

2017 Update to IESO's Solar PV and Wind Cost Outlooks

Prepared for Internal IESO Discussion

Planning, Acquisition, and Operations
January 12, 2018



Background

- Planning utilizes renewable cost outlooks to help inform ongoing power system planning activities and to help inform discussions within the IESO and with stakeholders. Specific examples of areas where these cost outlooks are used include:
 - Resource planning studies such as Ontario Planning Outlook (OPO) & LTEP
 - Context for comparing options to help inform investment decisions
 - Evaluation of alternative supply portfolios
 - Avoided cost estimates for Conservation and GreenON programs
 - Ontario Fair Hydro Plan studies
 - Grid parity/net-metering assessments
 - General market intelligence
- Solar PV and wind cost outlooks are of particular focus here. Planning produces updates to these outlooks every 2 years. The last update was produced in 2015 and prior to that in 2012 and 2014.
 - The 2015 update helped inform the 2016 OPO. Cost outlooks were included in the OPO document itself (page 13)
 - In past years, outlooks for installed cost (in \$/kW) of different size tranches of wind and solar resources were developed
 - In recent updates, in addition to installed cost, outlooks for all-in levelized unit energy costs (in \$/kWh) were also developed to reflect cost of ownership
- In preparation for future planning studies, cost outlooks have been revisited in light of more recent market information:
 - A number of new reports and outlooks have been released since the 2015 update
 - Ontario base year costs have been adjusted to reflect more recent cost information

Summary of observations

- A variety of industry projections out to 2050 now exist. IESO outlooks for solar PV and wind costs now extend out to 2050 to help inform ongoing planning assessments that require longer term outlooks.
- Solar PV capital costs and outlooks for costs continue to decline, driven by reductions in module costs and balance of system costs
 - Residential and Commercial/Industrial rooftop solar PV cost outlooks are lower than the 2015 update.
 - Utility scale solar PV capital costs are similar to the 2015 update. Levelized cost of ownership is marginally higher due improvements in how construction lead times and financing are reflected.
- Wind capital costs remain relatively stable over the outlook, reflecting the maturity of the technology. Marginal improvements are expected, driven by incremental technology improvements (turbine efficiency, taller towers, and longer blades)
 - Wind energy cost outlooks are lower than the 2015 update

\$/kW	2017	2035	2050
Residential Rooftop Solar	\$2,647	\$1,518	\$1,281
Commercial/Industrial Rooftop Solar	\$2,089	\$1,200	\$1,010
Utility Scale Solar	\$1,850	\$1,072	\$851
Utility Scale Wind	\$2,050	\$1,886	\$1,865

\$/MWh	2017	2035	2050
Residential Rooftop Solar	\$226	\$148	\$132
Commercial/Industrial Rooftop Solar	\$185	\$120	\$106
Utility Scale Solar	\$150	\$105	\$93
Utility Scale Wind	\$94	\$88	\$87

- Sensitivity analysis was performed on a number of key parameters. Levelized cost is most sensitive to capital cost and capacity factor assumptions.
- Industry trends will continue to be monitored. Cost outlooks will be updated as information materially changes.

1. Assessment approach, assumptions, and considerations

Approach to developing cost outlooks

- Methodology for developing capital cost outlooks:
 1. Determine base year 2017 Ontario capital cost
 2. Collect published cost outlooks by technology type
 3. Convert cost outlooks to \$2017 CAD
 4. Produce industry average cost outlook based on published outlooks
 5. Determine yearly percentage cost decline for industry average outlook
 6. Apply yearly percentage cost decline to 2017 Ontario capital cost to develop cost outlooks
- Methodology for developing levelized cost outlooks:
 1. For a given build year and installation type, use the capital cost outlook developed above
 2. Input performance and financing assumptions into a 20 year cash flow model
 3. Determine levelized energy rate cost (\$/MWh) that yields a 9% internal rate of return

Major changes since previous IESO studies

- The last two solar & wind cost outlooks developed capital cost and LUEC/PPA rate outlooks for specific procurement program tranches
 - microFIT Rooftop Solar PV (3-10 kW)
 - FIT Rooftop Solar PV (10-100 kW, 100-500 kW)
 - FIT Groundmount Solar PV (10-500 kW)
 - LRP Solar (>500 kW)
 - FIT Wind (<500 kW)
 - LRP Wind (>500 kW)
- As of the end of 2017, no future procurements are planned under any of the above programs
- For this study, outlooks are developed for the following categories:
 - Residential Rooftop Solar
 - Commercial & Industrial (C&I) Rooftop Solar
 - Utility Scale Solar
 - Utility Scale Wind
- A further assumption is that future rooftop solar installations will proceed under a net metering regime as opposed to a FIT-style contract
 - The benefits for a net metering participant are reduced electricity bills, through either self-consumption or bill credits for electricity exports. As such, income tax will no longer be applied to rooftop solar when determining levelized costs of energy.

Study financial assumptions: Based on a variety of sources, including the 2017 FIT Price Review, 2016 LRP results, a scan of industry data, internal analysis, and previous studies

\$2017 CAD	Residential Rooftop Solar	C&I Rooftop Solar	Utility Scale Solar	Utility Scale Wind
Initial Capacity Cost for base year 2017 (\$/kW)	\$2,647	\$2,089	\$1,850	\$2,050
Capacity (kW)	10	500	10,000	10,000
Average Capacity Factor	16.00%	16.00%	22.80%	34.80%
Annual Degradation Rate	0.50%	0.50%	0.50%	0.00%
Connection Costs	\$1,079	\$5,300	\$823,280	Included in installed cost
Approvals & Legal Costs	\$706	\$59,719	\$3,132,580	
Land Acquisition (\$/kW)	\$0	\$0	\$41	
O&M, Insurance, Lease (\$/kW-yr)	\$37.00	\$24.00	\$20.00	\$63.00
OPEX Escalation Rate	2%	2%	2%	2%
Construction Time (years)	1	2	3	2
Debt : Equity Ratio	70:30	80:20	80:20	80:20
Debt Term (yrs)	20	20	20	20
Interest Rate on Debt	5.00%	5.00%	5.00%	5.00%
Income Tax Rate	0.00%	0.00%	26.50%	26.50%
Blended CCA Rate	0.00%	0.00%	41.60%	37.40%
Expected After-Tax IRR on Equity	9.00%	9.00%	9.00%	9.00%

See Appendix for data sources.

A number of publicly available capital cost outlooks, many out as far as 2050, have been released since the previous study. All outlooks go to 2050 except IHS CERA, which is to 2040.

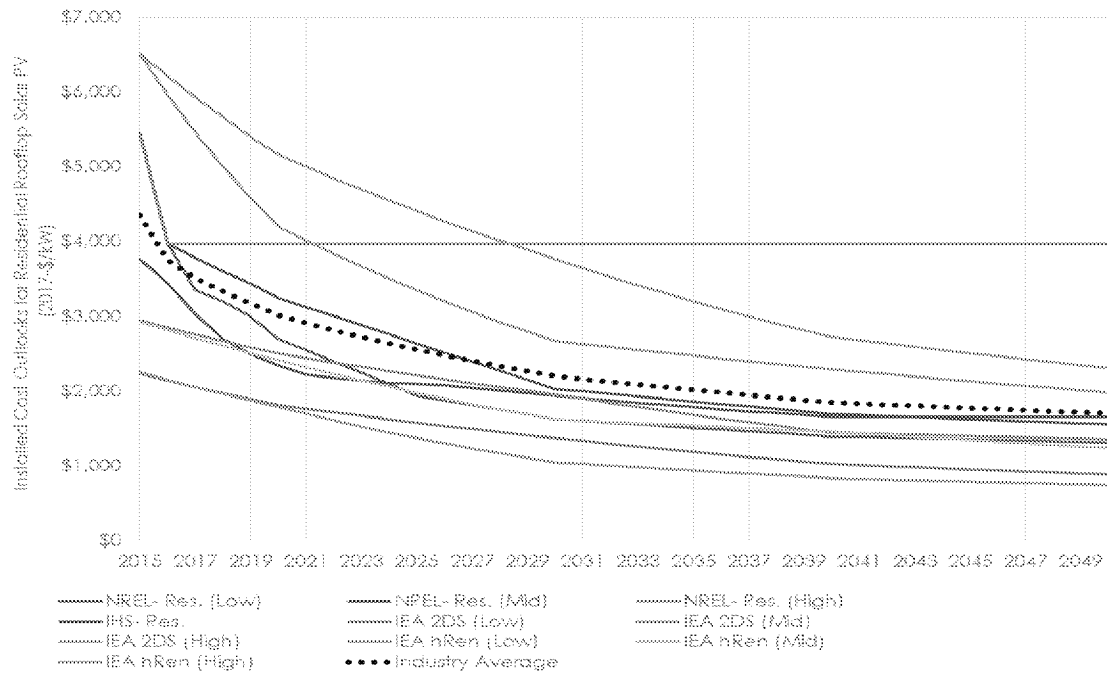
- A variety of industry reports were reviewed:
 - Global Wind Energy Council. Global Wind Energy Outlook 2016 (October, 2016)
 - * 4 Wind Outlooks
 - National Renewable Energy Laboratory. Annual Technology Baseline (August, 2017)
 - * 3 Wind Outlooks
 - * 3 Residential Rooftop Solar Outlooks
 - * 3 Commercial & Industrial Rooftop Solar Outlooks
 - * 3 Utility Scale Solar Outlooks
 - IHS CERA. US Solar/Wind PV Capital Cost and Required Price Outlook (August, 2017)
 - * 1 Wind Outlook
 - * 1 Residential Rooftop Solar Outlook
 - * 1 Commercial & Industrial Rooftop Solar Outlook
 - * 2 Utility Scale Solar Outlooks
 - Greenpeace. Energy Revolution 2015. (September 2015)
 - * 1 Wind Outlook
 - * 1 Solar Outlook
 - International Energy Agency. Energy Technology Perspectives 2014. (September, 2014)
 - * 12 Solar Outlooks
 - Agora Energiewende. (February 2015)
 - * 2 Utility Scale Solar Outlooks
- To allow for comparison, all cost outlooks are normalized for exchange rate and inflation into \$2017CAD

The previous outlooks developed by the IESO looked out 20 years ahead. The 2017 update extends the outlook out to 2050 due to better available industry information and needs driven by planning studies that look beyond the 20 year planning horizon.

- Many high quality industry projections released in recent years include cost outlooks that extend out to 2050. These were not available at the time of previous IESO updates.
- IESO has been asked to provide analysis to support the Ontario Fair Hydro Plan. To support financing decisions regarding the Ontario Fair Hydro Plan, the planning horizon is extended to 2050. Planning is required to make cost assumptions related to replacement assets at the end of life of existing assets.
- PSP recognizes that the uncertainty surrounding any outlook increases the further into the future one looks. Continued regular updates to the wind and solar cost outlooks allow for incorporating the latest available and reducing uncertainty in the near term.

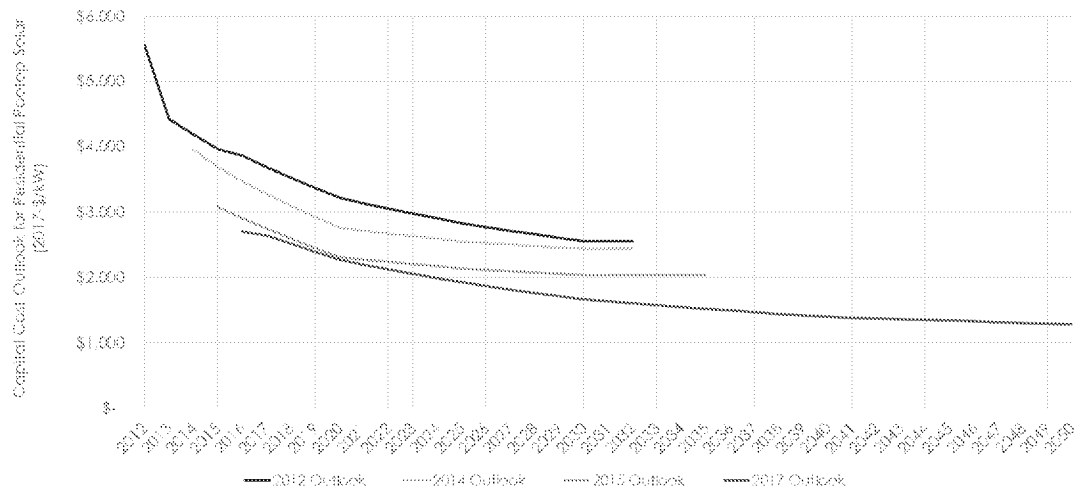
2. Updated assessment and discussion

Residential rooftop solar PV: Scan of industry capital cost outlooks



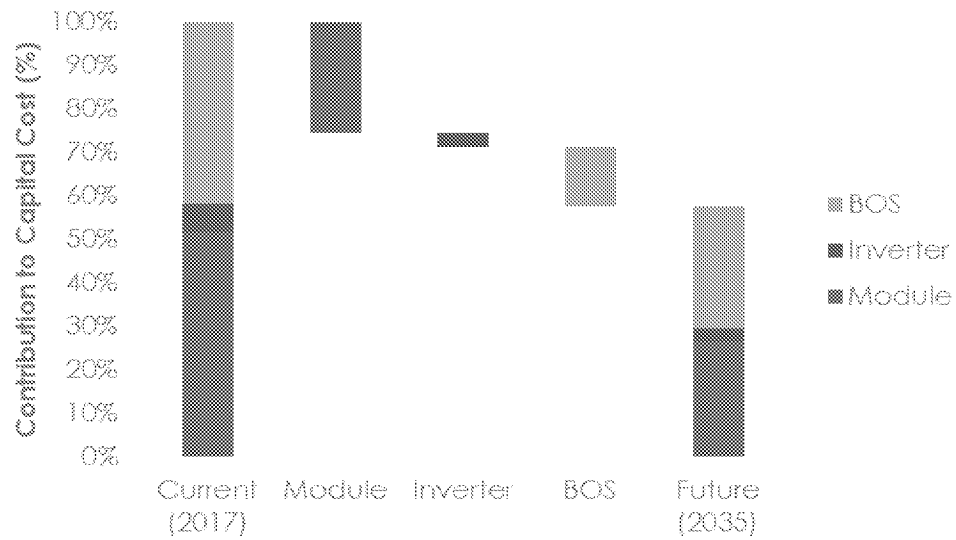
Residential rooftop solar PV: Updated IESO capital cost outlook

Using the 2017 benchmark capital cost of \$2,647/kW in tandem with industry average outlooks for rate of change in capital cost, outlooks for residential rooftop solar capital cost are developed. The 2017 outlook is comparable to the 2015 outlook through 2022, but declines more steeply after that date.



Residential rooftop solar PV: Drivers for cost decline

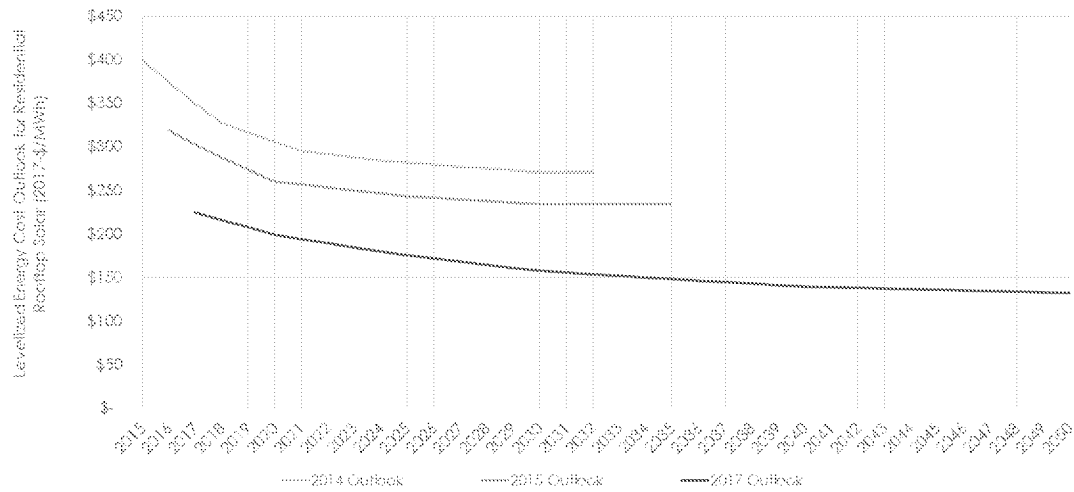
For the current outlook, solar capital costs decrease 42% by 2035. The primary drivers of the cost decline are a decrease in module price (60% of total decline) and the balance of system (BOS, 33% of total decline). The cost decline drivers consistent across solar installation types.



Sources: IHS CERA & Agora Energiewende

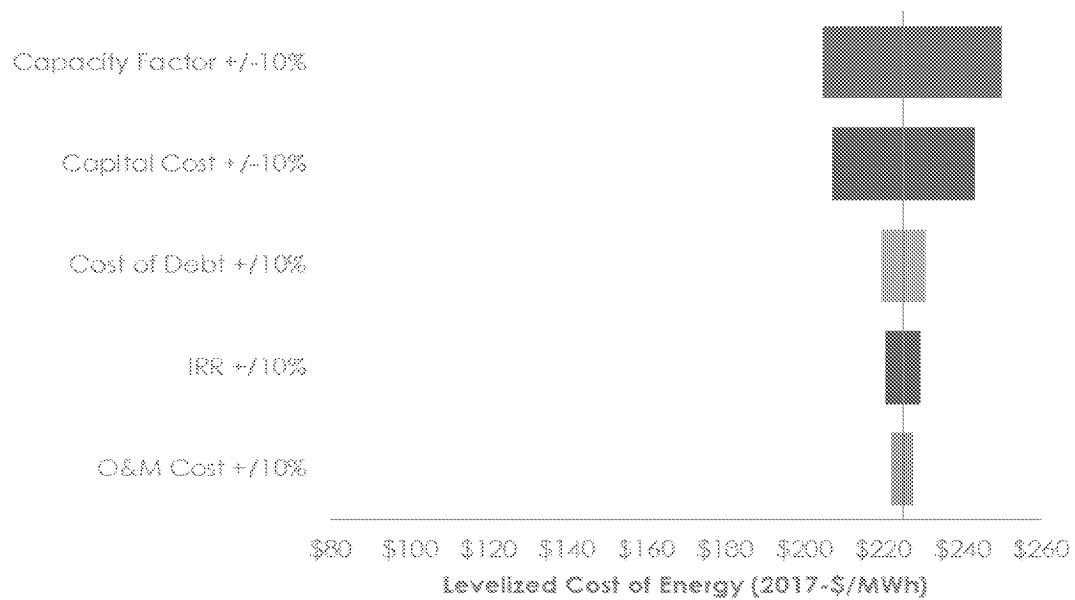
Residential rooftop solar PV: Levelized unit cost outlook

The capital cost outlooks are combined with operating and financing assumptions to develop levelized energy cost outlooks for residential rooftop solar. The major driver of the lower cost compared to previous studies is a change in assumed capacity factor from 13% to 16%, based on analysis of the historical performance of rooftop microFIT sites.

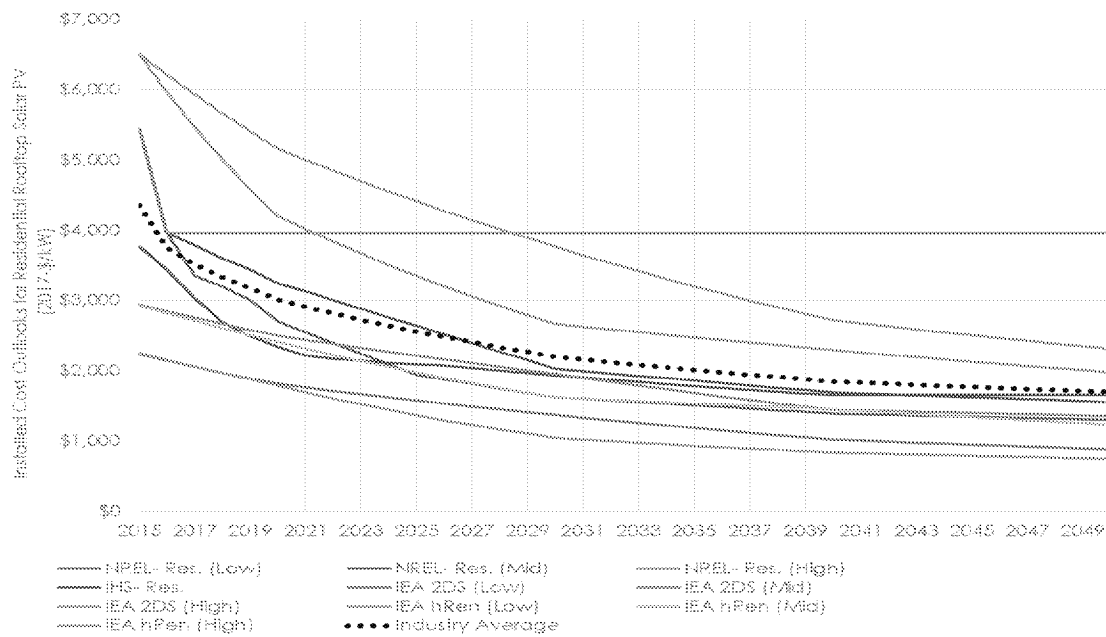


Residential rooftop solar PV: Cost sensitivity analysis

A sensitivity analysis was performed for the 2017 levelized energy cost for residential rooftop solar. The major sensitivities are capacity factor and capital cost.

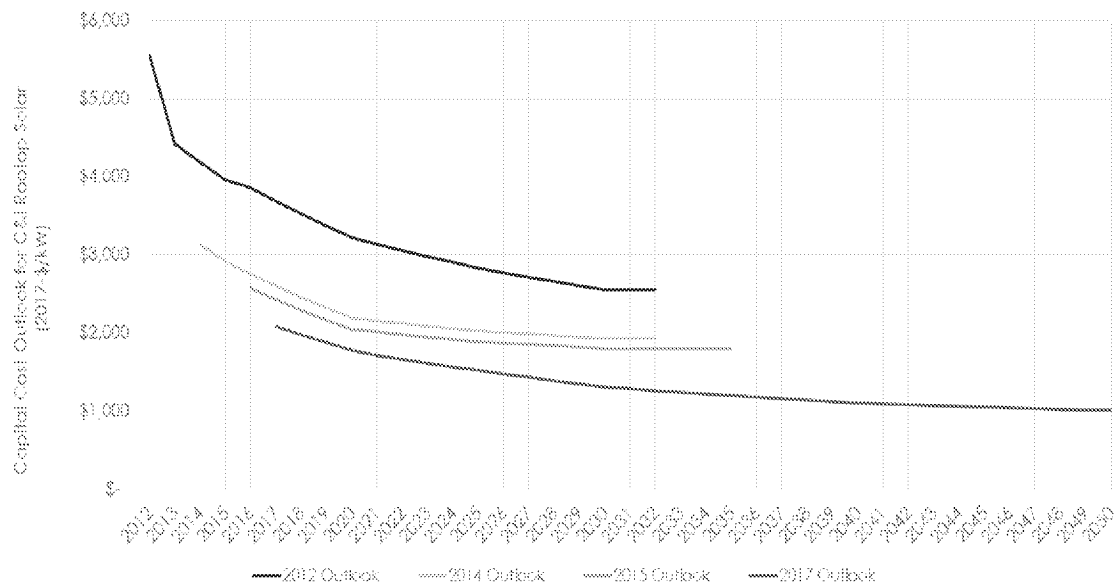


Commercial/industrial rooftop solar PV: Scan of industry capital cost outlooks



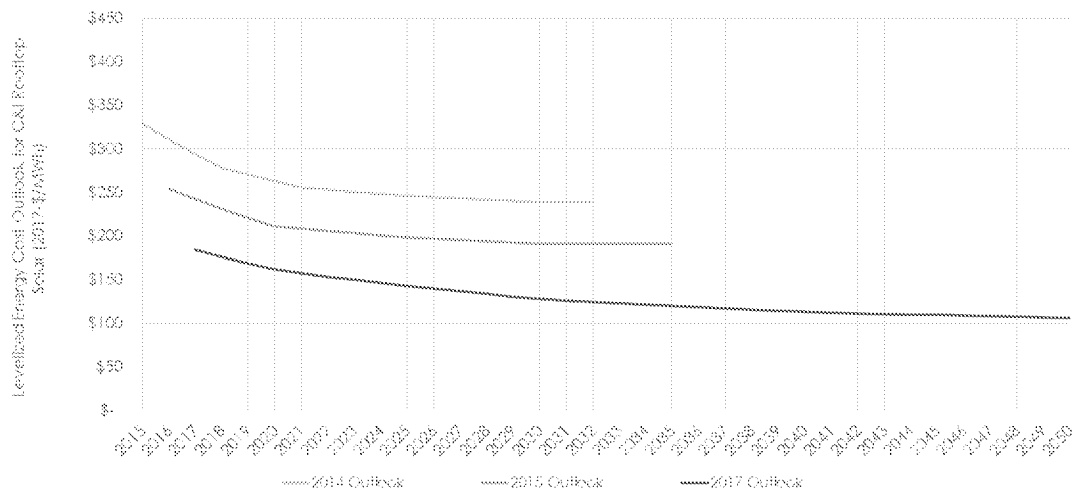
Commercial/industrial rooftop solar PV: Updated IESO capital cost outlook

Using the 2017 benchmark capital cost of \$2,089/kW in tandem with industry average outlooks for rate of change in capital cost, outlooks for C&I rooftop solar capital cost are developed. The 2017 outlook ranges from 13-33% lower than the 2015 outlook.



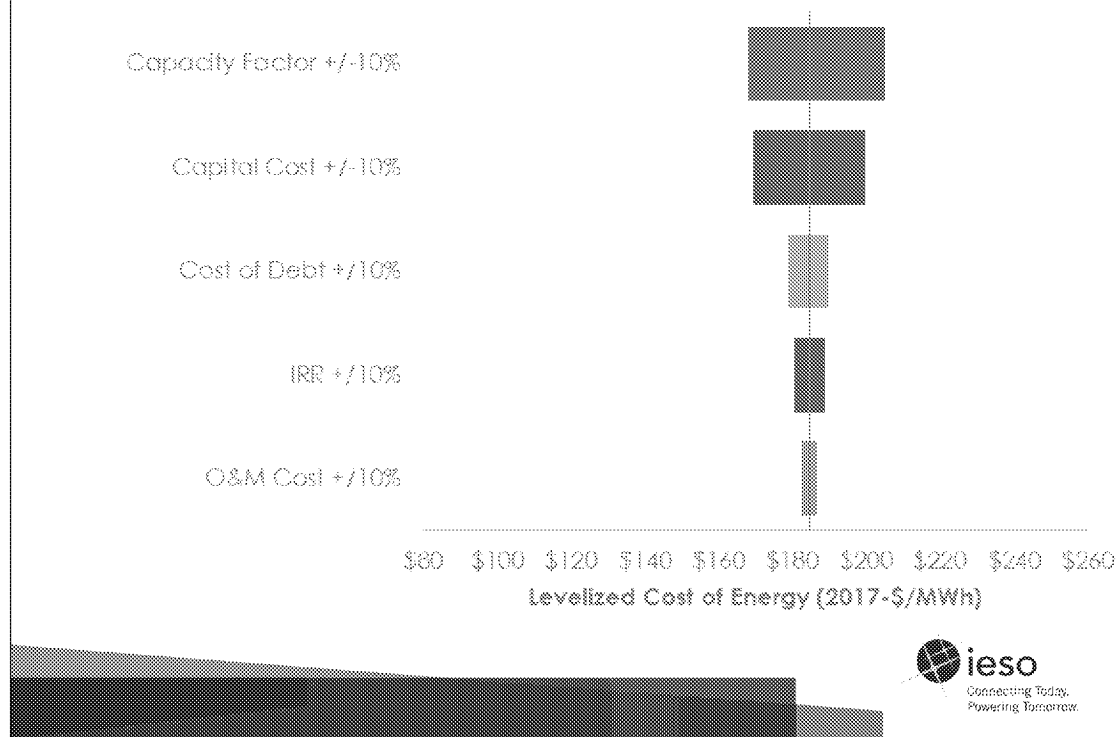
Commercial/industrial rooftop solar PV: Levelized unit cost outlook

The capital cost outlooks are combined with operating and financing assumptions to develop levelized energy cost outlooks for C&I rooftop solar. The major driver of the lower cost compared to previous studies is a 75% reduction in yearly O&M costs, based on an analysis of current industry assumptions and the 2017 FIT price review.

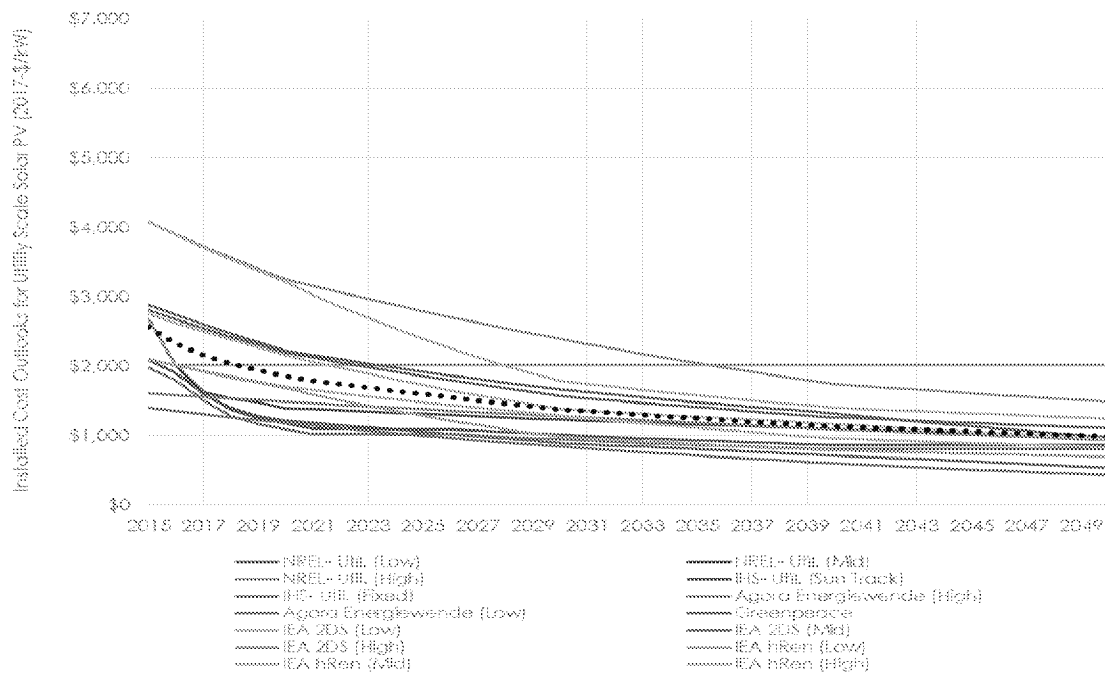


Commercial & industrial rooftop solar PV: Levelized cost sensitivity analysis

A sensitivity analysis was performed for the 2017 levelized energy cost for C&I rooftop solar. The major sensitivities are capacity factor and capital cost.

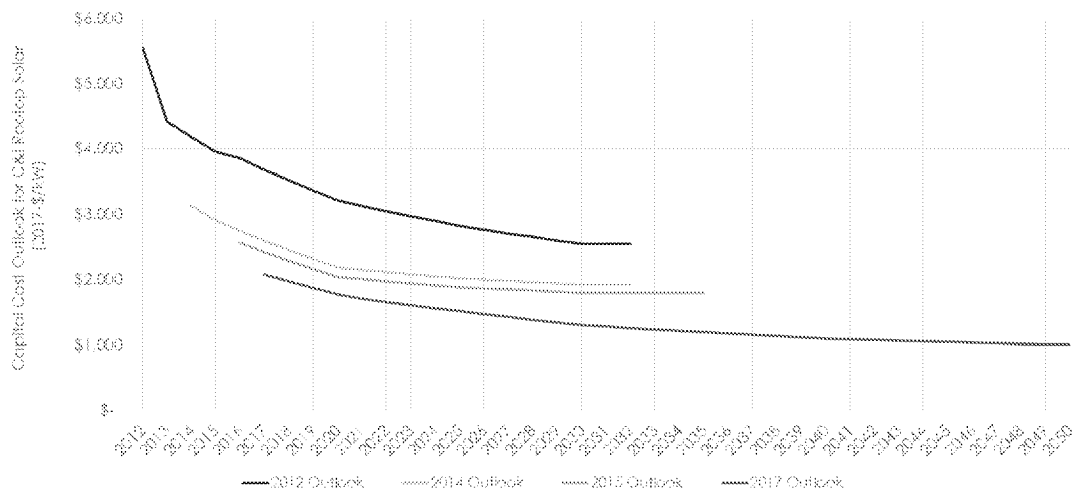


Utility scale solar PV: Scan of industry capital cost outlooks



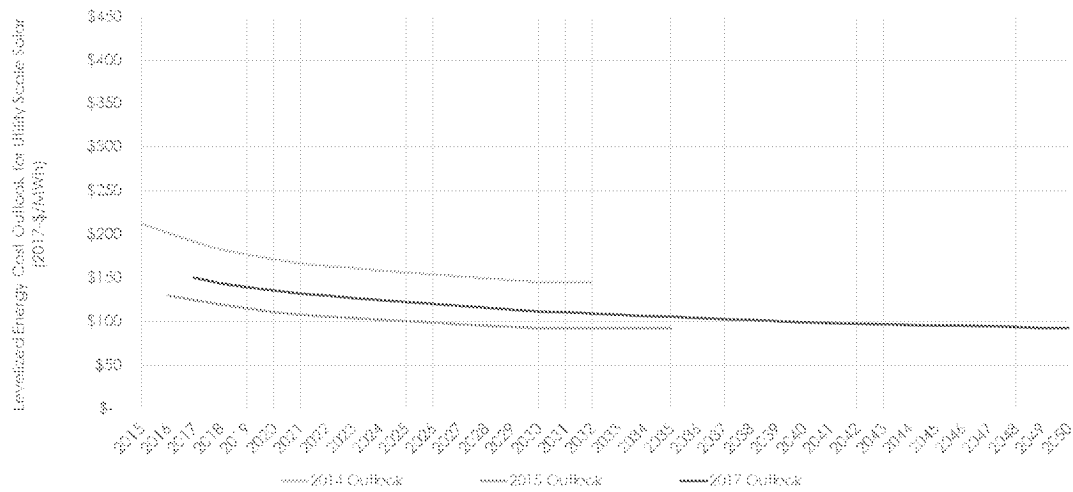
Utility scale solar PV: Updated IESO capital cost outlook

Using the 2017 benchmark capital cost of \$1,850/kW in tandem with industry average outlooks for rate of change in capital cost, outlooks for utility scale solar capital cost are developed. The 2017 outlook is not substantially different from the 2015 outlook.



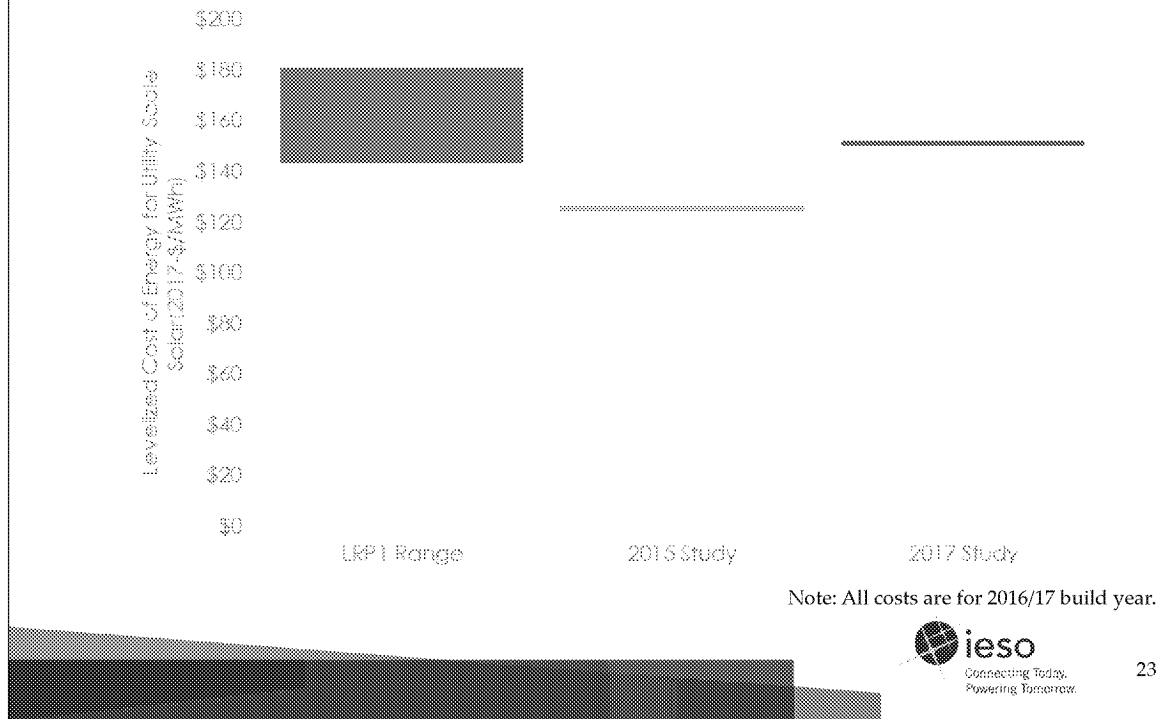
Utility scale solar PV: Levelized unit cost outlook

The capital cost outlooks are combined with operating and financing assumptions to develop levelized energy cost outlooks for utility scale solar. The current outlook is higher than the previous study due to improvements in how construction times and financing requirements were modeled.



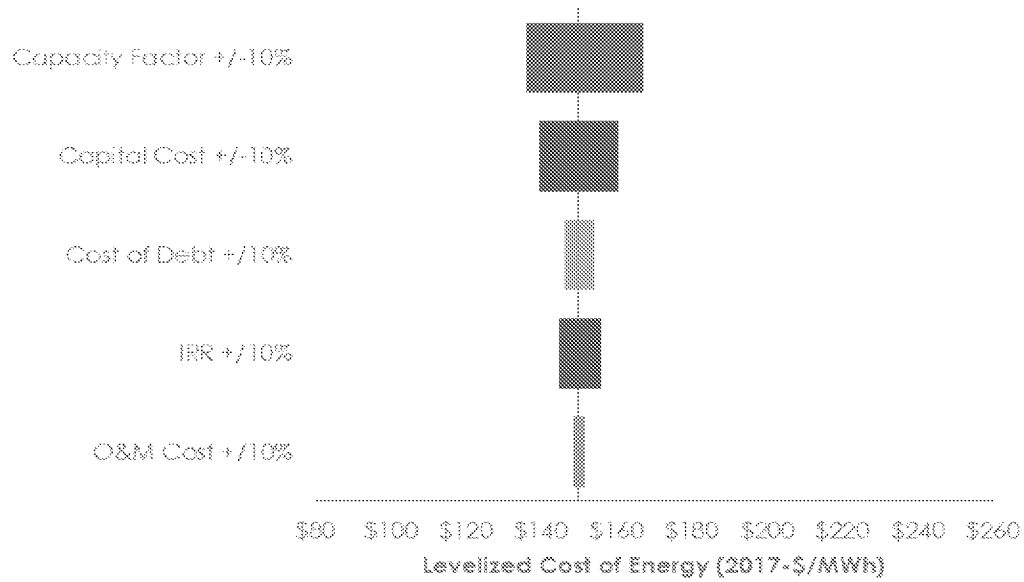
Utility scale solar PV: Comparison to LRP I and 2015 Study

The 2015 energy cost outlook for utility scale solar was much lower than the range of LRP1 awarded contracts. The current study is within the range of LRP1 costs.

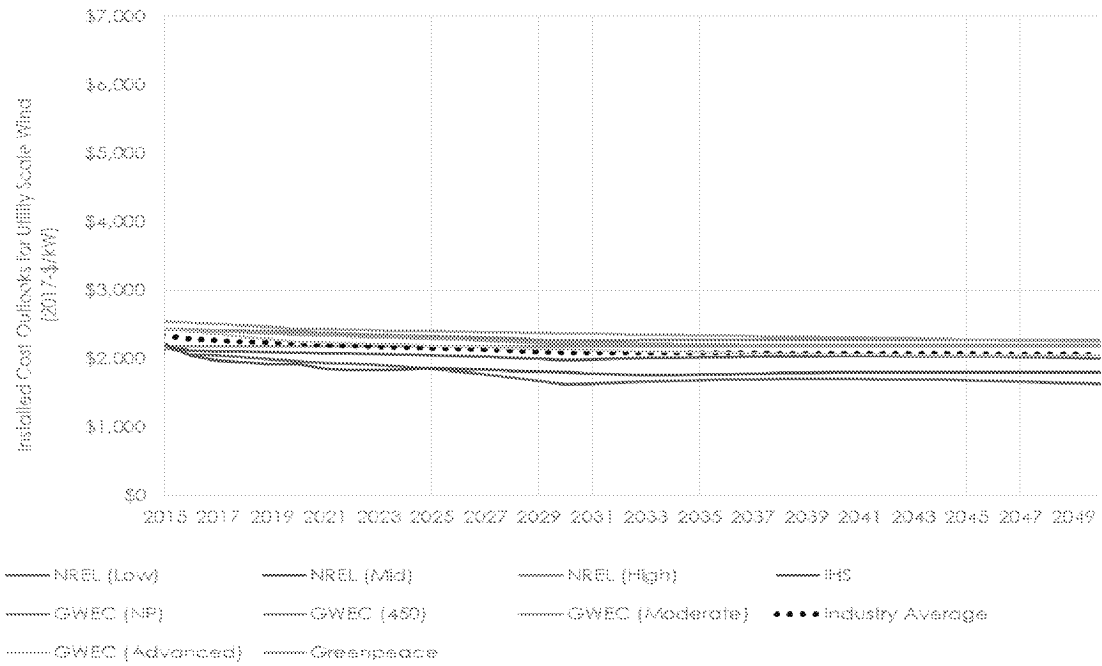


Utility scale solar PV: Levelized cost sensitivity analysis

A sensitivity analysis was performed for the 2017 levelized energy cost for utility scale solar. The major sensitivities are capacity factor and capital cost.

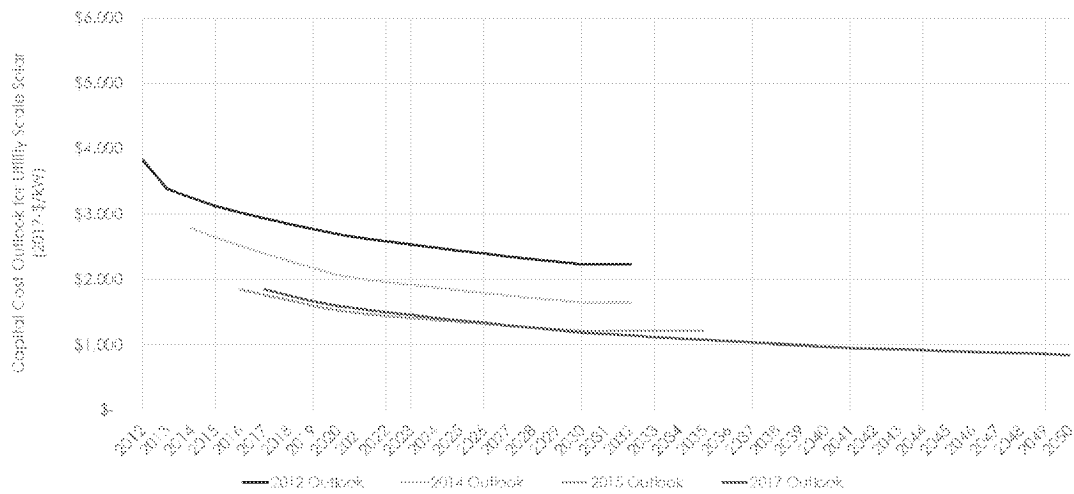


Utility scale wind: Scan of industry capital cost outlooks



Utility scale wind: Updated IESO capital cost outlook

Using the 2017 benchmark capital cost of \$2,050/kW in tandem with industry average outlooks for rate of change in capital cost, outlooks for utility scale wind capital cost are developed. The 2017 outlook is 2-4% lower than the 2015 outlook.

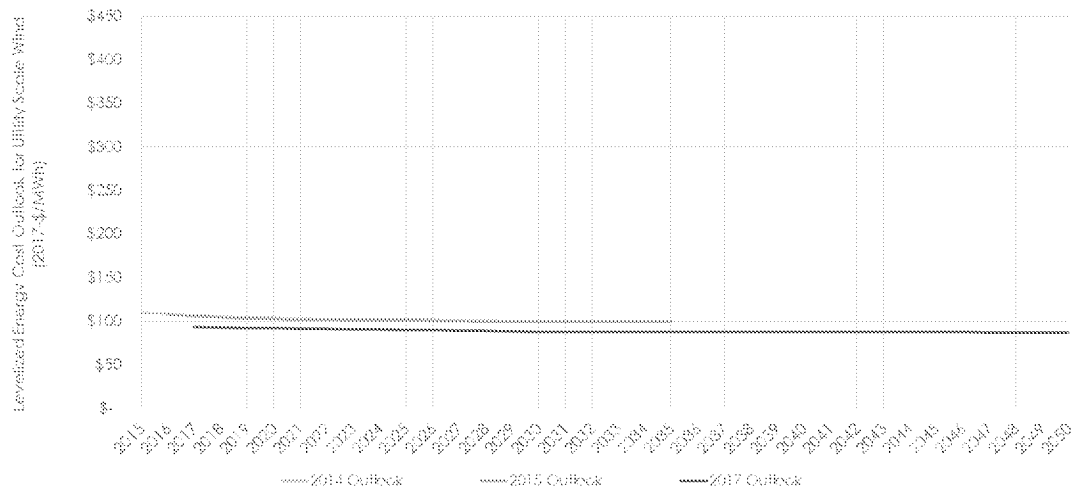


Utility scale wind: Drivers for cost decline

- In contrast to solar PV, utility scale wind capital costs outlooks only foresee slight declines in the future – about 8% by 2035 vs 42% for solar PV
- Future cost declines are mostly incremental technology and process improvements, for example:
 - Improved manufacturing techniques
 - Taller towers and larger rotor diameters, which improve efficiency
 - The upper limits on tower and rotor size may be reached soon, limiting the scope for further improvements
- Other factors such as exchange rate and price fluctuations driven by supply/demand can contribute to changes in wind technology costs looking ahead

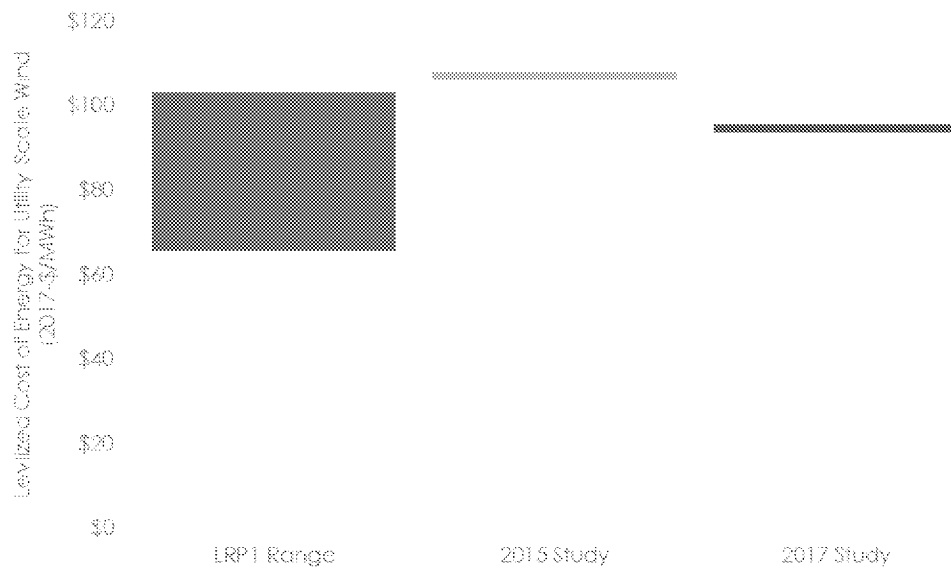
Utility scale wind: Levelized unit cost outlook

The capital cost outlooks are combined with operating and financing assumptions to develop levelized energy cost outlooks for utility scale wind. The current outlook is lower compared to previous studies due to a reduction in capital costs and yearly O&M costs, based on an analysis of current industry assumptions.



Utility scale wind: Comparison to LRP I and 2015 Study

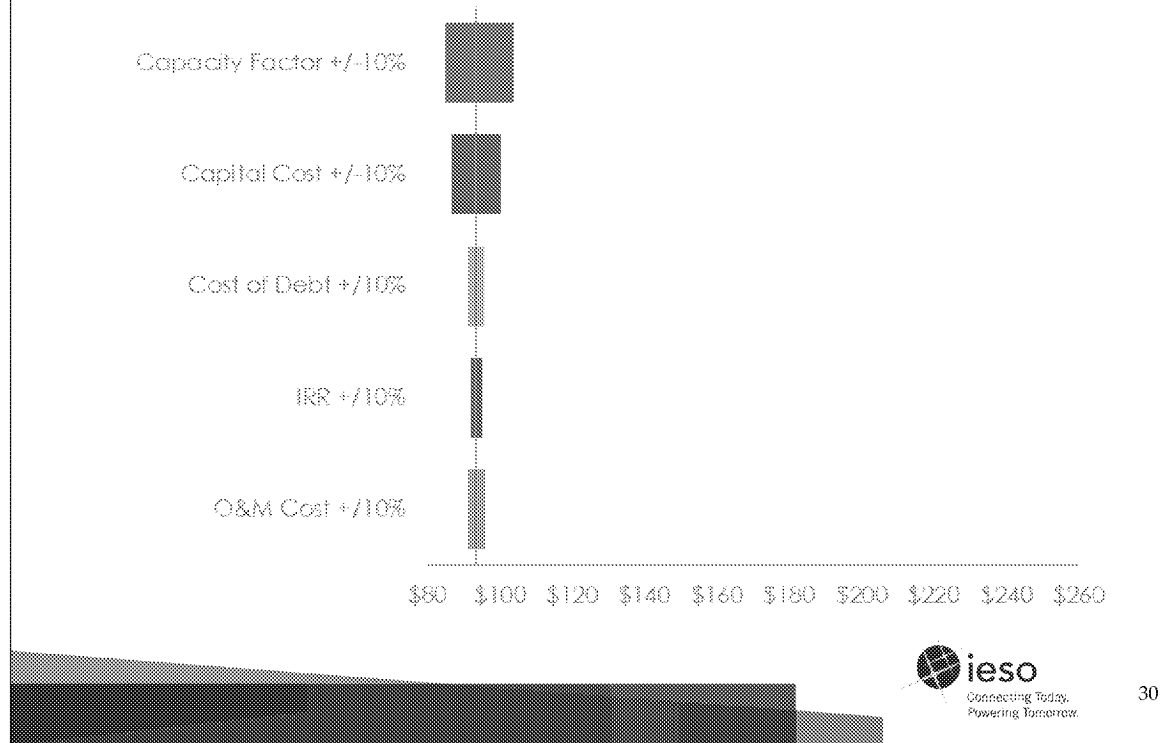
The 2015 energy cost outlook for utility scale solar was higher than the range of LRP1 awarded contracts. The current study is within the range of LRP1 costs.



Note: All costs are for 2016/17 build years.

Utility scale wind: Levelized cost sensitivity analysis

A sensitivity analysis was performed for the 2017 levelized energy cost for utility scale wind. The major sensitivities are capacity factor and capital cost.



3. Data tables and sources

Data table: 2017 updated capital cost outlook

Capital Cost Outlook (2017-\$/kW)

Build Year->	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Residential Rooftop Solar	\$2,647	\$2,514	\$2,393	\$2,272	\$2,193	\$2,123	\$2,055	\$1,988	\$1,925	\$1,870	\$1,815	\$1,761	\$1,709	\$1,658	\$1,629	\$1,600	\$1,572
C&I Rooftop Solar	\$2,089	\$1,973	\$1,876	\$1,784	\$1,716	\$1,664	\$1,615	\$1,567	\$1,522	\$1,478	\$1,434	\$1,392	\$1,350	\$1,310	\$1,287	\$1,264	\$1,242
Utility Scale Solar	\$1,850	\$1,747	\$1,667	\$1,596	\$1,541	\$1,496	\$1,453	\$1,411	\$1,372	\$1,334	\$1,294	\$1,256	\$1,219	\$1,184	\$1,160	\$1,137	\$1,115
Utility Scale Wind	\$2,050	\$2,036	\$2,020	\$2,006	\$1,991	\$1,981	\$1,972	\$1,964	\$1,955	\$1,943	\$1,931	\$1,917	\$1,903	\$1,888	\$1,887	\$1,887	\$1,886

Capital Cost Outlook (2017-\$/kW)

Build Year->	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Residential Rooftop Solar	\$1,544	\$1,518	\$1,492	\$1,466	\$1,441	\$1,417	\$1,393	\$1,381	\$1,370	\$1,358	\$1,347	\$1,335	\$1,324	\$1,313	\$1,302	\$1,292	\$1,281
C&I Rooftop Solar	\$1,221	\$1,200	\$1,180	\$1,160	\$1,141	\$1,122	\$1,104	\$1,094	\$1,084	\$1,074	\$1,065	\$1,055	\$1,046	\$1,037	\$1,028	\$1,019	\$1,010
Utility Scale Solar	\$1,093	\$1,072	\$1,051	\$1,031	\$1,011	\$991	\$972	\$959	\$946	\$934	\$921	\$909	\$897	\$885	\$874	\$862	\$851
Utility Scale Wind	\$1,886	\$1,886	\$1,886	\$1,885	\$1,885	\$1,884	\$1,883	\$1,882	\$1,881	\$1,880	\$1,878	\$1,877	\$1,875	\$1,873	\$1,870	\$1,868	\$1,865

Data table: 2017 updated levelized cost outlook

Levelized Cost Outlook (2017-\$/MWh)

Build Year->	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Residential Rooftop Solar	\$227.6	\$218.7	\$210.4	\$202.0	\$196.6	\$191.7	\$187.0	\$182.4	\$178.0	\$174.2	\$170.4	\$166.7	\$163.1	\$159.5	\$157.5	\$155.5	\$153.6
C&I Rooftop Solar	\$190.3	\$181.7	\$174.4	\$167.6	\$162.4	\$158.6	\$154.9	\$151.3	\$148.0	\$144.7	\$141.4	\$138.2	\$135.1	\$132.1	\$130.4	\$128.7	\$127.0
Utility Scale Solar	\$150.2	\$144.1	\$139.5	\$135.4	\$132.2	\$129.6	\$127.1	\$124.7	\$122.4	\$120.2	\$117.9	\$115.7	\$113.5	\$111.5	\$110.4	\$109.3	\$107.5
Utility Scale Wind	\$ 93.5	\$93.0	\$92.5	\$92.0	\$91.5	\$91.2	\$90.9	\$90.6	\$90.3	\$89.9	\$89.5	\$89.0	\$88.6	\$88.1	\$88.1	\$88.1	\$88.0

Levelized Cost Outlook (2017-\$/MWh)

Build Year->	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Residential Rooftop Solar	\$151.6	\$150.1	\$146.2	\$144.4	\$142.9	\$141.0	\$139.6	\$138.6	\$137.8	\$137.0	\$136.3	\$135.4	\$134.7	\$133.9	\$133.2	\$132.5	\$131.8
C&I Rooftop Solar	\$125.7	\$123.9	\$118.9	\$117.2	\$116.0	\$114.4	\$113.3	\$112.2	\$111.7	\$111.0	\$110.3	\$109.6	\$108.9	\$108.3	\$107.6	\$107.0	\$106.3
Utility Scale Solar	\$106.4	\$105.4	\$103.8	\$102.8	\$101.7	\$100.7	\$99.2	\$98.2	\$97.7	\$96.7	\$96.3	\$95.3	\$95.3	\$94.3	\$93.4	\$92.5	\$92.5
Utility Scale Wind	\$88.0	\$88.0	\$87.9	\$87.9	\$87.9	\$87.9	\$87.9	\$87.9	\$87.9	\$87.6	\$87.6	\$87.6	\$87.6	\$87.3	\$87.3	\$87.3	\$87.3

Data sources for study financial assumptions

Assumptions	Residential Rooftop Solar	C&I Rooftop Solar	Utility Scale Solar	Utility Scale Wind	Assumption Source	Residential Rooftop Solar	C&I Rooftop Solar	Utility Scale Solar	Utility Scale Wind
Initial Capacity Cost for 2017 base year (\$/kW)	\$2,647	\$2,089	\$1,850	\$2,050	Initial Capacity Cost for 2017 base year (\$/kW)	2017 Fit Price Review		2017 Data Review	
Capacity (kW)	10	500	10,000	10,000	Capacity (kW)	Previous Study			
Average Capacity Factor	16.00%	16.00%	22.80%	34.80%	Average Capacity Factor	Analysis of Historical Data		2017 FIT Price Review	Previous Study
Annual Degradation Rate	0.50%	0.50%	0.50%	0.00%	Annual Degradation Rate	NREL ATB			
Connection Costs	\$1,079	\$5,300	\$823,280	Included in installed cost	Connection Costs	2017 FIT Price Review	Previous Study		
Approvals & Legal Costs	\$706	\$59,719	\$3,132,580		Approvals & Legal Costs				
Land Acquisition (\$/kW)	\$0	\$0	\$41		Land Acquisition (\$/kW)				
O&M, Insurance, Lease (\$/kW-yr)	\$37.00	\$24.00	\$20.00		\$63.00				
OPEX Escalation Rate	2%	2%	2%	2%	OPEX Escalation Rate	2017 Data Review			
Construction Time (years)	1	2	3	2	Construction Time (years)	Previous Study			
Debt : Equity Ratio	70:30	80:20	80:20	80:20	Debt : Equity Ratio	Previous Study			
Debt Term (yrs)	20	20	20	20	Debt Term (yrs)				
Interest Rate on Debt	5.00%	5.00%	5.00%	5.00%	Interest Rate on Debt	Previous Study			
Income Tax Rate	0.0%	0.0%	26.50%	26.50%	Income Tax Rate				
Blended CCA Rate	0.0%	0.0%	41.60%	37.40%	Blended CCA Rate				
Expected After-Tax IRR on Equity	9.00%	9.00%	9.00%	9.00%	Expected After-Tax IRR on Equity	Previous Study			