WORLD RESOURCES INSTITUTE

WORKING PAPER

SOLAR ENERGY IN UTILITY INTEGRATED RESOURCE PLANS: FACTORS THAT CAN IMPACT CUSTOMER CLEAN ENERGY GOALS

CELINA BONUGLI, ERIC O'SHAUGHNESSY, HEIDI BISHOP RATZ, AND JOSEPH WOMBLE

EXECUTIVE SUMMARY

Highlights

- Many electric utilities utilize Integrated Resource Plans (IRPs) to develop and communicate a long-term vision for their resource development; as such, IRPs play a significant role in solar development and in how customers achieve their clean energy goals.
- For large-scale energy customers, including corporations and local governments, understanding how IRP processes impact resource decisions—and how this relates to achieving their clean energy targets—can influence their engagement with utilities and regulators.
- A range of barriers can limit solar energy in IRPs, including outdated or unfounded solar technology assumptions and modeling practices that do not enable solar to compete fairly with other resources in the process.
- These barriers can reduce the amount of solar in the grid mix or available to customers through utility programs, impacting the ability of customers to meet their clean energy targets.

Background

Large-scale energy customers, including corporations and local governments, are increasingly engaging in utility resource planning efforts to decarbonize the grid. These planning efforts affect the ability of large-scale energy customers to meet ambitious clean energy targets, by determining both the clean energy content of the grid mix and how that clean

CONTENTS

Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback, and to influence ongoing debate on emerging issues. Working papers may eventually be published in another form and their content may be revised.

Suggested Citation: Bonugli, Celina, E. O'Shaughnessy, H. Bishop Ratz, and J. Womble. 2021. "Solar Energy in Utility Integrated Resource Plans: Factors That Can Impact Customer Clean Energy Goals." Working Paper. Washington, DC: World Resources Institute. Available online at https://doi.org/10.46830/wriwp.21.00025

energy is made available to specific customers. For these customers, understanding and engaging with their utility's future resource plans is therefore a key element of clean energy procurement strategies. In this working paper, we focus on how these resource plans affect the role of solar in future grids and in customer clean energy portfolios within the United States.

IRPs compare alternative resource portfolios and identify optimal portfolios that maintain long-term resource adequacy and minimize grid costs. While IRP requirements and practices vary across the United States, state-mandated planning processes often require utilities to identify the best resource portfolio to meet reliability and public policy goals at least-cost over the next 15–20 years. In many cases, these plans are developed with input from stakeholders and approved by the state utility regulator.

IRP processes are complex and require assumptions and modeling that directly influence how solar energy is utilized or not. IRPs depend on models that identify "optimal" resource mixes based on cost and reliability parameters. IRP modeling is highly sensitive to the assumptions and inputs used. IRPs are forward-looking exercises that require utilities to develop a range of future scenarios to estimate the possible impacts of various resource options on resource adequacy and grid costs in IRP processes. Utilities seek accurate assumptions of future resource costs, system performance, and grid conditions. Further, utilities require sophisticated models that can identify the potential contributions of specific resources (e.g., solar) to future grid energy and capacity requirements. These models must also account for policy demands and uncertainties in future demand.

Solar energy presents unique challenges for resource planning. The output from solar energy is variable, meaning it fluctuates with the available sunlight. Variable energy sources pose unique but solvable challenges to grid operations and planning. In addition to technical challenges, IRPs require accurate projections of future solar deployment, but solar deployment can be difficult to project for three reasons. First, utilities rely on financial analyst forecasts of solar costs as inputs to their models. Those analysts tend to overestimate future solar costs, which results in underestimation of the future cost-effectiveness of solar. Second, the future grid value of solar depends on several uncertain factors, including the capacity value of solar and trends in other technologies such as energy storage. Third, around one-third of installed solar power to date has been deployed by electricity customers, often referred to as distributed or "behind-the-meter" solar. Distributed solar is a component of many large-scale customer clean energy procurement strategies. However, because it tends to be outside the direct control of utilities, utilities face challenges in accurately integrating distributed solar deployment into IRPs.

About This Working Paper

The objective of this working paper is to raise awareness among large-scale customers, utilities, and regulators of some of the current barriers that limit solar energy in utility IRPs. Our hope is that, by increasing awareness and understanding, this paper can identify issues that could impact the attainment of customer clean energy goals, empower utilities to proactively address solar energy barriers and evolve IRP processes, and equip regulators with key considerations during the review and approval process.

This working paper focuses on key issues that influence the amount of solar energy incorporated in IRPs. We focus on solar energy because it will be critical for achieving clean energy and decarbonization targets. We also focus on solar because it is uniquely modular: it can be implemented at utility scales but also at smaller distributed scales by individual customers. Distributed solar entails unique resource planning challenges. Differences in modeling choices across utilities may also impact how solar is evaluated against other resources within resource portfolios. Certain modeling choices, such as treating solar as a fixed rather than selectable resource or treating distributed solar as exogenous, can limit the role of solar in IRPs. Although this working paper is focused on solar energy, some of the barriers identified may also be relevant for other renewable energy resources, such as wind energy. Furthermore, this working paper primarily focuses on solar as evaluated and utilized in IRP processes. During the IRP development processes, solar influences both forecasting assumptions and the evaluation and selection of resource portfolios to meet demand. And in some cases, when customer programs are explored in the IRP to meet demand, IRPs can also influence access to or availability of solar. Small-scale solar that is customer-deployed or otherwise accessed through third-party developers is primarily outside the scope of this working paper as this is largely outside of the IRP development process.

Conclusions

A variety of barriers can limit the role of solar energy in IRPs. These barriers include outdated or unfounded assumptions about solar energy technologies—particularly in terms of costs, capacity values, and grid integration— and modeling practices that do not enable solar to fairly compete with other resources. Other noteworthy barriers include incongruence between utility business models and distributed solar, and limited regulator authority.

Large-scale energy customers, utilities, and regulators can all play distinct roles to overcome these barriers and ensure that IRPs adapt to the growing role of solar in future resource planning.

- Customers can engage more actively in the IRP development process, for example, by engaging early and often to share desired solar outcomes, actively assessing their utility's IRP for factors that can limit solar and, when needed, requesting action from either the utility or regulator (e.g., requesting that utilities implement best practices for integrating solar into IRPs) and proactively working with utilities to more effectively integrate solar into IRPs.[1]
- Utilities can lead by example by providing transparency around assumptions and data used, engaging with customers early in the planning process to improve IRP forecasting and to better incorporate customer demand through either increased utilization of renewables in the overall grid mix and/or improvement or development of customer renewable energy programs into IRPs (e.g., utility green tariffs), and ultimately embracing new IRP practices that enable solar energy to play a more central role in future resource portfolios, where appropriate. Utilities can also enhance or develop and implement processes to review assumptions and methodologies from previous IRPs to identify what worked and what didn't in terms of yielding accurate projections for solar energy.

1. BACKGROUND: HOW INTEGRATED RESOURCE PLANS AFFECT SOLAR PROCUREMENT AND DEPLOYMENT

1.1 Importance of Solar Energy in Achieving State, Utility, and Customer Clean Energy Targets

Across the United States, 30 states plus the District of Columbia and Puerto Rico have set either renewable energy standards or 100 percent clean energy targets. These targets aim to power grids with 100 percent carbon-free electricity by dates between 2040 and 2050 (Julin and Paulos 2021). Similarly, 51 utilities have set carbon-free or net-zero goals by 2050 (SEPA 2021). Large utility customers such as corporations and local governments are similarly committing to clean energy. More than 300 companies have joined RE100, a global initiative of businesses that are committed to transitioning their operations to 100 percent renewable electricity (RE100 n.d.). More than 170 cities have also committed to 100 percent renewable or clean energy (Sierra Club n.d.). These large-scale customer targets often aim to achieve 100 percent decarbonization faster than state and utility targets (O'Shaughnessy et al. 2021). As a result, even in states with 100 percent targets, large-scale energy customers are accelerating the clean energy transition.

Solar energy is a critical resource for achieving state, utility, and large-scale customer clean energy goals. Solar is one of the primary sources of clean power in all major deep decarbonization studies (Jenkins et al. 2018; Larson et al. 2020; Bouckaert et al. 2021). Barring significant unforeseen technological innovations in other clean energy technologies, there is simply no pathway to meeting these ambitious targets where solar does not play a significant role. Given the central role of solar as a driver of grid decarbonization, all types of solar energy should be deployed as effectively as possible.

1.2 Overview of IRPs

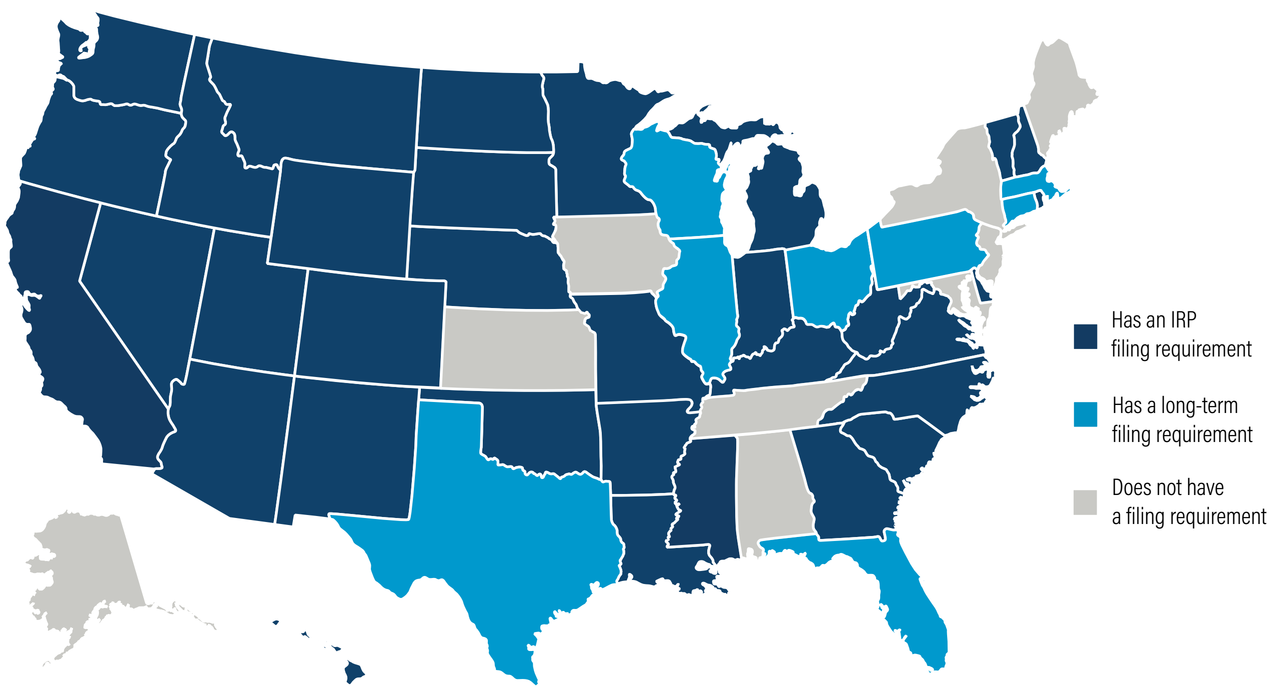
Integrated Resource Plans (IRPs) are utilized by many electric utilities and utility regulators in the United States to develop and communicate a long-term vision for resource development. IRPs are particularly important tools for vertically integrated investor-owned utilities

(IOUs) that are responsible for long-term resource procurement (Bonugli and Ratz 2021). Although IRPs are not strictly limited to these utilities, vertically integrated IOU IRPs cover the majority of resources subject to resource planning.

IRPs are used to evaluate and communicate possible scenarios of the specific resource portfolios that will ensure resource adequacy, maintain system reliability, achieve public policy goals, and minimize costs and long-term risks to grid operations (Sterling et al. 2013; Kahrl et al. 2016). IRPs usually cover a 10–20 year time frame and are developed every 2–5 years. Unlike traditional long-term utility planning, IRP requirements mandate examination of demand-side resources (e.g., energy efficiency, demand response) in addition to supply-side resources (new generation or power purchases). IRPs typically address questions about the trade-offs between different options, such as building new generation assets, purchasing energy from other generators, integrating distributed energy resources (DERs),[2] investing in energy efficiency programs, and/or investing in demand response programs.

The use of IRPs and IRP requirements varies by state and utility. Figure 1 shows which states require IRPs, although utilities may choose to develop plans even if they are not required to do so.

Figure 1 | **States with Requirements to File an IRP or Other Long-Term Plan**



Source: Graphic based on data from the Regulatory Assistance Project, Power Suite, and various commission websites.

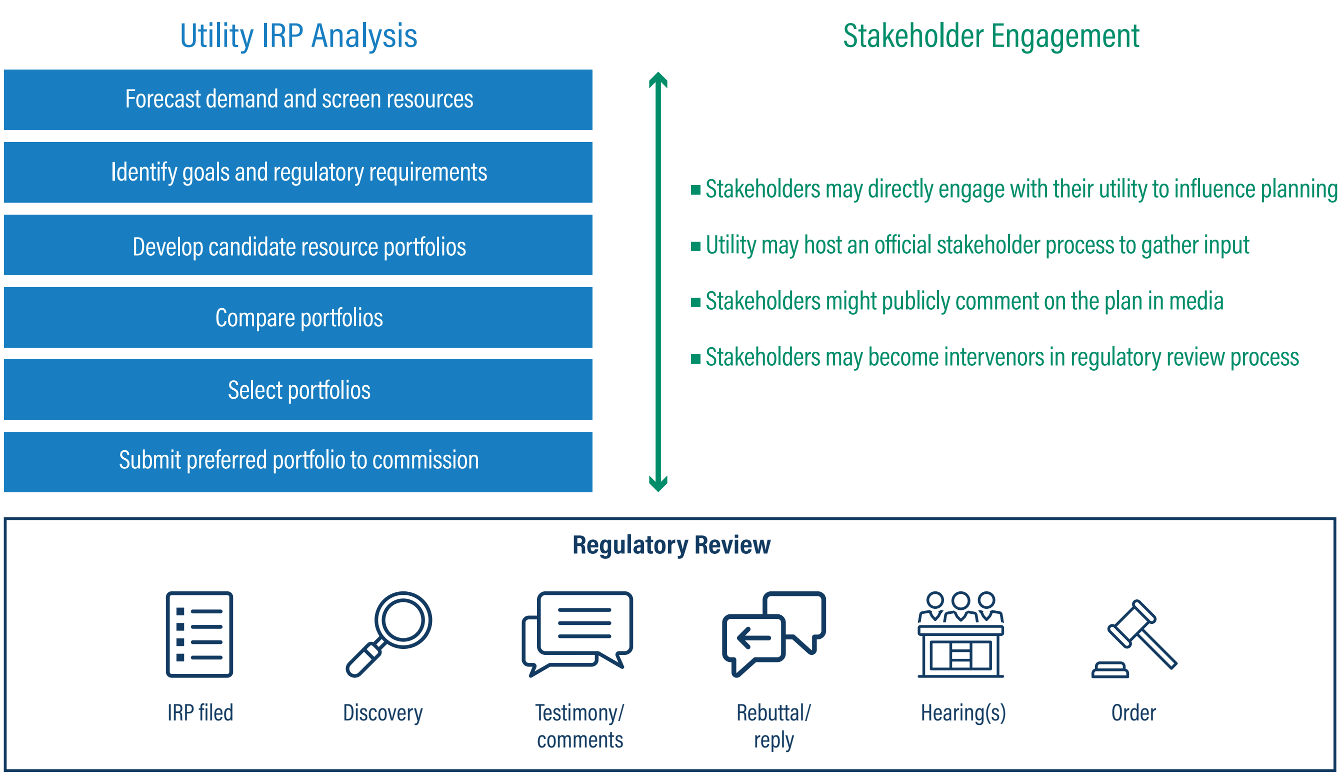
Most IRPs follow a similar process for developing and examining potential resource portfolios. Figure 2 illustrates an example of this process, including utility analysis and the selection of a preferred resource portfolio, as well as potential stakeholder engagement and approval of the resource plan with the state regulator. This process, including details on stakeholder engagement and the regulatory review, is further explored in Appendix B. An important step is regulatory review, where the utility IRP is submitted to a utility regulator, most commonly a Public Utilities Commission (PUC).[3] The PUC has varying levels of authority over the IRP. In some cases, PUCs can require changes to IRPs, while in others, PUC authority is restricted to simply recognizing IRP completion.

Due to the long planning horizon of a decade or more, IRPs are generally nonbinding. However, IRPs still tend to influence future resource decisions by creating guidance or otherwise setting expectations for future resource procurement, rate proceedings, cost recovery, and customer programs that will be subject to regulatory approval. Moreover, in some cases, the IRP may include a near-term action plan, such as a solicitation for procurement.

1.3 IRPs Play a Significant Role in Solar Development and in How Customers Achieve Their Clean Energy Goals

There are a variety of factors that influence solar energy procurement and deployment. One key process is IRPs. As initially explored above, during the IRP development process, solar influences both forecasting assumptions (e.g., through an examination of current and anticipated use of utility programs or customer or third-party-generated direct procurement) and the evaluation and selection of resource portfolios to meet demand. And in some cases, when customer programs are explored in the IRP as a means to meet demand, IRPs can also influence access to or availability of solar.

Figure 2 | **Elements of an IRP Development Process**



Note: This graphic shows a generalized example of the IRP development process. It does not capture all the variations of analysis, review, or stakeholder engagement, nor the iterations between steps. In this graphic, the regulatory review processes illustrated reflect states in which the regulator has a high level of regulatory oversight.

Source: Bonugli and Ratz 2021.

Generally speaking, large-scale customers can access the benefits of solar to achieve their clean energy targets in three ways, as listed below. Utilities' consideration of solar energy in IRPs therefore influences each of the basic pathways customers can access solar, affecting their procurement strategy.

- **Grid mix:** Customers can access solar energy through their standard or default energy supply via their underlying grid mix. This is often considered a customer's baseline and influences the remaining efforts or actions required in customers' procurement strategies. Utilities can select solar as a resource, influencing the carbon intensity of the future grid mix, and in turn, the amount of clean energy that customers would need to procure to achieve their own decarbonization targets.
- **Customer programs:** Customers can buy solar energy above and beyond what is provided by the grid mix through participation in utility renewable energy programs. Utilities can assess customer program participation as an indicator of customer demand to influence additional use of renewables.
- **Customer or third-party-generated direct procurement:** Depending on state legislation and other energy market opportunities, where available, customers can buy solar directly, typically by contracting with a solar developer and buying output from on- or off-site solar systems. This can occur at very small scale (e.g., rooftop photovoltaic [PV] systems) as well as very large scale (e.g., power purchase agreements [PPAs]). Utilities can account for direct solar procurement in IRPs by projecting customer-generated or third-party direct procurement of solar and factoring that deployment into their demand calculation and estimation of resource needs.

1.4 Customer Engagement in IRPs

Stakeholders engaged in IRP processes, especially the regulatory review process, have traditionally been industry trade groups, customer advocacy groups, or environmental nongovernmental organizations (NGOs). However, as large-scale energy customers are becoming increasingly aware of how utility IRPs affect their own clean energy targets and the future carbon intensity of the grid, they have increased their level of engagement. Customers can engage in IRPs in a variety of ways (Box 1).

Corporate customers across the country have engaged in various IRP processes for several years. Similarly, local governments have expanded their regulatory engagement to include IRP processes. In 2018 and 2019, approximately 10 local governments engaged in their relevant IRP processes. This has been done both individually and collaboratively with other local governments or similar customers. For example, in 2018, six cities and counties as part of the King County–Cities Climate Collaboration in Washington State participated in the regulatory process by collectively filing comments on a proposed IRP.[4]

In some cases, corporations and local governments are collaborating, for example, by pooling their knowledge or resources, monitoring each other's efforts, or even collectively engaging. In a recent IRP filing in North Carolina, this full range of customer engagement was present. Several major tech companies—including Apple Inc., Facebook Inc., and Google—collectively submitted comments to the North Carolina Utilities Commission,[5] and many other commercial customers, such as Biogen, Burt's Bees, Sierra Nevada, Novozymes, and Unilever, also submitted collective comments.[6] Moreover, through one collective effort, 11 local governments in North Carolina submitted comments to illustrate how the IRP influenced their greenhouse gas (GHG) reduction goals.[7]

As customers increasingly engage with IRPs, it will be helpful for them and for other stakeholders to have a better understanding of utility assumptions and modeling approaches, as well as of the barriers to fully considering and utilizing renewable energy options such as solar. This is the topic of the following section.

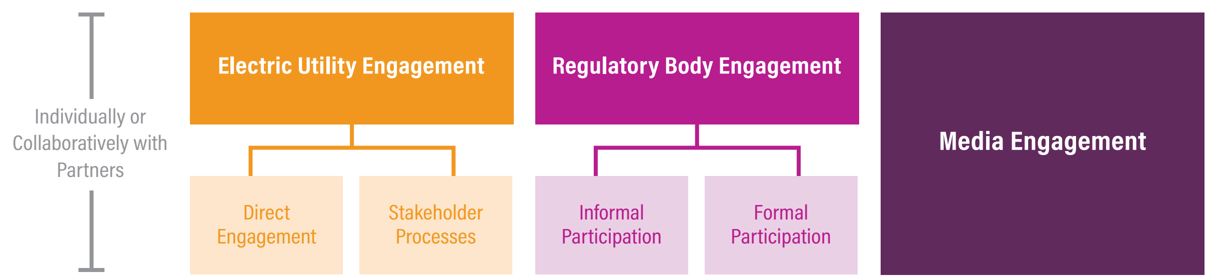
BOX 1 | Introduction to IRP Engagement Opportunities

IRP engagement typically occurs via three main pathways: engagement with the electric utility through direct communication or participation in utility stakeholder outreach processes; engagement with the regulatory body (e.g., Public Utilities Commission) by, for example, commenting on proposed plans informally through public opportunities or as an official party to the proceeding; and through media engagement (Figure B.1).

Figure B.1 is not comprehensive; IRP engagement opportunities will vary among states and utilities (e.g., some utilities may not offer stakeholder engagement), and in some cases there may be additional engagement opportunities not included in this illustration.

For additional information on IRP engagement pathways, and some ideas for how to strategically engage in IRP processes, see the IRP Support Package.

FIGURE B.1 | OVERVIEW OF GENERAL IRP ENGAGEMENT PATHWAYS



Note: These pathways are not mutually exclusive.

Source: Bonugli and Ratz 2021.

2. CURRENT BARRIERS TO SOLAR ENERGY IN IRPS

A variety of factors can limit the role of solar energy in IRPs. For the purposes of this working paper, we categorize *technical* barriers to solar energy that may naturally limit its role due to technological characteristics (e.g., variability) and *structural* barriers that inhibit the most efficient use of solar energy in IRPs. Technical solar energy barriers may include, for example, intermittency limitations (e.g., reliance on available sunlight) or the currently high costs for large-scale energy storage. All energy resources have distinct sets of technical barriers. These technical barriers are important to understand, and utilities should be transparent in communicating how they affect the future role of solar on the grid. However, this working paper focuses primarily on the structural barriers that may be preventing solar from being deployed in cost-effective ways that could decarbonize grids while maintaining system reliability—but that can potentially be overcome.

One goal of this section is to equip large-scale energy customers with the skills to distinguish between technical challenges, such as solar integration, from limitations that can be placed on the role of solar energy because of the ways in which IRPs are developed. To illustrate with a simple hypothetical example, consider the following assertion: *"Solar curtailment is projected to increase by 2040. Transmission upgrades required to prevent this curtailment add to the integration costs of solar."*

The first sentence states a widely accepted integration challenge: the inflexibility of solar will result in increasing levels of unused or "curtailed" output. Utilities can and should discuss how increasing curtailment will affect future solar output. This first sentence is an example of a technical barrier to solar integration. However, the second sentence assumes that curtailment must be prevented through transmission system upgrades. While transmission upgrades *can* help alleviate curtailment, there is no justifiable reason that *only* such upgrades can alleviate curtailment, given evidence that other approaches, such as storage, managed electric vehicle (EV) charging, or load shifting may be viable, or that simply allowing some level of curtailment during certain hours can be a cost-effective way to integrate solar onto the grid (Nelson et al. 2018).

This section explores a number of key structural barriers that could limit the role of solar energy in IRPs. The set of barriers we discuss here is not comprehensive. We have categorized the primary structural barriers covered in this paper into two further subcategories:

- Outdated or unfounded (i.e., without supporting evidence) assumptions regarding solar technology
- Modeling practices that can limit solar relative to other resources

We also recognize additional barriers related to utility business models and regulatory oversight that influence how efficiently solar energy is used in IRPs.

2.1. Outdated or Unfounded Assumptions Regarding Solar Technology

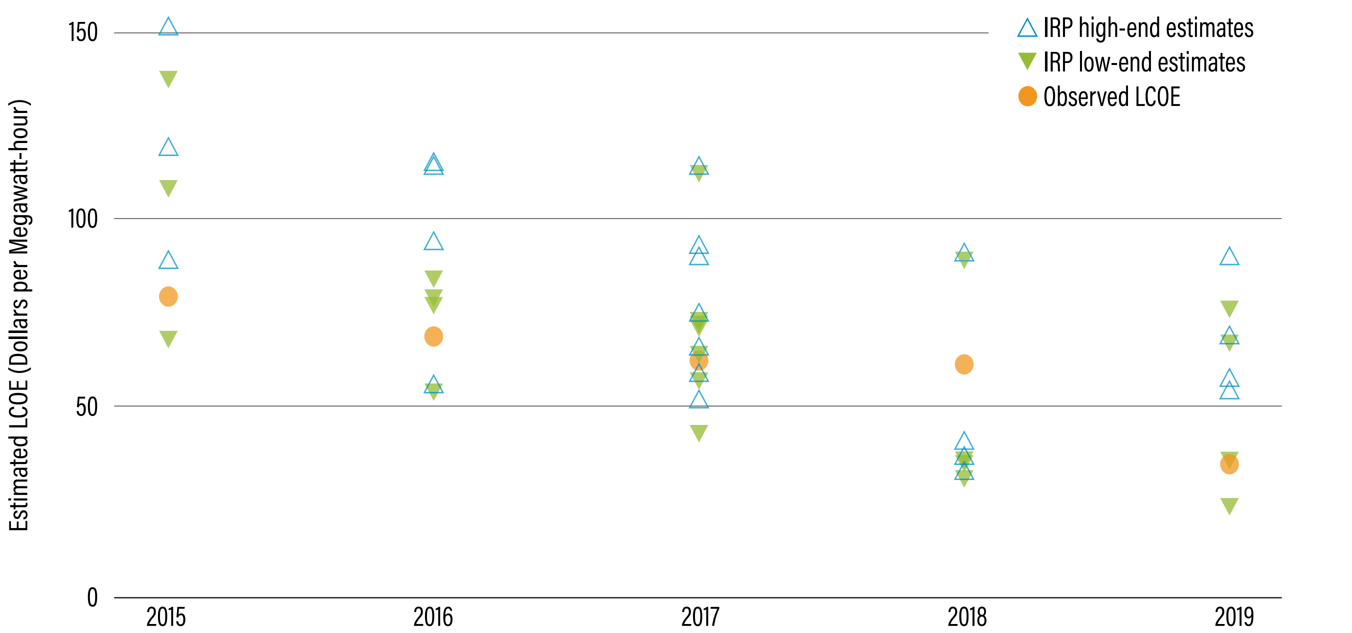
IRPs present scenarios of uncertain future conditions. As such, utilities must rely on various assumptions that could shape the future role of resources such as solar in providing energy, capacity, and other grid services. An IRP's value in driving optimal future investments is directly linked to its accuracy in describing current and likely future scenarios. The role of solar in IRPs, in particular, relies on assumptions in three areas: future costs, capacity value, and grid integration costs (Sterling et al. 2013).

Future Costs

Solar cost projections are one of the most important assumptions affecting the treatment of solar in IRPs (Sterling et al. 2013).[8] Limited access to solar data has posed a barrier to proper valuation of solar in IRP modeling (Mills and Wiser 2012; Sterling et al. 2013). Solar data have become more broadly available over time, including in several publicly available data sets compiled by the Lawrence Berkeley National Laboratory in the United States (Barbose et al. 2020; Bolinger et al. 2020). Importantly, these data sets include estimates for different solar technologies, such as separate estimates for tracking systems, which entail higher up-front costs but can significantly increase system output. Still, available data do not necessarily translate into accurate projections. Analysts have consistently overestimated future solar costs by underestimating the pace of solar cost reductions, particularly hardware cost reductions (Creutzig et al. 2017; Victoria et al. 2021). To cite an extreme example, several utilities interviewed in Sterling et al. (2013) stated that solar prices had reached their minimum in 2013. Yet solar prices have declined an additional 60 percent since that time (Bolinger et al. 2020), and most analysts project significant future reductions. If acted upon, these inaccurate utility perceptions would have inefficiently reduced the deployment of solar energy.

To better understand how cost data for solar are being used in practice, we examined 59 IRPs from the Midcontinent Independent System Operator (MISO) and non-regional transmission organization (non-RTO) West regions.[9] This sample included 42 IRPs from the American Clean Power Association Utility Integrated Resource Database, and 17 more recently published IRPs from the same utilities. Figure 3 shows IRP estimates in the non-RTO West regions for those IRPs that published solar levelized cost of electricity (LCOE) estimates. We compare these estimates to LCOE estimates based on empirically observed price and cost data (Bolinger et al. 2020). In the non-RTO West, 18 of 26 (69 percent) utility LCOE estimates exceeded the observed LCOE, while in MISO 13 of 22 (59 percent) estimates exceeded the observed LCOE.

Figure 3 | **Examples of Solar Cost Estimates in Non-RTO West IRPs**



Note: LCOE = Levelized cost of electricity.

Source: Based on raw data from American Clean Power Association (2019) and Lawrence Berkeley National Laboratory (2021), modified/aggregated by World Resources Institute.

Comparing cost assumptions used in one plan with the assumptions used in others can be a difficult task without transparency regarding the data sources used by the utilities and the adjustments made to the data. Even when sources for current or projected future prices are clearly cited, many are combined with the outputs of the utility's private Request for Proposals (RFP) process or from consultation with local engineering firms, resulting in unique cost estimates that cannot be reconstructed by third parties. The use of third-party cost data that are behind a paywall can also prevent IRP cost projection transparency.

Projecting future solar costs is, arguably, no easier today than it was 10 years ago. However, utility projections that yield future solar costs significantly higher than projections from third-party analyses should be cause for skepticism.

Solar costs have already declined precipitously, such that solar is today the cheapest form of electricity in a growing number of locations around the globe (Nemet 2019). As a result, in the long term, costs will become less relevant as a factor shaping the role of solar in grid transformation and planning (Kahrl et al. 2016). Continually falling solar costs shift the emphasis onto other factors such as the capacity value of solar and grid integration costs.

Utilities, however, are increasingly recognizing the need to use more accurate costs in their modeling (Kahrl et al. 2016). Some approaches include seeking projections from third-party analysts, exploring multiple scenarios under different assumed levels of future solar costs, using market data and bids as inputs in addition to estimated costs (further explored in Section 3), and increasing the frequency of IRP updates or review to continually acknowledge change in prices (Cleary and Ratz 2021).

Capacity Value

An additional challenge affecting the treatment of solar in IRPs is the ability to accurately predict how the capacity value of solar may change over time. Traditionally, a generator's capacity value represents the percentage of system capacity that is available to meet peak demand. On most grids in the United States, demand peaks on hot, sunny days in the late summer months due to increased demand from air conditioning. As the grid integrates more variable energy resources and energy storage technologies, determining the capacity value of any resource has become more complex. Solar capacity values are relatively high on summer-peaking grids because of longer days and better sun angles. As more solar comes online and powers more peak demand, grid peaks tend to shift to later in the day, to hours on either side of sunset depending on load shapes driven by consumer and business practices. As a result, solar capacity values tend to decline with increasing solar penetration. Further, in the future, some grids may become winter- rather than summer-peaking as a result of the electrification of building space and water heating loads (Specian et al. 2021). Shifts toward winter peaks will reduce solar capacity values, given that solar system output is diminished during the winter months. Declining solar capacity values can be mitigated by measures to better align solar output with peak demand. These measures vary based on local grid conditions, but examples include solar tracking systems, alternative orientations (i.e., azimuths), alternative tilt angles, and energy storage.

Utilities use various methods to estimate and project solar capacity value in IRPs, which leads to a wide range in predicted future value (Kahrl et al. 2016). Mills and Wiser (2012) found that most utilities relied on relatively simple approximation methods for solar capacity value rather than sophisticated modeling. The authors posit that the use of rough heuristics could explain the significant variation in capacity value across IRPs. Further, only 1 of the 16 utilities in their survey accounted for changes in solar capacity credit over time. To our knowledge, no more recent survey of solar capacity values in IRPs is available. Capacity valuation based on these simple approximations may be efficient for planning purposes at low solar penetration levels. However, the use of overly simplified approximations of solar capacity value could pose barriers to solar in IRPs. It is likely that some utilities have implemented more sophisticated methods for estimating solar capacity values as solar penetration has increased.

As an example, consider the following, which is paraphrased from a published IRP. A utility used analyses from two existing PV facilities to determine firm summer and winter capacity values for all utility-scale PV facilities in its territory. The utility used that methodology to justify a capacity value of around 50 percent for the summer peak and no capacity value for the winter peak. This methodology relies on a very small sample to justify capacity values that are substantially lower than similar values estimated on other grids. Customers could encourage the utility or the Public Utilities Commission, in this example, to test the robustness of this methodology through third-party modeling.

Grid Integration Costs

The integration of solar and other variable renewable energy sources onto transmission and distribution networks (i.e., grid integration) entails solvable but real challenges (Kahrl et al. 2016; Schlag et al. 2020; Cole et al. 2017). The variability of these resources requires that other resources must compensate for fluctuations in their output. For instance, the grid must rapidly adjust power output when a cloud reduces output from a large solar array, and then again adjust output when the cloud passes and the solar system ramps back up. Small-scale solar systems installed in distribution networks (as opposed to the bulk power system) entail additional grid integration challenges (Schwarz et al. 2019).

Utilities can and should address how grid integration costs affect the long-term role of solar in IRPs. As with other assumptions discussed in this section, problems can arise when solar grid integration costs are treated in an arbitrary way.

As an example, consider the following illustrative passage based on a published IRP: *[A] The integration of intermittent solar generation poses grid operational and planning challenges. [B] As solar penetration increases, the utility must make additional system-level upgrades to address challenges associated with grid stability and reliability issues caused by solar. Some of the costs of these upgrades are reflected in interconnection costs, which [C] the utility assumes to begin at $110/kilowatt (kW), rising to $350/kW in a high solar penetration future scenario.*

Part [A] of this passage falls within the technical barriers that limit solar energy. Part [B], however, notes that solar grid integration challenges could force the utility to make “system-level upgrades” to address “grid stability and reliability issues caused” by solar, asserting the existence of a systematic issue without providing evidence or justification. While it is true that increasing solar penetration may require measures to address grid stability and reliability, these measures need not necessarily take the form of system-level upgrades. For instance, utilities could explore non-wires solutions as ways to defer system upgrades and address stability issues at lower costs. Part [C] states the utility's assumption on solar interconnection costs, which compose one part of overall integration costs. The utility in this example does not provide the basis for the interconnection cost assumptions, which are higher than benchmarked interconnection costs of $30–70/kW for utility-scale systems (Feldman et al. 2021). The lack of transparency does not mean that the assumptions are necessarily flawed, but that they have relatively significant consequences: even a 10 percent error in the $350/kW assumption would result in a 4 percent over or underestimation of future solar costs (based on current installed prices for utility-scale solar).

2.2 Modeling Practices That Can Limit Solar Relative to Other Resources

This section identifies barriers across various stages of the utility IRP modeling process that influence the treatment of solar in IRPs. (More details on each stage are provided in Appendix B.) These barriers may manifest as inefficient restrictions on solar in IRP resource portfolios.

A range of modeling tools is available; the most popular models include Aurora, Strategist, System Optimizer, PLEXOS, PROSYM, EnCompass, EGEAS, and WIS:dom (Desu 2019; Cleary and Ratz 2021). Power system modeling tools continue to become more sophisticated as modeling capabilities improve and models adapt to evolving grid conditions. To provide a recent example, the WIS:dom model was augmented to model grid operations down to the distribution level to more accurately assess the implications of growing distributed solar penetrations, among other factors (Clack et al. 2020). Utilities may choose to employ one or several modeling tools.

To our knowledge, no individual model artificially advantages or disadvantages specific resources such as solar. However, user inputs to different models can create artificial advantages or disadvantages for specific resources (Wilson and Biewald 2013). For instance, some models require users to restrict the candidate resources that can be selected by the model, creating the possibility that users could constrain specific resources such as solar. Here, we provide a summary of a few of the more common issues that can arise in each stage of IRP modeling.

Incomplete Data in the Demand Forecasting Stage

The purpose of the demand forecasting stage is to inform the utility of likely future power and energy requirements (Wilson and Biewald 2013). One element that may affect a utility's ability to effectively forecast demand is the lack of visibility or complexity in determining the amount of distributed solar deployed and how distributed solar can serve the grid. From the utility's perspective, distributed solar is a type of negative load, such that uncertain future deployment of distributed solar equates to greater uncertainty in demand forecasting. Demand forecasting is further complicated by the increasing electrification of end uses that formerly relied on direct fuel combustion, such as natural gas for building heating or gasoline for vehicles.

Utilities are increasingly interested in linking IRP forecasting processes to distribution modeling and planning (Cleary and Ratz 2021). A recent paper from the Smart Electric Power Alliance (SEPA) highlights growing interest across states to move from traditional distribution plans, which "focus on assessing the performance of the grid within the context of anticipated changes in load along the system" toward more integrated distribution plans that may include coordinating with generation or transmission planning, as well as taking a more proactive approach to distributed energy resources (DERs) (Chew and Culter 2020). One example of this approach is Hawaii's current reconsideration of utility planning processes (Box 2).

BOX 2 | Hawaiian Electric Company's Integrated Grid Planning Process

In 2017, after regulators rejected two of Hawaii Electric's Power Supply Improvement Plans (PSIPs) before finally approving the third, the utility developed its new Integrated Grid Planning (IGP) process to highlight customer engagement and stakeholder input (Hawaiian Electric Company 2018). The IGP process is intended to harmonize resource, transmission, and distribution planning processes and "assesses the physical, operational, technological, and behavioral changes to the electric grid necessary to enable safe, reliable, and affordable service that satisfies customers' evolving service expectations and use of distributed resources."

Hawaiian Electric Company's (HECO's) IGP process involves stakeholder engagement groups, including seven technical working groups, that allow for stakeholder input and feedback. Among them, the Forecast Assumptions Working Group provides feedback and comments on the forecasting considerations used during the IGP process, including economic drivers (population, jobs, and income), weather, electricity prices (fuel prices and capital expenditures), energy efficiency, distributed energy resources, electrification of transportation, and other adjustments. HECO's DER forecasts consider the impacts of behind-the-meter PV and battery energy storage systems as well as known projects for other technologies (such as wind). The forecast estimates new additions of DER capacity in each month by island, rate class, and program, and projects the resulting monthly sales impact from these additions.

A caveat is that Hawaii's electric system is in many ways unlike that of other U.S. states. Each island relies on a completely independent grid, imposing far more significant balancing challenges than those faced by mainland grids. Further, the island grids rely on high-cost fuel imports that result in the highest electricity prices in the country, driving large incentives for PV and battery adoption. In addition, land area is limited, making distributed resources much more critical to deep decarbonization (Cross-Call et al. 2020).

Source: Hawaiian Electric Company 2018.

Restricted Consideration of Solar in the Resource Screen Stage

Following demand forecasting, utilities typically initiate a resource screen. Utilities take various approaches to determine which resources will be eligible for consideration (Kahrl et al. 2016). One factor in these approaches is particularly relevant to this discussion: whether solar is treated as a "fixed" or "selectable" resource.

FIXED RESOURCE APPROACHES CAN RESTRICT THE DEPLOYMENT OF SOLAR

Under a fixed resource approach, utilities assume a fixed share of renewable energy in the generating mix in future scenarios without conducting additional initial assessments. For example, the amount of renewable energy considered may be based on what the state requires through a Renewable Portfolio Standard (RPS). In contrast, other utilities determine the share of renewable energy, among other resources, based on economic considerations determined through capacity expansion modeling. With capacity expansion modeling, the utility can make resource assessments based on technical, economic, and policy considerations, which enables renewable energy to become a "selectable" resource, as in the model it can select the appropriate amount of the resources needed to meet demand, whether individually or as part of a portfolio of resources (see Appendix B). Under this approach, the share of solar or other renewable energy in meeting demand is flexible; the role of solar energy can grow as it becomes more cost-effective (Kahrl et al. 2016).

Fixed approaches are based on the assumption that solar and other clean energy resources could not compete with other resources on a cost basis. As clean energy costs have declined, fixed approaches have become increasingly rare (Kahrl et al. 2016). Where fixed approaches are still applied, they can pose barriers to an efficient role for solar in IRPs if otherwise cost-effective solar is not given a chance to compete to meet future grid needs.

To overcome assumptions around the level of or how renewable energy is assessed, some states are utilizing modeling parameters that more accurately capture the future role of solar. For example, Oregon's IRP Guideline 1(a) requires that "consistent assumptions and methods should be used for evaluation of all resources" (Oregon PUC 2007). In Michigan, state law requires the Michigan Public Service Commission develop modeling parameters and assumptions that utilities must follow in their IRPs, including permitting solar as a selectable resource.

Limitations That Prevent the Inclusion of and/or Fair Comparison of Solar in the Candidate Resource Portfolio Development and Comparison Stage

The next step in the IRP analysis is for utilities to consider "candidate resource portfolios"—possible combinations of resources that could meet future needs. How these portfolios are developed, as well as how portfolios that include solar energy are compared to portfolios that do not, can play a key role in limiting the amount of solar energy.

OMISSION OF CUSTOMER DEMAND

An omission of customer demand can reduce the contribution of solar and clean energy more broadly in IRPs, either at the grid mix level or through the availability of customer renewable energy programs. By failing to capture customer demand, utilities omit the fact that some large-scale customers are willing to invest in solar resources above and beyond what the utility may otherwise provide, either through their default utility service or by voluntarily participating in utility renewable energy programs. Failure to fully encompass customer demand for renewable energy from IRPs fails to capture the impacts of aggregated customer interest to increase the overall amount of solar on the grid and potentially even reduce the continued investment in traditional power resources.

Some utilities have begun to account directly for customer demand in their IRPs. For instance, in Georgia Power's 2016 and 2019 IRPs, in demonstrating how the utility would meet future demand, the utility carved out 200 megawatts (MW) and 1,000 MW of future renewable energy procurement (including but not limited to solar) for customer green tariff programs in their respective IRP processes.

DIFFERENTIAL TREATMENT CAN KEEP UTILITIES FROM ACTIVELY PLANNING FOR DISTRIBUTED SOLAR

Distributed solar can provide grid benefits comparable to centralized solar, such as additional energy, capacity, transmission and distribution, and fuel costs (Burtraw and Duncan 2018). Currently, distributed solar (including from small and large customers) accounts for about 35 gigawatts (GW) and around 37 percent of cumulative solar capacity, and continues to emerge as a growing resource (Wood Mackenzie 2021).

IRPs generally treat distributed solar as a fixed or exogenous resource (ScottMadden 2015; Kahrl et al. 2016). That is, utilities treat distributed solar as a random variable outside their control. The exogenous treatment of distributed solar reflects genuine constraints: utilities cannot directly control most distributed solar (e.g., through curtailment) in the same way they can control utility-scale systems. Further, utilities cannot plan for distributed solar deployment as precisely as they can plan for utility-scale solar procurement, given that deployment of these resources is primarily driven by customers.

Even if distributed solar remains exogenous, utilities can more effectively integrate these resources into IRP modeling (ScottMadden 2015), thus potentially increasing the overall contribution of solar in the grid mix. A first step is to ensure that utilities use separate and accurate data and assumptions for distributed solar, which follows a unique trajectory from other forms of solar. For instance, distributed solar is more costly on a per-unit basis (e.g., $/kWh) than utility-scale solar due to economies of scale. However, customers are motivated by a variety of economic and noneconomic factors (e.g., environmental motivations) and are often willing to invest in small-scale projects that may seem uneconomical in IRP modeling. Further, utilities can take measures to ensure that distributed solar yields more system value. For instance, some states and utilities are exploring rate structures that incentivize distributed solar deployment in certain locations more than in others. Such localized tariffs afford some indirect control over distributed solar siting and deployment, even if deployment remains exogenous in IRPs.

MUST-TAKE REQUIREMENTS CAN BURDEN SOLAR ENERGY WITH ADDITIONAL COSTS

Solar energy is generally treated as "must-take," meaning that the utility must accommodate available solar output even to the extent of scaling back other generators when necessary (Nelson et al. 2018). Must-take requirements reflect one of the key benefits of solar: the fact that solar generates electricity with no marginal costs (no fuel costs). This makes solar the priority generator in grid dispatch (along with wind). However, must-take requirements can also restrict solar as a candidate resource (Nelson et al. 2018). Rigid must-take requirements effectively force utilities to compensate for large fluctuations in solar output by the ramping up and down of dispatchable generators, typically natural gas. Utilities may, rightfully, account for these ramping costs in their IRPs, and may add long-term costs for additional capacity to accommodate growing penetrations of must-take solar.

Allowing curtailment of utility-scale solar by removing rigid must-take requirements could relieve these constraints and reduce solar grid integration costs (O'Shaughnessy et al. 2020). Some utilities may already be responding by relaxing must-take requirements. For instance, in its 2021 IRP, El Paso Electric notes that "solar and wind are must-take but at higher integration levels can be downward dispatched to some degree by curtailing surplus energy." Another solution is to implement flexible interconnection agreements, wherein customers agree to allow grid operator control over distributed solar (including curtailment when necessary) in return for an expedited interconnection process (Horowitz et al. 2019). Further, as storage costs decline, storage will become an increasingly cost-effective way to handle fluctuations in solar output, as discussed further below.

SOLAR PLUS STORAGE POSES UNIQUE SYSTEM BENEFITS AND MODELING CHALLENGES

Most of the challenges associated with solar integration to grids are due to the variability of the solar resource. At high levels of solar penetration, there are times when solar systems will generate less than expected (e.g., cloud cover) and other times when solar systems will generate more than the system can absorb, resulting in curtailment. Front-of-the-meter, utility-scale energy storage can mitigate these challenges by storing solar output and controlling when the output is delivered to the grid (Denholm and Margolis 2016). As with solar power, the costs of battery energy storage are declining rapidly, driving accelerated deployments of grid-scale and distributed storage. As a result, utility projections for the future role of energy storage can affect projections for the future role of solar.

Energy storage can provide a myriad of grid services, including generation, capacity, and ancillary services (Fitzgerald et al. 2015). In part due to its versatility, energy storage does not always fit neatly into the models and planning practices used in IRPs (ESA 2018; Cooke et al. 2019). Many utilities have incorporated energy storage into IRPs, but some utilities consider only a limited range of potential grid services that could be provided by storage (ESA 2018; Cooke et al. 2019). Further, IRPs generally do not consider the beneficial role of energy storage in facilitating renewable energy integration (ESA 2018; Cooke et al. 2019). For instance, missing opportunities for cost-effective storage deployment would, all else being equal, increase long-term projections for solar curtailment (Denholm and Margolis 2016).

To fully capture the benefits of solar plus storage, utilities should pay attention to and employ emerging best practices. These practices include subhourly modeling intervals to capture both capacity and flexibility contributions (five-minute intervals), net-cost analysis that examines cost of storage net of its flexibility benefits, and models that explicitly address flexibility and risk (Cleary and Ratz 2021).

2.3 Additional Barriers

Utility business models and existing structures for regulatory oversight in IRPs can also pose barriers to solar. Customers can also engage in IRPs to address or overcome these barriers; however, this paper does not fully explore these actions.

Incongruence with Utility Business Models and Practices

Under the traditional vertically integrated utility business model, utilities are structured to make a profit through a regulated rate of return on their investments. Due to various regulatory and market factors, utilities tend to procure solar contractually from independent power producers (IPPs) rather than directly own solar assets. Utilities do not earn their regulated return on power purchased from IPPs, thus they face little incentive to proactively pursue solar projects outside of state mandates. Falling solar costs have sparked renewed interest in utility ownership of solar, which could alleviate the incongruence between utility business models and solar deployment (Shimamoto 2018).

Utility business models are also generally incongruent with distributed solar (Cross-Call et al. 2018). Distributed solar reduces utility revenues by lowering demand for grid electricity. The utility business model disincentivizes the utility from promoting distributed solar deployment so as to minimize the impacts of that deployment on future utility returns (Graffy and Kihm 2014; Rule 2015). The incentive to underestimate future distributed solar does not mean that all utilities do so. However, there are several documented cases of PUCs questioning distributed solar projections in utility IRPs.

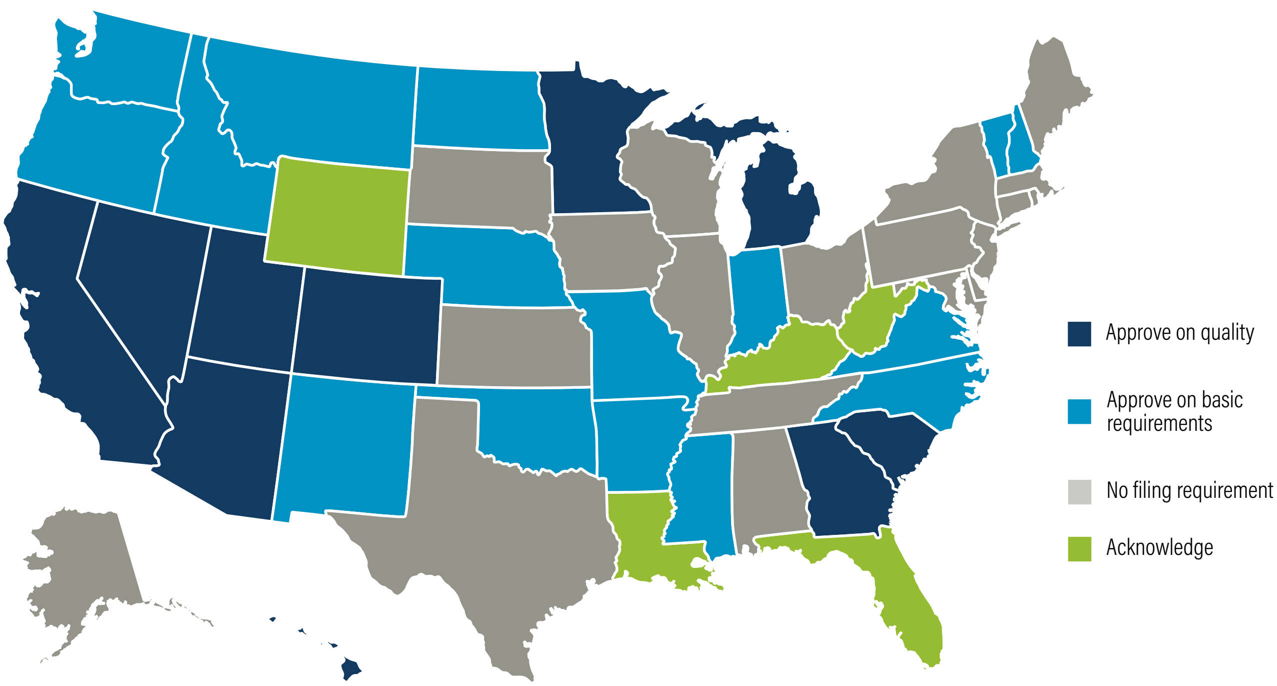
One illustrative example of the impacts of utility business models on the treatment of solar in IRPs is the HECO 2014 IRP. In rejecting that IRP, the Hawaii PUC noted that "utility-owned generation creates inherent financial conflicts that can complicate, and in some cases impede, development of IPP generation projects." Further, the PUC argued that "in recent years, Hawaii has seen exponential growth in rooftop solar PV systems...the utilities will need to plan proactively for future additions of [distributed energy resources]. The rapid adoption of these technologies will require the utilities to design programs and develop distribution system infrastructure to optimize the system and maximize customer benefits" (Hawaii PUC 2014). The PUC went on to require HECO to file plans to optimally interconnect solar on distribution networks (see Box 2).

Limited Regulatory Oversight

As noted earlier and further explored in Appendix B, many states require the utility to submit the IRP to PUCs for review. Regulatory bodies in different states have varying levels of oversight and authority. In some cases, the regulatory body may modify, accept, or reject the proposed IRP. In other states, the regulatory body is limited to simply acknowledging whether the plan meets state requirements. Figure 4 summarizes the roles of state regulators in the IRP process.

Regulatory review, where it occurs, is critical to ensuring that utilities adhere to the intended objectives of IRPs (Volk et al. 2018). Regulatory review can prevent uncompetitive practices; for example, utilities designing their IRPs to bolster utility profits rather than minimize grid costs. Further, the regulatory review process offers a final opportunity to increase transparency and stakeholder input in utility IRPs. One risk to regulatory review is that the process is subject to regulatory capture, wherein regulators are disproportionately influenced by the perspectives of regulated utilities (Volk et al. 2018).

Figure 4 | **State Regulatory Body Roles in IRP Process**



Source: Based on raw data from Other Organizations (2021), modified/aggregated by World Resources Institute.

3. OPPORTUNITIES FOR CUSTOMERS AND UTILITIES TO IMPROVE TREATMENT OF SOLAR IN IRPS

Utilities and large-scale energy customers have distinct opportunities to optimize the treatment of solar energy, as well as other resources, in planning processes such as IRPs. In this section, we briefly explore these opportunities and offer specific examples of customer engagement and utility best practices.

3.1 Customers

Customers can engage in IRP processes in a variety of ways (see Box 1). In this section we describe some specific engagement opportunities for customers to address the barriers to solar energy discussed in Section 2.[10] Many of these opportunities can be pursued strategically through one or many of the engagement pathways identified in Box 1.

Overall considerations:

- **Become educated, empowered IRP stakeholders.** Actively seek out resources and guidance to better understand how the IRP impacts customer clean energy goals.
- **Request increased transparency.** Engage with utilities and regulators to ensure key utility IRP assumptions and modeling approaches are straightforward, accurate when compared to third-party estimates, and distributed in a timely manner.
- **Provide data on clean energy demand.** Share desired customer clean energy targets and anticipated energy actions that may influence IRP forecasting and resource candidate portfolio considerations. For example, customers can be transparent about anticipated distributed solar adoption and electrification efforts, which would influence growth in demand, as well as any plans for energy efficiency, energy storage, or demand flexibility—all of which would reduce demand or otherwise serve as beneficial grid assets. Insight into anticipated customer action not only can improve forecasting assumptions but can also inform the resource screen and resource portfolio developments as utilities have additional awareness on customer actions or assets than can be utilized.
- **Assess assumptions regarding solar technology.** Explore the assumptions behind utility cost projections. Ask utilities to use projections from third-party analysts or consider exploring multiple scenarios under different assumed levels of future solar costs, and to potentially consider a Request for Proposals (RFP) or all-source procurement. Request the use of more detailed estimations that accurately reflect the capacity value of solar energy over time. Request details on how integration issues were addressed, including through energy storage and non-wires solutions, and explore how the utility has estimated integration costs.
- **Assess utility modeling practices.** Confirm or request that the initial screening of resources ensures that solar technologies are able to compete against other resources. Ensure storage or hybrid systems are included. Request that demand- and supply-side resources are evaluated on comparable terms. Examine the assumptions regarding solar plus storage and distributed solar.
- **Identify best practices.** Encourage utilities and regulators to embrace emerging IRP best practices (see further discussion in the following section). For example:
  - Encourage a holistic or combined analysis of distribution and resource needs.
  - Request that the utility uses new data and modeling approaches designed to capture solar plus storage. Seek models that use sub-hourly planning to capture both capacity and flexibility contributions (five-minute intervals) and increase the granularity of considerations while maintaining reasonable model run times and modeling intervals.
- **Understand the inherent utility business model.** Identify how solar energy may be valued or not, to identify potential uncompetitive practices (e.g., claims or assumptions that disadvantage customer-owned and IPP solar in IRPs).
- **Seek corrections to barriers.** Ask for action from the utility during the utility analysis or stakeholder engagement processes and/or from the regulators during the review process. For example, where utilities use assumptions that conflict with standard assumptions, customers could work with utilities or regulators to understand the justification for such deviations or, in some cases, seek updated assumptions.

3.2 Utilities

Utilities can work with stakeholders and regulators to continue to evolve IRP processes and proactively consider solar energy as efficiently as possible. Actions available to utilities include the following:

- **Define customer engagement strategies.** Utilities can proactively engage customers, especially large-scale customers, to make better demand forecasts based on planned customer investments. Utilities can define a formal strategy for customer engagement and on how to act on feedback from that engagement (Wilson and Biewald 2013; ScottMadden 2015).
- **Provide transparency.** Publish the basis for IRP assumptions on technologies and cost, modeling approaches, steps to achieving clean or GHG targets, the barriers and opportunities inherent in the assumptions and modeling, etc. Make this available early on. Avoid relying on outdated assumptions to project the future role of solar in IRPs. IRPs are complex documents involving thousands of assumptions and calculations. Opaque descriptions of these assumptions and calculations make IRPs less accessible, could cause clear errors to go overlooked, and can disguise the ways in which certain resources are favored or penalized. Transparency is key; utilities should aim for maximum transparency in describing assumptions, calculations, and modeling.
- **Proactively integrate customer demand.** Move beyond load growth and resource adequacy to a more comprehensive review of investment drivers, including customer behavior. Kahrl et al. (2016) highlight such a move as an emerging need. Proactively engage with customers throughout the IRP development process to share information and align or even strengthen goals and actions. In this way, utilities and customers can work together to deliver more transformation across the electricity system at a lower cost.[11] Some utilities have already begun to integrate customer demand into IRPs (ScottMadden 2015).
- **Connect distribution modeling and planning processes to IRPs.** There is increasing interest in linking IRP processes to distribution modeling and planning to enhance forecasting and better utilize DERs (Cleary and Ratz 2021). See the above subsection on "Incomplete Data in the Demand Forecasting Stage (p. 11)."
- **Use market-based data.** Some utilities have begun to explore and implement alternative ways to project future resource costs more accurately. One alternative is a market-based IRP, wherein the utility issues a preliminary RFP based on preliminary modeling results (Bade 2018) and then incorporates that market-based data from bids into resource planning and optimization (Cleary and Ratz 2021). Market-based IRPs allow—or compel—utilities to ground their future cost projections in market expectations.
- **Utilize all-source procurement practices.** All-source procurement approaches allow a full range of potential resources to compete on equal footing. Through this technology-neutral approach, utilities can eliminate unnecessary IRP biases toward centralized, utility-scale assets (Teplin et al. 2019). Further, all-source planning may reveal opportunities to use clean energy technologies such as solar to decarbonize grids and save costs. A handful of utilities across the United States have begun to utilize this procurement approach (Box 3).

BOX 3 | Northern Indiana Public Service Company's All-Source Procurement Approach

In November 2018, Northern Indiana Public Service Company (NIPSCO) filed its 2018 IRP with the Indiana Utility Regulatory Commission, seeking to replace all its coal infrastructure with more economical resources including 1,485 MW of solar and wind, demand-side management, and other resources by 2023 (Gheorghiu 2019). The objective of the IRP was to "ensure that NIPSCO can confidently transition to the least-cost, cleanest supply portfolio available while maintaining reliability, diversity and flexibility for technology and market changes during this period" (NIPSCO 2018).

To do this successfully, the utility modeled hundreds of scenarios and found that a renewable energy pathway in the IRP was almost $900 million cheaper than other alternatives over the coming two decades, and showed projected prices for solar and wind ranging from $27/MWh to $40/MWh—less than half the cost of operating NIPSCO's existing coal fleet, which ranged from $57/MWh to $82/MWh. New to the process in the 2018 IRP, NIPSCO also implemented a market-based strategy by issuing a formal Request for Proposals (RFP) to help inform the planning process, and to gain better information on available real projects at real costs from within the marketplace.

Source: NIPSCO 2018.

- **Adopt a more holistic and comprehensive approach.** There is an emerging need to improve resource planning and find alignment across the various elements of resource planning. This is in large part driven by cost uncertainties, shifting consumer preferences, and the availability of new technologies at lower costs. Several states are now committing to actions including development of more holistic analysis of distribution and resource needs, better alignment of planning with state priorities (such as decarbonization and renewable targets), and expansion of forums for stakeholder input into planning (Sass Byrnett et al. 2021).[12]
- **Implement practices to apply lessons learned.** Utilities can constantly evaluate previous IRP assumptions and methodologies to see what worked and what did not (Dixit et al. 2014). Specifically regarding solar, utilities can analyze previous solar assumptions and methodologies and identify approaches that yielded more accurate projections for solar energy costs, capacity values, distributed solar deployment, and other relevant factors.

For all parties, it will also be important to share knowledge and resources on the rapidly evolving U.S. clean energy market and how IRPs could be adapted to accommodate this evolution to enhance awareness of opportunities and challenges; develop a common understanding; and work toward a more collaborative, shared vision. When helpful, all parties should also seek guidance from technical groups and other advocates.

4. CONCLUSIONS

IRP processes are constantly evolving to address changing grid conditions. The rapid rise of solar energy has, in some cases, outpaced IRP evolution, resulting in IRPs that aren't able to fully take advantage of solar as clean and cost-effective resources. These barriers to solar energy include outdated or unfounded assumptions about solar energy technologies, particularly related to costs, capacity value, and grid integration. We also identify several modeling practices that can limit the amount of solar called for in IRPs, including how selected resources are defined, whether solar can compete against other resources based on economics, how customer demand is forecasted, how distributed solar is estimated, and whether modeling captures the full range of potential benefits from solar plus storage. Given the direct role of IRPs in driving solar development and facilitating or hindering the achievement of clean energy targets, large-scale energy customers, utilities, and regulators can all play a role in ensuring that IRPs evolve alongside the rapid expansion of solar and clean energy more broadly. Customers can engage in utility and regulatory processes to address some of the issues identified in this paper. With an increased awareness of some approaches that may unnecessarily burden or limit solar energy deployment, utilities and regulators can also continue to enhance and evolve IRP processes.

Although this working paper discusses some existing barriers, these are specific to particular market or regulatory contexts, and new issues are likely to emerge over time as technologies and grid conditions change. Where possible, stakeholders should continue to collaborate and collectively identify solutions to address the barriers identified here or new barriers that present themselves over time.

APPENDIX A. METHODOLOGY

Scope

This working paper focuses on the role of IRPs in influencing future deployment of solar energy technologies. We narrow our focus to solar energy as solar has a unique set of characteristics that can complicate its treatment in IRPs. Three specific characteristics are particularly germane to this working paper. First, future solar costs are consistently overestimated because solar cost reductions continually outperform analyst expectations (Haegel et al. 2017; Victoria et al. 2021). Second, solar is distinct from wind in that the solar resource follows more consistent daily and seasonal patterns. One consequence of these daily and seasonal patterns is that the marginal value of solar tends to decline as more solar is integrated into the grid at any given point (Mills and Wiser 2012). There is no consensus on how to account for this value deflation in grid planning. Third, solar is uniquely modular: it can be deployed at utility scale (e.g., hundreds of megawatts) but also at very small scales (e.g., kilowatts). The modularity of solar makes it a particularly attractive investment for both utilities and customers. Indeed, solar deployment to date has been roughly evenly split, with utility-scale projects accounting for about two-thirds of capacity and small-scale customer-owned or "distributed" projects accounting for the remaining third (Wood Mackenzie 2021). Utilities do not necessarily have the same long-term control over the deployment of distributed solar systems as they have over utility-scale systems. Distributed solar poses specific challenges to grid planning (Kahrl et al. 2016). Notwithstanding these distinguishing features, some of the barriers identified in this working paper are applicable to other clean energy technologies, including wind energy.

Source

The information presented in this working paper was developed primarily through direct experience supporting customer engagement in IRP planning, data analysis, a literature review of existing studies of barriers to solar IRPs, and some brief expert interviews.

Data Analysis

The authors and research team used a variety of data platforms including but not limited to the following:

- The American Clean Power Association Utility Integrated Resource Database
  - This database provides summarized data from a variety of IRPs published between 2015 and 2019, largely in the non-regional transmission organization (non-RTO) West and Midcontinent Independent System Operator (MISO) regions.
- The Lawrence Berkeley National Laboratory's Resource Planning Portal
  - The Lawrence Berkeley National Laboratory portal covers a wider set of resource planning documents, including Long-Term Transmission Plans and Supplemental Surveys, and provides information on existing and planned capacity expansion and type of resources.
- Publicly available regulatory dockets
  - Each state's regulatory body typically hosts publicly available information related to the IRP approval. This typically includes the IRP and related appendixes, testimony, etc.

Literature Review

Research for this working paper also included a literature review to identify trends and challenges already documented in relation to solar development driven by IRPs. The literature review looked for resources that spoke broadly to the evolution of IRPs and resource planning to provide important context on the issues impacting planning and what future barriers may be. While the data set for this paper covers the past 5 years, our literature review spanned the past 10 years to provide more context on how the industry has evolved in response to documented barriers. Researchers looked across academic journals; technical reports from national laboratories; reports from industry experts such as consultants; research publications from think tanks, nonprofits, and advocates; and short articles or press clips designed for broad audiences.[13]

Expert Interviews

Research for the report was guided by several interviews conducted with experts to help identify barriers, on either solar development or utility resource planning, and a broad set of case studies across different states and wholesale markets that showcased some of the most common barriers to solar in utility IRPs. The case studies were then narrowed down and chosen with the intent to show a range of different utilities, states, markets, and challenges to solar adoption across the country. Experts were asked a set of standardized interview questions and were then given an overview of research goals in terms of the barriers examined: Are IRPs using sufficient data on solar, accurate data, consistent data; and what examples of utility innovation exist? Experts were asked if they knew about relevant cost databases or data sources. They were also asked if the barriers listed reflected their experience with IRPs, if there were additional barriers to address, and if they had examples of IRPs that were relevant. Finally, experts were asked how the research could be structured to be most useful to large customers, other stakeholders, and regulators.

Direct Experience Supporting Customers in IRP Engagement

Finally, through the Bloomberg American Cities Climate Challenge (ACCC) City Renewables Accelerator (CRA), a project designed to provide cities with technical assistance in achieving their clean energy goals, World Resources Institute (WRI) staff supported several cities engaging in their local IRP processes. This experience informed researchers on which IRP barriers for solar development large customers may be most interested in examining and addressing.

Limitations

We note two key limitations with the discussion provided in this working paper. First, our evaluation of barriers to solar in IRPs was based on a scarce literature. As a result, we rely in some instances on relatively dated studies that do not necessarily reflect existing barriers to solar in IRPs. Second, the identification of barriers is based on largely qualitative findings, inputs from external expert reviewers, and the judgment of the authors. Empirical research is insufficient in demonstrating the actual magnitude of the barriers discussed in this paper. For instance, we do not know with any certainty the long-term implications of flawed IRP assumptions on solar deployment.

APPENDIX B. OVERVIEW OF INTEGRATED RESOURCE PLANNING PROCESSES

As introduced in the report, Figure 2 illustrates an example of the IRP development process, including utility analysis and selection of a preferred resource portfolio, as well as potential stakeholder engagement and approval of the resource plan with the state regulator.

Steps in Utility IRP Analysis

Utility IRP analysis (blue in Figure 2) often begins with the utility estimating its forecast of future demand for electricity and an assessment of the range of resources it could utilize to meet future demand. Demand forecasting considers how customer demand for electricity (load) may increase or decrease, and how demand may be offset by energy efficiency or demand side management. The utility then assesses resources it already has, such as existing generation plants and power supply contracts, and the range of new resources it could utilize to meet demand. This first comparison across resources, commonly known as a resource screen, looks at either high-level technical considerations or at a relatively uncomplicated assessment of the levelized cost per megawatt-hour (MWh) (Cooke et al. 2019).

Around the same time,[14] the utility will consider the regulatory requirements and state goals within its service territory. Examples include requirements of the types of analysis to perform and applicable clean energy standards or energy efficiency requirements. The utility will also consider its own goals for the planning processes, which may include renewable energy goals, grid decarbonization, or an effort to meet customer needs.

Taking these factors into consideration, the utility then develops candidate resource portfolios, which represent different mixes of energy resources the utility could adopt. These portfolios are often developed using capacity expansion models (CEMs), which consider system constraints and the cost of various resource options.

The next step is often to compare how these portfolios perform under various future scenarios in terms of the utility's goals, such as least-cost, environmental impacts, or fuel diversity. Production cost models are often used to show the outcomes of each candidate portfolio based on variables, such as resource portfolios across future scenarios. A production cost model can be used to make assumptions about key variables changing demand scenarios (potentially from electrification of the transportation sector) and high or low costs for different resources.

Utilities will evaluate these candidate portfolios, as well as conduct qualitative analysis and consider impacts such as job creation, clean energy policy goals, or stakeholder views (Kahrl et al. 2016), to ultimately make a decision on a "preferred portfolio." If necessary, the utility will then submit the plan to its state regulator for acknowledgment or approval.

Stakeholder Engagement

Stakeholder engagement (green in Figure 2) often happens concurrently with the utility IRP analysis. Large customers interested in planning outcomes may reach out to their utility for direct discussions, publicly comment as key elements of analysis are made public, and participate in official utility stakeholder outreach. Stakeholder outreach varies by state and utility but is often facilitated at public events or discussions hosted by the utility to provide stakeholders with information on what the planning process will look like, updates as analysis is completed, and presentation of portfolios. Interested stakeholders may include large customers, cities and communities, public interest groups, public institutions, and clean energy advocates.

Altogether, the IRP development processes typically begin 18 to 24 months before any final selection of a plan or submittal of a proposal plan for a review process.

Varying Levels of State Regulatory Oversight of IRPs

In states where the IRP process concludes with the final preferred portfolio being submitted to the state utility regulatory body, stakeholders can also engage in the approval process by becoming intervenors (green in Figure 2) if there is a docketed approval process. In cases where there is a structured public review of the planning process and selection of the portfolio (dark blue in Figure 2), the role of the regulator can vary.

In states that require an IRP, the regulatory body—known as the Public Utilities Commission (PUC), State Corporation Commission (SCC), Public Service Commission (PSC), etc.—may have authority to approve or deny utility plans. The regulatory body receives its authority from the state statute or rule and may have the ability to approve or deny an IRP, request modifications, or simply acknowledge an IRP. While an approved IRP is often just a reference document for the utility's future procurement and operation decisions or only includes a short-term action plan, regulatory review can greatly impact utility planning.

Levels of regulatory oversight can be categorized as acknowledgment, approval based on basic requirements, and approval based on quality.

- **Acknowledge:** In some states the commission does not have authority to order the utility to modify, reevaluate, and resubmit its plan even if it receives significant comments by intervenors or staff. The commission, at most, will summarize its review and offer recommendations for the utility's subsequent filings.
- **Approve on Basic Requirements:** In other states with a structured public review process, there are usually basic requirements that utilities must follow while developing their integrated resource plan. These rules are stated within the rule or regulation governing the utility's integrated resource plans.
- **Approve on Quality:** Some state commissions, often with clean energy goals or Renewable Portfolio Standard (RPS) requirements, conduct a thorough review of the IRP, and then either approve, recommend changes, or reject the IRP.

Figure 4 on page 15 captures these levels of regulatory oversight per state, as of the release of this report.

ABBREVIATIONS

DERs	Distributed Energy Resources
GW	Gigawatt
HECO	Hawaiian Electric Company
IGP	Integrated Grid Planning
IPP	Independent Power Producer
IRPs	Integrated Resource Plans
kW/kWh	Kilowatt/Kilowatt-hour
LCOE	Levelized Cost of Electricity
MISO	Midcontinent Independent System Operator
NIPSCO	Northern Indiana Public Service Company
PUC	Public Utilities Commission
PV	Photovoltaic
RFP	Request for Proposals
RPS	Renewable Portfolio Standard
RTO	Regional Transmission Organization

GLOSSARY

Capacity value	The share of a generator's rated capacity that is reliably available during grid peak demand periods.
Capital costs	Up-front expenses associated with the construction and maintenance of solar installations.
Demand-side management	Modification of consumer demand based on signals or incentives from utilities or third parties.
Distributed energy resources (DERs)	Small-scale energy generation technologies and storage technologies that produce electricity generation when needed. DERs are connected to the grid on a local distribution system.
Energy efficiency	Reduction of energy use, without changing customer utility, through more efficient equipment or other tools.
Photovoltaic (PV)	Photovoltaic (PV) technology converts light into electricity through a process that occurs in semiconductors.
Resource adequacy	The ability of supply- and demand-side resources to meet grid demand.
Solar tracking	A rack mounting system that enables the PV system to point more directly at the sun throughout the day. Tracking systems produce more electricity than fixed-mount systems and can track on a single or dual axis.
Solar production profile	Solar production profile defines how solar generation changes with time during a day, month, season, or year.

ENDNOTES

1. See the IRP Support Package for additional information on how the timing, approach, and requests made during IRP engagement can be pursued more collaboratively with the utility.
2. Although outside the scope of this working paper, small-scale solar has numerous unique benefits. Specifically, small-scale solar, such as community solar projects, could potentially be supported in disadvantaged communities, converting solar into a potential tool for energy justice (Ramanan et al. 2021).
3. Note that for many municipal utilities and Generation and Transmission (G&T) cooperatives, IRPs are only subject to board approval, without oversight from the state regulatory body.
4. See more details on local government IRP efforts on the Bloomberg American Cities Climate Challenge Renewables Accelerator's engagement tracker: https://cityrenewables.org/engagement-tracker/.
5. To view tech companies' comments, see https://starw1.ncuc.net/NCUC/ViewFile.aspx?Id=207f5818-e246-47fb-a2f4-373093f37a98.
6. Commercial customers' comments can be viewed at https://starw1.ncuc.net/NCUC/ViewFile.aspx?Id=ba7949fe-9f47-4ea1-b70f-8639d0dfc420.
7. To view North Carolina local government comments, see https://starw1.ncuc.net/NCUC/ViewFile.aspx?Id=bf1e6203-0b2b-410d-9917-132ffbda49a6 and https://starw1.ncuc.net/NCUC/ViewFile.aspx?Id=89ea4133-5690-4a79-b039-df7992736373.
8. Several metrics are used to discuss solar costs, including capital costs, total installed price, and the levelized cost of electricity. The distinctions between these metrics are not relevant to the purposes of this discussion.
9. In areas where the vertically integrated utility model persists, such as MISO, the non-RTO West, California, and the Southeast, IRPs are more likely to drive resource planning. Due to this more direct link between IRPs and resource outcomes, as well as data availability, we focused on MISO and the non-RTO West.
10. We recognize that customers have historically had limited opportunities to engage in IRPs for a variety of reasons, including limited knowledge of the opportunity, lack of guidance on how to engage, and minimal resources and capacity to engage (especially considering the wide array of tasks local governments are responsible for). The IRP Support Package and this working paper are designed to help overcome these challenges to engagement.
11. To further explore the opportunity to optimize customer demand, see the "Pathways to Integrating Customer Clean Energy Demand in Utility Planning" at https://wriorg.s3.amazonaws.com/s3fs-public/uploads/pathways-integrating-customer-clean-energy-demand-utility-planning_1.pdf.
12. Additional information on states' commitments to comprehensive and aligned resource planning can be found at https://pubs.naruc.org/pub/14F19AC8-155D-0A36-311F-4002BC140969.
13. Keywords for the literature review included solar cost, solar capital costs, solar LCOE, solar plus storage, distributed storage, PV, barriers, IRP, utility resource planning, and solar modeling.
14. Sometimes the review of goals and regulations occurs before or during load forecasting and the resource screen.

REFERENCES

American Clean Power Association (ACP). 2019. "ACP Utility Integrated Resource Database (IRP)."

APS (Arizona Public Service). 2017. "2017 Integrated Resource Plan." https://www.aps.com/-/media/APS/APSCOM-PDFs/About/Our-Company/Doing-business-with-us/Resource-Planning-and-Management/APSPreliminary2017IRP_ResourcePlanning-15-0094_030116.ashx?la=en&hash=DDB0E7FF8C3F623DCAC7A6F22A7B7643.

Bade, G. 2018. "Market-Based IRPs: A New Paradigm for Grid Planning?" *Utility Dive*, April 2. https://www.utilitydive.com/news/market-based-irps-a-new-paradigm-for-grid-planning/520376/.

Barbose, G., N. Darghouth, E. O'Shaughnessy, and S. Forrester. 2020. "Distributed Solar 2020 Data Update." Berkeley, CA: Lawrence Berkeley National Laboratory. https://emp.lbl.gov/sites/default/files/distributed_solar_2020_data_update.pdf.

Bolinger, M., J. Seel, D. Robson, and C. Warner. 2020. "Utility-Scale Solar Data Update: 2020 Edition." Berkeley, CA: Lawrence Berkeley National Laboratory. https://emp.lbl.gov/sites/default/files/2020_utility-scale_solar_data_update.pdf.

Bonugli, C., and H. Ratz. 2021. "Integrated Resource Plan (IRP) Support Package." Washington, DC: World Resources Institute. https://cityrenewables.org/wp-content/uploads/edd/2021/06/Integrated-Resource-Plan-Support-Package.pdf.

Bouckaert, S., A. Fernandez Pales, C. McGlade, U. Remme, and B. Wanner. 2021. "Net Zero by 2050: A Roadmap for the Global Energy Sector." Paris: International Energy Agency.

Burtraw, D., and J. Duncan. 2018. "Does Integrated Resource Planning Effectively Integrate Demand-Side Resources?" Washington, DC: Resources for the Future. https://media.rff.org/documents/RFF-Rpt-Burtraw-Duncan-2.pdf.

Chew, B., and H. Culter. 2020. "Integrated Distribution Planning: A Framework for the Future." Washington, DC: Smart Electric Power Alliance (SEPA). https://sepapower.org/resource/integrated-distribution-planning-a-framework-for-the-future/.

Clack, C.T.M., A. Choukulkar, B. Coté, and S.A. McKee. 2020. "Why Local Solar for All Costs Less: A New Roadmap for the Lowest Cost Grid." Boulder, CO: Vibrant Clean Energy.

Cleary, K., and H. Ratz. 2021. "Experience with Competitive Procurements and Centralized Resource Planning to Advance Clean Electricity." Washington, DC: Resources for the Future. https://www.rff.org/publications/working-papers/experience-with-competitive-procurements-and-centralized-resource-planning-to-advance-clean-electricity/.

Cole, W., B. Frew, T. Mai, Y. Sun, J. Bistline, G. Blanford, D. Young, et al. 2017. "Variable Renewable Energy in Long-Term Planning Models: A Multi-model Perspective." Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy18osti/70528.pdf.

Cooke, A.L., J.B. Twitchell, and R.S. O'Neill. 2019. "Energy Storage in Integrated Resource Plans." Richland, WA: Pacific Northwest National Laboratory. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-28627.pdf.

Creutzig, F., P. Agoston, J.C. Goldschmidt, G. Luderer, G. Nemet, and R.C. Pietzcker. 2017. "The Underestimated Potential of Solar to Mitigate Climate Change." *Nature Energy* 2: 17140.

Cross-Call, D., R. Gold, L. Guccione, M. Henchen, and V. Lacy. 2018. "Reimagining the Utility: Evolving the Functions and Business Model of Utilities to Achieve a Low-Carbon Grid." Basalt, CO: RMI. https://rmi.org/wp-content/uploads/2018/01/reimagining_the_utility_report.pdf.

Cross-Call, D., J. Prince, and P. Bronski. 2020. "Powering Paradise: How Hawaii Is Leaving Fossil Fuels and Forging a Path to a 100% Clean Energy Economy. Basalt, CO: RMI. https://rmi.org/insight/powering-paradise.

Denholm, P., and R. Margolis. 2016. "Energy Storage Requirements for Achieving 50% Solar Photovoltaic Energy Penetration in California." Golden, CO: National Renewable Energy Laboratory.

Desu, M. 2019. "Decarbonizing the Global Energy System: The Impact and Cost of Using Fragmented Grid Planning Models to Guide Investment Decisions." Golden, CO: National Renewable Energy Laboratory, Open Energy Modeling Forum.

Dixit, S., A. Chitnis, B. Jairaj, S. Martin, D. Wood, and A. Kundu. 2014. "10 Questions to Ask about Integrated Resources Planning." Working Paper. Washington, DC: World Resources Institute. http://www.wri.org/publication/10-questions-integrated-resource-planning.

Driscoll, W. 2019. "Here's How Utilities Use Their Resource Plans to Block Solar Power." *PV Magazine*. https://pv-magazine-usa.com/2019/12/23/heres-how-utilities-block-solar-power-in-their-resource-plans/.

Donofrio, L. 2020. "In the Matter of the Application of DTE Electric Company for Approval of Its Integrated Resource Plan Pursuant to MCL 460.6t, and for Other Relief MPSC Case No: U-20471." Lansing: Michigan Public Service Commission. https://mi-psc.force.com/sfc/servlet.shepherd/version/download/068t000000CIEbLAAX.

ESA (Energy Storage Association). 2018. "Advanced Energy Storage in Integrated Resource Planning (IRP)." Washington, DC: Energy Storage Association. https://energystorage.org/wp/wp-content/uploads/2019/09/esa_irp_primer_2018_final.pdf.

Feldman, D., V. Ramasamy, R. Fu, A. Ramdas, J. Desai, and R. Margolis. 2021. "U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020." Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy21osti/77324.pdf.

Fitzgerald, G., J. Mandel, J. Morris, and H. Touati. 2015. "The Economics of Battery Energy Storage." Basalt, CO: RMI. https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf.

Georgia Power Company. 2016. "Georgia Power Company's 2016 Integrated Resource Plan." Atlanta: Georgia Public Service Commission.

Gheorghiu, I. 2019. "NIPSCO to Replace Coal with 2.3 GW of Solar, Storage in Latest RFP." *Utility Dive*, October 19. https://www.utilitydive.com/news/nipsco-to-replace-coal-with-23-gw-of-solar-storage-in-latest-rfp/564427/.

Gorman, W., A. Mills, M. Bolinger, R. Wiser, N. Singhal, E. Ela, and E. O'Shaughnessy. 2020. "Motivations and Options for Deploying Hybrid Generator-Plus-Battery Projects within the Bulk Power System." *Electricity Journal* 33 (5): 15.

Graffy, E., and S. Kihm. 2014. "Does Disruptive Competition Mean a Death Spiral for Electric Utilities?" *Energy Law Journal* 35 (1): 1–44.

Haegel, N. M., R. Margolis, T. Buonassisi, D. Feldman, A. Froitzheim, R. Garabedian, M. Green, et al. 2017. "Terawatt-Scale Photovoltaics: Trajectories and Challenges." *Science* 356 (6334): 141–43.

Hawaiian Electric Company. 2018. "Hawaiian Electric Companies' Integrated Grid Planning Workplan." Honolulu: Hawaiian Electric Company. https://www.hawaiianelectric.com/documents/clean_energy_hawaii/integrated_grid_planning/dkt_20180165_20181214_igp_workplan.pdf.

Hawaii PUC (Public Utilities Commission). 2014. "Commission's Inclinations on the Future of Hawaii's Electric Utilities: Aligning the Utility Business Model with Customer Interests and Public Policy Goals." Hilo: Hawaii PUC. http://www.puc.hawaii.gov/wp-content/uploads/2014/04/Commissions-Inclinations.pdf.

Horowitz, K., Z. Peterson, M. Coddington, F. Ding, B. Sigrin, D. Saleem, S.E. Baldwin, et al. 2019. "An Overview of Distributed Energy Resource Interconnection: Current Practices and Emerging Solutions." Golden, CO: National Renewable Energy Laboratory.

Jenkins, J., M. Luke, and S. Thernstrom. 2018. "Getting to Zero Carbon Emissions in the Electric Power Sector." *Joule* 2: 2498–510.

Julin, K., and B. Paulos. 2021. "U.S. Power Sector Is Halfway to Zero Carbon Emissions: New Berkeley Lab Study Reviews Progress towards a Carbon-Free Power Sector." Berkeley, CA: Lawrence Berkeley National Laboratory. https://newscenter.lbl.gov/2021/04/13/u-s-power-sector-is-halfway-to-zero-carbon-emissions/.

Kahrl, F., A. Mills, L. Lavin, N. Ryan, and A. Olsen. 2016. "The Future of Electricity Resource Planning: Future Electric Utility Regulation Series Report #6." Berkeley, CA: Lawrence Berkeley National Laboratory. https://eta-publications.lbl.gov/sites/default/files/lbnl-1006269.pdf.

Larson, E., C. Greig, J. Jenkins, E. Mayfield, A. Pascale, C. Zhang, J. Drossman, et al. 2020. "Net-Zero America: Potential Pathways, Infrastructure, and Impacts, interim Report." Princeton, NJ: Princeton University, Andlinger Center for Energy and the Environment.

Lawrence Berkeley National Laboratory. 2021. "Resource Planning Portal."

Miggiani, R. 2019. "Transforming the Creation of Integrated Resource Plans (IRPs)." *Toward Humanity*, March 20. http://www.solari.net/toward-humanity/2019/03/20/transforming-the-creation-of-integrated-resource-plans-irps/.

Mills, A., and R. Wiser. 2012. "An Evaluation of Solar Valuation Methods Used in Utility Planning and Procurement Processes." Berkeley, CA: Lawrence Berkeley National Laboratory. http://www.brightsourceenergy.com/stuff/contentmgr/files/0/3fa99df0a3131dad626ef77b71d9ff63/attachment/lbnl_solar_valuation.pdf.

Nelson, J., S. Kasina, J. Stevens, J. Moore, and A. Olson. 2018. "Investigating the Economic Value of Flexible Solar Power Plant Operation." San Francisco: Energy+Environmental Economics.

Nemet, G.F. 2019. "How Solar Energy Became Cheap." New York: Routledge.

NIPSCO (Northern Indiana Public Service Company) LLC. 2018. "2018 Integrated Resource Plan." Merrillville, IN: NIPSCO. https://www.nipsco.com/docs/librariesprovider11/rates-and-tariffs/irp/2018-nipsco-irp.pdf?sfvrsn=15.

Oregon PUC (Public Utility Commission). 2007. "In the Matter of Public Utility Commission of Oregon Investigation into Integrated Resource Planning." https://apps.puc.state.or.us/orders/2007ords/07-047.pdf.

O'Shaughnessy, E., J. Cruce, and K. Xu. 2020. "Too Much of a Good Thing? Global Trends in the Curtailment of Solar PV Energy." *Solar Energy* 208: 1068–77.

O'Shaughnessy, E., J. Heeter, C. Shah, and S. Koebrich. 2021. "Corporate Acceleration of the Renewable Energy Transition and Implications for Electric Grids." *Renewable and Sustainable Energy Reviews* 146: 111160.

Ramanan, A., S. Beland, Y. Yacoby, and N. Hernandez Hammer. 2021. "Community Outreach and Solar Equity." Montpelier, VT: Clean Energy States Alliance.

RE100. n.d. "RE100 Members." https://www.there100.org/companies. Accessed on August 27, 2021.

Rule, T. 2015. "Solar Energy, Utilities, and Fairness." *San Diego Journal of Climate & Energy Law* 6: 115–48. https://digital.sandiego.edu/cgi/viewcontent.cgi?article=1060&context=jcel.

Sass Byrnett, D., K. Verclas, and J. Zetterberg. 2021. "Blueprint for State Action: NARUC-NASEO Task Force on Comprehensive Electricity Planning." Washington, DC: National Association of Regulatory Utility Commissioners (NARUC). https://pubs.naruc.org/pub/14F19AC8-155D-0A36-311F-4002BC140969.

Schlag, N., Z. Ming, and A. Olson. 2020. "Adding It All Up: Counting the Capacity Contribution of Variable and Duration-Limited Resources." *Utility Dive*, September 10. https://www.utilitydive.com/news/adding-it-all-up-counting-the-capacity-contribution-of-variable-and-durati/584843/.

Schwarz, M., J. Ossenbrink, C. Knoeri, and V.H. Hoffmann. 2019. "Addressing Integration Challenges of High Shares of Residential Solar Photovoltaics with Battery Storage and Smart Policy Designs." *Environmental Research Letters* 14: 074002.

ScottMadden. 2015. "Best Practices in Integrated Resource Planning." Atlanta, GA: ScottMadden, Inc. https://www.scottmadden.com/content/uploads/2018/08/Best-Practices-in-Integrated-Resource-Planning.pdf.

Sierra Club. n.d. "Committed: What Are 100% Clean Energy Commitments?" Oakland, CA: Sierra Club. https://www.sierraclub.org/ready-for-100/commitments. Accessed on August 27, 2021.

SEPA (Smart Electric Power Alliance). 2021. "Utilities' Path to a Carbon-Free Energy System by 2050." Washington, DC: SEPA. https://sepapower.org/utility-transformation-challenge/utility-carbon-reduction-tracker/.

Shimamoto, S. 2018. "The Emergence of Utility-Owned Renewable Energy under Build-Transfer Agreements." *Insights*. Skadden, Arps, Slate, Meagher & Flom LLP and Affiliates, September 24. https://www.skadden.com/insights/publications/2018/09/quarterly-insights/the-emergence-of-utility-owned-renewable-energy.

Specian, M., C. Cohn, and D. York. 2021. "Demand-Side Solutions to Winter Peaks and Constraints." Washington, DC: American Council for an Energy Efficient Economy. https://www.aceee.org/research-report/u2101.

Sterling, J., J. McLaren, M. Taylor, and K. Cory. 2013. "Treatment of Solar Generation in Electric Resource Planning: Technical Report NREL/TP-A20-60047." Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy14osti/60047.pdf.

St. John, J. 2020. "Arizona Public Service Lays Out Its Options for Reaching Zero-Carbon Energy by 2050." *GreenTech Media*, June 30. https://www.greentechmedia.com/articles/read/arizona-utility-aps-charts-path-to-zero-carbon-energy-by-2050.

Teplin, C., M. Dyson, A. Engel, and G. Glazer. 2019. "The Growing Market for Clean Energy Portfolios: Economic Opportunities for a Shift from New Gas-Fired Generation to Clean Energy across the United States." Basalt, CO: RMI.

Trabish, H. 2020. "Battery Energy Storage Is Getting Cheaper, but How Much Deployment Is Too Much?" *Utility Dive*, June 30. https://www.utilitydive.com/news/battery-energy-storage-is-getting-cheaper-but-how-much-deployment-is-too-m/579183/.

Valeri, L.M. 2019. "INSIDER: Not All Electricity Is Equal—Uses and Misuses of Levelized Cost of Electricity (LCOE)." Washington, DC: World Resources Institute. https://www.wri.org/blog/2019/08/insider-not-all-electricity-equal-uses-and-misuses-levelized-cost-electricity-lcoe.

Victoria, M., N. Haegel, I. Marius Peters, R. Sinton, A. Jäger-Waldau, C. del Cañizo, C. Breyer, et al. 2021. "Solar Photovoltaics Is Ready to Power a Sustainable Future." *Joule* 5: 1–6.

Volk, D., J. Shenot, R. Allen, and D. Milazi. 2018. "Insights on Planning for Power System Regulators." Abu Dhabi: International Renewable Energy Agency. https://irena.org/publications/2018/Jun/Insights-on-planning-for-power-system-regulators.

Weaver, J., S. Schewel, B. Saffo, L. Lavelle, B. Howerton, N. Vaughan, R. Price, et al. 2021. "RE: Duke Energy Progress and Duke Energy Carolinas Jointly Submitted 2020 Biennial Integrated Resource Plan, Docket No. E-100, Sub 165." Raleigh: North Carolina Utilities Commission. https://starw1.ncuc.net/NCUC/ViewFile.aspx?Id=bf1e6203-0b2b-410d-9917-132ffbda49a6.

Wilson, J. D., M. O'Boyle, R. Lehr, and M. Detsky. 2020. "Making the Most of the Power Plant Market: Best Practices for All-Source Electric Generation Procurement." San Francisco: Energy Innovation Policy & Technology LLC. https://energyinnovation.org/wp-content/uploads/2020/04/All-Source-Utility-Electricity-Generation-Procurement-Best-Practices.pdf.

Wilson, R., and B. Biewald. 2013. "Best Practice in Electric Utility Integrated Resource Planning." Montpelier, VT: Regulatory Assistance Project.

Wilson, R., N. Peluso, and A. Allison. 2019. "North Carolina's Clean Energy Future: An Alternative to Duke's Integrated Resource Plan." Cambridge, MA: Synapse Energy Economics, Inc. http://gridlab.org/wp-content/uploads/2019/04/NC-Clean-Energy-Report_Final_20190307-DB.pdf.

Wood Mackenzie. 2021. "U.S. Solar Market Insight: 2020 Year-in-Review." Edinburgh, UK.

ACKNOWLEDGMENTS

The content of this paper is the sole responsibility of the authors. However, the authors thank the following individuals who offered perspectives and insights during phone interviews: Christian Martinez and John Sterling (First Solar), Kathleen Spees (Brattle), Lauren Shwisberg (RMI), and Kevin Lucas (Solar Energy Industries Association). Norma Hutchinson, Kevin Kurkul, and Priyanka Roche played essential research roles and made significant contributions to this report. Lori Bird served as the project lead and overseeing director, providing strategic advice and guidance.

This report was made possible thanks to the support of the U.S. Department of Energy through the Office of Energy Efficiency and Renewable Energy under the Solar Energy Technologies Office Award Number DE-EE0009003.

This report was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied; or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed; or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

The authors thank the following people for their peer review and helpful insights and comments during the development of this paper: Maya Kelty (3Degrees), Ben Foster (Fosterra), Jake Duncan (IMT), Julia Eagles (IMT), Cory Felder (RMI), Tyler Fitch (Vote Solar), Alex Dane (WRI), Bharath Jairaj (WRI India), and Robi Robichaud (WRI).

The authors also thank Laura Malaguzzi Valeri, Emilia Suarez, and Renee Pineda of WRI's Research, Data, and Innovation office for their insights; Emily Matthews and Shazia Amin for copyediting; Romain Warnault for coordinating the production process; and Jennifer Lockard for design and layout.

ABOUT THE AUTHORS

Celina Bonugli is an Associate, Clean Energy Innovation, with the U.S. Energy Program at World Resources Institute. She supports the facilitation of electric utility and large-scale energy buyer collaboration to spur innovative solutions that decarbonize the electricity sector, increase grid efficiencies, and integrate new technologies to reduce greenhouse gas emissions. For the Renewables Accelerator initiative, which provides technical support to U.S. municipal governments as they procure renewable energy, Celina leads the electric utility and regulatory engagement strategy, consultation, and resource development.

Contact: celina.bonugli@wri.org

Eric O'Shaughnessy is an independent renewable energy research consultant. His research focuses on distributed solar and energy resource markets.

Contact: eric.oshaughnessy@cleankws.com

Heidi Bishop Ratz was formerly a Manager, U.S. Electricity Markets, with the Global Energy and Climate Programs at World Resources Institute. She is now a Senior Manager, Policy and Market Innovations, at the Renewable Energy Buyers Alliance. During Heidi's time at WRI, she provided project management, partner engagement, and research to drive the transition to a low-carbon economy in the United States. This involved research and analysis to support WRI's existing and emerging U.S. energy initiatives related to deep decarbonization, electricity market design, innovative utility regulatory policy, and/or promotion of zero- and low-carbon energy, demand response, energy storage, and energy efficiency.

Contact: hratz@rebuyers.org

Joseph Womble is a Research Assistant with the U.S. Energy program at World Resources Institute. He provides research and facilitates local engagement to advance the clean energy transition among municipalities and large energy buyers. This includes educating municipalities and business districts on renewable energy opportunities in their jurisdictions, forming creative solutions to increase low-income participation in community solar programs, and providing support to cities looking to increase renewable energy within wholesale markets.

Contact: joseph.womble@wri.org

ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.