Value of Distributed Generation

Solar PV Methodology

April 2015

Acadia Center
Advancing the Clean Energy Future

Study Methodology

Overview

Acadia Center assessed the grid and societal value of six marginal 1 kW solar photovoltaic ("solar PV") systems to better understand the overall value that solar PV provides to the grid, ratepayers, and society as well as the impact that system orientation has on the results. As a starting point, NREL's PVWatts Calculator[1] was used to estimate the hourly output profiles for six different solar PV system orientations: 1) south-facing (azimuth of 180 degrees) with a 35 degree tilt from horizontal; 2) south-facing with a 20 degree tilt; 3) west-facing (azimuth of 270 degrees) with a 35 degree tilt; 4) west-facing with a 20 degree tilt; 5) west-facing with a 5 degree tilt; and, 6) a 2-axis tracking system.

The solar PV output was then used to estimate avoided costs and benefits for 11 components, which combined make up the grid value or societal value of the resource. The components assessed in this study include:

- Grid Value
    - Avoided energy costs
    - Avoided capacity costs
    - Avoided transmission costs
    - Avoided distribution costs
    - DRIPE energy
    - DRIPE capacity
    - Avoided carbon dioxide (CO_2) compliance costs
    - Avoided nitrogen oxides (NO_x) compliance costs
- Societal Value
    - Net social cost of CO_2
    - Net social cost of sulfur dioxide (SO_2)
    - Net social cost of NO_x

Locational value and economic benefits are important components of the value of distributed resources like solar PV but were beyond the scope of this analysis. It should also be noted that subsidies received by fossil fuel companies are not included in the avoided cost calculations. Finally, the cost of integrating solar, which was estimated in other studies,[2] is not included and therefore the results represent the gross value of solar.

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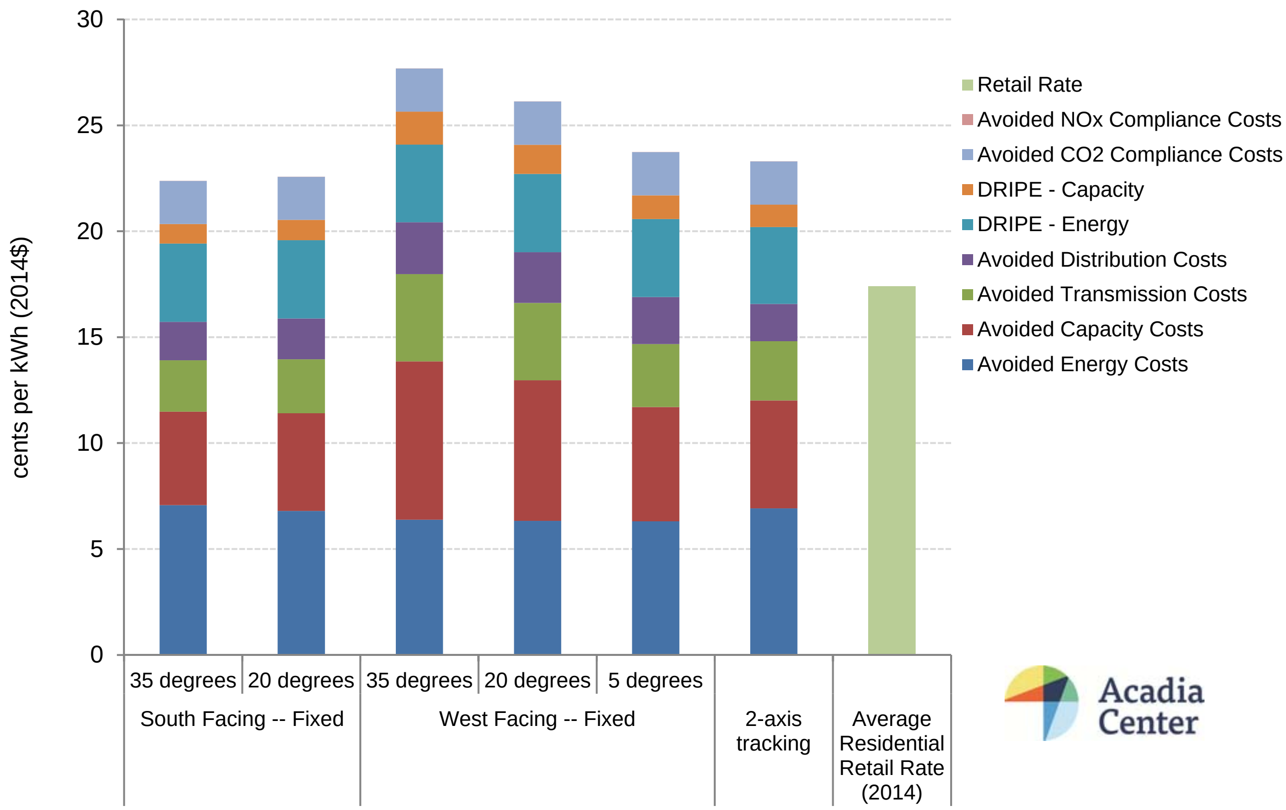
[1] Available at: http://pvwatts.nrel.gov/

[2] Norris, B., P. Gruenhagen, R. Grace, P. Yuen, R. Perez, and K. Rábago (2014). *Maine Distributed Solar Valuation Study*. Prepared for the Maine Public Utilities Commission. Available at: http://www.nrcm.org/wp-content/uploads/2015/03/MPUCValueofSolarReport.pdf. The Maine study estimates that the 25-year levelized cost for solar integration is 0.5 cents/kWh.

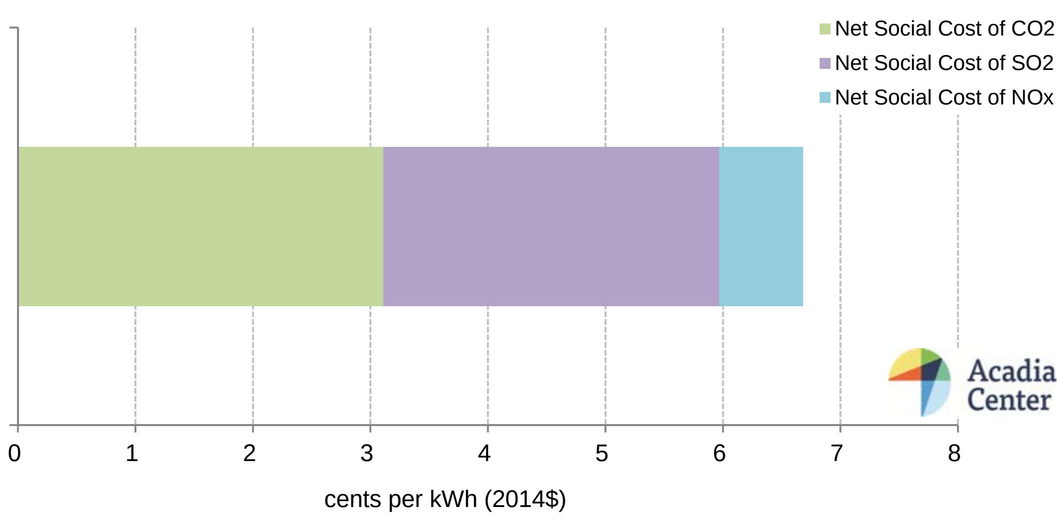
For each system orientation a 25-year levelized avoided costs or benefits, in 2014 dollars, is established for the above components. The overall grid and societal values are the sum total of each of the components. The following sections present the methodology used to calculate each component.

Example: Grid Value of Solar PV in Massachusetts – 25-year Levelized Cost (2014$)



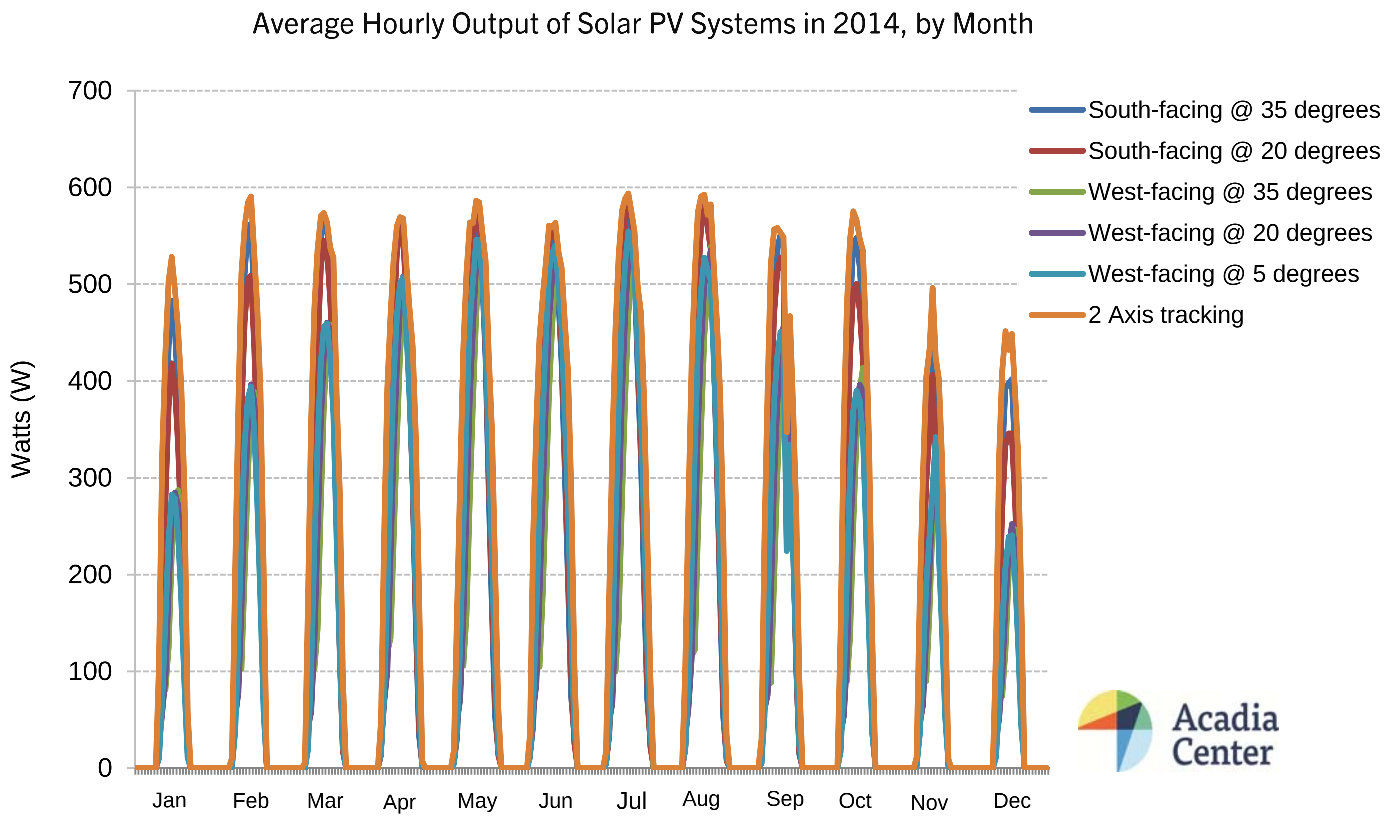
Note: Where appropriate, avoided reserve capacity costs, transmission and distribution losses, and a wholesale risk premium or price hedge are included in the calculations.

Example: Additional Societal Benefits of Solar PV in Massachusetts – 25-year Levelized Cost (2014$)



1. Avoided Energy

Hourly solar PV generation profiles are established using NREL's PVWatts calculator for six different system orientations at a specified location in a state (at or near the population center). The six different solar PV system orientations are: 1) south-facing (azimuth of 180 degrees) with a 35 degree tilt from horizontal; 2) south-facing with a 20 degree tilt; 3) west-facing (azimuth of 270 degrees) with a 35 degree tilt; 4) west-facing with a 20 degree tilt; 5) west-facing with a 5 degree tilt; and, 6) a 2-axis tracking system. PVWatt's default settings are used, except for adjustments to location, orientation (azimuth and tilt), and system size (1 kW marginal system vs. 4 kW).



The average annual unit cost of avoided energy in 2014 is equal to the weighted average of ISO-NE's hourly day ahead Locational Marginal Prices in 2014 that correspond to solar PV system output ($/MWh). To establish avoided energy costs thru 2038, as a first step embedded CO2 and NOx compliance costs from Synapse's 2013 Avoided Energy Supply Cost study ("AESC 2013") were converted to 2014$ and subtracted from the 2014 value (in 2014$).[3]

Starting in 2015, the avoided energy values are then reduced using an annual PV degradation rate of 0.5%.[4] Energy prices were then escalated annually using a factor equal to the constant annual escalation rate from EIA's

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[3] Synapse Energy Economics Inc. (2013). *Avoided Energy Supply Costs in New England: 2013 Report*. Available at: http://www.synapse-energy.com/sites/default/files/SynapseReport.2013-07.AESC .AESC-2013.13-029-Report.pdf. See Exhibit 4-1 on page 4-4. Note: the Synapse scenario which includes RGGI plus a federal program starting in 2020 was used in this assessment. For 2031 to 2038 values were held constant at $43.14 (2013$).

[4] From *Maine Distributed Solar Valuation Methodology (DRAFT)* of October 23, 2014. Available on the Maine Public Utilities Commission website (Docket 2014-00171).

forecasted natural gas prices for electricity power generation from 2014 to 2038. The escalation rate is equal to 2.9% (real).[5] Annual transmission and distribution losses of 11.0% as well as a wholesale risk premium and other ISO-NE costs of 9.0% are then factored in.[6] [7]

A real discount rate of 1.36%[8] is used to establish the present value and an inflation rate of 2.00% to calculate the 25-year levelized cost of avoided energy (in 2014$) for each of the six solar PV system orientations.

2. Avoided Capacity Costs

Capacity prices are based on the capacity clearing price, by regional segment, in the ISO-NE Forward Capacity Market (FCM) auctions. For 2014 thru 2018, actual FCM auction results are used (i.e. auctions 5 thru 9). For 2019, the capacity price is from modeling completed for ISO-NE to estimate capacity prices under the new FCM rules.[9] Future year (2020 thru 2038) costs were held constant at the 2019 value except for MA and CT where the 2019 value is reduced linearly over five years to bring it in line with the Rest of Pool value from the modeling exercise.

Starting in 2015, the avoided capacity values (2014$ per kW-month) are reduced using an annual PV degradation rate of 0.5%. Annual transmission and distribution losses of 11.0%, a wholesale risk premium and other ISO-NE costs of 9.0%, and a reserve margin requirement of 13.6%[10] are then factored in and the annual values are multiplied by 12 to converted from $/kW-month to $/kW-year.

A real discount rate of 1.36% is used to establish the present value and an inflation rate of 2.00% to calculate the 25-year levelized cost of avoided capacity (in 2014$) for each of the six solar PV system orientations.

The avoided capacity value is then discounted to reflect the fact that solar PV is not available to generate power and therefore act as a capacity resource during all hours of the day. The discount factor used in this study is based on the methodology used by ISO-NE to establish its Seasonal Claimed Capability (SCC) factor (i.e. the factor applied to solar resources that participate in the FCM).

ISO-NE Intermittent Reliability Hours for Calculating Seasonal Claimed Capability

Season	Month	Hour
Summer	June thru September	14 thru 18
Winter	October thru May	18 & 19

[5] EIA Annual Energy Outlook 2014 available at: http://www.eia.gov/oiaf/aeo/tablebrowser/#release=AEO2014&subject=0-AEO2014&table=3-AEO2014&region=1-0&cases=ref2014-d102413a

[6] Lazar, J., X. Baldwin (2011). Valuing the Contribution of Energy Efficiency to Avoided Marginal Line Losses and Reserve Requirements. Available at: www.raponline.org/document/download/id/4537

[7] Synapse Energy Economics Inc. (2013). *Avoided Energy Supply Costs in New England: 2013 Report*. Available at: http://www.synapse-energy.com/sites/default/files/SynapseReport.2013-07.AESC_.AESC-2013.13-029-Report.pdf. Note that 15% is the wholesale risk premium in the *2014 Integrated Resource Plan for Connecticut – Draft for Public Comment* of December 11, 2014. Page 54, footnote 118. Available at: http://www.ct.gov/deep/lib/deep/energy/irp/2014_irp_draft.pdf

[8] Ibid. This real discount rate reflects 30-year Utility States Treasury yields as of February 2013.

[9] *FCM Sloped Demand Curve: Capacity Zone demand curves – ISO's proposed zone sloped demand curves and overview of simulation model updates for evaluating zone curves*. Presentation by Matt Brewster to NEPOOL Markets Committee (October 7-8, 2014).

[10] Norris, B., P. Gruenhagen, R. Grace, P. Yuen, R. Perez, and K. Rábago (2014). *Maine Distributed Solar Valuation Study.* Prepared for the Maine Public Utilities Commission. Note: this is a more conservative estimate than the reserve marginal requirement of 17.2% in the AESC 2013 study.

Acadia Center calculated a discount factor unique to each of the six solar PV systems assessed in its study by establishing the median hourly real power output (from PVWatts) during ISO-NE's intermittent reliability hours for each system. During the period of time that daylight savings time is used the hours in the table above are adjusted (e.g. winter hours become 17 & 18) so that output during reliability hours are in the prevailing time (i.e. hour 17 of the solar PV output is actually 4pm).

The levelized capacity values are multiplied by the associated SCC discount factor and then divided by each system's total annual production (from PVWatts) to convert from 2014$/kW-year to 2014$/kWh per kW.

3. Avoided Transmission Capacity Costs

Avoided transmission costs are based on the Regional Network Service (RNS) rate of $89.89/kW-year effective June 1, 2014.[11] Starting in 2015 the rate is reduced using an annual PV degradation rate of 0.5%. A real discount rate of 1.36% is used to establish the present value and an inflation rate of 2.00% to calculate the 25-year levelized cost of avoided transmission capacity costs (in 2014$).

The levelized transmission costs are divided by the total annual production (from PVWatts) from each of the six PV system orientations to convert from 2014$/kW-year to 2014$/kWh per kW, and then multiplied by the associated SCC discount factor, described above in the avoided capacity cost section, to establish the range of avoided transmission capacity costs for the six system orientations.

4. Avoided Distribution Capacity Costs

Avoided distribution costs for 2014 are from the AESC 2013 study (Appendix G, Exhibit G-1) – weighted average of utilities' costs in a specific state based on sales – and escalated from 2013$ to 2014$. Starting in 2015 the rate is reduced using an annual PV degradation rate of 0.5%. A real discount rate of 1.36% is used to establish the present value and an inflation rate of 2.00% to calculate the 25-year levelized cost of avoided distribution capacity costs (in 2014$).

The levelized distribution costs are divided by the total annual production (from PVWatts) from each of the six PV system orientations to convert from 2014$/kW-year to 2014$/kWh per kW, and then multiplied by a distribution peak coincidence factor unique to each of the solar PV system orientations to establish the range of avoided distribution capacity costs.

The distribution peak coincidence factors are generated by first isolating the top 5% of ISO-NE's hourly demand in 2014. Within this subset of load, the number of month/hour pairs are counted (e.g. month 7/hour 18 was a top load hour 19 times in 2014). Average PV output during month/hour pairs that occurred 9 time or more were used to establish the average system output during top demand hours (assumed to drive investment in the distribution system), when divided by the system rating convention (MW-AC) generate the distribution peak coincidence factors.

[11] *See* http://www.iso-ne.com/trans/services/types_apps/rns_through_out_rates.pdf

Example: Solar PV's Distribution Peak Coincidence Factors in Massachusetts (2014)

			Average PV System Ouput (W)					
			South Facing -- Fixed		West Facing -- Fixed			2-axis tracking
Month	Hour	# Pairs	35 degrees	20 degrees	35 degrees	20 degrees	5 degrees	
1	18	13	0.00	0.00	0.00	0.00	0.00	0.00
1	19	13	0.00	0.00	0.00	0.00	0.00	0.00
1	20	11	0.00	0.00	0.00	0.00	0.00	0.00
7	10	9	492.05	508.04	273.95	384.38	467.26	575.82
7	11	10	553.67	565.09	381.24	466.19	522.92	588.47
7	12	14	582.80	592.16	467.45	525.07	554.22	593.86
7	13	14	559.07	569.51	514.41	543.25	544.68	575.33
7	14	14	508.76	521.50	529.68	533.91	511.45	553.79
7	15	15	410.97	427.00	489.65	473.96	433.80	497.45
7	16	16	320.99	342.35	459.57	425.54	367.50	470.69
7	17	17	188.19	212.71	354.70	313.25	252.03	379.13
7	18	15	72.85	92.07	211.74	177.28	130.45	244.97
7	19	13	26.03	22.15	70.37	54.79	35.67	93.11
7	20	12	0.08	0.00	0.43	0.15	0.00	0.96
7	21	11	0.00	0.00	0.00	0.00	0.00	0.00
7	22	10	0.00	0.00	0.00	0.00	0.00	0.00
8	15	9	538.63	535.53	538.33	535.33	504.39	582.59
8	15	9	429.36	432.25	496.74	472.82	423.40	520.13
8	16	9	309.36	317.55	435.56	394.06	328.82	460.94
8	17	9	175.14	188.84	344.62	292.17	218.96	386.49
Average Output			258.40	266.34	278.42	279.61	264.78	326.19
Distribution Peak Coincidence Factors			**25.8%**	**26.6%**	**27.8%**	**28.0%**	**26.5%**	**32.6%**

5. DRIPE –Energy

Demand Reduction Induced Price Effects (DRIPE) energy values are from the AESC 2013 study. Winter on-peak, winter off-peak, summer on-peak, summer off-peak are reported for each year (2014-2023) by state and for the rest-of-pool.[12] The following table presents the DRIPE energy values (nominal $/MWh) used for Massachusetts.

[12] Synapse Energy Economics Inc. (2013). *Avoided Energy Supply Costs in New England: 2013 Report*. Available at: http://www.synapse-energy.com/sites/default/files/SynapseReport.2013-07.AESC_.AESC-2013.13-029-Report.pdf

Example: DRIPE Energy Values (nominal $/MWh) for Massachusetts and Rest-of-Pool (2014-2023)

	Winter On Peak		Winter Off Peak		Summer On Peak		Summer Off Peak	
	MA	Rest	MA	Rest	MA	Rest	MA	Rest
2014	15.26	16.56	5.94	4.63	12.28	13.32	4.74	3.70
2015	57.86	63.29	22.79	18.00	48.60	53.15	18.28	14.44
2016	60.00	66.03	23.74	18.90	53.00	58.32	19.47	15.49
2017	58.99	64.71	23.03	18.29	60.76	66.66	21.24	16.87
2018	57.22	62.78	22.38	17.79	60.22	66.06	20.77	16.51
2019	49.70	54.54	19.21	15.27	52.25	57.33	17.72	14.09
2020	43.81	48.25	17.04	13.61	43.38	47.78	15.80	12.62
2021	31.98	35.17	12.73	10.17	33.11	36.41	11.79	9.42
2022	21.76	23.93	8.61	6.89	21.34	23.47	7.97	6.37
2023	11.00	12.07	4.35	3.47	11.16	12.24	4.05	3.24

DRIPE energy values were matched with the hourly PV system output profiles based on season (winter or summer) and hour (on peak or off-peak). A weighted average of hourly DRIPE energy values corresponding with each of the six PV systems' output was generated for 2014 thru 2023 for both the state and rest of pool.

A real discount rate of 1.36% is used to establish the present value and an inflation rate of 2.00% to calculate the 25-year levelized cost from DRIPE energy (in 2014$). The final DRIPE energy values are the sum of the in-state effects and the effect to the rest-of-pool.

6. DRIPE – Capacity

Annual DRIPE capacity values for each state and the ISO-NE region are from the AESC 2013 study.[13] Since the 2018 FCM auction has already occurred only values starting in 2019 were used (i.e. 2019 thru 2024). The annual values are converted to 2014$ and from $/kW-month to $/kW-year.

A real discount rate of 1.36% is used to establish the present value and an inflation rate of 2.00% to calculate the 25-year levelized cost for DRIPE capacity (in 2014$). The state and rest-of-pool levelized values are summed together and divided by the total annual production (from PVWatts) from each of the six PV system orientations to convert from 2014$/kW-year to 2014$/kWh per kW,

The levelized values are then multiplied by the discount factor, or Seasonal Claimed Capability factor, outlined in the section on avoided capacity costs to generate the final DRIPE capacity values.

7. Avoided CO2 Compliance Costs

Avoided CO2 compliance costs are the embedded costs associated with meeting existing and proposed greenhouse gas (GHG) emissions reduction requirements. For Massachusetts these costs are equal to the compliance costs associated with the Global Warming Solutions Act (GWSA) targets.[14] Otherwise, avoided CO2

[13] Ibid.

[14] Corrected Second Amended Testimony o f Tim Woolf in DPU Docket 14-86, December 4, 2014. Available at: http://www.synapse-energy.com/sites/default/files/Woolf%20Second%20Amended%20Direct%20Testimony%20Regarding%20the%20Avoided%20Costs%20of%20Complying%20with%20the%20Global%20Warming%20Solutions%20Act.pdf

compliance costs are equal to the values outlined in the AESC 2013 study under the Synapse scenario which includes RGGI compliance costs and the costs of a federal program beginning in 2020.[15]

Emissions rates from the AESC 2013 study were used to calculate dollars per MWh, where necessary. Starting in 2015, the CO2 compliance costs (2014$ per MWh) are reduced using an annual PV degradation rate of 0.5%. A real discount rate of 1.36% is then used to establish the present value and an inflation rate of 2.00% to calculate the 25-year levelized cost of avoiding a marginal unit of GHG emissions (in 2014$).

8. Avoided NOx Compliance Costs

Avoided NOx compliance costs are the embedded costs associate with meeting existing nitrogen oxides reduction requirements. Avoided NOx compliance costs are equal to the values outlined in the AESC 2013 study.

Emissions rates from the AESC 2013 study were used to calculate dollars per MWh. Starting in 2015, the NOx compliance costs (2014$ per MWh) are reduced using an annual PV degradation rate of 0.5%. A real discount rate of 1.36% is then used to establish the present value and an inflation rate of 2.00% to calculate the 25-year levelized cost of avoiding a marginal unit of NOx emissions (in 2014$).

9. Net Social Cost of CO2

The net social cost of CO2 is the difference between the social cost of carbon and CO2 compliance costs. The social cost of carbon used in this assessment is the value recommended in the AESC 2013 study: $100 per short ton (2013$).

Emissions rates from the AESC 2013 study were used to calculate dollars per MWh, where necessary. CO2 compliance costs are then subtracted from the gross social cost of carbon. For Massachusetts, the CO2 compliance costs are equal to the compliance costs associated with the GWSA targets. For the other state, the CO2 compliance costs are the RGGI + Federal scenario from AESC 2013 (as described above).

Starting in 2015, the net social cost of CO2 (2014$ per MWh) is reduced using an annual PV degradation rate of 0.5%. A real discount rate of 1.36% is then used to establish the present value and an inflation rate of 2.00% to calculate the 25-year levelized cost (in 2014$).

10. Net Social Cost of SO2

The net social cost of SO2 is the difference between the social cost of SO2 and SO2 compliance costs. SO2 compliance costs are assumed to be zero. The social cost of SO2 is based on the EPA's *Regulatory Impact Analysis for the Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants*.[16] The EPA analysis provides a range of values for 2020, 2025 and 2030. Acadia Center's analysis uses the midpoint value for the eastern region under the 3% discount rate scenario for each of these years and extrapolates linearly to generate values for 2014 thru 2038. These value are converted from 2011$ to 2014$.

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[15] Synapse Energy Economics Inc. (2013). *Avoided Energy Supply Costs in New England: 2013 Report*. *See* Exhibit 4-1 on pg. 4-4. Available at: http://www.synapse-energy.com/sites/default/files/SynapseReport.2013-07.AESC_.AESC-2013.13-029-Report.pdf

[16] EPA *Regulatory Impact Analysis for the Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants*. June 2014. Available at: http://www2.epa.gov/sites/production/files/2014-06/documents/20140602ria-clean-power-plan.pdf. See Tables 4-7, 4-8 and 4-9.

The regional average annual (all hours) Locational Marginal Unit marginal emissions rate (emitting LMUs) for SO2 from ISO-NE's 2013 emissions report is used to calculate $/MWh.[17] This value is equal to 0.69 lbs/MWh.

Starting in 2015, the net social cost of SO2 (2014$ per MWh) is reduced using an annual PV degradation rate of 0.5%. A real discount rate of 1.36% is then used to establish the present value and an inflation rate of 2.00% to calculate the 25-year levelized cost (in 2014$).

11. Net Social Cost of NOx

The net social cost of NOx is the difference between the social cost of carbon and NOx compliance costs. As with SO2, the social cost of NOx is based on the EPA's *Regulatory Impact Analysis for the Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants*.[18] The EPA analysis provides a range of values for 2020, 2025 and 2030. Acadia Center's analysis uses the midpoint value for the eastern region under the 3% discount rate scenario for each of these years and extrapolates linearly to generate values for 2014 thru 2038. These value are converted from 2011$ to 2014$.

Emissions rates from the AESC 2013 study were used to calculate dollars per MWh. NOx compliance costs – also from the AESC 2013 study as outlined above – are then subtracted from the gross social cost of NOx.

Starting in 2015, the net social cost of NOx (2014$ per MWh) is reduced using an annual PV degradation rate of 0.5%. A real discount rate of 1.36% is then used to establish the present value and an inflation rate of 2.00% to calculate the 25-year levelized cost (in 2014$).

For more information:

Jamie Howland, Director, Climate and Energy Analysis Center, jhowland@acadiacenter.org, 860-246-7121 x 201
Leslie Malone, Senior Analyst, Energy and Climate, lmalone@acadiacenter.org, 401-276-0600

[17] 2013 ISO New England Electric Generator Air Emissions Report. December 2014. Available at: http://www.iso-ne.com/static-assets/documents/2014/12/2013_emissions_report_final.pdf

[18] EPA *Regulatory Impact Analysis for the Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants*. June 2014. Available at: http://www2.epa.gov/sites/production/files/2014-06/documents/20140602ria-clean-power-plan.pdf. See Tables 4-7, 4-8 and 4-9.