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The social cost of carbon: implications for modernizing our electricity system

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Abstract The US government must use an official estimate of the "social cost of carbon" (SCC) to estimate carbon emission reduction benefits for proposed environmental standards expected to reduce CO_2 emissions. The SCC is a monetized value of the marginal benefit of reducing one metric ton of CO_2. Estimates of the SCC vary widely. The US government uses values of $11, $33, and $52 per metric ton of CO_2, classifying the middle value as the central figure and the two others for use in sensitivity analyses. Three other estimates using the same government model but lower discount rates put the figures at $62, $122, and $266/ton. In this article, we calculate, on a cents-per-kilowatt-hour basis, the environmental cost of CO_2 emissions from fossil fuel generation and add it to production costs. With this, we compare the total social cost (generation plus environmental costs) of building new generation from traditional fossil fuels versus cleaner technologies. We also examine the cost of replacing existing coal generation with cleaner options, ranging from conventional natural gas to solar photovoltaic. We find that for most SCC values, it is more economically efficient (from a social cost–benefit perspective) for the new generation to come from any of these cleaner sources rather than conventional coal, and in several instances, the cleanest sources are preferable to conventional natural gas. For existing generation, for five of the six SCC estimates we examined, replacing the average existing coal plant with conventional natural gas, natural gas with carbon capture and storage, or wind increases economic efficiency. At the two highest SCCs, solar photovoltaic and coal with carbon capture and storage are also more efficient than maintaining a typical coal plant.

Keywords Social cost of carbon · Cost–benefit analysis · Climate change · Regulatory impact analysis

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Introduction

This paper extends the work of Johnson and Hope (2012), who reestimated the US government's estimates of climate change damages, called the "social cost of carbon" (SCC), to more fully account for impacts on future generations. To demonstrate the policy implications of their SCC estimates, Johnson and Hope (JH) incorporated the costs of pollution into the cost of electricity generation from coal, natural gas, onshore wind, and solar photovoltaic.

They found that at all of their SCCs, building new generation from the cleaner sources they examined was less expensive (inclusive of pollution costs) than from coal. Comparing the cleanest technologies to natural gas, wind and solar were more efficient at some of JH's estimates. In contrast, at all of the government SCC values, natural gas was always more efficient than any of the other technologies.

Here, we extend JH's analysis in three ways. First, we add two options to their set of cleaner technologies, coal and natural gas using carbon capture and storage technology (CCS). Second, we assess the cost of continuing to operate a typical coal plant in the existing fleet versus replacing it with cleaner generation. Third, we update their analysis using the most recent government estimates of the SCC and generation costs. Specifically, we use SCC government estimates published in July 2013, which are significantly higher than the original values used in JH.[1] We also use the most recent projections from the Energy Information Administration (EIA) for electricity generation costs, which show significantly lower estimates for wind and solar photovoltaic compared to 2012 values.

Overall, for new generation, we find that all JH and government SCCs justified conventional natural gas, natural gas

[1] The US Government revised its SCC numbers (US Government 2013) using the same three models it used in 2010 (US Government 2010), updated to incorporate more recent climate science. The 2010 values were $5, $21, and $35 per metric ton of CO_2; the revised values are $11, $33, and $52. The new estimates were released while this article was in press. Accordingly, results were updated prior to publication.

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with CCS, and wind over conventional coal. Most estimates also justified solar and coal with CCS over conventional coal, and wind over natural gas. For existing generation, at all of JH's SCCs, continuing to operate some of the dirtiest coal plants is more expensive than replacing them with natural gas, natural gas with CCS, or wind; at their two highest estimates, this is also true for new coal with CCS and solar photovoltaic. For the government's SCCs, we found that its central and upper end values justify replacing a dirty coal plant with new natural gas, natural gas with CCS, or wind. At the government's lowest SCC value, the cost of new natural gas generation is equal to the cost of existing coal.

Contrasting Johnson and Hope (2012) carbon damage estimates with US Government estimates

Before presenting our results in more detail, we give some brief background on the difference between JH's SCC estimates and those used by the government.

Their results diverged from the original government estimates based upon assumed discount rates. Drawing from the economics literature, JH used intergenerational values of 1, 1.5, and 2 % per year and calculated the SCC per metric ton of CO_2 emitted in 2010 at $266, $122, and $62, respectively. The government's estimates used discount rates of 2.5, 3, and 5 % per year, with corresponding SCC estimates of $35, $21, and $5, respectively.[2] The updated government estimates are now $52, $33, and $11, using the same discount rates but newer versions of the three models used to calculate damages.[3]

Very briefly, discounting assumes that a dollar today is more valuable than one received in the future, hence when applied to anticipated damages resulting from climate change, it lowers how we value environmental damages inflicted on future generations. The higher the discount rate, the lower is the SCC. An in depth discussion of how the discount rate is derived, how it works, and the justifications for using different rates can be found in JH. The climate economic models used to estimate damages are also described in detail there.

[2] The government also had an upper bound "sensitivity" estimate of $90/ton, the 95th percentile value using a 3 % discount rate. Here, we present only mean estimates from both the US government and JH at the different discount rates. In addition, for comparability with government estimates and JH, all SCC estimates are in 2007$ for a metric ton of carbon emitted in 2010 for the main comparisons. We also give results when 2018 government SCCs generated qualitatively different results over 2010 government SCCs.

[3] As discussed in an earlier footnote, the increased values are a result of more recent science being incorporated into the earlier model versions, with greater climate impacts and associated costs. Importantly, we did not reestimate Johnson and Hope's original calculations with the updated models; were they to be similarly revised, the SCC values at their discount rates would also be significantly higher.

Table 1 Generation costs of different technologies, excluding CO_2 and SO_2 damages

	Cost in cents/kWh (2007$)
Existing coal fleet (average)[a]	3.0
New conventional natural gas[b]	6.2
New onshore wind[b]	8.0
New natural gas with capture[b, c]	8.6
New conventional coal[b]	9.3
New coal with capture[b, c]	12.6
New solar photovoltaic[b]	13.3

[a] Source: SNL Financial database, total operating and maintenance costs of the 2010 coal fleet divided by total generation

[b] Source: Annual Energy Outlook 2013, US Energy Information Administration, converted from 2011$ to 2007$, for comparability with SCC estimates

[c] These costs exclude any offsetting revenue from selling CO_2, e.g., for enhanced oil recovery

Producer costs of electricity generation

Table 1 summarizes average costs *to electricity generators* of seven technology categories: new conventional coal- and natural gas-fired power plants, new coal and natural gas plants equipped with CCS, new onshore wind, new solar photovoltaic, and, finally, an existing average coal plant (Note that for the rest of this piece, we sometimes drop the term "conventional" before "natural gas" and "coal" when CCS technology is not assumed). Methods and assumptions are described in the appendix.

For new generation, we used estimates of levelized cost[4] for plants beginning operations in 2018 from the Department of Energy's 2013 Annual Energy Outlook in cents per kilowatt hour (kWh). Future values are more relevant for policy analysis than current generation costs, as carbon standards

[4] Levelized cost represents the total cost of building and operating a generating plant over an assumed financial life and duty cycle, converted to equal annual payments and expressed in terms of real dollars that remove the impact of inflation. It includes overnight capital cost, fuel cost, fixed and variable operation and maintenance costs, financing costs, and an assumed utilization rate for each plant type. Various incentives including state or federal tax credits, which would lower producer costs, are not assumed. An ideal comparison of costs would be one that adjusted for the intermittency of renewable sources, which is not captured in a levelized cost comparison. Adjusting for this factor is beyond the scope of this analysis, so the estimates here should be viewed as a first approximation. An important recent analysis by the National Renewable Energy Laboratoty (2012), however, concluded that with the proper set of policies, the nation could reliably get 80 % of its electricity from renewable sources by 2050. In addition, renewable energy has much lower operation and maintenance costs than traditional generation, so that over time its higher upfront investment costs can be recouped through these savings. Another study just released by Synapse Energy Economics (Vitolo et al. 2013) finds that at a high level of renewable penetration reliability would not be a problem and would cost less than business as usual.

Table 2 Building new conventional coal and natural gas versus cleaner sources (2007$) (revised WG SCCs)

Cost in cents/kWh (2007$)	Imputed cost using Johnson/Hope revised SCC estimates[a]			Imputed cost using government SCC estimates[a]		
	1 % discount rate ($266/ton of CO_2)	1.5 % discount rate ($122/ton of CO_2)	2 % discount rate ($62/ton of CO_2)	2.5 % discount rate ($52/ton of CO_2)	3 % discount rate ($33/ton of CO_2)	5 % discount rate ($11/ton of CO_2)
New coal (total cost)[b]	31.9	20.3	15.5	14.7	13.2	11.4
(Generation cost)	9.3	9.3	9.3	9.3	9.3	9.3
(SO_2 damages)[c]	1.2	1.2	1.2	1.2	1.2	1.2
(CO_2 damages)	21.4	9.8	5.0	4.2	2.7	0.9
New natural gas (total cost)[b]	16.3	10.8	8.6	8.2	7.5	6.6
(Generation cost)	6.2	6.2	6.2	6.2	6.2	6.2
(SO_2 damages)[c]	negligible	negligible	negligible	negligible	negligible	negligible
(CO_2 damages)	10.1	4.6	2.4	2.0	1.3	0.4
New coal with capture[b]	15.1	13.8	13.2	13.1	13.0	12.7
New solar photovoltaic	13.3	13.3	13.3	13.3	13.3	13.3
New natural gas with capture[b]	9.8	9.2	8.9	8.8	8.8	8.7
New onshore wind	8	8	8	8	8	8

[a] SCC estimates are per metric ton of CO_2 emitted in 2010 for both JH and government values (for comparability between the two); generation costs are for plants constructed in 2018

[b] Inclusive of CO_2 and SO_2 damages. Note that generation from wind and solar photovoltaic have zero emissions of these pollutants

[c] In contrast to CO_2, SO_2 damages are not noticeably affected by discounting as damages from these pollutants are immediate without subsequent damages occurring over many years. SO_2 emission rates are assumed to be in compliance with new standards (for non-CO_2 pollutants) in effect by 2016

will not come into effect until several years after final rulemakings are promulgated.

To estimate costs for an average existing coal plant, we divided total operation and maintenance expenses of the entire fleet by its total generation. These expenses include only those needed for continued operation (e.g., fuel, labor, and maintenance).[5] They exclude future investments some plants would need in order to be in full compliance with the new standards coming into effect in 2016 (for non-CO_2 pollutants). To the extent that these costs are large (for plants without any control technologies they can be significant), we underestimate the cost of continued operation. Offsetting this, we would also overestimate SO_2 pollution damages (see below) associated with these plants once pollution controls are installed.

Real cost of electricity generation (generator costs plus pollution externalities)

When assessing what types of electricity are best for society overall (not just producers), one must add to a generator's cost the damages to society resulting from pollution externalities (i.e., "internalize" these damages into production cost).

[5] A small fraction of costs that cannot be avoided even after a plant ceases operation are included in this measure, such as rental fees that must be paid until a lease expires. However, operation and maintenance cost, and purchases of emission allowances, account for the majority of costs associated with operation (plants that reduce pollution below standards can sell excess emission allowances, lowering their operation costs).

In addition to the damages from CO_2 pollution, we include impacts from the power sector's sulfur dioxide (SO_2) emissions which, every year, cause thousands of premature deaths, heart attacks and incidents of respiratory disease (e.g., asthma and bronchitis), millions of lost work and school days, and a variety of damages to ecosystems and property (US EPA 2011a, b).

Table 2 shows costs for newly built generation coming online in 2018 inclusive of CO_2 and SO_2 pollution damages, for four cleaner options versus coal and natural gas.[6] Carbon costs are based upon the estimated damages per ton of CO_2 emitted in 2010 at the different discount rates,[7] translated into cents per kilowatt hour of generation. It should be noted that the government applies different discount rates to SO_2 damages than to CO_2 damages[8]; nevertheless, SO_2 damages are

[6] While the market has all but abandoned new coal generation, we include it here for completeness.

[7] SCC estimates are per metric ton of CO_2 emitted in 2010 for both JH and government values (for comparability between the two); generation costs are for plants constructed in 2018.

[8] The US Office of Management and Budget (OMB; 2003) guidelines specify two standard rates of 3 and 7 %, regularly applied to benefits and costs that occur within the current generation. However, the government used 5 % as its upper value rather than 7 % for climate damages for the reason that they are expected to primarily and directly affect consumption rather than the allocation of capital. A rate of 7 % corresponds to returns on capital investments (see p. 33 of OMB Circular A-4 and JH for further explanation).

Table 3 Replacing existing coal with cleaner sources (2007$) (revised WG SCCs)

Cost in cents/ kWh (2007$)	Imputed cost using Johnson/Hope revised SCC estimates[a]			Imputed cost using government SCC estimates[a]		
	1 % discount rate ($266/ton of CO_2)	1.5 % discount rate ($122/ton of CO_2)	2 % discount rate ($62/ton of CO_2)	2.5 % discount rate ($52/ton of CO_2)	3 % discount rate ($33/ton of CO_2)	5 % discount rate ($11/ton of CO_2)
Existing coal (total cost)[b]	34.5	18.7	12.2	11.1	9.0	6.6
(Generation cost)[c]	3.0	3.0	3.0	3.0	3.0	3.0
(SO_2 damages)[d]	2.4	2.4	2.4	2.4	2.4	2.4
(CO_2damages)[a]	29.1	13.3	6.8	5.7	3.6	1.2
New natural gas[b]	16.3	10.8	8.6	8.2	7.5	6.6
New coal with capture[b]	15.1	13.8	13.2	13.1	13.0	12.7
New solar photovoltaic	13.3	13.3	13.3	13.3	13.3	13.3
New natural gas with capture[b]	9.8	9.2	8.9	8.8	8.8	8.7
New onshore wind	8.0	8.0	8.0	8.0	8.0	8.0

[a] SCC estimates are per metric ton of CO_2 emitted in 2010 for both JH and government values (for comparability between the two); generation costs are for plants constructed in 2018

[b] Inclusive of SO_2 and CO_2 costs. Note that generation from wind and solar photovoltaic have zero emissions of these pollutants

[c] Source: SNL Financial (2010) database, total operating and maintenance costs of the 2010 coal fleet divided by total generation

[d] In contrast to CO_2, SO_2 damages are not noticeably affected by discounting as damages from these pollutants are immediate without subsequent damages occurring over many years. SO_2 emission rates are assumed to be in compliance with new standards (for non-CO_2 pollutants) in effect by 2016

not noticeably affected by discounting because its impacts are more immediate.

At any of the JH SCCs, new conventional coal is more expensive than the cleaner options once pollution damages are incorporated into costs. With respect to natural gas, this result also holds for wind and at Johnson and Hope's two highest estimates for natural gas with CCS. Specifically, at $266/ton of CO_2, natural gas is 16.3 cents/kWh versus 9.8 cents for natural gas with CCS. At $122/ton, costs are 10.8 versus 9.2 cents, respectively. At their highest estimate ($266/ton), new conventional natural gas is also more expensive than coal with CCS and solar (16.3 cents versus 15.1 and 13.3, respectively).

For all of the government SCCs, three of the five cleaner technologies are more efficient than new coal: conventional natural gas, natural gas with CCS, and wind. Coal with CCS is more efficient at the upper end and central SCCs (13.1 versus 14.7 cents and 13 versus 13.2 cents, respectively) and solar at its highest SCC (13.3 versus 14.7 cents). At its central estimate, solar is about equal to coal (13.3 versus 13.2 cents). For new natural gas, wind is comparatively more efficient at the upper end SCC (8 versus 8.2 cents) and only somewhat more expensive at its central value (8 versus 7.5 cents). This latter result is important because natural gas has significant upstream emissions of methane, a much more potent greenhouse gas than CO_2. After accounting for this pollution, wind could very well be lower cost than natural gas.[9]

Although not presented in the tables of this paper, we also examined whether any additional technologies would be competitive with conventional fossil fuels at the administration's SCC value for emissions in 2018 (linearly interpolated between the 2015 and 2020 estimates, for comparison with the 2018 EIA generation cost estimates. No future SCC schedule was available in JH, so we were not able to do the same with respect to their estimates).

For 2018,[10] in addition to being cheaper than new coal at the administration's upper bound SCC, solar is also cheaper at the 3 % discount rate (13.3 versus 13.8 cents), making all five cleaner technologies more efficient than new coal at the government's central SCC value. Equally important, new wind is only marginally more expensive than natural gas, 8 versus 7.8 cents.

Relative costs of an average existing coal plant versus new cleaner generation

Table 3 compares five cleaner technologies to existing coal plants' generation. New conventional natural gas is included among these, which has roughly half the CO2 emissions of conventional new coal, and relatively small combustion emissions of other pollutants.[11]

[9] There are estimates of the social cost of methane and upstream emissions; however, internalizing these costs into generation costs was beyond the scope of this analysis.

[10] The 2018 values equal $62, $41, and $12/ton CO_2 for discount rates of 2.5, 3, and 5 %, respectively.

[11] Methane leaks from the natural gas system are uncertain but may be high enough to significantly increase the life cycle costs of gas plants.

At any of JH's climate damage estimates, continuing to operate an average coal plant is more expensive than replacing it with conventional natural gas, natural gas with CCS, or wind. At their two highest estimates, an average coal plant is also more expensive than new coal with CCS or solar. Specifically, at \$266/ton CO_2, the average coal plant costs 34.5 cents/kWh (more than ten times its direct generation costs) versus 15.1 and 13.3 cents/kWh, respectively, for new coal with CCS and solar. At \$122/ton CO_2, the average coal plant costs 18.7 cents/kWh versus 13.8 and 13.3 cents/kWh, respectively.

At the government's SCCs, the average existing coal plant is more expensive than new conventional natural gas at the upper end and central values and equal at the lower bound. Specifically, at \$52/ton CO2, coal costs 11.1 cents/kWh versus 8.2 cents for new conventional natural gas; at \$33/ton of CO2, coal costs 9 cents/kWh versus 7.5 cents for natural gas; and at \$11/ton of CO2, both cost 6.6 cents/kWh. At the upper end and central estimates, natural gas with CCS and wind are also advantageous over average existing coal plants (11.1 versus 8.8 and 8 cents, at \$52/ton of CO2 and 9 versus 8.8 and 8 cents at \$33/ton, respectively).

Relative to CO2 emitted in 2010, we did not find any additional cleaner technologies competitive with fossil fuels using the interpolated 2018 government values, with respect to existing generation.

Conservative estimates

Pollution damages at JH's discount rates are underestimated relative to administration values with respect to both the SCC estimates and generation costs.

JH relied upon older versions of the models, while the administration's newly published versions were updated to reflect more recent science. Holding the discount rate constant, JH's SCCs would be much higher with the updated models. JH also did not estimate SCC values for emissions in the future years (the SCC rises over time, reflecting increasing marginal costs of CO2 emissions).

Generation costs are likely to be overestimated for the cleanest technologies, to the extent that innovation is likely to bring down their costs. If one looks at past projections by EIA for developing technologies, one consistently finds cost overestimates. Further, EIA's generation cost estimates exclude upstream externalities associated with fossil fuel extraction, such as methane emissions from natural gas wells and spills from pipeline transmission, and land disturbances from coal mining.

Summary and concluding remarks

Using the SCC estimates developed in Johnson and Hope (2012), who reestimated the government's SCCs with lower discount rates, we compare the real societal cost of electricity generation across seven technology categories (conventional coal and natural gas, coal and natural gas with carbon capture and storage, onshore wind, solar photovoltaic, and existing coal generation) at both their SCCs and the government values derived from higher discount rates (using estimates for CO_2 emitted in 2010 for most comparisons, unless otherwise noted).

For new generation, we find JH's SCCs justify all of the cleaner technologies over new coal, at each discount rate examined. For the government SCCs, this is also true for natural gas, natural gas with CCS, and wind. In addition, both solar and coal with CCS are more efficient than conventional coal at the administration's lower discount rate and coal with CCS at its central rate. Solar is about equal to coal at the central discount rate for 2010 emissions but more efficient in 2018. Compared to natural gas, for JH's SCCs all of the cleaner sources are more efficient at one or more SCC value, while wind is justified at the government's lower bound discount rate. Further, after accounting for upstream methane emissions, wind is likely to be justified over natural gas at the government's central discount rate and possibly its highest.

For existing coal generation, all discount rates except the highest government value make replacing the average coal plant with new natural gas, natural gas with CCS, or wind more efficient than continuing to operate it. In addition, conventional natural gas costs the same as existing coal at the government's highest discount rate. Building new coal with CCS or solar is more efficient than continuing to operate a typical coal plant at JH's two lowest discount rates.

The conclusions presented here hinge to a large degree on the extent to which damages to future generations are valued similarly to people alive today and the near future. Because JH discount future damages to a much smaller degree than the government, the cleanest forms of generation are less costly to society than traditional fossil fuel based generation when using their SCCs. However, several cleaner technologies are also more efficient at the government's SCCs, just to a lesser degree.

Our estimates have important policy implications. For new electricity generation, they justify a much stronger standard than proposed last year by the Environmental Protection Agency, which was based upon natural gas emission rates. For existing source standards, which the EPA is also required to issue, they justify replacing a significant portion of the current coal fleet with new cleaner generation.

Methodology

SO_2 damages/ton from new electricity generation were taken from a recent regulatory impact analysis by the Environmental Protection Agency for the Transport Rule (2011a). SO_2 costs for existing generation were estimated using the analysis in

Lashof et al. (2012). The model used in that analysis was developed by Abt Associates, which employs the same framework as that used by EPA as approved by both the EPA's Science Advisory Board and the National Academy of Sciences. SO_2 damages for both analyses assumed emissions occurred in the eastern portion of the USA (territory east of the Rocky Mountains), where most coal-fired electricity in the USA is generated. Damages are derived using an average from two widely-used estimates of the relationship between fine particle concentrations and health impacts, for emission levels that are assumed to be in compliance with new standards (for non-CO_2 pollutants) in 2016.

We do not include EPA's estimates of damages from nitrogen oxide (NOx), as we could not isolate NOx emissions attributable only to coal combustion, though these damages are far smaller than damages from SO_2. In addition, a very large number of health and ecological damages are excluded from SO_2 and NOx emission damage estimates (see Table 5–1 for a list of excluded human health effects and Table 6–12 for ecological effects, in EPA's benefit cost analysis of the Clean Air Act (2011b)). They also exclude other externalities associated with power plants, such as methane emissions from natural gas wells and land disturbance from coal mining.

Pollution damages were incorporated into new fossil fuel electricity generation costs as follows: \$damages/kWh = (total annual tons of emissions × \$damage/ton)/total number of annual kilowatt hours), for a model 600 net megawatt (MW) power plant operating at an 85 % capacity factor. For example, a model coal plant emits 3.6 million tons of CO2 per year and generates 4.467 million kWhs of electricity (1.7 million tons of CO_2 for a comparable natural gas plant). A carbon damage estimate of \$33 per ton of CO_2 thus generates 2.7 cents/kWh in pollution costs for a new coal plant, while damages of \$52/ton of CO_2 generates 4.2 cents/kWh in damages. For CO2 emissions from conventional coal, coal with CCS, and natural gas, we used model plants provided in EPA's regulatory impact analysis for proposed new carbon standards (2012). For natural gas with CCS, we used emission estimates based upon net generation of a model plant estimated by the Department of Energy (2007). The same formula was used for renewables; however, the assumed capacity factors differ across these technologies as defined by the Energy Information Administration (EIA).

For our existing coal generation cost, we divided total operation and maintenance expenses of the entire 2010 fleet by total generation, using plant-specific data from SNL Financial. These expenses include only those needed for continued operation (e.g., fuel, labor, and maintenance). While it may cost less to continue running some of the cheapest coal plants than to replace them with cleaner generation, we were constrained to looking at the average costs of operating the entire coal fleet because we did not attempt to predict future emission rates and operating costs at the individual plant level. For example, we did not assess the costs of replacing only the most expensive coal plants because we did not calculate their SO_2 damages individually. As described in the main text, our estimate excludes future investments plants would be required to make in order to be in full compliance with the new standards (for non-CO_2 pollutants). To the extent that these costs are large (for plants without any control technologies they can be significant), we underestimate the cost of continued operation. A small fraction of costs that cannot be avoided even after a plant ceases operation are included in our measure, such as rental fees that must be paid until a lease expires. However, operation and maintenance costs, and purchases of emission allowances, account for the majority of costs associated with operation (plants that reduce pollution below standards can sell excess emission allowances, lowering their operation costs).

Finally, we note that to the extent that EIA overestimates wind and solar costs, as it has in the past, costs for these technologies are overestimated. They are also likely to be overestimated because EIA assumes that all new generation would require new transmission rather than use of current lines. In the opposite direction, grid interconnection requirements and the intermittency of renewable sources that can raise costs are not captured. As noted in an earlier footnote, adjusting for these factors is beyond the scope of this analysis. An important recent analysis by the Hand et al. (2012), however, concluded that with a proper set of policies the nation could reliably get 80 % of its electricity from renewable sources by 2050. In addition, renewable energy has much lower operation and maintenance costs than traditional generation, so that over time its higher upfront investment costs can be recouped through these savings. Another study released by Synapse Energy Economics in April 2013 (Vitolo et al.) finds that at a high level of renewable penetration reliability would not be a problem and would cost less than business as usual.

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