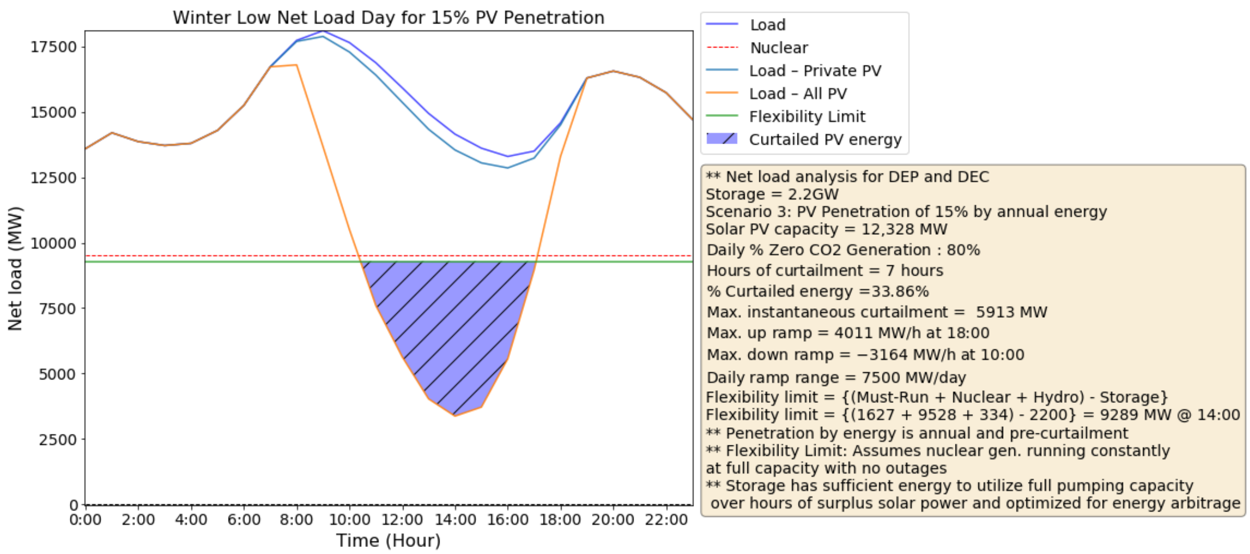

Winter Peak Net Load Day for 10% PV Penetration
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Net load (MW)
Time (Hour)
0
5000
10000
15000
20000
25000
30000
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 2: PV Penetration of 10% by annual energy
Solar PV capacity = 8,219 MW
Daily % Zero CO2 Generation : 49%
Hours of curtailment = 0 hours
% Curtailed energy =0.00%
Max. instantaneous curtailment = 0 MW
Max. up ramp = 4384 MW/h at 18:00
Max. down ramp = −4354 MW/h at 10:00
Daily ramp range = 16876 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(3368 + 9528 + 401) - 2200} = 11,097 MW @ 14:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

Seasonal Low Net Load Days: 15% PV Penetration

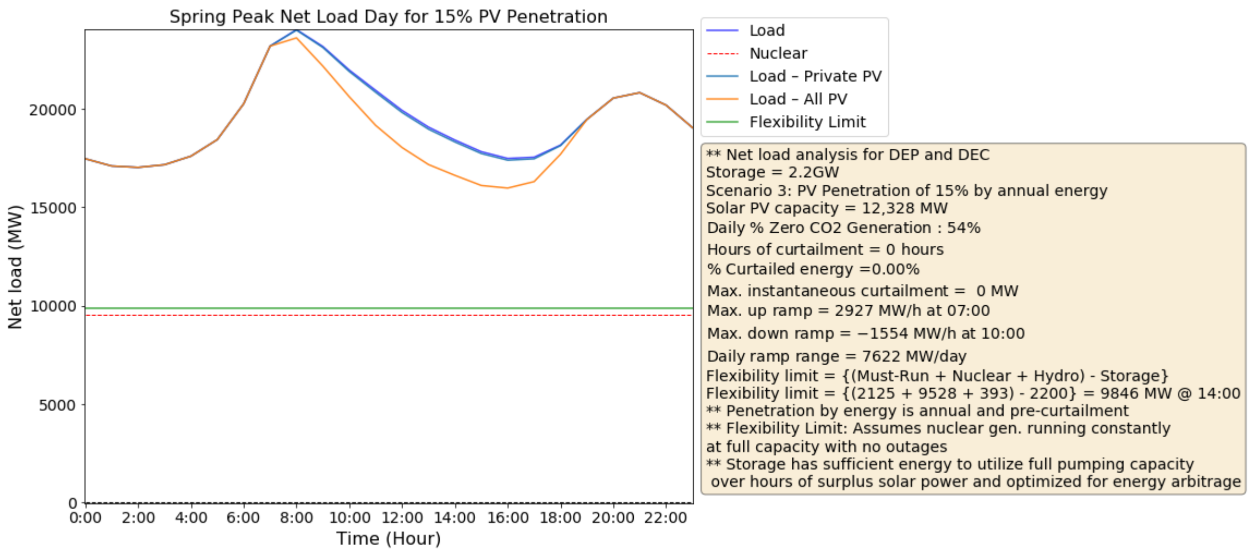


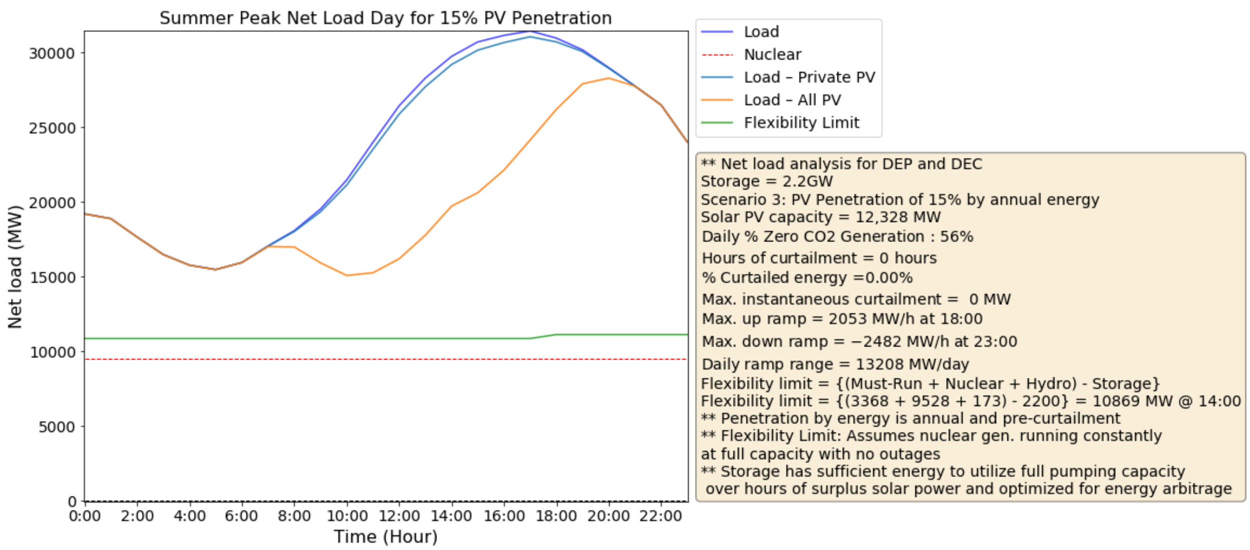


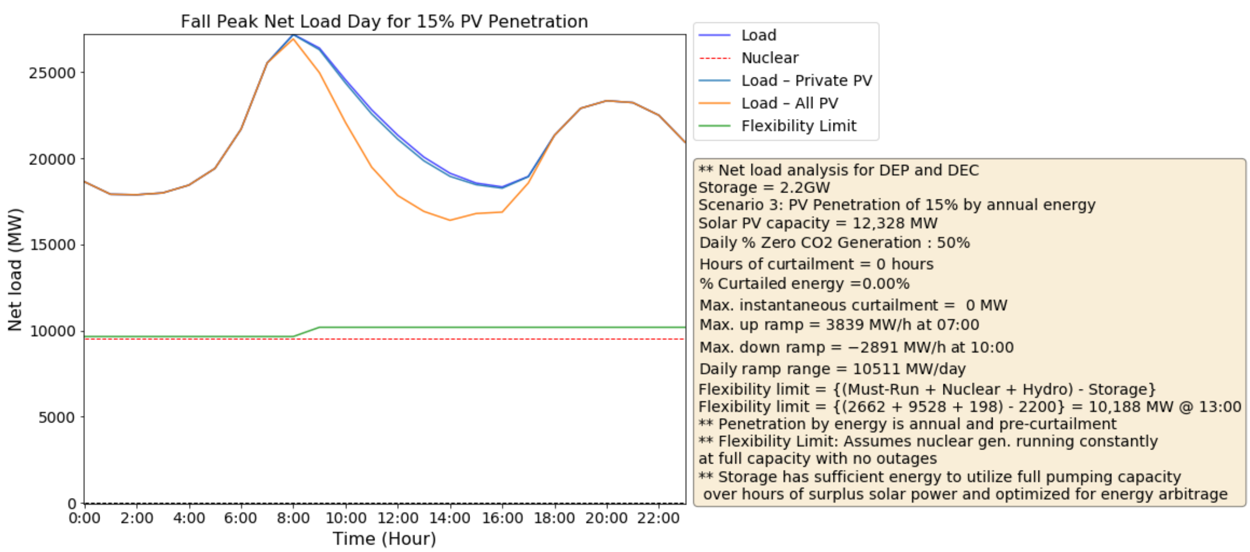

Fall Low Net Load Day for 15% PV Penetration
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 3: PV Penetration of 15% by annual energy
Solar PV capacity = 12,328 MW
Daily % Zero CO2 Generation : 92%
Hours of curtailment = 7 hours
% Curtailed energy =35.36%
Max. instantaneous curtailment = 5314 MW
Max. up ramp = 3706 MW/h at 17:00
Max. down ramp = −2744 MW/h at 09:00
Daily ramp range = 7583 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(671 + 9528 + 198) - 2200} = 8197 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

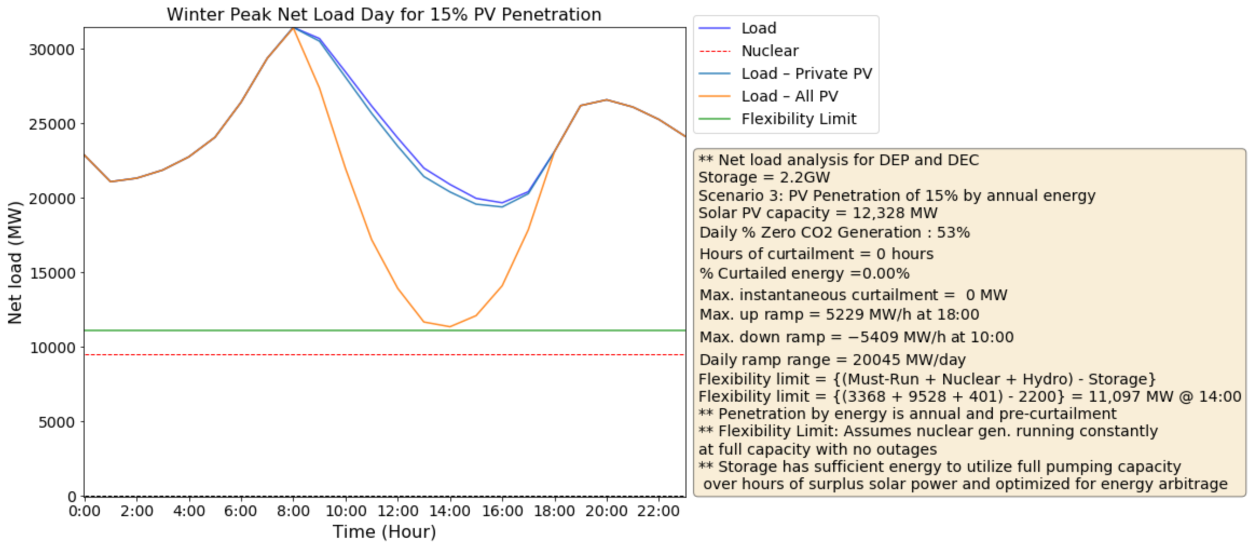

Winter Low Net Load Day for 15% PV Penetration
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 3: PV Penetration of 15% by annual energy
Solar PV capacity = 12,328 MW
Daily % Zero CO2 Generation : 80%
Hours of curtailment = 7 hours
% Curtailed energy =33.86%
Max. instantaneous curtailment = 5913 MW
Max. up ramp = 4011 MW/h at 18:00
Max. down ramp = −3164 MW/h at 10:00
Daily ramp range = 7500 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1627 + 9528 + 334) - 2200} = 9289 MW @ 14:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

Seasonal Peak Net Load Days: 15% PV Penetration

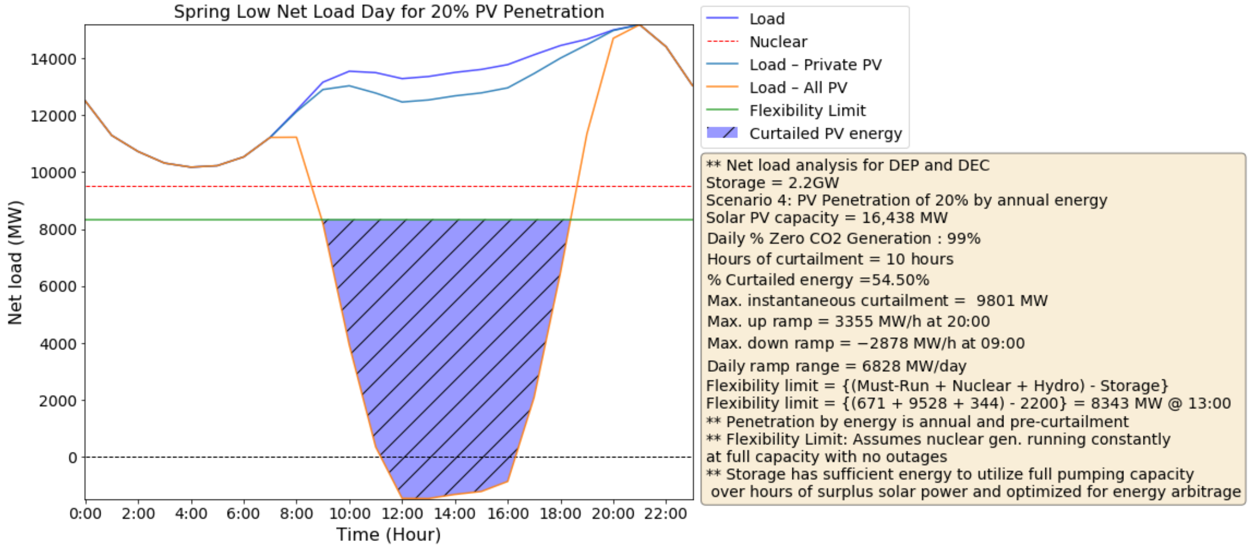


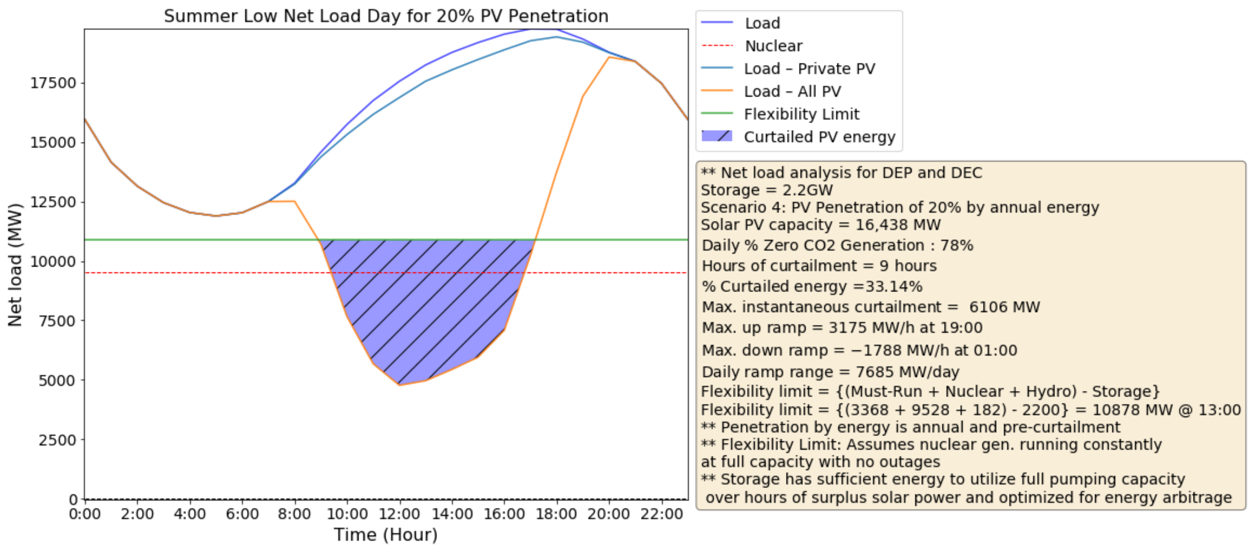


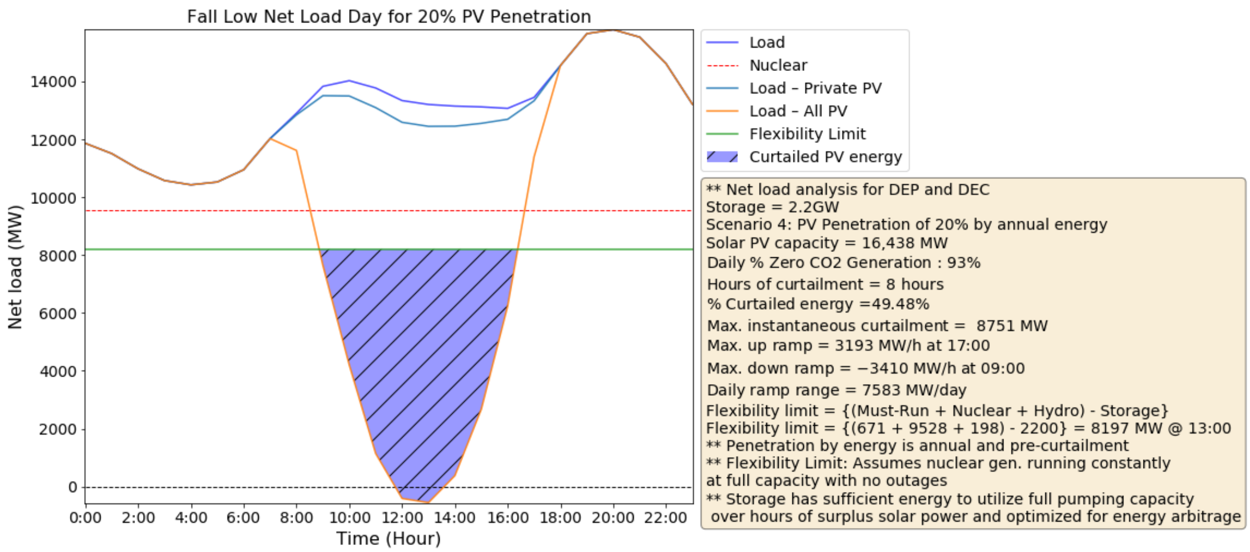


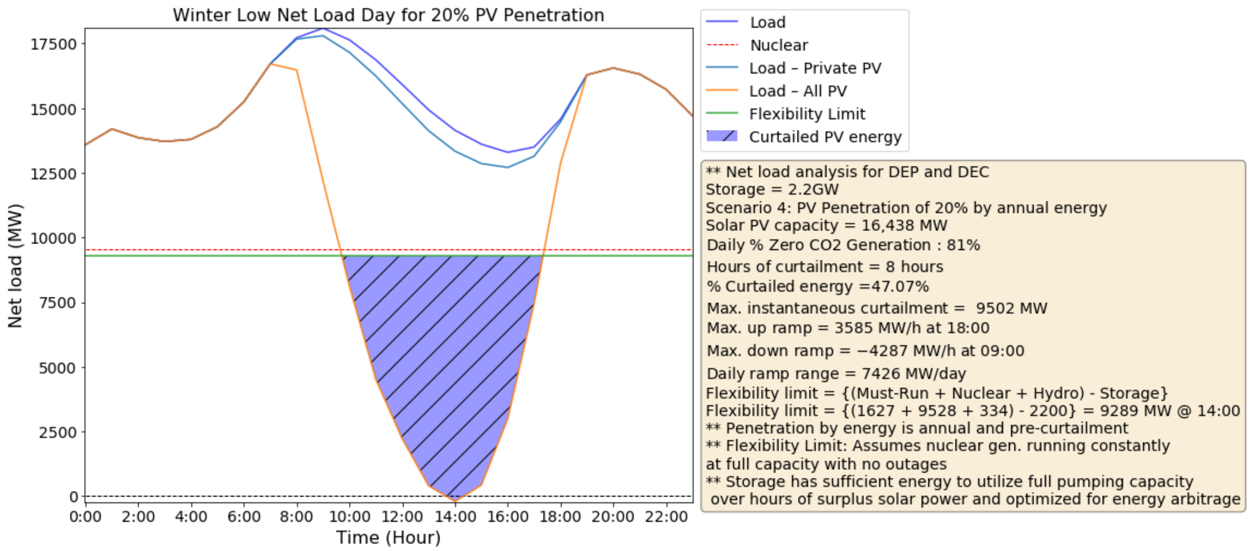

Winter Peak Net Load Day for 15% PV Penetration
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Net load (MW)
Time (Hour)
** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 3: PV Penetration of 15% by annual energy
Solar PV capacity = 12,328 MW
Daily % Zero CO2 Generation : 53%
Hours of curtailment = 0 hours
% Curtailed energy =0.00%
Max. instantaneous curtailment = 0 MW
Max. up ramp = 5229 MW/h at 18:00
Max. down ramp = −5409 MW/h at 10:00
Daily ramp range = 20045 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(3368 + 9528 + 401) - 2200} = 11,097 MW @ 14:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

Seasonal Low Net Load Days: 20% PV Penetration

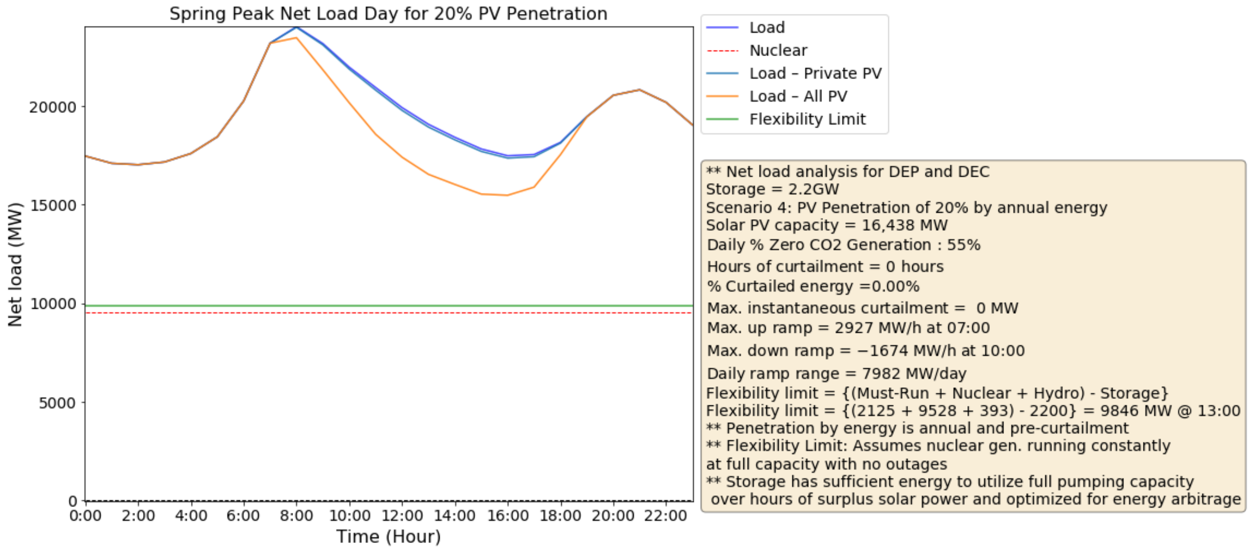


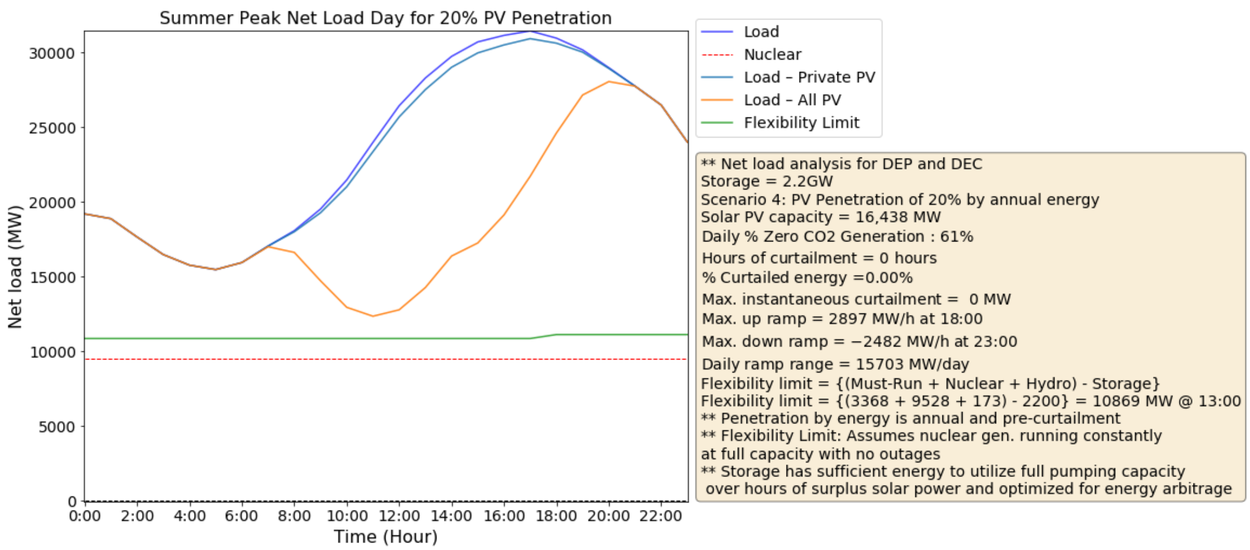


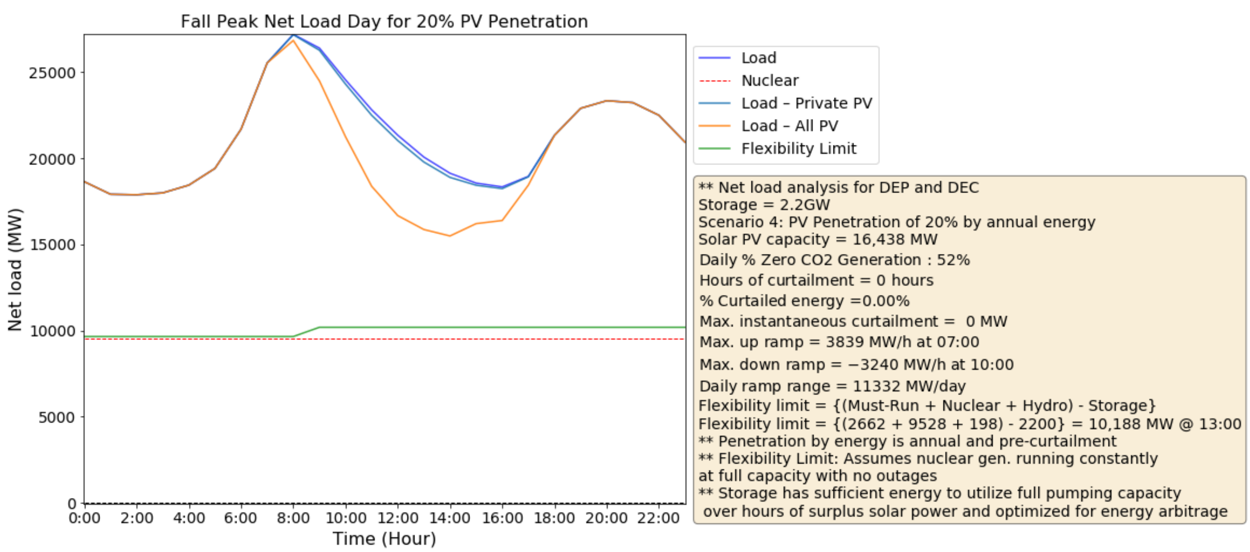


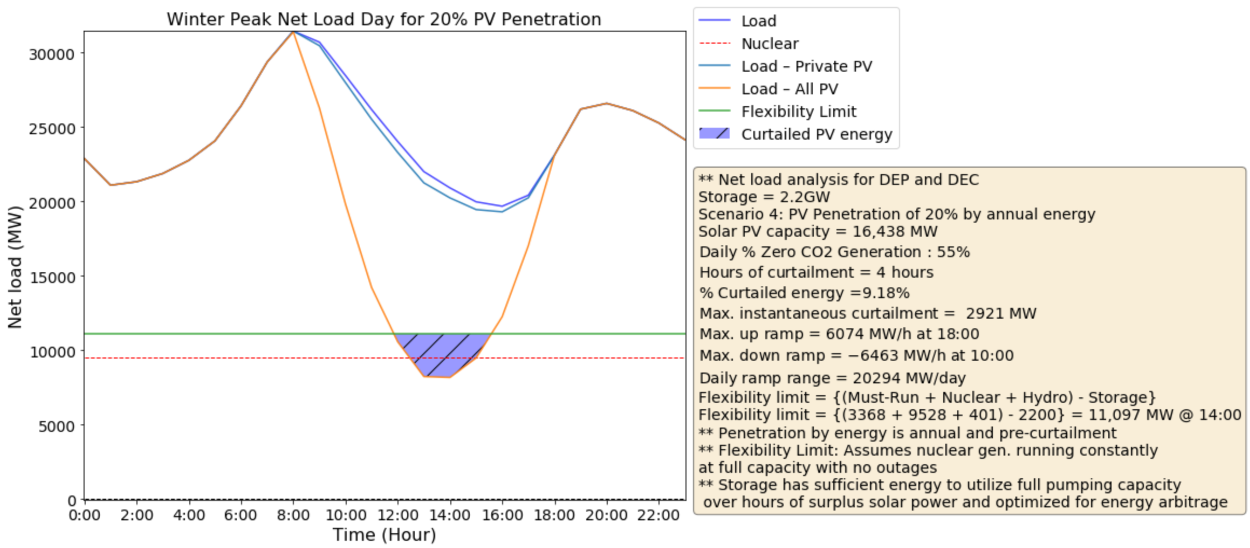

Winter Low Net Load Day for 20% PV Penetration
Net load (MW)
Time (Hour)
0
2500
5000
7500
10000
12500
15000
17500
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 4: PV Penetration of 20% by annual energy
Solar PV capacity = 16,438 MW
Daily % Zero CO2 Generation : 81%
Hours of curtailment = 8 hours
% Curtailed energy =47.07%
Max. instantaneous curtailment = 9502 MW
Max. up ramp = 3585 MW/h at 18:00
Max. down ramp = −4287 MW/h at 09:00
Daily ramp range = 7426 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1627 + 9528 + 334) - 2200} = 9289 MW @ 14:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

Seasonal Peak Net Load Days: 20% PV Penetration

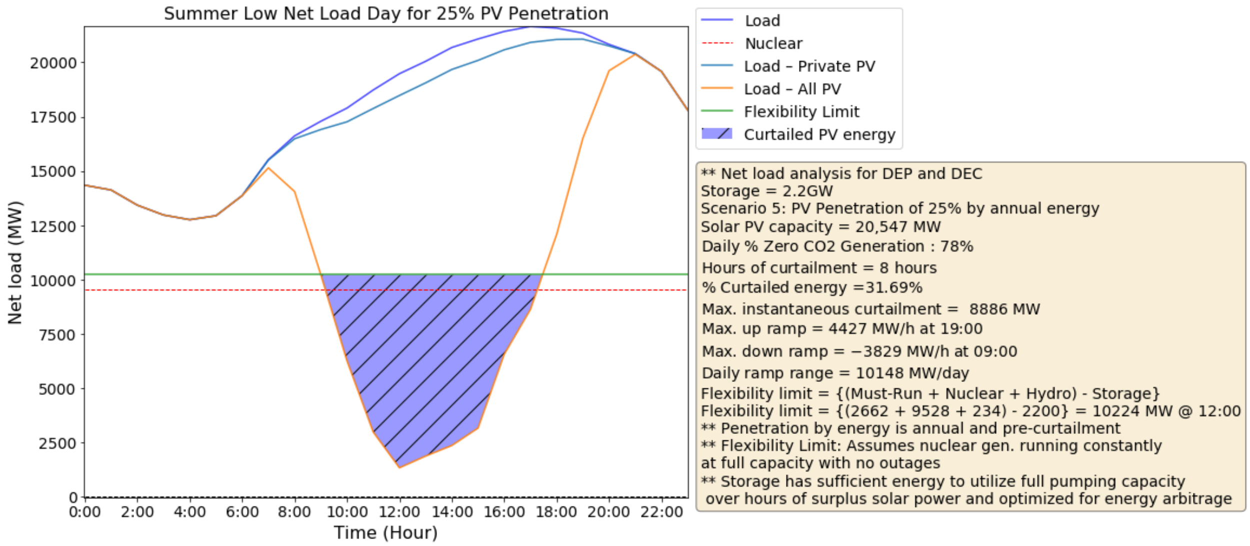


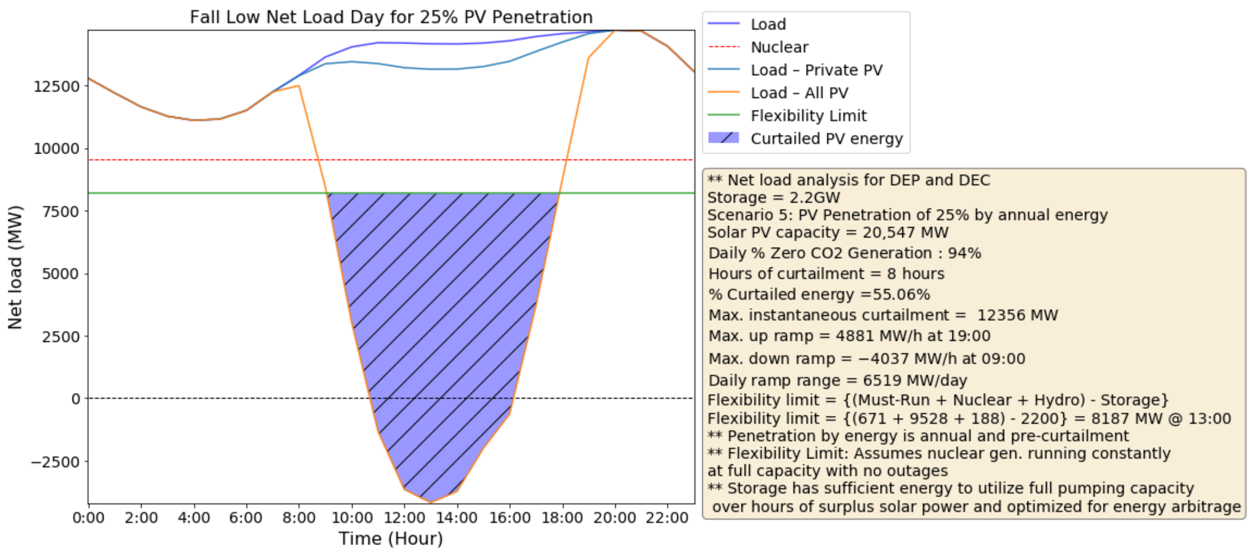


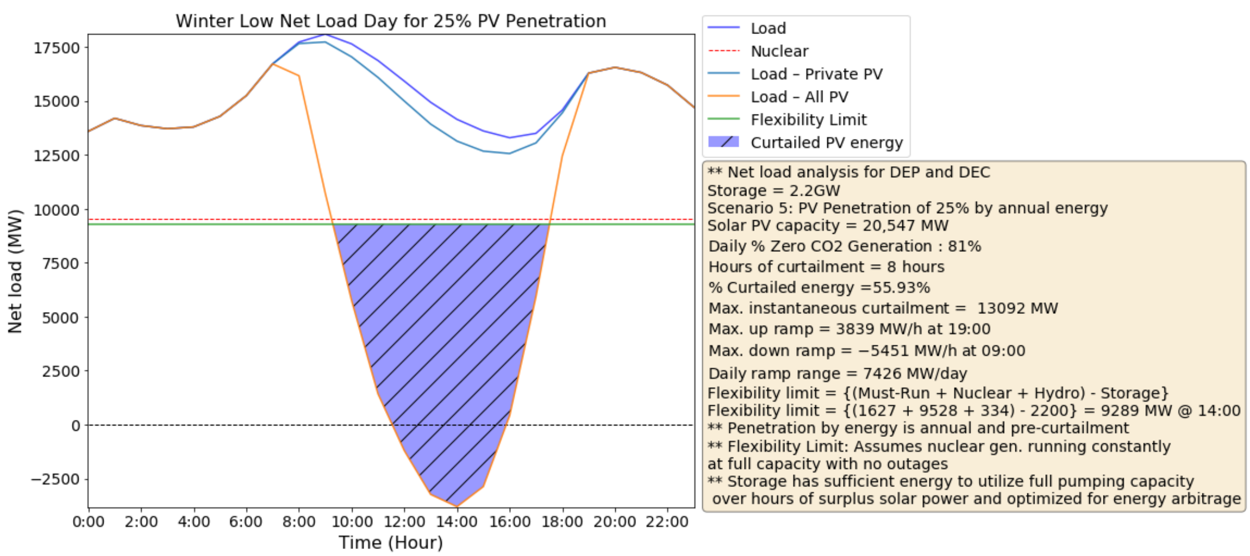



Winter Peak Net Load Day for 20% PV Penetration
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 4: PV Penetration of 20% by annual energy
Solar PV capacity = 16,438 MW
Daily % Zero CO2 Generation : 55%
Hours of curtailment = 4 hours
% Curtailed energy =9.18%
Max. instantaneous curtailment = 2921 MW
Max. up ramp = 6074 MW/h at 18:00
Max. down ramp = −6463 MW/h at 10:00
Daily ramp range = 20294 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(3368 + 9528 + 401) - 2200} = 11,097 MW @ 14:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

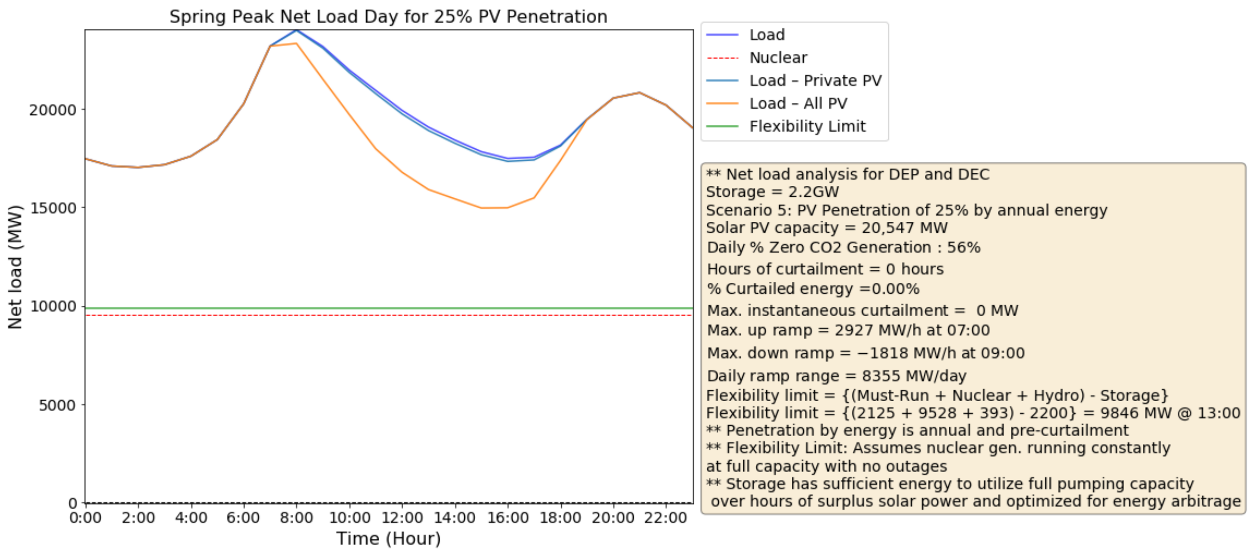
Seasonal Low Net Load Days: 25% PV Penetration

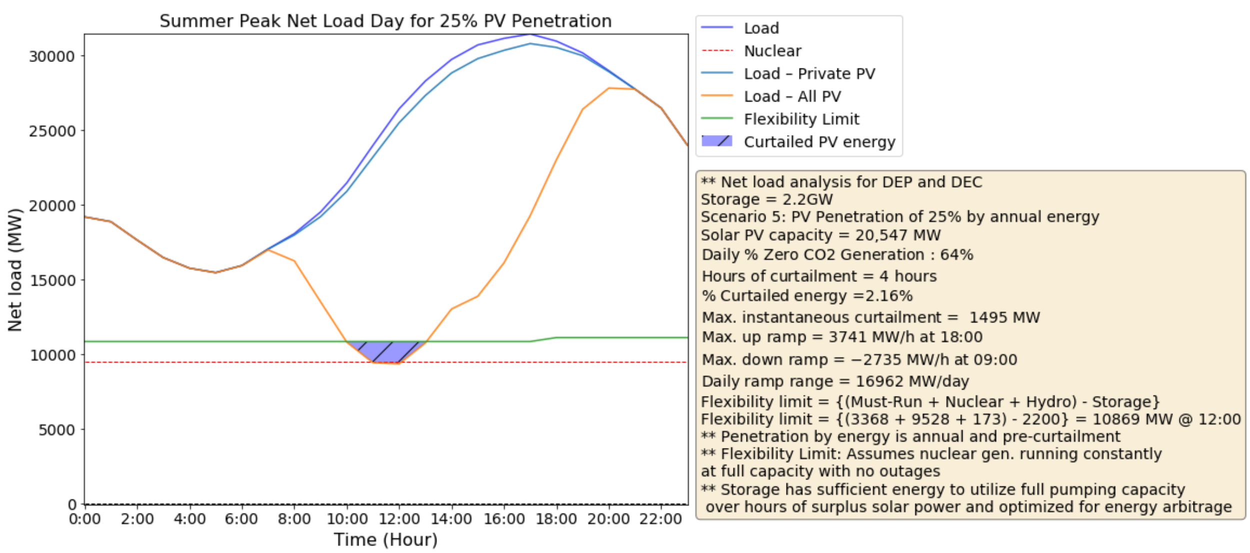


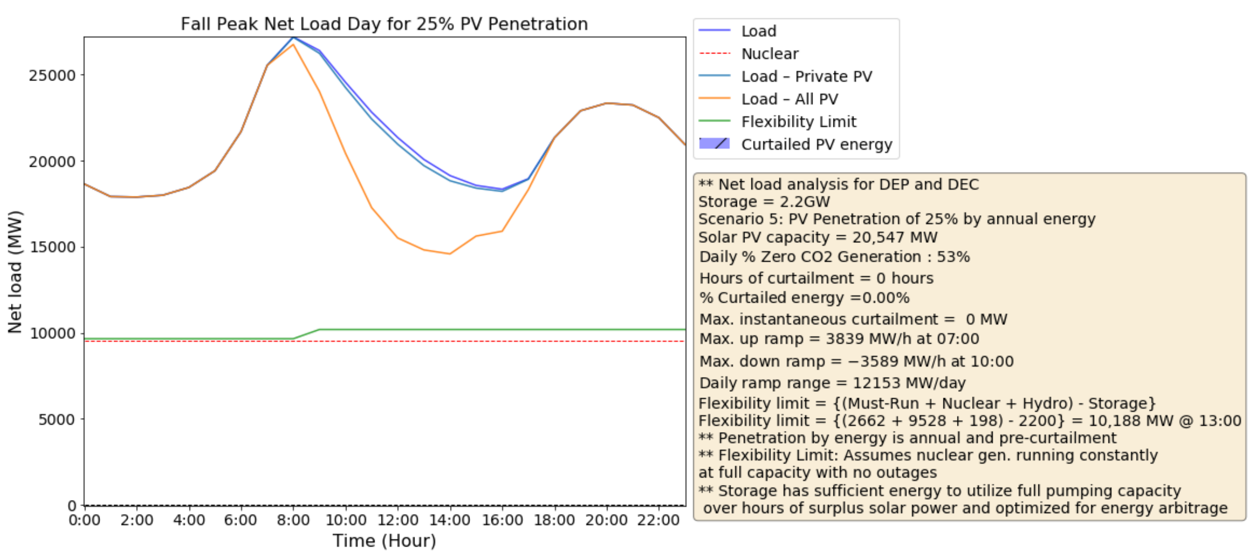


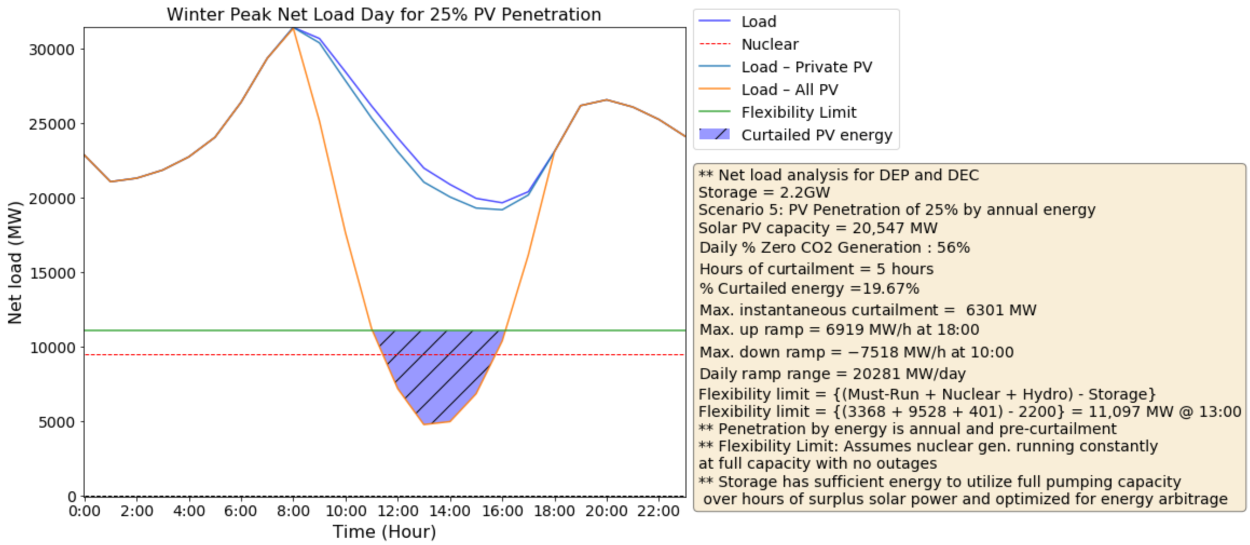


Seasonal Peak Net Load Days: 25% PV Penetration

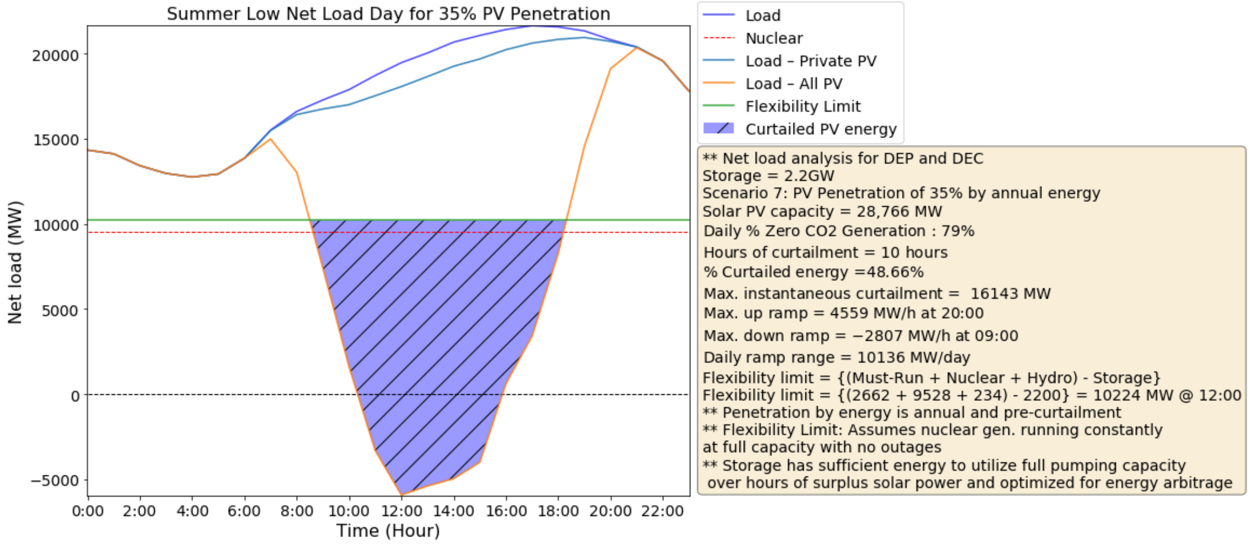


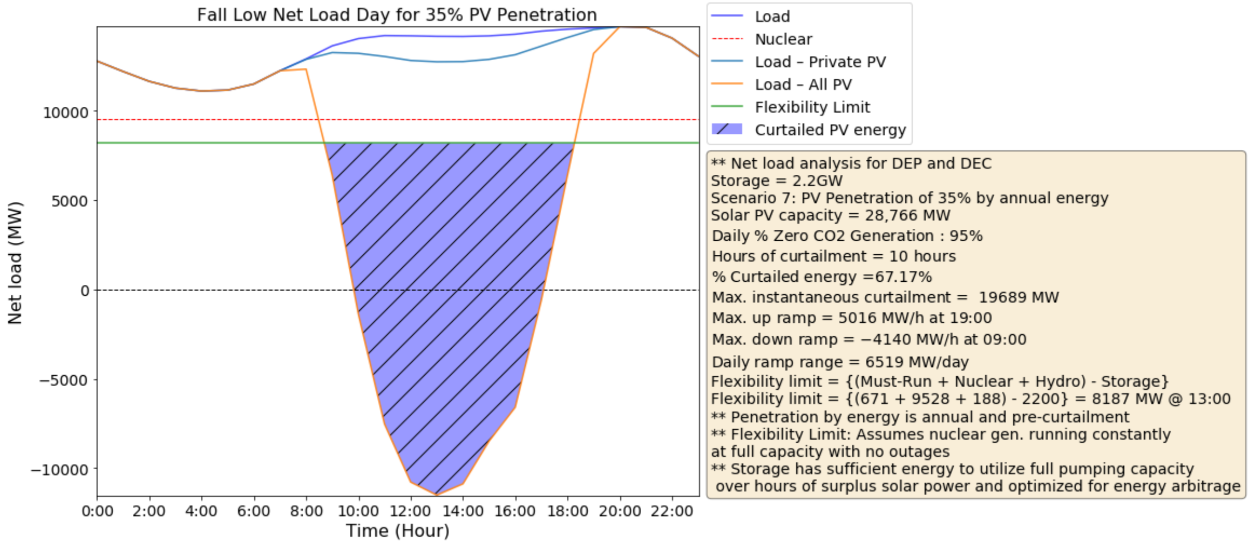


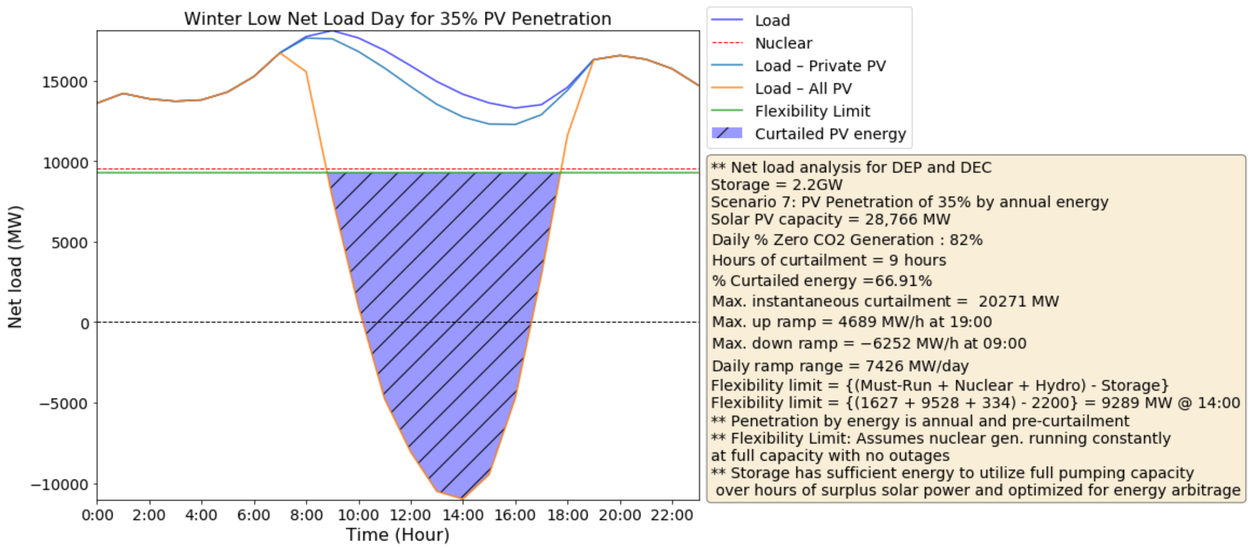



Winter Peak Net Load Day for 25% PV Penetration
Net load (MW)
Time (Hour)
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0
5000
10000
15000
20000
25000
30000
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 5: PV Penetration of 25% by annual energy
Solar PV capacity = 20,547 MW
Daily % Zero CO2 Generation : 56%
Hours of curtailment = 5 hours
% Curtailed energy =19.67%
Max. instantaneous curtailment = 6301 MW
Max. up ramp = 6919 MW/h at 18:00
Max. down ramp = −7518 MW/h at 10:00
Daily ramp range = 20281 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(3368 + 9528 + 401) - 2200} = 11,097 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

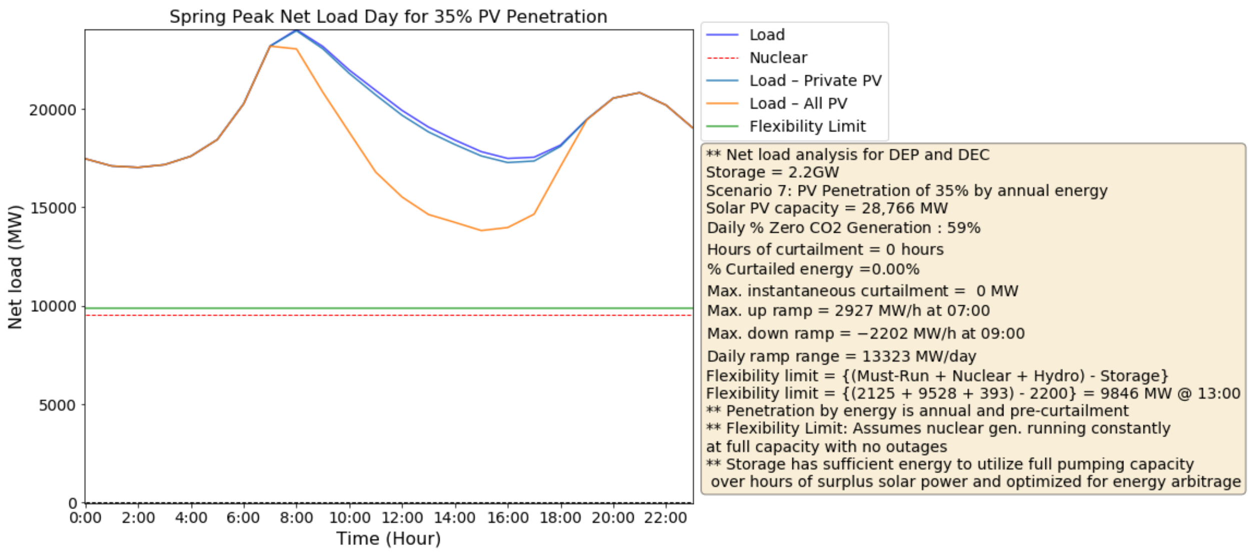
Seasonal Low Net Load Days: 35% PV Penetration

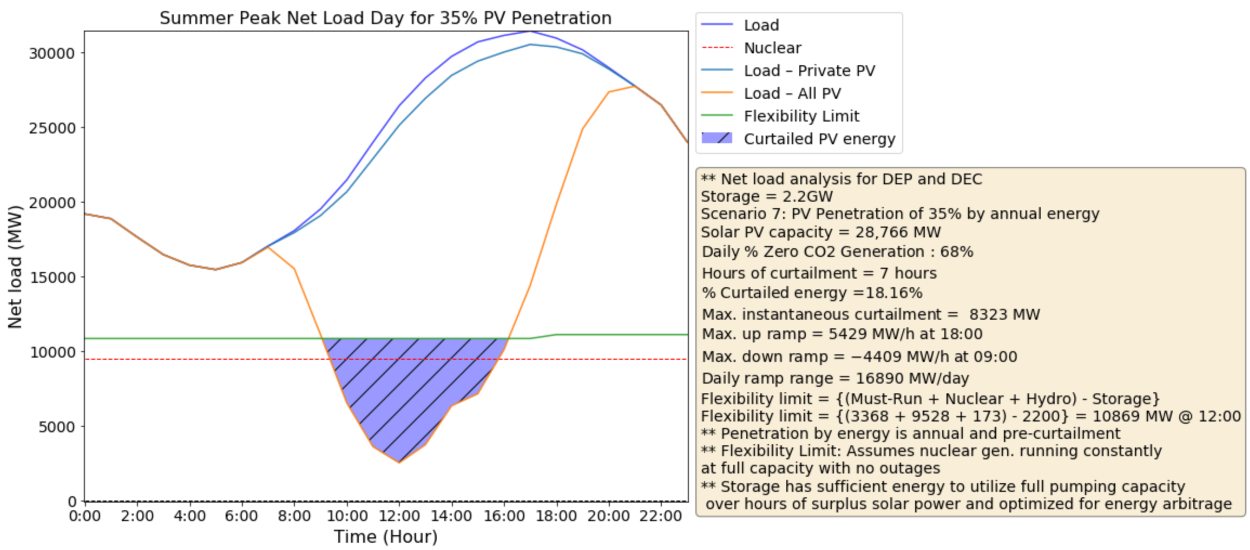


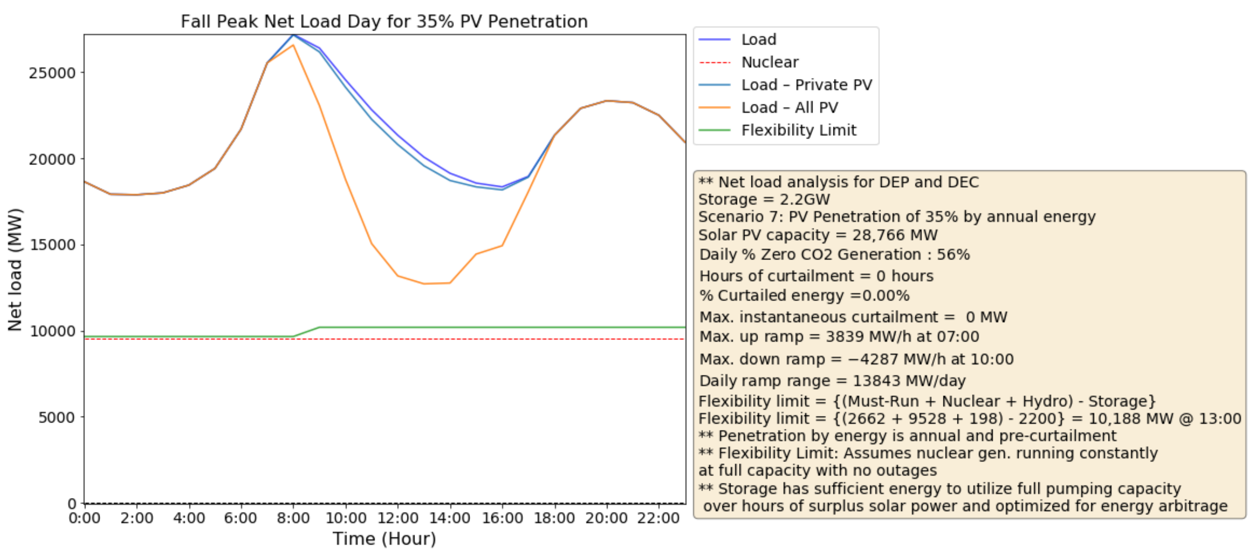


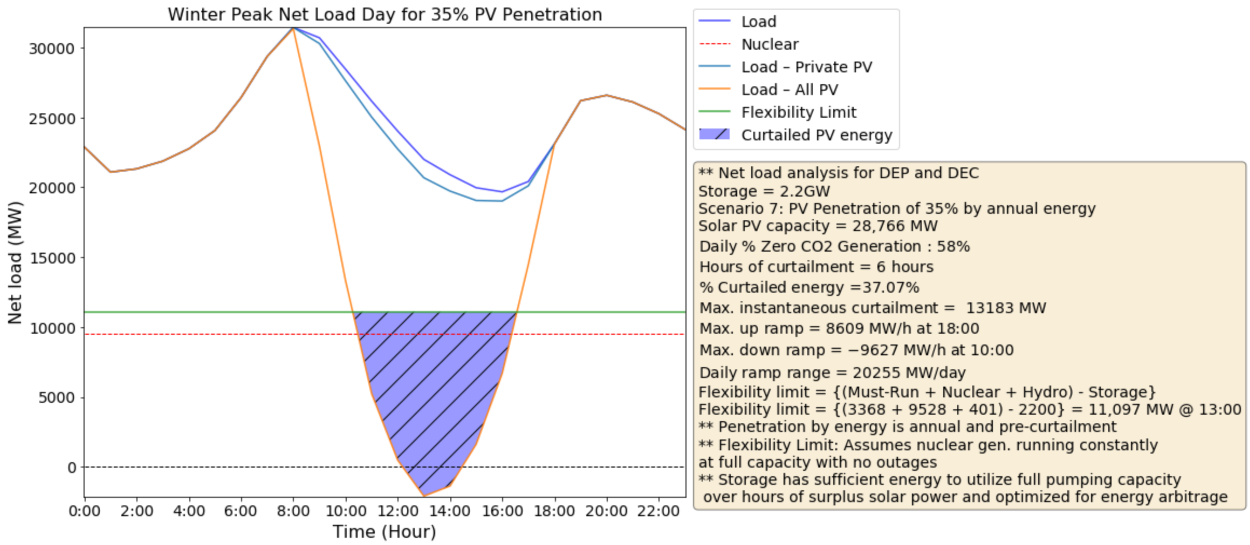


Seasonal Peak Net Load Days: 35% PV Penetration



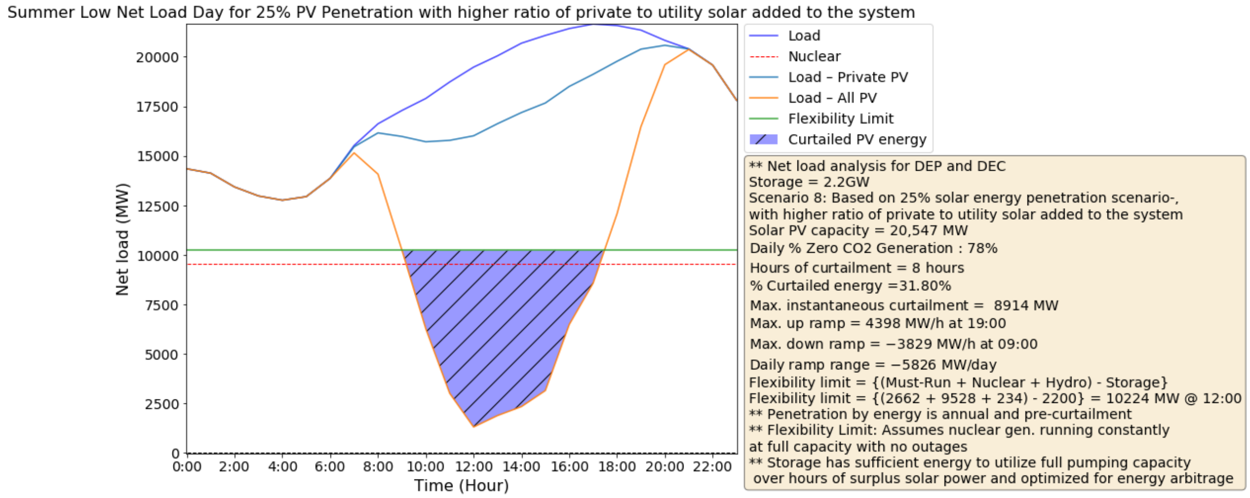


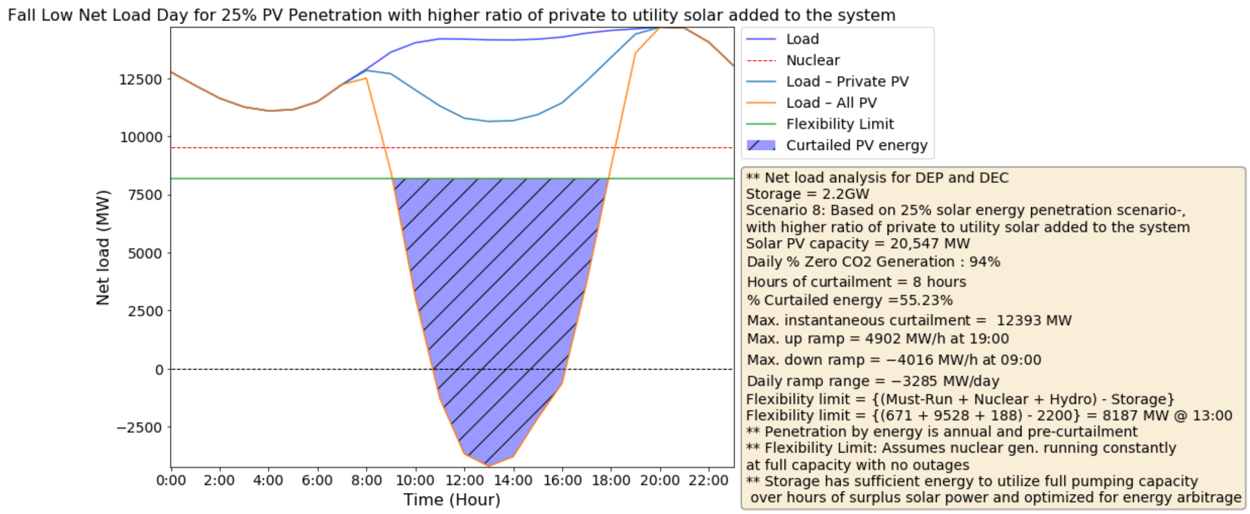


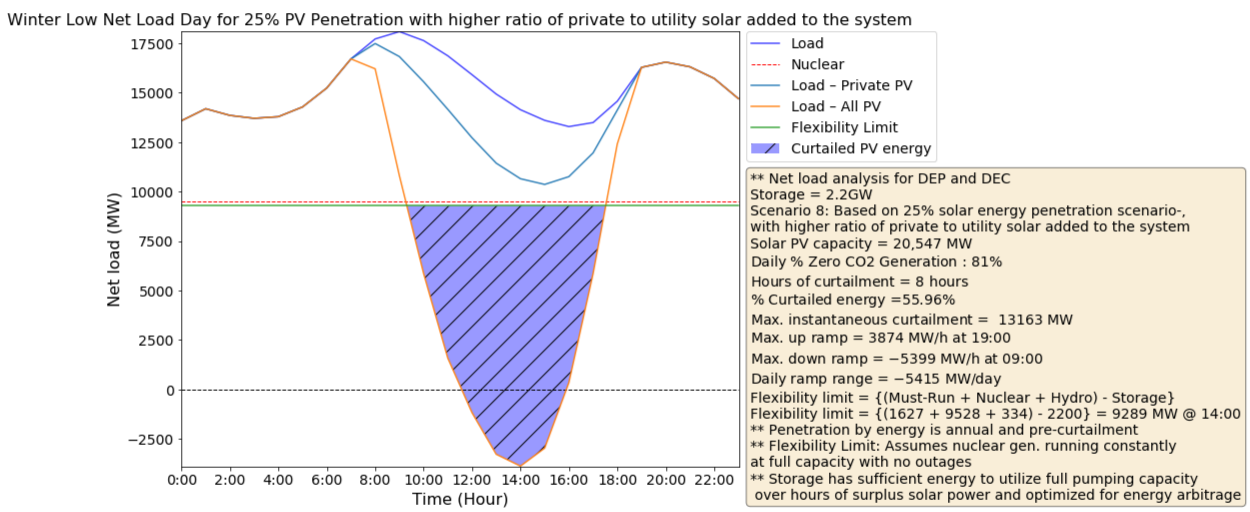

Winter Peak Net Load Day for 35% PV Penetration
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 7: PV Penetration of 35% by annual energy
Solar PV capacity = 28,766 MW
Daily % Zero CO2 Generation : 58%
Hours of curtailment = 6 hours
% Curtailed energy =37.07%
Max. instantaneous curtailment = 13183 MW
Max. up ramp = 8609 MW/h at 18:00
Max. down ramp = −9627 MW/h at 10:00
Daily ramp range = 20255 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(3368 + 9528 + 401) - 2200} = 11,097 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

Scenario 8: 25% PV Penetration and Increased Proportion of Distributed Solar

Seasonal Low Net Load Days

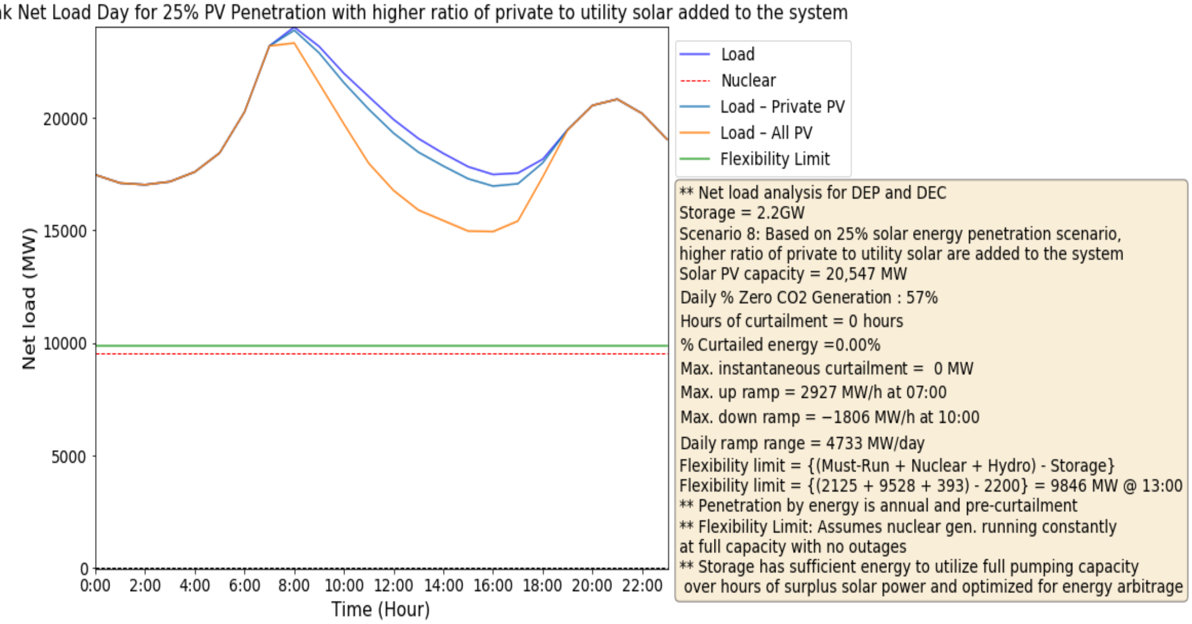




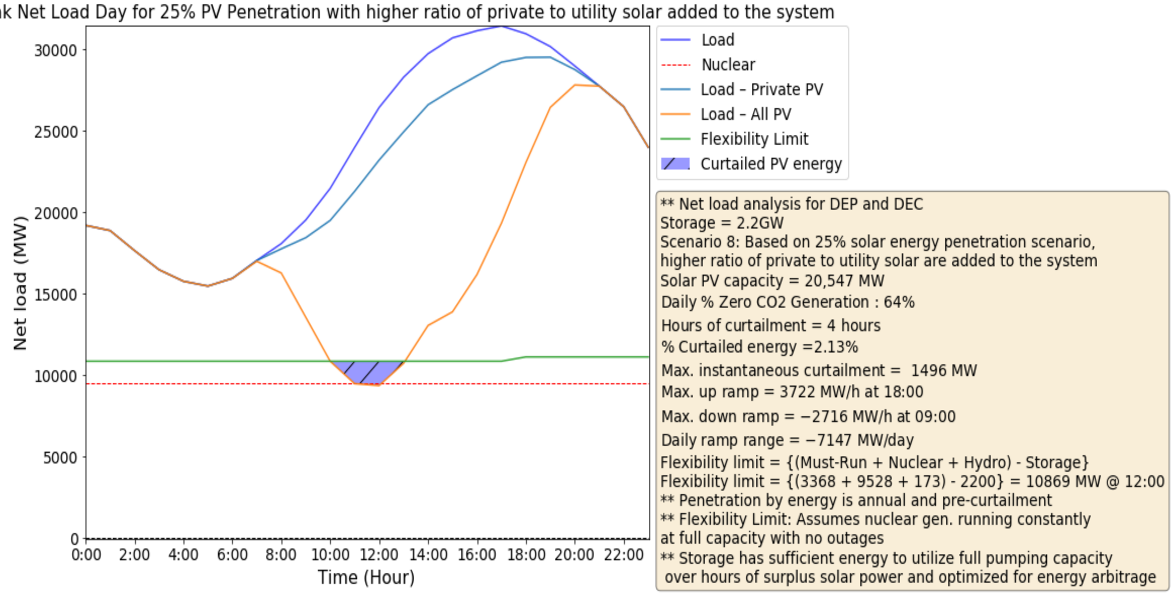


Seasonal Peak Net Load Days

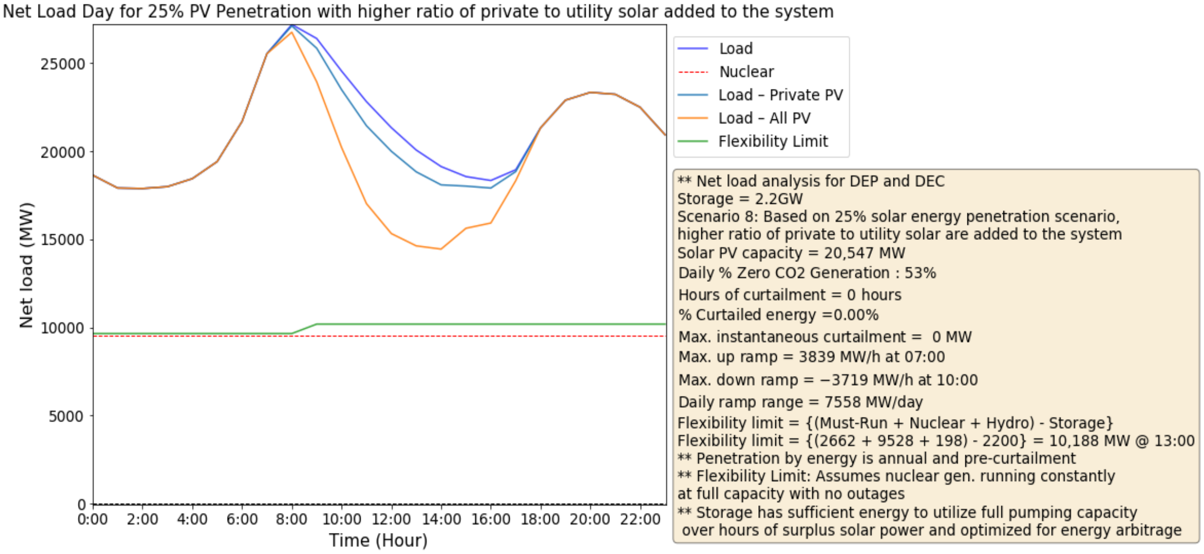
Spring Peak Net Load Day for 25% PV Penetration with higher ratio of private to utility solar added to the system



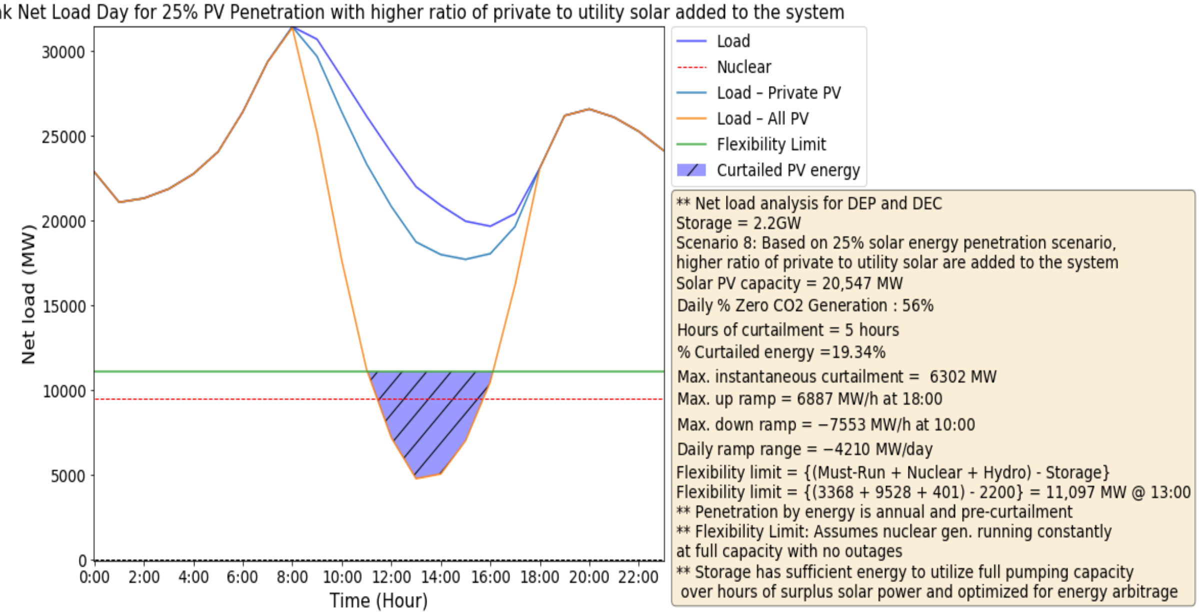
Summer Peak Net Load Day for 25% PV Penetration with higher ratio of private to utility solar added to the system



Fall Peak Net Load Day for 25% PV Penetration with higher ratio of private to utility solar added to the system

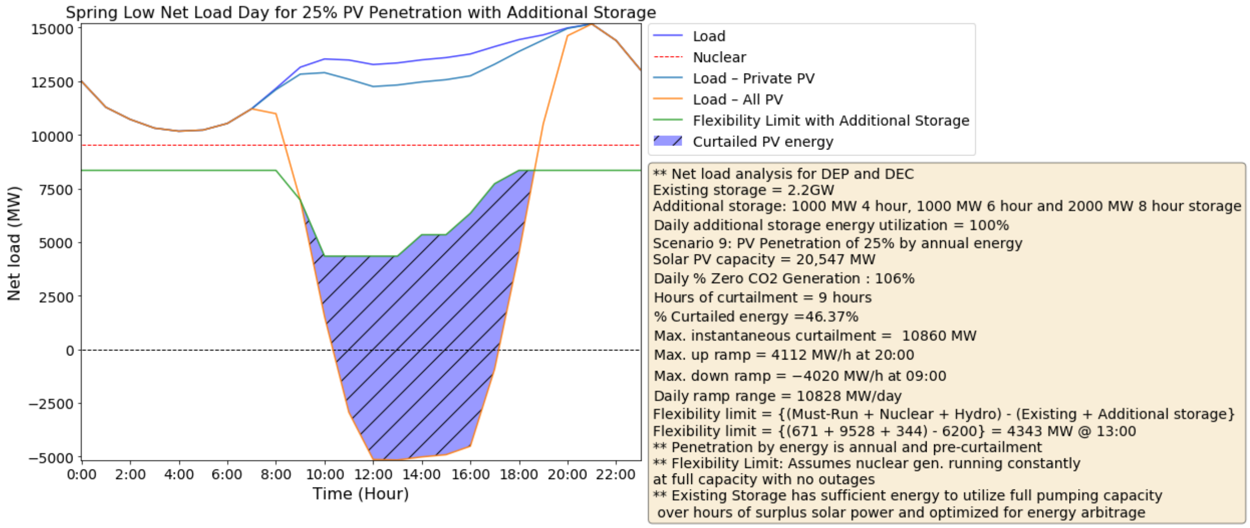


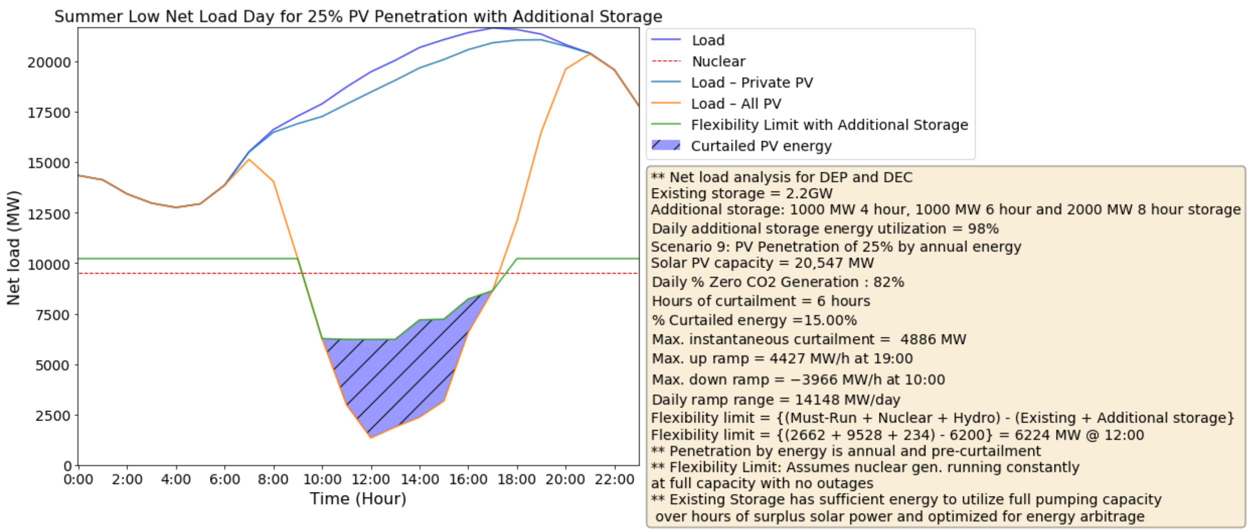
Winter Peak Net Load Day for 25% PV Penetration with higher ratio of private to utility solar added to the system

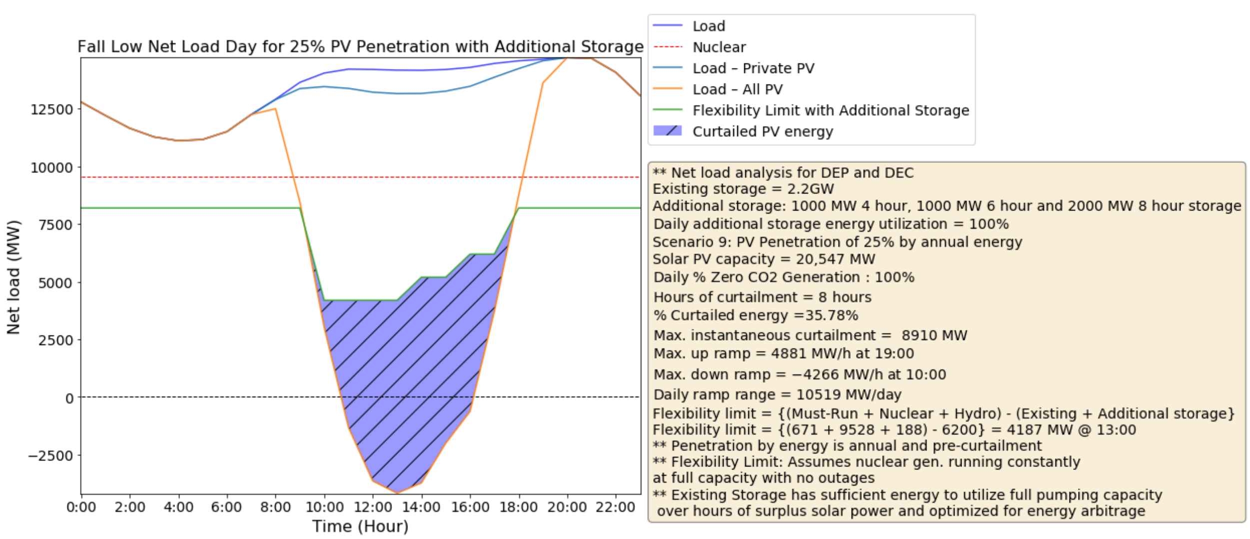


Scenario 9: 25% PV Penetration and Additional Storage

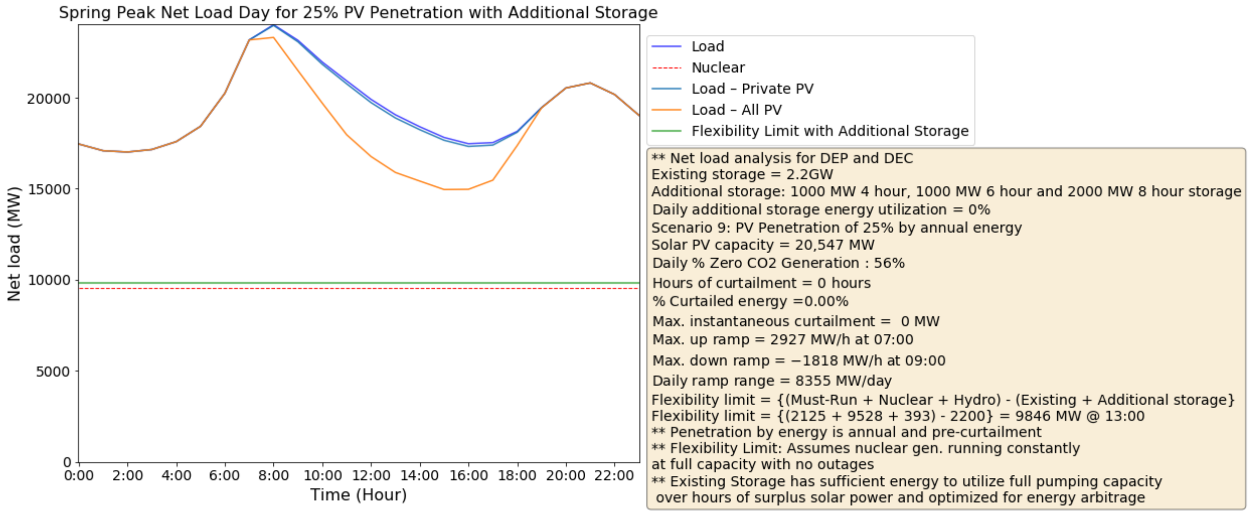
Seasonal Low Net Load Days

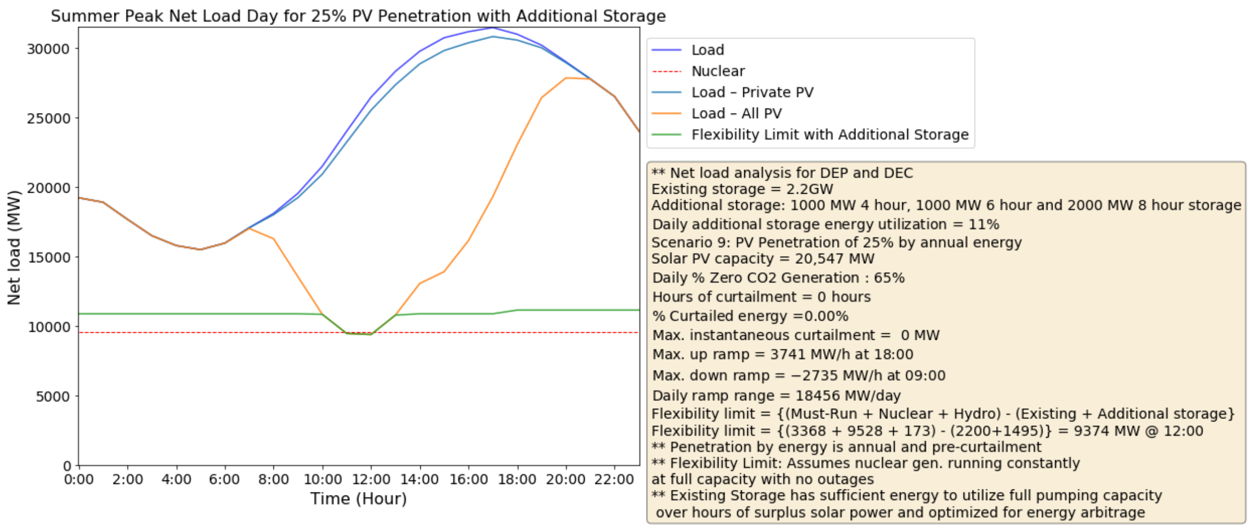


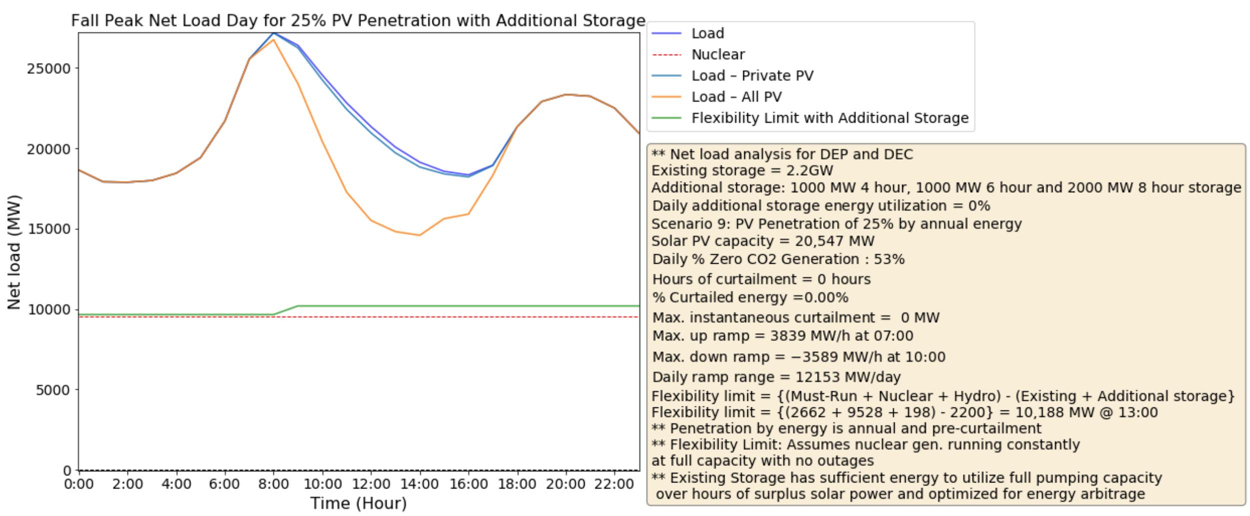


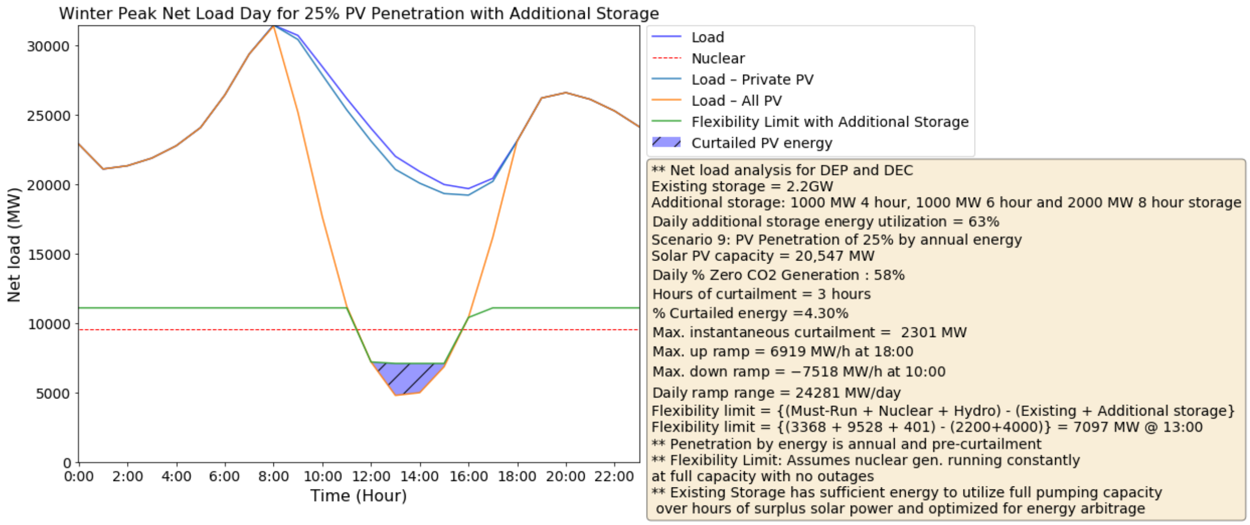


Seasonal Peak Net Load Days



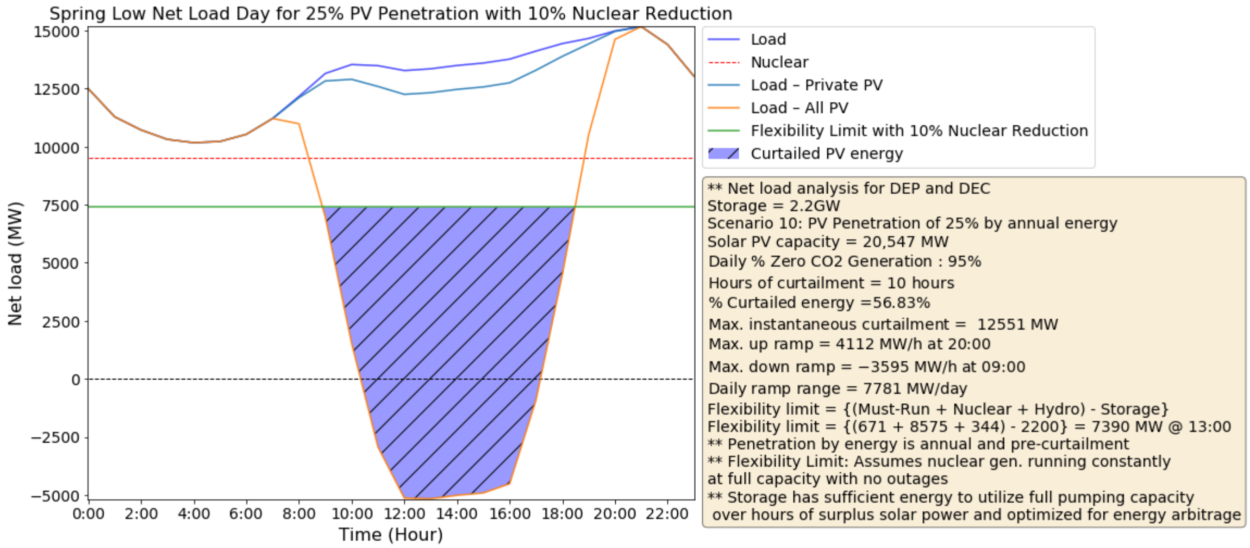


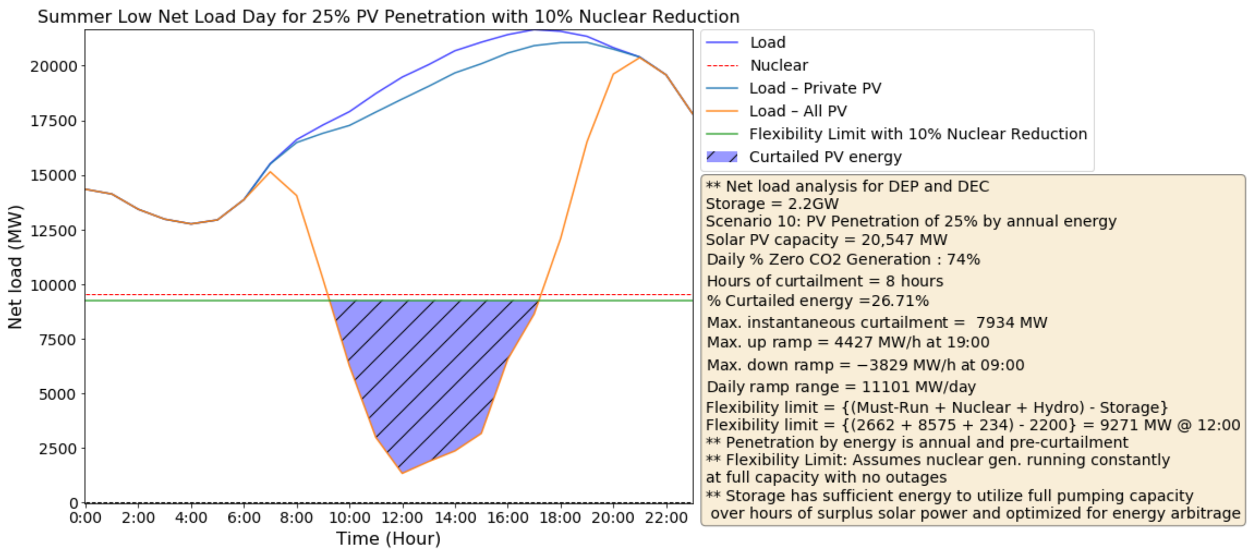


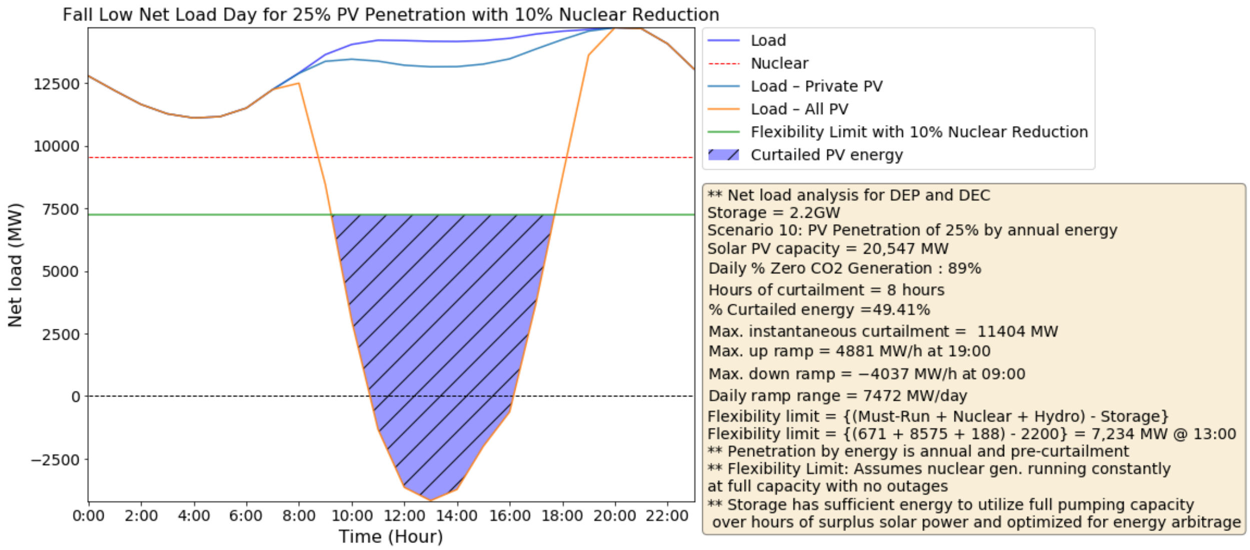

Winter Peak Net Load Day for 25% PV Penetration with Additional Storage
Net load (MW)
30000
25000
20000
15000
10000
5000
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit with Additional Storage
Curtailed PV energy
** Net load analysis for DEP and DEC
Existing storage = 2.2GW
Additional storage: 1000 MW 4 hour, 1000 MW 6 hour and 2000 MW 8 hour storage
Daily additional storage energy utilization = 63%
Scenario 9: PV Penetration of 25% by annual energy
Solar PV capacity = 20,547 MW
Daily % Zero CO2 Generation : 58%
Hours of curtailment = 3 hours
% Curtailed energy =4.30%
Max. instantaneous curtailment = 2301 MW
Max. up ramp = 6919 MW/h at 18:00
Max. down ramp = −7518 MW/h at 10:00
Daily ramp range = 24281 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - (Existing + Additional storage}
Flexibility limit = {(3368 + 9528 + 401) - (2200+4000)} = 7097 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Existing Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

Scenario 10: 25% PV Penetration and Generation Retirement

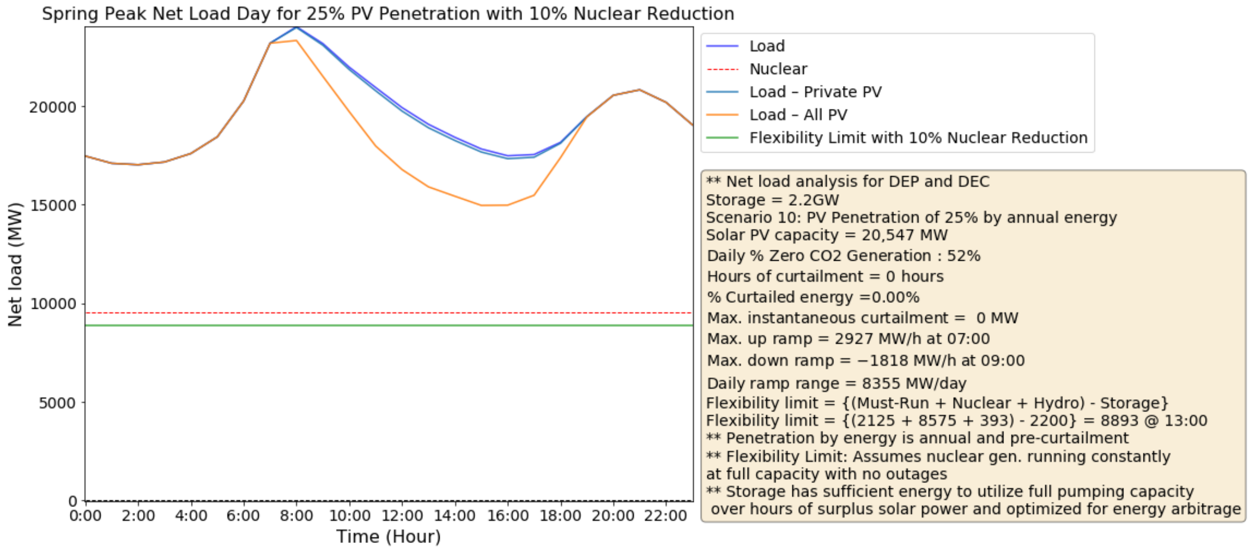
Seasonal Low Net Load Days

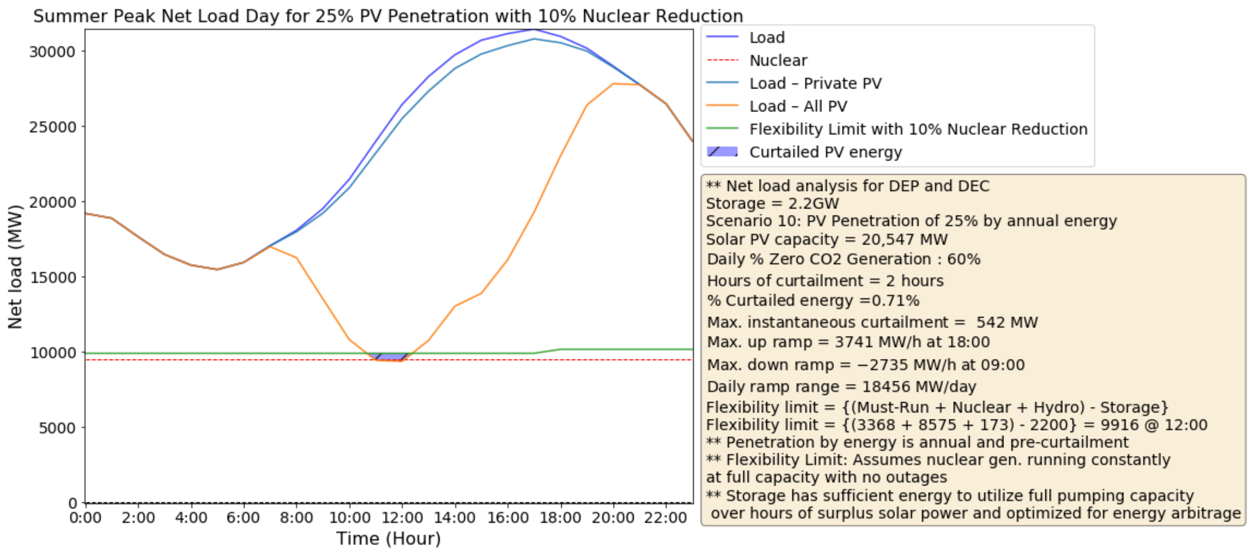


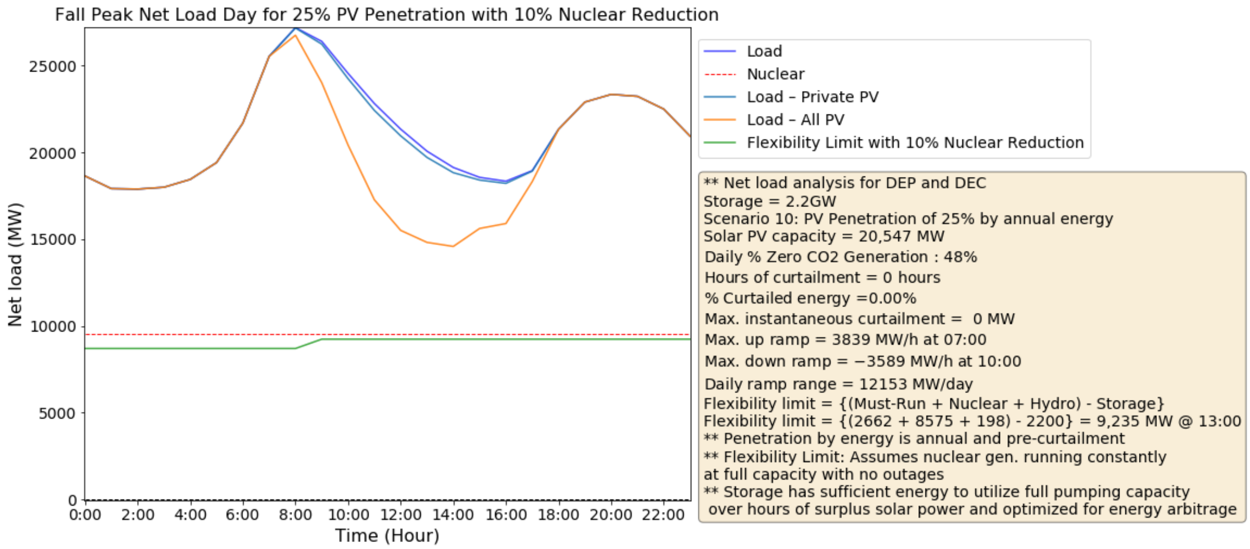


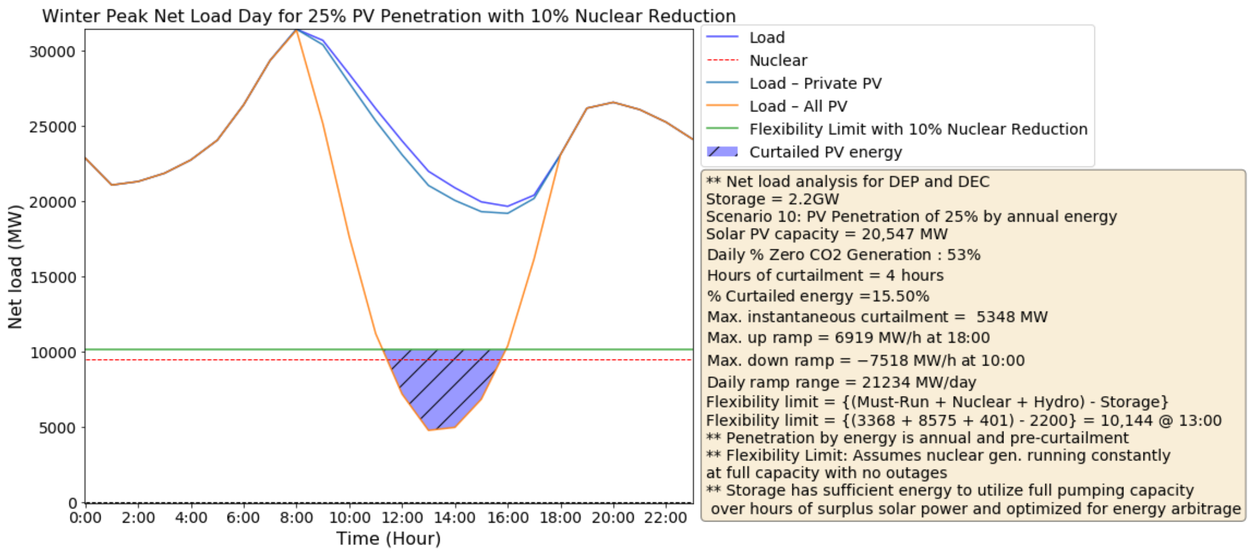

Fall Low Net Load Day for 25% PV Penetration with 10% Nuclear Reduction
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit with 10% Nuclear Reduction
Curtailed PV energy
** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 10: PV Penetration of 25% by annual energy
Solar PV capacity = 20,547 MW
Daily % Zero CO2 Generation : 89%
Hours of curtailment = 8 hours
% Curtailed energy =49.41%
Max. instantaneous curtailment = 11404 MW
Max. up ramp = 4881 MW/h at 19:00
Max. down ramp = −4037 MW/h at 09:00
Daily ramp range = 7472 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(671 + 8575 + 188) - 2200} = 7,234 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

Seasonal Peak Net Load Days



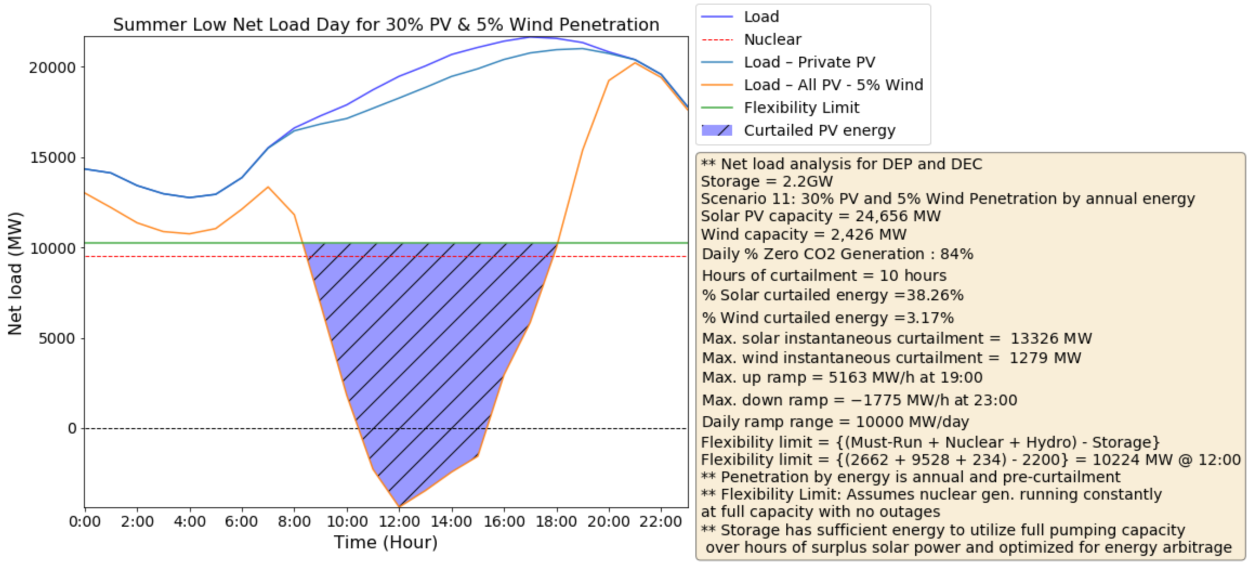


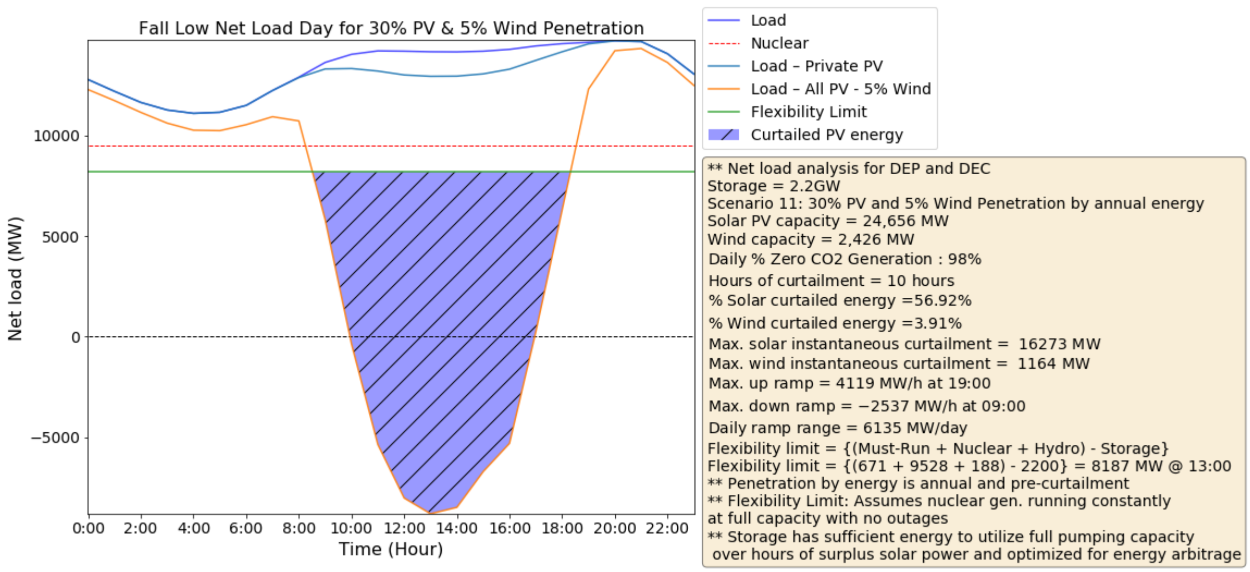

Fall Peak Net Load Day for 25% PV Penetration with 10% Nuclear Reduction
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit with 10% Nuclear Reduction
** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 10: PV Penetration of 25% by annual energy
Solar PV capacity = 20,547 MW
Daily % Zero CO2 Generation : 48%
Hours of curtailment = 0 hours
% Curtailed energy =0.00%
Max. instantaneous curtailment = 0 MW
Max. up ramp = 3839 MW/h at 07:00
Max. down ramp = −3589 MW/h at 10:00
Daily ramp range = 12153 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(2662 + 8575 + 198) - 2200} = 9,235 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

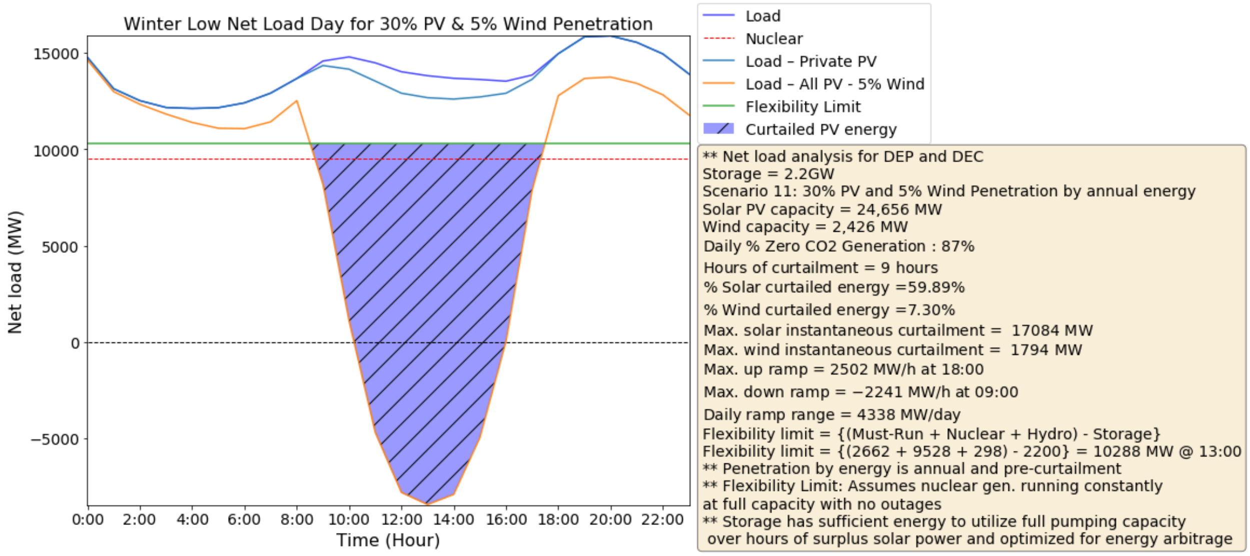

Winter Peak Net Load Day for 25% PV Penetration with 10% Nuclear Reduction
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit with 10% Nuclear Reduction
Curtailed PV energy
** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 10: PV Penetration of 25% by annual energy
Solar PV capacity = 20,547 MW
Daily % Zero CO2 Generation : 53%
Hours of curtailment = 4 hours
% Curtailed energy =15.50%
Max. instantaneous curtailment = 5348 MW
Max. up ramp = 6919 MW/h at 18:00
Max. down ramp = −7518 MW/h at 10:00
Daily ramp range = 21234 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(3368 + 8575 + 401) - 2200} = 10,144 @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

Scenario 11: 30% PV and 5% Wind Penetration

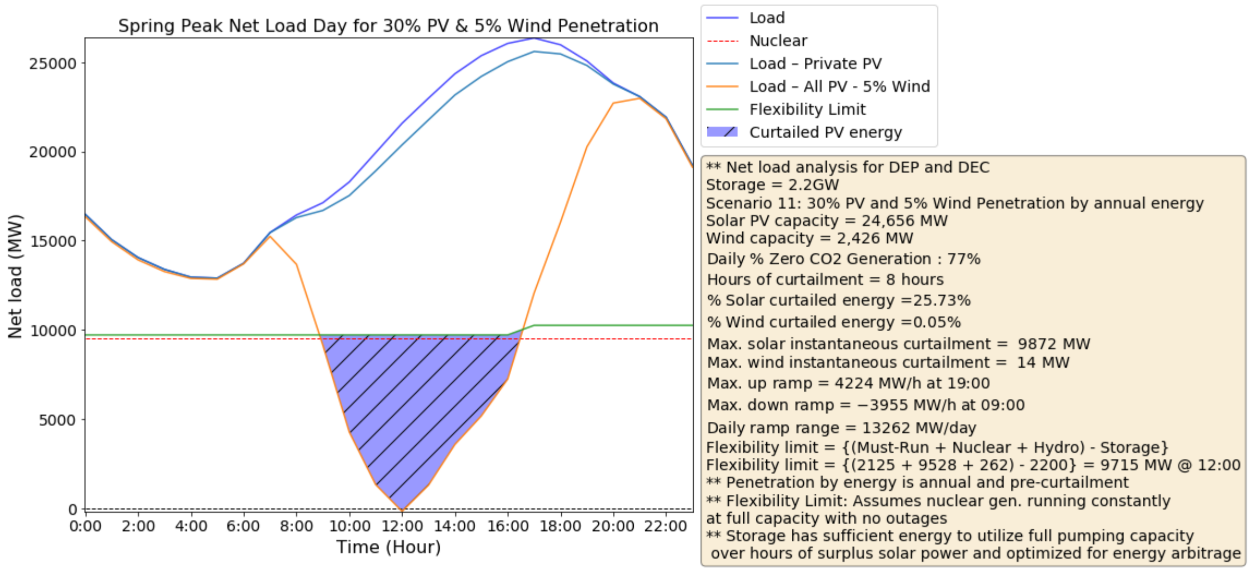
Seasonal Low Net Load Days

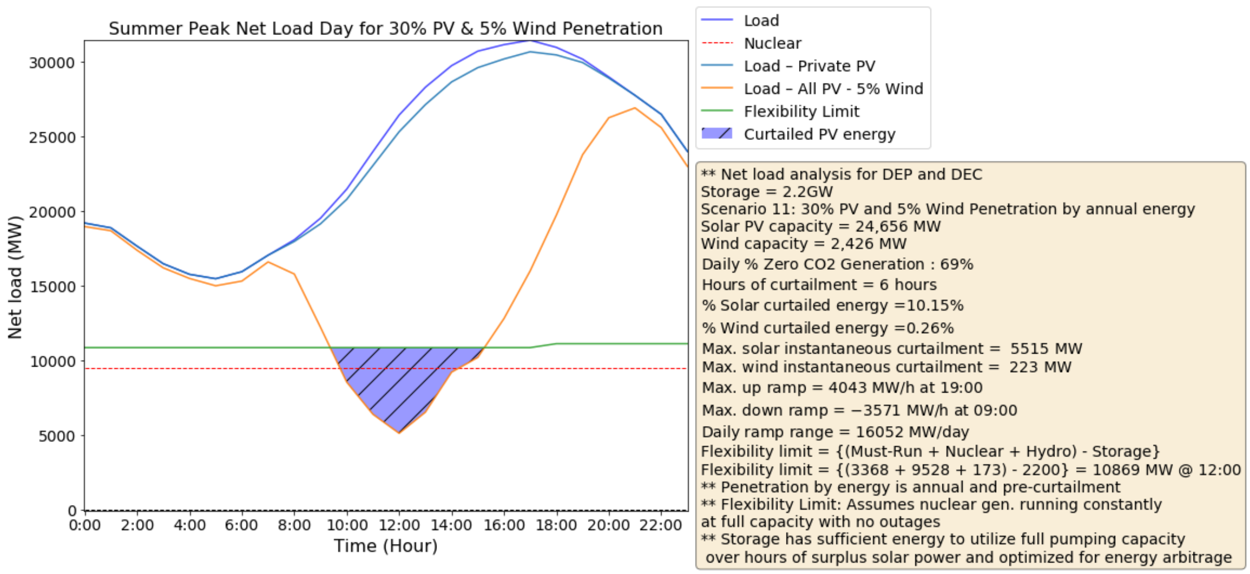


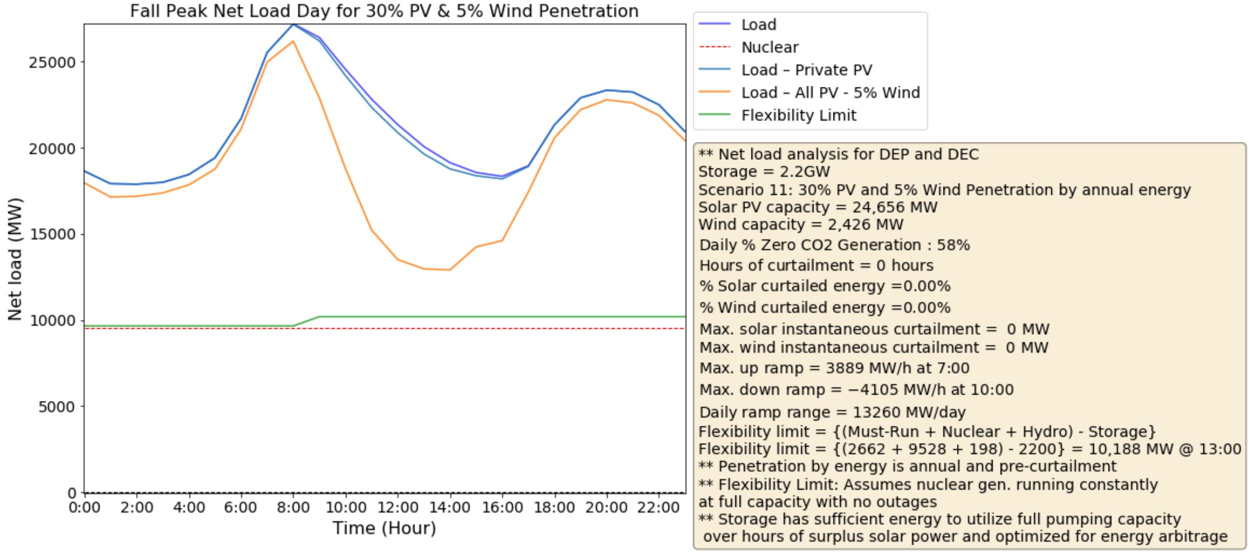


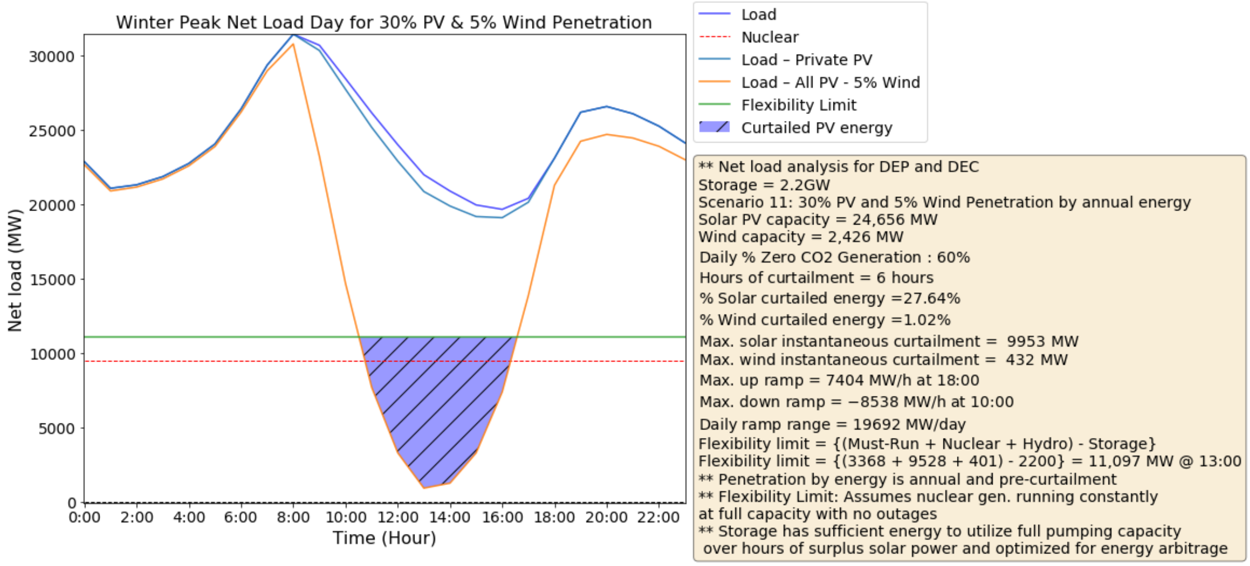

Winter Low Net Load Day for 30% PV & 5% Wind Penetration
Load
Nuclear
Load – Private PV
Load – All PV - 5% Wind
Flexibility Limit
Curtailed PV energy
15000
10000
5000
0
−5000
Net load (MW)
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time (Hour)
** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 11: 30% PV and 5% Wind Penetration by annual energy
Solar PV capacity = 24,656 MW
Wind capacity = 2,426 MW
Daily % Zero CO2 Generation : 87%
Hours of curtailment = 9 hours
% Solar curtailed energy =59.89%
% Wind curtailed energy =7.30%
Max. solar instantaneous curtailment = 17084 MW
Max. wind instantaneous curtailment = 1794 MW
Max. up ramp = 2502 MW/h at 18:00
Max. down ramp = −2241 MW/h at 09:00
Daily ramp range = 4338 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(2662 + 9528 + 298) - 2200} = 10288 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

Seasonal Peak Net Load Days



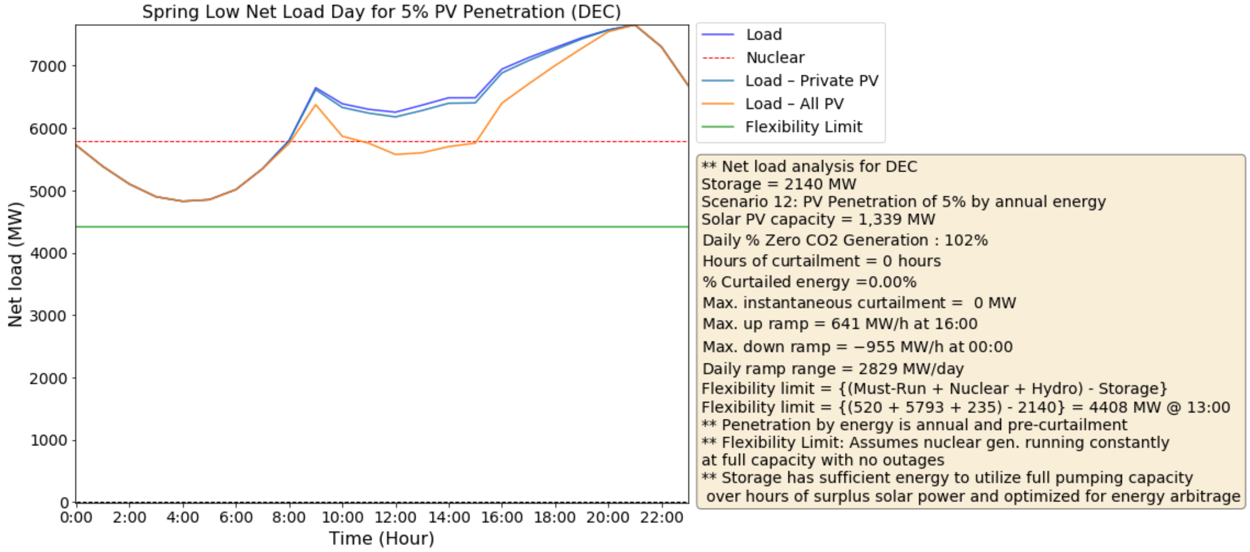


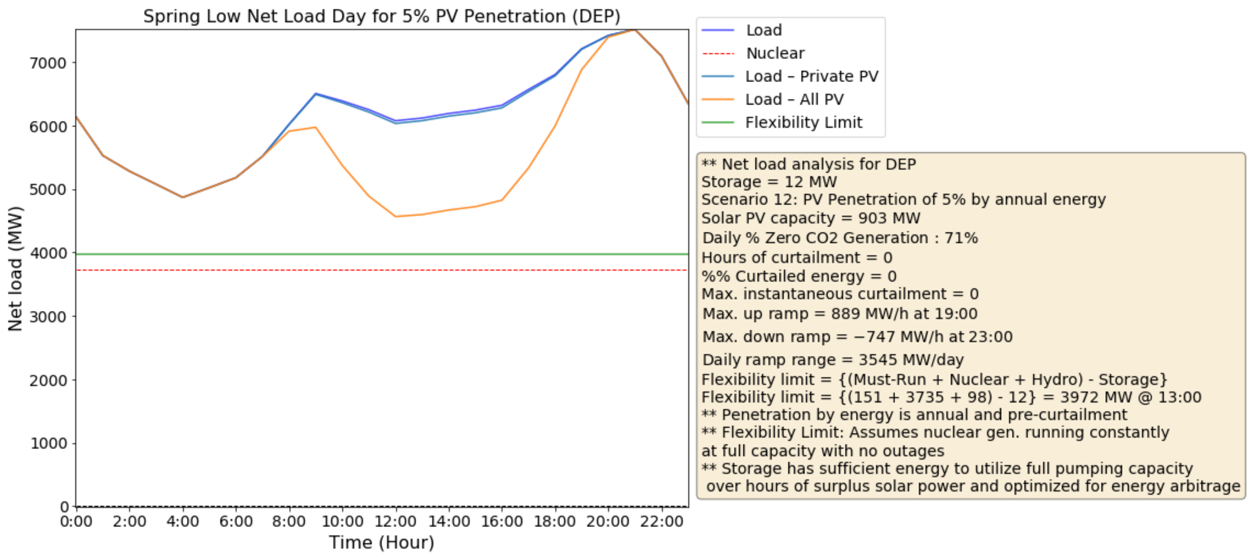

Fall Peak Net Load Day for 30% PV & 5% Wind Penetration
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV - 5% Wind
Flexibility Limit
** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 11: 30% PV and 5% Wind Penetration by annual energy
Solar PV capacity = 24,656 MW
Wind capacity = 2,426 MW
Daily % Zero CO2 Generation : 58%
Hours of curtailment = 0 hours
% Solar curtailed energy =0.00%
% Wind curtailed energy =0.00%
Max. solar instantaneous curtailment = 0 MW
Max. wind instantaneous curtailment = 0 MW
Max. up ramp = 3889 MW/h at 7:00
Max. down ramp = −4105 MW/h at 10:00
Daily ramp range = 13260 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(2662 + 9528 + 198) - 2200} = 10,188 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

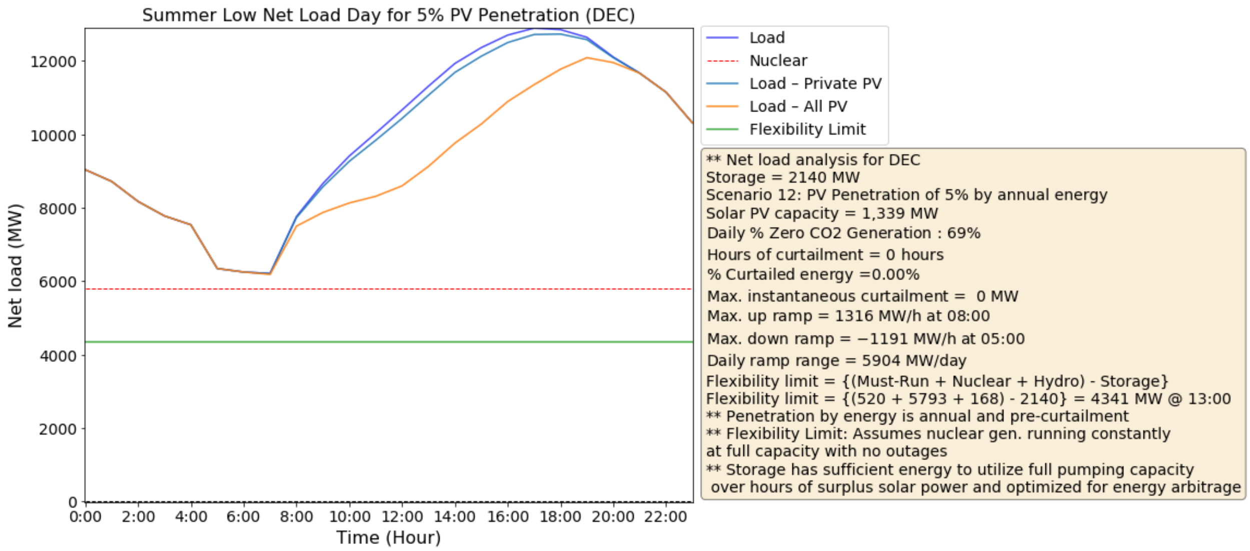

Winter Peak Net Load Day for 30% PV & 5% Wind Penetration
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV - 5% Wind
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 11: 30% PV and 5% Wind Penetration by annual energy
Solar PV capacity = 24,656 MW
Wind capacity = 2,426 MW
Daily % Zero CO2 Generation : 60%
Hours of curtailment = 6 hours
% Solar curtailed energy =27.64%
% Wind curtailed energy =1.02%
Max. solar instantaneous curtailment = 9953 MW
Max. wind instantaneous curtailment = 432 MW
Max. up ramp = 7404 MW/h at 18:00
Max. down ramp = −8538 MW/h at 10:00
Daily ramp range = 19692 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(3368 + 9528 + 401) - 2200} = 11,097 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

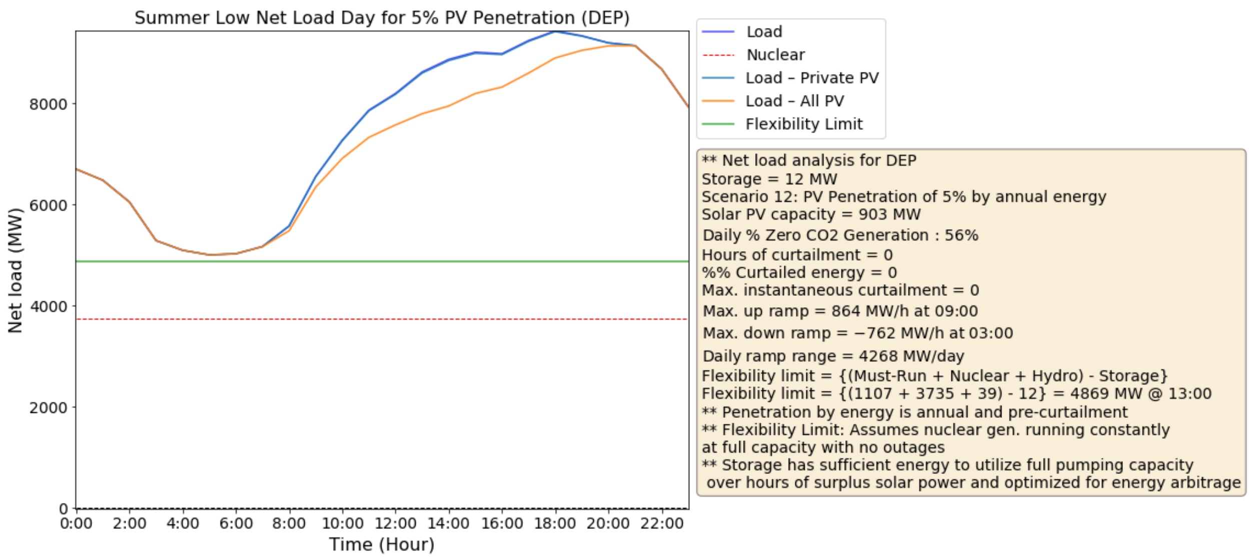
Scenario 12: DEC and DEP Modeled as Separate Balancing Authorities with 5%, 10%, and 15% PV Penetration

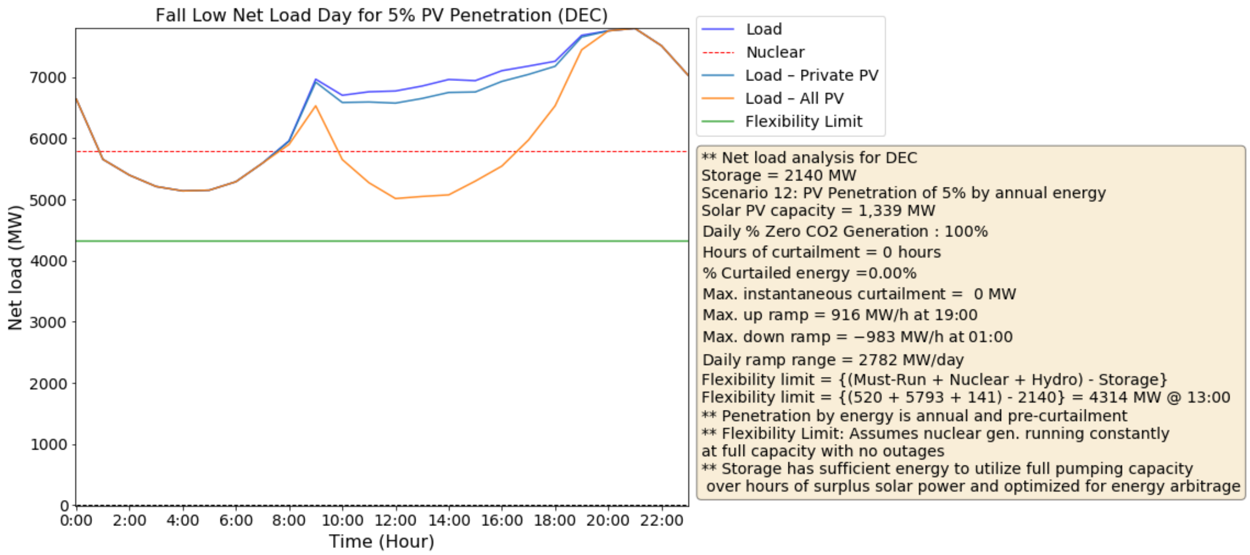
Seasonal Low Net Load Days: 5% PV Penetration

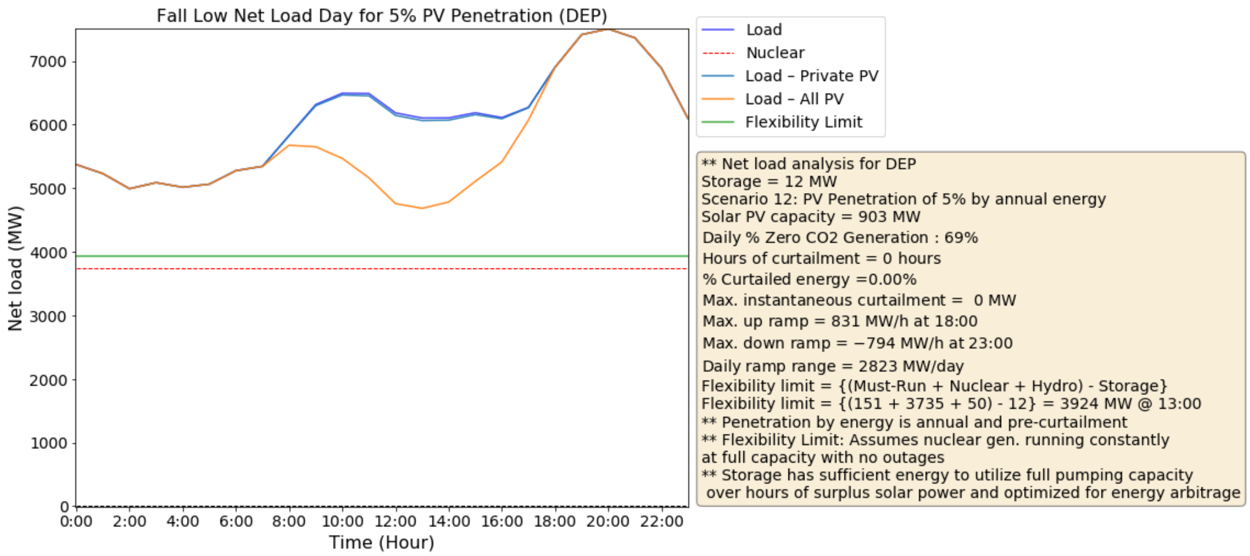


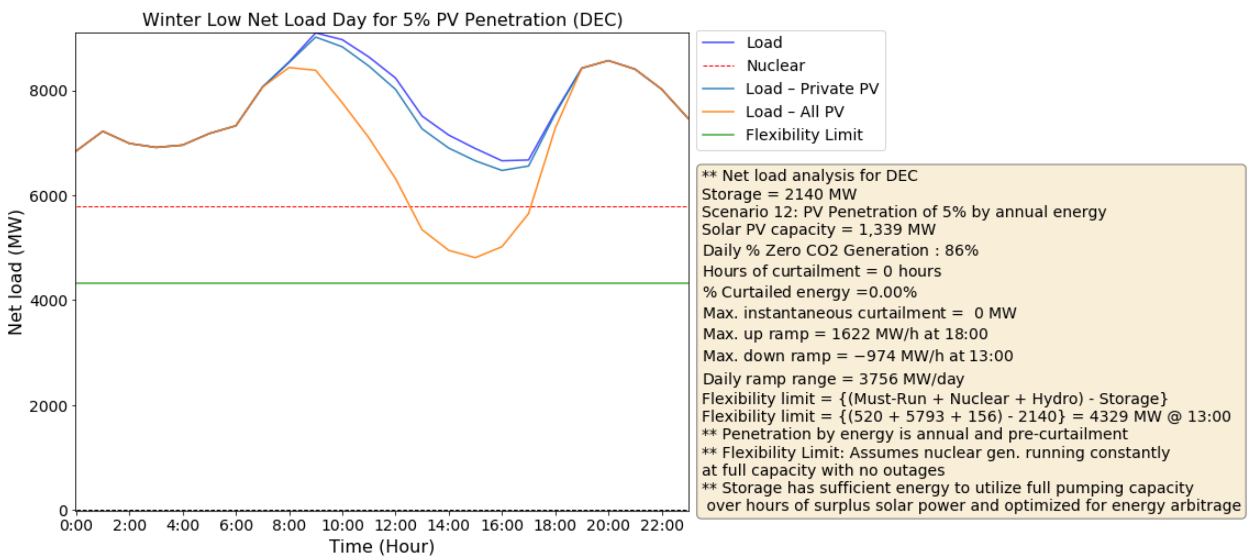


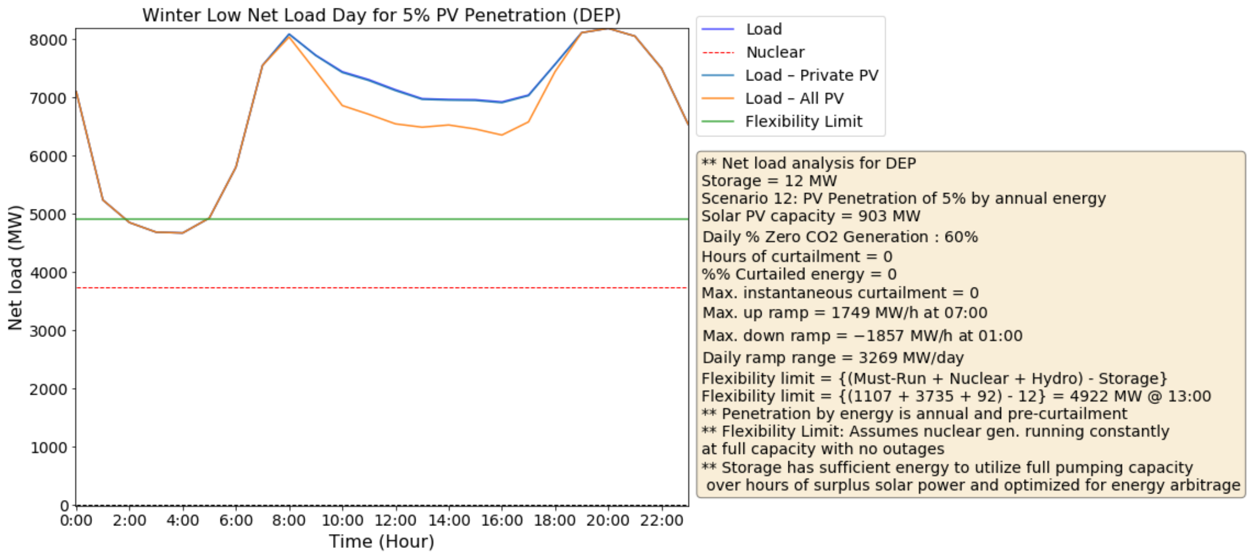

Summer Low Net Load Day for 5% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEC
Storage = 2140 MW
Scenario 12: PV Penetration of 5% by annual energy
Solar PV capacity = 1,339 MW
Daily % Zero CO2 Generation : 69%
Hours of curtailment = 0 hours
% Curtailed energy =0.00%
Max. instantaneous curtailment = 0 MW
Max. up ramp = 1316 MW/h at 08:00
Max. down ramp = −1191 MW/h at 05:00
Daily ramp range = 5904 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(520 + 5793 + 168) - 2140} = 4341 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage


Summer Low Net Load Day for 5% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEP
Storage = 12 MW
Scenario 12: PV Penetration of 5% by annual energy
Solar PV capacity = 903 MW
Daily % Zero CO2 Generation : 56%
Hours of curtailment = 0
%% Curtailed energy = 0
Max. instantaneous curtailment = 0
Max. up ramp = 864 MW/h at 09:00
Max. down ramp = −762 MW/h at 03:00
Daily ramp range = 4268 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1107 + 3735 + 39) - 12} = 4869 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

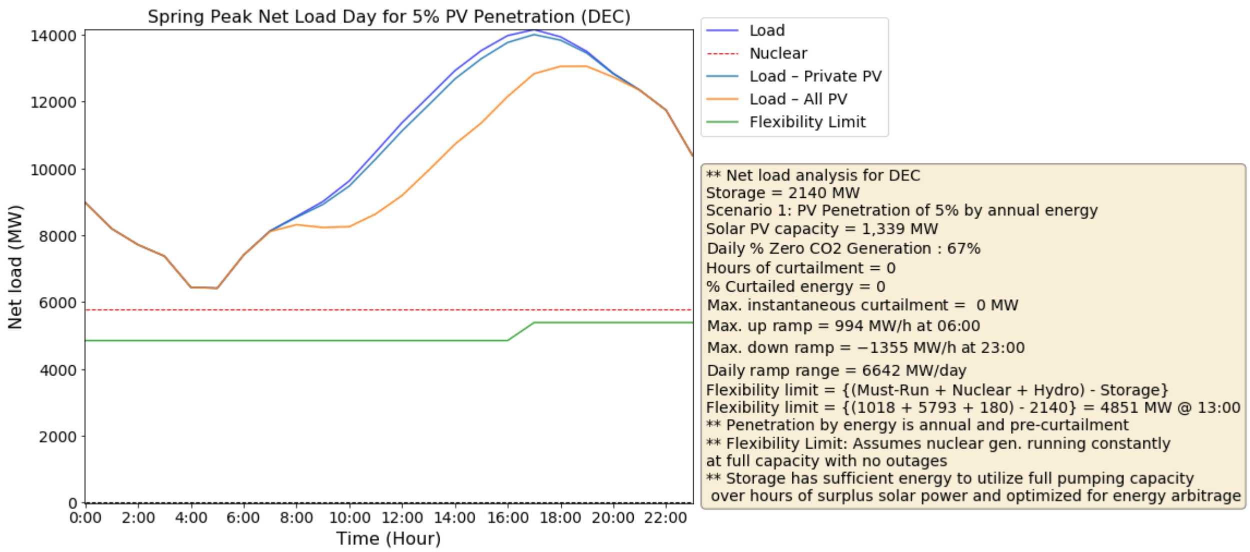

Fall Low Net Load Day for 5% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEC
Storage = 2140 MW
Scenario 12: PV Penetration of 5% by annual energy
Solar PV capacity = 1,339 MW
Daily % Zero CO2 Generation : 100%
Hours of curtailment = 0 hours
% Curtailed energy =0.00%
Max. instantaneous curtailment = 0 MW
Max. up ramp = 916 MW/h at 19:00
Max. down ramp = −983 MW/h at 01:00
Daily ramp range = 2782 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(520 + 5793 + 141) - 2140} = 4314 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

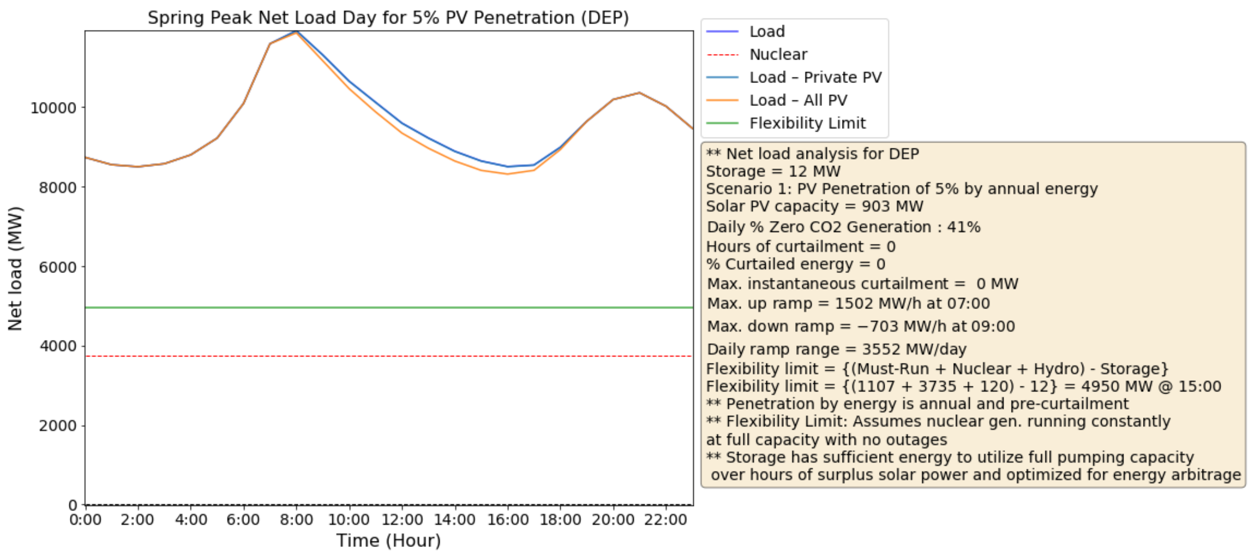

Fall Low Net Load Day for 5% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEP
Storage = 12 MW
Scenario 12: PV Penetration of 5% by annual energy
Solar PV capacity = 903 MW
Daily % Zero CO2 Generation : 69%
Hours of curtailment = 0 hours
% Curtailed energy =0.00%
Max. instantaneous curtailment = 0 MW
Max. up ramp = 831 MW/h at 18:00
Max. down ramp = −794 MW/h at 23:00
Daily ramp range = 2823 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(151 + 3735 + 50) - 12} = 3924 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

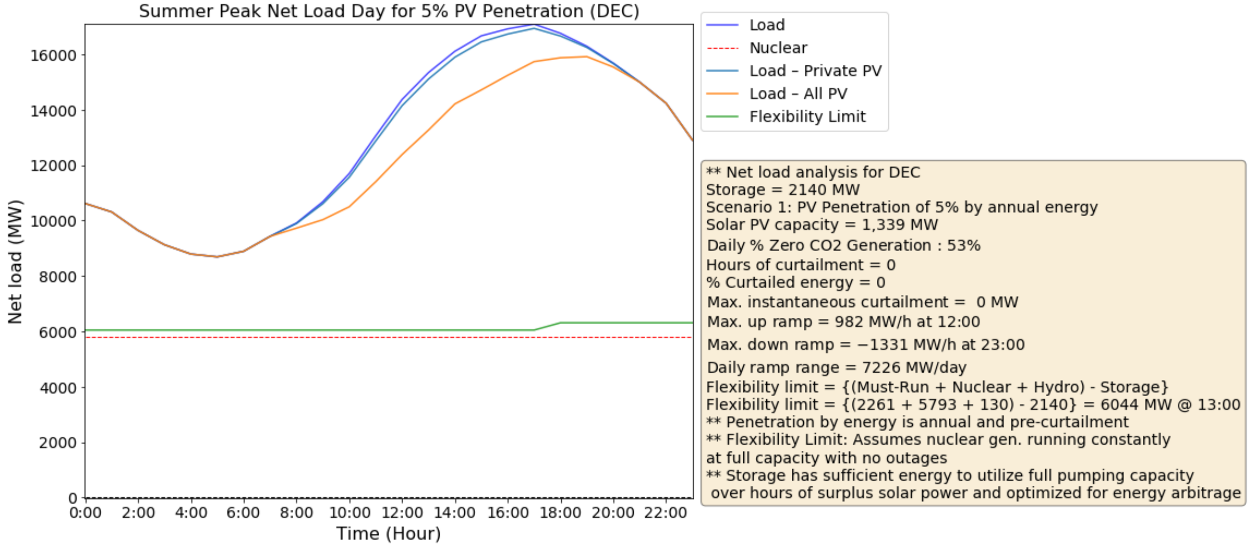

Winter Low Net Load Day for 5% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEC
Storage = 2140 MW
Scenario 12: PV Penetration of 5% by annual energy
Solar PV capacity = 1,339 MW
Daily % Zero CO2 Generation : 86%
Hours of curtailment = 0 hours
% Curtailed energy =0.00%
Max. instantaneous curtailment = 0 MW
Max. up ramp = 1622 MW/h at 18:00
Max. down ramp = −974 MW/h at 13:00
Daily ramp range = 3756 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(520 + 5793 + 156) - 2140} = 4329 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

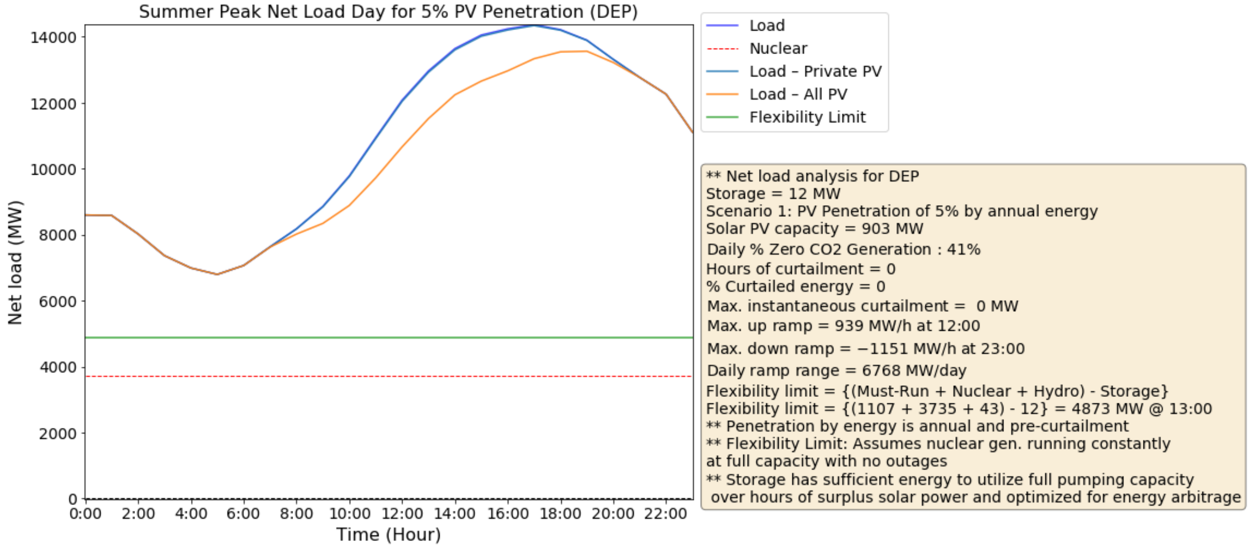

Winter Low Net Load Day for 5% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEP
Storage = 12 MW
Scenario 12: PV Penetration of 5% by annual energy
Solar PV capacity = 903 MW
Daily % Zero CO2 Generation : 60%
Hours of curtailment = 0
%% Curtailed energy = 0
Max. instantaneous curtailment = 0
Max. up ramp = 1749 MW/h at 07:00
Max. down ramp = −1857 MW/h at 01:00
Daily ramp range = 3269 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1107 + 3735 + 92) - 12} = 4922 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

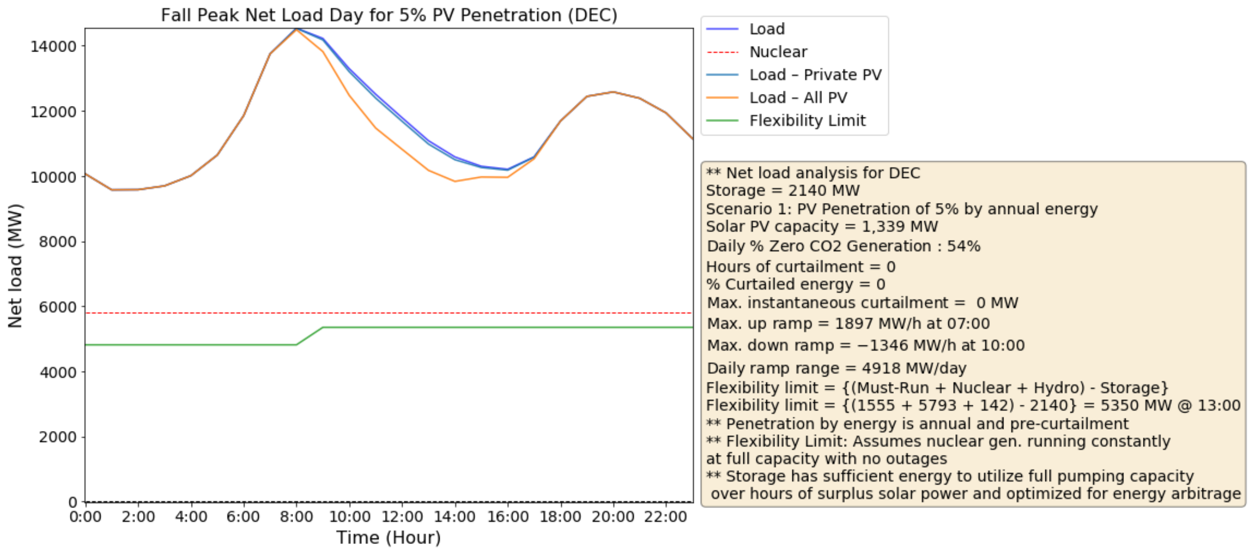
Seasonal Peak Net Load Days: 5% PV Penetration

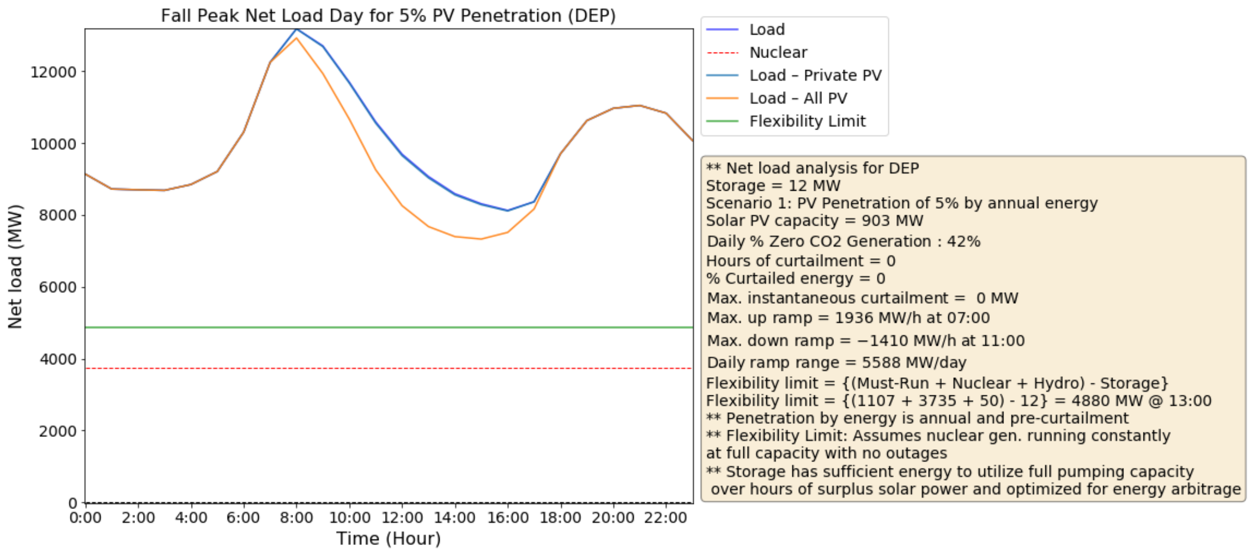


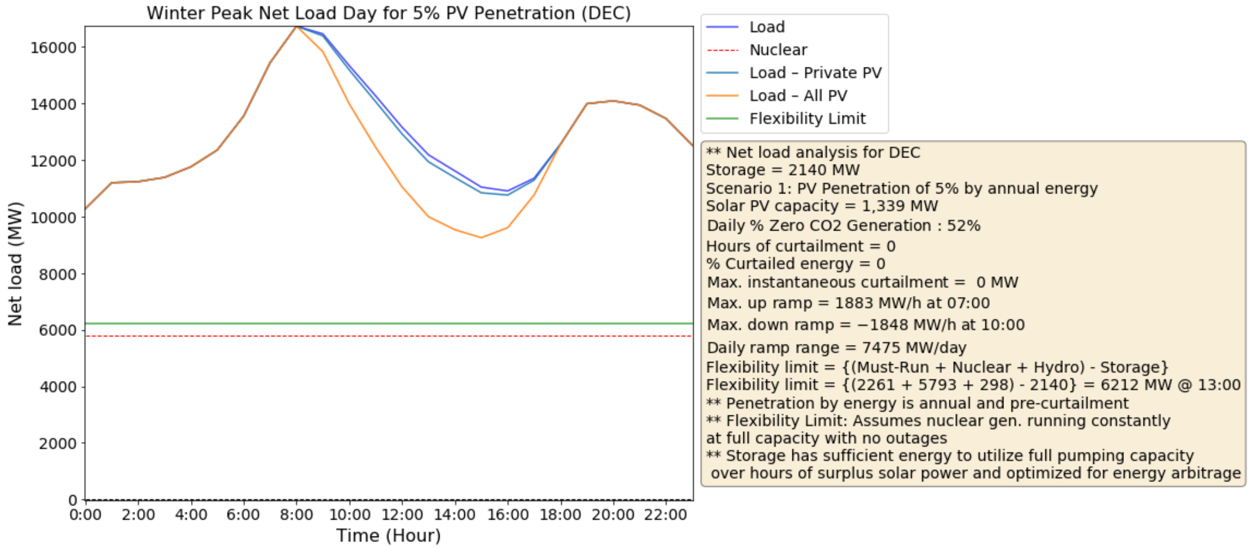


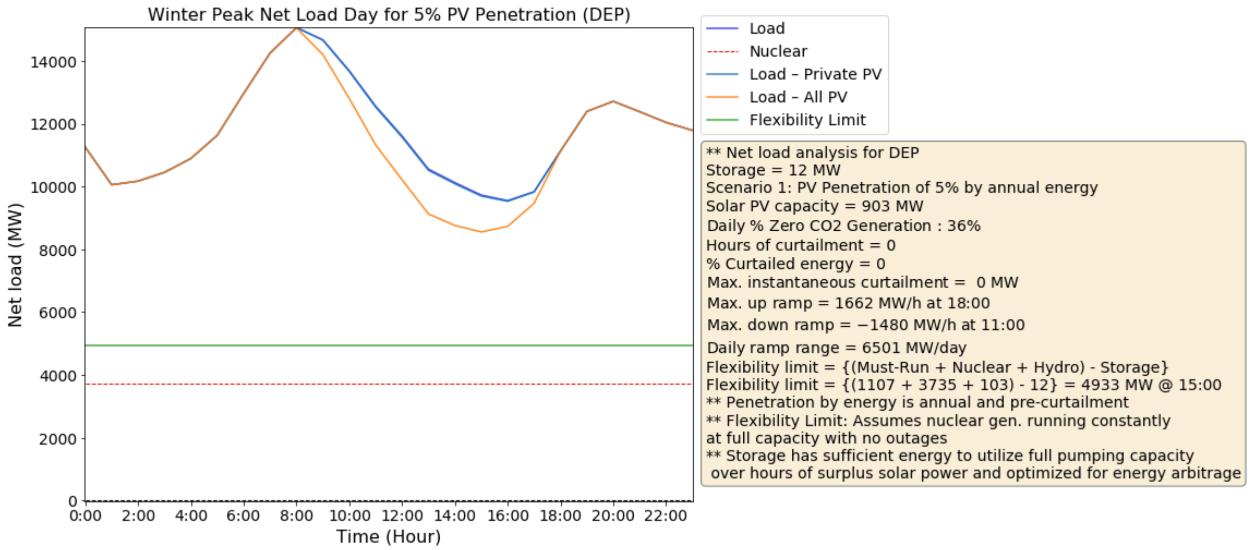

Summer Peak Net Load Day for 5% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEC
Storage = 2140 MW
Scenario 1: PV Penetration of 5% by annual energy
Solar PV capacity = 1,339 MW
Daily % Zero CO2 Generation : 53%
Hours of curtailment = 0
% Curtailed energy = 0
Max. instantaneous curtailment = 0 MW
Max. up ramp = 982 MW/h at 12:00
Max. down ramp = −1331 MW/h at 23:00
Daily ramp range = 7226 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(2261 + 5793 + 130) - 2140} = 6044 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage


Summer Peak Net Load Day for 5% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEP
Storage = 12 MW
Scenario 1: PV Penetration of 5% by annual energy
Solar PV capacity = 903 MW
Daily % Zero CO2 Generation : 41%
Hours of curtailment = 0
% Curtailed energy = 0
Max. instantaneous curtailment = 0 MW
Max. up ramp = 939 MW/h at 12:00
Max. down ramp = −1151 MW/h at 23:00
Daily ramp range = 6768 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1107 + 3735 + 43) - 12} = 4873 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

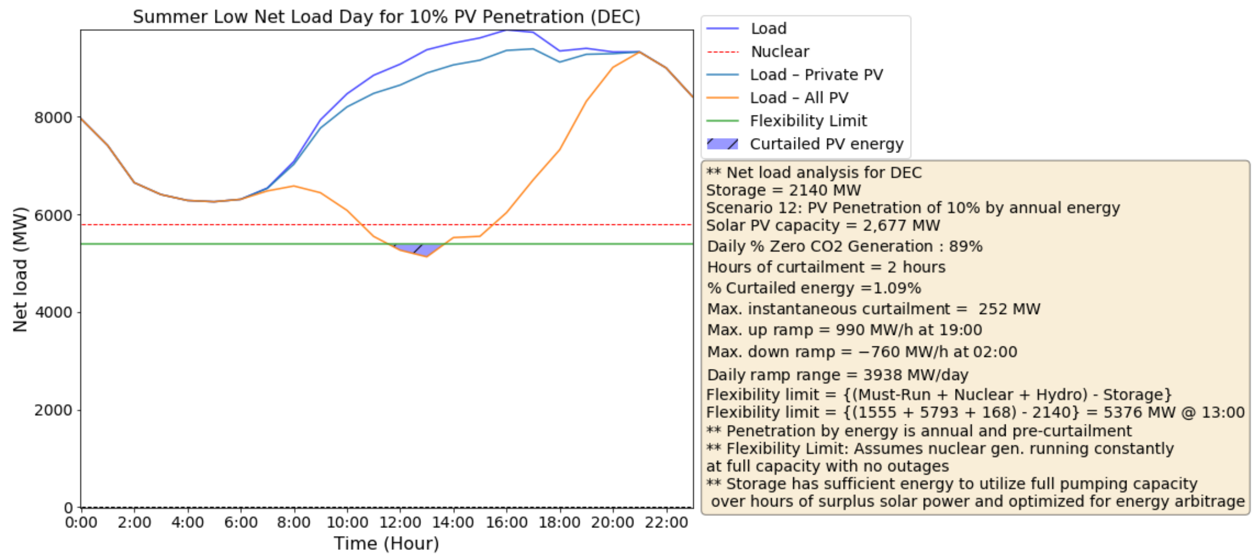

Fall Peak Net Load Day for 5% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEC
Storage = 2140 MW
Scenario 1: PV Penetration of 5% by annual energy
Solar PV capacity = 1,339 MW
Daily % Zero CO2 Generation : 54%
Hours of curtailment = 0
% Curtailed energy = 0
Max. instantaneous curtailment = 0 MW
Max. up ramp = 1897 MW/h at 07:00
Max. down ramp = −1346 MW/h at 10:00
Daily ramp range = 4918 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1555 + 5793 + 142) - 2140} = 5350 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

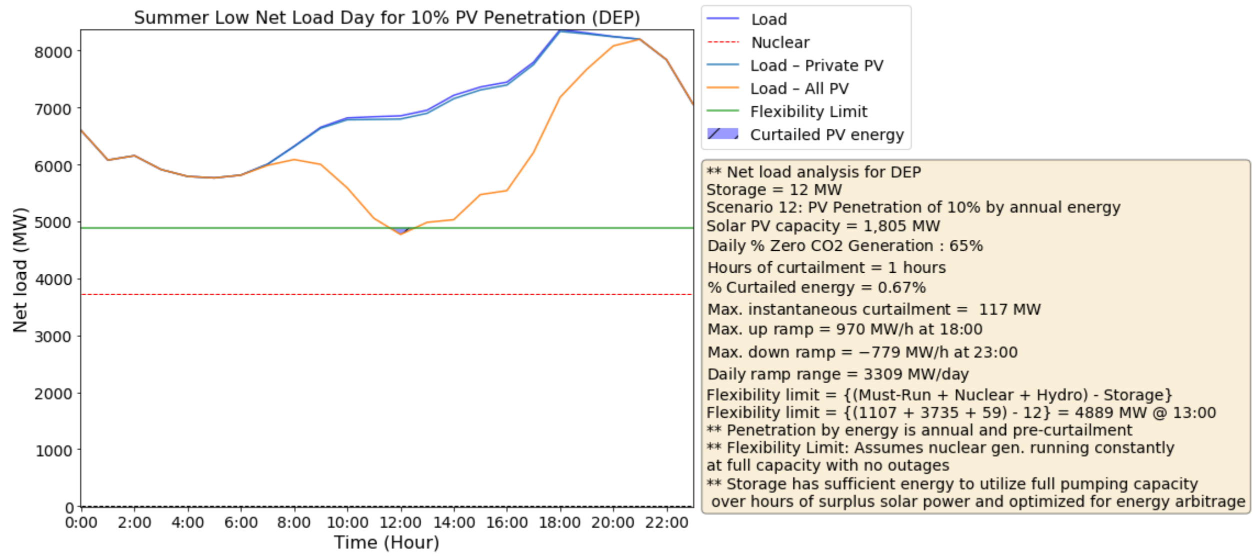

Fall Peak Net Load Day for 5% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEP
Storage = 12 MW
Scenario 1: PV Penetration of 5% by annual energy
Solar PV capacity = 903 MW
Daily % Zero CO2 Generation : 42%
Hours of curtailment = 0
% Curtailed energy = 0
Max. instantaneous curtailment = 0 MW
Max. up ramp = 1936 MW/h at 07:00
Max. down ramp = −1410 MW/h at 11:00
Daily ramp range = 5588 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1107 + 3735 + 50) - 12} = 4880 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

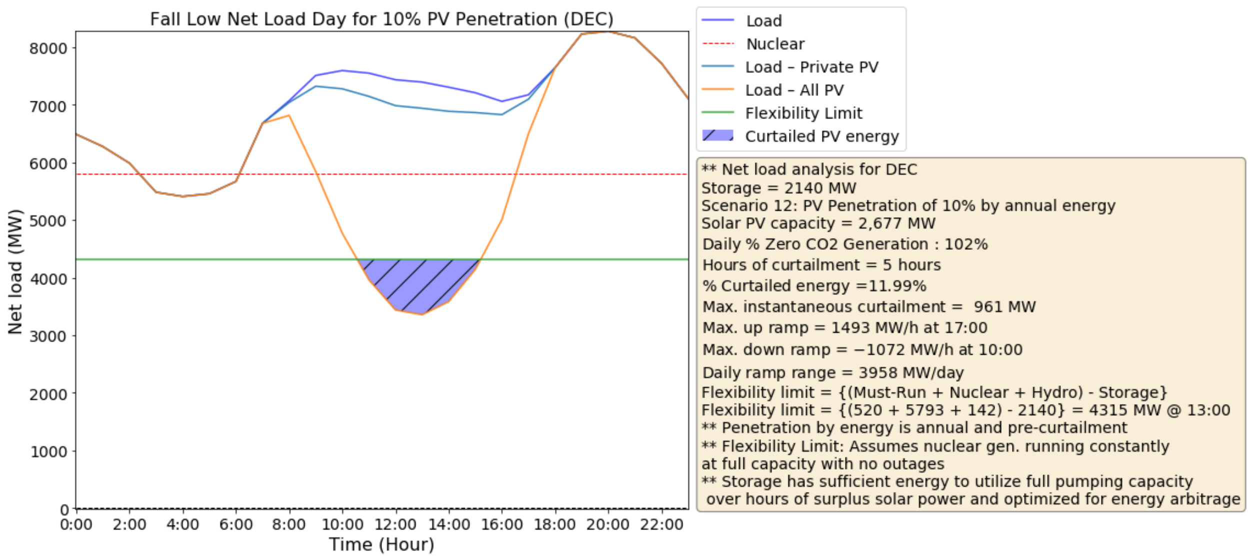

Winter Peak Net Load Day for 5% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEC
Storage = 2140 MW
Scenario 1: PV Penetration of 5% by annual energy
Solar PV capacity = 1,339 MW
Daily % Zero CO2 Generation : 52%
Hours of curtailment = 0
% Curtailed energy = 0
Max. instantaneous curtailment = 0 MW
Max. up ramp = 1883 MW/h at 07:00
Max. down ramp = −1848 MW/h at 10:00
Daily ramp range = 7475 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(2261 + 5793 + 298) - 2140} = 6212 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

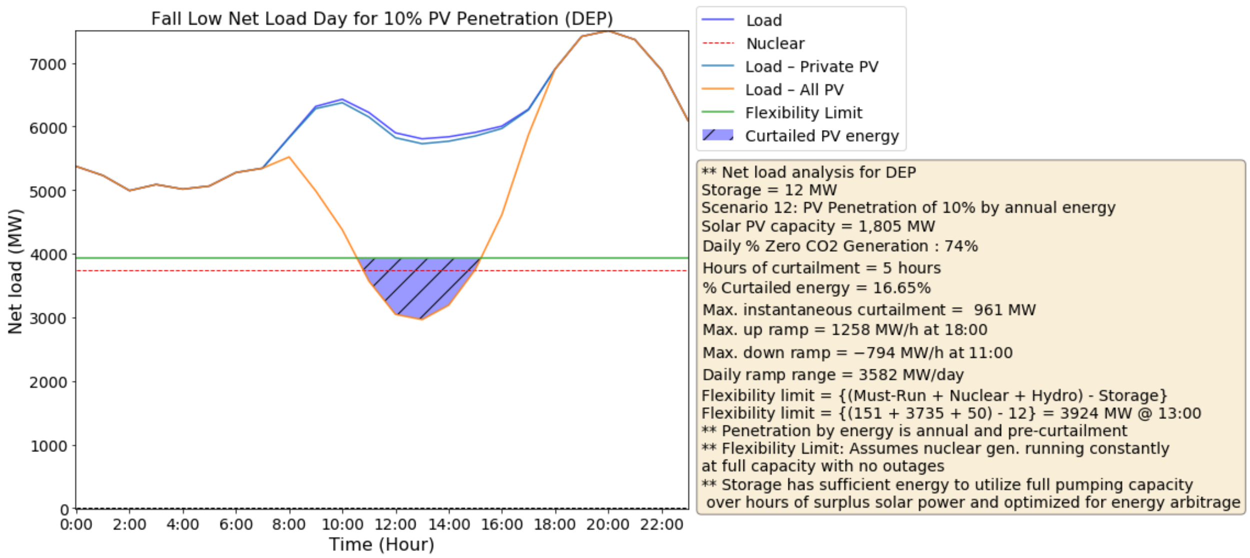

Winter Peak Net Load Day for 5% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEP
Storage = 12 MW
Scenario 1: PV Penetration of 5% by annual energy
Solar PV capacity = 903 MW
Daily % Zero CO2 Generation : 36%
Hours of curtailment = 0
% Curtailed energy = 0
Max. instantaneous curtailment = 0 MW
Max. up ramp = 1662 MW/h at 18:00
Max. down ramp = −1480 MW/h at 11:00
Daily ramp range = 6501 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1107 + 3735 + 103) - 12} = 4933 MW @ 15:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

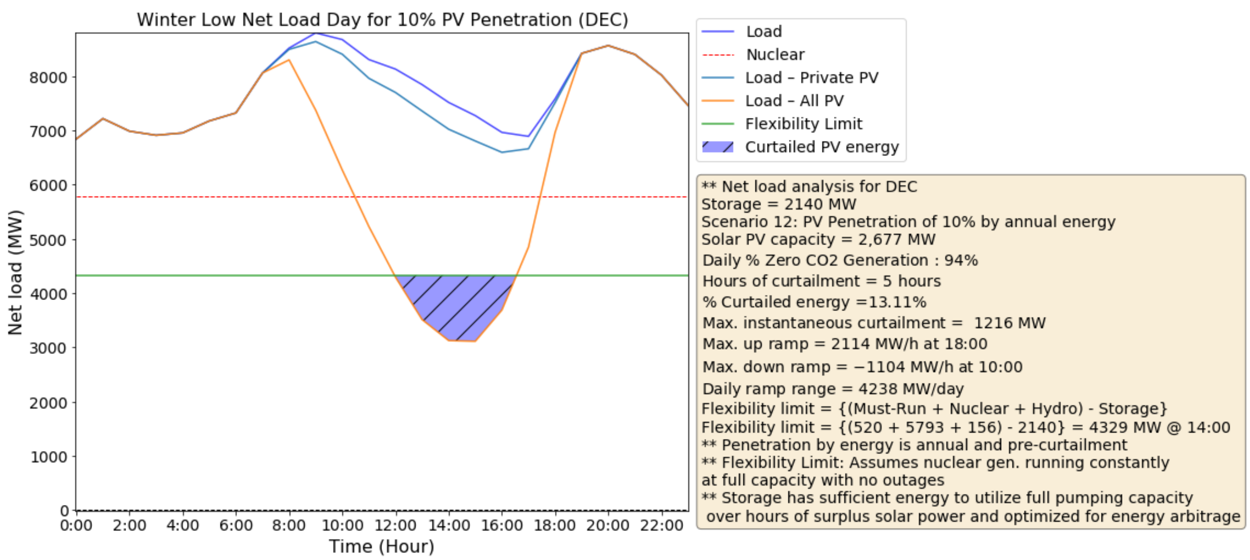
Seasonal Low Net Load Days: 10% PV Penetration

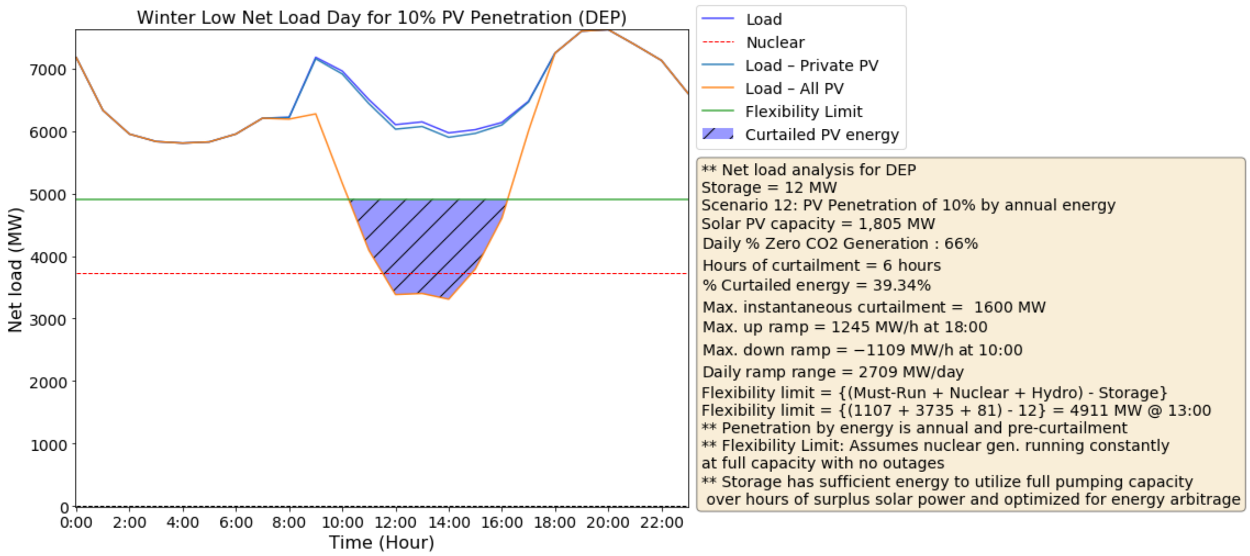




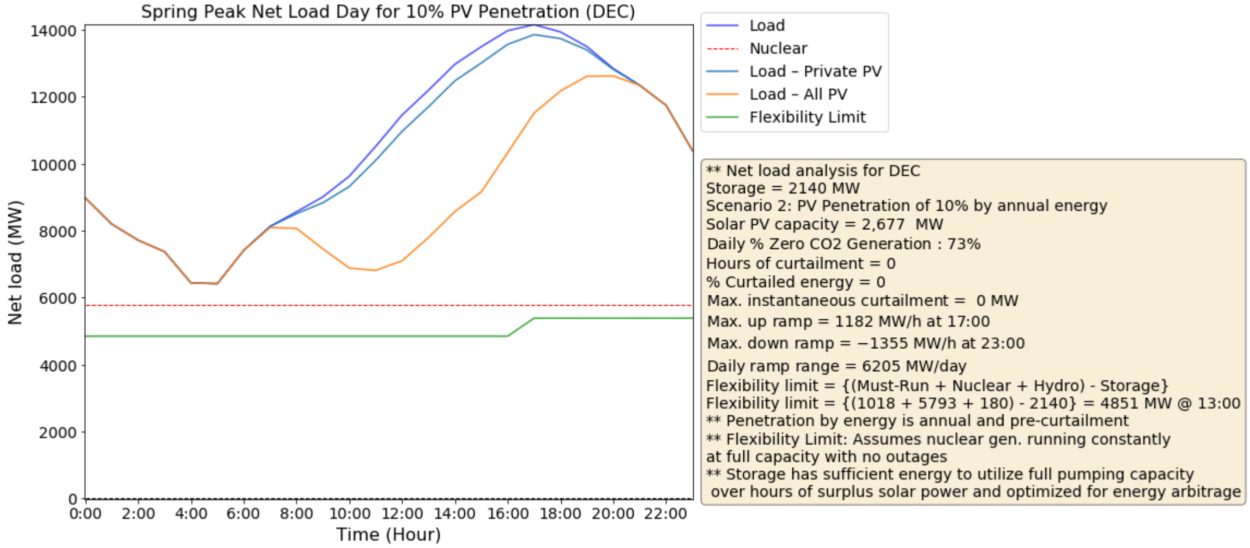

Fall Low Net Load Day for 10% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEC
Storage = 2140 MW
Scenario 12: PV Penetration of 10% by annual energy
Solar PV capacity = 2,677 MW
Daily % Zero CO2 Generation : 102%
Hours of curtailment = 5 hours
% Curtailed energy =11.99%
Max. instantaneous curtailment = 961 MW
Max. up ramp = 1493 MW/h at 17:00
Max. down ramp = −1072 MW/h at 10:00
Daily ramp range = 3958 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(520 + 5793 + 142) - 2140} = 4315 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

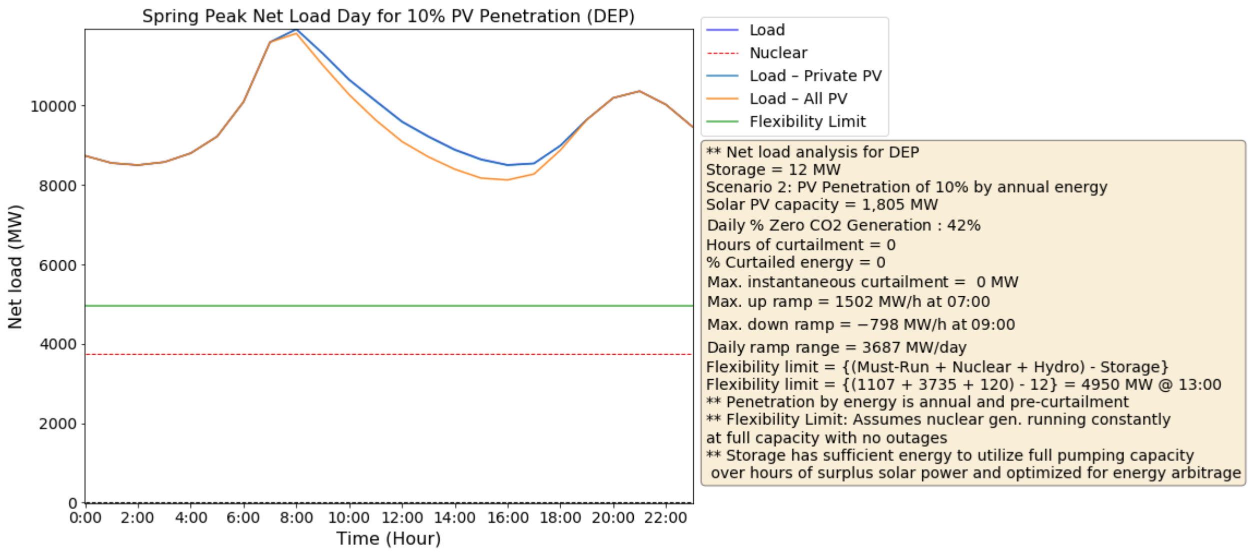

Fall Low Net Load Day for 10% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEP
Storage = 12 MW
Scenario 12: PV Penetration of 10% by annual energy
Solar PV capacity = 1,805 MW
Daily % Zero CO2 Generation : 74%
Hours of curtailment = 5 hours
% Curtailed energy = 16.65%
Max. instantaneous curtailment = 961 MW
Max. up ramp = 1258 MW/h at 18:00
Max. down ramp = −794 MW/h at 11:00
Daily ramp range = 3582 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(151 + 3735 + 50) - 12} = 3924 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

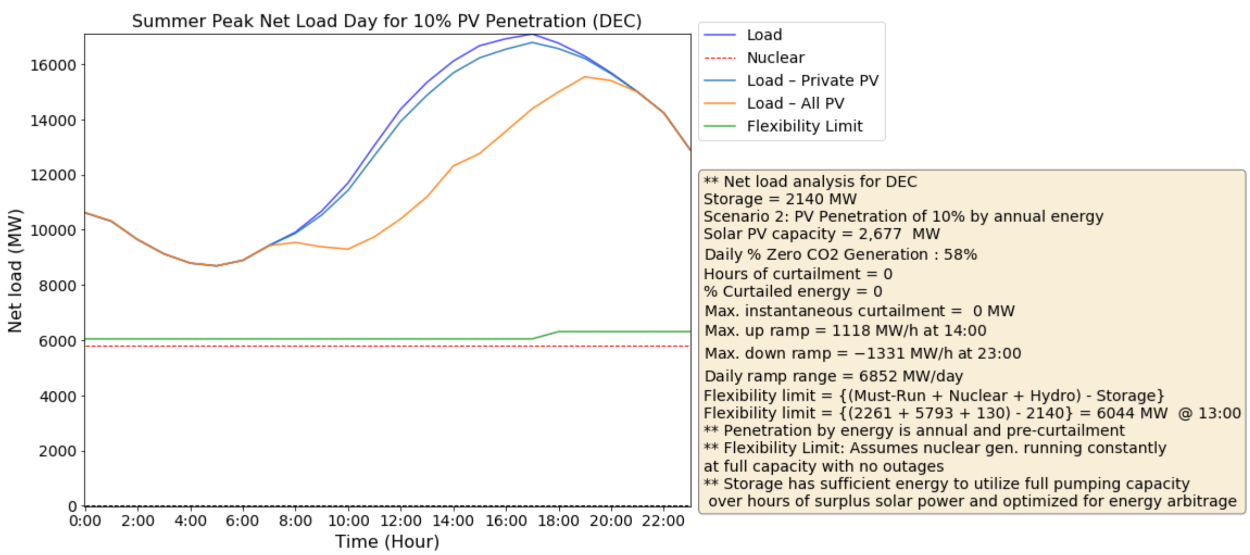

Winter Low Net Load Day for 10% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEC
Storage = 2140 MW
Scenario 12: PV Penetration of 10% by annual energy
Solar PV capacity = 2,677 MW
Daily % Zero CO2 Generation : 94%
Hours of curtailment = 5 hours
% Curtailed energy =13.11%
Max. instantaneous curtailment = 1216 MW
Max. up ramp = 2114 MW/h at 18:00
Max. down ramp = −1104 MW/h at 10:00
Daily ramp range = 4238 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(520 + 5793 + 156) - 2140} = 4329 MW @ 14:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

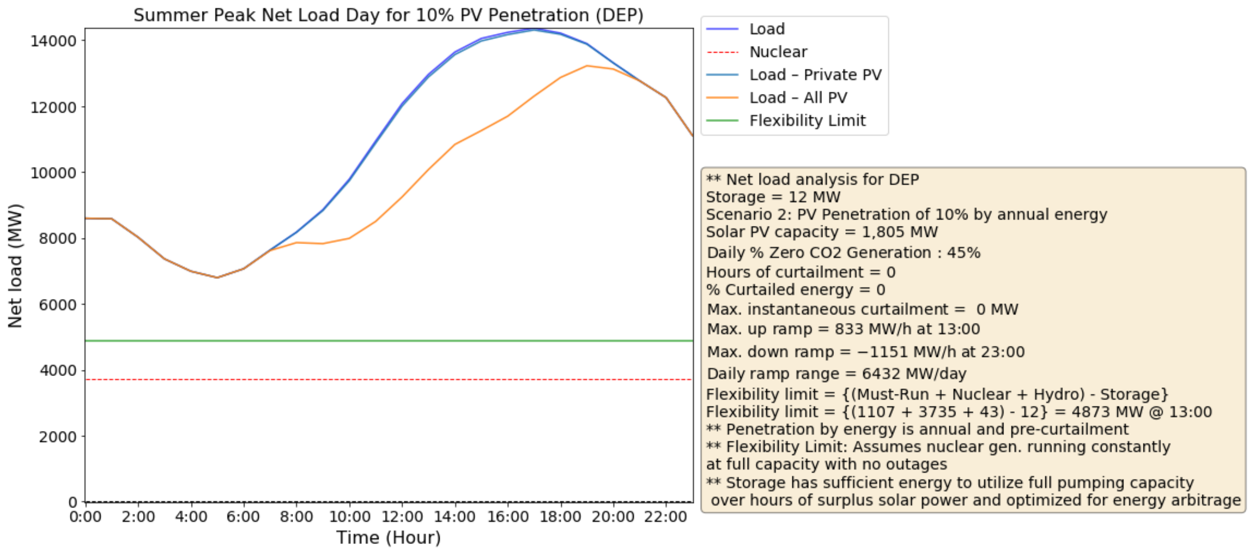

Winter Low Net Load Day for 10% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEP
Storage = 12 MW
Scenario 12: PV Penetration of 10% by annual energy
Solar PV capacity = 1,805 MW
Daily % Zero CO2 Generation : 66%
Hours of curtailment = 6 hours
% Curtailed energy = 39.34%
Max. instantaneous curtailment = 1600 MW
Max. up ramp = 1245 MW/h at 18:00
Max. down ramp = −1109 MW/h at 10:00
Daily ramp range = 2709 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1107 + 3735 + 81) - 12} = 4911 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

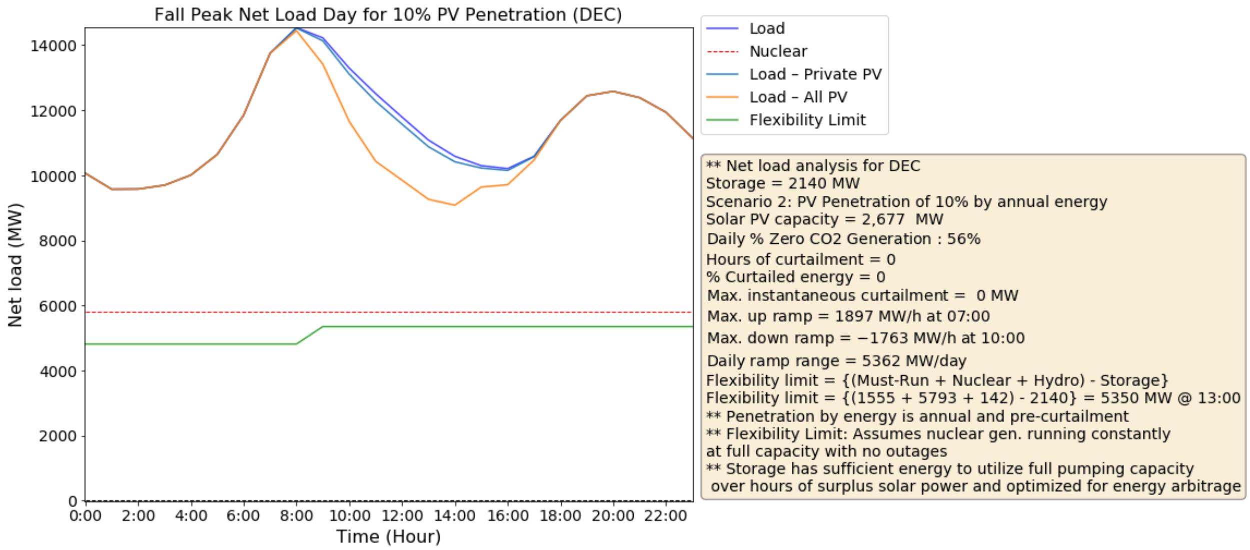
Seasonal Peak Net Load Days: 10% PV Penetration

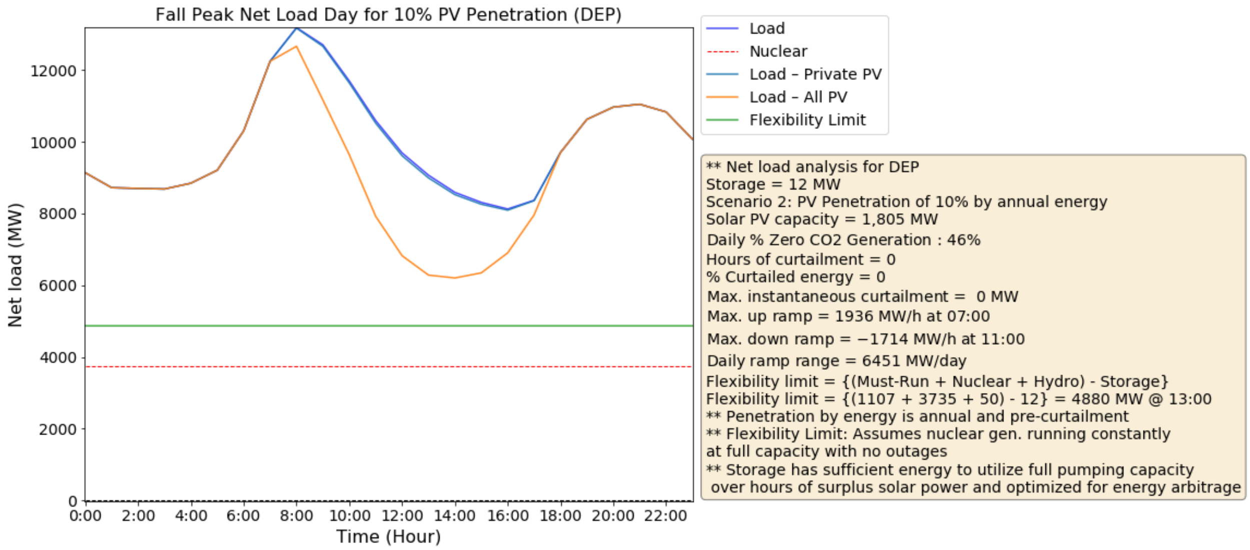


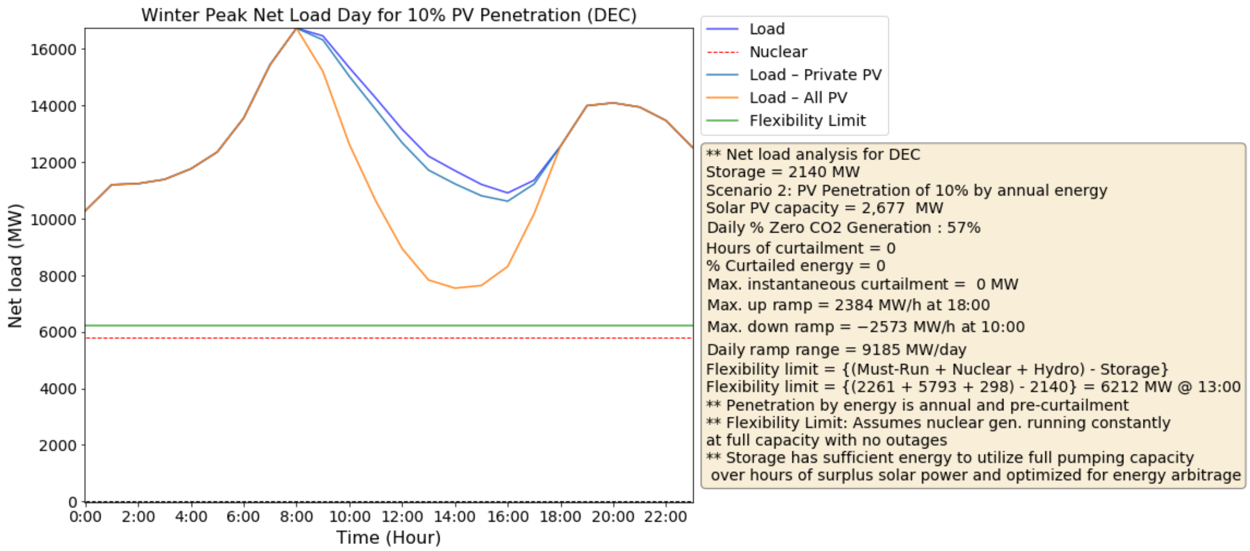


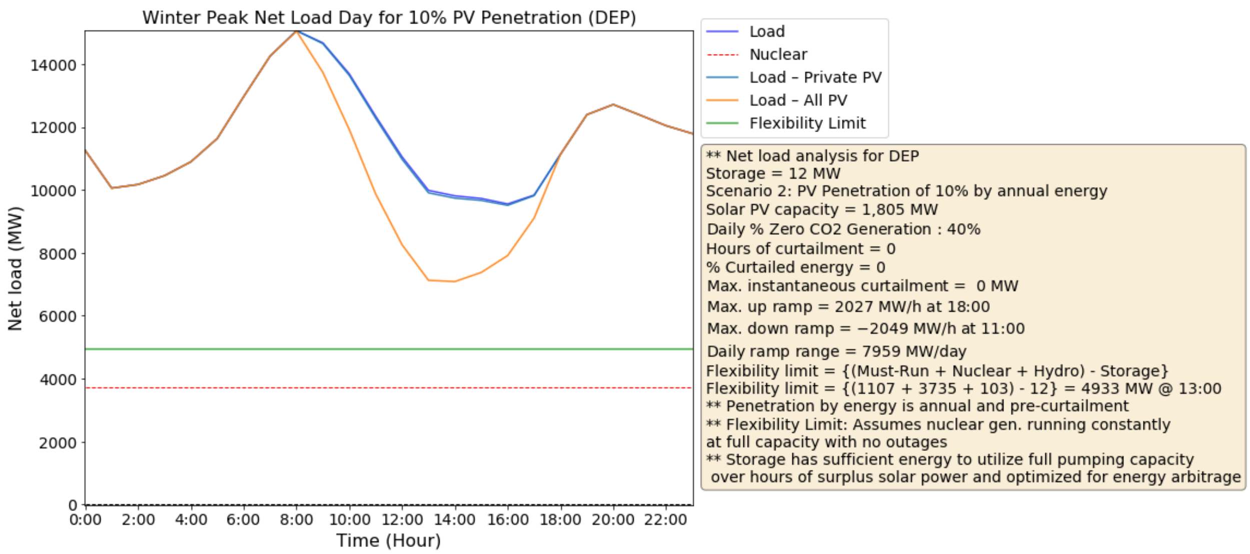



Summer Peak Net Load Day for 10% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load - Private PV
Load - All PV
Flexibility Limit
** Net load analysis for DEP
Storage = 12 MW
Scenario 2: PV Penetration of 10% by annual energy
Solar PV capacity = 1,805 MW
Daily % Zero CO2 Generation : 45%
Hours of curtailment = 0
% Curtailed energy = 0
Max. instantaneous curtailment = 0 MW
Max. up ramp = 833 MW/h at 13:00
Max. down ramp = −1151 MW/h at 23:00
Daily ramp range = 6432 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1107 + 3735 + 43) - 12} = 4873 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

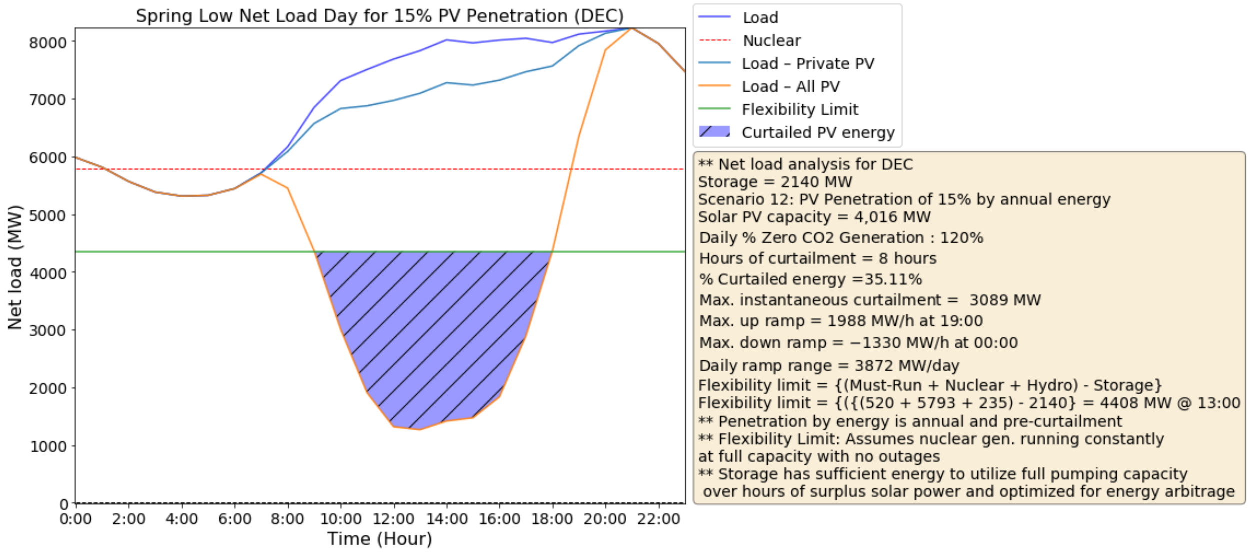

Fall Peak Net Load Day for 10% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load - Private PV
Load - All PV
Flexibility Limit
** Net load analysis for DEC
Storage = 2140 MW
Scenario 2: PV Penetration of 10% by annual energy
Solar PV capacity = 2,677 MW
Daily % Zero CO2 Generation : 56%
Hours of curtailment = 0
% Curtailed energy = 0
Max. instantaneous curtailment = 0 MW
Max. up ramp = 1897 MW/h at 07:00
Max. down ramp = −1763 MW/h at 10:00
Daily ramp range = 5362 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1555 + 5793 + 142) - 2140} = 5350 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

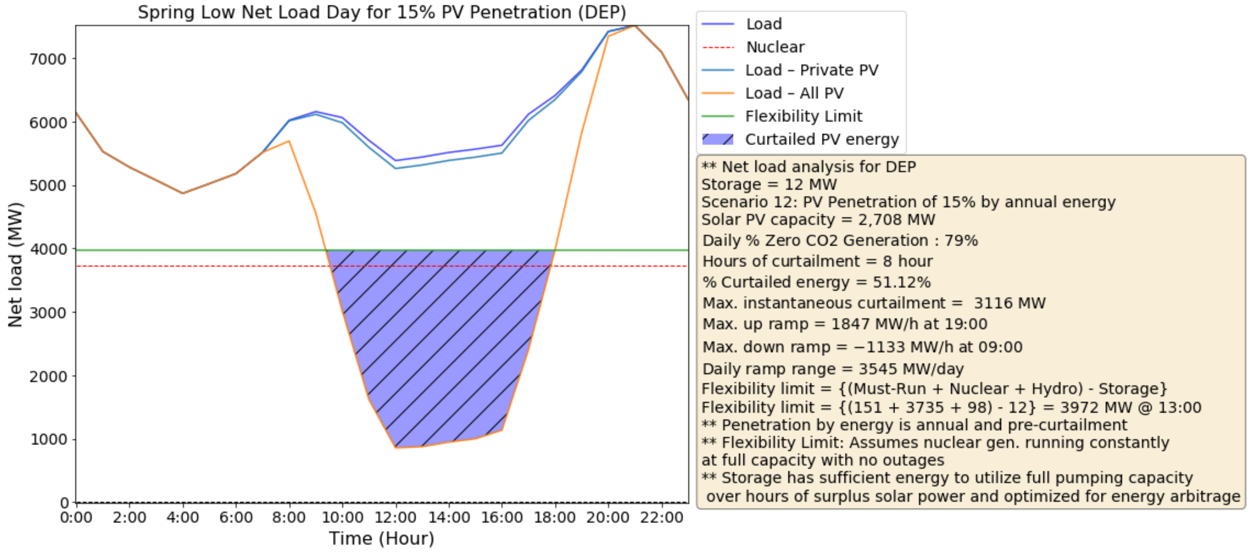

Fall Peak Net Load Day for 10% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load - Private PV
Load - All PV
Flexibility Limit
** Net load analysis for DEP
Storage = 12 MW
Scenario 2: PV Penetration of 10% by annual energy
Solar PV capacity = 1,805 MW
Daily % Zero CO2 Generation : 46%
Hours of curtailment = 0
% Curtailed energy = 0
Max. instantaneous curtailment = 0 MW
Max. up ramp = 1936 MW/h at 07:00
Max. down ramp = −1714 MW/h at 11:00
Daily ramp range = 6451 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1107 + 3735 + 50) - 12} = 4880 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

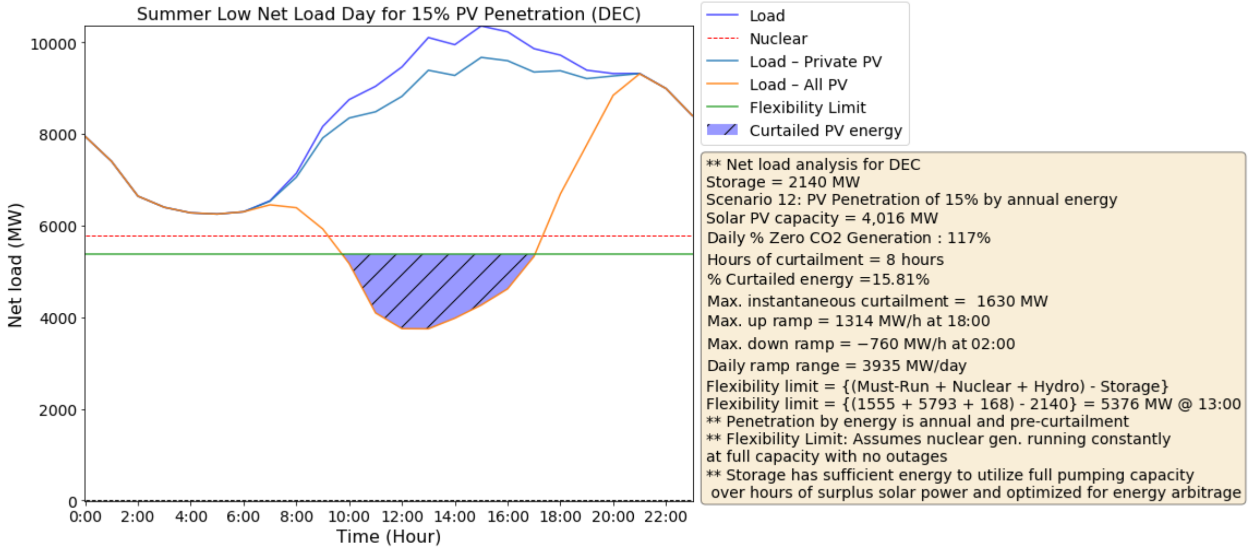

Winter Peak Net Load Day for 10% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEC
Storage = 2140 MW
Scenario 2: PV Penetration of 10% by annual energy
Solar PV capacity = 2,677 MW
Daily % Zero CO2 Generation : 57%
Hours of curtailment = 0
% Curtailed energy = 0
Max. instantaneous curtailment = 0 MW
Max. up ramp = 2384 MW/h at 18:00
Max. down ramp = −2573 MW/h at 10:00
Daily ramp range = 9185 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(2261 + 5793 + 298) - 2140} = 6212 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

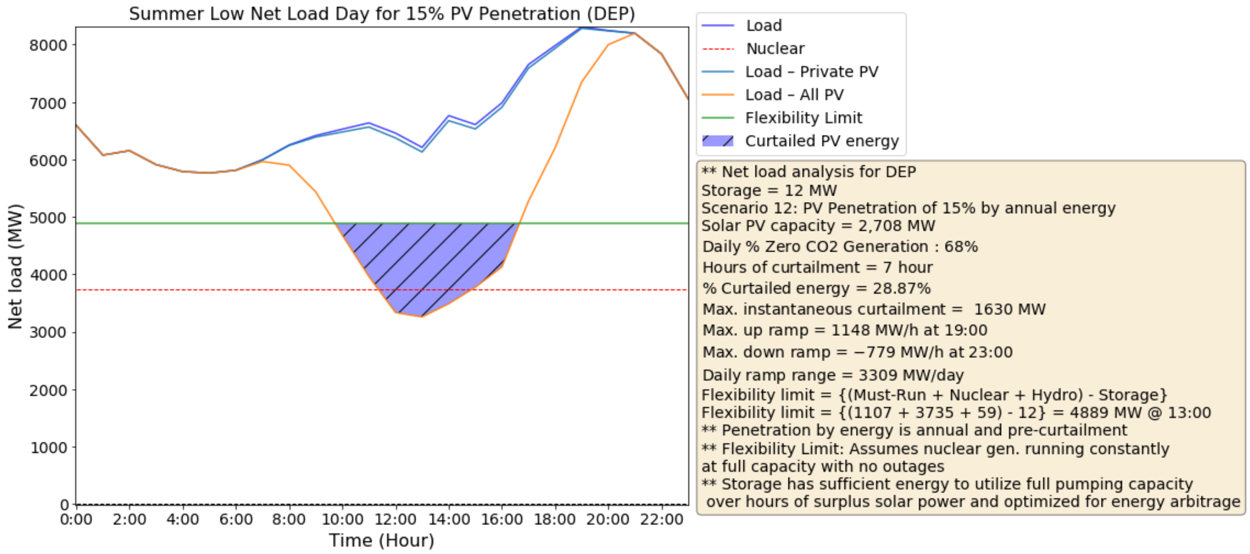

Winter Peak Net Load Day for 10% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEP
Storage = 12 MW
Scenario 2: PV Penetration of 10% by annual energy
Solar PV capacity = 1,805 MW
Daily % Zero CO2 Generation : 40%
Hours of curtailment = 0
% Curtailed energy = 0
Max. instantaneous curtailment = 0 MW
Max. up ramp = 2027 MW/h at 18:00
Max. down ramp = −2049 MW/h at 11:00
Daily ramp range = 7959 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1107 + 3735 + 103) - 12} = 4933 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

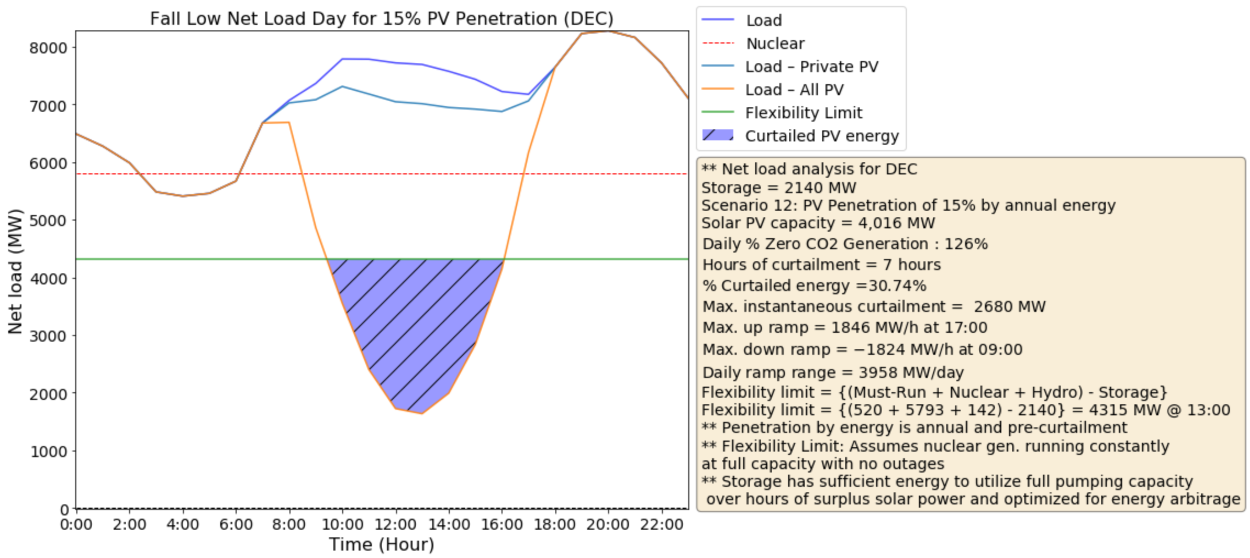
Seasonal Low Net Load Days: 15% PV Penetration

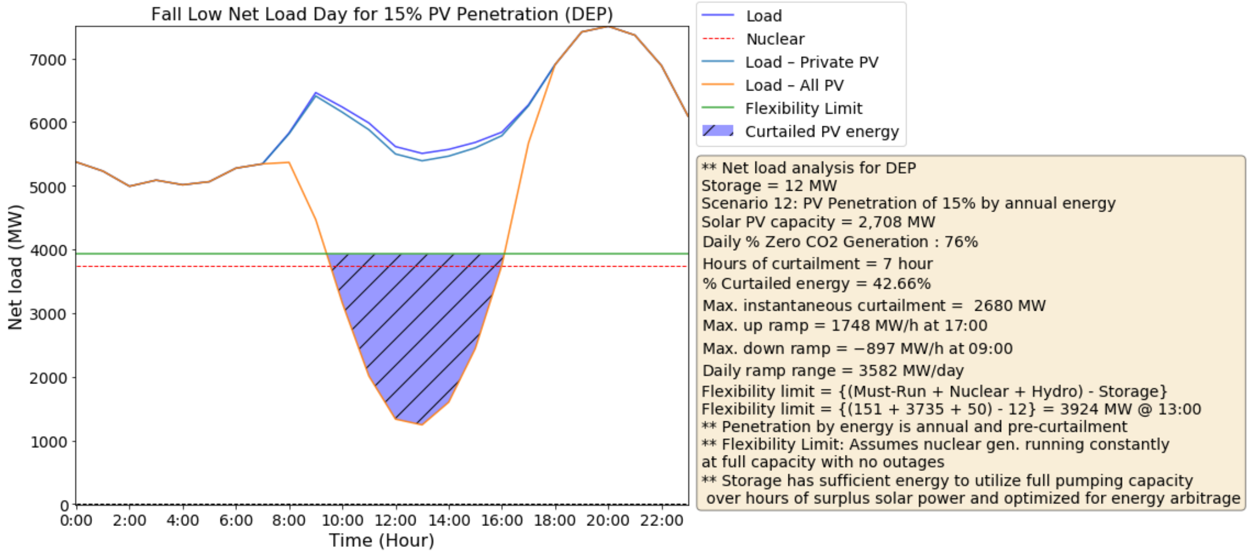


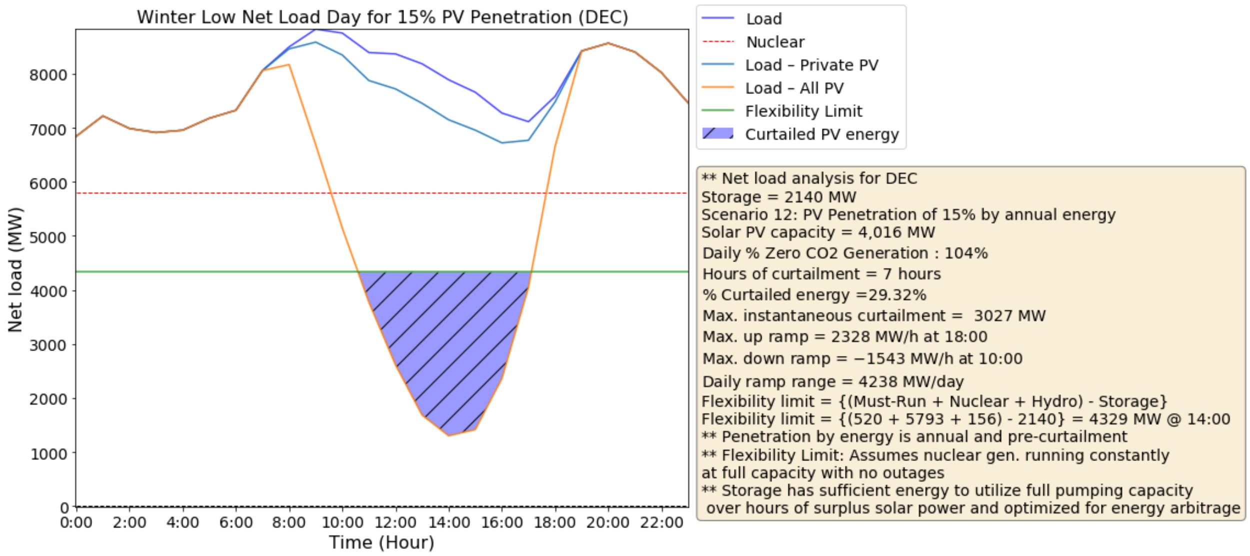


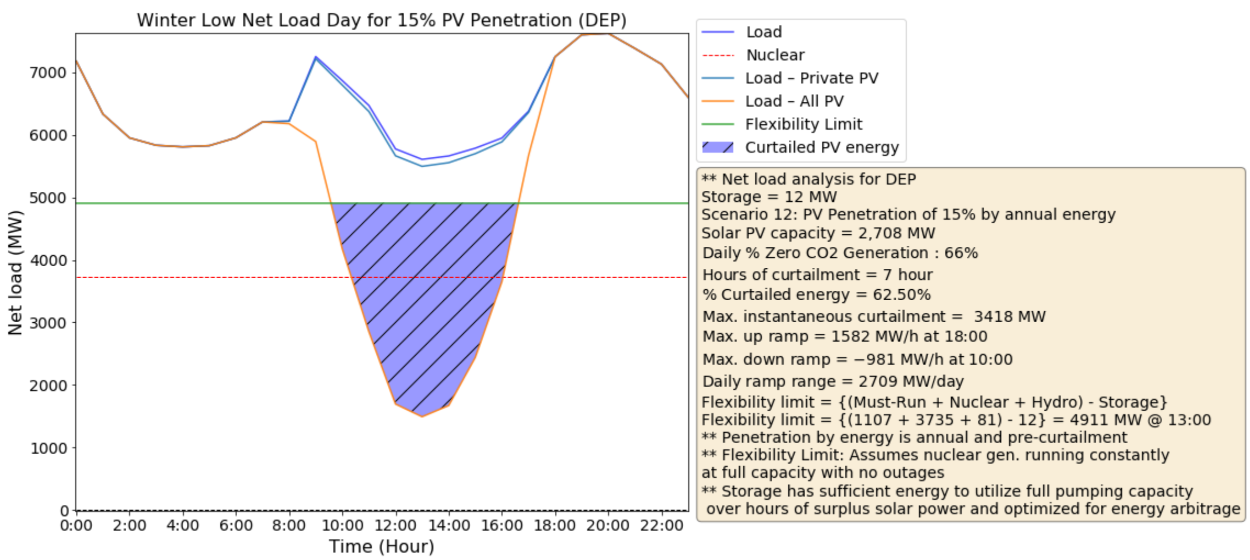

Summer Low Net Load Day for 15% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEC
Storage = 2140 MW
Scenario 12: PV Penetration of 15% by annual energy
Solar PV capacity = 4,016 MW
Daily % Zero CO2 Generation : 117%
Hours of curtailment = 8 hours
% Curtailed energy =15.81%
Max. instantaneous curtailment = 1630 MW
Max. up ramp = 1314 MW/h at 18:00
Max. down ramp = −760 MW/h at 02:00
Daily ramp range = 3935 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1555 + 5793 + 168) - 2140} = 5376 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage


Summer Low Net Load Day for 15% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEP
Storage = 12 MW
Scenario 12: PV Penetration of 15% by annual energy
Solar PV capacity = 2,708 MW
Daily % Zero CO2 Generation : 68%
Hours of curtailment = 7 hour
% Curtailed energy = 28.87%
Max. instantaneous curtailment = 1630 MW
Max. up ramp = 1148 MW/h at 19:00
Max. down ramp = −779 MW/h at 23:00
Daily ramp range = 3309 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1107 + 3735 + 59) - 12} = 4889 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

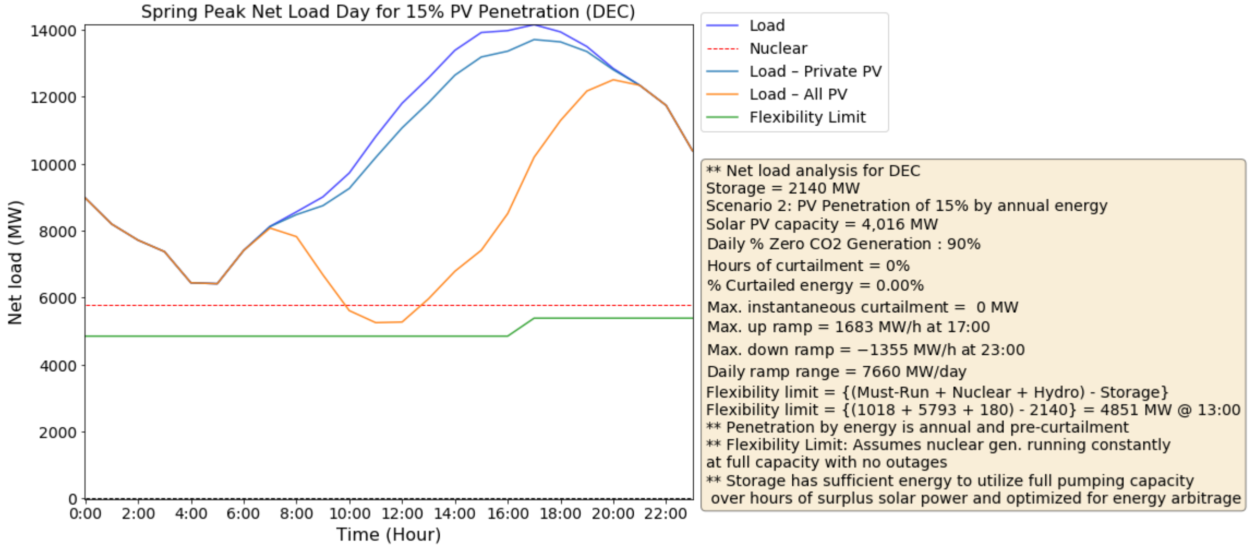

Fall Low Net Load Day for 15% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEC
Storage = 2140 MW
Scenario 12: PV Penetration of 15% by annual energy
Solar PV capacity = 4,016 MW
Daily % Zero CO2 Generation : 126%
Hours of curtailment = 7 hours
% Curtailed energy =30.74%
Max. instantaneous curtailment = 2680 MW
Max. up ramp = 1846 MW/h at 17:00
Max. down ramp = −1824 MW/h at 09:00
Daily ramp range = 3958 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(520 + 5793 + 142) - 2140} = 4315 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

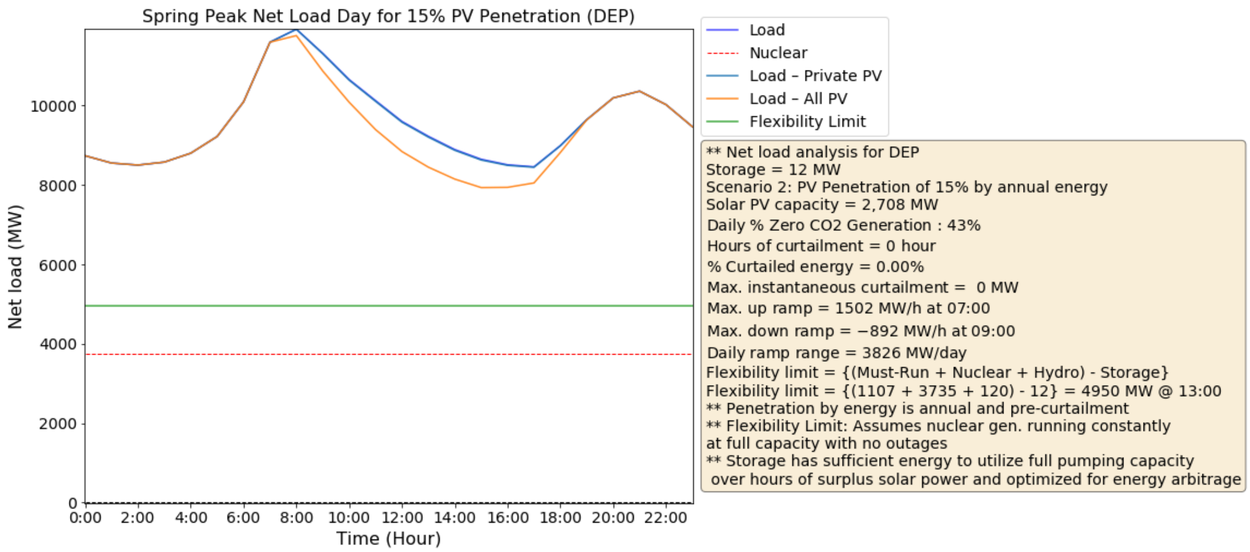

Fall Low Net Load Day for 15% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEP
Storage = 12 MW
Scenario 12: PV Penetration of 15% by annual energy
Solar PV capacity = 2,708 MW
Daily % Zero CO2 Generation : 76%
Hours of curtailment = 7 hour
% Curtailed energy = 42.66%
Max. instantaneous curtailment = 2680 MW
Max. up ramp = 1748 MW/h at 17:00
Max. down ramp = −897 MW/h at 09:00
Daily ramp range = 3582 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(151 + 3735 + 50) - 12} = 3924 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

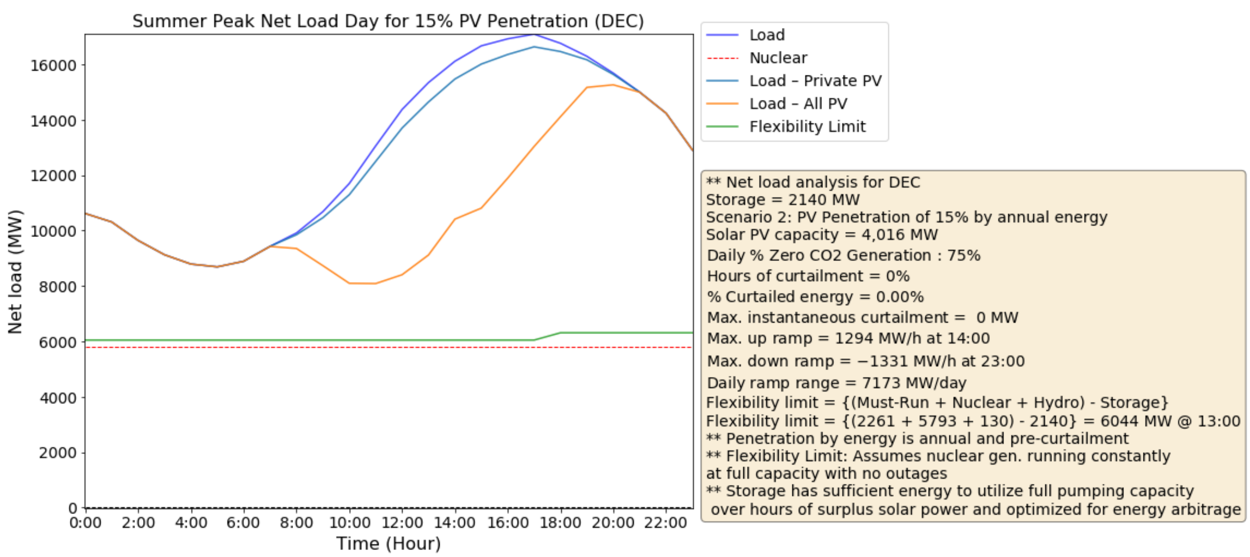

Winter Low Net Load Day for 15% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEC
Storage = 2140 MW
Scenario 12: PV Penetration of 15% by annual energy
Solar PV capacity = 4,016 MW
Daily % Zero CO2 Generation : 104%
Hours of curtailment = 7 hours
% Curtailed energy =29.32%
Max. instantaneous curtailment = 3027 MW
Max. up ramp = 2328 MW/h at 18:00
Max. down ramp = −1543 MW/h at 10:00
Daily ramp range = 4238 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(520 + 5793 + 156) - 2140} = 4329 MW @ 14:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

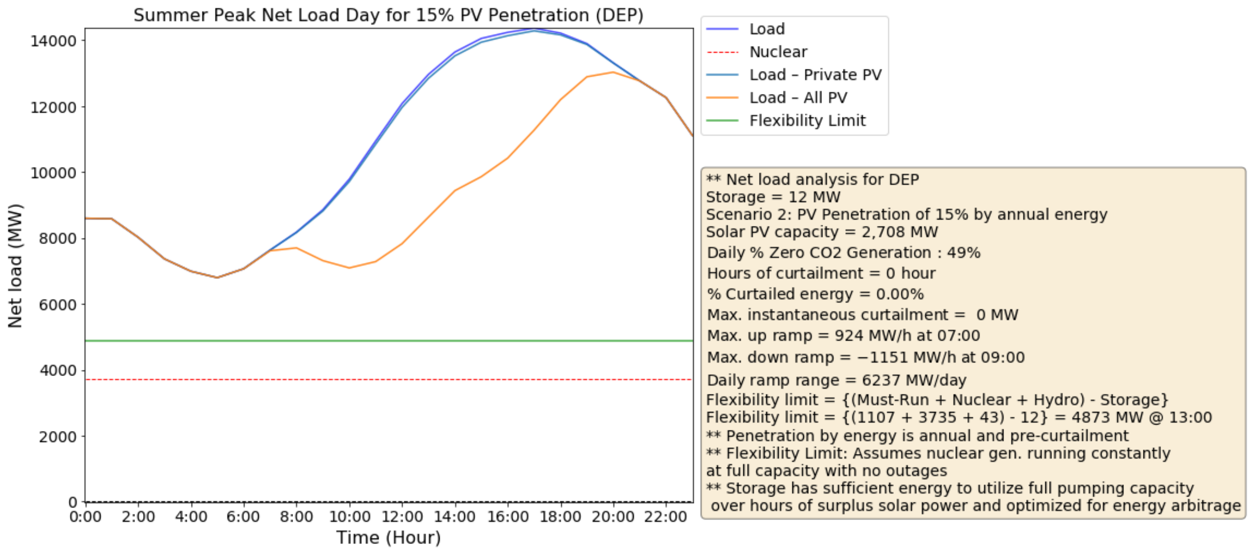

Winter Low Net Load Day for 15% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEP
Storage = 12 MW
Scenario 12: PV Penetration of 15% by annual energy
Solar PV capacity = 2,708 MW
Daily % Zero CO2 Generation : 66%
Hours of curtailment = 7 hour
% Curtailed energy = 62.50%
Max. instantaneous curtailment = 3418 MW
Max. up ramp = 1582 MW/h at 18:00
Max. down ramp = −981 MW/h at 10:00
Daily ramp range = 2709 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1107 + 3735 + 81) - 12} = 4911 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

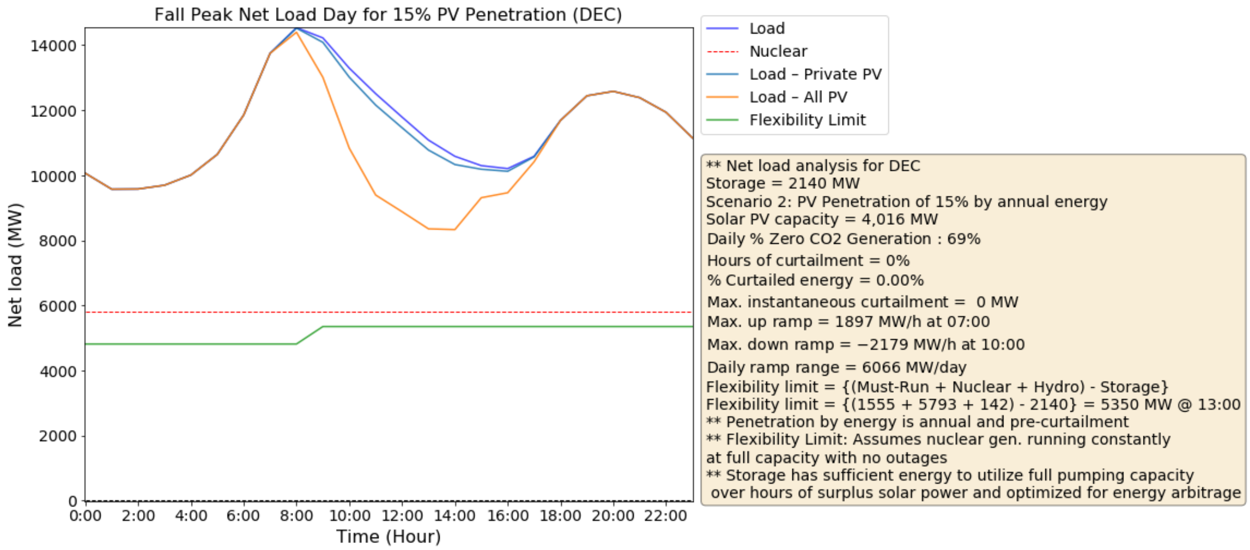
Seasonal Peak Net Load Days: 15% PV Penetration

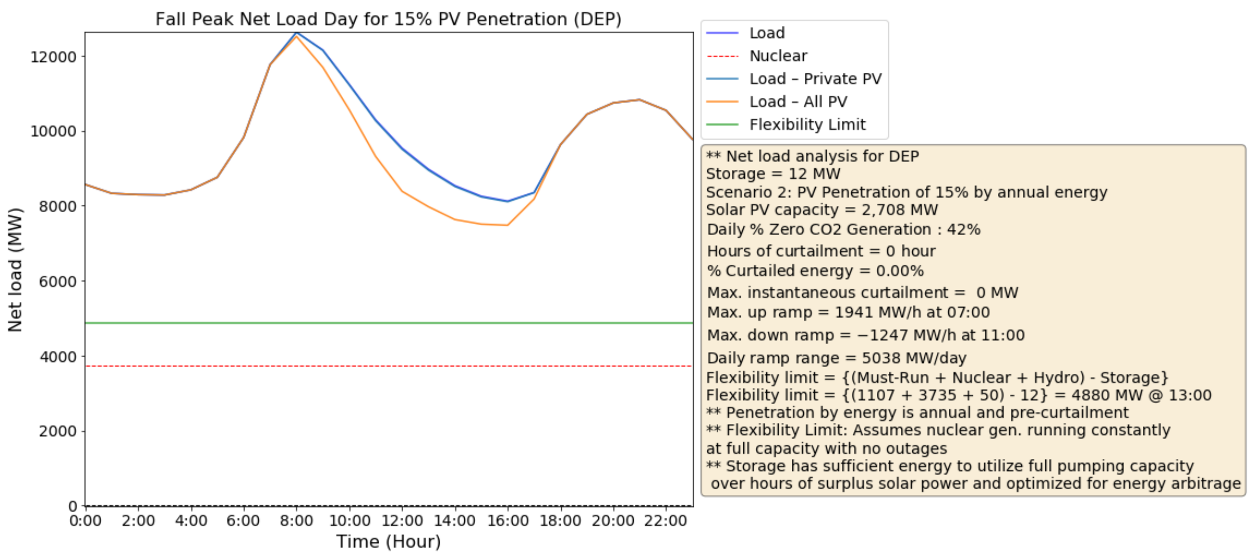


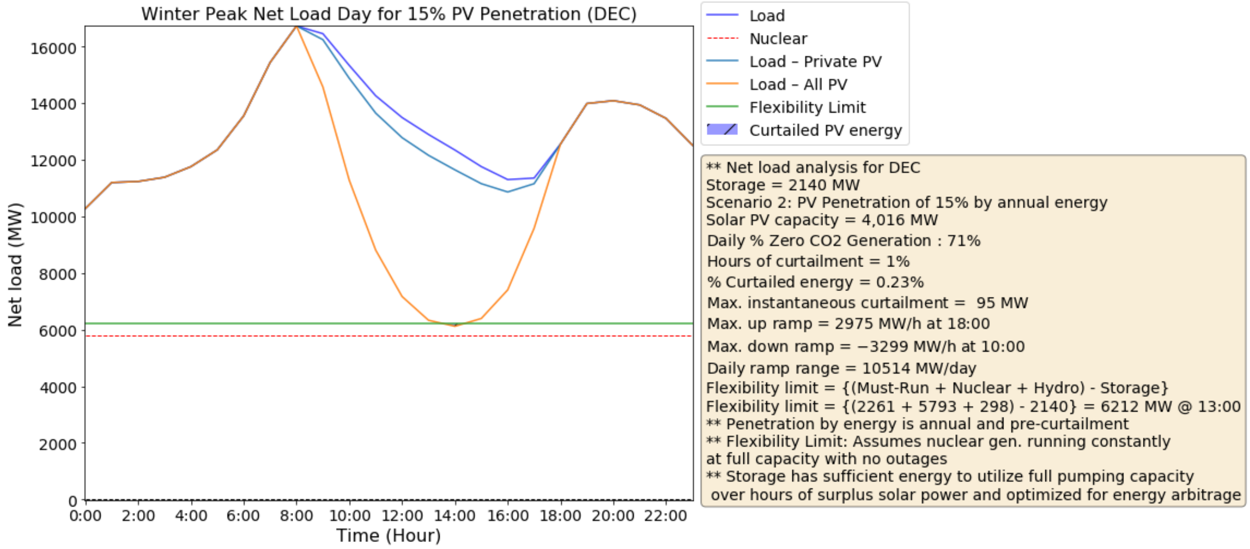


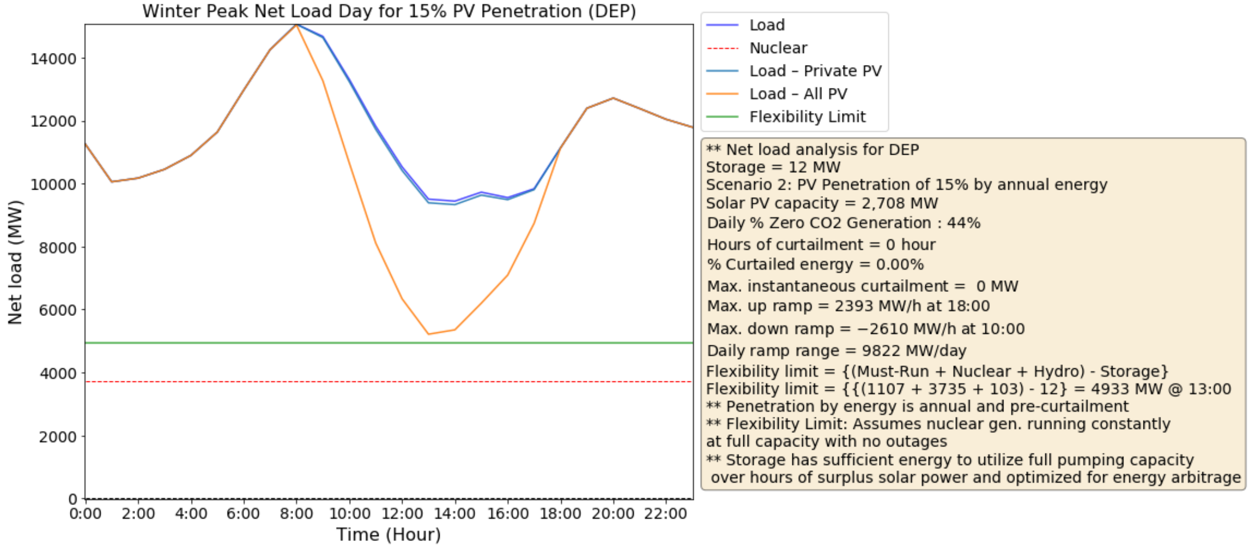



Summer Peak Net Load Day for 15% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load - Private PV
Load - All PV
Flexibility Limit
** Net load analysis for DEP
Storage = 12 MW
Scenario 2: PV Penetration of 15% by annual energy
Solar PV capacity = 2,708 MW
Daily % Zero CO2 Generation : 49%
Hours of curtailment = 0 hour
% Curtailed energy = 0.00%
Max. instantaneous curtailment = 0 MW
Max. up ramp = 924 MW/h at 07:00
Max. down ramp = −1151 MW/h at 09:00
Daily ramp range = 6237 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1107 + 3735 + 43) - 12} = 4873 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage


Fall Peak Net Load Day for 15% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load - Private PV
Load - All PV
Flexibility Limit
** Net load analysis for DEC
Storage = 2140 MW
Scenario 2: PV Penetration of 15% by annual energy
Solar PV capacity = 4,016 MW
Daily % Zero CO2 Generation : 69%
Hours of curtailment = 0%
% Curtailed energy = 0.00%
Max. instantaneous curtailment = 0 MW
Max. up ramp = 1897 MW/h at 07:00
Max. down ramp = −2179 MW/h at 10:00
Daily ramp range = 6066 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1555 + 5793 + 142) - 2140} = 5350 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage


Fall Peak Net Load Day for 15% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load - Private PV
Load - All PV
Flexibility Limit
** Net load analysis for DEP
Storage = 12 MW
Scenario 2: PV Penetration of 15% by annual energy
Solar PV capacity = 2,708 MW
Daily % Zero CO2 Generation : 42%
Hours of curtailment = 0 hour
% Curtailed energy = 0.00%
Max. instantaneous curtailment = 0 MW
Max. up ramp = 1941 MW/h at 07:00
Max. down ramp = −1247 MW/h at 11:00
Daily ramp range = 5038 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(1107 + 3735 + 50) - 12} = 4880 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage


Winter Peak Net Load Day for 15% PV Penetration (DEC)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
Curtailed PV energy
** Net load analysis for DEC
Storage = 2140 MW
Scenario 2: PV Penetration of 15% by annual energy
Solar PV capacity = 4,016 MW
Daily % Zero CO2 Generation : 71%
Hours of curtailment = 1%
% Curtailed energy = 0.23%
Max. instantaneous curtailment = 95 MW
Max. up ramp = 2975 MW/h at 18:00
Max. down ramp = −3299 MW/h at 10:00
Daily ramp range = 10514 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(2261 + 5793 + 298) - 2140} = 6212 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage


Winter Peak Net Load Day for 15% PV Penetration (DEP)
Net load (MW)
Time (Hour)
Load
Nuclear
Load – Private PV
Load – All PV
Flexibility Limit
** Net load analysis for DEP
Storage = 12 MW
Scenario 2: PV Penetration of 15% by annual energy
Solar PV capacity = 2,708 MW
Daily % Zero CO2 Generation : 44%
Hours of curtailment = 0 hour
% Curtailed energy = 0.00%
Max. instantaneous curtailment = 0 MW
Max. up ramp = 2393 MW/h at 18:00
Max. down ramp = −2610 MW/h at 10:00
Daily ramp range = 9822 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {{(1107 + 3735 + 103) - 12} = 4933 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly
at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity
over hours of surplus solar power and optimized for energy arbitrage

A.5 Geospatial Analysis

Several maps were produced for the purpose of visualizing available solar and wind resource in North & South Carolina, and show the *typical* exclusions applied in our technical potential analysis. The technical potential shows a broad overview of technically developable resources. This type of analysis does not take into account economic or market factors.

The technical potential analysis uses time-series data to calculate potential system generation across multiple years or weather data. This type of analysis can be useful for narrowing down places for further exploration for development.

Capacity Factors

Capacity factors were produced for photovoltaic (PV) and wind generating systems using the System Advisor Model (SAM) (Freeman et al., 2018). Input resource time-series data for calculating capacity factors include the National Solar Radiation Database (NSRDB) (Sengupta et al., 2018) for PV systems, and the Wind Integration National Dataset (WIND) Toolkit (Draxl, Clifton, Hodge, & McCaa, 2015) for wind systems. The capacity factors produced reflect the multi-year mean capacity factors across all available resource years. For the NSRDB, this encompasses the years 1998-2017 inclusive, for the WIND Toolkit, this covers years 2007-2013 inclusive.

The system configurations used in this analysis are described below:

PV

Array Type	1-Axis Tracking
Azimuth	180 Degrees (South)
Tilt	0 Degrees
Module Type	Standard
Inverter Efficiency	96%
DC/AC Ratio	1.3
Losses	14.07%

Wind

	Land-Based	Offshore
Hub Height	80m	100m
Wind Shear Coefficient	0.143	0.143
Rotor Diameter	92m / 108m / 117m	155m
Wind Turbulence Coefficient	0.10	0.10
Losses	15%	15%
Availability	98%	98%

Rotor diameter and power curves for land-based turbines depends on multi-year mean wind speed using the logic below:

- ws* <= 5.5 m/s: 117m Rotor Diameter
- 5.5 m/s < ws <= 10 m/s: 108m Rotor Diameter
- ws > 10 m/s: 92m Rotor Diameter

*ws = wind speed (m/s)

Exclusions

In order to determine locations for further investigation of new PV or wind development, assumptions are made based on land categories and use-type to exclude locations from consideration. The exclusions used in this analysis may be adjusted and new data used in the future to account for more locally-sourced data or other assumptions that aren't considered at this time.

PV

The land exclusions used for PV include the following:

Slope > 5%
Urban Areas
Water and Wetlands
Parks and Landmarks
National Parks and Other Environmentally or Culturally Sensitive Areas

Wind

The land exclusions used for wind analysis include the following:

Slope > 20%
Urban Areas
Water and Wetlands
Forests
National Parks and Other Environmentally or Culturally Sensitive Areas

Maps

The results of the Technical Potential analysis are visualized in maps and web application layers. The descriptions of the maps can be found below. Due to their large size, they have been sent to Duke in a separate file.

1. Duke GHI-01.jpg: Multi-year mean Global Horizontal Irradiance (GHI) from the NSRDB.
2. Duke GHI with Exclusions-01.jpg: Multi-year mean GHI from the NSRDB with excluded areas removed using the PV exclusion logic listed above.
3. Duke PV CF-01.jpg: Multi-year mean capacity factors using the PV system configurations listed above.
4. Duke PV with Exclusions-01.jpg: Multi-year mean capacity factors using the PV system configurations listed above and excluded areas removed using the PV exclusion logic listed above.
5. Duke Wind Speed 80-01.jpg: Multi-year mean wind speed from the WIND Toolkit.
6. Duke Wind Speed 80 with Exclusions-01.jpg: Multi-year mean wind speed from the WIND Toolkit with excluded areas removed using the wind exclusion logic listed above.
7. Duke Wind CF-01.jpg: Multi-year mean capacity factors using the wind system configurations listed above.
8. Duke Wind CF with Exclusions-01.jpg: Multi-year mean capacity factors using the wind system configurations listed above with excluded areas removed using the wind exclusion logic listed above.

Jennings Exhibit No. 17
Docket No. E-7, Sub 1229

/A

Webinar: National Renewable Energy Laboratory (NREL) Reviews the Duke Energy Carbon-Free Resource Integration Study

Bri-Mathias Hodge, Scott Haase (NREL)
Ken Jennings (Duke Energy)
January 17th, 2020

Agenda

- **Webinar Welcome and Instructions** – Terri Edwards, Duke Energy
- **Study Purpose and Background** – Ken Jennings, Duke Energy
- **Integration with Clean Energy Plan** – Tim Profeta, Nicholas Institute
- **NREL Phase 1 Analysis** – Scott Haase and Bri-Mathias Hodge, NREL
- **Next Steps, Wrap Up** – Ken Jennings, Duke Energy

Background and Overview

- Duke Energy contracted with **National Renewable Energy Laboratory (NREL),** an industry-respected, leading research institution, to conduct a study of the Carolinas' system.

- The study will be conducted in two phases. NREL recently completed **Phase 1** and has started **Phase 2.**

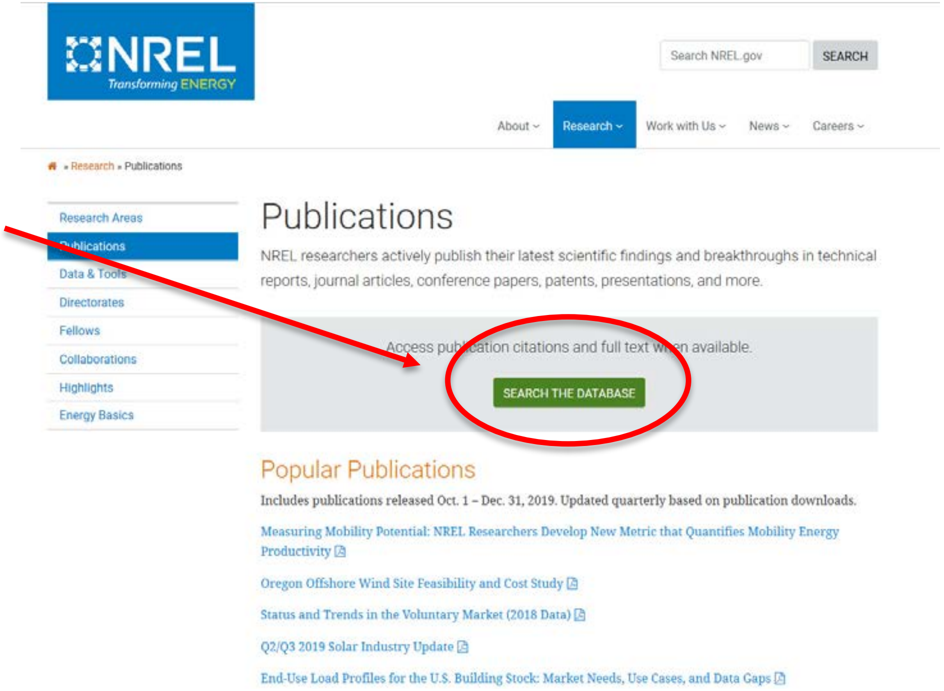
- Phase 1 is a **preliminary evaluation**; Phase 2 will incorporate costs and transmission impacts.

- As we advance towards a lower carbon future, these studies will help us understand the operational impacts, benefits and limitations of solar.

- The study will also inform other fleet transformation analyses, including how different clean energy technologies can contribute to a carbon-free future.

How to Access the Phase 1 Study

Final report posted here: https://www.nrel.gov/docs/fy20osti/74337.pdf



Phase 1: What is Covered and What Isn't

Covered	Not Covered
How different resource mixes could contribute to carbon-free energy on the DEC and DEP Systems	Comprehensive system planning including unit commitment/economic dispatch for energy and reserves
Impacts of integrating significant amounts of new solar photovoltaic (PV) power into Duke's service territory under a variety of scenarios	Constraints of thermal generation and must-run units (assumed to be flexible)
Curtailment quantities with limited system flexibility	Detailed interconnection analysis or transmission considerations
Introducing other scenarios such as wind, storage and how they contribute to total annual percentage of carbon-free generation	Market models and cost of various options

Agenda

- **Webinar Welcome and Instructions** – Terri Edwards, Duke Energy
- **Study Purpose and Background** – Ken Jennings, Duke Energy
- **Integration with Clean Energy Plan** – Tim Profeta, Nicholas Institute
- **NREL Phase 1 Analysis** – Scott Haase and Bri-Mathias Hodge, NREL
- **Next Steps, Wrap Up** – Ken Jennings, Duke Energy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NREL at a Glance

2,200

Employees,

including postdoctoral researchers, interns, visiting professionals, and subcontractors

World-class

facilities, renowned technology experts

over 800

Partnerships

with industry, academia, and government

Campus

campus operates as a living laboratory

$400M+ annually

Approximate Operating Budget

NREL Core Capabilities: Foundation for Innovation

Analysis and System Integration

Decision Science and Analysis

Systems Engineering and Integration

Policy and Markets

Innovation and Application

Biological and Bioprocess Engineering

Chemical Engineering

Mechanical Design and Engineering

Power Systems and Electrical Engineering

Foundational Knowledge

Applied Materials Science and Engineering

Biological Systems Science

Chemical and Molecular Science

Crosscutting

Advanced Computer Science, Visualization, and Data

Large-Scale User Facilities

Technology Focus

Renewable Power

Solar

Wind

Water

Geothermal

Sustainable Transportation

Advanced Mobility

Vehicle Technologies

Hydrogen

Energy Efficiency

Buildings

Advanced Manufacturing

Government Energy Management

Energy Systems Integration

High-Performance Computing

Data and Visualizations

Scope of Work

Net Load Analysis

- Compared estimated hourly solar, wind, net load, and system minimum generation time series for different scenarios.
- Created initial estimates of possible curtailment, key periods of ramping, and load-following requirements.

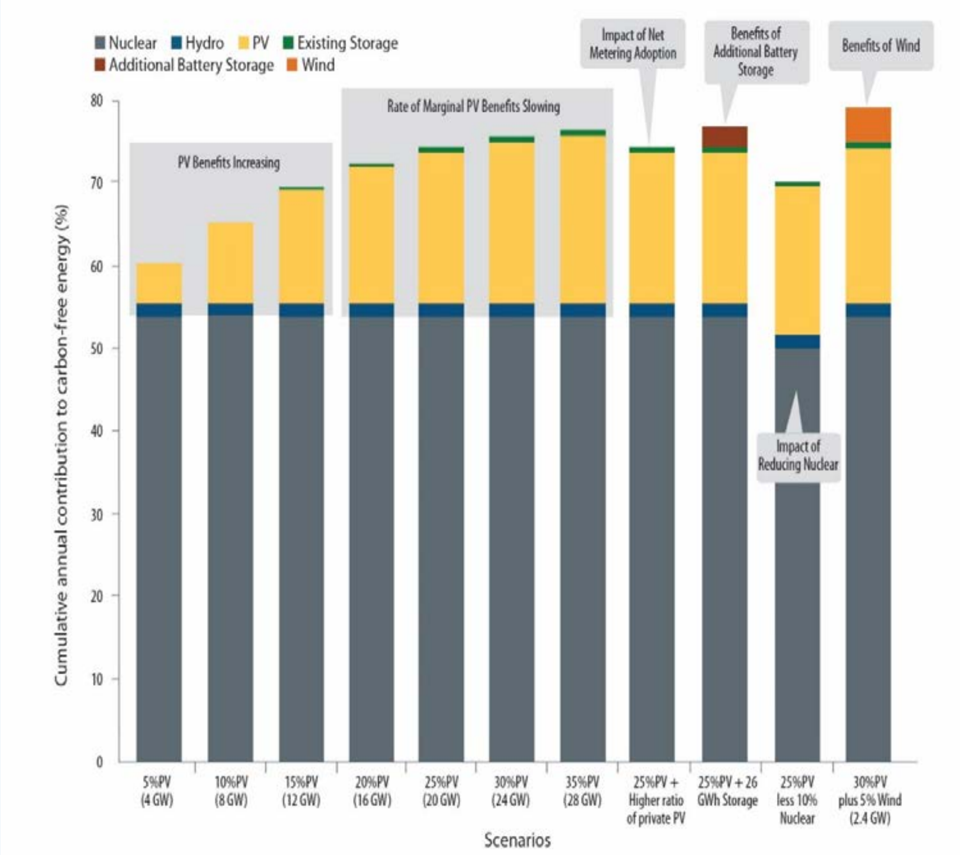
Geospatial Analysis Maps with Interactive Web App

- Created wind power and solar power resource maps with technical exclusions and interactive web application to understand potential renewable energy locations.

Literature Review

- Referenced previous studies regarding challenges and opportunities from integrating wind and solar into various power systems drawing key conclusions that likely apply to the Duke service territory.

Summary of scenarios



Key Findings:

- Net load analysis highlights challenges and opportunities with integrating solar PV
- Average annual % of load met by carbon-free generation ranges from 60-79%
- Nuclear remains greatest contributor to carbon-free energy
- Above 15% solar PV, required curtailment grows
- The highest share of carbon-free generation is achieved by the scenario with the most resource diversity.
- Solar power curtailment is greater under separate balancing authorities

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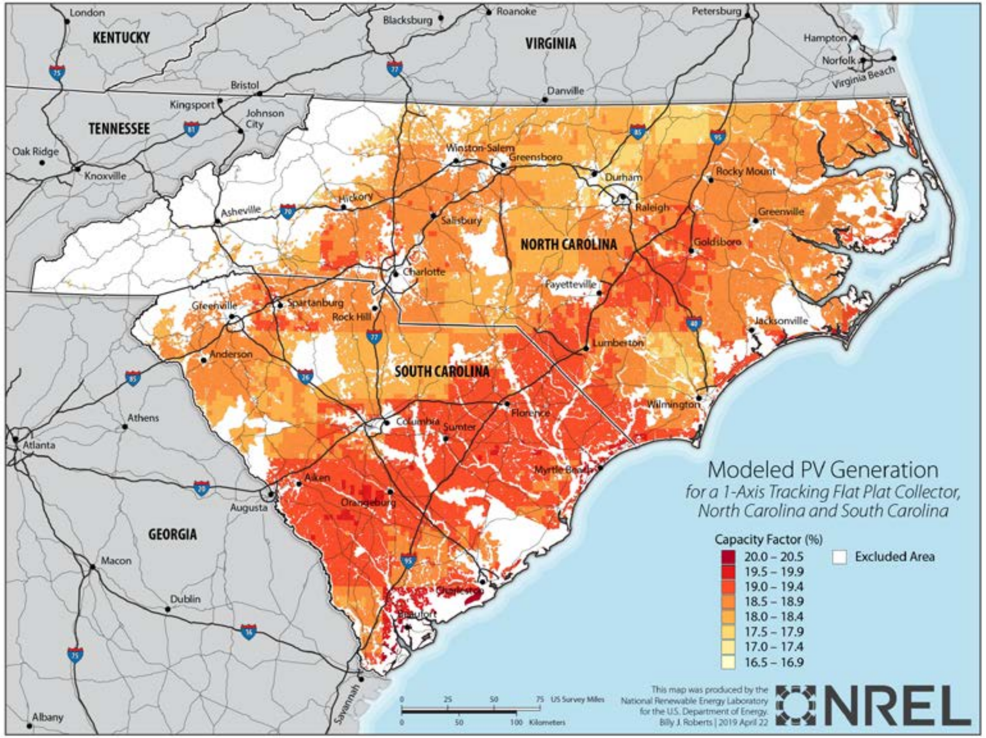
Solar Energy Resource in the Carolinas Region



- Uses NREL's System Advisor Model (SAM)
- Input data from the National Solar Radiation Database (NSRDB)
- Capacity factors represent mean capacity factors across all available resource years (1997 – 2017 inclusive)
- Exclusions based on land categories and use-type

Scenarios

Scenario	Definition
1. Solar energy penetration 5%	4,109 MW, 5.5% of total solar is rooftop
2. Solar energy penetration 10%	8,219 MW, 5.5% of total solar is rooftop
3. Solar energy penetration 15%	12,328 MW, 5.5% of total solar is rooftop
4. Solar energy penetration 20%	16,438 MW, 5.5% of total solar is rooftop
5. Solar energy penetration 25%	20,547 MW, 5.5% of total solar is rooftop
6. Solar energy penetration 30%	24,656 MW, 5.5% of total solar is rooftop
7. Solar energy penetration 35%	28,766 MW, 5.5% of total solar is rooftop
8. Higher ratio of distributed to utility solar added to the system	Based on the 25% solar energy penetration scenario, 18.91% of PV is uncurtailable rooftop.
9. Additional storage	Based on the 25% solar energy penetration scenario, addition of 1,000 MW of 4-hour storage, 1,000 MW of 6-hour storage, and 2,000 MW of 8-hour storage
10. Nuclear retirement	Based on the 25% solar energy penetration scenario, assume a 10% nuclear reduction
11. Additional wind energy penetration 5%	Based on the 30% solar energy penetration scenario, an additional 5% wind energy penetration is added.
12. Scenarios 1–3 modeled with two balancing authorities	Based on scenarios 1–3 inclusive, DEP and DEC are analyzed separately with an interconnection limit between, defined in the appendix

Assumptions

- 2019 hourly forecasted load data and solar PV time-series supplied by Duke Energy
- Thermal generation, excluding nuclear, has no flexibility constraints such as minimum stable level, ramp rates or outage rates
- PV is non-dispatchable
- Rooftop PV is not curtailable, utility PV is curtailable
- Existing storage is 2.2 GW of pumped storage hydropower and has sufficient energy capacity to use full pumping capacity during all hours of surplus solar power each day and is optimized for load shifting.
- Must-run units have a 1 week minimum up-time
- Nuclear units have a 0% outage rate
- No contingency reserve is considered
- No imports or exports are considered
- Individual scenarios methods explained later…

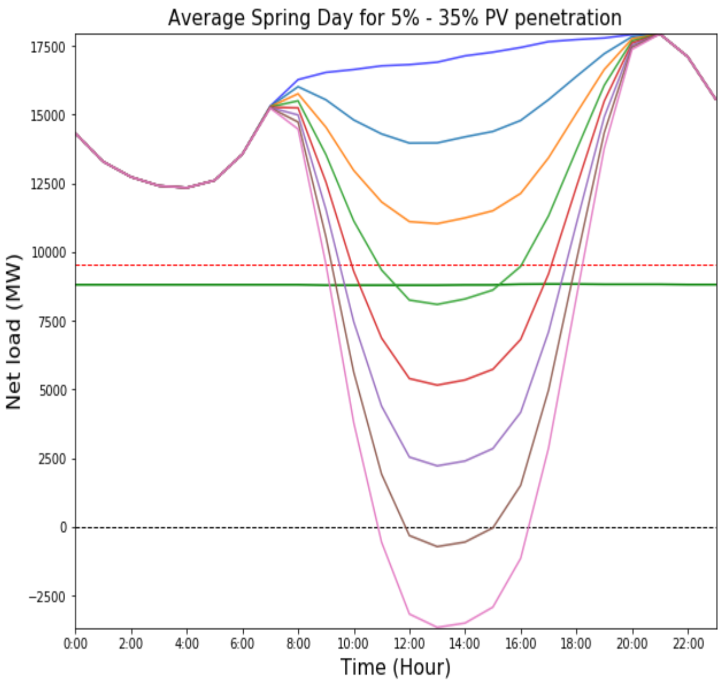
Definitions

- Penetration is in terms of annual energy and pre-curtailment
- Inflexibility limit defined by:
  - Must-run units for local voltage constraints
  - Fixed hydro power schedules
  - Nuclear output at constant maximum capacity
  - Existing storage
- Percentage of curtailed energy is a percentage of total PV output energy
- Daily percentage of carbon-free generation includes solar power, wind power, hydropower and nuclear (using storage)
- Maximum up-ramp and down-ramp times presented are ending times of each ramp

Scenarios 1 – 7: 5% - 35% Solar Energy Penetration

PV penetration (%)	5	10	15	20	25	30	35
PV capacity (MW)	4,109	8,219	12,328	16,438	20,547	24,656	28,766
Average Percentage Curtailed Energy, %	0	1	8	17	27	35	42
Marginal Curtailment, %	-	2.2	21.4	46.3	64.6	76.7	83.2
Load met by carbon-free generation, %	63	68	72	74	76	77	77

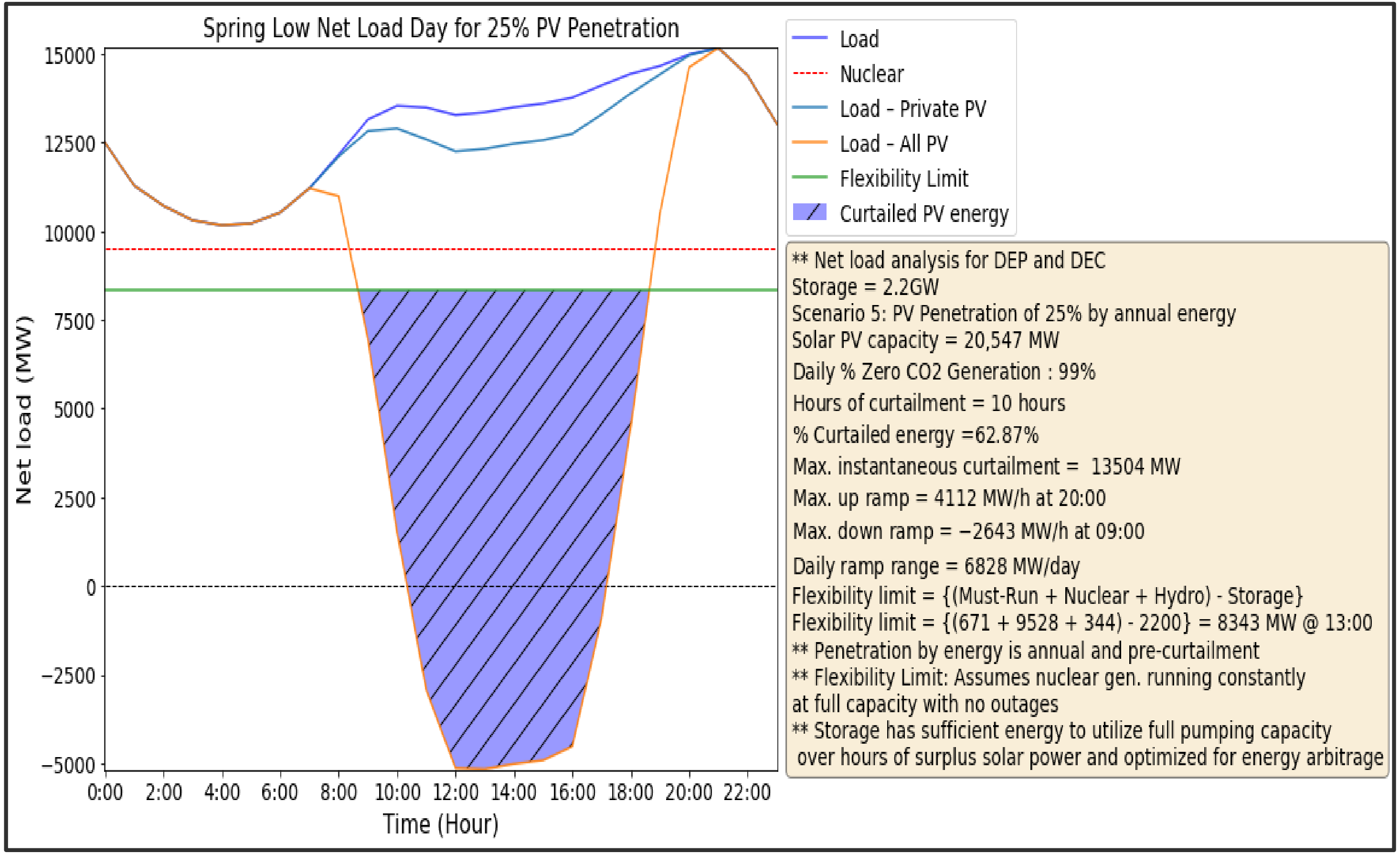
Annual Economic Indicators



** Net load analysis for DEP and DEC
Storage = 2.2GW
Daily % Zero CO2 Gen.:
5% PV - 70%
10%PV - 76%
15% PV - 81%
20% PV - 83%
25% PV - 85%
30% PV - 85%
35% PV - 86%
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity over hours of surplus solar power and optimized for energy arbitrage

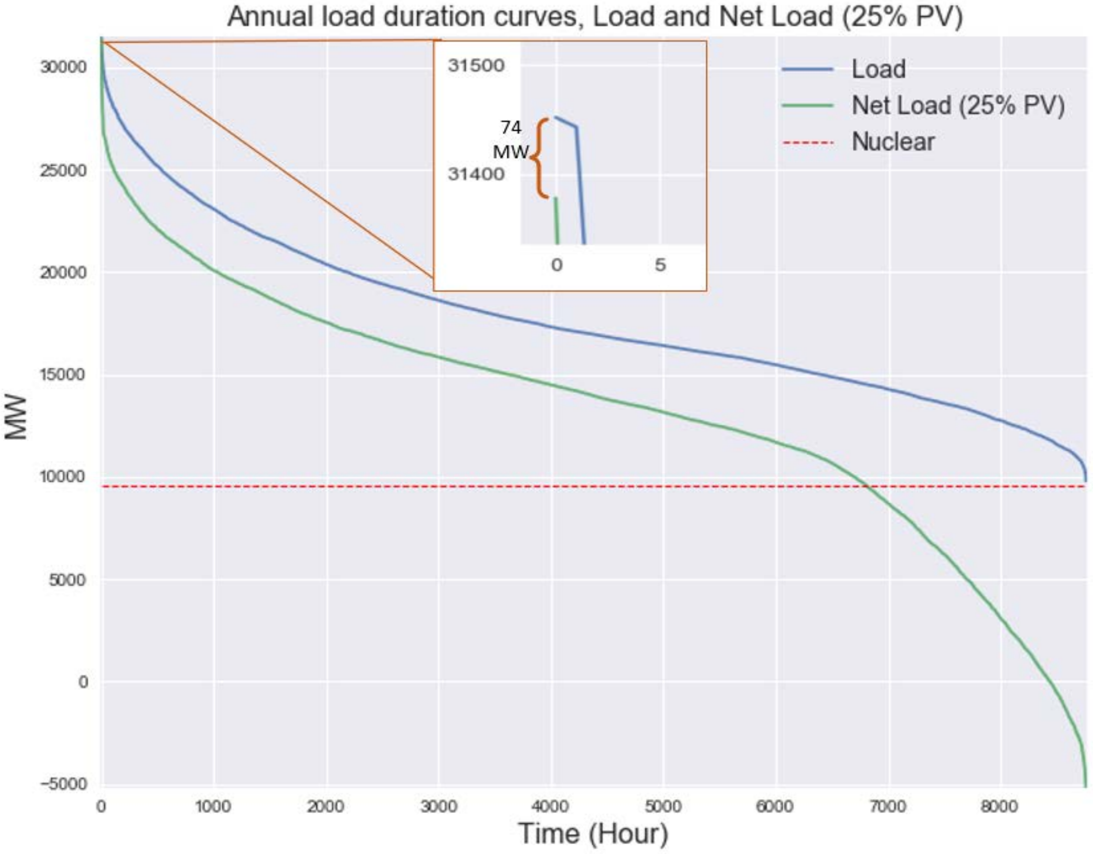
Here we show spring, as it is the highest curtailment season

Peak Load Day for 25% PV Penetration



The peak load day in summer experiences the least curtailment (2.16%)

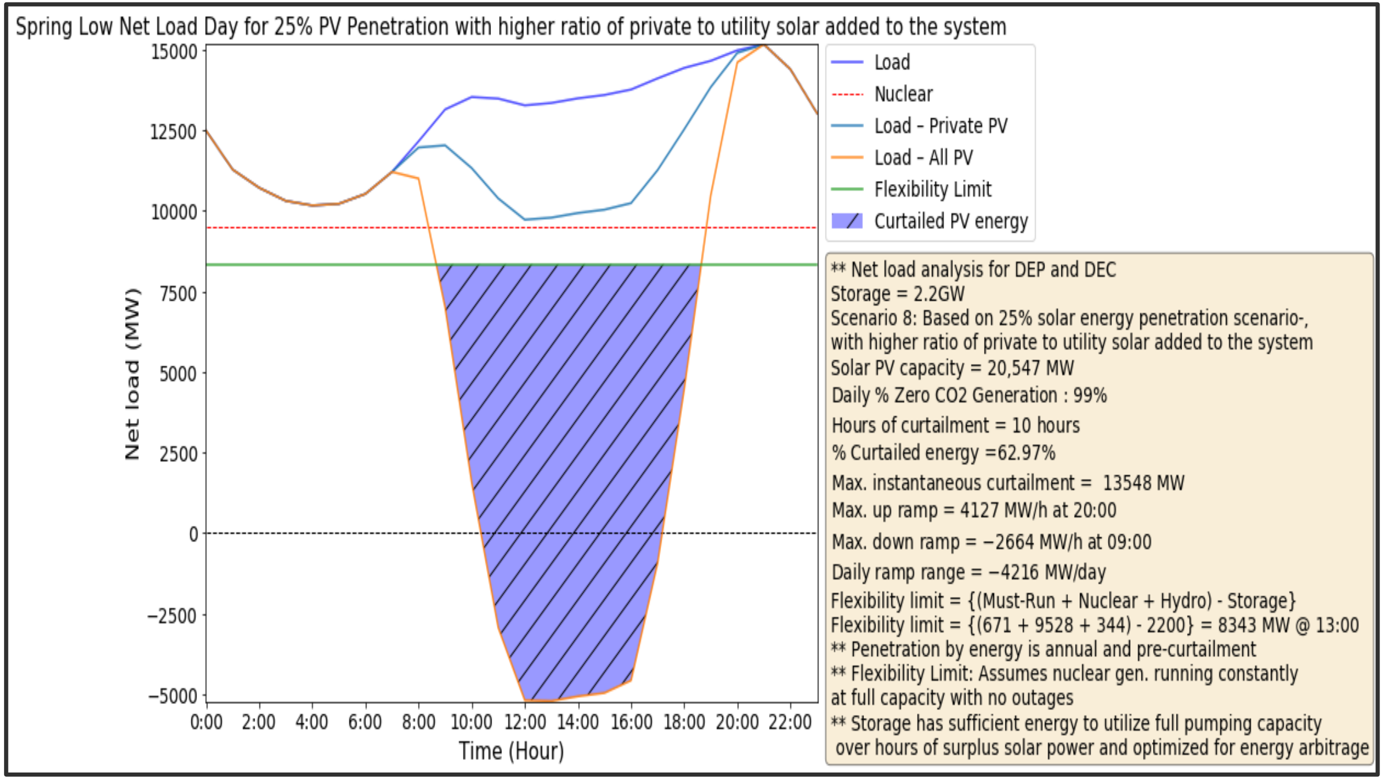
Load Duration Curves for the Existing Load and Projected 25% PV Penetration Case



With the addition of 25% PV penetration:

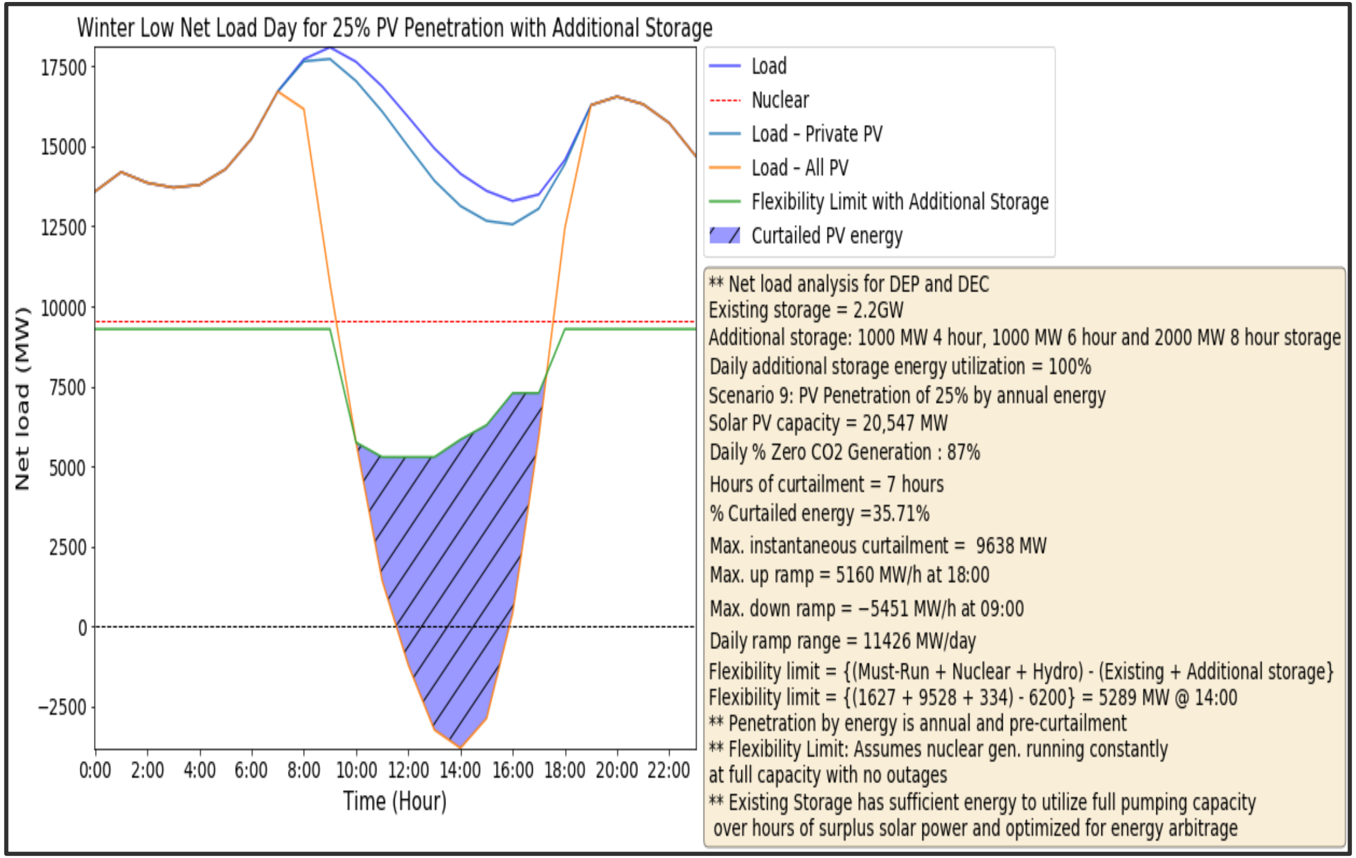
- Peak load is reduced
- Annual minimum load drops below the nuclear output

Scenario 8: Increased Portion of Distributed Solar Energy



- Rooftop PV is not curtailable
- Based on 25% PV Penetration case
- 18.91% of PV is rooftop. This is the highest percentage from NREL-developed Standard Scenarios
- More utility PV must be curtailed
- Comparing to the base 25% case, 33.2% of utility solar is curtailed as opposed to 28.5%
- Rooftop PV never requires curtailment, even at 25% total PV penetration

Scenario 9:
Additional Storage Capabilities

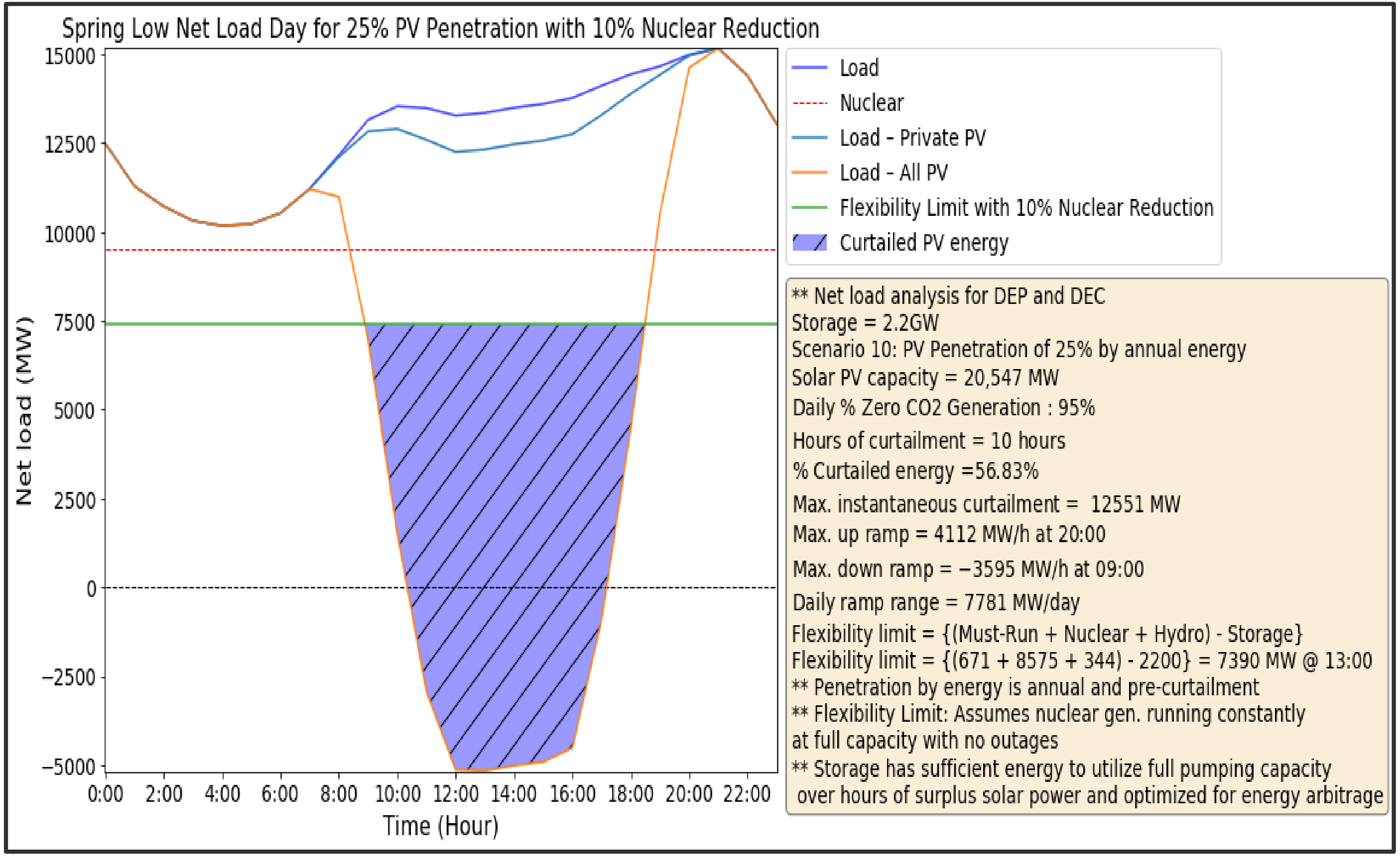


- Starts with the 25% PV penetration base case
- 1,000 MW of 4-hour, 1,000 MW of 6-hour and 2,000 MW of 8-hour (26,000 MWh)
- Annual contribution of the addition storage amounts to 3.7% of annual load
- Renewable energy is stored and released the same day with 80% round-trip efficiency

Compared to the 25% PV penetration case:

- Solar curtailment reduces from 26.9% to 14.8%
- carbon-free contribution rises from 75.7% to 78.4% (more than 35% PV penetration case

Scenario 10 : Generation Retirement

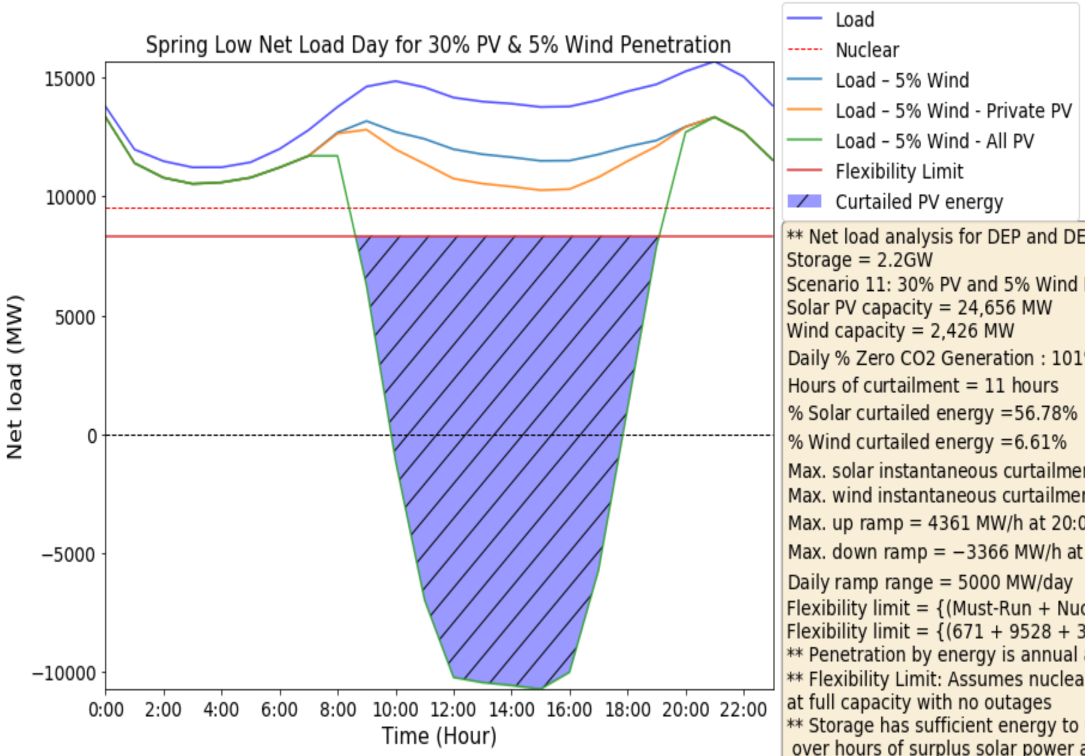


- Based on 25% PV penetration case, 10% of nuclear power is retired and assumed replaced with flexible thermal generation

Compared to the 25% PV penetration case:

- Curtailment of solar PV decreases from 26.9% to 22.2%
- Load met by carbon-free energy decreases from 75.7% to 71.2%

Scenario 11: Additional Wind Energy Penetration



** Net load analysis for DEP and DEC
Storage = 2.2GW
Scenario 11: 30% PV and 5% Wind Penetration by annual energy
Solar PV capacity = 24,656 MW
Wind capacity = 2,426 MW
Daily % Zero CO2 Generation : 101%
Hours of curtailment = 11 hours
% Solar curtailed energy =56.78%
% Wind curtailed energy =6.61%
Max. solar instantaneous curtailment = 17295 MW
Max. wind instantaneous curtailment = 1763 MW
Max. up ramp = 4361 MW/h at 20:00
Max. down ramp = −3366 MW/h at 09:00
Daily ramp range = 5000 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(671 + 9528 + 344) - 2200} = 8343 MW @ 15:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity over hours of surplus solar power and optimized for energy arbitrage

- Based on 30% PV penetration case, 5% penetration of wind power added

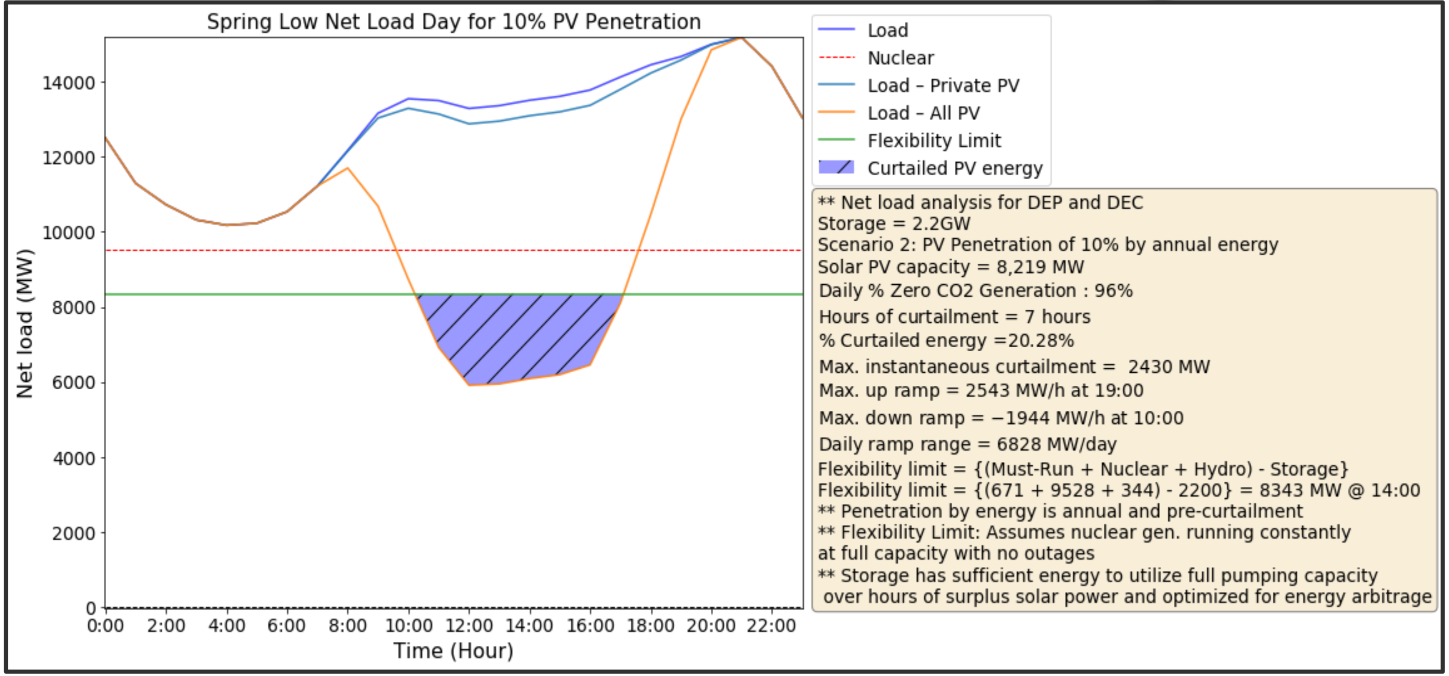
Compared to the 35% PV penetration case:

- Total renewable energy curtailment is reduced from 42% to 33.9% (37.6% solar is curtailed and 8.1% wind is curtailed)
- Total renewable energy marginal curtailment is reduced from 83.2% to 26.3%
- Load met by carbon-free increases from 77.5% to 80.7% (greatest of all scenarios)

Scenario 12:

DEC and DEP Modeled as Individual Balancing Authorities with a Limited Interconnection

Chart
DEP and DEC modeled as a single region with unlimited transmission capabilities



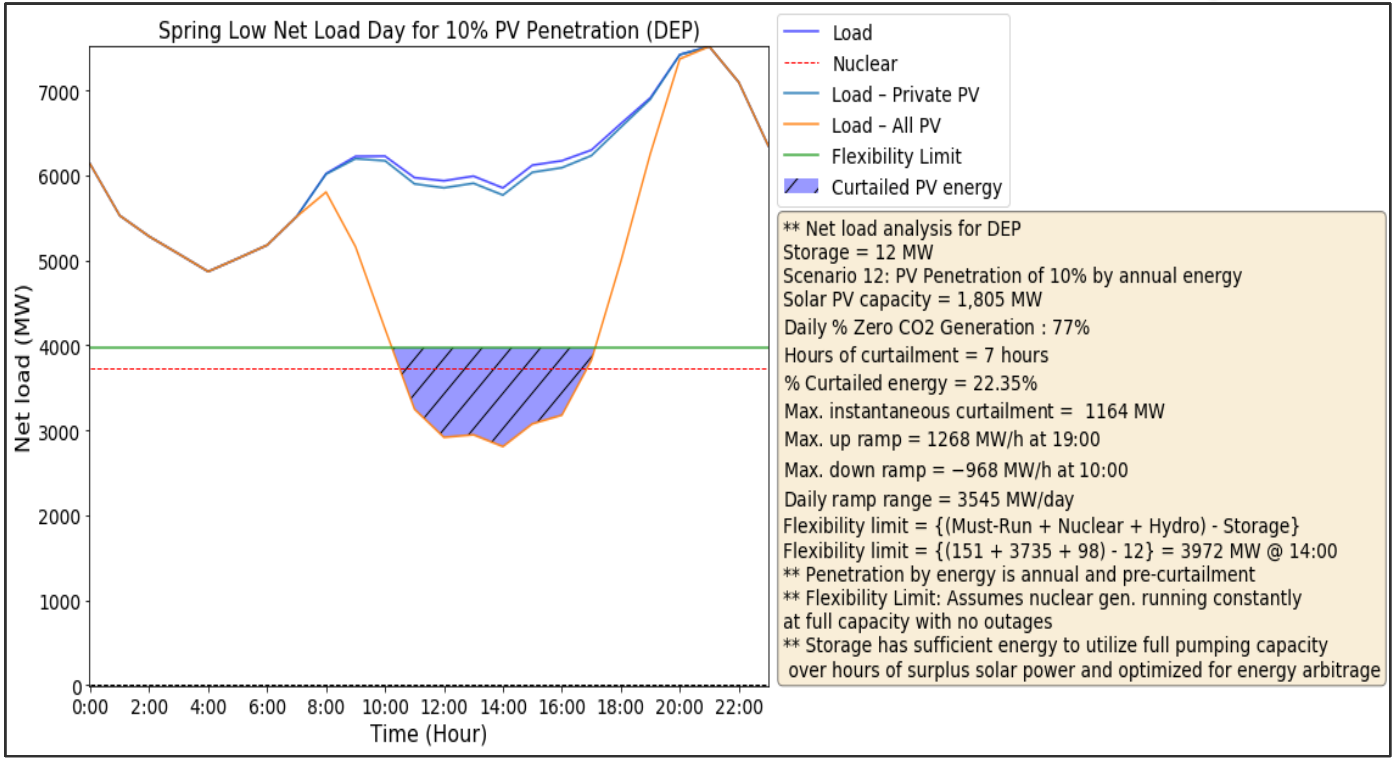
10% PV penetration is the lowest PV penetration scenario where curtailment occurs and the day pictured here has the highest curtailment at 20.28%.

- Based on 5%, 10% and 15% solar PV penetration case
- DEC and DEP are modeled separately with the inflexibility line, solar power profiles and load split between the two regions
- JDA interconnection is modeled with values that are directional and time dependent (night / day)
- Interconnection balances net load without an understanding of markets

Scenario 12:

DEC and DEP Modeled as Individual Balancing Authorities with a Limited Interconnection

Chart
DEP after interconnection

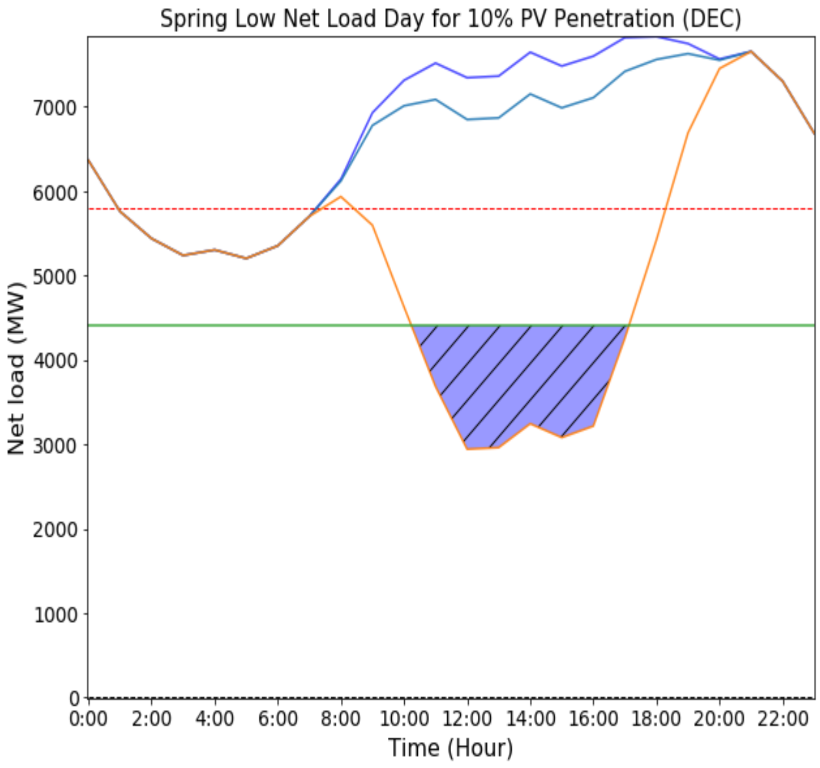


- Curtailed energy = 22.35%

Scenario 12:

DEC and DEP Modeled as Individual Balancing Authorities with a Limited Interconnection

Chart
DEC after interconnection



** Net load analysis for DEC
Storage = 2140 MW
Scenario 12: PV Penetration of 10% by annual energy
Solar PV capacity = 2,677 MW
Daily % Zero CO2 Generation : 113%
Hours of curtailment = 7 hours
% Curtailed energy =20.09%
Max. instantaneous curtailment = 1466 MW
Max. up ramp = 1268 MW/h at 19:00
Max. down ramp = −968 MW/h at 10:00
Daily ramp range = 3246 MW/day
Flexibility limit = {(Must-Run + Nuclear + Hydro) - Storage}
Flexibility limit = {(520 + 5793 + 235) - 2140} = 4408 MW @ 13:00
** Penetration by energy is annual and pre-curtailment
** Flexibility Limit: Assumes nuclear gen. running constantly at full capacity with no outages
** Storage has sufficient energy to utilize full pumping capacity over hours of surplus solar power and optimized for energy arbitrage

Curtailed energy = 20.09%

Scenario 12:

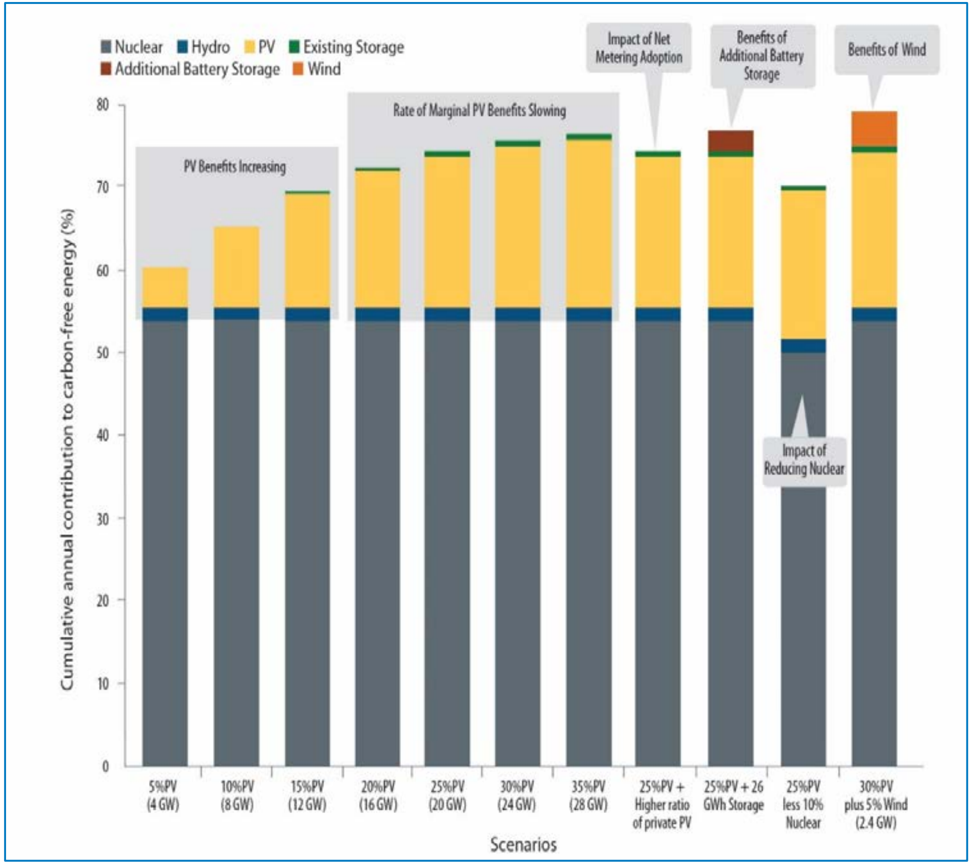
DEC and DEP Modeled as Individual Balancing Authorities with a Limited Interconnection

Comparison of Curtailment of the System Modeled With and Without the Interconnection Modeled

% PV Penetration	Copper plate Curtailment (MW)	Copper plate Percentage Curtailment	Curtailment with JDA modeled (MW)	Percentage Curtailment with JDA modeled
5%	1,570	0.0%	1,361	0.0%
10%	172,444	1.1%	191,306	1.2%
15%	1,824,853	7.9%	1,928,162	8.3%

- This table shows the potential reduction in curtailment possible by upgrading the interconnection between DEP and DEC
- Considering the location of new solar can help minimize transmission constraints, especially for large penetrations

Summary of scenarios



Key Findings:

- Net load analysis highlights challenges and opportunities with integrating solar PV
- Average annual % of load met by carbon-free generation ranges from 60-79%
- Nuclear remains greatest contributor to carbon-free energy
- Above 15% solar PV, required curtailment grows
- The highest share of carbon-free generation is achieved by the scenario with the most resource diversity.
- Solar power curtailment is greater under separate balancing authorities

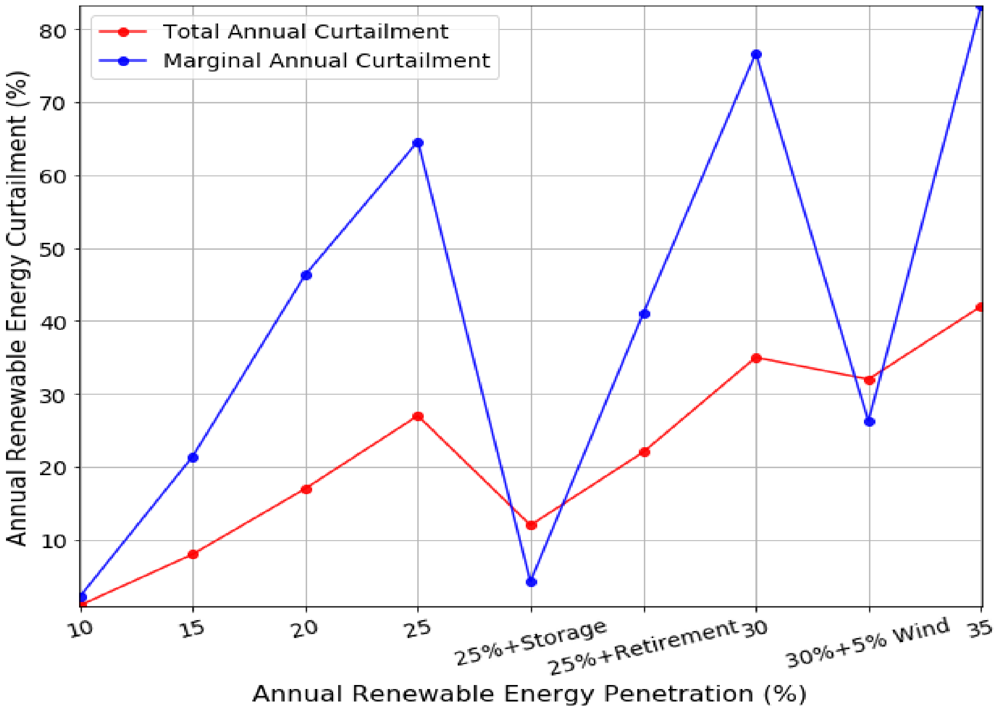
Annual Summary of Flexibility Metrics

Annual Flexibility Indicators

Scenario	5%	10%	15%	20%	25%	30%	35%	High DPV	Storag e	Nuclear Retirement	Wind
Load met by carbon-free generation, %	63	68	72	74	76	77	77	76	78	71	81
Maximum Instantaneous Curtailment, MW	530	3,323	6,618	10,003	13,504	17,207	20,909	13,548	11,073	12,551	17,486
Maximum up-ramp, MW/h	4,039	4,384	5,341	6,609	7,252	8,362	9,472	7,278	7,876	7,481	8,401
Maximum down-ramp, MW/h	5,873	5,873	5,873	6,699	7,894	9,090	10,286	7,906	7,894	7,894	9,555

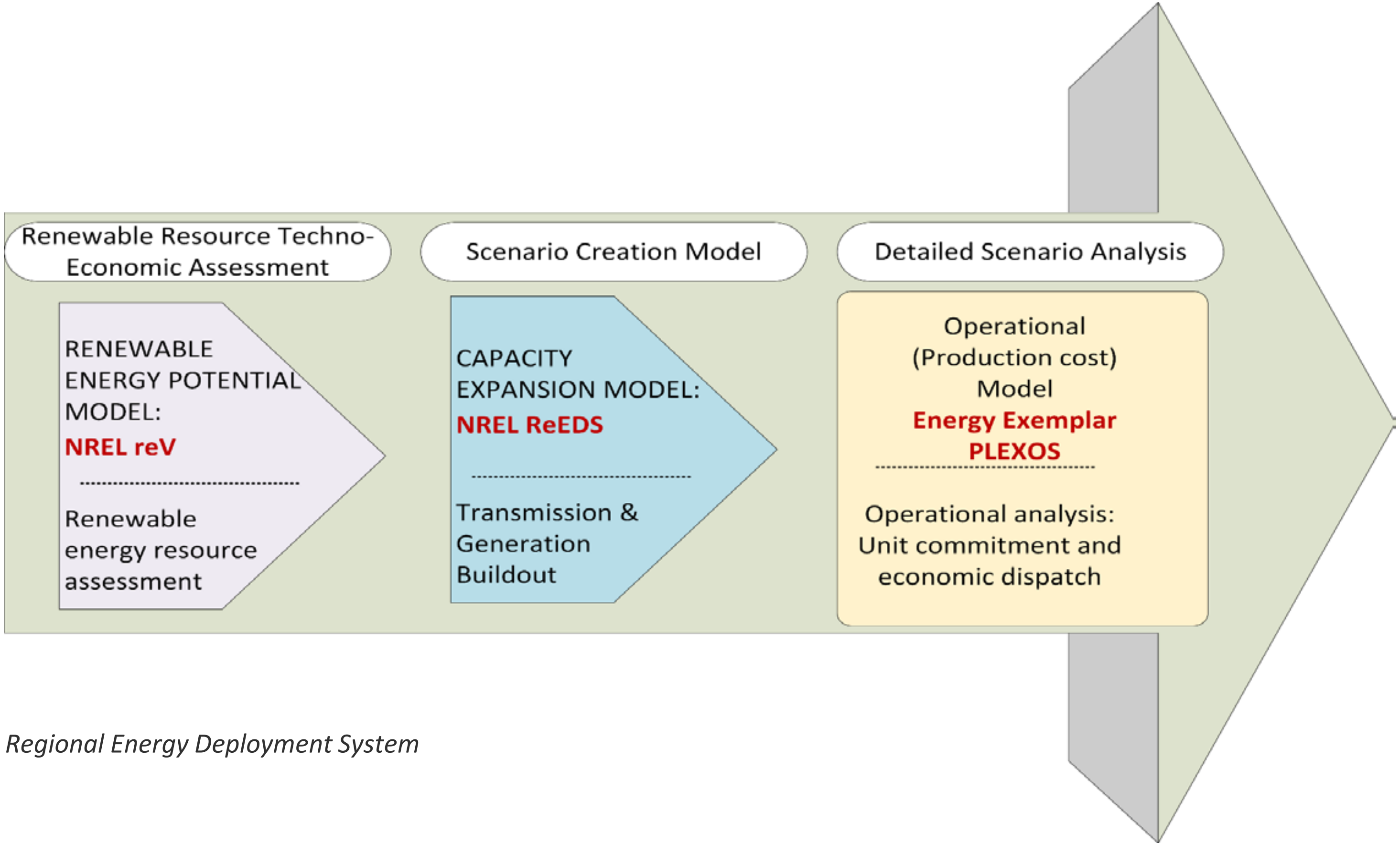
- Maximum instantaneous curtailment occurs in winter for penetrations up to and including 20% and then occurs in spring
- All maximum ramps happen in winter
- Transmission and nuclear retirement are both challenges with increasing PV penetration

Annual Summary of Opportunities and Conclusion



- Duke Energy endeavors to increase the portion of load met by carbon-free generation
- This net load analysis highlights challenges and opportunities with integrating solar PV and applying a selection of solutions
- Curtailment will likely begin at 10% PV penetration
- Greatest curtailment occurs during spring which is also when the greatest portion of load is met by carbon-free generation
- The benefits of adding wind power compared to solar power increase as solar PV penetration increases
- Further analysis with more advanced models would better evaluate options and impacts

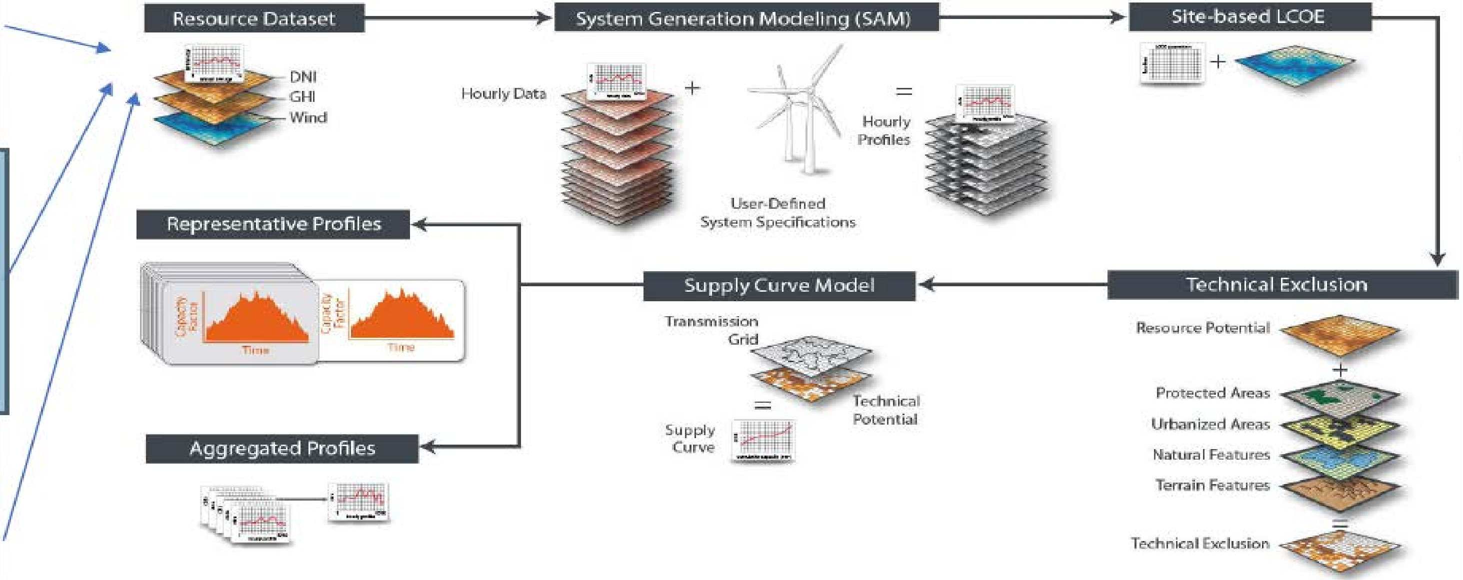
Carbon-Free Resource Integration Study – Phase 2



**ReEDS: Regional Energy Deployment System*

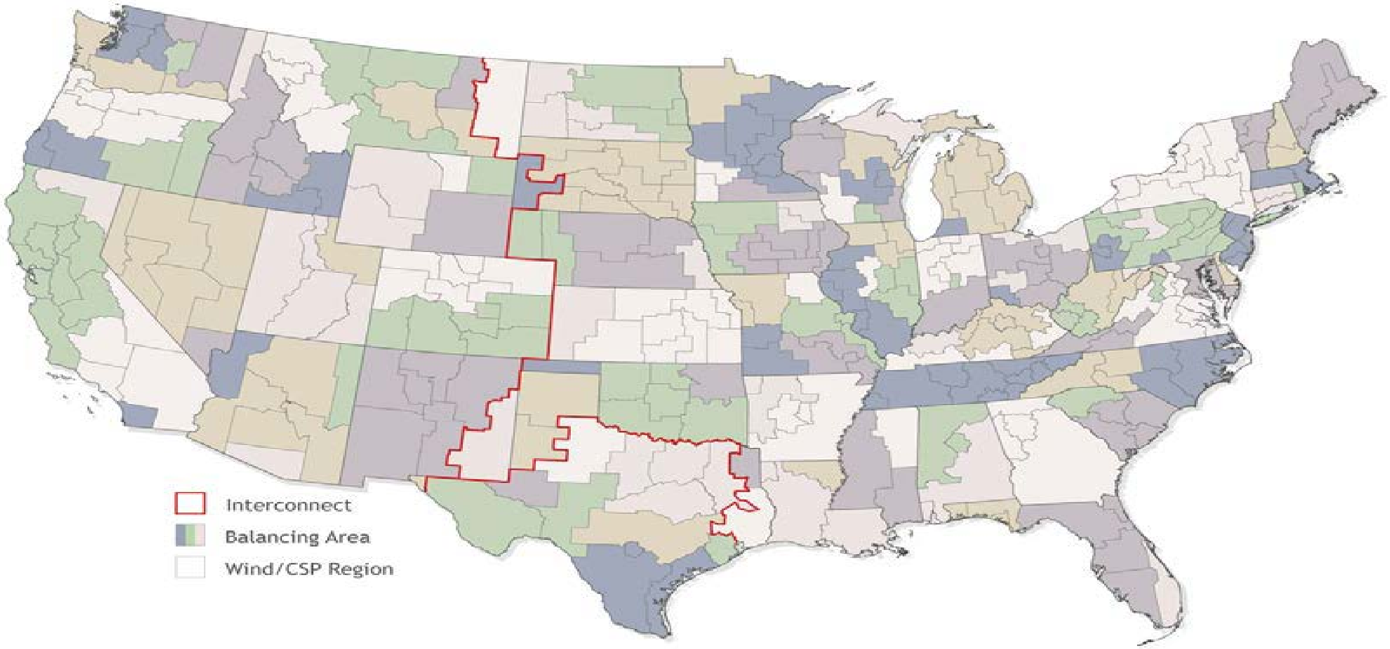
Renewable Energy Potential Model – NREL reV

- Resource Assessment (Geospatial data science modeling)



Capacity Expansion Model – NREL ReEDS

- ReEDS includes 3 interconnections, 134 model BAs, and 356 Wind and CSP resource regions
- Transmission and generation buildout
- Scenario creation model
- Optimal investment pathways



Summary of the Standard Scenarios

Non-Policy Scenarios

Fuel Cost

- High Oil & Gas Resource (AEO 2018)
- Low Oil & Gas Resource (AEO 2018)

Mid-case

- Reference or Mid-level Assumptions

Combinations

- Low/High NG Price with
  - Low/High RE Cost
  - Low/High Geo Cost
  - Low/High CSP Cost
  - Low/High Hydro Cost
  - Low/High Offshore Wind Cost

Demand

- Low Demand
- High Demand
- Vehicle Electrification

Technology Cost

- Low RE Cost
- High RE Cost
- Low Wind Cost
- Low PV Cost
- Low Geo Cost
- Low CSP Cost
- Low Hydro Cost
- Low Offshore Wind Cost
- Nuclear Breakthrough
- Low Battery Cost
- High Battery Cost

Other

- Extended Cost Recovery
- Climate Change Impacts
- Reduced RE Resource
- Transmission Expansion Barriers
- Restricted Cooling Water

Retirements

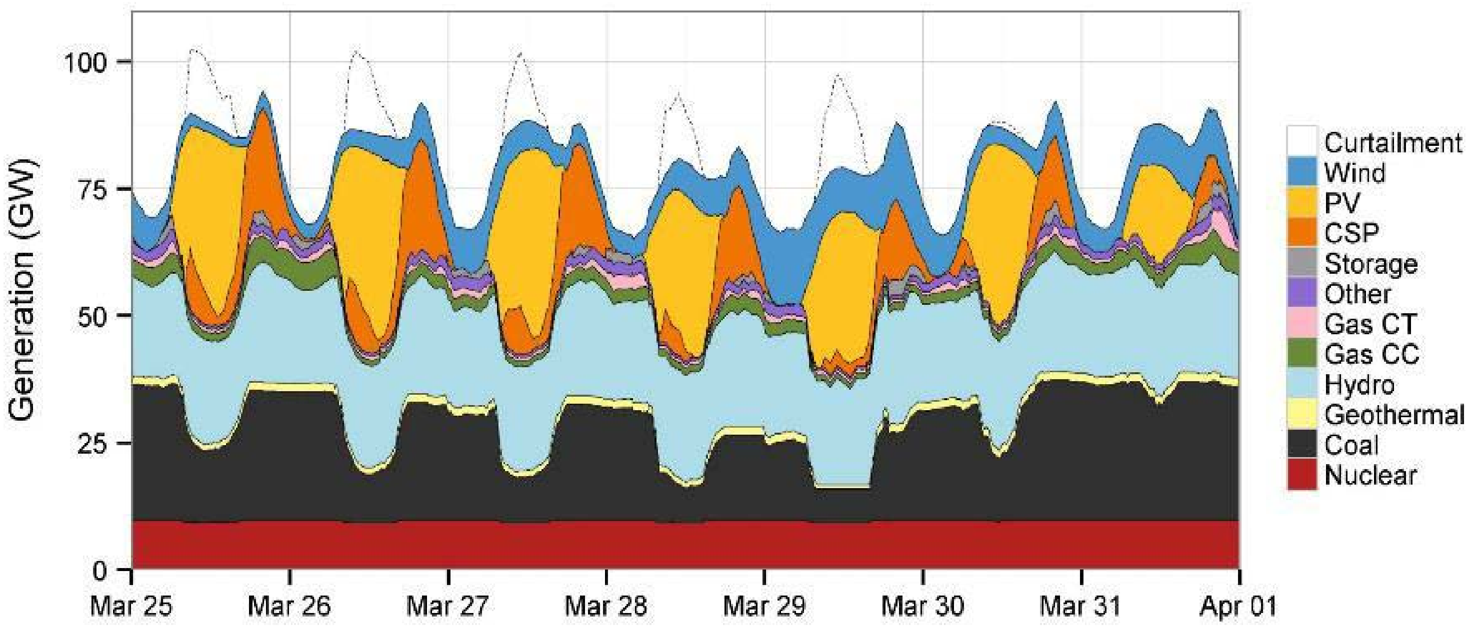
- 80 Year Nuclear
- 60 Year Nuclear
- Accelerated Nuclear Retirement
- Accelerated Retirements
- Extended Lifetimes

Policy

- National 80% RPS by 2050
- 83% CO_2 Reduction by 2050
- ITC & PTC Extension to 2030

Operational (Production cost) Model – Energy Exemplar PLEXOS

- Detailed scenario analysis from NREL ReEDS simulations
- Optimizes unit commitment and economic dispatch up to 5-minute resolution
- Minimizes the cost of power system operations



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Thank you – any questions?

Agenda

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- **Next Steps, Wrap Up** – Ken Jennings, Duke Energy

APPENDIX

Scenario	Definition	Annual Load Met by Carbon Free Generation (%)	Annual Curtailed Energy (%)	Annual Hours of Curtailment	Annual Maximum Instantaneous Curtailment (MW)
1. Solar energy penetration 5%—both balancing authorities as a single region	4,109 MW, 5.5% of total solar is rooftop	63%	0%	6	530
2. Solar energy penetration 10%—both balancing authorities as a single region	8,219 MW, 5.5% of total solar is rooftop	68%	1%	179	3,323
3. Solar energy penetration 15%—both balancing authorities as a single region	12,328 MW, 5.5% of total solar is rooftop	72%	8%	882	6,618
4. Solar energy penetration 20%—both balancing authorities as a single region	16,438 MW, 5.5% of total solar is rooftop	74%	17%	1,506	10,003
5. Solar energy penetration 25%—both balancing authorities as a single region	20,547 MW, 5.5% of total solar is rooftop	76%	27%	2,016	13,504
6. Solar energy penetration 30%—both balancing authorities as a single region	24,656 MW, 5.5% of total solar is rooftop	77%	35%	2,355	17,207
7. Solar energy penetration 35%—both balancing authorities as a single region	28,766 MW, 5.5% of total solar is rooftop	77%	42%	2,587	20,909
8. Higher ratio of distributed to utility solar added to the system—both balancing authorities as a single region	Based on the 25% solar energy penetration scenario, 18.91% of PV is uncurtailable rooftop.	76%	36%	2,017	13,548
9. Additional storage—both balancing authorities as a single region	Based on the 25% solar energy penetration scenario, addition of 1,000 MW of 4-hour storage, 1,000 MW of 6-hour storage, and 2,000 MW of 8-hour storage	78%	12%	1,239	11,073
10. Nuclear retirement—both balancing authorities as a single region	Based on the 25% solar energy penetration scenario, assume a 10% nuclear reduction	71%	22%	1,804	12,551
11. Additional wind energy penetration 5—both balancing authorities as a single region	Based on the 30% solar energy penetration scenario, an additional 5% wind energy penetration is added.	81%	32%	2,486	17,486
12—DEC 5%	Based on scenarios 1–3 inclusive, DEP and DEC are analyzed separately with an interconnection limit between	73%	0%	5	246
12—DEC 10%		78%	1%	213	1,886
12—DEC 15%		94%	7%	912	3,418
12—DEP 5%		52%	0%	5	246
12—DEP 10%		56%	1%	205	1,600
12—DEP 15%		60%	10%	905	3,418

Average Seasonal Percentage of Load Met by Carbon-Free Generation for Each Scenario

Scenario	Spring	Summer	Fall	Winter	Annual
1. Solar energy penetration 5%—both balancing authorities as a single region	70%	56%	67%	59%	63%
2. Solar energy penetration 10%—both balancing authorities as a single region	76%	60%	72%	63%	68%
3. Solar energy penetration 15%—both balancing authorities as a single region	81%	65%	75%	65%	72%
4. Solar energy penetration 20%—both balancing authorities as a single region	83%	69%	78%	67%	74%
5. Solar energy penetration 25%—both balancing authorities as a single region	84%	71%	79%	68%	76%
6. Solar energy penetration 30%—both balancing authorities as a single region	85%	73%	80%	69%	77%
7. Solar energy penetration 35%—both balancing authorities as a single region	86%	74%	81%	69%	77%
8. Higher ratio of distributed to utility solar added to the system—both balancing authorities as a single region	84%	71%	79%	68%	76%
9. Additional storage—both balancing authorities as a single region	88%	72%	82%	70%	78%
10. Nuclear retirement—both balancing authorities as a single region	80%	67%	74%	64%	71%
11. Additional wind energy penetration 5—both balancing authorities as a single region	90%	76%	84%	73%	81%
12 – DEC 5%	82%	63%	78%	68%	73%
12 – DEC 10%	89%	68%	84%	72%	78%
12 – DEC 15%	106%	86%	100%	86%	94%
12 – DEP 5%	57%	47%	54%	48%	52%
12 – DEP 10%	63%	52%	59%	52%	56%
12 – DEP 15%	66%	56%	62%	54%	60%

Average Percentage Curtailed Energy

Scenario	Spring	Summer	Fall	Winter	Annual
1	0%	0%	0%	0%	0%
2	2%	0%	1%	2%	1%
3	12%	1%	10%	10%	8%
4	25%	4%	22%	22%	17%
5	36%	12%	32%	31%	27%
6	44%	21%	40%	39%	35%
7	50%	29%	46%	45%	42%
8	47%	16%	42%	41%	36%
9	19%	2%	15%	14%	12%
10	30%	8%	27%	26%	22%
11	40%	20%	36%	34%	32%
12 – DEC 5%	0%	0%	0%	0%	0%
12 – DEC 10%	2%	0%	1%	1%	1%
12 – DEC 15%	11%	1%	9%	10%	7%
12 – DEP 5%	0%	0%	0%	0%	0%
12 – DEP 10%	2%	0%	1%	1%	1%
12 – DEP 15%	15%	2%	30%	31%	10%

Hours of Curtailment per Season

Scenario	Spring	Summer	Fall	Winter	Annual
1	0	0	0	6	6
2	76	0	45	58	179
3	351	36	275	220	882
4	533	216	403	354	1,506
5	636	458	494	428	2,016
6	707	598	562	488	2,355
7	752	700	610	525	2,587
8	634	454	496	433	2,017
9	484	136	341	278	1,239
10	593	363	457	391	1,804
11	746	650	584	506	2,486
12 – DEC 5%	0	0	0	5	5
12 – DEC 10%	91	2	54	66	213
12 – DEC 15%	358	53	278	223	912
12 – DEP 5%	0	0	0	5	5
12 – DEP 10%	90	1	51	63	205
12 – DEP 15%	361	45	282	217	905

Maximum instantaneous curtailment of each season (MW)

Scenario	Spring	Summer	Fall	Winter
1	0	0	0	530
2	2430	0	2752	3233
3	6113	2913	5897	6618
4	9801	6106	9183	10003
5	13504	9299	12560	13389
6	17207	12542	16023	16774
7	20909	16143	19689	20271
8	13548	9248	12568	13452
9	11073	5769	9185	9842
10	12551	8346	11607	12436
11	17486	13326	16273	17084
12 – DEC 5%	0	0	0	246
12 – DEC 10%	1466	252	1390	1886
12 – DEC 15%	3116	1878	2958	3418
12 – DEP 5%	0	0	0	246
12 – DEP 10%	1234	117	1390	1600
12 – DEP 15%	3116	1630	2958	3418

IV. ACTUAL TOTAL AND INCREMENTAL COSTS INCURRED IN 2019

REPS compliance costs incurred for calendar year 2019 comprise the cost of energy purchases and the cost of purchases of various types of RECs, the cost of solar distributed generation at Duke Energy Carolinas-owned facilities, and other reasonable and prudent costs incurred to meet the requirements of the REPS statute. In addition, annual Solar Rebate Program costs incurred pursuant to N.C. Gen. Stat. § 62-155 are recovered in the REPS rider as directed in N.C. Gen. Stat. § 62-133.8(h)(1)d.

Actual Costs Incurred	Energy and REC Costs	Other	Total Costs
REPS compliance - avoided cost	$ 79,364,959	$ 0	$ 79,364,959
REPS compliance – incremental cost	$ 29,350,739	$ 2,229,681	$ 31,580,420 (a)
REPS compliance - total cost	**$ 108,715,698**	**$ 2,229,681**	**$ 110,945,379**
Solar Rebate Program cost	$ 0	$ 886,071	$ 886,071 (b)
Incremental REPS compliance costs and Solar Rebate Program costs for REPS rider recovery		(a) + (b) above	**$ 32,466,491**

V. ACTUAL INCREMENTAL COSTS COMPARISON TO THE ANNUAL COST CAP AS OF THE PREVIOUS CALENDAR YEAR

Account Type	Total 2018 Year-end number of Retail Accounts(1)	Annual Per-Account Cost Cap	Total Annual Cost Cap
Residential	1,866,080	$27	$ 50,384,167
General	262,147	$150	$ 39,322,037
Industrial	4,957	$1000	$ 4,957,270
Total annual REPS Compliance cost cap - 2019			**$ 94,663,474**
Incremental REPS Compliance costs incurred - 2019			(a) **$ 31,580,420**

(1) Includes number of retail accounts for Duke Energy Carolinas and its Wholesale REPS customers.

/A

DUKE ENERGY CAROLINAS, LLC
Docket No. E-7, Sub 1229

Calculate DEC NC Retail monthly REPS rider components:

North Carolina Retail

Line No.	Customer Class	Total Projected Number of Accounts -Duke Retail[(1)]	Annual REPS EMF Under/(Over)-Collection	Receipts for Contract Amendments, Penalties, Change-of-control, Etc. [(3)]	Total EMF costs/(credits)	Monthly EMF Rider[(2)]	Projected Total Incremental Costs	Monthly REPS Rider[(2)]
1	Residential	1,769,590	$ 318,382	$ (588,018)	$ (269,636)	$ (0.01)	$ 16,863,752	$ 0.79
2	General	251,109	$ (35,187)	$ (423,355)	$ (458,542)	$ (0.15)	$ 12,019,120	$ 3.99
3	Industrial	4,737	$ 139,203	$ (34,799)	$ 104,404	$ 1.84	$ 947,859	$ 16.67
4		**2,025,436**	**$ 422,398**	**$ (1,046,172)**	**$ (623,774)**		**$ 29,830,731**	
			Williams Ex. No. 2 Pg 3 Line No. 4				**Williams Ex. No. 3 Pg 3 Line No. 4**	

Compare total annual REPS charges per account to per-account cost caps:

North Carolina Retail

Line No.	Customer Class	Monthly EMF Rider[(2)]	Monthly REPS Rider[(2)]	Combined Monthly Rider[(2)]	Regulatory Fee Multiplier	Total Monthly REPS Charge including Regulatory Fee	Total Annual REPS Charge including Regulatory Fee	Annual Per-Account Cost Cap	Information only: Total Annual REPS Charge excluding solar rebate cost - for per-account cap comparison only
5	Residential	$ (0.01)	$ 0.79	$ 0.78	1.001302	**$ 0.78**	$ 9.36	$ 27.00	$ 8.88
6	General	$ (0.15)	$ 3.99	$ 3.84	1.001302	**$ 3.84**	$ 46.08	$ 150.00	$ 43.32
7	Industrial	$ 1.84	$ 16.67	$ 18.51	1.001302	**$ 18.53**	$ 222.36	$ 1,000.00	$ 203.28

Notes:

(1) Projected number of accounts subject to REPS charge during the billing period.
(2) Per account rate calculations apply to Duke Energy Carolinas NC Retail customers only.
(3) Credit for receipts for contract amendments, penalties, change-of-control, etc

Customer Class	Total contract receipts - EMF Period Jan 2019 - Dec 2019	NC retail percentage of EMF Period costs - Williams Exhibit No. 2, Pg 1	Allocation to customer class - Williams Exhibit No. 2, Pg 2	Receipts for contract amendments, penalties, change-of-control, etc.
Residential			56.21%	$ (588,018)
General			40.47%	$ (423,355)
Industrial			3.33%	$ (34,799)
Total contract payments received	$ (1,118,900) [(a)]	$ (1,046,172)	100.00%	$ (1,046,172)
		93.50%		

Duke Energy Carolinas, LLC

Electricity No. 4
North Carolina Twelfth Revised Leaf No. 68
Superseding North Carolina Eleventh Revised Leaf No. 68

REPS (NC)
RENEWABLE ENERGY PORTFOLIO STANDARD RIDER

APPLICABILITY (North Carolina Only)
Service supplied to the Company's retail customer agreements is subject to a REPS Monthly Charge. This charge is adjusted annually, pursuant to North Carolina General Statute 62-133.8 and North Carolina Utilities Commission Rule R8-67 as ordered by the North Carolina Utilities Commission. This Rider is not applicable to agreements for the Company's outdoor lighting rate schedules, OL, PL, NL, nor for services defined as auxiliary to another agreement. An auxiliary service is defined as a non-demand metered, nonresidential service, provided on Schedule SGS, at the same premises, with the same service address, and with the same account name as an agreement for which a monthly REPS charge has been applied.

APPROVED REPS MONTHLY CHARGE
The Commission has ordered that a REPS Monthly Charge, which includes an Experience Modification Factor (EMF), be included in the customers' bills as follows:

RESIDENTIAL SERVICE AGREEMENTS	
REPS Monthly Charge	$ 0.79
Experience Modification Factor	($ 0.01)
Net REPS Monthly Charge	$ 0.78
Regulatory Fee Multiplier	1.001302
Total REPS Monthly Charge per agreement per month	$ 0.78
GENERAL SERVICE AGREEMENTS	
REPS Monthly Charge	$ 3.99
Experience Modification Factor	($ 0.15)
Net REPS Monthly Charge	$ 3.84
Regulatory Fee Multiplier	1.001302
Total REPS Monthly Charge per agreement per month	$ 3.84
INDUSTRIAL SERVICE AGREEMENTS	
REPS Monthly Charge	$ 16.67
Experience Modification Factor	$ 1.84
Net REPS Monthly Charge	$ 18.51
Regulatory Fee Multiplier	1.001302
Total REPS Monthly Charge per agreement per month	$ 18.53

USE OF RIDER
The REPS Billing Factor is not included in the Company's current rate schedules and will apply as a separate charge to each agreement for service covered under this Rider as described above, unless the service qualifies for a waiver of the REPS Billing Factor for an auxiliary service. An auxiliary service is a non-demand metered nonresidential service, on Schedule SGS for the same customer at the same service location.

To qualify for an auxiliary service, not subject to this Rider, the Customer must notify the Company and the Company must verify that such agreement is considered an auxiliary service, after which the REPS Billing Factor will not be applied to qualifying auxiliary service agreements. The Customer shall also be responsible for notifying the Company of any change in service that would no longer qualify the service as auxiliary.

/A

DUKE ENERGY CAROLINAS, LLC
Docket No. E-7, Sub 1229

Worksheet detailing energy efficiency certificate ("EEC") inventory

EEC inventory reconciliation - as of December 31, 2018	EECs [1]	Reference
EECs carried forward at Dec 31, 2013	2,709,318	2013 Compliance Report - Docket No. E-7, Sub 1052
EECs generated for 2014 per Company's annual update	2,011,450	E-7, Sub 1074, Williams Exhibit No. 6
Less: EECs used for compliance for 2014	415,459	2014 Compliance Report - Docket No. E-7, Sub 1074
EECs carried forward at Dec 31, 2014	4,305,309	2014 Compliance Report - Docket No. E-7, Sub 1074
EECs generated for 2015 per Company's annual update	2,310,608	E-7, Sub 1106, Williams Exhibit No. 6
Less: EECs used for compliance for 2015	855,980	2015 Compliance Report - Docket No. E-7, Sub 1106
EECs carried forward at Dec 31, 2015	5,759,937	2015 Compliance Report - Docket No. E-7, Sub 1106
EECs generated for 2016 per Company's annual update	2,152,597	E-7, Sub 1131, Williams Exhibit No. 6
Less: EECs used for compliance for 2016	866,492	2016 Compliance Report - Docket No. E-7, Sub 1131
EECs carried forward at Dec 31, 2016	7,046,042	2016 Compliance Report - Docket No. E-7, Sub 1131
EECs generated for 2017 per Company's annual update	2,531,010	E-7, Sub 1162, Williams Exhibit No. 6
Less: EECs used for compliance for 2017	863,135	2017 Compliance Report - Docket No. E-7, Sub 1162
EECs carried forward at Dec 31, 2017	8,713,917	2017 Compliance Report - Docket No. E-7, Sub 1162
EECs generated for 2018 per Company's annual update	3,060,454	E-7, Sub 1191, Williams Exhibit No. 6
Less: EECs used for compliance for 2018	1,400,307	2018 Compliance Report - Docket No. E-7, Sub 1191
EECs carried forward at Dec 31, 2018	10,374,064	2018 Compliance Report - Docket No. E-7, Sub 1191
EECs generated for 2019 per Company's annual update	3,044,778	Company workpapers [a]
Less: EECs used for compliance for 2019	1,487,017	2019 Compliance Report - Docket No. E-7, Sub 1229
EECs carried forward at Dec 31, 2019	11,931,825	2019 Compliance Report - Docket No. E-7, Sub 1229

Summary workpapers - EECs generated

	Program year							
Update for 2019 EECs generated - as of year-end 2019:	**2009 - 2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Total**
Current view at year-end 2019	3,578,636	1,881,130	2,195,026	2,292,223	2,612,972	2,821,394	3,267,747	18,649,128
Previously reported current view at year-end 2018	3,578,636	1,881,130	2,195,026	2,292,223	2,613,127	3,044,208		15,604,350
Total adjustments to previously reported results	0	0	0	0	(155)	(222,814)		
Updated EECs created and available for 2019	(b)	(b)	(b)	(b)	(c)	(d)		**3,044,778** (a)

detail of adjustments at page 2 of 2

Footnote:
[1] Calculated EECs originate from details contained in the databases supporting Duke Energy Carolinas' energy efficiency filings, and are specific to North Carolina, calculated at the generation station level, are inclusive of free-ridership EE savings, and assume savings intiated in a program year continue only for the duration of the life of the applicable measure.

Detail for adjustments to previously reported results through program year 2018:

Adjustment type	Program	2013	2014	2015	2016	2017	2018	Total
		Program year						
º Evaluation, Measurement, & Verification ("EM&V"):								
	Home Energy Comparison Report (HECR)	-	-	-	-	-	(222,685)	(222,685)
	HVAC Energy Efficiency (HVAC EE)	-	-	-	-	(113)	(508)	(621)
	Income Qualified Energy Efficiency and Weatherization Assistance (IQEE & WA)	-	-	-	-	-	418	418
	Energy Efficient Appliances and Devices (EEAD)	-	-	-	-	(34)	(167)	(201)
	Multi-Family Energy Efficiency (MFAM)	-	-	-	-	(8)	(22)	(30)
	Energy Efficiency Education (K12)	-	-	-	-	-	116	116
º Total EM&V adjustments		-	-	-	-	**(155)**	**(222,848)**	**(223,003)**
º Participation updates/adjustments								
	EnergyWise for Business (EWB)	-	-	-	-	-	26	26
	Non Residential Smart Saver Energy Efficient Lighting Products (NRLTG)	-	-	-	-	-	10	10
	Non Residential Smart Saver Energy Efficient Food Service Products (NRFS)	-	-	-	-	-	(2)	(2)
º Total participation adjustments		-	-	-	-	-	**34**	**34**
Total adjustments to prior program years incorporated into 2019 current view - EE savings for REPS		**0** (b)	**0** (b)	**0** (b)	**0** (b)	**(155)** (c)	**(222,814)** (d)	**(222,969)**

EM&V reports applicable to results reported above - filed as exhibits to the testimony of DEC witness Robert Evans in DEC's energy efficiency **Docket No. E-2, Sub 1230 - Evans Exhibit No. 8:**

Program	**EM&V Reports**	**Report Finalization Date**	**Evaluation Type**
IQEE & WA	Duke Energy Carolinas and Duke Energy Progress 2017 Neighborhood Energy Saver Program Evaluation Report - Final	11/30/2019	Process and Impact
HECR	My Home Energy Report Program Evaluation	7/10/2019	Process and Impact
PWRSHR	Duke Energy PowerShare Program 2018 Evaluation Report for Duke Energy Carolinas	5/2/2019	Process and Impact
HVAC EE	Smart $aver Evaluation Report — May 1, 2016 – April 30, 2017 (Revised)	3/15/2019	Process and Impact
K12	Energy Efficiency Education in Schools Program Year 2017-2018 Evaluation Report	2/1/2019	Process and Impact
NRCUST	Smart $aver® Non-Residential Custom Program Years 2016-2017 Evaluation Report	11/29/2018	Process and Impact

Calculate DEC NC Retail monthly REPS rider components:

North Carolina Retail

Line No.	Customer Class	Total Projected Number of Accounts -Duke Retail[1]	Annual REPS EMF Under/(Over)-Collection	Receipts for Contract Amendments, Penalties, Change-of-control, Etc. [3]	Total EMF costs/(credits)	Monthly EMF Rider[2]	Projected Total Incremental Costs	Monthly REPS Rider[2]
1	Residential	1,769,590	$ 260,340	$ (588,889)	$ (328,549)	$ (0.02)	$ 16,899,388	$ 0.80
2	General	251,109	$ (108,375)	$ (423,261)	$ (531,636)	$ (0.18)	$ 12,011,561	$ 3.99
3	Industrial	4,737	$ 111,738	$ (34,022)	$ 77,716	$ 1.37	$ 919,782	$ 16.18
4		**2,025,436**	**$ 263,703**	**$ (1,046,172)**	**$ (782,469)**		**$ 29,830,731**	
			Revised Williams Ex. No. 2 Pg 3 Line No. 4				Revised Williams Ex. No. 3 Pg 3 Line No. 4	

Compare total annual REPS charges per account to per-account cost caps:

North Carolina Retail

Line No.	Customer Class	Monthly EMF Rider[2]	Monthly REPS Rider[2]	Combined Monthly Rider[2]	Regulatory Fee Multiplier	Total Monthly REPS Charge including Regulatory Fee	Total Annual REPS Charge including Regulatory Fee	Annual Per-Account Cost Cap	Information only: Total Annual REPS Charge excluding solar rebate cost - for per-account cap comparison only
5	Residential	$ (0.02)	$ 0.80	$ 0.78	1.001302	**$ 0.78**	$ 9.36	$ 27.00	$ 8.88
6	General	$ (0.18)	$ 3.99	$ 3.81	1.001302	**$ 3.81**	$ 45.72	$ 150.00	$ 43.08
7	Industrial	$ 1.37	$ 16.18	$ 17.55	1.001302	**$ 17.57**	$ 210.84	$ 1,000.00	$ 191.88

Notes:

(1) Projected number of accounts subject to REPS charge during the billing period.

(2) Per account rate calculations apply to Duke Energy Carolinas NC Retail customers only.

(3) Credit for receipts for contract amendments, penalties, change-of-control, etc

Customer Class	Total contract receipts - EMF Period Jan 2019 - Dec 2019	NC retail percentage of EMF Period costs - Revised Williams Exhibit No. 2, Pg 1	Allocation to customer class - Revised Williams Exhibit No. 2, Pg 2	Receipts for contract amendments, penalties, change-of-control, etc.
Residential			56.29%	$ (588,889)
General			40.46%	$ (423,261)
Industrial			3.25%	$ (34,022)
Total contract payments received	$ (1,118,900) (a)	$ (1,046,172)	100.00%	$ (1,046,172)
		93.50%		

REPS (NC)
RENEWABLE ENERGY PORTFOLIO STANDARD RIDER

APPLICABILITY (North Carolina Only)
Service supplied to the Company's retail customer agreements is subject to a REPS Monthly Charge. This charge is adjusted annually, pursuant to North Carolina General Statute 62-133.8 and North Carolina Utilities Commission Rule R8-67 as ordered by the North Carolina Utilities Commission. This Rider is not applicable to agreements for the Company's outdoor lighting rate schedules, OL, PL, NL, nor for services defined as auxiliary to another agreement. An auxiliary service is defined as a non-demand metered, nonresidential service, provided on Schedule SGS, at the same premises, with the same service address, and with the same account name as an agreement for which a monthly REPS charge has been applied.

APPROVED REPS MONTHLY CHARGE
The Commission has ordered that a REPS Monthly Charge, which includes an Experience Modification Factor (EMF), be included in the customers' bills as follows:

RESIDENTIAL SERVICE AGREEMENTS	
REPS Monthly Charge	$ 0.80
Experience Modification Factor	($ (0.02)
Net REPS Monthly Charge	$ 0.78
Regulatory Fee Multiplier	1.001302
Total REPS Monthly Charge per agreement per month	$ 0.78
GENERAL SERVICE AGREEMENTS	
REPS Monthly Charge	$ 3.99
Experience Modification Factor	($ 0.18)
Net REPS Monthly Charge	$ 3.81
Regulatory Fee Multiplier	1.001302
Total REPS Monthly Charge per agreement per month	$ 3.81
INDUSTRIAL SERVICE AGREEMENTS	
REPS Monthly Charge	$ 16.18
Experience Modification Factor	$ 1.37
Net REPS Monthly Charge	$ 17.55
Regulatory Fee Multiplier	1.001302
Total REPS Monthly Charge per agreement per month	$ 17.57

USE OF RIDER
The REPS Billing Factor is not included in the Company's current rate schedules and will apply as a separate charge to each agreement for service covered under this Rider as described above, unless the service qualifies for a waiver of the REPS Billing Factor for an auxiliary service. An auxiliary service is a non-demand metered nonresidential service, on Schedule SGS for the same customer at the same service location.

To qualify for an auxiliary service, not subject to this Rider, the Customer must notify the Company and the Company must verify that such agreement is considered an auxiliary service, after which the REPS Billing Factor will not be applied to qualifying auxiliary service agreements. The Customer shall also be responsible for notifying the Company of any change in service that would no longer qualify the service as auxiliary.