# Initial Estimate of Energy Storage Required for Climate Leadership and Community Protection Act Solar and Wind Resources

White Paper Prepared for
New York Department of Public Service
Case 19-E-0530
Resource Adequacy Matters

Prepared by Roger Caiazza
Liverpool, NY 13090

**Executive Summary**

The notice soliciting comments on the Commission's resource adequacy inquiry included the question whether the State's energy policies and mandates are compatible with the NYISO's resource adequacy mechanisms. This White Paper provides an example of the kind of analysis that the Commission should do to determine if the State's energy policies and mandates are feasible. This is a necessary first step before even considering compatibility.

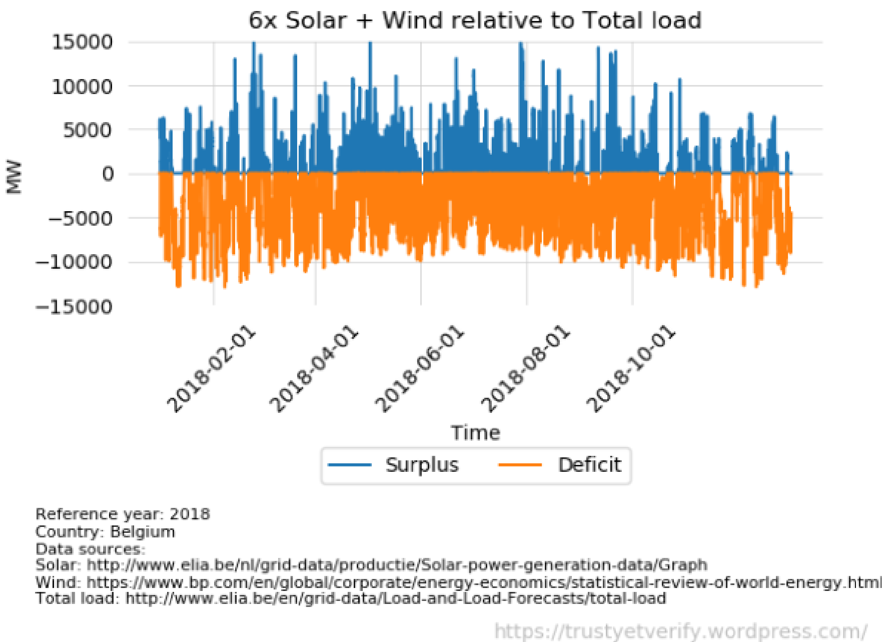
The Climate Leadership and Community Protection Act (CLCPA) includes a mandate to generate zero GHG emissions from electricity production by 2040. This analysis provides an initial estimate of the energy storage required to replace existing fossil fuel generation and the closure of Indian Point. It assumes that this generation will be replaced by proposed to date and additional wind and solar and arbitrarily picks an example deficit period when an aggressive solar and wind resource implementation scenario does not completely replace observed fossil generation.

There are a couple of take away points. Firstly, adding solar and wind capacity increases overall production and production peaks but does not increase output nearly as much during production valleys. Intuitively it is obvious that no amount of additional solar and wind capacity will help during a light wind night and this analysis graphically confirms that. Secondly, the amount of energy storage necessary to replace the deficits that result is significant. Because energy storage is expensive the expected costs are high. In this example it is estimated that the energy storage batteries alone will need to be over $12 billion. That number does not include siting, application, interconnection and other developer costs and there was no attempt made to find the worst-case situation. Consequently, the number could well be an under-estimate of actual costs.

**Approach**

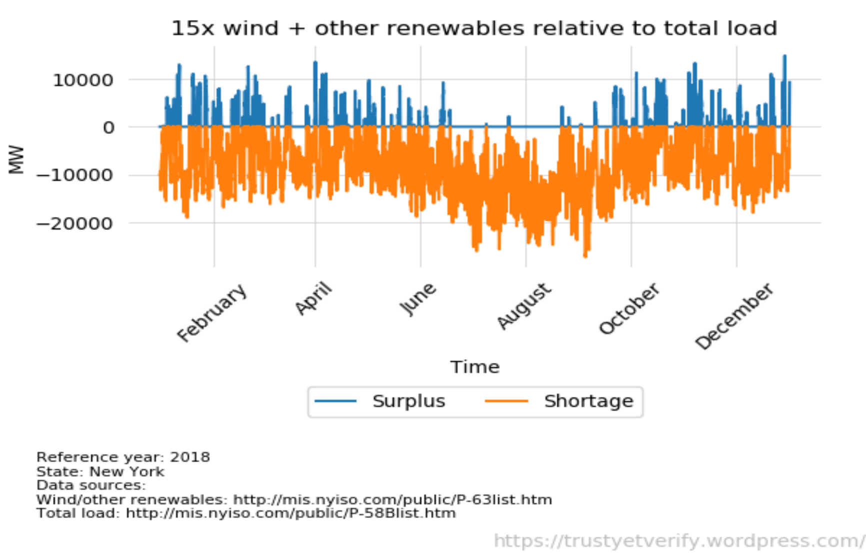
This analysis of real-world data evaluates the potential energy storage needed with a simple solar and wind capacity data analysis "model". The methodology was developed at the Trust, yet Verify blog and applied to Belgian data. In a recent post the author obtained Belgian solar generation, wind generation, and total load data for an entire year. The solar and wind data were summed together for every time period, in his case 15 minutes. Then he projected solar and wind by multiplying the observed sum by different values. In Figure 1 results for a six-fold increase are shown. Each period with surplus is in blue while deficits are gold. The results graphically show that additional intermittent wind and solar capacity increases production peaks but does not increase production nearly as much during production valleys. In addition, the results show that as capacity increases more balancing mechanisms will be required.

**Figure 1: Increase Existing Solar and Wind Six Times Relative to Total Load in Belgium**



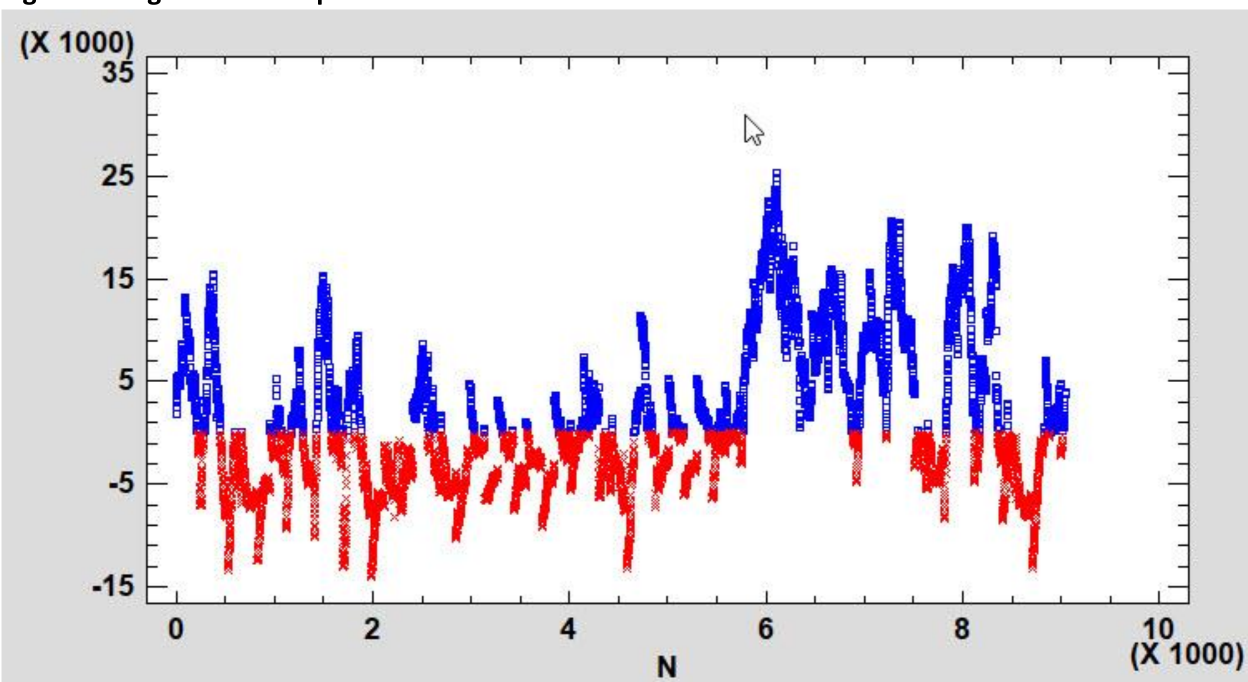

The Trust Yet Verify blog author did the same analysis for the 2018 historical data available at the New York Independent System Operator (NYISO) real-time fuel mix data dashboard. In Figure 2 his results for a fifteen-fold increase in New York wind and "other renewables" are shown. Comparing the Belgian and New York data shows that there is relatively more renewable energy available in Belgium. Despite increasing New York wind and "other renewable" capacity fifteen times there still are many periods of deficits. Further complicating things is the NYISO "other renewable" category that includes methane, refuse, or wood firing. Those other sources are not intermittent so we get mixed signals. Also note that Belgium has a winter peak whereas New York has a summer peak.

**Figure 2: Increase Existing Wind and Other Renewables Relative to Total Load in New York.**



The initial New York results indicated that August has significant deficits so I looked at August 2018 data myself in a multiple step process of increasing sophistication. My primary concern is the effect of the CLCPA on future capacity. Keep in mind that the target is to eliminate fossil fuel use so I first compared solar and wind only to fossil load, i.e., the output from the generators listed as fossil in the NYISO Gold Book Table III-3a: Capability by Zone and Type. Using the same approach as the Trust, yet Verify blog author but only using renewables to replace fossil load gives a similar result. Note that surpluses are blue and deficits are red. There are more surpluses simply because fossil load is less than total load. Note, however, that even if the wind and other renewable categories are increased 26 times the current rate existing fossil cannot be replaced without a lot of shortages.

**Figure 3: August 2018 Simple Model 26 * New York Wind + Other Renewables vs. fossil load**



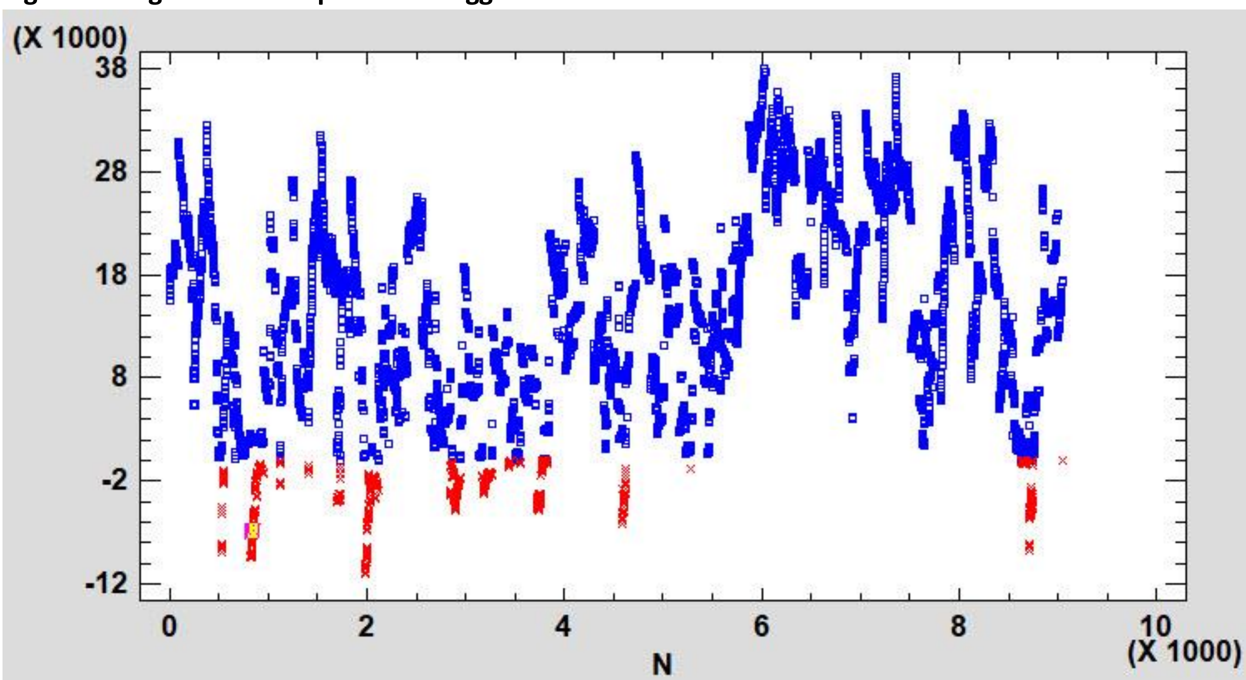

In my second step I refined the Trust, yet Verify simple model approach estimate by incorporating reasonable assumptions about the future using assumptions about the availability of nuclear, solar, and wind. The biggest future change is the forced shutdown of the Indian Pont nuclear facility in the next several years. Because wind and solar sources are intermittent the amount of time when they are available at full load is not constant. For example, solar availability varies during the day and over the month of August there will be periods when the wind is blowing less than optimal. On the other hand assuming that Indian Point capacity is not available at its rated capability is a reasonable assumption because it usually runs at full load except for maintenance.

This more refined analysis projects wind and solar capacity from an aggressive CLCPA implementation plan. In this analysis I want to make a projection that minimizes the amount of energy storage needed. I don't think there will be any significant increase in hydro or the other renewable category sources of methane, refuse, or wood firing and they are not intermittent so I made no changes to those categories. Because New York is shutting down 2,067 MW of nuclear at Indian Point in the next several years I subtracted that amount from every hour. I multiplied the existing onshore wind resource twenty times to estimate future availability. The CLCPA plan currently calls for 9,000 MW of off-shore wind power but

I doubled that amount. The CLCPA plan also calls for 6,000 MW of solar PV power but I doubled that amount too. In order to account for daylight I added 6,000 MW to every time period from 0700 to 1955. In order to account for wind intermittency I made some assumptions about availability and scaled the offshore wind resource down when the on shore resource was below half of the observed maximum.

The refined projections are shown in Figure 4. There are many periods of surpluses (all the renewables minus the existing fossil resource shown in blue) but there are still periods with deficits even with the best case assumptions about renewable availability. The key point is that over-building renewables still leaves the state with deficit periods that will have to be addressed by energy storage or by imports.

**Figure 4: August 2018 Simple Model Aggressive CLCPA Resources vs. Fossil Load**



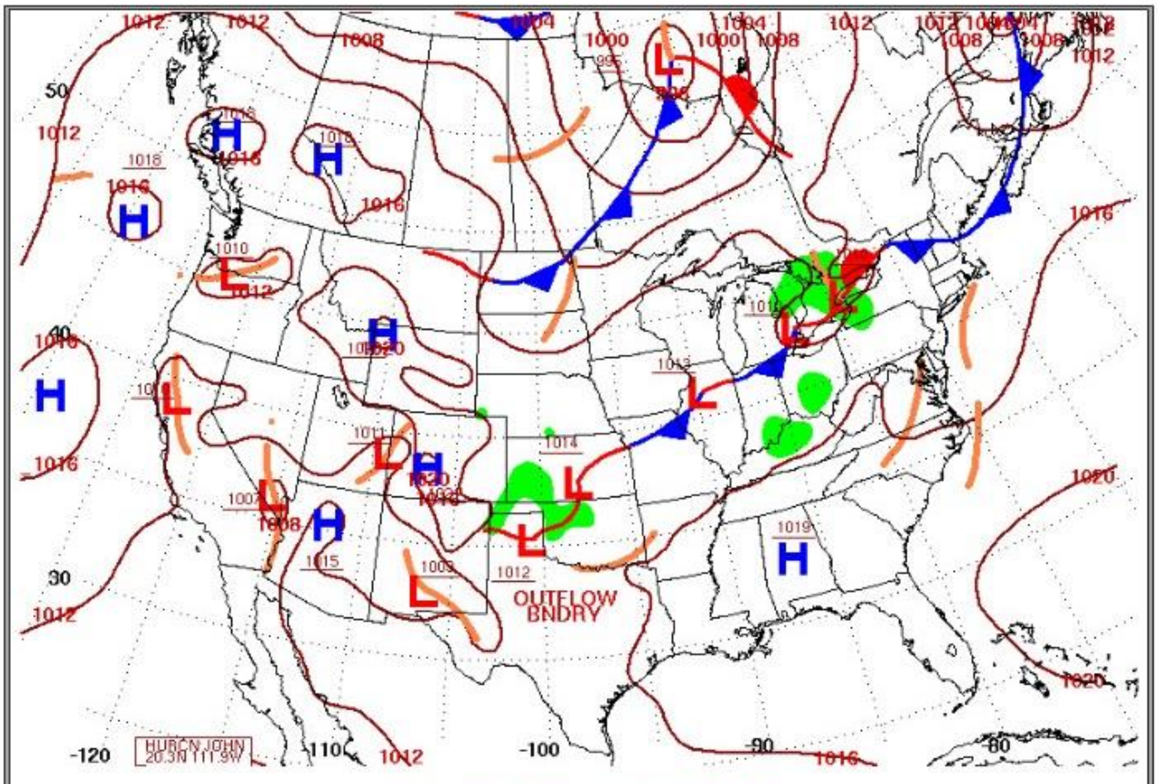

**Resource Adequacy**

The Commission's resource adequacy inquiry has to address the ambitious CLCPA goal to use renewable electric energy to completely replace the current fossil fuel load. I believe this analysis demonstrates that the peak energy load may not be the critical planning scenario in the future. Instead, a calm night with low wind capacity and no solar capacity could be more important for planning even if the period does not have the highest load.

In my final application of this approach I looked at one historical deficit period. For this analysis it is assumed that the onshore wind presumption that additional wind would be proportional to existing wind is adequate. However, I did try to modify the offshore wind and the solar components. In order to do that I chose a shorter period and collected meteorological data to get a better estimate of potential solar and off-shore wind capacity. I arbitrarily chose a seven hour deficit period on the early morning of August 8, 2018 when winds were light and the sun was either not up or not at full strength to look at the potential magnitude of energy storage required to balance the deficit.

In order to characterize the off-shore wind potential I found a National Oceanic and Atmospheric Administration buoy located 30 NM south of Islip, NY (40°15'3" N 73°9'52" W) that I used to represent NY offshore wind resource availability. I downloaded hourly NDBC data for 2018 and scanned the data. As noted August 8 had light winds. The surface weather map for 8 August 2019 (Figure 5) shows that there was a large high pressure system dominating the east coast. As a result, I am confident that this buoy characterizes NY offshore wind speeds and thus the resource of NY offshore wind.

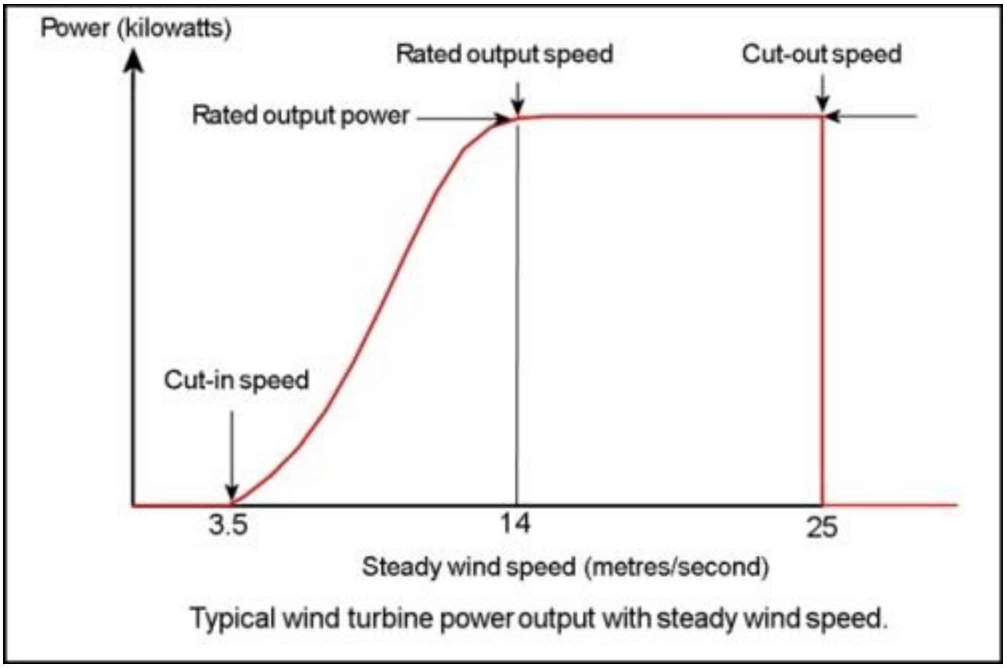
**Figure 5 Surface Weather Map at 0700 EST on August 8, 2018**



Surface Weather Map at 7:00 A.M. E.S.T.

This analysis characterizes wind energy as a function of observed wind as follows. I found a wind turbine power output variation curve (Figure 6) and developed a simple equation for the curve and estimated that the output of 18,000 MW of New York offshore wind equals 1714 times the wind speed minus 6000. I assumed that the observed wind speed at the hub height is proportional to the logarithm of the height above ground. For the calculations I assumed a hub height of 85 m and a surface roughness of 0.0003 while the buoy anemometer height is 4 m. The NY offshore wind output capacity in MW was calculated for every hour using this approach.

Figure 6: Wind Turbine Power Output Variation with Steady Wind Speed.




The solar output is a function of the observed solar irradiation in watts per meter squared. I assumed that 12,000 MW of solar capacity could be added in response to the CLCPA but that will be installed state wide. I downloaded solar irradiance maps from the NYS Mesonet archive. I accessed the solar irradiation map in the spatial analysis directory to get solar irradiation maps and as an added bonus the maps also include gridded winds. The gridded wind maps confirm that there were light winds across NY during this period. The NYS Mesonet Solar Irradiance Map shown in Figure 7 is an example of these maps and can be reproduced at this link. In this case there is a lot of solar irradiation variation across the state which makes a state-wide single estimate weak but sufficient for this first cut analysis. I estimate that the highest irradiance was 900 W/m2 and the lowest was around 100 W/m2. For this hour I guessed 600 W/m2 for the state. To do this better one would have to determine where the solar panels might be located to weight the observations. The available maps for the entire period are included in Energy Storage White Paper Appendix 1.

In order to calculate solar energy output, I assumed that the CLCPA solar buildout produces 12,000 MW when the solar irradiation equals 800 watts per square meter (the PVUSA test condition) and I did not account for any other factors such as the cell temperature or any losses. So my naïve formula for solar output was simply the observed input solar irradiation times 12,000 divided by 800. Note that this means solar output is greater than 12,000 MW whenever solar irradiation is greater than 800.

Figure 7: Solar Irradiance Map  8 August 2018 at 1525 UTC

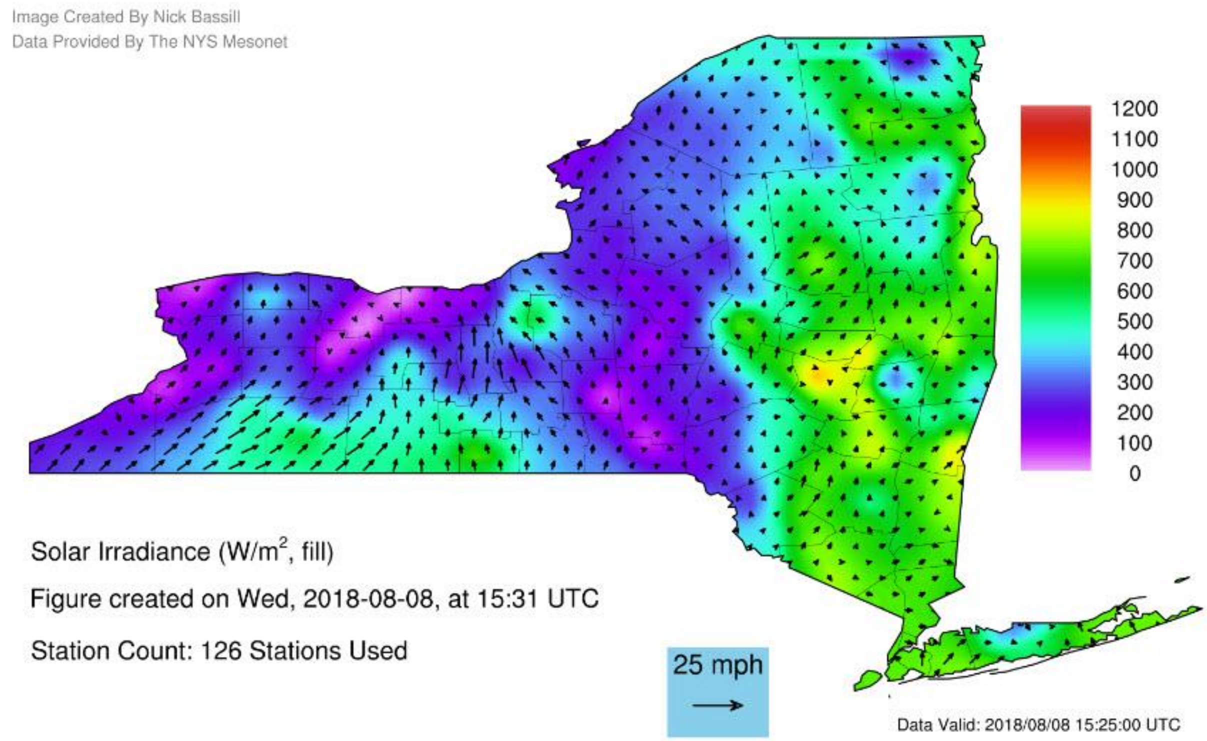



Table 1 lists 5-minute from the 0300 to 0955 EDT deficit period when the assumed aggressive CLCPA renewable capacity could not replace the observed fossil capacity and loss of the Indian Point nuclear facility.   The first three data columns list the total NYISO state-wide generation load, the NYISO total load, and the fossil generation load.  The next three columns list the onshore wind load, CLCPA solar load, and the CLCPE off-shore wind load calculated as described above.  The column headed CLCPA renewables minus fossil and Indian Point is the margin between the aggressive CLCPA renewables and the observed fossil and Indian Point loads.  The last three columns present the meteorological data used.   In this period all the five-minute periods were negative.  This illustrates my concern that the future CLCPA constraint may not be the peak load but instead a night-time low wind period.

**Table 1: Deficit Example of Simple Model of Intermittent Wind and Solar Generation vs. Fossil Generation Replacement and Indian Point Shutdown**

| Date Time (EDT) | Generation Load (MW) | Total Load (MW) | Fossil Load (MW) | Onshore Wind Load (MW) | Offshore CLCPA wind | CLCPA solar Load (MW) | CLCPA Renewables - Fossil and Indian Point (MW Margin) | Buoy Wind Speed (m/s) | Hub Wind Speed (m/s) | Solar Irradiance W/m2 |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/8/2018 03:00 | 14,873 | 16,821 | 7,364 | 960 | 7,596 | 0 | -875 | 6.0 | 7.9 | 0 |
| 8/8/2018 03:05 | 15,067 | 16,781 | 7,467 | 960 | 7,596 | 0 | -978 | 6.0 | 7.9 | 0 |
| 8/8/2018 03:10 | 15,017 | 16,734 | 7,456 | 960 | 7,596 | 0 | -967 | 6.0 | 7.9 | 0 |
| 8/8/2018 03:15 | 15,004 | 16,754 | 7,456 | 920 | 7,596 | 0 | -1,007 | 6.0 | 7.9 | 0 |
| 8/8/2018 03:20 | 14,999 | 16,747 | 7,476 | 840 | 7,596 | 0 | -1,107 | 6.0 | 7.9 | 0 |
| 8/8/2018 03:25 | 14,983 | 16,744 | 7,495 | 800 | 7,596 | 0 | -1,166 | 6.0 | 7.9 | 0 |
| 8/8/2018 03:30 | 14,928 | 16,722 | 7,477 | 800 | 7,596 | 0 | -1,148 | 6.0 | 7.9 | 0 |
| 8/8/2018 03:35 | 14,914 | 16,689 | 7,451 | 780 | 7,596 | 0 | -1,142 | 6.0 | 7.9 | 0 |
| 8/8/2018 03:40 | 14,911 | 16,619 | 7,468 | 720 | 7,596 | 0 | -1,219 | 6.0 | 7.9 | 0 |
| 8/8/2018 03:45 | 14,911 | 16,659 | 7,485 | 660 | 7,596 | 0 | -1,296 | 6.0 | 7.9 | 0 |
| 8/8/2018 03:50 | 14,948 | 16,610 | 7,519 | 600 | 7,596 | 0 | -1,390 | 6.0 | 7.9 | 0 |
| 8/8/2018 03:55 | 14,941 | 16,614 | 7,510 | 600 | 7,596 | 0 | -1,381 | 6.0 | 7.9 | 0 |
| 8/8/2018 04:00 | 14,934 | 16,655 | 7,512 | 700 | 1,024 | 0 | -7,855 | 3.1 | 4.1 | 0 |
| 8/8/2018 04:05 | 14,984 | 16,604 | 7,516 | 840 | 1,024 | 0 | -7,719 | 3.1 | 4.1 | 0 |
| 8/8/2018 04:10 | 15,014 | 16,608 | 7,524 | 880 | 1,024 | 0 | -7,687 | 3.1 | 4.1 | 0 |
| 8/8/2018 04:15 | 15,104 | 16,674 | 7,560 | 840 | 1,024 | 0 | -7,763 | 3.1 | 4.1 | 0 |
| 8/8/2018 04:20 | 15,121 | 16,668 | 7,591 | 740 | 1,024 | 0 | -7,894 | 3.1 | 4.1 | 0 |
| 8/8/2018 04:25 | 15,126 | 16,639 | 7,632 | 640 | 1,024 | 0 | -8,035 | 3.1 | 4.1 | 0 |
| 8/8/2018 04:30 | 15,092 | 16,612 | 7,617 | 560 | 1,024 | 0 | -8,100 | 3.1 | 4.1 | 0 |
| 8/8/2018 04:35 | 15,119 | 16,621 | 7,628 | 540 | 1,024 | 0 | -8,131 | 3.1 | 4.1 | 0 |
| 8/8/2018 04:40 | 15,136 | 16,684 | 7,635 | 560 | 1,024 | 0 | -8,118 | 3.1 | 4.1 | 0 |
| 8/8/2018 04:45 | 15,107 | 16,693 | 7,635 | 580 | 1,024 | 0 | -8,098 | 3.1 | 4.1 | 0 |
| 8/8/2018 04:50 | 15,146 | 16,720 | 7,635 | 640 | 1,024 | 0 | -8,038 | 3.1 | 4.1 | 0 |
| 8/8/2018 04:55 | 15,160 | 16,728 | 7,622 | 680 | 1,024 | 0 | -7,985 | 3.1 | 4.1 | 0 |
| 8/8/2018 05:00 | 15,170 | 16,807 | 7,624 | 600 | 4,197 | 0 | -4,894 | 4.5 | 5.9 | 0 |
| 8/8/2018 05:05 | 15,169 | 16,847 | 7,609 | 600 | 4,197 | 0 | -4,879 | 4.5 | 5.9 | 0 |
| 8/8/2018 05:10 | 15,207 | 16,948 | 7,643 | 680 | 4,197 | 0 | -4,833 | 4.5 | 5.9 | 0 |
| 8/8/2018 05:15 | 15,272 | 16,982 | 7,718 | 740 | 4,197 | 0 | -4,848 | 4.5 | 5.9 | 0 |
| 8/8/2018 05:20 | 15,320 | 17,013 | 7,780 | 740 | 4,197 | 0 | -4,910 | 4.5 | 5.9 | 0 |
| 8/8/2018 05:25 | 15,388 | 17,116 | 7,858 | 760 | 4,197 | 0 | -4,968 | 4.5 | 5.9 | 0 |

**Table 1, cont.: Deficit Example of Simple Model of Intermittent Wind and Solar Generation vs. Fossil Generation Replacement and Indian Point Shutdown**

| Date Time (EDT) | Generation Load (MW) | Total Load (MW) | Fossil Load (MW) | Onshore Wind Load (MW) | Offshore CLCPA wind | CLCPA solar Load (MW) | CLCPA Renewables - Fossil and Indian Point (MW Margin) | Buoy Wind Speed (m/s) | Hub Wind Speed (m/s) | Solar Irradiance W/m2 |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/8/2018 05:30 | 15,458 | 17,166 | 7,931 | 720 | 4,197 | 0 | -5,081 | 4.5 | 5.9 | 0 |
| 8/8/2018 05:35 | 15,577 | 17,231 | 8,012 | 720 | 4,197 | 0 | -5,162 | 4.5 | 5.9 | 0 |
| 8/8/2018 05:40 | 15,664 | 17,282 | 8,077 | 660 | 4,197 | 0 | -5,287 | 4.5 | 5.9 | 0 |
| 8/8/2018 05:45 | 15,793 | 17,334 | 8,168 | 680 | 4,197 | 0 | -5,358 | 4.5 | 5.9 | 0 |
| 8/8/2018 05:50 | 15,900 | 17,416 | 8,270 | 740 | 4,197 | 0 | -5,400 | 4.5 | 5.9 | 0 |
| 8/8/2018 05:55 | 15,964 | 17,447 | 8,337 | 760 | 4,197 | 0 | -5,447 | 4.5 | 5.9 | 0 |
| 8/8/2018 06:00 | 15,922 | 17,512 | 8,307 | 800 | 2,157 | 0 | -7,417 | 3.6 | 4.8 | 0 |
| 8/8/2018 06:05 | 15,821 | 17,554 | 8,257 | 760 | 2,157 | 0 | -7,407 | 3.6 | 4.8 | 0 |
| 8/8/2018 06:10 | 15,769 | 17,704 | 8,253 | 720 | 2,157 | 0 | -7,443 | 3.6 | 4.8 | 0 |
| 8/8/2018 06:15 | 15,923 | 17,824 | 8,357 | 840 | 2,157 | 0 | -7,427 | 3.6 | 4.8 | 0 |
| 8/8/2018 06:20 | 16,086 | 17,912 | 8,420 | 1320 | 2,157 | 0 | -7,010 | 3.6 | 4.8 | 0 |
| 8/8/2018 06:25 | 16,130 | 18,028 | 8,459 | 1300 | 2,157 | 750 | -6,319 | 3.6 | 4.8 | 50 |
| 8/8/2018 06:30 | 16,124 | 18,099 | 8,452 | 1200 | 2,157 | 750 | -6,412 | 3.6 | 4.8 | 50 |
| 8/8/2018 06:35 | 16,291 | 18,150 | 8,550 | 1140 | 2,157 | 750 | -6,570 | 3.6 | 4.8 | 50 |
| 8/8/2018 06:40 | 16,451 | 18,287 | 8,657 | 1120 | 2,157 | 750 | -6,697 | 3.6 | 4.8 | 50 |
| 8/8/2018 06:45 | 16,541 | 18,391 | 8,759 | 1160 | 2,157 | 750 | -6,759 | 3.6 | 4.8 | 50 |
| 8/8/2018 06:50 | 16,786 | 18,474 | 8,878 | 1200 | 2,157 | 750 | -6,838 | 3.6 | 4.8 | 50 |
| 8/8/2018 06:55 | 17,051 | 18,659 | 9,009 | 1140 | 2,157 | 2,250 | -5,529 | 3.6 | 4.8 | 150 |
| 8/8/2018 07:00 | 17,109 | 18,735 | 9,049 | 1060 | 798 | 2,250 | -7,008 | 3.0 | 4.0 | 150 |
| 8/8/2018 07:05 | 17,198 | 18,920 | 9,046 | 940 | 798 | 2,250 | -7,125 | 3.0 | 4.0 | 150 |
| 8/8/2018 07:10 | 17,417 | 19,132 | 9,131 | 820 | 798 | 2,250 | -7,330 | 3.0 | 4.0 | 150 |
| 8/8/2018 07:15 | 17,643 | 19,262 | 9,262 | 680 | 798 | 2,250 | -7,601 | 3.0 | 4.0 | 150 |
| 8/8/2018 07:20 | 17,819 | 19,414 | 9,378 | 520 | 798 | 2,250 | -7,877 | 3.0 | 4.0 | 150 |
| 8/8/2018 07:25 | 18,039 | 19,545 | 9,509 | 460 | 798 | 3,000 | -7,318 | 3.0 | 4.0 | 200 |
| 8/8/2018 07:30 | 18,341 | 19,650 | 9,605 | 440 | 798 | 3,000 | -7,434 | 3.0 | 4.0 | 200 |
| 8/8/2018 07:35 | 18,333 | 19,781 | 9,705 | 540 | 798 | 3,000 | -7,434 | 3.0 | 4.0 | 200 |
| 8/8/2018 07:40 | 18,306 | 19,918 | 9,771 | 600 | 798 | 3,000 | -7,440 | 3.0 | 4.0 | 200 |

**Table 1, cont.: Deficit Example of Simple Model of Intermittent Wind and Solar Generation vs. Fossil Generation Replacement and Indian Point Shutdown**

| Date Time (EDT) | Generation Load (MW) | Total Load (MW) | Fossil Load (MW) | Onshore Wind Load (MW) | Offshore CLCPA wind | CLCPA solar Load (MW) | CLCPA Renewables - Fossil and Indian Point (MW Margin) | Buoy Wind Speed (m/s) | Hub Wind Speed (m/s) | Solar Irradiance W/m2 |
|---|---|---|---|---|---|---|---|---|---|---|
| 8/8/2018 07:45 | 18,339 | 19,965 | 9,857 | 560 | 798 | 3,000 | -7,566 | 3.0 | 4.0 | 200 |
| 8/8/2018 07:50 | 18,606 | 20,128 | 10,044 | 600 | 798 | 3,000 | -7,713 | 3.0 | 4.0 | 200 |
| 8/8/2018 07:55 | 18,818 | 20,204 | 10,214 | 700 | 798 | 3,750 | -7,033 | 3.0 | 4.0 | 250 |
| 8/8/2018 08:00 | 18,973 | 20,399 | 10,362 | 680 | 3,064 | 3,750 | -4,935 | 4.0 | 5.3 | 250 |
| 8/8/2018 08:05 | 19,364 | 20,443 | 10,710 | 660 | 3,064 | 3,750 | -5,303 | 4.0 | 5.3 | 250 |
| 8/8/2018 08:10 | 19,743 | 20,669 | 10,936 | 640 | 3,064 | 3,750 | -5,549 | 4.0 | 5.3 | 250 |
| 8/8/2018 08:15 | 19,980 | 20,759 | 11,092 | 580 | 3,064 | 3,750 | -5,765 | 4.0 | 5.3 | 250 |
| 8/8/2018 08:20 | 20,135 | 20,923 | 11,245 | 540 | 3,064 | 3,750 | -5,958 | 4.0 | 5.3 | 250 |
| 8/8/2018 08:25 | 20,220 | 20,976 | 11,351 | 560 | 3,064 | 4,500 | -5,294 | 4.0 | 5.3 | 300 |
| 8/8/2018 08:30 | 20,318 | 21,022 | 11,446 | 520 | 3,064 | 4,500 | -5,429 | 4.0 | 5.3 | 300 |
| 8/8/2018 08:35 | 20,321 | 21,143 | 11,507 | 460 | 3,064 | 4,500 | -5,550 | 4.0 | 5.3 | 300 |
| 8/8/2018 08:40 | 20,297 | 21,286 | 11,542 | 480 | 3,064 | 4,500 | -5,565 | 4.0 | 5.3 | 300 |
| 8/8/2018 08:45 | 20,367 | 21,332 | 11,595 | 540 | 3,064 | 4,500 | -5,558 | 4.0 | 5.3 | 300 |
| 8/8/2018 08:50 | 20,388 | 21,399 | 11,665 | 540 | 3,064 | 4,500 | -5,628 | 4.0 | 5.3 | 300 |
| 8/8/2018 08:55 | 20,351 | 21,490 | 11,674 | 540 | 3,064 | 6,750 | -3,387 | 4.0 | 5.3 | 450 |
| 8/8/2018 09:00 | 20,472 | 21,578 | 11,768 | 540 | 2,611 | 6,750 | -3,934 | 3.8 | 5.0 | 450 |
| 8/8/2018 09:05 | 20,585 | 21,618 | 11,915 | 480 | 2,611 | 6,750 | -4,141 | 3.8 | 5.0 | 450 |
| 8/8/2018 09:10 | 20,557 | 21,772 | 11,956 | 500 | 2,611 | 6,750 | -4,162 | 3.8 | 5.0 | 450 |
| 8/8/2018 09:15 | 20,602 | 21,856 | 11,974 | 700 | 2,611 | 6,750 | -3,980 | 3.8 | 5.0 | 450 |
| 8/8/2018 09:20 | 20,682 | 21,975 | 12,026 | 660 | 2,611 | 6,750 | -4,072 | 3.8 | 5.0 | 450 |
| 8/8/2018 09:25 | 20,750 | 22,037 | 12,073 | 760 | 2,611 | 7,500 | -3,269 | 3.8 | 5.0 | 500 |
| 8/8/2018 09:30 | 20,884 | 22,133 | 12,151 | 840 | 2,611 | 7,500 | -3,267 | 3.8 | 5.0 | 500 |
| 8/8/2018 09:35 | 20,908 | 22,214 | 12,206 | 960 | 2,611 | 7,500 | -3,202 | 3.8 | 5.0 | 500 |
| 8/8/2018 09:40 | 20,965 | 22,276 | 12,234 | 1100 | 2,611 | 7,500 | -3,090 | 3.8 | 5.0 | 500 |
| 8/8/2018 09:45 | 21,018 | 22,364 | 12,265 | 1480 | 2,611 | 7,500 | -2,741 | 3.8 | 5.0 | 500 |
| 8/8/2018 09:50 | 21,084 | 22,478 | 12,301 | 2080 | 2,611 | 7,500 | -2,177 | 3.8 | 5.0 | 500 |
| 8/8/2018 09:55 | 21,101 | 22,563 | 12,340 | 2560 | 2,611 | 8,250 | -986 | 3.8 | 5.0 | 550 |

**Energy Storage Requirements and Costs**

I am unfamiliar with an analysis that attempted to determine how much storage capacity would be required to meet a real-world generation capacity deficit in New York State so I did not have an example methodology to use. Clearly the total capacity has to exceed the observed deficit. In this case I estimate that the total deficit equals the sum of the average of the twelve 5-minute deficits each hour or 33,548 MWh. I think that the maximum output of the necessary energy storage has to equal the largest 5-minute deficit or 8,131 MW.

After that it is not clear how best to divvy up the energy storage requirements. I assumed that the least cost energy storage approach would maximize energy storage duration based on lower costs per MWh in a recently released report from the National Renewable Energy Lab (NREL): "2018 U.S. Utility-Scale Photovoltaics-Plus-Energy Storage System Cost Benchmark". The report estimates costs for engineering, procurement and construction (EPC) and development including permitting, land acquisition and interconnection.

Unfortunately, the NREL document does not list costs for durations greater than four hours. Table 3 in the NREL document, Detailed Cost Breakdown for a 60-MW U.S. Li-ion Standalone Storage System with Durations of 0.5–4 Hours, provides the information necessary to extend their projections to different durations (Table 2). For example, NREL estimated the installation labor and expense cost ranging from 0.5 hours to 4 hours. I fit a linear regression model to describe the relationship between that and other costs and energy storage duration so I could extend the cost estimates. I use Statgraphics Centurion software from StatPoint Technologies, Inc. to do my statistical analyses because it provides flexible plotting and regression tools. Statgraphics enables the user to choose the best relationship from 27 different linear regression equations. In this evaluation in every instance, the reciprocal-X model (Y = a + b/X) statistic was the best choice and every regression had an R-squared coefficient great than 99.9% which indicates a strong relationship and suggests that these estimates are adequate for this analysis. Table 3 lists the estimated cost breakdown $/kWh parameters for the six capacity and duration U.S. Li-ion standalone storage systems I estimate are required to prevent a deficit in this example. The table provides the parameters so that the $/kWh value so any duration system can be calculated.

Table 2: NREL Detailed Cost Breakdown from "[2018 U.S. Utility-Scale Photovoltaics-Plus-Energy Storage System Cost Benchmark".]()

**Table 3. Detailed Cost Breakdown for a 60-MW U.S. Li-ion Standalone Storage System with Durations of 0.5–4 Hours**

| | 60-MW, 4-hour Duration, 240-MWh | | | 60-MW, 2-hour Duration, 120-MWh | | | 60-MW, 1-hour Duration, 60-MWh | | | 60-MW, 0.5-hour Duration, 30-MWh | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Model Component** | **Total Cost ($)** | **$/kWh** | **$/W** | **Total Cost ($)** | **$/kWh** | **$/W** | **Total Cost ($)** | **$/kWh** | **$/W** | **Total Cost ($)** | **$/kWh** | **$/W** |
| Li-ion battery | 50,160,000 | 209 | 0.84 | 25,080,000 | 209 | 0.42 | 12,540,000 | 209 | 0.21 | 6,270,000 | 209 | 0.10 |
| Battery central inverter | 4,200,000 | 18 | 0.07 | 4,200,000 | 35 | 0.07 | 4,200,000 | 70 | 0.07 | 4,200,000 | 140 | 0.07 |
| Structural BOS | 3,121,131 | 13 | 0.05 | 1,813,452 | 15 | 0.03 | 1,159,612 | 19 | 0.02 | 832,692 | 28 | 0.01 |
| Electrical BOS | 8,602,825 | 36 | 0.14 | 6,119,167 | 51 | 0.10 | 4,877,337 | 81 | 0.08 | 4,256,423 | 142 | 0.07 |
| Installation labor & equipment | 5,479,149 | 23 | 0.09 | 4,322,275 | 36 | 0.07 | 3,743,838 | 62 | 0.06 | 3,454,619 | 115 | 0.06 |
| EPC overhead | 2,775,545 | 12 | 0.05 | 1,948,565 | 16 | 0.03 | 1,535,075 | 26 | 0.03 | 1,328,330 | 44 | 0.02 |
| Sales tax | 5,293,460 | 22 | 0.09 | 3,083,292 | 26 | 0.05 | 1,978,209 | 33 | 0.03 | 1,425,667 | 48 | 0.02 |
| **∑ EPC cost** | **79,632,110** | **332** | **1.33** | **46,566,751** | **388** | **0.78** | **30,034,071** | **501** | **0.50** | **21,767,732** | **726** | **0.36** |
| Land acquisition | 250,000 | 1 | 0.00 | 250,000 | 2 | 0.00 | 250,000 | 4 | 0.00 | 250,000 | 8 | 0.00 |
| Permitting fee | 295,289 | 1 | 0.00 | 295,289 | 2 | 0.00 | 295,289 | 5 | 0.00 | 295,289 | 10 | 0.00 |
| Interconnection fee | 1,802,363 | 8 | 0.03 | 1,802,363 | 15 | 0.03 | 1,802,363 | 30 | 0.03 | 1,802,363 | 60 | 0.03 |
| Contingency | 2,477,135 | 10 | 0.04 | 1,476,303 | 12 | 0.02 | 975,887 | 16 | 0.02 | 725,679 | 24 | 0.01 |
| Developer overhead | 2,477,135 | 10 | 0.04 | 1,476,303 | 12 | 0.02 | 975,887 | 16 | 0.02 | 725,679 | 24 | 0.01 |
| EPC/developer net profit | 4,346,702 | 18 | 0.07 | 2,593,350 | 22 | 0.04 | 1,716,675 | 29 | 0.03 | 1,278,337 | 43 | 0.02 |
| **∑ Developer cost** | **11,648,623** | **49** | **0.19** | **7,893,608** | **66** | **0.13** | **6,016,101** | **100** | **0.10** | **5,077,347** | **169** | **0.08** |
| **∑ Total energy storage system cost** | **91,280,733** | **380** | **1.52** | **54,460,359** | **454** | **0.91** | **36,050,172** | **601** | **0.60** | **26,845,079** | **895** | **0.45** |

**Table3: Calculated Cost Breakdown $/kWh Parameters for a U.S. Li-ion Standalone Storage System for Different Durations**

| | | | Duration | 7 | 6 | 5 | 1 | 2 | 1 |
|---|---|---|---|---|---|---|---|---|---|
| | | | **Capacity** | **60** | **1,300** | **2,750** | **2,690** | **1,250** | **1,870** |
| | **$/kWh Parameters** | | | | | | | | |
| **Model Component** | **Intercept** | **Slope** | **R squared** | **$/kWh** | **$/kWh** | **$/kWh** | **$/kWh** | **$/kWh** | **$/kWh** |
| Li-ion battery | Fixed $/kWh | | | 209 | 209 | 209 | 209 | 209 | 209 |
| Battery central inverter | 0.30348 | 69.8087 | 100% | 10.3 | 11.9 | 14.3 | 70.1 | 35.2 | 70.1 |
| Structural BOS | 10.6957 | 8.5913 | 99.95% | 11.9 | 12.1 | 12.4 | 19.3 | 15.0 | 19.3 |
| Electrical BOS | 20.6957 | 60.5913 | 100% | 29.4 | 30.8 | 32.8 | 81.3 | 51.0 | 81.3 |
| Installation labor & equipment | 9.69565 | 52.5913 | 100% | 17.2 | 18.5 | 20.2 | 62.3 | 36.0 | 62.3 |
| EPC overhead | 7.21739 | 18.4348 | 99.94% | 9.9 | 10.3 | 10.9 | 25.7 | 16.4 | 25.7 |
| Sales tax | 18.3913 | 14.7826 | 99.80% | 20.5 | 20.9 | 21.3 | 33.2 | 25.8 | 33.2 |
| **∑ EPC cost** | | | | **308** | **313** | **321** | **501** | **388** | **501** |
| Land acquisition | Fixed total cost | | | 0.60 | 0.00 | 0.02 | 0.00 | 0.10 | 0.00 |
| Permitting fee | Fixed total cost | | | 0.70 | 0.00 | 0.02 | 0.00 | 0.12 | 0.00 |
| Interconnection fee | Fixed total cost | | | 4 | 0 | 0 | 0 | 1 | 0 |
| Contingency | 8 | 8 | 100.00% | 9.1 | 9.3 | 9.6 | 16.0 | 12.0 | 16.0 |
| Developer overhead | 8 | 8 | 100.00% | 9.1 | 9.3 | 9.6 | 16.0 | 12.0 | 16.0 |
| EPC/developer net profit | 14.6957 | 14.1913 | 99.97% | 16.7 | 17.1 | 17.5 | 28.9 | 21.8 | 28.9 |
| **∑ Developer cost** | | | | **41** | **36** | **37** | **61** | **47** | **61** |
| **∑ Total energy storage system cost** | | | | **349** | **349** | **358** | **562** | **435** | **562** |

Table 4 estimates the energy storage needs and my projection for the amount of different duration energy storage needed to cover the projected seven hour deficit on August 8, 2018. In the first hour of the deficit period the hourly average was 1,140 MW but the peak was 1,390 MW so I project 1,400 MW at 7-hour duration could be used. The next hour had the peak 5-minute deficit of 8,131 MW. In order to meet that and subsequent hours I project 1,300 MW at 6-hour duration, 2,750 MW at 5-hour duration and 2,690 MW at 1-hour duration would cover that peak and most of the subsequent deficits. In order to cover subsequent peaks I added 1,250 MW at 2-hour duration and 620 MW at 1-hour duration. The total MWh stored (37,160) exceeds the observed total deficit (33,548) by 3,612 so there is a lot of room for refining this analysis but that has to be weighed against the fact that no attempt was made to find the worst case period.

If we combine the estimated energy storage resources required with the NREL energy storage benchmark costs we can estimate potential costs. In this example I only calculated the EPC costs. Clearly it will not be possible to build a single facility to cover the calculated requirements. In order to cover the deficit of energy produced by solar and wind resources at an aggressive level over current on-shore wind and proposed CLCPA solar and wind, $12.5 billion dollars for just the batteries will be required to replace existing fossil generation and Indian Point.

**Table 4: Estimated Energy Storage Required and Potential Price Necessary to Prevent Deficit on August 8 2018**

| | | | | Energy Storage Systems | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Average** | **Minimum** | **Total (MWhr)** | 9,800 | 7,800 | 13,750 | 2,690 | 2,500 | 620 | **Total** | **Storage** |
| | **Deficit** | **Deficit** | **Capacity (MW)** | 1,400 | 1,300 | 2,750 | 2,690 | 1,250 | 620 | **Storage** | **Margin** |
| **Date Time (EDT)** | **MWhr** | **MW5-min** | **Duration (Hr)** | 7 | 6 | 5 | 1 | 2 | 1 | **Used** | **(MW)** |
| 8/8/2018 03:00 | -1,140 | -1,390 | | 1,400 | | | | | | 1,400 | 10 |
| 8/8/2018 04:00 | -7,951 | -8,131 | | 1,400 | 1,300 | 2,750 | 2,690 | | | 8,140 | 9 |
| 8/8/2018 05:00 | -5,089 | -5,447 | | 1,400 | 1,300 | 2,750 | | | | 5,450 | 3 |
| 8/8/2018 06:00 | -6,819 | -7,443 | | 1,400 | 1,300 | 2,750 | | 1,250 | | 6,700 | -743 |
| 8/8/2018 07:00 | -7,407 | -7,877 | | 1,400 | 1,300 | 2,750 | | 1,250 | 620 | 7,320 | -557 |
| 8/8/2018 08:00 | -5,327 | -5,958 | | 1,400 | 1,300 | 2,750 | | | | 5,450 | -508 |
| 8/8/2018 09:00 | -3,252 | -4,162 | | 1,400 | 1,300 | | | | | 2,700 | -1,462 |
| Total | -36,985 | | | | | | | | | | |

**NREL Energy Storage Benchmark Prices ($millions)**

| | | | | | | |
|---|---|---|---|---|---|---|
| $/KWhr | $ 308 | $ 313 | $ 321 | $ 501 | $ 388 | $ 501 |
| Battery Total | $ 3,020 | $ 2,445 | $ 4,413 | $ 1,347 | $ 971 | $ 310 |
| **Grand total** | **$ 12,506** | | | | | |