

RETHINKING THE ROLE OF CAPACITY EXPANSION MODELING

**An alternative approach for reliable
and economic portfolio design
under uncertainty**

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Derek Stenclik
Telos Energy, Inc.

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CONTEXT

Capacity expansion modeling is a crucial part of power system planning. It's the foundation of the utility's IRP, setting a roadmap for net investments, retirements, and meeting policy goals of renewable energy production or emissions reductions. It also serves a central role for deregulated markets, ensuring that independent system operators are reliably planning their system today, and the future. Given the lead time for new resource procurement, a clear view of the future is critical to make decisions today that ensure reliability in the future. However, capacity expansion modeling is fraught with challenges, some of these challenges being familiar ones, such as the uncertainty of future technology and fuel costs, as well as new challenges that are emerging given the increased penetration of variable renewable and storage growth. Our tool is one approach to tackle some of these challenges while emphasizing the value of transparency for decision makers, and flexibility for planners.

THE CHALLENGES

The industry's current approaches to capacity expansion modeling are insufficient. In the majority of cases it provides a single cost-optimum solution, leaving planners, regulators, and stakeholders grappling with the various "what ifs." What if solar costs come down? What if offshore wind is not feasible? What if fuel prices double? While scenario and sensitivity analysis can help answer some of these questions, we're often stuck with a narrow selection of portfolios guiding our decisions.

These are just a few examples of the various **uncertainties** that decision makers, planners and other stakeholders must contend with during the planning process. It's not uncommon for IRP planning and stakeholders to spend several months, if not longer, developing assumptions on fuel





prices, technology costs, load forecasts, and other inputs, knowing full well these inputs are all characterized by uncertainty and error margins. For many jurisdictions, in the past, resource planning was a simple choice, often choosing between new gas or new coal. Today, resource planning involves multiple new technology choices—wind, solar, geothermal, thermal resources, and storage of various durations and technologies. Because of this, if technology costs or fuel prices change, this generally justifies a full repeat of the capacity expansion modeling exercise and associated analytical framework (such as production cost modeling) to remain relevant.

Most capacity expansion models and users of these models tend to **over-prioritize cost optimization**. There are two dimensions to this issue. First, keeping costs manageable and lower rates for customers is critical, but decision-making is never made solely by costs alone. Think of the last time you purchased a vehicle—your decisions were made not just on cost (the price of the car and the costs to run it), but often more importantly on the features it provides. The same is true for utility planning. Key factors like reliability, community acceptance, land use, emissions, and technology risks are equally—if not more important. The second dimension is that typically the least cost portfolio is emphasized and often presented as the preferred plan. Seeing the lowest cost option is important. However, if the second cheapest option is only a few percent more expensive than the cheapest option, the second cheapest portfolio should be considered and included in the overall analysis. However, the capacity expansion modeling process and tools leave these as afterthoughts—often requiring planners to adjust portfolios outside of the optimization, with limited transparency.

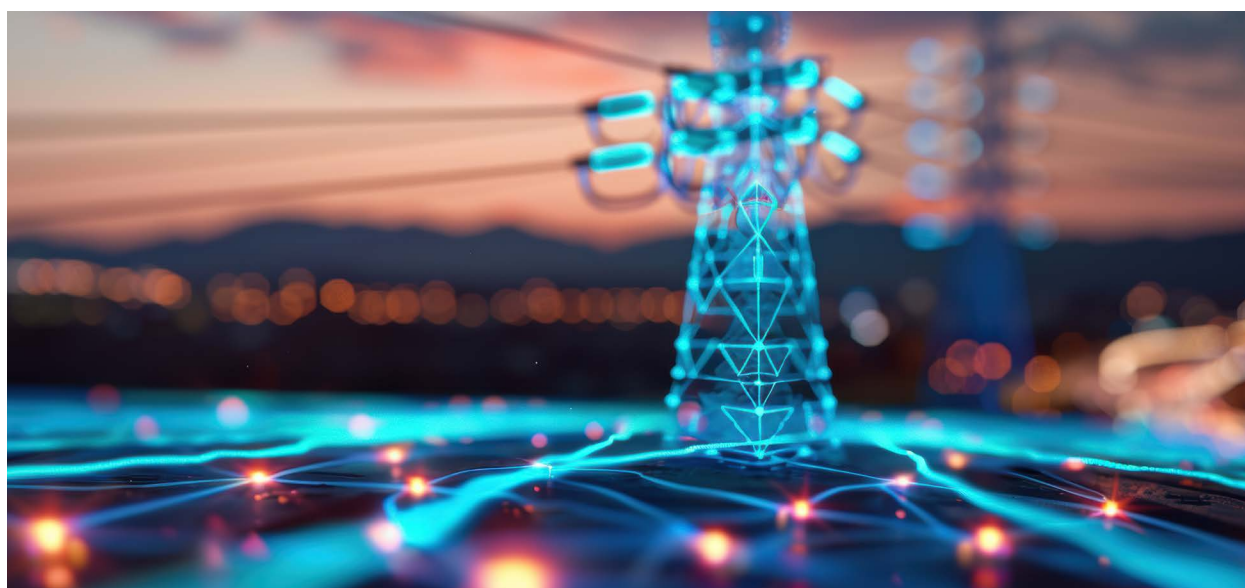
Not only does cost optimization provide a **narrow view of options**, it is computationally intensive. Models will canvass a wide array of options and try to determine the least cost in a single optimization process. This is often computationally intractable, requiring planners to make simplifications and modeling shortcuts. As a common example of these simplifications, capacity expansion modeling uses “day sampling,” or selecting only a handful of days across the year to make investment decisions. As our power systems become more weather dependent, it is critical to assess not only a handful of days, but a full 8760-hour chronology, and also spanning multiple weather years. This is critical not only to characterize the performance of renewable energy, but the important charging and discharging cycles of battery energy storage, increasingly complicated ancillary service products, and operating constraints. Because many of these phenomena cannot be realistically included in capacity expansion models directly, the emphasis on companion tools, such as production cost models, will increase.

Finally, the complexity of modeling can limit **transparency** between the utility and stakeholders—including regulators, customers, environmental advocates, developers, and others. Oftentimes the utility conducts all of the modeling, providing only a handful of scenarios or portfolios to review.

OUR PROPOSED ALTERNATIVE

An alternative approach to today's optimal capacity expansion modeling is to develop a robust screening method and tool that allows users to parse through hundreds of unique portfolios across a wide range of uncertain parameters. In lieu of seeding the capacity expansion model with inputs and using it to optimize a single portfolio, the method skips the capacity expansion model completely and instead seeds a production cost model (PCM) with hundreds, or even thousands, of unique portfolios. The production cost model is initialized with a starting set of assumptions on operating costs (such as fuel costs) and then executed through a detailed 8,760 hour economic dispatch across multiple weather years. Total portfolio costs are then calculated exogenously based on the PCM dispatch results, allowing a user to post-process operating costs with new assumptions. Key parameters like capital costs, fuel prices, O&M costs, emissions costs, and even the value of lost load (VoLL) can be quantified after the PCM simulations are conducted. Users can then compare results—including costs, emissions, renewable production, land use, and reliability—across hundreds or thousands of unique portfolios. This six step process is outlined below.

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- STEP 1** **Develop select baseline model years (e.g., 2030, 2040, 2050)**
 - STEP 2** **Identify new resource or specific retirement candidates**
 - STEP 3** **Develop hundreds of unique portfolios, either through random sampling of parameter distributions or deterministically**
 - STEP 4** **Conduct 8760-hour production cost simulations across multiple weather years**
 - STEP 5** **Tabulate results and recalculate with different assumptions**
 - STEP 6** **Visualize portfolios and make preferred selections**



Among these steps, perhaps Step 3 requires the most explanation. This can be best explained through an example. Consider that we are designing portfolios for a small power system that has a peak load of 1000 MW. We first define a range of how much each resource we would like to consider, in MW terms. This can be set intentionally wide. In our approach, we conducted monte-carlo sampling to develop 1000's of unique portfolios selecting different combinations of those resources. However, to ensure that we did not include portfolios that would obviously be unable to meet load, we eliminated all portfolios where available energy fell 30% below or above load.

This process will inherently develop some portfolios that are both underbuilt and unable to serve load, and overbuilt which include resources that are not needed. This is an intentional outcome. Overbuilt portfolios can be filtered out on cost alone later, while underbuilt portfolios can either be removed by filtering them out based on unserved energy criteria -or- by pricing the value of lost load (on a \$/MWh basis) to explicitly incorporate the natural cost-reliability tradeoff.

Importantly this process does not require planning reserve margins (PRM) or effective load carrying capability (ELCC) to determine the amount of resources to add for reliability. Instead challenging load periods and resource unavailability are directly incorporated into the hourly simulations.

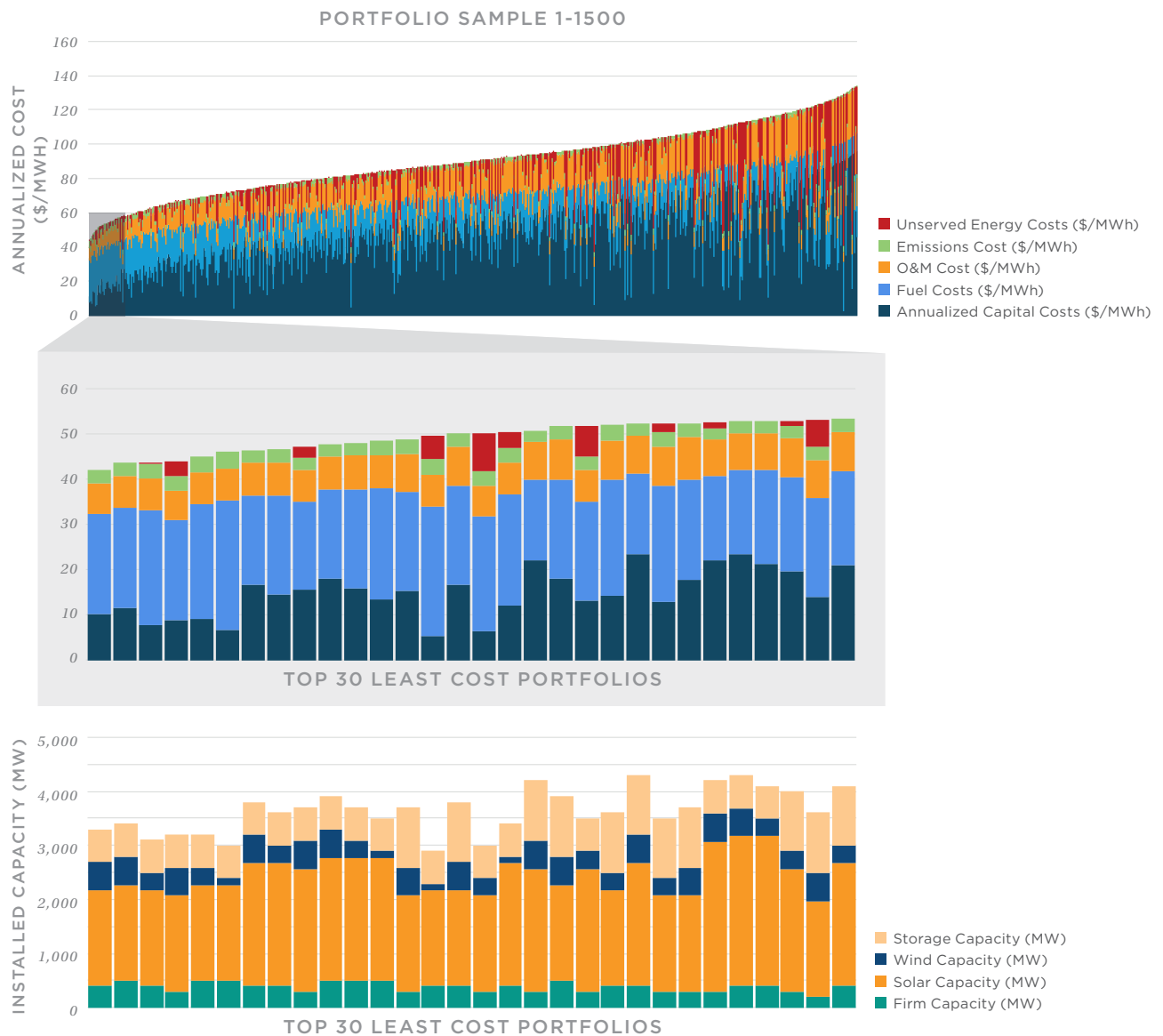
Another key benefit of this method is that it enables rapid sensitivity analysis, allowing users to make adjustments to key assumptions and immediately see the impact on the results. Ultimately the user can select a portfolio that best meets their multiple objectives—not just the one that is lowest cost.

For this approach to be valid, there is one important assumption and simplification—that there is a single fuel on the margin and that the dispatch order between units does not change. In other words, coal and gas generators are dispatched according to an initial fuel price assumption, and while changes to fuel costs can be calculated exogenously, it does not change the underlying dispatch. While this is a simplification it is a reasonable one—most long-term planning does not need to evaluate whether coal or gas is on the margin. In return, the modeling can be much more detailed than capacity expansion modeling on other parameters to include hourly chronology, improved storage optimization, detailed operating reserves and constraints, and more granular (even nodal) transmission topology.

It is worth noting that this approach creates vast amounts of data. While this is a benefit of the approach, it can also be a drawback, since it requires automated and flexible data visualization. So rather than developing new modeling tools, the approach focuses on leveraging existing tools with improved visualization and portfolio comparisons. In fact, the tool is designed to work with any production cost modeling tool.

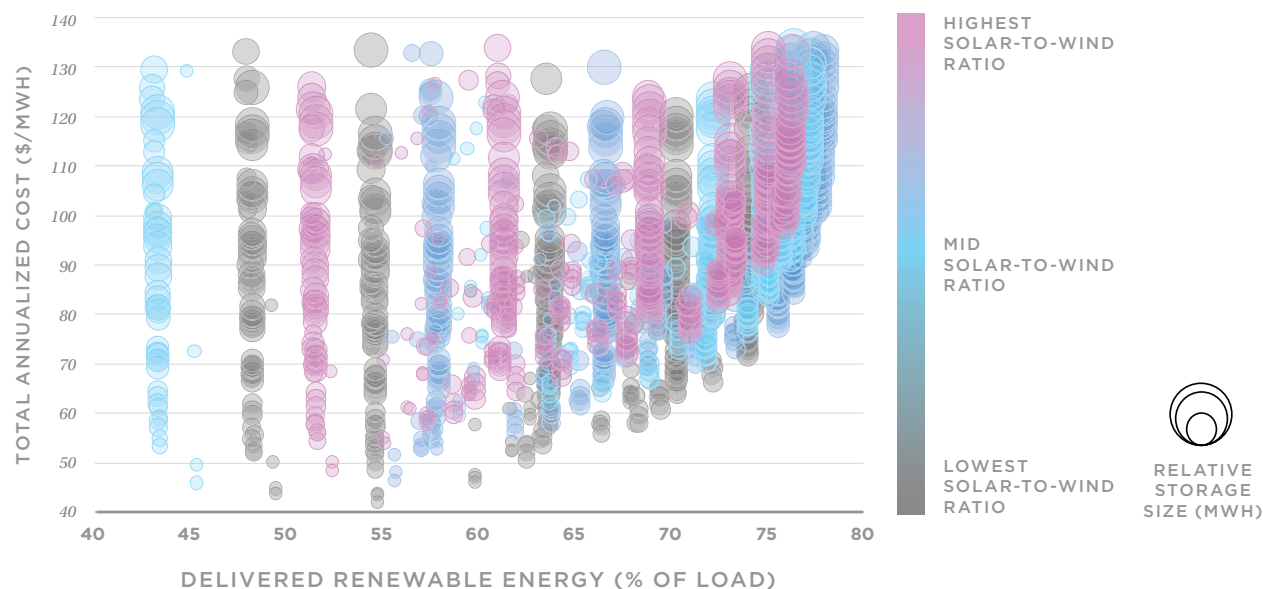
An example of these visualizations is provided in Figure 1 below. The top frame shows how total annualized costs can be calculated for over 1600 portfolios for an island power system; portfolios are sorted from least cost to highest cost. The middle frame focuses on the top 20 portfolios and the lower frame shows the resource selection for these top 20 least cost portfolios. The tool user then has the ability to sort, filter, and exclude portfolios based on their own preferences and objectives.

FIGURE 1. Portfolio ranking by cost (top, middle) and resource additions (bottom)



Further data analysis can also be conducted to better understand trends in the resulting portfolios. Figure 2, shows a four-dimensional scatter plot, quantifying each of the 1600+ portfolios based on their renewable contributions (x-axis), total annualized cost (y-axis), land use (circle size), and ratio of wind to solar additions (color). By giving users flexibility to inspect the data across a wide set of parameters may be able to help identify portfolios that meet multiple objectives. Perhaps most importantly, figures like this can automatically adjust based on changes to inputs and assumptions, without rerunning the computationally-intensive production cost models.

FIGURE 2. Portfolio cost (y-axis) as a function of renewable share (x-axis), colored by the ratio of solar buildout relative to wind.



ADVANTAGES OF THIS TECHNIQUE

The benefits of this approach are significant and overcome many of the limitations found in today's leading capacity expansion modeling approaches. In particular, there are five benefits this new method affords practitioners, regulators, and stakeholders.

- 1. Provides hundreds or thousands of potential portfolios:** rather than resulting in a single, cost-optimal portfolio, this approach develops a wide array of unique portfolios. This helps overcome uncertainty and shows portfolios with very similar, but not necessarily equal cost. It allows for non-cost portfolio rankings, including objectives like emissions reductions, land use, resource diversity, and equity. Practitioners can then select the portfolio that best meets their needs, properly balancing multiple objectives.
- 2. Better reflects uncertainty in resource capital costs and fuel costs:** unlike capacity expansion modeling that requires these parameters to be treated as fixed inputs, our method allows these to be determined, and modified outside of the modeling framework and allows users to recalculate the results after simulations are complete. The resulting tool allows users to test a wide range of values to better capture uncertainty and sensitivity of portfolios to key assumptions. This overcomes what today is a long and contentious stakeholder process to develop these inputs up front and accelerates portfolio re-costing when assumptions undoubtedly change over time. It also makes the tool more flexible to better assimilate changes to policy, technology advancements, or volatility in commodity markets.
- 3. Conducts detailed 8760 chronological modeling:** Because this approach leverages production cost modeling instead of optimal capacity expansion modeling, less simplification is required. As a result, it is able to better capture detailed considerations for

unit commitment and dispatch. This includes a full representation of chronology—across a full 8760 dispatch and multiple weather years—and a better representation of operating constraints like reserves, heat rates, and generator constraints. This is increasingly important as the power system integrates higher levels of battery energy storage and charge and discharge cycles need to be reflected. The approach can also incorporate more granular transmission representation.

- 4. Allows for an efficient and collaborative stakeholder process:** While the method uses robust and detailed production cost modeling software (which does require modeling expertise), the final portfolio comparisons are easy to conduct, fully accessible, and transparent. This allows for collaboration and better interaction between utility planners, regulators, and stakeholders. For example, the utility or RTO can run detailed simulations and provide a simplified tool to stakeholders to develop their own portfolios, cost assumptions, and results. Stakeholders can then filter or sort portfolios by non-cost objectives, including land-use, emissions, renewable level, technology exclusions, or equity concerns. These alternative portfolios can easily be compared across stakeholder groups.
- 5. Improved computing capabilities and faster analysis:** the proposed method does not require a single optimization problem, which oftentimes are slow to compute and require simplification. Instead, the process simply aggregates and summarizes hundreds or thousands of discrete simulations. This process is better suited for parallel computing, allowing users to split simulations across hundreds of CPUs and stitching together results afterwards.

ADDITIONAL CONSIDERATIONS

While the approach is a significant step forward in resource planning, there are some important considerations and limitations. For one, the process still requires resource adequacy analysis. While a benefit of the approach is that it does not rely on a planning reserve margin or resource accreditation, resulting portfolios can and should be back-checked in a probabilistic resource adequacy model to quantify reliability metrics. This is not a limitation, but rather a best practice in any resource planning process.

In addition, the process does not directly consider the timing of new resource additions and retirements. Instead, practitioners are expected to run important years of the horizon and develop marking posts of various resource additions and portfolios for each stop of the way. Planners can then run preferred portfolios for intermediate years to develop full NPV calculations and revenue requirements, similar to current capacity expansion planning approaches.

Despite these limitations, the new proposed method provides a unique opportunity to review a wide range of system portfolios to develop a low cost, reliable, and preferred portfolio that overcomes uncertainty in a transparent and flexible manner.

TEST IT OUT FOR YOURSELF!

Are you interested to learn more about this tool? The best way to understand its benefits is to use it for yourself. To highlight the important benefits of ***an efficient and collaborative stakeholder process***, we have a representative grid planning exercise available at telos.energy/demo. Feel free to design your own portfolio, it only takes a few minutes—no training required!



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