BRIGDING THE ANALYTICS–OPERATIONS PERFORMANCE GAP FOR SOLAR + STORAGE

How Software Impacts Customer Savings Across the Project Lifecycle and What to Do About It

Dr. Mahdi Motalleb
Qiao Li
Emerson Reiter

www.nikolapower.com

Executive Summary

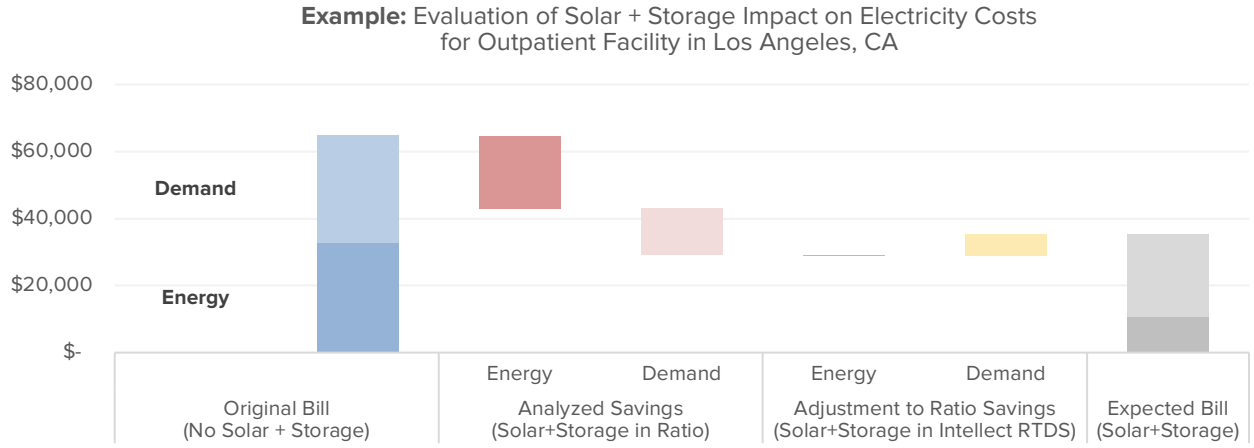
Nikola Power is a clean energy technology company that enables project developers, EPCs, and asset owners to take solar + storage opportunities from development to deployment. To do this, Nikola Power has developed two software tools with a focus on the commercial and industrial (C&I) market segment:

- Ratio, a web-based analytical tool that enables the design and analysis of cost-effective solar + storage systems, and
- Intellect, an advanced energy management system (EMS) that autonomously operates solar + storage systems in the field to maximize customer savings.

Nikola Power has developed software for both analytics and operations because energy storage is very different from other clean energy technologies such as wind and solar. Analyzing the value of a wind or solar project largely comes down to predicting physical phenomena such as wind speed or irradiation. In addition, achieving the analyzed value in the operations phase is generally a passive process, with data monitoring and regular maintenance being the main activities. By contrast, the value of energy storage is entirely dependent on active, intelligent management of its operations, i.e. its charging/discharging pattern, so an understanding of future operations is critical to modeling its economic value during project development.

To explore analytics-operations consistency, Nikola Power has examined twenty potential projects, comprised of five building types across four different utility territories, using both Ratio and a virtual simulator of Intellect. Due to the differences in computational techniques – Ratio uses “perfect foresight” across an entire year, while Intellect operates sequentially and using real forecasts of solar and load – the savings in Ratio are expected to represent an optimistic estimate of savings, with Intellect delivering savings close to but below those values.

In our comparison, the share of savings from the Ratio tool that were achieved by Intellect operations varied from 51% to 118%, with an average of 82%. Predictions of energy charges and savings were highly consistent between the two tools, while demand charges and savings showed greater gaps due to the time-sensitive nature of power delivery to reduce peak demand. The data gathered in these analyses will enable Nikola Power to identify key factors that drive differences between Ratio and Intellect results, improve the predictive power of Ratio for demand-focused applications, and generate final customer savings guarantees in a more accurate way.



Background

Nikola Power seeks to speed the growth of solar + storage deployments by providing the tools to analyze, finance, and operate solar + storage systems. To enable this process, Nikola Power has developed two software tools, Ratio and Intellect.

Ratio is a web-based analytical tool that enables the design of cost-effective solar + storage systems for C&I end customers. Ratio users – typically project developers – will enter key parameters about solar + storage system technical characteristics, cost parameters, and customer load patterns, from which Ratio generates optimal annual operations of the solar + storage system and cash flow statements for the life of the project. Crucially, Ratio allows users to evaluate the *net savings* (utility bill savings, less the costs of the solar + storage system), empowering them to find the most cost-effective system configuration for the given customer.

Intellect is Nikola Power's energy management system (EMS) for optimally scheduling and controlling energy storage systems (ESS) in real-time. Intellect achieves this through three major functions:

- Forecasting: Accurate load and solar production forecasts are integral to the successful operation of the solar + storage system and have been developed using advanced artificial intelligence techniques. Intellect produces load and solar forecasts on a rolling basis at least every hour, increasing the accuracy of input data for optimization.
- Optimization: The optimization determines how to minimize the customer's bill through the coordinated use of solar power, storage power, and grid power, and also updates on a rolling basis. Intellect's cost-minimization functions account for all relevant operating costs and constraints, including energy charges, demand charges, and battery wear cost.
- Control: Intellect has been flexibly designed to quickly integrate with all critical solar + storage equipment, including solar inverters, battery inverters, battery management systems, and load sensors.

The purpose of providing two software tools under one roof is to create consistency between analytics and operations. In a perfect world, project analysis and field operations would be performed using a single tool; in fact, Ratio and Intellect share the same core optimization function. However, other differences are inevitable and lead to huge computational and usability challenges. For example, Intellect moves sequentially through time, forecasting and optimizing at each step, while Ratio uses "perfect foresight" and optimizes across the full year simultaneously. As a result, generating a full year of operational data in Ratio takes under a minute, while executing a similar analysis with Intellect takes 4 hours. Imagine trying to design a solar + storage system if you have to wait half a day for results!

However, a quick-computing analysis tool such as Ratio is only valuable if the results are consistent with those produced by Intellect. If operations differ significantly from the analysis, long-term asset owners will become more skeptical of solar + storage projects and demand higher returns, project developers will be forced to focus on only high-value projects, and fewer solar + storage deployments will be completed. We are sharing the following analysis to confirm that Ratio's quick computations are consistent enough with Intellect results, identify gaps between the tools, and explore ways that Nikola Power can better serve developers, asset owners, and end customers.

Methodology

Scenarios

In order to compare the performance of Ratio and Intellect for solar + storage systems, we first built a consistent scenario set by drawing on the results of NREL's extensive 2018 study of solar + storage for commercial buildings using the REopt technoeconomic model.[1] Targeting scenarios that delivered substantial customer savings and adopting the rough equipment configurations specified by the NREL REopt study, we produced a "scenario space" of 20 different configurations, as shown in Table 1. The scenarios were defined by two main parameters.

Geographical Location: the four locations determined

- The typical meteorological year (TMY) weather data to be used in simulating annual profiles of hourly solar production and hourly building electricity loads.
- The electric utility service territory and rate structure applied in a given scenario.

Building Type: the five building types determined

- The characteristics of the building as defined in the EnergyPlus building energy modeling software to produce an annual load profile.[2]
- The size of the solar array and battery energy storage system to be modeled in the solar + storage system operations. These values were adapted from the NREL REopt study.

				Geographical Location	San Francisco, CA	New York City, NY	Los Angeles, CA	Albuquerque, NM
				TMY3 Location	San Francisco Intl Airport	LaGuardia Intl Airport	Los Angeles Intl Airport	Albuquerque Intl Airport
				Utility Company	Pacific Gas and Electric (PG&E)	Consolidated Edison (ConEd)	Los Angeles Dept. of Water and Power (LADWP)	Public Service Company of New Mexico (PNM)
				Utility Rate	E-19 Medium General Demand TOU Option R (Secondary Voluntary)	SC-9 General Large Voluntary TOD Service (NYC)	Primary Service A-2 Rate(B) Time Of Use	3B General Power TOU (PNM-Owned Transformer)
Building Type	Solar PV Capacity (kW)	Battery Power (kW)	Battery Energy (kWh)					
Strip Mall	175	30	60					
Outpatient	450	50	200					
Medium Office	280	30	120					
Primary School	350	50	150					
Large Office	2,000	125	500					

20 scenarios evaluated
(5 building types across 4 locations)

Table 1: Configuration of Solar + Storage Scenarios to be Evaluated in Ratio and Intellect

Execution

Ratio is designed, by its nature, to produce full-year operations of a solar + storage system in a short amount of time, by using perfect foresight computational techniques. However, Intellect is designed to be field-deployed and can control equipment in real-time, so without modification, gathering a year of data under twenty scenarios would require twenty operational solar + storage sites and a year of elapsed time to collect the required amount of data. In order to gather

[1] McLaren, Joyce A., Anderson, Katherine H., Laws, Nicholas D., Gagnon, Pieter J., DiOrio, Nicholas A., and Li, Xiangkun. *Identifying Critical Factors in the Cost-Effectiveness of Solar and Battery Storage in Commercial Buildings*. United States: N. p., 2018. Web. doi:10.2172/1422883. Data retrieved from https://public.tableau.com/profile/joyce.mclaren#!/vizhome/SunLampResults-24April2017-forwebv4/TitleNREL

[2] For more information about building types see: https://openei.org/wiki/Commercial_Reference_Buildings

operational data much more quickly, Nikola Power developed a real-time data simulator (RTDS) for Intellect which operates as follows:

- The Intellect RTDS uses the same forecasting, optimization, and control logic as a field-deployed Intellect EMS.
- Like a field deployment, the Intellect RTDS operates sequentially in time: at time t_0, it forecasts solar production and site load over the next 24 hours, develops an optimal dispatch schedule for the battery over that time, then controls the battery system to operate according to that schedule. At time t_1, the entire process repeats, with t_1 conditions determined in part by the operations defined at time t_0.
- Intellect RTDS represents a huge speed benefit over real-world testing because no time needs to elapse before advancing to the next timestep; each forecast-optimize-control cycle takes roughly 3 seconds but no "operational period" (5 minutes, 15 minutes, 1 hour) need play out before proceeding to the next period.
- The Intellect RTDS represents all physical equipment (solar array, load meter, energy storage system) with external software modules that represent key parameters (solar production, load levels, state of charge) according to pre-loaded time series (for solar and wind) or technical parameters (power limits, round-trip efficiencies, etc.).
- In these scenarios, only one year of historical data of solar and load data is available, so 5 months of data was used for training the machine learning/forecasting algorithms and then the performance of the system is evaluated across the remaining 7 months.
- Intellect RTDS simulations took 4-5 hours to complete on a Linux-based PC running Ubuntu 16.05 with 1.8 GHz processor and 16 GB RAM.

Table 2 highlights some of the critical features of Nikola Power software tools and the differences and similarities between them.

Software Features	**Ratio**	**Intellect RTDS**	**Intellect EMS**
Computational Environment	Web-based	Local computer	Field deployment
Data Sources	User-supplied solar and load profiles	Simulated solar inverter and load sensors with user-supplied time-series	Data collected on-site in real time from solar inverters, load sensors
Operational Horizon	Simultaneous optimization of operations across full year	Sequential optimization with optimization across rolling 24-hour window	Sequential optimization with optimization across rolling 24-hour window
Forecast Accuracy	Perfect – user-supplied solar and load profiles taken as given values	Real-world accuracy – forecast modules are trained on portion of data set, then develop forecasts of simulated solar and load for each operational cycle	Real-world accuracy – forecast modules are trained on historical data, then develop forecasts of site solar and load for each operational cycle
Time to Produce One Year of Operational Data	1 minute	4 hours	1 year

Table 2: Key Characteristics of Nikola Power Software Tools

Results

Figure 1 shows the original billed costs for energy, demand, and total charges, as well as the modified bills achieved by the use of the specified solar + storage system in Ratio and Intellect RTDS across all locations and building types.

Considered by building type, the large office has by far the largest electricity bill, which is logical considering its total modeled square footage is more than 6x the next largest building type. The effects of rate design on the customer bill can also be seen in the variation by location. The New York City (ConEd) scenarios are by far the most heavily weighted towards demand charges, while the San Francisco (PG&E) cases skew towards energy charges, with the Albuquerque (PNM) and Los Angeles (LADWP) cases falling somewhere in between.

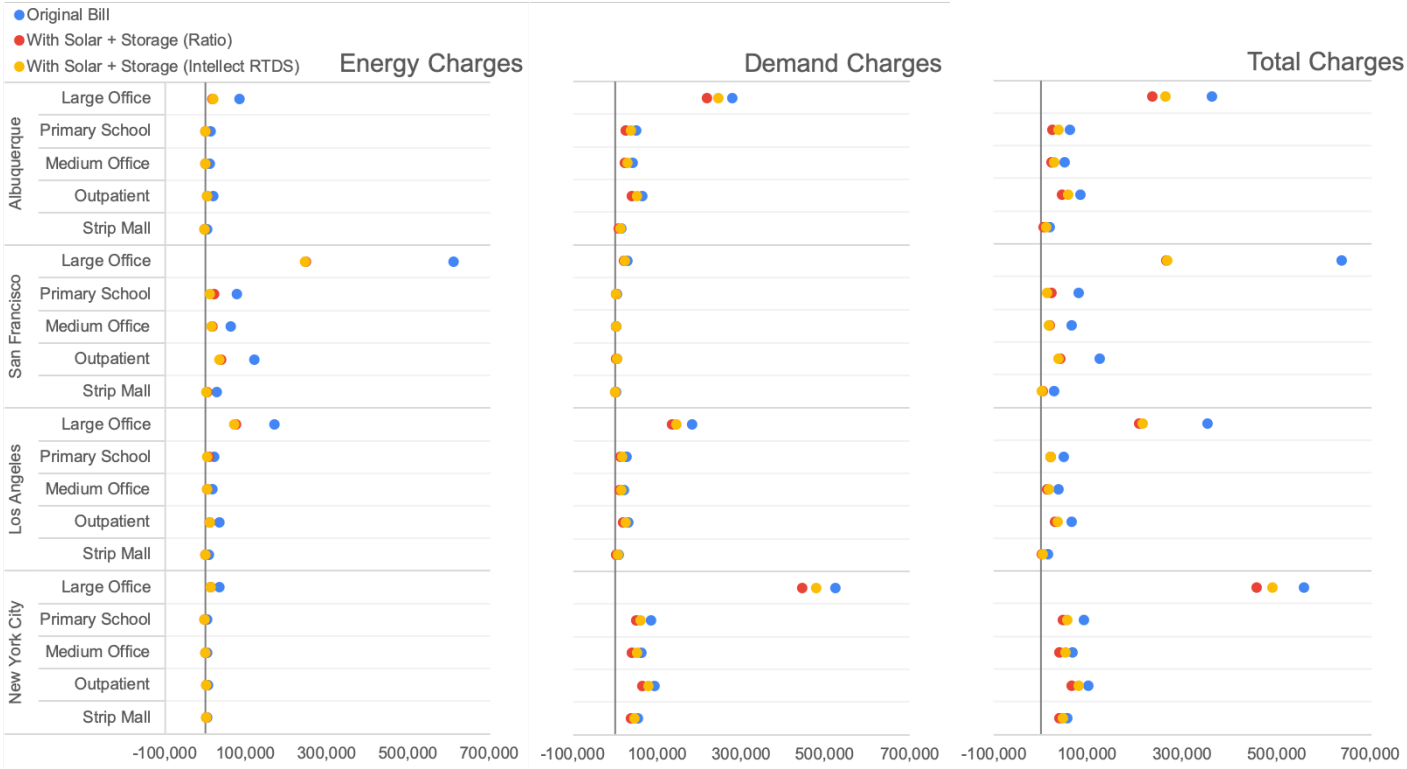


Figure 1: Original Bill Costs ($) of Energy, Demand, and Total Charges (blue) without Solar + Storage and Costs with Solar + Storage as Modeled in Ratio (red) and Intellect RTDS (yellow)

When evaluating the consistency between analytics (Ratio) and operations (Intellect RTDS), end customers and asset owners alike will be focused on the customer bill savings above all else: what savings were promised? And what was actually delivered? As a percentage of the original costs, both Ratio and Intellect RTDS demonstrate substantial annual savings from the REopt-specified equipment specifications, as shown in Figure 2.[3]

[3] Since this analysis focused on the consistency of *bill savings* achieved by a given solar + storage system in Ratio and Intellect RTDS, costs to the customer for the use of the solar + storage system (paid via PPA, lease, or other structure) were not included here. Ratio does have the capability to determine the solar + storage system design that delivers the greatest *net savings* (bill savings less PPA/other costs).

Furthermore, bill savings estimates are quite closely aligned between Ratio and Intellect RTDS. The results for energy cost savings were highly consistent between the two tools, but larger differences between the two software tools were shown in demand charge savings. The relationship between total savings depended the weighting of the bill towards demand or energy costs. As first seen in Figure 1, San Francisco scenarios were heavily weighted towards energy costs, so total bill savings were highly consistent. New York scenarios, by contrast, were weighted towards demand costs, so total bill savings diverged between Ratio and Intellect RTDS. Reasons for these differences with respect to energy and demand are presented below.

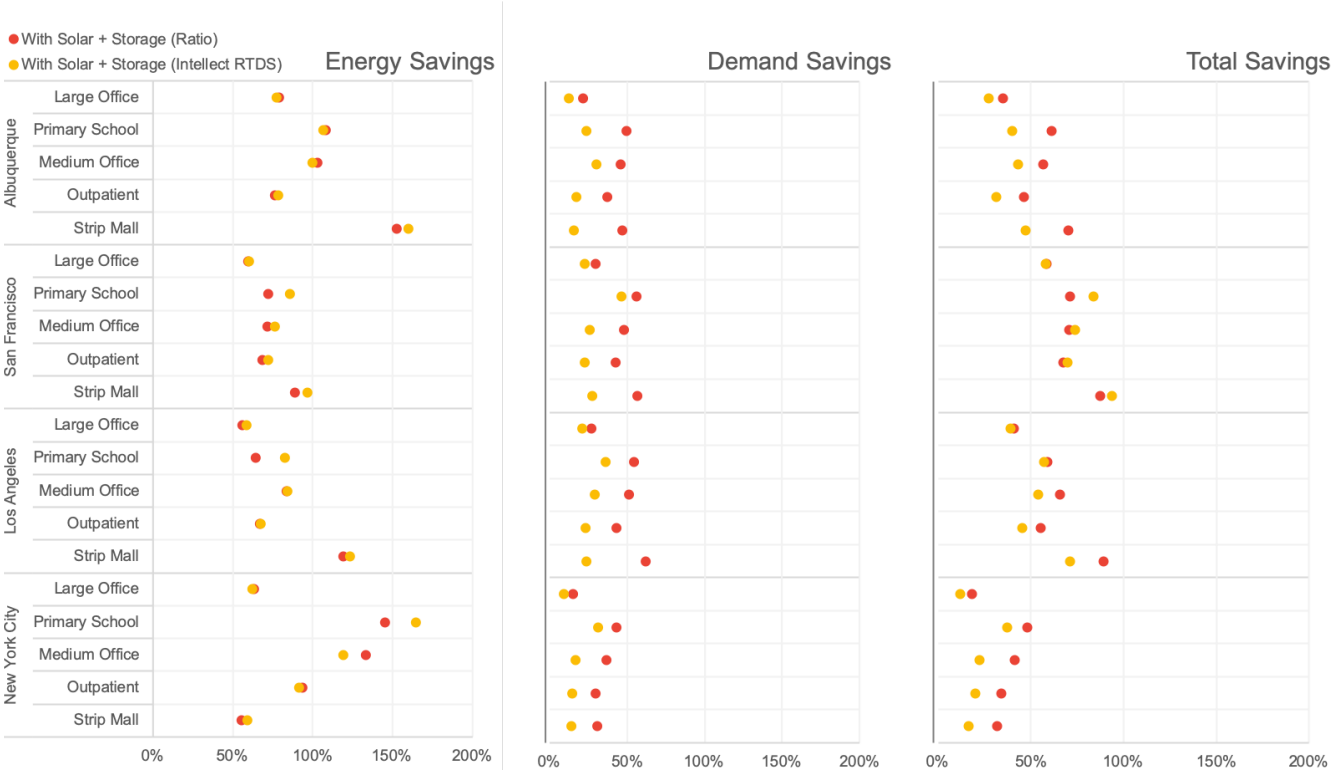


Figure 2: Bill Savings (as % of costs) for Energy, Demand, and Total Charges Delivered by a Solar + Storage System as Modeled in Ratio (red) and Intellect RTDS (yellow)

Finally, we present a single unifying metric, the Performance Ratio, for evaluation of the consistency between Ratio analysis and Intellect RTDS results in Figure 3. Calculated as

$$\frac{(Original\ Bill\ [\$] - Intellect\ RTDS\ Bill\ [\$])}{(Original\ Bill\ [\$] - Ratio\ Bill\ [\$])}$$

this metric sets forth how closely we expect the savings achieved by Intellect to align with the those projected by the perfect foresight methodology of Ratio. Perfect consistency would be represented by a 100% Performance Ratio, with numbers above 100% indicating that Intellect RTDS offers the prospect for even higher savings than those shown in Ratio.

In addition, for the purposes of this evaluation, energy costs were allowed to be driven negative (savings in excess of 100%) by assuming unlimited net energy metering with no caps on excess compensation. This was appropriate since equipment sizes were considered fixed for a given building type for all locations considered in the study. If savings in excess of 100% are prohibited by an actual rate structure, equipment would be downsized according to the net savings capabilities of Ratio.

With respect to the energy charge portion of a customer's bill, the Performance Ratio is centered around 100%, with the Primary School offering an opportunity for higher savings in several locations. This generally conforms with expectations, as most energy cost savings achieved in these scenarios are attributable to the solar energy production of the solar + storage system, which is identical between Ratio and Intellect RTDS. Where energy costs are high, as in the San Francisco scenarios, there is some time-shifting of energy by the storage system, but the volume of energy transferred is far lower than the amount produced by the solar system.

By contrast, the Performance Ratio for demand charges is centered around 50%, with demand savings at the Large Office and Primary School somewhat more achievable. Though unfortunate, lower Performance Ratios for demand are also to be expected. While reductions in energy costs are minimally time-sensitive (especially under robust net energy metering policies, as used here), demand charge savings require delivery of battery power to offset high consumption at exactly the right time. In the perfect foresight of Ratio, the optimal schedule is determined with 100%-accurate visibility into load and solar production levels across the entire year, so the battery will be used judiciously to reduce peak demand. However, as described in Table 2, the Intellect RTDS steps forward in time with only a 24-hour operational horizon, informed by internal load and solar forecasts that inevitably include some level of error. These two factors – shortened operational horizon and forecasting inaccuracies – can easily result in the battery being caught "out of position": having just discharged to manage what was perceived to be a peak demand event, the partially-depleted battery may be less able to address a subsequent peak.

Finally, the total Performance Ratio is directly related to the share of customer's savings that are attributable to energy or demand. For the San Francisco cases, the total Performance Ratio is near 100% because customer costs and savings are almost entirely energy-driven, while some of the New York City cases are at or below 50% due to the emphasis on peak demand.

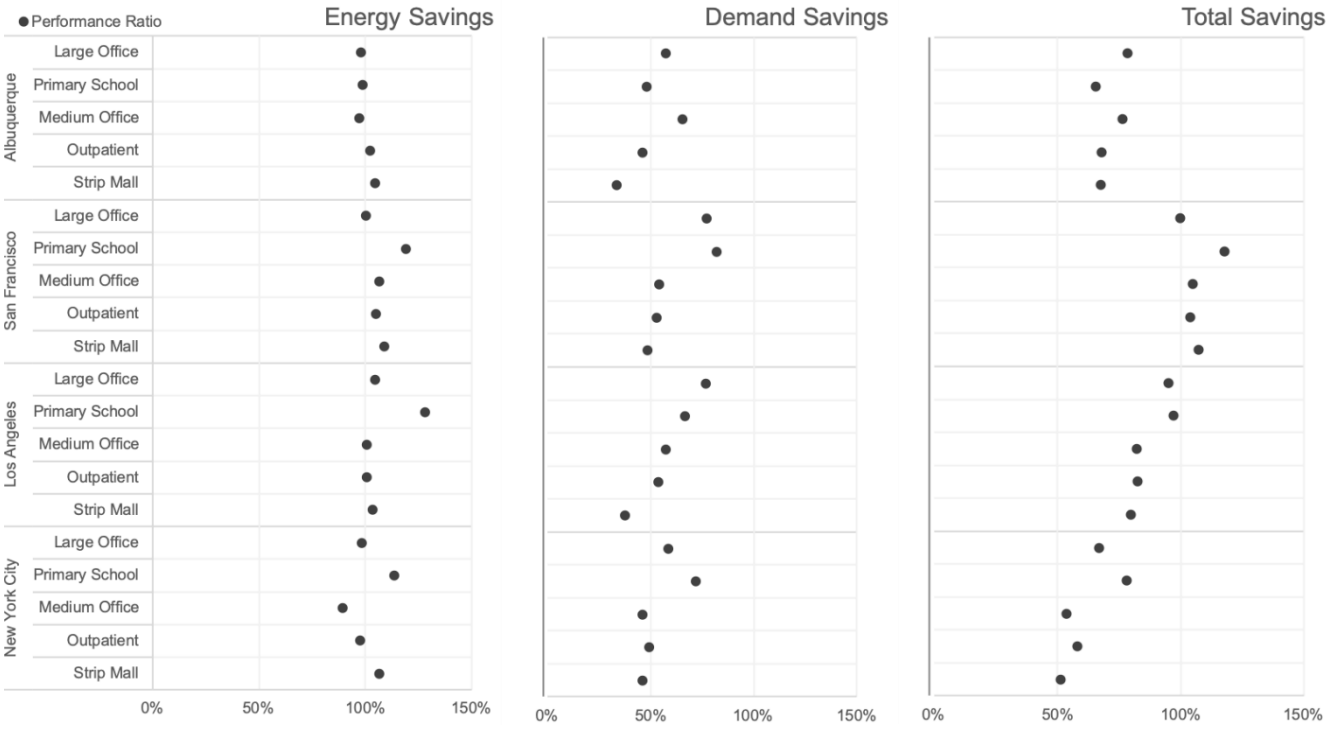


Figure 3: The Performance Ratio (%) with Respect to Energy, Demand, and Total Charges for a Solar + Storage System Modeled in the Nikola Power Platform

What It Means for You and Your Customers

In the earliest days of C&I solar + storage, projects could be sold to customers and asset owners on little more than a good projected savings figure. But customers are getting savvier and the industry is growing warier. For the end customer, a good savings figure must now be paired with technical validation and a performance guarantee of some kind. Meanwhile, asset owners, independent engineers, and technology providers are seeing achieved savings from early deployments falling 20-50% below the originally projected customer savings. Over time, this underperformance will sour end customers on solar + storage and make it harder for project developers to sell their projects to long-term asset owners.

How can project developers navigate this challenging environment? Nikola Power's platform already provides a leg up because Ratio and Intellect are built on the same optimization engine, an improvement over using multiple tools from different vendors in different phases of the project lifecycle. In the future, the Nikola Power platform will drive greater project developer success by helping them:

Make better promises: project developers shouldn't have to rely strictly on the savings generated by a "perfect foresight" analysis when working with customers. Nikola Power is developing ways to accurately discount or adjust the projected savings from Ratio by examining factors like the predictability of the load profile, battery state of charge metrics, etc. This would give developers accurate results while keeping the ability to iterate on system designs quickly.

Use the right tool for the job: solar project developers often use one analytical tool for rapid iteration through system design options and another tool for final bankable assessments. Similarly, project developers on the Nikola Power platform can use Ratio for quick exploration of solar + storage designs before working with the Nikola Power team to complete a bankable assessment using the Intellect RTDS. This process can help developers build a positive track record with end customers and trust with the asset owners who buy and operate their projects.

Create peace of mind: Final project evaluations in Intellect RTDS can also form the basis of more accurate customer savings guarantees. Instead of guaranteeing a fixed percentage of Ratio savings for every project, Nikola Power will soon be able to deliver more robust guarantees based on the more realistic operations of Intellect RTDS.

The success of the solar + storage industry ultimately depends on its ability to consistently deliver real value to customers. Nikola Power is developing the tools that enable project developers to do exactly that. To find out more about how Nikola Power can help you serve your customers better, please get in touch with us at info@nikolapower.com.