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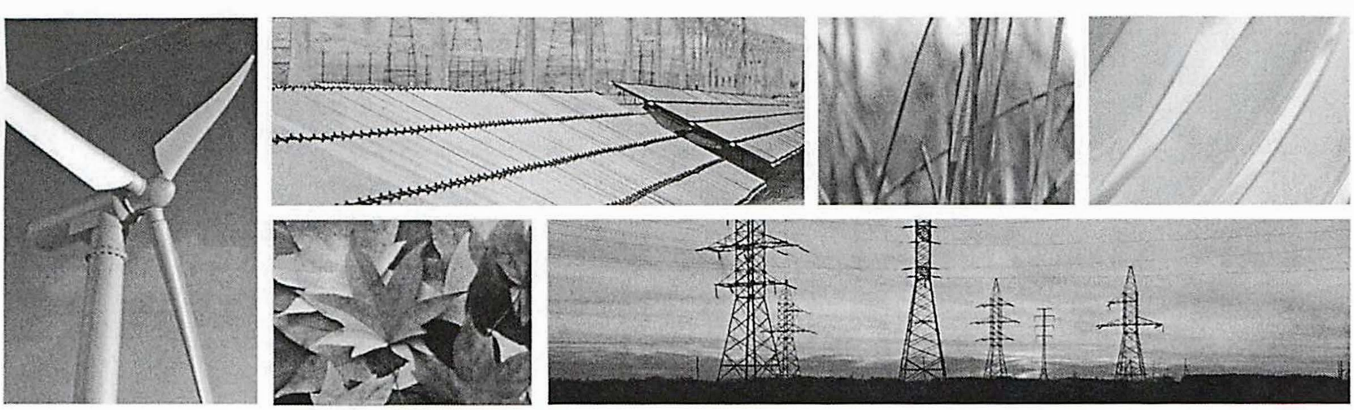
Investigating the Economic Value of Flexible Solar Power Plant Operation

October 2018



Energy+Environmental Economics

Investigating the Economic Value of Flexible Solar Power Plant Operation

October 2018

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Abstract

Solar power is growing rapidly around the world, driven by dramatic cost reductions and increased interest in carbon-free energy sources. Solar is a variable resource, requiring grid operators to increase the available operating range on conventional generators, sometimes by committing additional units to ensure enough grid flexibility to balance the system. At very high levels of penetration, operators may not have enough flexibility on conventional generators to ensure reliable operations.

However, modern solar power plants can be operated flexibly; in fact, they can respond to dispatch instructions much more quickly than conventional generators. Flexible solar not only contributes to solving operating challenges related to solar variability but can also provide essential grid services. This study simulates operations of an actual utility system -- Tampa Electric Company (TECO) – and its generation portfolio to investigate the economic value of using solar as a flexible resource. The study explores four solar operating modes: "Must-Take," "Curtailable," "Downward Dispatch," and "Full Flexibility."

The study finds that for this relatively small utility system, *Must-Take* solar becomes infeasible once solar penetration exceeds 14% of annual energy supply due to unavoidable oversupply during low demand periods, necessitating a shift to the *Curtailable* mode of solar operations. As the penetration continues to grow, the operating reserves needed to accommodate solar uncertainty become a significant cost driver, leading to more conservative thermal plant operations and increasingly large amounts of solar curtailment. Flexible solar reduces uncertainty, enabling leaner operations and providing significant economic value. At penetration levels exceeding 20% on the TECO system, solar curtailment can be reduced by more than half by moving from the *Curtailable* to the *Full Flexibility* solar operating mode. This results in significant additional value due to reduced fuel costs, operations and maintenance costs, and air emissions.

Finally, the study evaluates the impact of flexible solar in combination with energy storage. We find that flexible solar can provide some of the same grid services as energy storage, thereby reducing the value of storage on a high-solar grid.

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1 Introduction

Solar electricity is becoming an important part of the electric generation portfolio in many regions due to rapidly declining costs and policies favoring non-emitting renewable generation. The installed capacity of solar has grown exponentially over the past two decades.

Further solar growth is expected in subsequent decades. Policy targets for renewable energy installation and decarbonization of the energy system are driving solar installations around the world. Both India and China have targets to reach more than 100 GW of installed solar capacity by the early 2020s.[1] California and Hawaii have passed legislation to reach 100% renewable or zero-carbon electricity by 2045, and it is expected that solar energy will be one of the primary energy sources used meet these ambitious targets. Recent analysis on deep decarbonization pathways in California suggests that solar power could supply a large fraction of the economy-wide demand for energy by 2050.[2] Europe is also expected to increase solar energy capacity to meet decarbonization targets.

1.1 Operational challenges and opportunities

Existing or "conventional" utility-scale solar is typically designed and operated to generate and deliver the maximum amount of electricity in real-time. This approach is motivated by the desire to minimize the cost per unit of energy by amortizing the capital cost of solar across the maximum amount of energy that system could produce.

Increasing the level of solar can make it more challenging for grid operators to balance electricity supply and demand. For example, grid operators must manage rapid increases in solar generation during sunrise

[1] International Energy Agency, "IEA/IRENA Joint Policies and Measures Database: Global Renewable Energy," accessed September 2018, https://www.iea.org/policiesandmeasures/renewableenergy/.

[2] A. Mahone, Z. Subin, J. Kahn-Lang, D. Allen, V. Li, G. De Moor, N. Ryan and S. Price, "Deep Decarbonization in a High Renewables Future: Updated Results from the California PATHWAYS Model," Energy and Environmental Economics, Inc., June 2018, https://www.ethree.com/wp-content/uploads/2018/06/Deep_Decarbonization_in_a_High_Renewables_Future_CEC-500-2018-012-1.pdf.

and rapid decreases in solar production during sunset, in addition to variations in solar output caused by regional weather conditions. This often requires managing ramping events by rapidly varying the output of conventional thermal generation. At higher levels of solar penetration, operational challenges become more acute.

Many operational challenges can be addressed by making utility-scale solar available to provide flexibility for grid operations when needed. For example, ramping demands on conventional generation resources can be reduced if solar plants can control ramp rates during both morning and evening hours, thereby providing the means to flexibly operate the grid even in the presence of higher levels of solar generation. While operating solar generators in a flexible manner leads to occasional curtailment of solar output, this may still be a more economical operating mode than other options.

Recent studies have shown that utility-scale solar photovoltaic (PV) plants can provide essential grid reliability services that are typically associated with conventional generation.[3] In the most recent study, First Solar teamed with the National Renewable Energy Laboratory (NREL) and the California Independent System Operator (CAISO) to test a 300 MW utility-scale photovoltaic power plant in California. The power plant was equipped with advanced power controls by combining multiple power-electronic inverters and advanced plant-level controls. The test demonstrated that PV plants can have the technical capabilities to provide grid services such as spinning reserves, load following, voltage support, ramping, frequency response, variability smoothing, frequency regulation, and power quality improvement. Specifically, the tests included various forms of active power controls such as automatic generation control and frequency regulation, droop response, and reactive power/voltage/power factor controls. The results showed that regulation accuracy by the PV plant is significantly better than fast-ramping gas turbine technologies.

By leveraging the full suite of operational capabilities of utility-scale solar resources, solar can go beyond a simple energy source and become an important tool to help operators meet flexibility and reliability

[3] See V. Gevorgian and B. O'Neill, "Advanced Grid-Friendly Controls Demonstration Project for Utility-Scale PV Power Plants," National Renewable Energy Laboratory, January 2016, https://www.nrel.gov/docs/fy16osti/65368.pdf; M. Morjaria, D. Anichkov, V. Chadliev and S. Soni, "A Grid-Friendly Plant: The Role of Utility-Scale Photovoltaic Plants in Grid Stability and Reliability," IEEE Power and Energy Magazine, vol. 12, no. 3, 2014; and California ISO, National Renewable Energy Laboratory, and First Solar, "Using Renewables to Operate a Low-Carbon Grid: Demonstration of Advanced Reliability Services from a Utility-scale Solar PV Plant," 2017, https://www.caiso.com/documents/usingrenewablestooperatelow-carbongrid.pdf.

needs of the grid. To date, the economic value of including solar as an active participant in balancing requirements has not been widely studied. To quantify the value of flexible solar operation, our study introduces solar flexibility constraints into a detailed multi-stage production cost model. We do not explore the economic value of voltage control in this study.

Recent cost declines in energy storage technologies enable solar to further extend its capability by providing firm dispatchable capabilities, which in turn enables even higher solar penetrations. Adding storage to the grid can shift energy to when it is most needed, even if the sun has already set. Adding storage to a grid can combine the flexibility of solar with the firm capacity and energy shifting capabilities of storage, but requires significant capital investment in storage resources. The last section of this study investigates the interplay of solar flexibility and storage value.

1.2 Uncertainty and variability in grid operations

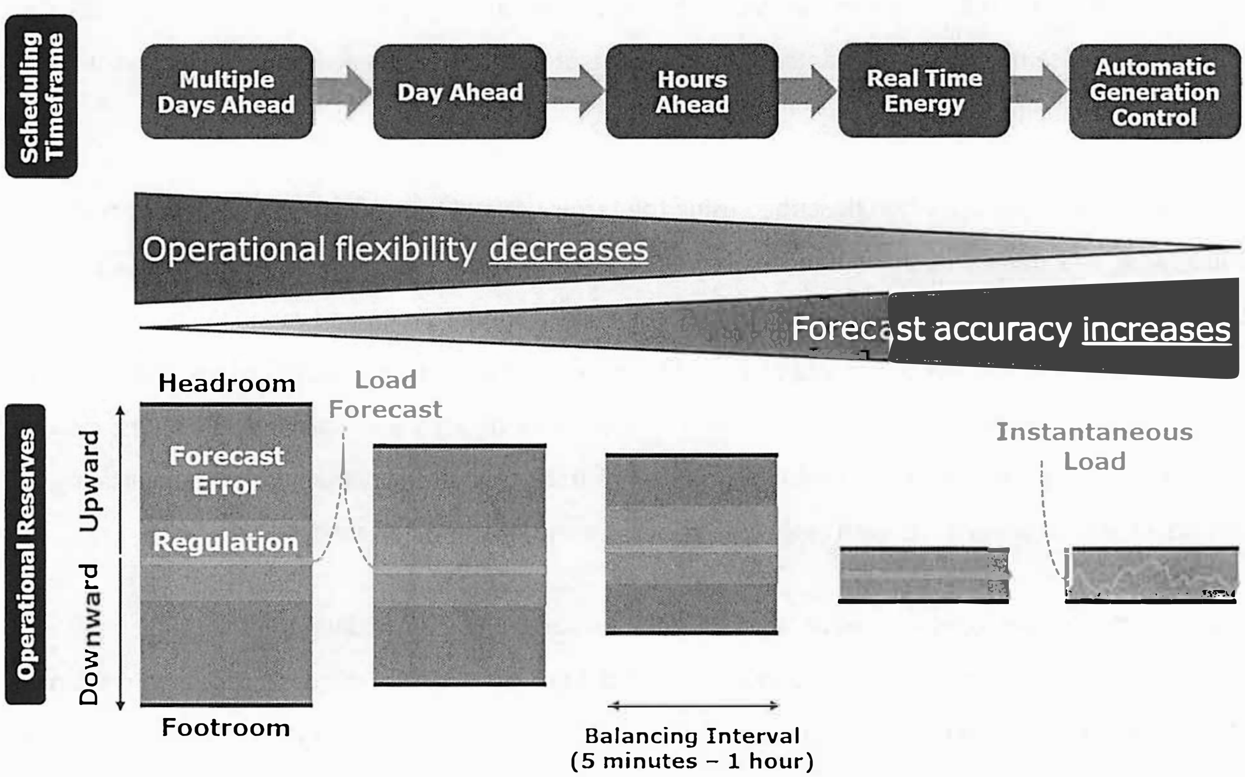
Much like musicians following the conductor in an orchestra, the system operator coordinates the dispatch of an ensemble of power plants. The system operator's goal is to meet demand at least cost while maintaining reliability.

Operational challenges are often described using the terms *variability* and *uncertainty*. Variability refers to increases and decreases in demand or resource availability that would exist even with a perfect forecast. For example, diurnal patterns in human activity are a source of demand variability because these patterns occur naturally over the course of a day. Uncertainty represents the inability to perfectly forecast future demand or other grid conditions. Even in the absence of wind and solar power plants, system operators must maintain system reliability at all times under significant variability and uncertainty of demand, as well as uncertainty with respect to generator and transmission availability.

To balance the system, operators must have information about the level of uncertainty in their forecasts as well as the capabilities of their resources to respond. Forecast accuracy increases closer to real time, but the ability to respond to unexpected events decreases because the operating range of conventional power plants is smaller over shorter time intervals. This problem is magnified by the challenges of generator scheduling ("unit commitment"), because thermal generators typically require significant lead time – hours to days, or even weeks – to be turned on or off. Once running, thermal plants must generate at minimum levels that are typically at least 20 – 50% of maximum output. For some coal-fired generation, the minimum generation level can be as high as 70%. Thus, system operators must frequently make decisions about which units will be operating and at what levels far in advance, and with imperfect information about the level of demand and renewable production.

If actual demand turns out to be much higher than forecasted, there may not be enough resources available to meet demand. To deal with this uncertainty, grid operators maintain a safety margin on top of forecasted demand ("headroom") when scheduling power plants so that a demand under-forecast does not turn into a power shortage. This is shown schematically in Figure 1. In the opposite direction, operators may also retain the ability to turn down or turn off generation ("footroom") to avoid oversupply conditions in the event of a demand over-forecast.

Figure 1: Commitment timeframes, forecast uncertainty, headroom and footroom



System operators are constantly balancing economics and reliability when making commitment and dispatch decisions. If they are conservative and commit too many power plants, generators will be forced to run at less efficient set points or cycle on and off quickly, both of which can be costly. If operators are not conservative enough, they may have to buy expensive energy from neighbors in real-time, call on expensive demand response resources, or incur penalties for violating reliability standards. The worst case is that there simply is not enough generation capacity committed to serve demand and the operator must temporarily disconnect customer loads.

In addition to the challenges of forecasting demand long before real-time, operators must also be prepared for the natural variability of demand in real-time. Common practice is to hold headroom and footroom on quick-moving units ("regulation") to ensure adequate flexibility. Organized markets – the California Independent System Operator (CAISO), the Electric Reliability Council of Texas (ERCOT), PJM Interconnection, the Midcontinent Independent System Operator (MISO), etc. – procure regulation as part of market operations, and centrally dispatched utilities typically have a similar requirement in their dispatch procedures. Operators also address variability by committing units more frequently closer to real-time operations. It is common to commit and dispatch generators on an hourly basis a day-ahead of real-time, and every five to fifteen minutes during real-time operations.

Increasing the level of solar (and wind) generation on the grid increases the variability and uncertainty of electricity supply, both because of imperfect forecasts of wind and solar output and because of fluctuations in output on a minute-to-minute basis. This frequently increases the overall forecast error and regulation requirements needed to balance supply and demand. Higher balancing requirements raise the stakes of power plant commitment decisions.

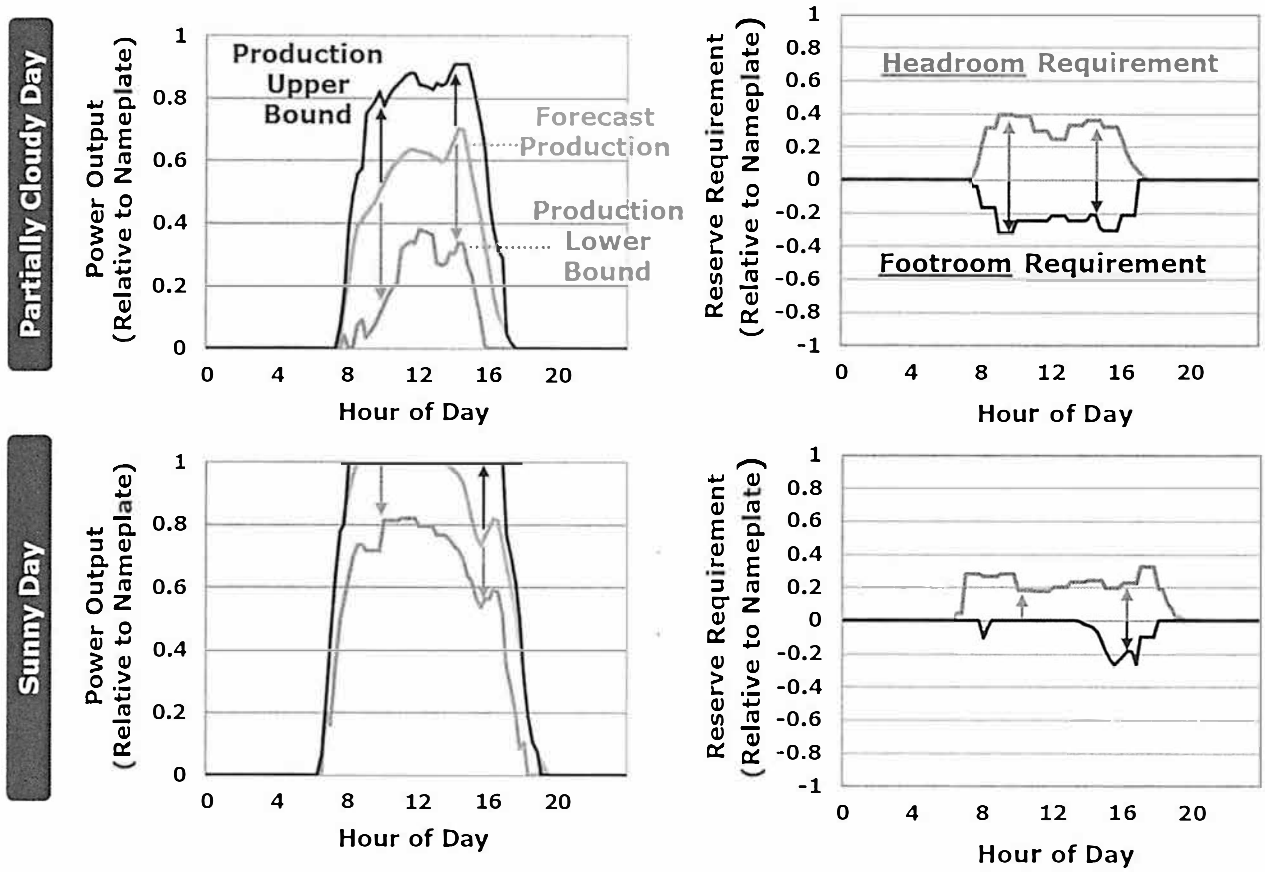
1.3 System balancing with flexible solar generators

Many modern solar power plants have the technical capabilities to contribute to regulation and balancing requirements through precise output control – this is referred to as "flexible" or "dispatchable" solar. In this operating mode, the entire suite of solar dispatch capabilities is made available to the system operator in determining economic dispatch. System operators can elect to use the solar resources to provide energy or essential grid services (e.g., regulation reserves), and this choice may vary by dispatch time interval throughout the day. Provision of these services requires downward dispatch of solar, and some services require the plant operator to maintain headroom to enable upward dispatch. While this results in lost solar production, solar plants incur no measurable variable costs from providing these services. Instead, the cost of solar providing these services is an opportunity cost that can be estimated in the context of economic dispatch. Obtaining grid services from solar plants can, in some instances, enable system operators to reduce fuel costs by reducing thermal generator commitments and increasing the efficiency at which they operate.

Sourcing essential grid services from solar requires the system operator to have an appropriate degree of confidence in the level of solar output minutes, hours, or days ahead of real-time dispatch. As shown in Figure 2, historical solar forecast errors can be used to calculate expected lower and upper bounds on solar production when making commitment decisions ahead of real-time. The lower and upper bounds are used to 1) set system-wide headroom and footroom needs for solar forecast error, and 2) if solar is represented as dispatchable, set limits on how much the solar plant could be dispatched. There are a variety of means for establishing confidence bounds, and this would be an interesting topic for future research. For the current study, we use a single standard deviation above and below the solar forecast as the upper and lower bounds when committing units ahead of real-time.

Our study focuses on the flexible operation of solar power plants in the absence of battery storage. To date, much emphasis has been placed on the role that storage can play in managing solar and wind variability and uncertainty. In this study, we focus on the operation of the solar or wind power plants themselves, and the economic benefits that may result from operating these assets in a more flexible manner. Interactions with battery storage value are explored in a sensitivity study.

Figure 2: Confidence in solar forecasts hours ahead of real-time (left) and resulting forecast error reserve levels (right) on an example partly cloudy day (top) and sunny day (bottom), normalized to solar power plant capacity. As discussed below, reserve requirements must be met by non-solar resources if solar flexibility is not integrated into system operator dispatch procedures, but can be partially met by solar power plants when solar is represented as more flexible.



1.4 Solar operating modes

In this study we explore different solar "operating modes," which represent the extent to which system operators have incorporated the inherent flexibility of many modern utility-scale solar power plants into their operational procedures. We define four solar operating modes to explore the value of solar dispatch flexibility, ordered from least to most flexible:

Solar Operating Mode	Solar can be curtailed	Solar can contribute to footroom requirements	Solar can contribute to headroom requirements
Must-Take	×	×	×
Curtailable	✓	×	×
Downward Dispatch	✓	✓	×
Full Flexibility	✓	✓	✓

In the Must-Take and Curtailable operating modes, other resources – in this study, thermal generators and batteries – are committed such that solar can produce at maximum possible output even in the case of solar under- or over-forecast. In the Downward Dispatch operating mode, solar can be dispatched downward (curtailed) to meet footroom requirements but cannot contribute to headroom requirements. In the Full Flexibility operating mode, solar can be fully dispatched to meet grid needs via economic optimization of energy production and operational reserves while accounting for physical limits imposed by solar insolation availability. When solar is scheduled to be curtailed ahead of real-time, the amount of forecast error headroom that is held on other resources is reduced.

Renewable integration studies include a range of assumptions with respect to solar (or wind) operating modes. Most studies simulate solar (or wind) in Curtailable or Downward Dispatch operating mode, though the implementation of solar operating mode in these studies depends on modeling methodology and may not map precisely onto the operating modes defined above. A smaller set of studies explores the Full Flexibility operating mode for solar, frequently as a sensitivity study. Appendix B, "Prior Research," contains citations to example renewable integration studies.

1.4.1 MUST-TAKE OPERATING MODE

Many system operators and solar integration studies treat solar power plants as "must-take." The common convention is to subtract solar production from electricity demand, which assumes there is neither the ability nor the desire to control solar output. The resulting "net load" is the amount of power that must be produced by other "dispatchable" resources.

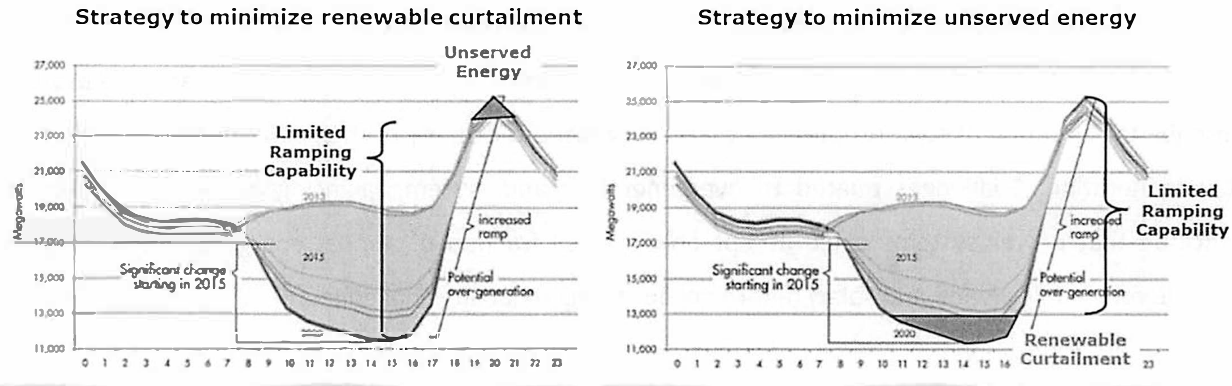
Quick thought experiments demonstrate that the concept of net load was not designed for high penetrations of solar. What if there is so much solar on the grid that there is more solar electricity production than demand? In this scenario, net load would be negative. Balancing supply and demand with negative net load would be very challenging, requiring some level of exports, flexible demand, or energy storage. In the extreme case, the system simply cannot be brought into balance without drastic action such as the temporary disconnection of generators. The term "solar overgeneration" has been used to describe the situation of solar production levels that exceed the ability of the power system to absorb all solar generation. Challenges related to overgeneration and system balancing led early analyses to conclude that power systems could accept only a small fraction of annual energy penetration from variable renewables (wind and solar) before encountering reliability challenges.

It is worthwhile to note that present-day rooftop solar installations are operated as "must-take" because they are almost never visible to or curtailable by the system operator. One of the corollaries to this study's conclusions is that reaching high rooftop solar penetrations will require some control of these resources – operator dispatch signals, pricing mechanisms, local autonomous control, or other control methods.

The CAISO's widely-circulated "duck curve" is a prominent example of operational concerns in the context of must-take solar.[4] Figure 3, based on the duck curve, demonstrates this phenomenon for a system with limited ramping capability. In the left panel, operational limitations lead to a reliability problem: unserved energy, which occurs when the system cannot ramp up fast enough to meet high demand in the evening. In the right panel, prospective curtailment of renewable generation has been used to avoid loss of load by ensuring that sufficient upward ramping capability is online and available. However, this strategy comes at the cost of lost renewable production.

[4] California ISO, "What the duck curve tells us about managing a green grid," 2016, https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf.

Figure 3: Prospective curtailment of renewable energy resources eliminates a reliability challenge, but introduces an economic challenge



1.4.2 CURTAILABLE OPERATING MODE

As solar penetration has increased, curtailment of solar output has become a reality during hours in which inflexibility, lack of load, or transmission constraints prevent absorption of all available solar energy. Curtailment can occur through analog means if necessary – for example, a phone call from the system operator to the plant operator requesting a reduction in output. Increasingly, solar and wind generators are providing decremental energy bids into organized markets such as CAISO, MISO and ERCOT, enabling curtailment to occur as a market outcome rather than through an emergency phone call. In many instances, power purchase agreements (PPA) between independent power producers (IPP) and utility off-takers of solar project output have evolved to accommodate some degree of curtailment flexibility to reflect this emerging reality. Many regions (e.g., Germany, Denmark, California, Hawaii, etc.) have successfully reached higher penetrations of variable renewables – as high as 42% of annual energy in the case of Denmark – by using renewable curtailment and interties with neighboring regions as important integration tools.[5]

Solar curtailment to date has been largely, if not exclusively, focused on avoiding oversupply. Even though solar output can be controlled to an extent, many renewable integration studies and grid operators continue to include solar forecast error in their calculations of headroom and footroom balancing

[5] A. Bloom, U. Helman, H. Holttinen, K. Summers, J. Bakke, G. Brinkman and A. Lopez, "It's Indisputable: Five Facts About Planning and Operating Modern Power Systems," IEEE Power and Energy Magazine, 2017.

requirements while excluding solar generators from meeting any portion of those requirements. In other words, solar can be curtailed during normal grid operations, but regulation and forecast error reserve requirements are still determined based on net load and must be met by resources other than solar generators. We refer to solar operated in this mode as "Curtailable," since curtailment is used only to avoid oversupply and the precise control of solar output is not considered in generator scheduling and economic dispatch.

1.4.3 DOWNWARD DISPATCH OPERATING MODE

The deployment of more variable renewable capacity has increased the need for "downward" flexibility, or footroom. If renewable production unexpectedly increases, other resources must ramp downward to accommodate the additional energy flowing onto the system. This is particularly a concern in real-time, after commitment decisions have been made. In this case, insufficient footroom might result in large quantities of energy flowing onto neighboring systems, violating North American Electric Reliability Corporation (NERC) control performance standards.

However, if the system operator can control output from the solar plant in real-time, it is possible to reduce solar generation to avoid overgeneration conditions. Utilizing the footroom that is available on a flexible solar resource reduces or eliminates the need to hold footroom on other resources to accommodate unexpected spikes in solar production. Stated differently, solar can provide its own downward reserves or footroom. Consequently, our simulations with the Downward Dispatch solar operating mode system operations do not require any footroom for solar uncertainty and variability.

But solar that can be dispatched downward is not limited to providing *its own* footroom – it can also provide footroom to accommodate unexpected decreases in *demand*. In other words, flexible solar can be used to provide the downward regulation service that system operators have for more than a century sourced exclusively from conventional generators. If enough solar is forecasted to be online in real-time, operators can plan to dispatch solar downwards if demand drops unexpectedly. In this study, we limit the footroom that solar can provide for meeting variability and uncertainty in demand to the lower bound of forecasted solar production potential – the distance between zero and the light blue Production Lower

Bound line in Figure 2. This limit ensures that footroom on solar will be available even if solar generation is over-forecasted.

One potential issue with relying on variable renewables for balancing services is that the operator cannot be certain that the resource will produce enough power to provide the balancing service. This concern is minimal in the case of solar footroom, because the service is needed predominantly *during the times when solar is producing too much energy*. Our production simulation results do not show any significant overgeneration events in real-time even at very high solar penetration levels, indicating that system operators can rely on solar to provide footroom when necessary. With enough flexible solar on the grid, it is unlikely that system operators will have reliability concerns related to downward flexibility in the daytime, although operators will continue to need footroom to cover load variations during nighttime hours.

1.4.4 FULL FLEXIBILITY OPERATING MODE

In this study, the Full Flexibility solar operating mode includes the most options of any operating mode for solar to contribute to essential grid services, and the highest degree of integration of solar resource characteristics into system operator dispatch procedures. The Full Flexibility operating mode includes all the footroom capability of solar from the Downward Dispatch operating mode but also allows solar to provide headroom (upward) flexibility.

Relying on solar to provide *headroom* (regulation up, spinning reserve, etc.) requires 1) plant output to be curtailed intentionally or under-scheduled (scheduled below the maximum available energy production) in order to create headroom, and 2) system operator confidence that additional solar production potential will be realized if called upon. We posit that solar can be forecasted with sufficient confidence within a lower bound as discussed above, but we recognize that system operators will naturally be conservative when relying on solar in the upward direction.

Under-scheduling solar reduces the uncertainty of solar production, and therefore the headroom that would be required for solar forecast error. For example, if at the day-ahead scheduling period it is anticipated that solar would be curtailed on the operating day due to oversupply, system operators can reduce the amount of headroom they would otherwise procure to accommodate a potential solar over-forecast. Put another way, headroom needed on other resources for solar forecast error is reduced when the operator forecasts the need to curtail solar before real-time.

In addition to reducing headroom reserves associated with solar forecast error, under-scheduled solar could be a potent provider of upward ramping service. Solar power plants can ramp up much more quickly than their conventional counterparts, suggesting that solar may be particularly well suited to provide frequency regulation or fast frequency response. This is especially true given that the supply of these fast-timescale balancing services tends to be the most limited during times of low demand and high variable renewable production.

In this study, we have allowed solar to provide upward regulation with available headroom. To ensure that the regulation headroom on solar is available in real-time, we require that additional forecast error headroom is held on other resources when scheduling solar regulation capacity before real-time. A summary of how solar provides headroom and footroom in this study is presented in Table 6 in Appendix A. We do not simulate the provision of fast frequency response in this study, nor do we simulate solar providing contingency reserve and headroom for load under-forecast events, although we believe it should be possible for solar to provide these services given enough certainty on solar production potential. This means that there may be additional value for solar headroom that is not included in this study, especially at higher solar penetration levels.

2 Description of Case Study

2.1.1 SYSTEM DESCRIPTION

To demonstrate the economic value of dispatching solar, we use the PLEXOS Integrated Energy Model to simulate unit commitment and dispatch of an actual utility system – Tampa Electric Company (TECO). TECO has good solar resource availability and a peak demand of ~ 5 GW. TECO operates its electricity system as a Balancing Authority.

TECO was an active participant in the study and provided data on its system, including real-time and forecast demand data, fuel cost projections, and detailed, unit-specific information on its thermal generation portfolio. Our study represents a snapshot of the TECO system in 2019.

TECO's thermal generation portfolio is similar to that found in many areas of the United States and other countries, making the results of this study broadly applicable. The expected 2019 portfolio consists of 60% of thermal capacity from natural gas combined cycle units, 6% from natural gas simple cycle combustion turbines, 20% from natural gas steam turbines, and 13% from coal steam and integrated gasification combined cycle units. TECO's generation portfolio does not include nuclear, wind, other renewable resources, or substantial behind-the-meter solar.

2.1.2 SOLAR DEPLOYMENT LEVELS

We simulate a range of utility-scale solar deployment levels ranging from 0% (no solar) to 28% annual energy penetration potential. The upper end of this range represents higher levels of solar energy than are currently operational in any balancing area in the United States. Annual solar energy penetration potential refers to the amount of energy available from a given capacity of solar energy facilities – the amount that would be produced in the absence of curtailment – normalized to annual balancing area electricity demand. We simulate each penetration level with four different solar operating modes: Must-Take, Curtailable, Downward Dispatch, and Full Flexibility.

This study focuses on operational cost savings of adding solar generation assets to the electricity system and does not include a full cost-benefit analysis of solar deployment. The solar penetration levels studied herein are academic in nature and are not indicative of TECO's future resource acquisition plans. TECO is currently developing 600 MW solar (~7% annual energy penetration) and a 10 MW / 27 MWh storage facility.

2.1.3 SOLAR PRODUCTION DATA

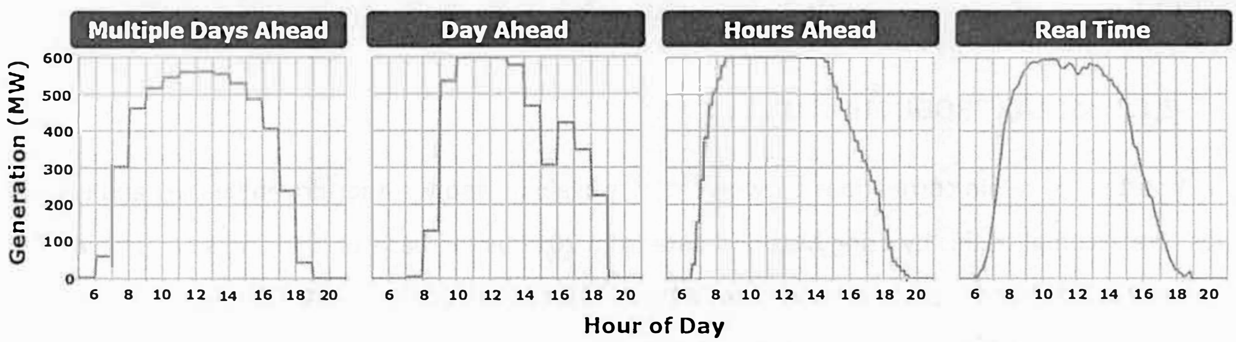
It is important to retain correlations between solar availability and weather-driven heating and cooling loads. We accomplish this by using historical data from 2017 as the basis of load and solar profiles. For demand, 2017 demand profiles are scaled to 2019 using projected 2019 annual TECO demand. For solar, TECO identified 15 sites in its service territory that are being considered for solar development. Locus Energy produced simulated 5-minute solar insolation data from 2017 for each site, and First Solar transformed the insolation data into solar plant output potential. We aggregate solar profiles for the 15 sites into a single TECO-wide solar profile and scale this profile to installed solar capacity. This approach assumes that all solar development occurs within TECO's service territory – a relatively small portion of the Florida peninsula – which therefore would not materially increase the geographic diversity of TECO's solar resources at higher levels of solar penetration. It may be possible to reduce the variability and uncertainty of solar generation by deploying solar power plants over a larger footprint.

Historical solar forecast data is not available from the Locus Energy dataset, so we synthesize solar forecasts through a day-matching algorithm utilizing a National Renewable Laboratory (NREL) solar dataset.[6] Three separate forecast error profiles from the Tampa area were averaged to generate one TECO-wide profile. The NREL dataset contains forecasts for one day ahead and four hours ahead of real-time, but TECO also uses forecasts to make commitment decisions for coal and gas steam units many days ahead of real-time. To generate multiple day-ahead solar forecasts, we simply use the month-hour

[6]National Renewable Energy Laboratory, "Solar Power Data for Integration Studies," accessed March 2018, https://www.nrel.gov/grid/solar-power-data.html.

average of the First Solar output profiles. Figure 4 shows how solar forecasts change ahead of real-time operations.

Figure 4: Solar profiles used for unit commitment across different timeframes from an example June day. Profiles are for 600 MW of installed solar capacity.



2.1.4 PLEXOS PRODUCTION COST MODEL

System operators have imperfect information about future grid conditions when making key operational decisions. The PLEXOS model we use in this study optimizes system unit commitment and dispatch for each day of the year in four sequential stages: multiple days-ahead, day-ahead, hours-ahead, and real-time (Table 1). The goal of each stage of the model is to represent the quality of information that TECO system operators would have at key operational decision points. To this end, load and solar production profiles are updated with better forecasts after each stage.

Table 1. PLEXOS model stages

Unit commitment stage	Dispatch and commitment decision timestep	Look-ahead length (after operating day)	Load timeseries data (provided by TECO)	Solar timeseries data
Multiple days-ahead	Hourly	Six days	Multiple days ahead forecast	Month-hour average of 5-minute real-time profiles
Day-ahead	Hourly	Eight hours	Day ahead forecast	NREL day ahead forecast
Hours-ahead	Every 15 minutes	Two hours	Average of day-of forecast and actual 5-minute demand	NREL 4-hour ahead forecast
Real-time	Every 5 minutes	None	Actual 5-minute demand profile	Simulated 5-minute profile

Based on input from TECO, each class of thermal generator is assigned a final stage beyond which commitment decisions are not allowed to be changed (Table 2). This reflects operational practice where, as real-time approaches, commitments of relatively inflexible units cannot be changed. For combined cycle gas turbines, multiple configurations (e.g., 1x1, 2x1, etc.) are modeled with the steam turbine's commitment decision preceding the associated combustion turbine commitments.

Table 2. Timing of final commitment decisions for each generator class

Generator Class	Final Commitment Decision Made in Stage:
Coal integrated gasification combined cycle	Not economically dispatched (must-run)
Simple cycle coal steam turbine	Multiple days-ahead
Simple cycle gas steam turbine	Multiple days-ahead
Steam turbine of gas combined cycle	Day-ahead (or must-run, depending on unit)
Combustion turbine of gas combined cycle	Hours-ahead
Market transactions	Hours-ahead
Simple cycle gas combustion turbine	Real-time

Thermal generators are represented using standard unit commitment and dispatch constraints, including ramping limitations, minimum uptime and minimum downtime constraints, and co-optimized energy and reserve provision. Reserve calculations and requirements are described in Appendix A. Generator economics are reflected via heat rate curves, variable operations and maintenance costs, fuel offtake at startup, and startup costs. TECO also provided unit-specific maintenance and outage schedules. Consistent with current TECO dispatch practices, a price on CO_2 emissions was not included.

For simplicity of case construction and interpretation, market transactions with external entities are restricted to hours in which the TECO system does not have enough generation available to serve load. Market transactions are limited by hourly transmission availability data provided by TECO. Exports from the TECO system to external entities were not considered. In reality, TECO would have additional opportunities to deliver solar energy to external entities and reduce operating cost beyond what is simulated here.

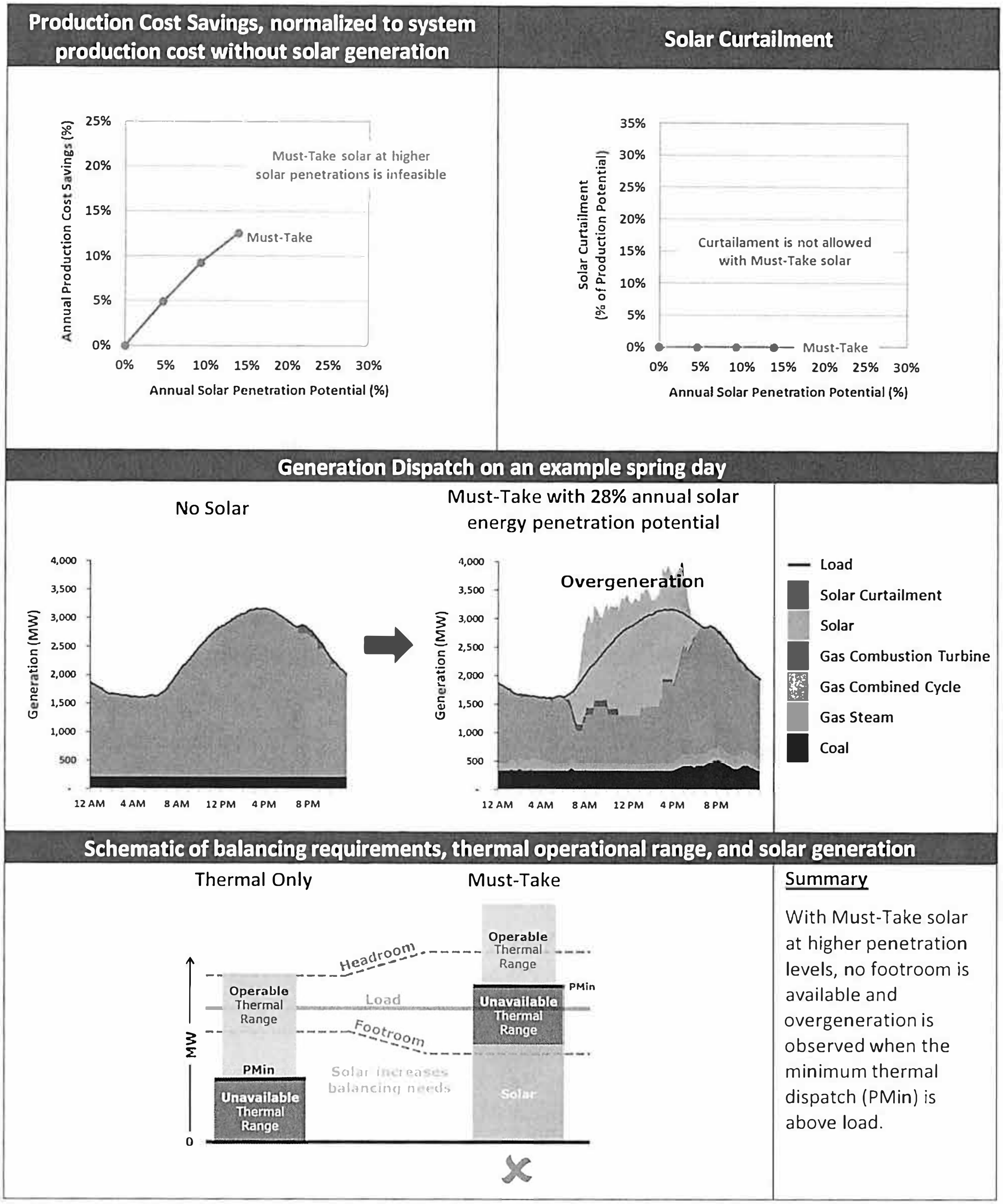
3 Flexible Solar Production Simulation Results

3.1 "Must-Take" operating mode: Limited by overgeneration

We first explore the limits of the Must-Take solar operating mode. We find that Must-Take solar can be absorbed by the TECO system up to about 14% of annual energy penetration potential. At solar penetrations above this level, we begin to observe overgeneration conditions, indicating that the system does not have enough flexibility to balance supply and demand while also accepting every MWh of solar generation. An example dispatch day demonstrating overgeneration conditions is shown in the middle panel of Figure 5. Solar penetrations above 14% on the TECO system are infeasible in Must-Take operating mode.

The appearance of overgeneration indicates that solar curtailment is a necessary tool to balance the system above a threshold level of solar penetration. This result is generalizable to any system, though the annual energy penetration threshold will depend on the characteristics of each individual system, including the load shape and the flexibility of its generation fleet. Shown schematically in the bottom panel of Figure 5, Must-Take solar at high solar generation levels can cause conflicting requirements to 1) accept all solar generation and 2) maintain headroom and footroom on thermal generation. Most thermal generators have minimum power (PMin) requirements; if turned on, a typical thermal generator must generate at a minimum of 20 – 50% of its rated capacity (PMax). The commitment decision for many generators must be made hours to days ahead of real-time, when the actual real-time solar output is not known with great certainty. Committing enough generation capacity to create the headroom and footroom required to plan for many possible levels of solar generation (cloudy to sunny) exhausts the operational range (PMin to PMax) of the thermal fleet. Our results demonstrate that planning to absorb all solar generation is untenable at higher solar penetration levels.

Figure 5: Summary: "Must-Take" Operating Mode



3.2 "Curtailable" operating mode: Feasible dispatch

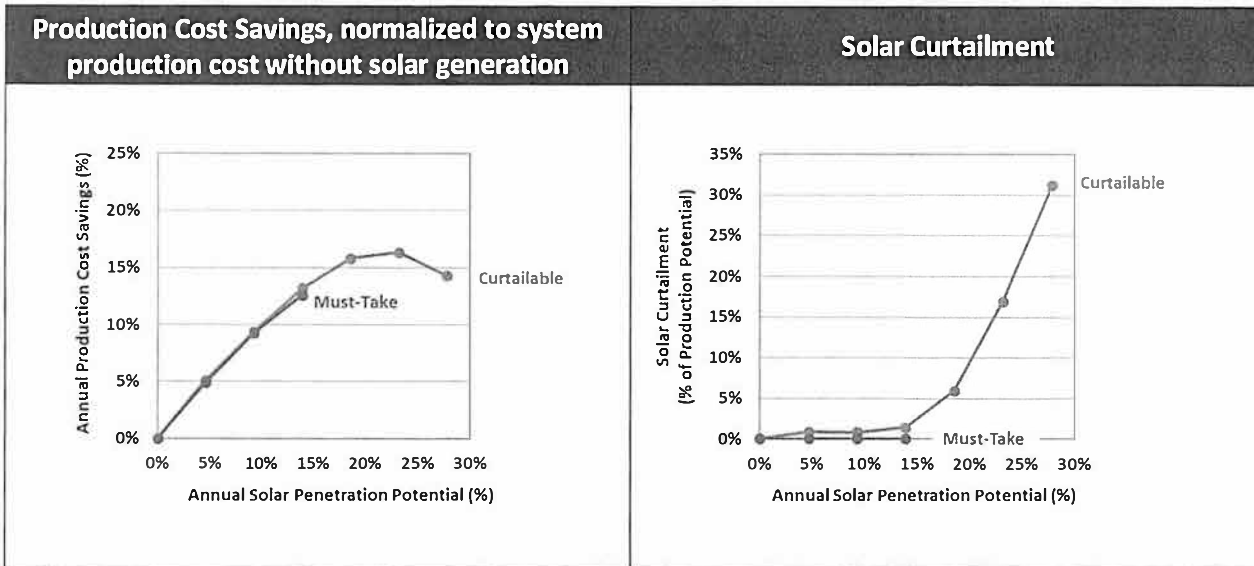
A key indicator of inadequate operational flexibility is the curtailment of variable renewable generation. As shown in the top right panel of Figure 6, solar can contribute up to 14% of energy with very low levels of curtailment, indicating that the thermal generation fleet has adequate flexibility to integrate up to this level of solar generation with minimal challenges. Since very little solar curtailment is necessary at this level of solar penetration, increasing the flexibility of solar generation provides limited additional value.

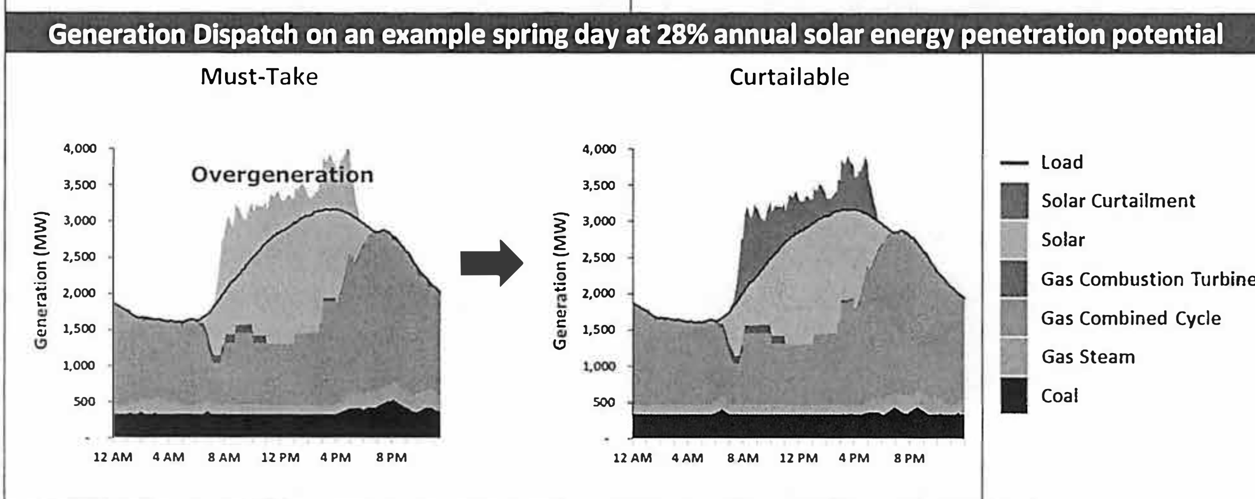
At intermediate levels of solar penetration on the TECO system (~15 – 25% solar energy penetration), curtailing solar generation allows what would otherwise be an inoperable system with Must-Take solar to become operable. Curtailing solar enables more thermal generators to be committed, thereby creating enough space within the dispatch stack to maintain adequate headroom and footroom on thermal units (Figure 6, bottom panel). Even though the system is operable, curtailment levels resulting from this operational strategy become very high as more solar is added to the system. Adding more solar causes additional thermal units to be committed to meet increased operational reserve requirements. Committing these units causes more fuel to be burned in conventional generators, which in turn reduces the energy value of solar generation.

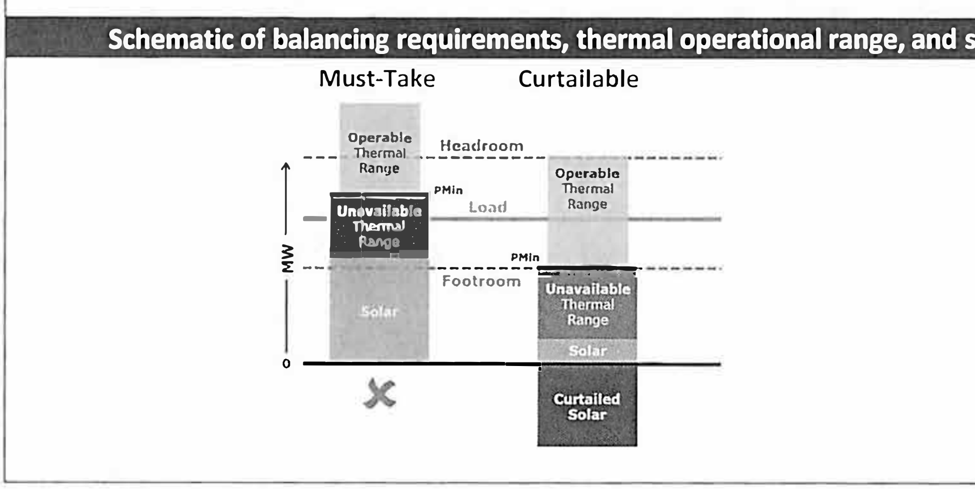
The energy value (Figure 6, top panel) on the TECO system of additional solar energy in Curtailable operating mode decays rapidly above about 14% solar energy penetration. The energy value (or, equivalently, the production cost savings) is calculated as the change in annual production costs as solar penetration increases, excluding the capital cost of additional solar resources. Solar provides very little marginal energy value at penetration levels above 19%. In the extreme – above 23% solar energy production potential – solar has a *negative* marginal energy value. This occurs because the increase in headroom and footroom required to balance solar forecast error is so large, and the fuel penalty for providing these reserves on thermal units so significant, that adding solar actually increases fuel consumption. The relatively small footprint of TECO's balancing area and solar resources contribute to the steep drop-off in energy value in Curtailable operating mode. The solar penetration level at which Curtailable operating mode becomes ineffective will be system-specific, but we expect that other systems will show similar dynamics as the level of solar generation is increased. Given the economic inefficiencies that result from Curtailable operating mode at higher levels of solar penetration, our results suggest that as more solar is deployed, system operators should adapt dispatch procedures to include more flexible solar plant operation.

[redacted]

Figure 6: Summary: "Curtailable" Operating Mode







Summary

Dispatch is feasible with Curtailable solar because solar generation can be reduced until thermal dispatch is within the operable range.

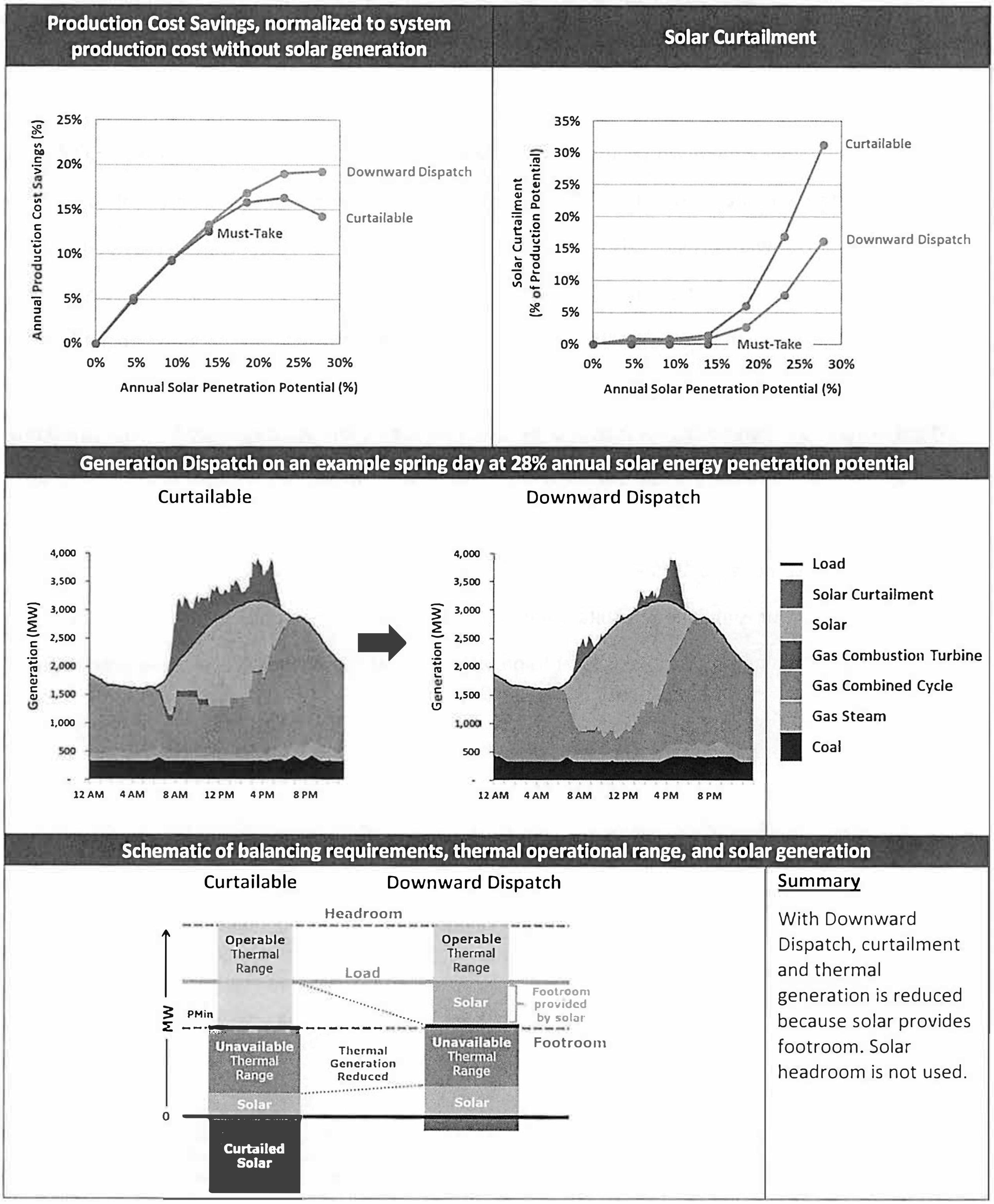
3.3 "Downward Dispatch" operating mode: Reduced curtailment and thermal commitment, and increased value

Compared to Curtailable operating mode, Downward Dispatch operating mode allows solar to retain value at higher levels of solar generation (Figure 7, top panel). Downward Dispatch improves on Curtailable by allowing the system operator to plan to turn down solar generation if solar is over-forecasted ahead of real-time operations. Downward Dispatch also allows regulation footroom requirements to be provided by solar generators. The middle and bottom panels of Figure 7 demonstrate that, during hours of very high solar output, downward dispatch of solar enables the operator to commit fewer thermal power plants, which reduces the minimum output requirement for thermal generation and increases the quantity of solar delivered to the grid. It may seem paradoxical, but in our simulations, solar in Downward Dispatch operating mode has *more opportunities* to be curtailed, but *less actual curtailment* is observed.[7] At 28% solar penetration potential, Downward Dispatch would reduce expected curtailment by half – from 31%, in Curtailable operating mode, to 16% – enabling solar to provide positive incremental value at higher solar penetration levels. Our simulation results show that, with the right economic dispatch rules, solar curtailment can be minimized by allowing solar to provide the most constrained grid services at key times.

[7] We do not estimate the amount of regulation that would be dispatched by AGC below the 5-minute timescale, and the resultant differences in energy production from AGC dispatch. In the Downward Dispatch and the Full Flexibility operating modes, we develop rules by which the system operator can rely on solar to provide downward regulation, but we do not assess whether it would be most economical to turn down solar or other resources in response to an AGC signal. In some instances, it may be more economical to turn thermal generation down instead of solar, thereby avoiding fuel costs.

[redacted]

Figure 7: Summary: "Downward Dispatch" Operating Mode



3.4 "Full Flexibility" operating mode: Additional value at higher solar penetrations

Sharing balancing requirements between thermal and solar generators becomes increasingly valuable as more solar capacity is added to the grid. Provision of balancing services from solar plants allows thermal generators to operate more efficiently by reducing the need for cycling and load following services, resulting in less fuel consumption. This also avoids commitment of inefficient thermal generation, reducing curtailment of solar during times of overgeneration.

Figure 8 shows that these savings can be substantial for the TECO system. The curtailment observed in Downward Dispatch operating mode on an example spring day (Figure 8, middle panel) suggests that at higher solar penetration levels, it could be particularly challenging to ramp TECO's thermal generation fleet down at sunrise and up at sunset. Operating solar in Full Flexibility operating mode would allow system operators to reduce forecast error headroom requirements and use any available solar headroom to meet regulation headroom requirements. On this example day, integrating these capabilities into operational procedures makes thermal generator ramping at sunrise and sunset more manageable.

Figure 8: Summary: "Full Flexibility" Operating Mode

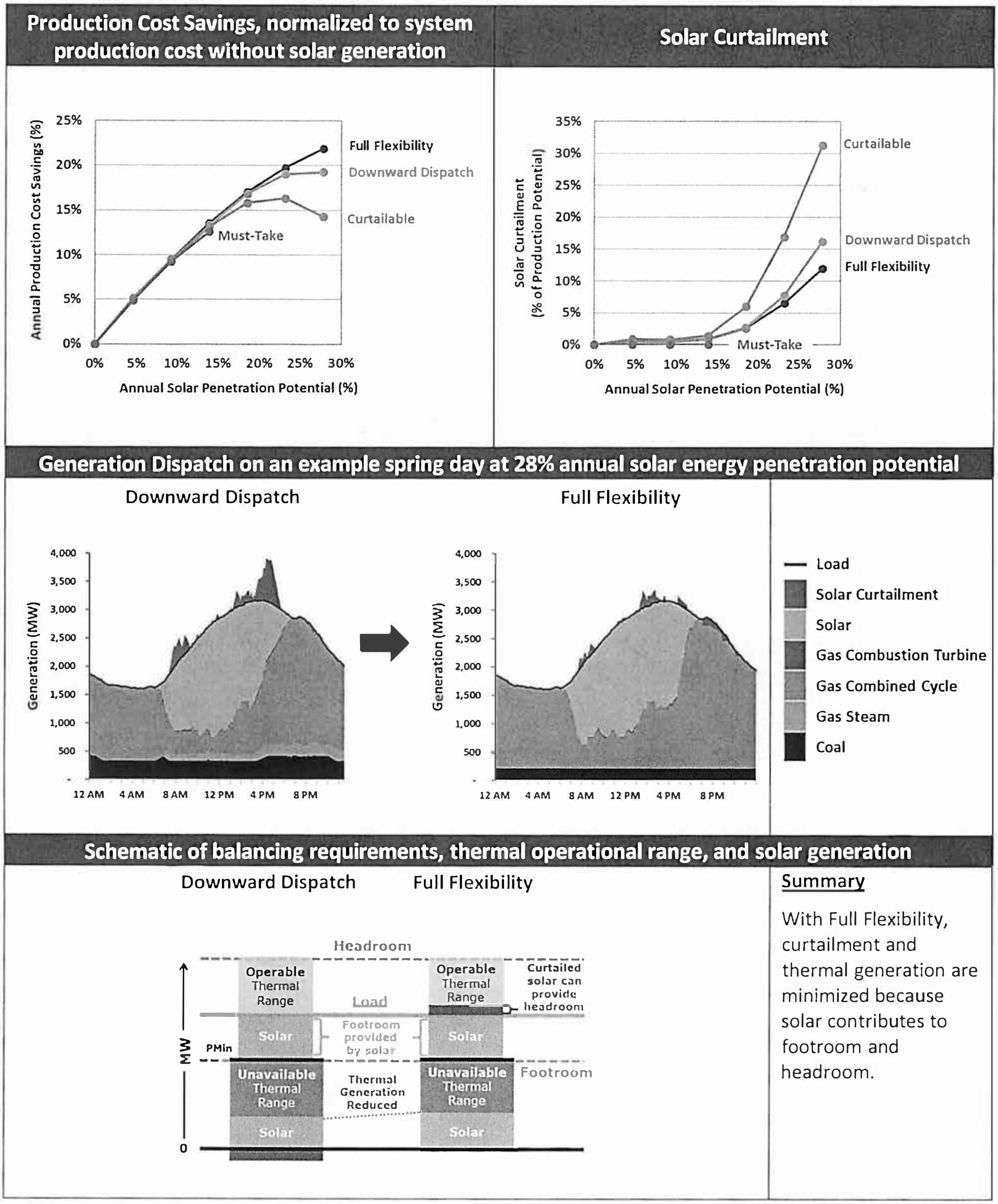
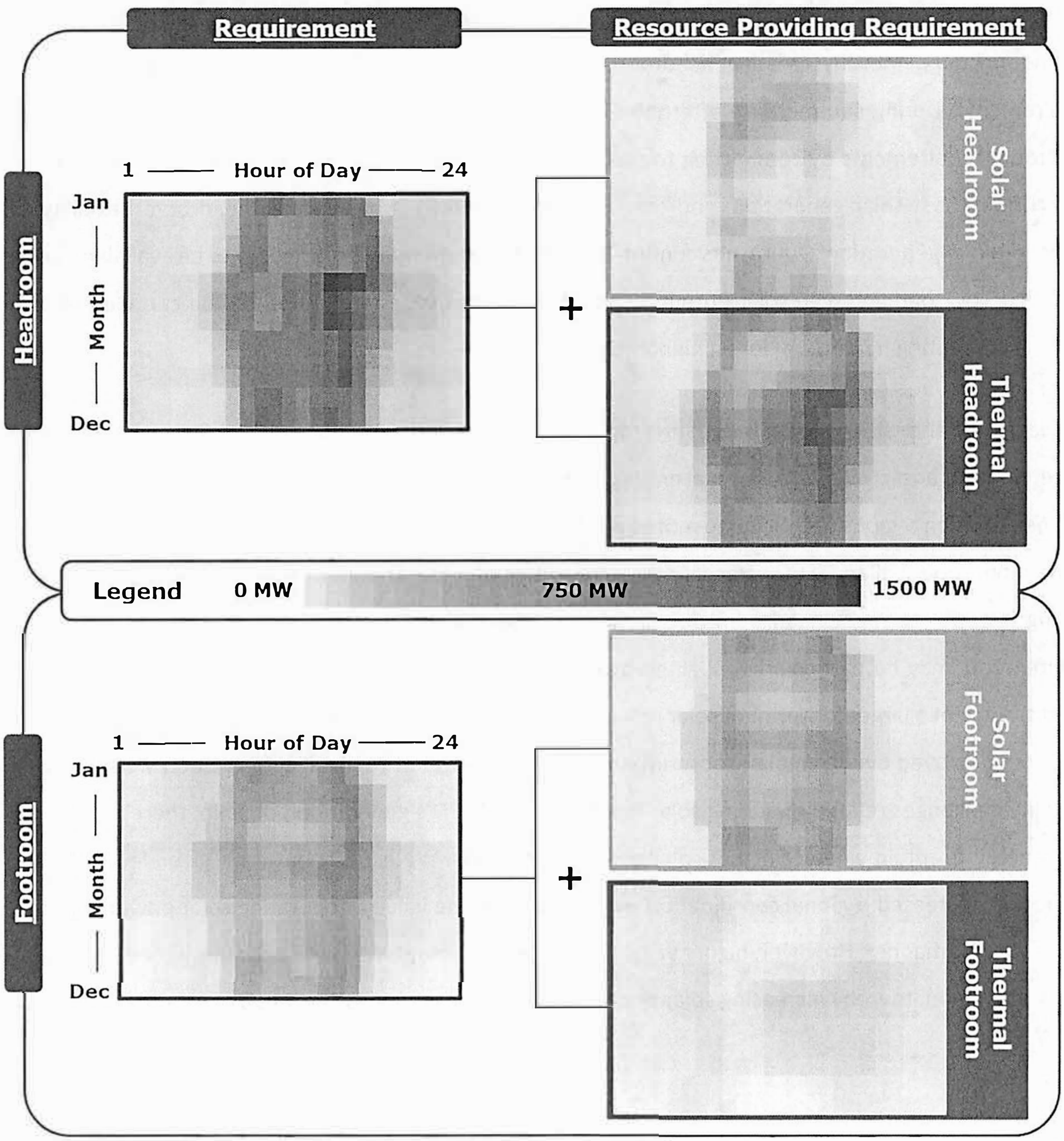


Figure 9 shows the distribution of headroom requirements between thermal and solar resources for the hours-ahead unit commitment stage. Footroom requirements during the daytime are met predominantly by solar.[8] Solar provides headroom to mitigate forecast uncertainties via committing to curtail and by committing to provide regulation. For example, solar is curtailed frequently in spring morning and early afternoon hours, thereby creating headroom that could be used productively to meet operational requirements. During summer late afternoon and early evening hours, solar does not typically reduce headroom requirements by committing to curtail because load is high enough in these hours to absorb (not curtail) most solar generation, and the TECO generation fleet has enough headroom flexibility to absorb all solar generation. Our results confirm that headroom on solar is most likely to be available during periods of low load and high solar output, but that solar generators are unlikely to be curtailed for the purpose of creating headroom during higher-load hours.

The scope of this study is limited to the operation of resources within TECO balancing area, and consequently transactions with external entities are not represented in detail. Energy market transactions with neighboring regions may become more valuable and/or frequent at higher solar penetrations. These transactions would allow TECO to access the capabilities of a larger pool of thermal resources, thereby making it easier to meet headroom, footroom, and ramping requirements. Forecast error headroom requirements may be particularly impacted by increased regional coordination, because the aggregate forecast error of a larger footprint of solar resources will be reduced relative to the same capacity of solar resources deployed over a smaller footprint. Increasing the level of regional coordination would reduce flexibility challenges related to adding solar resources into TECO's generation portfolio, thereby allowing solar energy to retain value at higher solar penetration levels. We expect that for a given level of solar generation, increased regional coordination would decrease the value of operating solar power plants in a more flexible manner. However, higher value for solar energy may hasten the pace of solar development across the region, thereby increasing solar penetration and consequently the value of solar flexibility.

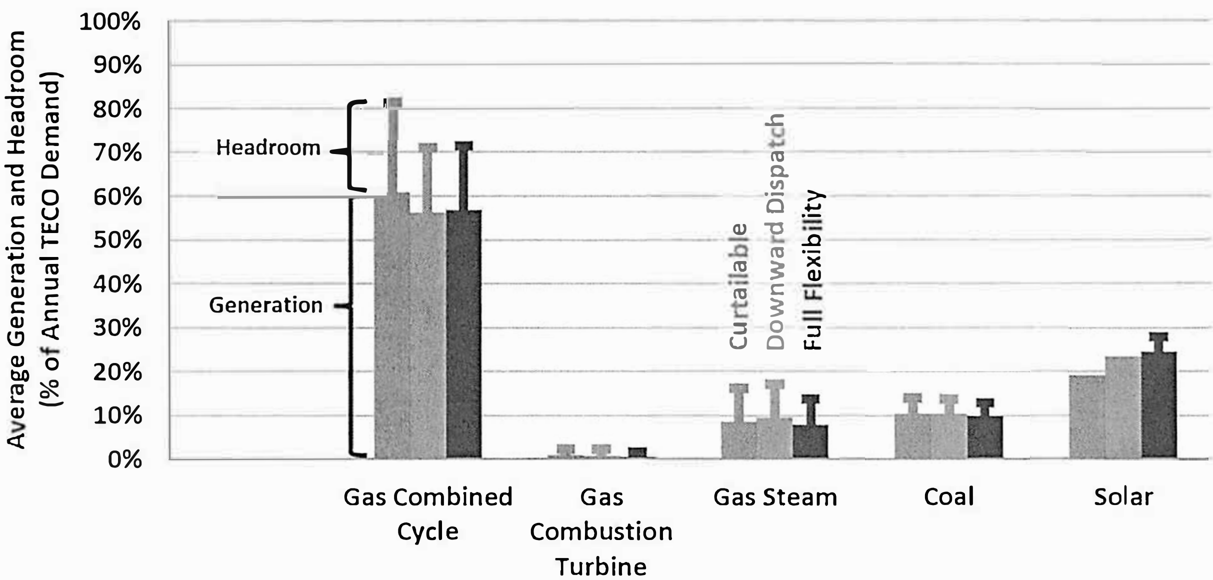
[8] When simulating the Downward Dispatch and Full Flexibility operating modes in PLEXOS, footroom requirements resulting from solar variability and uncertainty are not explicitly modeled because it is assumed that solar can provide these requirements if necessary. Simulation results do not show significant overgeneration events in real-time, confirming that footroom on solar for forecast error and within-hour variability is an effective balancing strategy. Our modeling does not simulate the dispatch of solar footroom held on AGC for balancing below the 5-minute timescale, but we expect solar to be effective on this timescale as well given the demonstrated capabilities of flexible solar plants.

Figure 9: Headroom and footroom requirements (left) and the portion of each requirement provided by solar and thermal resources (right) for the hours-ahead unit commitment stage at 28% annual solar energy production potential (2400 MW nameplate solar capacity) in the Full Flexibility operating mode. Values are month-hour averages.



Comparing thermal headroom and generation between the Curtailable and Full Flexibility operating modes (Figure 10, orange vs. dark blue bars) demonstrates that increasing solar flexibility reduces both thermal commitments and generation. The Curtailable, Downward Dispatch, and Full Flexibility simulations in Figure 10 have identical generator capacities and operational characteristics, except for their levels of solar flexibility. Note that no additional large capital investments would be necessary to reduce thermal capacity factors and commitment levels; increasing solar flexibility simply uses existing assets more efficiently, resulting in lower production costs.

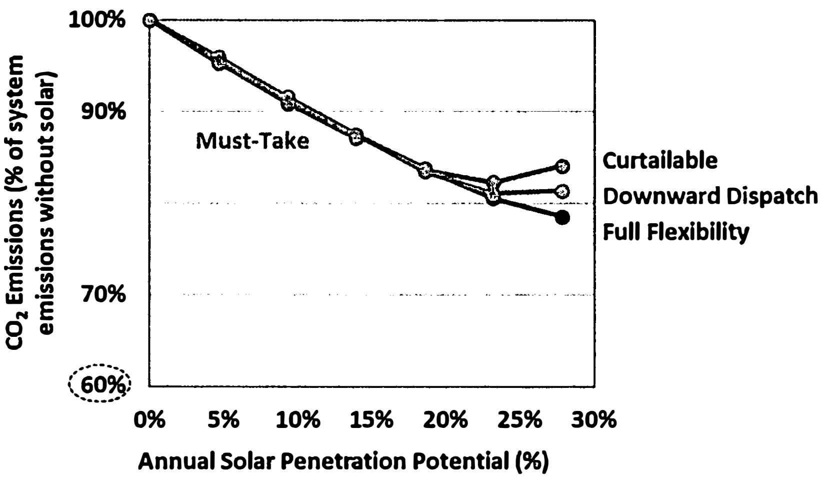
Figure 10: Annual average generation and headroom at 28% annual solar energy production potential, expressed as a fraction of annual TECO demand. Headroom is calculated as the difference between generation setpoint and committed capacity (or available production for solar) in real-time. Headroom on solar is only shown for the Full Flexibility operating mode.



3.5 CO_2 emissions results

Operating solar power plants in a more flexible manner enhances the ability of solar to reduce CO_2 emissions from electricity generation. As solar capacity increases, CO_2 emissions are reduced in all cases when solar is operated in Full Flexibility operating mode (Figure 11). At higher solar penetrations, Curtailable and Downward Dispatch operating modes result in more curtailment and higher levels of CO_2 emissions relative to Full Flexibility. At lower levels of solar penetration (less than ~19% annual solar penetration potential), we observe small differences in CO_2 emissions among the solar operating modes but do not believe them to be material.

Figure 11: CO_2 emissions as a function of solar deployment and solar operating mode



Flexibly scheduling and controlling solar plants can provide significant reliability, financial, and environmental value. Solar dispatch flexibility an important tool that grid operators can use to address challenges associated with higher solar penetrations and to integrate increasing amounts of solar cost-effectively. Dispatching solar power plants to the needs of the grid will reduce CO_2 emissions at higher solar penetrations and may reduce criteria pollutant emissions (such as NO_x), which can be significantly higher for power plants that frequently ramp up and down.

3.6 Summary tables

The numeric values in Table 3 and Table 4 indicate that increasing solar flexibility increases the value of solar energy and decreases solar curtailment. These values are for one specific system configuration, and depend on resource capabilities and capacity, fuel cost projections, and other many factors. Consequently, the values should not be applied to other jurisdictions or other TECO system conditions.

Table 3. Average and marginal energy value of solar, in $/MWh of solar production potential. The energy value of solar represents only production cost savings and does not include other value streams such as avoided peak capacity. The marginal energy value of solar is calculated as the change in production cost resulting from the addition of an incremental 400 MW of solar capacity.

Available Solar Generation			Average Energy Value of Solar ($/MWh)				Marginal Energy Value of Solar ($/MWh)			
Nameplate MW	Annual GWh	% of 2019 TECO Demand	Must-Take	Curtailable	Downward Dispatch	Full Flexibility	Must-Take	Curtailable	Downward Dispatch	Full Flexibility
400	958	4.6%	$28.7	$29.9	$30.1	$30.1	$28.7	$29.9	$30.1	$30.1
800	1,916	9.3%	$27.2	$27.5	$27.6	$27.8	$25.8	$25.1	$25.1	$25.5
1,200	2,874	13.9%	$24.6	$25.8	$26.1	$26.5	$19.5	$22.3	$23.2	$24.0
1,600	3,832	18.5%	N/A	$23.2	$24.7	$25.0	N/A	$15.5	$20.6	$20.5
2,000	4,790	23.2%	N/A	$19.2	$22.3	$23.2	N/A	$3.1	$12.8	$15.9
2,400	5,747	27.8%	N/A	$14.0	$18.9	$21.4	N/A	$ (12.1)	$1.4	$12.7

Table 4. Solar resource availability and solar curtailment results for each solar penetration level and operating mode.

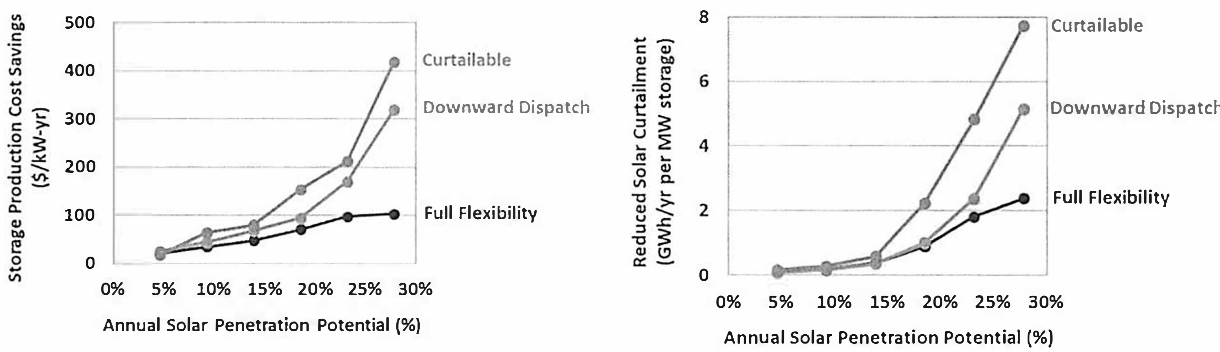
Available Solar Generation			Solar Curtailment (GWh)				Solar Curtailment (% of available solar energy)				Solar Penetration Achieved (% of 2019 TECO demand)			
Nameplate MW	Annual GWh	% of 2019 TECO Demand	Must-Take	Curtailable	Downward Dispatch	Full Flexibility	Must-Take	Curtailable	Downward Dispatch	Full Flexibility	Must-Take	Curtailable	Downward Dispatch	Full Flexibility
400	958	4.6%	0	8	5	5	0%	0.9%	0.5%	0.5%	4.6%	4.6%	4.6%	4.6%
800	1,916	9.3%	0	16	10	10	0%	0.8%	0.5%	0.5%	9.3%	9.2%	9.2%	9.2%
1,200	2,874	13.9%	0	41	24	26	0%	1.4%	0.8%	0.9%	13.9%	13.7%	13.8%	13.8%
1,600	3,832	18.5%	N/A	230	105	101	N/A	6.0%	2.7%	2.6%	N/A	17.4%	18.0%	18.0%
2,000	4,790	23.2%	N/A	811	370	311	N/A	16.9%	7.7%	6.5%	N/A	19.2%	21.4%	21.7%
2,400	5,747	27.8%	N/A	1,795	929	686	N/A	31.2%	16.2%	11.9%	N/A	19.1%	23.3%	24.5%

3.7 Sensitivity study: Incremental value of storage

Energy storage, particularly from fast-responding batteries such as lithium-ion, can quickly ramp from charging to discharge, providing an operating range that is double the nameplate capacity. Moreover, batteries can reduce fuel costs and avoid solar curtailment by charging during times of curtailment and discharging during times when thermal generation is on the margin.

For our final set of simulations, we add a small battery (50 MW, equivalent to ~1% of peak demand) with four hours of energy duration (200 MWh) to the TECO system at various levels of solar penetration to explore the value of storage in the context different solar operating modes. We find similar results to other storage production cost studies: storage provides production cost savings across all solar penetrations, with larger savings occurring at higher solar penetrations. Storage is used for a mix of regulation, forecast error reserves, and within-day energy shifting. Storage also reduces the magnitude of ramps during sunrise and sundown, which is more valuable at higher solar penetrations. The value of shifting energy increases significantly in the presence of solar curtailment (Figure 12). This study focuses on operational cost savings of storage, and therefore does not consider storage capital costs or a full cost-benefit analysis of storage.

Figure 12: Increasing solar operational flexibility can reduce the operational value of storage at a given solar penetration.



The opportunity for storage to add value is reduced when the system operator increases reliance on solar power plant flexibility, because flexible operation of solar can provide some of the same grid services as storage, especially footroom flexibility. Storage resources can be held in reserve ahead of real-time to address forecast errors in solar generation. The value of storage resources will be reduced if system operators can reduce forecast error footroom and headroom held on thermal generators by including solar curtailment in forecast error requirement calculations. In many renewable integration and storage valuation studies, a significant fraction of storage value comes from providing regulation. Solar resources could provide the same service during some portions of the day, potentially allowing the storage device to perform other functions. Also, solar curtailment decreases as solar operational flexibility is increased, thereby reducing the value of storage (see Figure 12) because fewer opportunities exist for energy shifting at a given solar penetration level. Renewable integration studies at higher renewable penetrations do not typically simulate wind or solar in the Full Flexibility operating mode, and therefore may overstate the value of storage. However, we recognize that if an electricity system already has a significant amount of storage or other flexible resources, the incremental value of increasing solar flexibility would be reduced relative to a system with less flexibility.

While our results suggest that increasing solar flexibility may reduce the need for storage (and/or other flexible resources) at intermediate solar penetrations, there is still a significant role for storage to play at high solar penetrations. As more and more solar is deployed in a grid, the operational value of adding energy storage will increase due to increased balancing requirements and increased solar curtailment. Storage can also provide significant system capacity value, whereas the marginal capacity contribution of solar resources tends to drop relatively quickly with increasing solar penetration.

4 Areas for Future Research

This study lays out some of the technical considerations that must be implemented to tap the full potential of flexible solar in grid operations. Further work is necessary on many fronts to fully realize the potential of flexible solar:

- Solar forecasts are key to unlocking the potential of flexible solar. Without some certainty on the possible bounds of power production, it is impossible to rely on a variable resource for balancing services, especially for services that require headroom. A method is needed to develop a confidence interval for flexible solar that is conservative enough to be workable in a control room while still providing a reasonable solar dispatch range. Providing footroom with solar requires significantly less forecast accuracy than is required to provide headroom.

- Disincentives for flexible solar exist in markets where Renewable Energy Certificates (RECs) are a primary revenue source, because RECs are only generated when the generator produces a MWh of renewable energy. A renewable power plant would not want to forgo REC revenue by offering to be dispatched unless doing so provided the generator with positive net revenue. Further research can shed light on the value of solar dispatch in a market with RECs.

- Many existing renewable power plants have contracts that do not envision using the plant for grid balancing, so contracts would need to be clarified or renegotiated to enable dispatchability from existing facilities.

- In organized electricity markets, it remains to be seen how variable renewables would bid their flexibility into energy and ancillary service markets. Existing methods of calculating opportunity cost for ancillary services are largely based on thermal opportunity cost of producing less energy and dispatching at less efficient setpoints. Compared to thermal generators, variable renewables have more uncertainty surrounding day-ahead or hour-ahead maximum production levels. Also, variable renewables may have no marginal cost of providing ancillary services if they are already curtailed due to system-wide conditions.

- Some organized markets do not separately procure upward (headroom) and downward (footroom) services. However, our study indicates that the cost for solar to provide headroom and footroom is highly asymmetric. Flexible solar is likely to have significantly higher value in markets, like the California ISO, with distinct upward and downward reserve products. Other market operators in areas with high wind and solar penetration should consider establishing separate downward and upward reserve products.

5 Conclusions

When envisioning a power system with large amounts of variable renewable energy, system planners must include information on the least-cost manner of reliably operating that system, in both the present and future. If system operators can control the power output of variable renewable resources, these resources can be viewed as assets that help to maintain reliability rather than liabilities that create operational challenges. Bringing the operational value of dispatching variable renewables into utility resource plans may change the investments made in resources going forward. The flexibility brought by dispatching variable renewable generators could reduce the need for investments in other types of flexible resources. But dispatching renewables helps to retain their value at higher penetrations, which may induce further renewable deployment and, in turn, increase the need for other flexible resources. In either scenario, reducing operational costs and CO_2 emissions from the power system is easier when solar power is treated as an active participant in grid balancing rather than an invisible part of the "net load."

6 Appendix A: Reserve Calculations and Requirements

Many renewable integration studies calculate headroom and footroom requirements such that unit commitment and dispatch decisions include enough flexibility to successfully navigate variability and uncertainty from load and variable renewable resources. Calculating reserve requirements is an active area of research, but at present most studies follow a similar calculation methodology.[9] In our study, we calculate reserve requirements largely using standard methods but make modifications necessitated by the multi-stage structure of our PLEXOS model and solar flexibility constraints.

We enforce three separate categories of reserve requirements in PLEXOS: forecast error (Section 6.1), regulation (Section 6.2), and contingency (Section 6.3). Section 6.4 describes how different classes of resources provide each category of reserves.

To calculate forecast error and regulation reserve requirements, we rely on year-long timeseries data for load and solar production. Both load and solar datasets include forecasted and real-time (5-minute actual) data. Solar timeseries data is described in Section 2.1.3. TECO provided a year-long timeseries of forecast and actual (5-minute) load data.

6.1 Forecast error reserves

Forecast error reserves ensure that enough capacity is committed before real-time such that load and solar forecast error do not cause reliability concerns. Both upward and downward requirements (headroom and footroom, respectively) are enforced in every model stage before real-time. Our

[9] E. Ibanez, I. Krad and E. Ela, "A Systematic Comparison of Operating Reserve Methodologies," National Renewable Energy Laboratory, 2014, https://www.nrel.gov/docs/fy14osti/61016.pdf; I. Krad, E. Ibanez and W. Gao, "A Comprehensive Comparison of Current Operating Reserve Methodologies," IEEE/PES Transmission and Distribution Conference and Exposition (T&D), 2016.

treatment of forecast error reserves is similar to "load following" or "flexibility" reserves in other renewable integration studies, with the exception that the within-hour variability traditionally associated with "load following" calculations is included as part of the regulation requirement in this study.

6.1.1 FORECAST ERROR REQUIREMENT CALCULATION

For each of the three model stages before real-time (i.e., multiple days-ahead, day-ahead, and hours-ahead), the difference between forecast and average actual output is calculated, resulting in a library of positive and negative MW forecast error values. The calculation is performed *individually* on demand and solar profiles. To capture correlations between demand and variable renewable resources, many studies in the literature subtract variable renewable output from demand to create a library of *net load* forecast error values. We do not employ this method because quantifying the level of solar forecast error is key to representing solar flexibility in the production simulation. At higher levels of solar penetration, we observe that solar forecast error is much larger than demand forecast error, which minimizes the difference between individual and net load forecast error calculation methodologies. In future analyses, it may be possible to retain correlations between solar and demand forecast errors when modeling solar flexibility.

To reflect different levels of forecast error at different times of the day, the library of forecast errors is divided into bins by hour of day. Because TECO experiences different weather conditions during different times of year, the hourly bins for solar forecast error are subdivided by season. Finally, to reflect differences in forecast accuracy resulting from cloud cover, the season-hour bins are divided into two separate bins: "cloudy" and "clear sky." Solar forecasts are placed into the "cloudy" bin if the forecasted solar output is less than 80% of an estimate of the clear sky output.

System operators make conservative decisions when committing generation units, but it is not common practice to commit units to prepare the system for *every* possible future level of load or solar production. In the case of extreme forecast error, operators can perform a set of emergency actions that fall outside of the scope of production cost modeling, such as making an emergency phone call to a neighboring balancing area, dispatching contingency reserves, or allowing a small imbalance in supply and demand (thereby causing area control error) for a short period of time. Consequently, an appropriate threshold for forecast error reserves must be defined beyond which the system operator does not need to hold headroom or footroom for forecast error. This threshold can be the product of a detailed analysis that compares the value of a more reliable system with the incremental cost of holding more reserves. In many studies, a detailed cost/benefit analysis is not within scope so reserve requirement levels are selected by choosing a percentage of forecast errors based on prior studies of similar systems. Commonly used thresholds are either ~68 – 70% (roughly one standard deviation, 1σ, for a normally distributed set of forecast errors) or 95% (2σ), meaning that the unit commitment simulation will ensure that all but ~28 – 30% or 5% (respectively) of all possible forecast errors can be met by available resources.

To calculate forecast error reserves for solar in our study, we truncate the library of forecast errors to include 70% (~1σ) of all forecast errors when committing units ahead of real-time (i.e., the multiple days-ahead, day-ahead, and hours-ahead unit commitment stages). Doing so results in forecast error reserve requirements in both the upward (headroom) and downward (footroom) directions because both under- and over-forecast events are included in the timeseries datasets. We follow the same procedure for load forecast error, except that we expand the range of forecast errors that we included in the hours-ahead stage to include 95% (2σ) of all forecast errors. We truncate the library of forecast errors separately for load and solar, and then add the result to obtain the final reserve requirement.

The final step of the forecast error reserve calculation ensures that solar forecast error reserve levels remain within the bounds of possible solar production. Because solar production cannot go below zero, the forecast error headroom requirement is adjusted if the forecasted solar production minus the headroom requirement is less than zero. Because solar production cannot go above the level at which the power plant would produce under clear sky conditions, the forecast error footroom requirement is adjusted if the forecasted solar production plus the footroom requirement is greater than an estimate of the clear sky production potential for a given timestep.

Studies in the literature demonstrate that forecast error for a geographically diverse set of variable renewable resources is typically lower than forecast error for the same capacity of resources installed on a smaller footprint. For this study we assume that all solar deployment will occur within the TECO service territory, which is a relativity small portion of the Florida peninsula. Consequently, we do not reduce the marginal forecast error contribution of additional solar resources as more solar is added to the TECO system. If solar resources were to be deployed on a larger geographic footprint, forecast error requirements would be reduced and consequently the benefits of flexible solar operation would be lower at a given solar penetration. Similarly, improved solar forecasting would decrease the cost of solar integration, which would raise the value of solar facilities at any solar penetration and decrease the value of flexible solar operation at a given solar penetration.

6.2 Regulation reserves

Regulation reserves are held for short-timescale variation – less than 1 hour – of load and variable renewable output. In our study regulation reserves represent the amount of within-timestep variability that the system operator must manage if average load and solar production are perfectly forecasted at an hourly timestep for the multiple days and day-ahead unit commitment stages, a 15-minute timestep in the hours-ahead unit commitment stage, or a 5-minute timestep in the real-time unit commitment stage.

6.2.1 REGULATION RESERVE REQUIREMENT CALCULATION

We calculate regulation requirements on two different timescales (hourly to 5-minute and 5-minute to automatic generation control (AGC)) and add the result to obtain the final reserve requirement. Only the 5-minute to AGC component of the regulation requirement is held in real-time dispatch, because the real-time stage economically commits and dispatches on 5-minute intervals, thereby removing the need to hold additional headroom and footroom for variability between hourly and 5-minute commitment intervals. Regulation requirements for solar are calculated from a real-time 5-minute production profile that is the average of many individual production profiles from across the TECO region.

<u>Hourly to 5-minute timescale:</u> Real-time 5-minute load or solar production profiles are subtracted from a linear interpolation between hourly (multiple days-ahead and day-ahead) or 15-minute (hours-ahead) averages of the same real time profile. As with the forecast error calculation, this results in a library of positive and negative error values. Errors are divided into bins by hour of day for load, and by hour of day, season, and a cloudy/clear sky binary for solar. We calculate the hourly to 5-minute regulation requirement by truncating the library of errors within each bin to include 95% of errors.

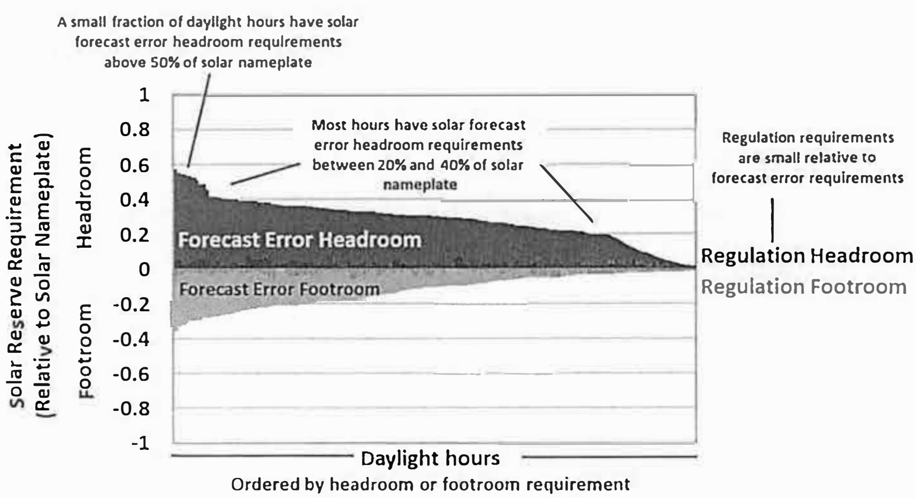
[redacted]

5-minute to AGC timescale: To calculate the solar component of the AGC requirement, we estimate the short-term variation in plant output on a 5-minute timescale. We compare a cloud cover persistence forecast based on solar output in one 5-minute timestep to actual solar output in the next 5-minute timestep. Similar to other calculations, we bin the result by hour of day and season, and then apply a 95% error cutoff.

We calculate the 5-minute to AGC requirement for demand as 1% of demand, a value frequently used in other production simulations.

Figure 13 shows the combined regulation and forecast error headroom and footroom requirements for solar uncertainty and variability for the hours-ahead unit commitment stage. Only daylight hours are depicted in Figure 13. Forecast error requirements are typically much larger than regulation requirements. The relatively large magnitude of the forecast error headroom requirements is in part due to the small geographic scope of the TECO balancing area.

Figure 13: Solar reserve requirement duration curve for the hours-ahead unit commitment stage.



6.3 Contingency reserves

Contingency reserves are held for infrequent but extreme events, typically the loss of a large generation unit or transmission line. In our simulations, contingency reserves are held in all model stages, including real-time, because system operators must always be prepared for contingency events. Consistent with current operational practice, contingency reserves are only enforced in the upward (headroom) direction.

6.3.1 CONTINGENCY REQUIREMENT CALCULATION

Contingency reserve requirements for the TECO system were implemented with input from TECO staff. The magnitude of reserve need is calculated endogenously in PLEXOS for every time step as the maximum of:

- TECO's largest generation contingency
- TECO's share of the Florida reserve sharing obligation
- A minimum contingency reserve level of 315 MW

6.4 How resources provided reserves

Table 5. How different classes of resources provide headroom and footroom capacity to each reserve type.

Resource	Forecast error	Regulation	Contingency
Online thermal	Headroom and footroom*	Headroom and footroom, subject to ramp rate limits	Headroom, subject to ramp rate limits
Offline thermal	Nameplate capacity of generators that could start within the required timeframe, but combustion turbines in a combined cycle can only contribute if the steam turbine was committed	Could not contribute	Nameplate capacity of simple cycle combustion turbines that can start within the required timeframe
Batteries	Available headroom and footroom	Available headroom and footroom	Available headroom
Demand response	Does not contribute	Does not contribute	Available capacity
Solar	See Table 6 below		

*Online generators that can shut down with sufficient speed contribute capacity equal to their minimum production (PMin) to forecast error reserve footroom, in addition to available footroom between their setpoint and PMin.

Table 6. Schematic representing how solar generators provide reserves in this study.

	Reserve Type	Source of need	How does solar provide?	
Total Headroom				
Headroom (MW)	Contingency	Largest contingency	Headroom on solar for contingency reserves is not modeled in this study, but would be possible with enough production potential certainty	
Headroom (MW)	Forecast Error + Regulation **Headroom**	Solar variability and uncertainty	Forecast error up from solar is reduced when solar is curtailed	When solar provides regulation headroom, more forecast error reserve is held in case of solar over-forecast
Headroom (MW)		Load variability and uncertainty	Headroom on solar for load under-forecast is not modeled in this study, but would be possible with enough production potential certainty	
Forecast Load				
Footroom (MW)	Forecast Error + Regulation **Footroom**	Load variability and uncertainty	Solar provides footroom for load over-forecast, limited by the amount of solar generation below the lower bound on solar production	
Footroom (MW)		Solar variability and uncertainty	Reserve need is not modeled because solar can be curtailed in real time if energy cannot be absorbed	
Total Footroom				

7 Appendix B: Prior Research

Prior research that simulates solar (or wind) in Curtailable or Downward Dispatch operating mode includes the following:

- GE Energy, "Western Wind and Solar Integration Study," National Renewable Energy Laboratory, May 2010, https://www.nrel.gov/docs/fy10osti/47434.pdf.
- Mills, A., A. Botterud, J. Wu, Z. Zhou, B.-M. Hodge and M. Heaney, "Integrating Solar PV in Utility System Operations," Argonne National Laboratory, 2013, http://eta-publications.lbl.gov/sites/default/files/lbnl-6525e.pdf.
- Eber, K. and D. Corbus, "Hawaii Solar Integration Study: Executive Summary," National Renewable Energy Laboratory, June 2013, https://www.nrel.gov/docs/fy13osti/57215.pdf.
- Energy and Environmental Economics, "Investigating a higher renewables portfolio standard in California," 2014, https://www.ethree.com/documents/E3_Final_RPS_Report_2014_01_06_with_appendices.pdf.
- California ISO, "Phase 1.A. Direct testimony of Dr. Shucheng Liu on behalf of the California Independent System Operator," 13 August 2014, http://www.caiso.com/Documents/Aug13_2014_InitialTestimony_ShuchengLiu_Phase1A_LTPP_R13-12-010.pdf.
- Energy and Environmental Economics, Inc. and National Renewable Energy Laboratory, "Western Interconnection Flexibility Assessment," Western Electricity Coordinating Council and Western Interstate Energy Board, 2015, https://www.ethree.com/wp-content/uploads/2017/02/WECC_Flexibility_Assessment_Report_2016-01-11.pdf.
- Brinkman, G., J. Jorgenson, A. Ehlen and J. Caldwell, "Low Carbon Grid Study: Analysis of a 50% Emission Reduction in California," National Renewable Energy Laboratory, January 2016, https://www.nrel.gov/docs/fy16osti/64884.pdf.
- Seel, J., A. Mills, R. Wiser, S. Deb, A. Asokkumar, M. Hassanzadeh and A. Aarabali, "Impacts of High Variable Renewable Energy Futures on Wholesale Electricity Prices, and on Electric-Sector Decision Making," Lawrence Berkeley National Laboratory, May 2018, http://eta-publications.lbl.gov/sites/default/files/report_pdf_0.pdf.

Prior research that simulates solar (or wind) in Full Flexibility operating mode – frequently as a sensitivity – includes the following:

- Van Hulle, F., I. Pineda and P. Wilczek, "Economic grid support services by wind and solar PV: A review of system needs, technology options, economic benefits and suitable market mechanisms," REserviceS project, September 2014, http://www.reservices-project.eu/wp-content/uploads/REserviceS-full-publication-EN.pdf.
- Nelson, J. and L. Wisland, "Achieving 50 Percent Renewable Electricity in California," Union of Concerned Scientists, August 2015, https://www.ucsusa.org/sites/default/files/attach/2015/08/Achieving-50-Percent-Renewable-Electricity-In-California.pdf.
- Tabone, M. D., C. Goebel and D. S. Callaway, "The effect of PV siting on power system flexibility needs," Solar Energy, vol. 139, pp. 776-786, 2016.
- Denholm, P., J. Novacheck, J. Jorgenson and M. O'Connell, "Impact of Flexibility Options on Grid Economic Carrying Capacity of Solar and Wind: Three Case Studies," National Renewable Energy Laboratory, December 2016, https://www.nrel.gov/docs/fy17osti/66854.pdf.
- Hale, E. T., B. Stoll and J. Novacheck, "Integrating solar into Florida's power system: Potential roles for flexibility," Solar Energy, vol. 170, pp. 741-751, 2018.

https://www.wsj.com/articles/SB10001424052702303448404577410473497091202

Tom Fanning: The Natural Gas Skeptic

'Nobody can sit here and tell me that it's going to be safe forever, safe in terms of economics and reliability,' says the Southern Company CEO.

A.P.S.C. DOCKET NO 32953
Sierra Club 's EX. NO. 2
WITNESS Kelley-Goss

By Joseph Rago

June 8, 2012 6:40 pm ET

New York

'I'm here to talk about what we're calling an 'all of the above' energy strategy," President Obama said the other day. Funny, Mitt Romney also calls it that. Everyone in Washington calls it that, and everyone claims to be in favor of it too: natural gas, solar, coal, biofuels, hydro, nuclear, oil, wind, the works. But almost nobody supports "all of the above," not really.

In theory, liberals want to phase out fossil fuels in the name of climate change. In theory, conservatives oppose subsidies for renewables, unless they like ethanol, but then they also support subsidies for nuclear and often oil and gas. And in practice, both political parties tend to dump ideology and support whatever status quo energy sources predominate in their home districts.

Tom Fanning's home district, so to speak, is Georgia and Alabama and parts of Mississippi and Florida—the region powered by Southern Company. The giant utility's CEO and chairman is among the few who take what he calls an "all the arrows in the quiver" approach—perhaps to differentiate himself from the Washingtonians—though he notes slyly that "We actually believe in the dogma."

Even as natural gas booms and coal-fired power falls dramatically, Southern is building new coal plants, in Kemper County, Miss. Outside Waynesboro, Ga., work is under way on the islands and cooling tower of what by 2016 will become the first new U.S. nuclear unit since the Jimmy Carter era. In Nacogdoches, Texas, Southern is building one of the country's largest commercial renewable-power stations, which will convert trash from lumber making and other forms of waste biomass into electricity.

For Mr. Fanning, this is common sense. He likens it to diversifying an investment portfolio: "You don't pick one stock." He may be right that "all of the above" is a sensible approach, but it isn't common—either in politics or in the electric industry. Mr. Fanning has emerged as one of the most trenchant (in fact, one of the only) critics of the transformative switch to gas from coal. Mr. Fanning explains, "It just doubles down your risk into one segment that looks promising today but nobody can sit here and tell me that it's going to be safe forever, safe in terms of economics and reliability."

In that sense, Southern's "genetic conservatism"—Mr. Fanning's term—may also be Exhibit A for the growing left-right coalition that wants to "make business boring again" in the too-big-to-fail era. They favor a return to something like the postwar business model that prevailed until the deregulation wave of the 1980s—safer but less competitive, more stable but also less entrepreneurial.

Boring is the wrong word for someone as effusive and iconoclastic as Mr. Fanning, but he does belong to a corporate culture that rejects barbarians-at-the-gate capitalism. He likes to invoke "Beta," the financial measure of the volatility of an asset in relation to the overall market. "Last year," he says proudly, "among the S&P 500, we had the second-lowest Beta. The only company that beat us was . . . Hormel. They make Spam! Southern may not be exciting, but we're dependable and we work like crazy to be dependable."

Those who favor a business world with less risk and fewer vampire squids, Mr. Fanning is your guy.

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Mr. Fanning sat down with the Journal editorial board recently amid "an historic shift" in the electric industry. King Coal is in twilight. For decades it was the engine of the U.S. power system, delivering nearly 60% of net generation by the 1980s. Southern illustrates the new reality; the share of its generation mix from coal has plunged to 35% in 2012 from 70% only five years ago. Meanwhile, gas has climbed to 47% from 16%.

One major reason, both at Southern and industry-wide, is the Environmental Protection Agency, which has been regulating against carbon like crazy. The EPA has effectively banned new coal and other rules are grinding down the existing fleet.

TERRY SHOFFNER

Mr. Fanning views the EPA's campaign as a special kind of recklessness. "It's terribly unwise in my view to create a regulatory regime that bans one of the nation's most plentiful resources. We own 28% of the world's coal reserves—we have a blessing of wealth. It should be brought to bear here in America. If not, due to regulatory policy, it will be burned for the benefit of the citizens of China or India or elsewhere." He's right: Exports have nearly doubled since 2007.

On the other hand, markets are demolishing coal more effectively than government. Since 1990, power companies have selected coal for merely 6% of new generation. Gas was the fuel for 77%, even as coal has been far more competitive than it is today.

Now gas enjoys a huge price advantage, driven by the hydraulic-fracturing techno-revolution and the vast shale reserves of the greater Midwest. When gas is trading at $6 per million British thermal units, it is 50% cheaper than coal over the life of a power plant. Today, gas is trading near $2.

Mr. Fanning isn't so sure. "When you think about the kind of time horizon that a business like ours is in, where you put capital-intensive assets in the ground with a 30- or 40-year economic life, you need to think long term," he says. So here's the skeptic's case.

"Nationwide, I think we're going to be consuming over 50% more gas going forward than we currently do," Mr. Fanning notes, "or at least there's a good potential for that." Demand for gas is growing not merely for baseload electricity but in manufacturing, chemicals, transportation, other industries. Consumption is also lagging below trend given the weak economy.

Even with many more wells and increased production, Mr. Fanning thinks gas prices will return to their historic oscillations and eventually spike. "Gas has traditionally been way more volatile certainly than coal and nuclear," he says. "So you're buying a more volatile product. You're creating a higher-Beta energy policy."

As coal recedes, Mr. Fanning warns that customers may be forced to rely on sources that are less productive and more expensive because there's nothing to pick up the slack. "If conventional coal is not going to get done, and there's only a few people who can do nuclear—this ain't a job for beginners—you're left with gas and, heaven forbid, renewables?" He cautions: "Now I'm as excited about renewables as anybody. But they're a niche play."

Other risks to ultracheap gas are political. Fracking could slow if government decides to "move beyond gas" with bad regulations, and a carbon tax or cap and trade could return. Natural-gas exports will also grow as the U.S. builds more terminals and producers see business opportunities in Europe and Asia. "You're going to see a harmonization of world-wide gas prices," much like the global commodity markets for oil. "Right now essentially the U.S. has a dividend coming to the economy in terms of cheap energy," says Mr. Fanning, who doesn't think it can last.

"Believe me," he continues. "I think gas will be the dominant resource going forward. But I am not willing to subject my customers to the risk of betting it all on gas."

***

For most of the 20th century, the consensus was that utilities like Southern were natural monopolies. The physics of electricity are simple and begat industrial organization: Because power can't be stored except in small quantities, supply and demand must be in balance at every instant. The thinking was that only one central authority could effectively manage the grid and coordinate the large-scale deployment of capital.

The same reasoning used to apply to the rest of the economy: Markets could only function if they were structured as cartels and competition suppressed. Thus the oligopolies in railroads, radio and television licenses, phone lines, air travel. Thus the separation of investment and commercial banking under the 1933 Glass-Steagall Act.

U.S. DEPARTMENT OF
ENERGY
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ENERGY EFFICIENCY & RENEWABLE ENERGY

WITNESS

WEATHERIZATION FUNDING

10%

55%

15%
HEALTH & SAFETY COSTS

20%
TRAINING & TECHNICAL ASSISTANCE COSTS

$4,[illegible]
AVERAGE WEATHERIZATION COST PER UNIT

A.P.S.C. DOCKET NO

Weatherization Works!

The U.S. Department of Energy's (DOE) Weatherization Assistance Program reduces energy costs for low-income households by increasing the energy e ciency of their homes, while ensuring their health and safety. The Program supports 8,500 jobs and provides weatherization services to approximately 35,000 homes every year using DOE funds. Through the weatherization improvements and upgrades, these households save on average $283 or more every year (*National Evaluation*).

A.P.S.C. DOCKET NO 32953

Sierra Club 's EX. NO. 3

Bahn Gross

8,500
JOBS SUPPORTED

$283
ANNUAL ENERGY COST SAVINGS
18%
ANNUAL HEATING CONSUMPTION SAVINGS
7%
ANNUAL ELECTRIC CONSUMPTION SAVINGS

FOR EVERY
$1.00
INVESTED IN WEATHERIZATION,
$1.72
IS GENERATED IN ENERGY BENEFITS AND
$2.78
IN NON-ENERGY BENEFITS.

Weatherizing a home as multiple benefits. In addition to the main goal of creating a more energy efficient dwelling, an investment in weatherization also has a positive impact on local employment and energy costs and generates energy and non-energy benefits for the community.

Weatherization In Action

Locally-based and professionally trained weatherization crews use computerized energy assessments and advanced diagnostic equipment, such as blower doors, manometers, and infrared cameras, to create a comprehensive analysis of the home to determine the most cost effective measures appropriate and to identify any health and safety concerns. Weatherization providers also thoroughly inspect households to ensure the occupant's safety, checking indoor air quality, combustion safety, carbon monoxide, and identifying mold infestations — which are all indications of energy waste.

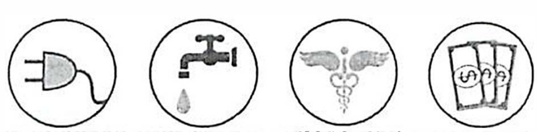
The auditor creates a customized work order and trained crews install the identi ed energy ef cient and health and safety measures. A certi ed Quality Control Inspector ensures all work is completed correctly and that the home is safe for the occupants.

Impact on Low-Income Americans

Low-income households carry a larger burden for energy costs, typically spending 16.3% of their total annual income versus 3.5% for other households *(2014 ORNL study)*. Often, they must cut back on healthcare, medicine, groceries, and childcare to pay their energy bills.

Weatherization helps alleviate this heavy energy burden through cost-effective building shell improvements such as insulation and air sealing, HVAC systems, lighting, and appliances.

The Benefits of a Weatherized Home



The program improves health and safety by eliminating any energy-related hazards. Once installed, energy-efficient Weatherization measures continue to save money and energy year after year and increase household incomes so funds can go towards key living expenses.

Funding & Leveraging

DOE provides core program funding to all 50 states, the District of Columbia, Native American Tribes, and the ve U.S. territories - American Samoa, Guam, Northern Mariana Islands, Puerto Rico, and the Virgin Islands through formula grants.

Once DOE awards the grants, states contract with nearly 800 local agencies nationwide. Community action agencies, other non-pro ts, and local governments use in-house employees and private contractors to deliver services to the low-income families.

In 2015, utilities and states supplemented DOE funding by providing an additional **$883 million, or $4.62 for every dollar invested by DOE** (*NASCSP Funding Survey 2015*).

EXHIBIT
9
PENGAD 800-631-6989

Impact on Communities

Weatherization not only helps households, it also helps revitalize communities by spurring economic growth and reducing environmental impact. Weatherization returns **$2.78** in non-energy benefits for every $1.00 invested in the Program (*National Evaluation*).

Non-energy benefits represent tremendous benefits for families whose homes receive Weatherization services. After Weatherization, families have homes that are more livable, resulting in fewer missed days of work (i.e. sick days, doctor visits), and decreased out of- pocket medical expenses by an average of **$514**. The total health and household-related benefits for each unit is **$14,148** (*National Evaluation*).

Typical Weatherization Measures

MECHANICAL MEASURES

- Clean, tune, repair, or replace heating and/or cooling systems.
- Install duct and heating pipe insulation.
- Repair leaks in heating/cooling ducts.
- Install programmable thermostats.
- Repair/replace water heaters.
- Install water heater tank insulation.
- Insulate water heating pipes.
- Install solar hot water heating system.

BUILDING SHELL MEASURES

- Install insulation where needed.
- Perform air sealing.
- Repair/replace windows/doors.
- Install window film, awnings and solar screens.
- Repair minor roof and wall leaks prior to attic or wall insulation.

HEALTH & SAFETY MEASURES

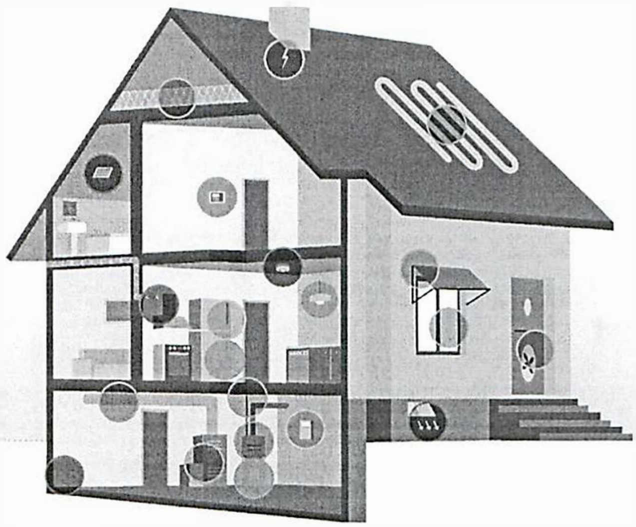
- Perform heating system safety testing.
- Perform combustion appliance safety testing.
- Repair/replace vent systems to ensure combustion gas draft safely outside.
- Install mechanical ventilation to ensure adequate indoor air quality.
- Install smoke and carbon monoxide alarms when needed.
- Evaluate mold/moisture hazards.
- Perform incidental safety repairs when needed.

Leading the Industry

Weatherization is always critical to introducing and deploying technology and facilitating greater industry adoption. An entire industry – the home performance industry – is based on the skills perfected by Weatherization. Over the past five years, the Weatherization network and the private sector have established the **Guidelines for Home Energy Professionals** including **Standard Work Specifications for Home Energy Upgrades (SWS)**, and **Home Energy Professional certifications** along with accreditation of energy-efficiency training programs.

Weatherization agencies also create a market for American manufacturing, using products and equipment from local sources, benefitting the business community in the regions they serve.

The Weatherization Assistance Program has created an industry, producing new jobs and technologies, all while helping the most vulnerable families in America. ■



ELECTRIC & WATER MEASURES

- Install efficient light sources.
- Install low-flow showerheads.
- Replace inefficient refrigerators with energy-efficient models.

CLIENT EDUCATION ACTIVITIES

- Educate on potential household hazards such as carbon monoxide, mold & moisture, fire, indoor air pollutants, lead paint and radon.
- Demonstrate the key functions of any new mechanical equipment or appliances.
- Discuss the benefits of using energy-efficient products.

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

For more information, visit: energy.gov

DOE/1561 · February 2018

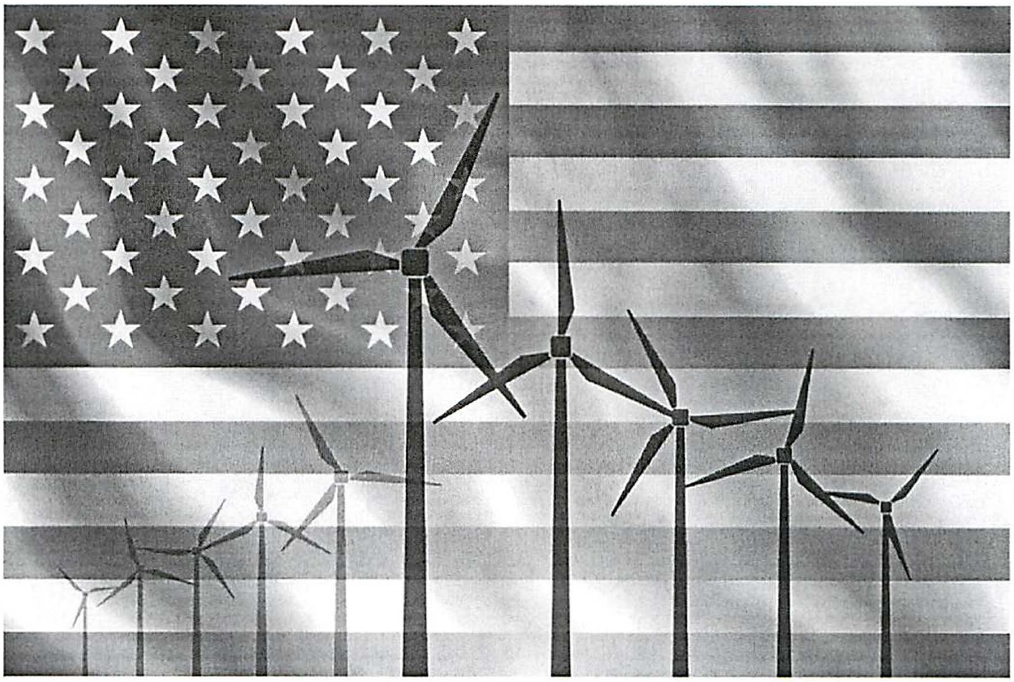
Vox

A.P.S.C. DOCKET NO. 32953
Sierra Club EX. NO. 4
BALLA-GROSS

Utilities have a problem: the public wants 100% renewable energy, and quick

The industry is groping for ways to talk the public down.

By David Roberts | @drvox | david@vox.com | Updated Oct 11, 2018, 9:19am EDT



American as apple pie. | Shutterstock

Renewable energy is hot. It has incredible momentum, not only in terms of deployment and costs but in terms of public opinion and cultural cachet. To put it simply: Everyone loves renewable energy. It's cleaner, it's high-tech, it's new jobs, it's the future.

And so more and more big energy customers are demanding the full meal deal: 100 percent renewable energy.

The Sierra Club notes that so far in the US, more than 80 cities, five counties, and two states have committed to 100 percent renewables. Six cities have already hit the target.

The group RE100 tracks **152 private companies across the globe** that have committed to 100 percent renewables, including Google, Ikea, Apple, Facebook, Microsoft, Coca-Cola, Nike, GM, and, uh, Lego.

The timing of all these targets (and thus their stringency) varies, everywhere from 2020 to 2050, but cumulatively, they are beginning to add up. Even if policymakers never force power utilities to produce renewable energy through mandates, if all the biggest customers demand it, utilities will be mandated to produce it in all but name.

The rapid spread and evident popularity of the 100 percent target has created an alarming situation for power utilities. Suffice to say, while there are some visionary utilities in the country, as an industry, they tend to be extremely small-c conservative.

They do not like the idea of being forced to transition entirely to renewable energy, certainly not in the next 10 to 15 years. For one thing, most of them don't believe the technology exists to make 100 percent work reliably; they believe that even with lots of storage, variable renewables will need to be balanced out by "dispatchable" power plants like natural gas. For another thing, getting to 100 percent quickly would mean lots of "stranded assets," i.e., shutting down profitable fossil fuel power plants.

LightRocket via Getty Images

In short, their customers are stampeding in a direction that terrifies them.

The industry's dilemma is brought home by a recent bit of market research and polling done on behalf of the Edison Electric Institute, a trade group for utilities. It was distributed at a **recent meeting of EEI board members and executives** and shared with me.

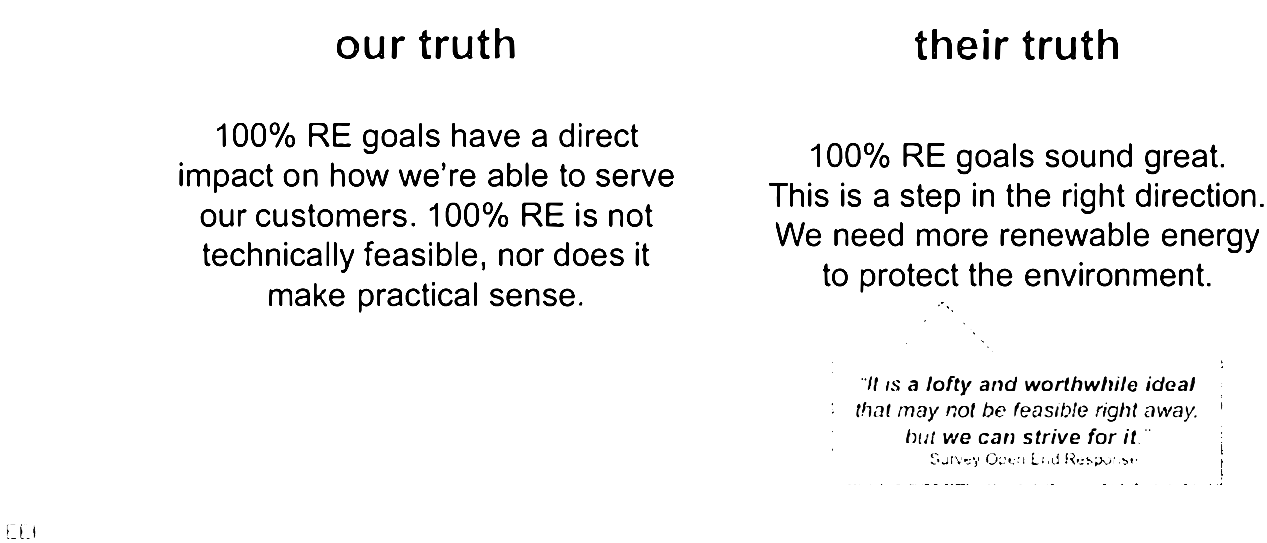
The work was done by the market research firm **Maslansky & Partners**, which analyzed existing utility messaging, interviewed utility execs and environmentalists, ran a national opinion survey, and did a couple of three-hour sit-downs with "media informed customers" in Minneapolis and Phoenix.

The results are striking. They do a great job of laying out the public opinion landscape on renewables, showing where different groups have advantages and disadvantages.

The takeaway: Renewables are a public opinion juggernaut. Being against them is no longer an option. The industry's best and only hope is to slow down the stampede a bit (and that's what they plan to try).

100 percent renewables is a wildly popular goal

The core of the industry's dilemma is captured in this slide (on the left is the industry perspective):



Utilities don't think it is wise or feasible to go 100 percent renewables. But the public loves it.

And I mean *loves* it. Check out these numbers from the opinion survey:

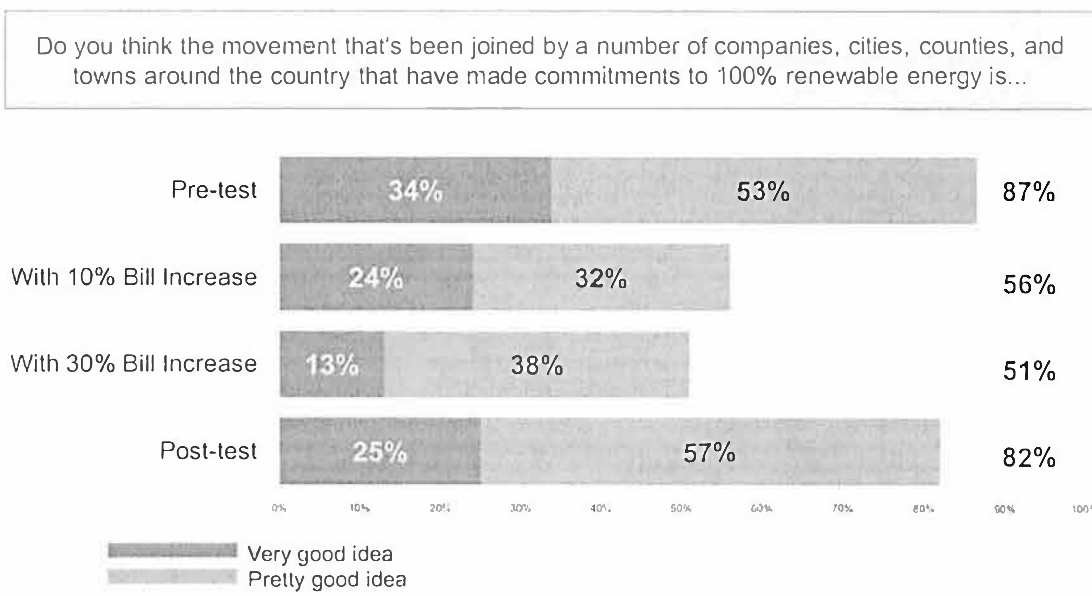
74%	think we should use solar "as much as possible"
70%	agree that "In the near future, we should produce 100% of our electricity from renewable energy sources such as solar and wind"

*"Renewable energy is never depleted, **it's always there**. Easily sourced and easily replaced."*
– Minneapolis

*"We need to get **off fossil fuels**."*
– Phoenix

In our polarized age, here is something we almost all agree on: Renewable energy is awesome.

Here's the most striking slide in the presentation:



EEI

In case you don't feel like squinting, let me draw your attention to the fact that a majority of those surveyed (51 percent) believe that 100 percent renewables is a good idea even if it raises their energy bills by *30 percent*.

That is wild. As anyone who's been in politics a while knows, Americans don't generally like people raising their bills, much less by a third. A majority that still favors it? That is political dynamite.

Insofar as utilities were in a public relations war over renewables, they've lost. They face a tidal wave. So what can they do?

Explaining why 100% renewables is impossible backfires

What they *can't* do is tell customers why they can't do it. Customers do not want to hear excuses.

They tested the following message (this is an excerpt, with emphasis added): "Today, we can choose between a balanced energy mix, which provides reliable energy whenever we need it, and 100% renewable energy. But we **cannot have both**. We also need to consider the costs. ... The logistics, resources, and costs would be immense."

Nope. Customers didn't want to hear it.

"You could tell what side he was leaning toward," said one Phoenix focus-group participant. "He offered no solutions. It was just problem, problem, problem."

"I want to hear about how the work would get done," said a Minneapolis participant. "I don't want to hear him complain about how much work it will take."

Other can't-do arguments drew similar reactions:

if we say...	they hear...excuses
× "Current battery storage technology **doesn't have nearly enough capacity** to supplement the variability of wind and solar."	*"The battery in my phone lasts all day. He's making excuses.* ***150 years ago, we were lighting candles. We can make the change****; we can do all this."* - Phoenix
× "We **would need to** put solar panels and wind turbines on thousands of acres of land."	*"****Land in the U.S. is plentiful****. That's the worst argument I've heard. "* -- Minneapolis

FEI

Can't-do arguments get a company branded as anti-renewables, and that means Bad Guy. After that, customers aren't listening.

If they want people to keep listening, utilities must begin by convincing them that they are on board with renewables. Thus, the very first piece of advice on "framing the conversation" reads, "Positive, pro-renewable message first ... every time."

An anti-renewables message, even a message that *implies* anti-renewables, is simply untenable.

That is worth noting. It's something I'm not sure US climate hawks or political types have entirely internalized. There aren't many contested political issues on which public opinion is so unequivocally on one side.

The public might be willing to let the experts work out the details

So utilities must convince customers that they support renewable energy, first thing, off the bat. (The best way to do that, of the options tested, was telling customers about investments — highlighting the rising level of investment in renewables. Money talks.)

If they can make that key connection, then they can swing the conversation around. Once customers are convinced that utilities are sincere about supporting renewables, they become more open to the message that getting to 100 percent will take some time, that it needs to be done deliberately, and that costs need to be taken into account.

"Given the cost and the complexities of it, it should be done gradually," one Phoenix respondent said. "Not the next five years, but maybe by the end of our lifetimes," said another.

The researchers tested the following message (excerpted): "[A balanced energy mix] helps us maintain consistent service for our customers and avoids over-reliance on a single fuel type or technology. This means we're able to bring our customers increasingly more renewable energy without asking them to compromise on reliability or cost."

That worked much better. "It seemed like we all have the same goal that we're working toward," said a respondent in Minneapolis. "In the meantime, they'll use a balance to serve us. It's sensible."

In fact, in terms of reasons not to rely entirely on renewables, by far the most potent argument was that it would slow the transition to clean energy: "We can get to cleaner energy faster and more effectively if we use a range of sources and technologies."

The state-of-the-art message for utilities, then, is this: Yes, we want to pursue renewables, but to protect consumers, we want to do it in a way that is "balanced, gradual, affordable, [and] reliable." That means we should avoid, ahem, "short-term mandates."

get them to listen	✓ Positive, pro-renewable message first…every time ✓ Embrace partnerships
show them a path	✓ Communicate how to do it right: **balanced, gradual, affordable, reliable**
broaden the context	✓ Expand the conversation to clean energy and carbon reduction ✓ Point to clear actions with measurable impact

(How much this message will merely cover for efforts to block legislation and slow the transition depends on the utility.)

On renewables, "yes, but" is the only countermessage left

So where does this leave us in terms of the messaging landscape?

In the 100 percent renewables debate, there are roughly three camps, at least among the researchers, energy executives, climate advocates, and journalists who pay attention to these sorts of things.

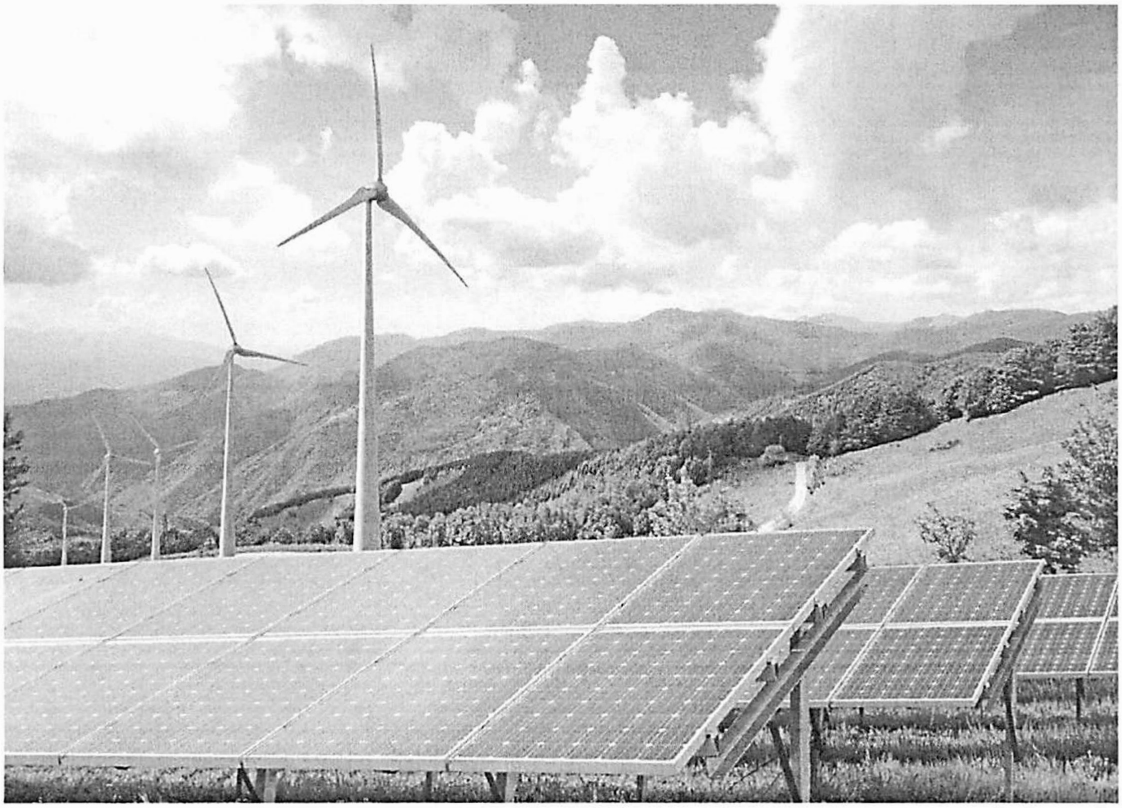
The first, with most **activists** and **advocates**, supports 100 percent renewables as a clear, intuitive, and inspiring target, an effective way to rally public support and speed the transition.

The second camp believes that the cheaper, safer way to get to carbon-free electricity is not to rely entirely on renewables but to supplement them with "firm" zero-carbon alternatives like hydro, nuclear, geothermal, biomass, or fossil fuels with carbon capture and sequestration. (See **this paper**, from a group of MIT researchers, for the best articulation of that argument.) This camp supports the strategy **California has taken**, which is to mandate 100 percent "zero carbon" rather than "renewable" resources, to leave flexibility.

The third camp, containing many utilities and conservatives, flatly doesn't believe 100 percent carbon-free electricity is possible anytime soon, and would just as soon not close working fossil fuel power plants before the end of their profitable lives. They would like to continue balancing the rising share of renewables with natural gas.

The first camp has won the public's heart. Big time. Everyone, even those gritting their teeth, has to signal support for renewables if they want to be taken seriously.

There is some room for the third camp to convince the public that the transition to renewables needs to proceed carefully and "gradually." That's the ground advocates and utilities will be fighting on in coming years: not whether to go, but how fast. (There's a lot of room within "not the next five years, but maybe by the end of our lifetimes.")



Get used to it. | Shutterstock

And there is some room for the second camp to convince the public that the transition to *clean* energy is best achieved by relying on sources beyond *renewable* energy, or at least by not locking ourselves into renewables prematurely. One of the survey's findings is that under a range of questions, the public does not have a strong preference between increasing renewables and reducing carbon emissions. I doubt most people differentiate the two at all — they are vaguely good, environmental-ish things.

Similarly, I doubt the public at large will care much about the distinction between "renewable" and "clean," which serves as a pretty good argument for the California approach. (The California approach, or at least earlier variants of it, has helped keep existing nuclear plants running in **Illinois** and **New York**.)

But these are implementation details. The decarbonization ship has sailed. Renewable energy is in the vanguard and, at least for now, it appears unstoppable. At this point, it is difficult to imagine what could turn the public against it. (Perhaps a giant wind spill?) The more relevant question is when lawmakers will catch on to renewable energy's full political potential.

The basic message from the public, if I could pull together all the strands of the research, is this: We want clean, modern energy, and we'll pay for it. We're willing to let experts work out the details, but we don't want to hear that it can't be done. Just do it.

Utilities can't make that sentiment go away, though they can and will try to soften it. In the meantime, in the off-chance that their messaging efforts fail, they'd better get serious about giving customers the clean energy they want.

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Item 1A. RISK FACTORS

In addition to the other information in this Form 10-K, including MANAGEMENT'S DISCUSSION AND ANALYSIS – FUTURE EARNINGS POTENTIAL in Item 7 of each registrant, and other documents filed by Southern Company and/or its subsidiaries with the SEC from time to time, the following factors should be carefully considered in evaluating Southern Company and its subsidiaries. Such factors could affect actual results and cause results to differ materially from those expressed in any forward-looking statements made by, or on behalf of, Southern Company and/or its subsidiaries.

UTILITY REGULATORY, LEGISLATIVE, AND LITIGATION RISKS

Southern Company and its subsidiaries are subject to substantial state and federal governmental regulation. Compliance with current and future regulatory requirements and procurement of necessary approvals, permits, and certificates may result in substantial costs to Southern Company and its subsidiaries.

Southern Company and its subsidiaries are subject to substantial regulation from federal, state, and local regulatory agencies and are required to comply with numerous laws and regulations and to obtain numerous permits, approvals, and certificates from governmental agencies. The traditional electric operating companies and the natural gas distribution utilities seek to recover their costs (including a reasonable return on invested capital) through their retail rates, which must be approved by the applicable state PSC or other applicable state regulatory agency. A state PSC or other applicable state regulatory agency, in a future rate proceeding, may alter the timing or amount of certain costs for which recovery is allowed or modify the current authorized rate of return. Rate refunds may also be required. Additionally, the rates charged to wholesale customers by the traditional electric operating companies and by Southern Power and the rates charged to natural gas transportation customers by Southern Company Gas' pipeline investments and for some of its storage assets must be approved by the FERC. These wholesale rates could be affected by changes to Southern Power's and the traditional electric operating companies' ability to conduct business pursuant to FERC market-based rate authority. Retaining this authority from the FERC is important to the traditional electric operating companies' and Southern Power's ability to remain competitive in the wholesale electric markets.

The impact of any future revision or changes in interpretations of existing regulations or the adoption of new laws and regulations applicable to Southern Company or any of its subsidiaries is uncertain. Changes in regulation or the imposition of additional regulations could influence the operating environment of Southern Company and its subsidiaries and may result in substantial costs or otherwise negatively affect their results of operations.

The Southern Company system's costs of compliance with environmental laws and satisfying related AROs are significant. The costs of compliance with current and future environmental laws and related AROs and the incurrence of environmental liabilities could negatively impact the net income, cash flows, and financial condition of the registrants.

The Southern Company system's operations are subject to extensive regulation by state and federal environmental agencies through a variety of laws and regulations. Compliance with existing environmental requirements involves significant capital and operating costs including the settlement of AROs, a major portion of which is expected to be recovered through existing ratemaking provisions or through market-based contracts. There is no assurance, however, that all such costs will be recovered. The registrants expect future compliance expenditures will continue to be significant.

The EPA has adopted and is implementing regulations governing air and water quality under the Clean Air Act and regulations governing cooling water intake structures and effluent guidelines for steam electric generating plants under the Clean Water Act. The EPA has also adopted regulations governing the disposal of CCR, including coal ash and gypsum, in landfills and surface impoundments at active generating power plants. The cost estimates for AROs related to the disposal of CCR are based on information using various assumptions related to closure and post-closure costs, timing of future cash outlays, inflation and discount rates, and the potential methods for complying with the CCR Rule. The traditional electric operating companies will continue to periodically update their ARO cost estimates.

Additionally, environmental laws and regulations covering the handling and disposal of waste and release of hazardous substances could require the Southern Company system to incur substantial costs to clean up affected sites, including certain current and former operating sites, and locations affected by historical operations or subject to contractual obligations.

Existing environmental laws and regulations may be revised or new environmental laws and regulations may be adopted or become applicable to the Southern Company system. In addition, existing environmental laws and regulations may be impacted by related legal challenges.

Litigation over environmental issues and claims of various types, including property damage, personal injury, common law nuisance, and citizen enforcement of environmental requirements has occurred throughout the U.S. This litigation has included claims for damages alleged to have been caused by CO_2 and other emissions, CCR, releases of regulated substances, and alleged exposure to regulated substances, and/or requests for injunctive relief in connection with such matters.