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Low-Carbon Electricity Pathways for the U.S. and the South: An Assessment of Costs and Options

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ABSTRACT

Since the release of the Clean Power Plan (CPP), stakeholders across the U.S. have vigorously debated the pros and cons of different options for reducing CO_2 emissions from existing power plants. By providing energy modeling relevant to these decisions, the authors seek to help policymakers and other stakeholders make well-informed choices. This paper uses the Georgia Institute of Technology's National Energy Modeling System to evaluate alternative low-carbon electricity pathways. Among the scenarios studied, we find that the least-cost compliance pathway involves a combination of renewable and energy-efficiency policies plus a modest price on carbon that could be expected to result from the Plan's implementation. In addition to transitioning to a low-carbon power system, this compliance pathway would produce substantial collateral benefits including lower electricity bills across all customer classes, greater GDP growth, and significant reductions in SO_2, NOx, and mercury emissions. The variation in compliance costs across the nation and within the South suggests that regional approaches to compliance would be most cost-effective. In addition, our modeling indicates that rate-based goals may generally be less costly than mass-based goals.

1. INTRODUCTION

Power plants are one of the largest sources of carbon pollution in the U.S., accounting for nearly 39% of annual CO_2 emissions from the combustion of fossil fuels (EIA, 2014, Table A.18). On June 2, 2014, the U.S. Environmental Protection Agency (EPA) proposed state-specific limits on CO_2 emissions from existing fossil fuel-fired electric generating units (EGUs) as part of its Clean Power Plan (CPP). Using its authority to control air pollution from stationary sources under Section 111 of the Clean Air, EPA is moving forward to establish carbon pollution standards:

> §111 (b) authorizes the federal program to address new, modified and reconstructed sources by establishing standards.
>
> §111 (d) authorizes a state-based program for existing sources. The EPA establishes guidelines under which the states design programs and achieve the needed reductions.[1]

§111 (d) provides the authority for the CPP. EPA is expected to publish a final rule in August 2015 requiring states to submit implementation plans as early as mid-2016. EPA is expected to offer states broad flexibility in the choice of compliance pathways; as a result, many states are vigorously engaged in examining alternative approaches to identify the compliance pathway that best meets their objectives.

The CPP proposes a customized goal of CO_2 emissions reductions for each state. Collectively, these goals would reduce the intensity of U.S. carbon emissions from the power sector (measured in pounds of CO_2 emitted per MWh of electricity generated from affected EGUs) to 30% below 2005 levels by 2030. Each state is not expected to reduce its emissions by 30%. Instead, the EPA developed a "best system of emissions reduction" that takes into account environmental protection goals, technical feasibility, and cost effectiveness. The individual state goals are customized to take into account each state's existing policies and current energy system. For example, the proposed plan would require Washington to cut its emissions by 72% in 2030 relative to 2012, while Kentucky has a proposed goal of only 18% emissions reduction. Georgia's proposed goal is a reduction of 44% from 2012 to 2030. This variation reflects potential emissions reductions available to states as well as reductions expected from existing policies and planned coal plant retirements. Figure 1 shows the variation in proposed state emission rate targets across the country.

[1] http://www2.epa.gov/carbon-pollution-standards/what-epa-doing

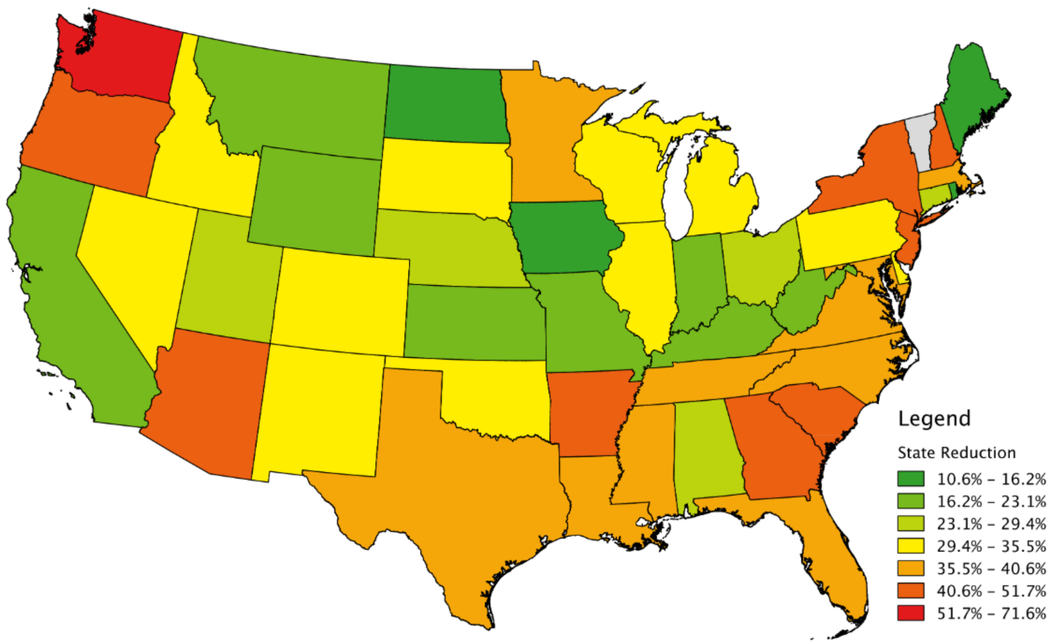

Figure 1. The Proposed Emissions Rate Reduction Targets
(Source of data: http://www.c2es.org/federal/executive/epa/carbon-pollution-standards-map)

Under §111(d), EPA is empowered to establish an "emission guideline" based on the best system of emission reduction. Once EPA guidance is finalized, states will be required to develop implementation plans to comply. States have until June 30, 2016 to submit their action plans but can request extensions until June 2017 for individual plans, or until June 2018 for multistate plans.

Compliance options include onsite actions at individual EGUs. For instance, states can undertake: (1) supply-side energy efficiency improvements ("heat rate improvements"), (2) fuel switching or co-firing of lower-carbon fuel; and (3) shifts in electricity generation from higher- to lower-emitting affected fossil units, such as the re-dispatch from coal to existing NGCC, with an increased utilization up to 70% of capacity. Heat-rate improvements could increase existing coal power plant efficiencies by 6%. More fully utilizing existing natural gas power plants would shift power generation from existing CO_2-intensive coal power plants with an average rate of 2080 lbs/MWh to natural gas plants with an average rate of 1220 lbs/MWh.[2]

Compliance options also include offsite actions that reduce or avoid emissions at affected EGUs. These include: (1) shifts from fossil generation to non-emitting generation such as nuclear or renewable generation and (2) reductions in fossil generation due to increases in end-use energy efficiency such as improvements in the efficiency of heating, cooling,

[2] http://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11

lighting, manufacturing processes. EPA characterized the best practice for energy efficiency as a 1.5% incremental savings as a percentage of retail sales and for the rate of improvement used a 0.2% per year starting in 2017 (Southworth and Schwimmer, 2015a).[3] For nuclear plants, 6% of 2012 nuclear capacity is considered to be "at risk" and contributes to the goal and all of the generation from units under construction and not operating in 2012 contributes to the goal. No additional new nuclear power plants were proposed other than those currently under construction in Georgia and South Carolina. In calculating state limits, EPA applied regional, annual RE growth rates to state 2012 RE levels, assuming that renewable electricity grows until the state reaches MWhs of renewable generation equal to 10% of 2012 generation or reaches 2029.

With the compliance flexibilities woven into the CPP, states have an array of options before them. On the supply side, they need to assess opportunities to shift the mix of fuels used to generate electricity in their state. On the demand side, they need to consider options for decreasing electricity consumption through energy-efficiency programs and policies. Administratively, states need to choose between adhering to an emissions intensity goal or an equivalent CO_2 emissions goal. In addition, they can elect to prepare an individual plan or a multistate plan, and in either event they can design a policy pathway that facilitates regional trading of allowances.

This report uses state-of-the-art energy analysis tools to evaluate the pros and cons of these alternatives compliance options. As an initiative of the Georgia Institute of Technology, we not only examine the costs and benefits of various policy pathways from a national perspective, but we also focus on the applicability of these pathways to the South, where opportunities and conditions may suggest alternative policy agendas. We begin with an overview of state goals for the Clean Power Plan (Section 2). Our research questions are specified in Section 3, which is followed by a description of our research methodology (Section 4). Findings are then presented, beginning with an assessment of the effectiveness, costs and benefits of alternative low-carbon policy pathways (Section 5), with a particular emphasis on their fuel mix implications. The modeling results are then used to inform the pros and cons of regional vs state approaches (Section 6) and mass vs rate goals (Section 7). The reduction of other air pollutants are described in Section 8, and conclusions are summarized in Section 9.

[3] http://www2.epa.gov/sites/production/files/2014-06/documents/20140602tsd-ghg-abatement-measures.pdf (Chapter 5, pg 5-30).

2. CONTEXT ON THE STATE GOALS FOR THE CLEAN POWER PLAN

EPA proposed rate-based CO_2 goals for states in June 2014. To illustrate the rate-based goal calculation, Figure 2 steps through the reductions proposed for the State of Tennessee, describing how each of the four building blocks are projected to be used to reduce the carbon intensity of the state's existing EGUs by 38.9%. Building block 3 (nuclear + renewables) accounts for more than half of the goal with a particularly large share coming from Tennessee's nuclear fleet (constituting a reduction of 365 lbs/MWh, which includes a nuclear unit scheduled to come on line at the end of 2015). The next largest contribution to the goal comes from building block 4: energy efficiency (representing a reduction of 159 lbs/MWh).

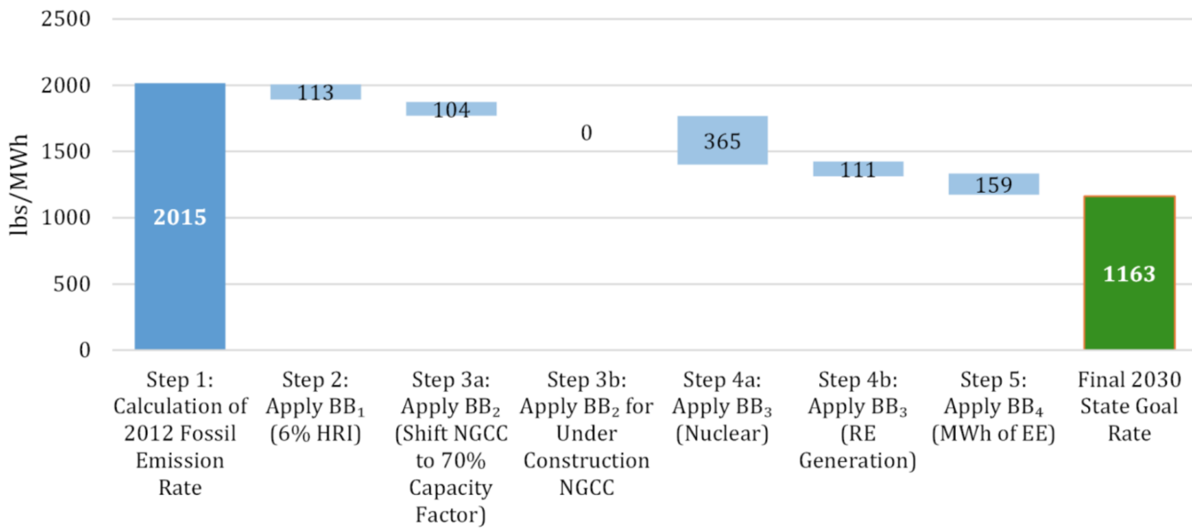

Figure 2. Calculation of the Rate-Based Goal for the State of Tennessee[4]

Across the 49 states with compliance targets,[5] the average goal calls for reducing emissions rates by 31.3%. Building block 2 (shifting to natural gas combined cycle – NGCC generation) accounts for 365 lb/MWh of the rate-based goal or 35% of the requirement. Building blocks 3 (renewables and nuclear power) and 4 (energy efficiency) account for 25% and 26%, respectively. Building block 1 (coal plant efficiency through, for instance, heat rate improvement – HRI) accounts for only 14%.

For states in the South, building blocks 2 (NGCC) and 3 (nuclear + renewables) are responsible for large shares of the required emissions reductions, at 39% and 31%, respectively). Energy efficiency accounts for only 18%, compared with 26% nationwide.

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[4] http://www2.epa.gov/sites/production/files/2014-09/cpp_state_goal_rate_calculation_viewer_-_final_3_0_0.xlsm

[5] Vermont and Washington, DC do not have compliance goals because they have no fossil-fueled EGUs.

Building block 1 is comparable to the rest of the U.S. in the portion of the goal that coal HRI is assigned.[6]

While EPA is expected to issue final rate-based goals, states may design their implementation plans to achieve an equivalent mass-based goal. Measured in million metric tons of CO_2, these goals would cap emissions so that covered EGUs do not exceed a particular aggregate level of emissions rather than capping the emissions rate.[7] EPA has published two types of preliminary mass-based goal: one is based on historical emissions from existing sources; a second goal caps existing sources and projected emissions that would result from demand growth between 2012 and 2030.

The percent reductions required by the rate-based goals are slightly higher for the South than for the U.S. as a whole, as shown in Figure 3. Specifically, the U.S. goal calls for a 34% reduction in its rate of CO_2 emission from existing EGUs, by 2030 compared to 2012. The South, on the other hand, has a 37% rate-based reduction goal for existing EGUs. The mass-based goals for existing units are more demanding for the South (32% vs 34%), but they are slightly less demanding when new units are included (21% vs 20%).

The percent reductions required by the rate and mass goals are highly correlated, as shown by the trend lines in Figure 3, which are based on goals for the seven NERC regions that comprise the South in this study along with the 14 states that are part of these NERC regions (these regions are described further in Section 4). The best fitting regression line between rate-based and mass-based goals for existing EGUs has a coefficient of determination of 80%. The best-fit line is less precise when comparing rate-based goals with mass-based goals for existing and new units, which is to be expected since new units are not included in the rate-based goals.

State goals in the South are wide-ranging. For example, Kentucky's rate-based goal and its mass-based goal for existing and new units both require the lowest percent reduction of any state in the South (<20% for both goals). The predominance of coal power generation in Kentucky is the basis of its low rates, since re-dispatching to natural gas is difficult in the short term, and there is no nuclear generation "at risk." At the other extreme, the same goals for South Carolina require the highest percent reduction (>50% for both goals). The predominance of nuclear power generation in South Carolina contributes to its high rates. Virginia is the largest outlier, with a stringent rate-based goal requiring nearly 40% reductions by 2030, but more lenient mass-based goals of less than 25% for existing affected units and less than 5% for existing plus new units.

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[6] http://www.c2es.org/federal/executive/epa/carbon-pollution-standards-map

[7] EPA Fact Sheet, http://www2.epa.gov/carbon-pollution-standards/fact-sheet-clean-power-plan-technical-support-document#print

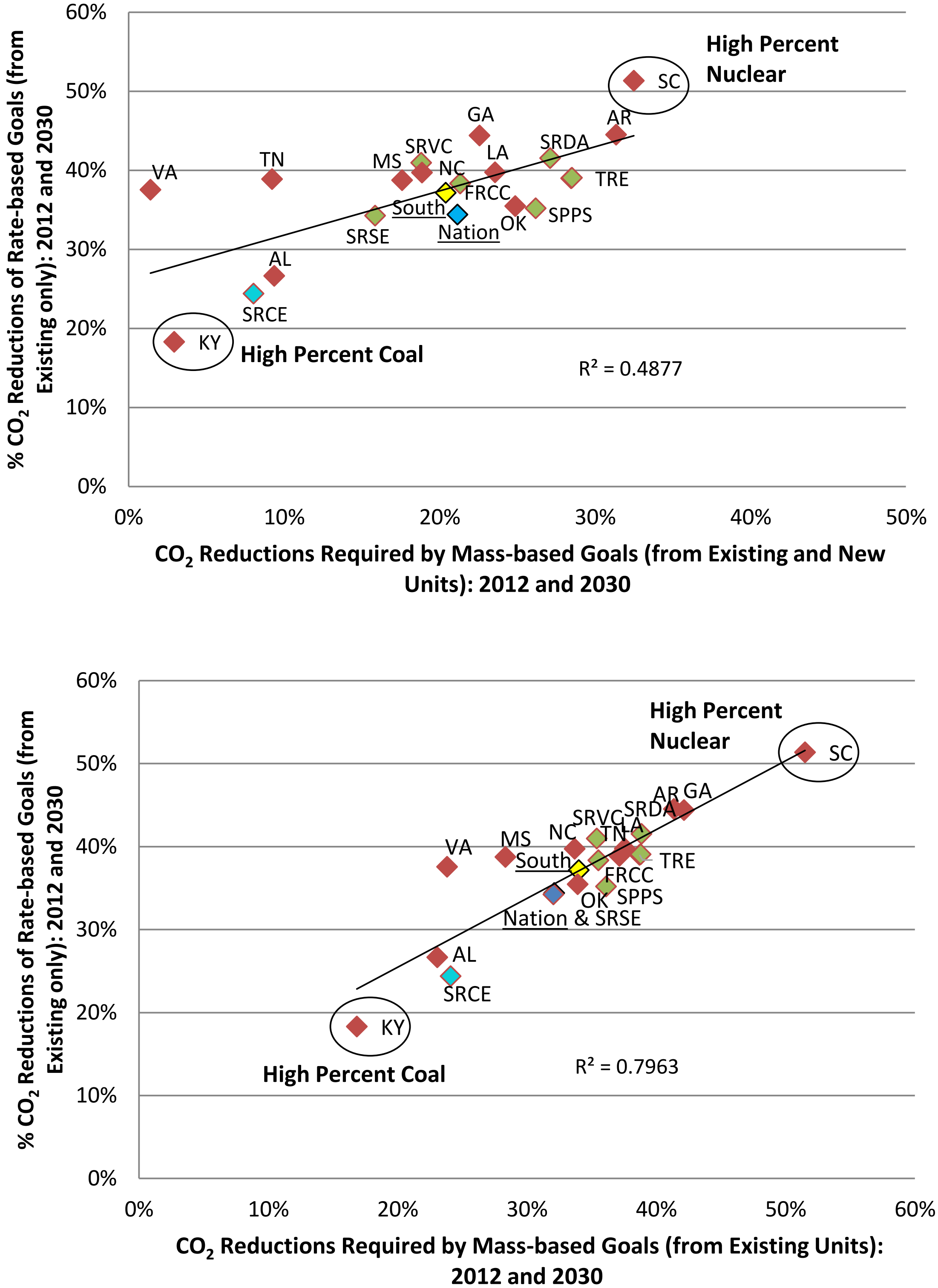


Figure 3. Rate-based vs. Mass-based Goals for States and NERC Regions in the South

(Sources: 2012 Emissions - EPA State CO_2 Emissions, http://epa.gov/statelocalclimate; 2030 Goals - EPA Fact Sheet, http://www2.epa.gov/carbon-pollution-standards/fact-sheet-clean-power-plan-technical-support-document#print)

3. RESEARCH QUESTIONS

Since the release of the Clean Power Plan, stakeholders across the country have vigorously debated the pros and cons of different compliance options. EPA received millions of comments on its proposed regulations covering many issues. In the South, the following themes dominate: legal concerns and policy/ equity concerns, technical concerns regarding state goal calculation, concerns about cost, grid reliability and adequacy, and the ability to reduce global GHG emissions, and technical concerns about under-construction nuclear and biomass in EPA goal calculations (Southworth, 2015; Southworth and Schwimmer, 2015b).

This paper addresses an array of important questions surrounding the Clean Power Plan. Through use of resource-planning optimization models, the paper addresses the question of what the nation's least-cost pathway for CPP compliance might be. The paper compares results for the nation with results for the South to answer whether and how the least-cost compliance pathway for the South differs from that of the nation. Moreover, the paper provides analysis of each major region of the South to explore differential impacts across southern regions. Of particular interest to many advocates of consumer interests and economic development, are questions about impacts on electricity rates, bills, and economic growth, which are also addressed. The regional modeling presented in the paper examines questions regarding the merits of regional approaches to compliance versus state-level approaches to compliance. Finally, the paper presents analysis on where the advantages and disadvantages lie in choosing between mass-based goals and rate based goals.

This paper does not describe a comprehensive cost-benefit analysis. It does, however, describe an array of costs and benefits associated with alternative approaches to complying with the proposed Clean Power Plan.

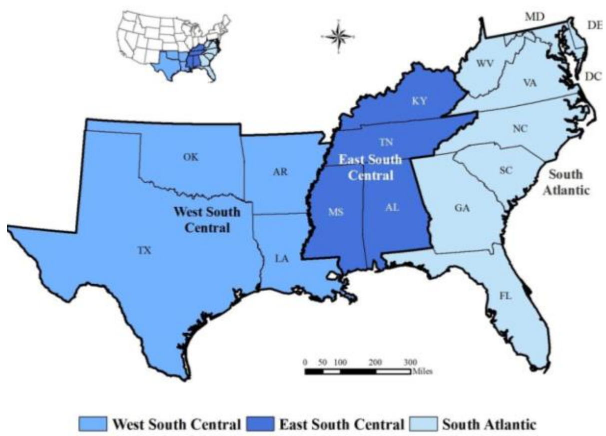
4. METHODOLOGY

The Georgia Institute of Technology's version of the National Energy Modeling System (GT-NEMS) is the principal tool used to generate the low-carbon pathways analyzed in this study to address our research questions. NEMS is "is arguably the most influential energy model in the United States" (Wilkerson, Cullenward, Davidian, & Weyant, 2013). GT-NEMS is based on the version of NEMS that generated the 2014 *Annual Energy Outlook* (EIA, 2014). The *Annual Energy Outlook* forecasts energy supply and demand for the U.S. through 2040. Other than modifications necessary to operate the NEMS model on networked servers at the Georgia Tech, GT-NEMS is equivalent to NEMS and is therefore described by its documentation (EIA, 2015).

GT-NEMS is a computational general equilibrium model based on microeconomic theory. Linear programming algorithms and other optimization techniques provide the foundation with which GT-NEMS develops forecasts of the US energy future. GT-NEMS uses twelve modules, plus a thirteenth integrating module, to simulate various sectors of the energy economy. These twelve sectors are each modeled by a respective module, and the corresponding twelve modules are: Macroeconomic Activity, Residential Demand, Commercial Demand, Industrial Demand, Transportation Demand, Oil and Natural Gas Supply, Natural Gas Transmission and Distribution, Coal Market, Renewable Fuels, Liquid Fuels (formerly the Petroleum Market Module), International Energy, and Electricity Market. GT-NEMS performs an iterative optimization process that results in the price and quantity that balance the demand and supply of numerous energy products. These results are intended as forecasts of general trends rather than specific predictions of future outcomes, making GT-NEMS well-suited for offering insights about alternative policy and technology scenarios.

GT-NEMS models electric power systems through a regional planning approach that makes use of one module, the Electricity Market Module, and its four constituent sub-modules. The Electricity Market Module divides the US into 22 regions based on North American Electricity Reliability Corporation regional boundaries. The Electricity Market Module performs separate projections of power demand and the cost-minimizing supply necessary to meet that demand for each region. In computing estimates of cost-minimizing supply choices, the Electricity Market Module uses survey data from EIA's Form 860, 861, and 923 surveys, as well as North American Electricity Reliability Corporation projections and data from the Federal Energy Regulatory Commission's Form 1 survey. These inputs are used to characterize end-use load shapes, costs and performance of capacity types, and other key variables within the Electricity Market Module.

GT-NEMS uses the 22 regions defined by the North American Electric Reliability Corporation (NERC) to forecast electricity supply and demand (Figure 4). The NERC regions in the South include four divisions of the Southeast Reliability Council (SRDA, SRCE, SRSE, and SRVC), the Southern Power Pool-South (SPPS), the Texas Reliability Entity (TRE), and the Florida Reliability Coordinating Council (FRCC). The demand-side modules of GT-NEMS are based on data for nine Census Divisions, including three that cover 16 states in the South and the District of Columbia (DC). With these geographic regions GT-NEMS projects the production, imports, conversion, consumption, and prices of energy, subject to assumptions about macroeconomic and financial factors, world energy markets, resource availability and costs, behavioral and technological choice criteria, cost and performance characteristics of energy technologies, and demographics." (EIA 2009).



Census Divisions in the South

NERC Regions in the South

Figure 4. Census Division and NERC Regions in The South

The low-carbon pathways are created by introducing carbon prices, strengthening energy-efficiency policies, and updating cost assumptions for solar photovoltaic (PV) systems. We examine these three types of pathways individually and in bundles. This generic approach to estimating the cost of achieving carbon emission reductions has been used by many researchers over the past several decades including, for instance, Bohringer, Rotherford and Tol (2009) and Brown et al. (2001).

We model prices levied on the carbon content of fossil fuels in the electric power sector. Three levels of prices are studied: \$10, \$20, and \$30 per metric ton of CO_2 (in 2012 dollars) applied in 2020 and operating through 2040. Because NEMS operates with foresight, changes in response to the carbon price begin earlier than 2020. The price needed to achieve a particular level of carbon emissions is one way to estimate compliance costs.

The introduction of various levels of carbon prices could be achieved by several different policy mechanisms. It could reflect the direct pricing of carbon emissions for states that choose that route. Alternatively, it could represent an indirect penalty on the continued use of high-carbon fuels. Finally, it could be the assumed allowance price for a metric ton of CO_2 emissions reduction for states that use trading schemes.

We strengthen energy-efficiency policies focused on electricity end-use demand. These policies induce investments in energy efficiency that go beyond the naturally occurring energy efficiency that is included in the Reference case. We start with the assumptions of EIA's High Demand Technology Side Case and then add the following features:

- Advanced energy-efficient equipment introduced earlier, with lower costs, and/or higher efficiencies
- Stronger building codes
- Stronger appliance and equipment standards
- Lower costs and extended tax credits for industrial combined heat and power
- Increased energy efficiency in five manufacturing sectors.

These changes are introduced throughout the planning period representing progressive improvements in energy-efficiency technologies. For many appliances the percentage of relative improvement is assumed to increase by 20 to 60 percent. The percentage of relative improvement refers to how much more the improvement is greater than the improvement in the Reference case. To illustrate, the 60 percent improvement in the efficiency of televisions compared to the base does not imply that televisions are using 60 percent less energy than the base case; rather, it means that the improvement seen in the base case at the given year is increased by 60 percent. In 2016, computers improve by 50 percent. In 2016, battery chargers improve 30 percent and again in 2018 by 40 percent. In that same year, microwaves improve 15 percent relative to the base. In most cases these improvements are associated with an "efficiency cost premium" that adds to the investment cost of the NEMS scenario. For example, in 2022, room AC units improve 28 percent relative to the base at a relative cost increase of 47 percent. The efficiency premium is typically in the 20 to 30 percent range. Many of these specifications come from Bianco, et al. (2013).[8]

We also update estimates of solar PV costs in the NEMS model. LBNL's tracking of solar PV prices was used to assess solar PV equipment costs in the NEMS Reference Case (Barbose et al., 2014). We concluded that the EIA's low-cost renewable side case with 20% lower equipment costs for residential and commercial solar PV compared with the Reference case, is in strong accord with LBNL's projections shown in Figure 5 (left). However, the utility-scale PV costs in $\$/W_{ac}$ are higher than our estimate of 2014 Q4 average installed $\$/W_{ac}$ based on GTM/SEIA (2015)'s Solar Market Intelligence data and Bolinger and Weaver (2014)'s comparison of $\$/W_{dc}$ and $\$/W_{dc}$ costs.[9] We therefore reduce the Reference case costs for utility-scale systems by 36%, bringing them into closer alignment with historic 2014 solar PV costs as shown in Figure 5 (right). By 2030 the updated trajectories

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[8] For further details on these energy-efficiency assumptions, see the document "Modeling an Integrated High Efficiency Scenario using the 2014 National Energy Modeling System" http://cepl.gatech.edu/drupal/node/88

[9] See Bolinger and Weaver (2014), pp. 12, Figure 5. The ratio of AC-basis costs to DC-basis costs for utility-scale PV is approximately 1.25. We multiply GTM/SEIA's $\$1.55/W_{dc}$ for Q4 2014 by 1.25 to arrive at an estimated Q4 2014 $\$1.94/W_{ac}$. Until 2020, $\$1.94/W_{ac}$ is still lower than utility PV prices in our scenario.

result in installed costs of approximately $\$1.75/W_{ac}$ for utility-scale PV, $\$2/W_{dc}$ for commercial-scale PV, and $\$2.50/W_{dc}$ for residential-scale PV in 2010 dollars.

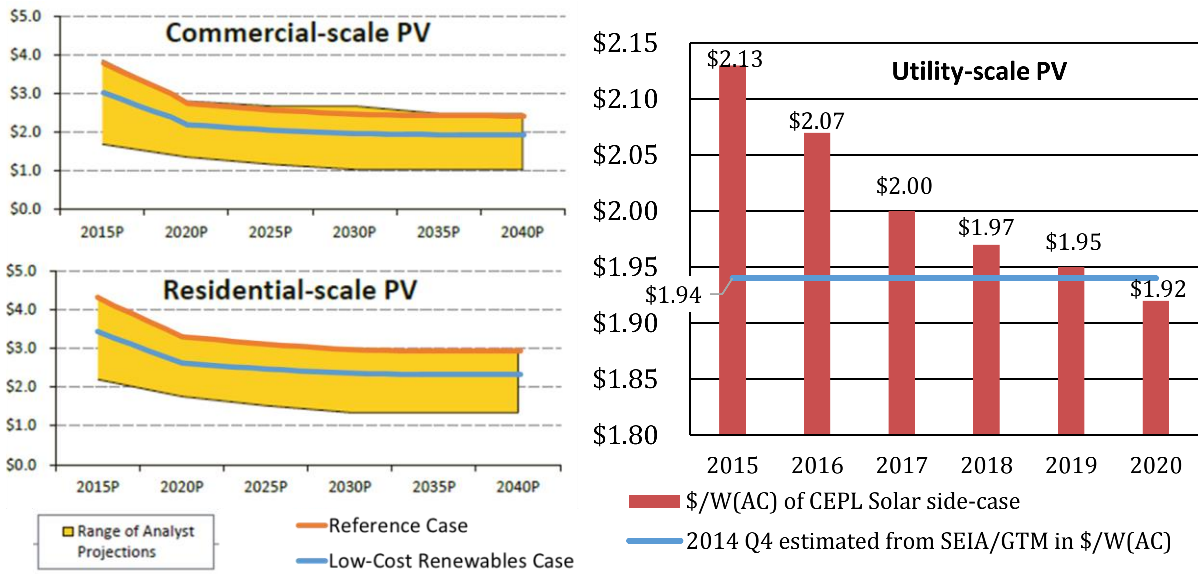


Figure 5. Current and Forecasted Cost of Solar Power[10]

Once we have run NEMS with these assumptions, we calculate the CO_2 mass and rate reductions for the U.S., the South, and the 7 NERC regions that comprise the South. This allows us to examine the projections relative to the two types of mass-based goals discussed by EPA: one for existing EGUs and the second for existing and new EGUs. Calculation of the rate-based goals is illustrated in Figure 6.

[10] The yellow areas in Figure 5 are taken from LBNL/NREL (2014) Tracking the Sun VII. Sources used by LBNL and NREL include: Bloomberg New Energy Finance, Q2 2014, "PV Market Outlook" (05/15/14); Greenpeace/EREC, "Energy Revolution," May 2014 (utility-scale only); International Energy Agency, "World Energy Outlook 2013," November 2013 (New Policy & 450 Scenarios for utility-scale & commercial-scale); U.S. Energy Information Administration, Annual Energy Outlook 2014 ER (December 2013).

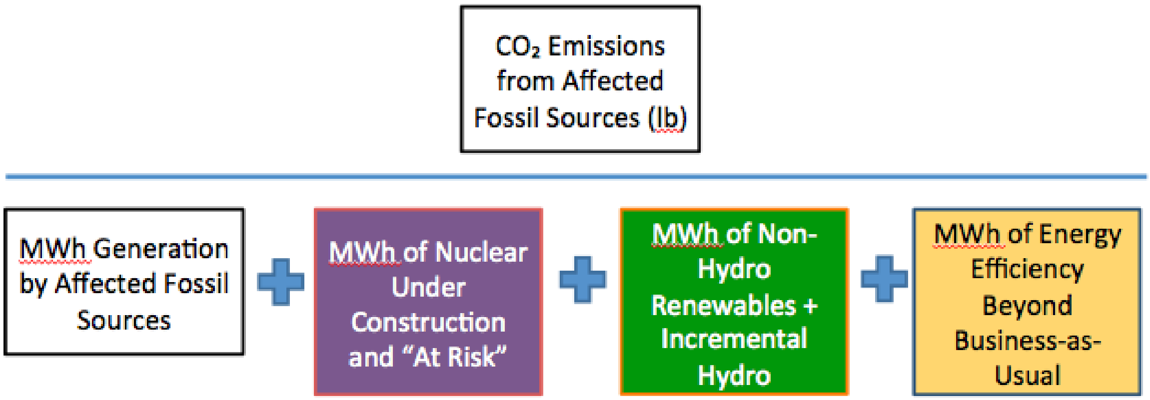


Figure 6. Calculation of Carbon Intensity Rate Goals

Plant-based CO_2 emissions data for 2012 are used to weight the state 2030 goals of the Clean Power Plan. A proportioning methodology was developed using NEMS Electricity Market Module's EMMDB data to calculate emissions from existing power plants by state and by NERC region, and to calculate fossil fuel generation by state and by NERC region. The veracity of this method was examined by comparing 2012 CO_2 emissions to the EPA's 2012 baseline data and EIA's State Energy Data System (SEDS) data.

The weights for calculating regional mass-based goals are based on the percentage of each state's fossil-fuel power plant emissions in 2012 that were located in the region. For example, 80% of Texas's 2012 emissions occurred in the TRE region. In contrast, the weights for rate-based goals are based on the percentage of a NERC region's fossil-fuel power plant emissions that originated from each state in 2012. For example, 98% of the emissions in the TRE region in 2012 originated in Texas. Both weights are estimated by using plant-by-plant CO2 emission data from the NEMS EMMDB file. (See Table A-1 in Appendix A for the weightings used for each type of goal.)

5. LEAST-COST COMPLIANCE SCENARIOS

5.1 IMPACT OF ALTERNATIVE SCENARIOS ON CO_2 EMISSIONS

In the absence of new policies, CO_2 emissions from the power sector are forecast to increase steadily from 2015 through 2040 (Figure 7). Our modeling suggests that lower solar costs (as forecast in the literature), a $10 or $20 price metric per ton of CO_2 emissions, or an integrated EE policy would each curtail this growth substantially. In isolation, however, none of them would achieve either the rate- or mass-based goals proposed for the U.S. and the South in 2030.

In combination, carbon prices, an integrated EE policy, and low-cost solar could achieve compliance with the CPP. In particular, the combination with a $10 price meets the rate-based CPP goals for both the U.S. and the South (with a small "overshoot" margin for the U.S., but not the South). The national CO_2 mass goal for existing + new sources could be met with a $15Fee+EE+Solar pathway, while an $18Fee+EE+Solar is needed for compliance in the South.

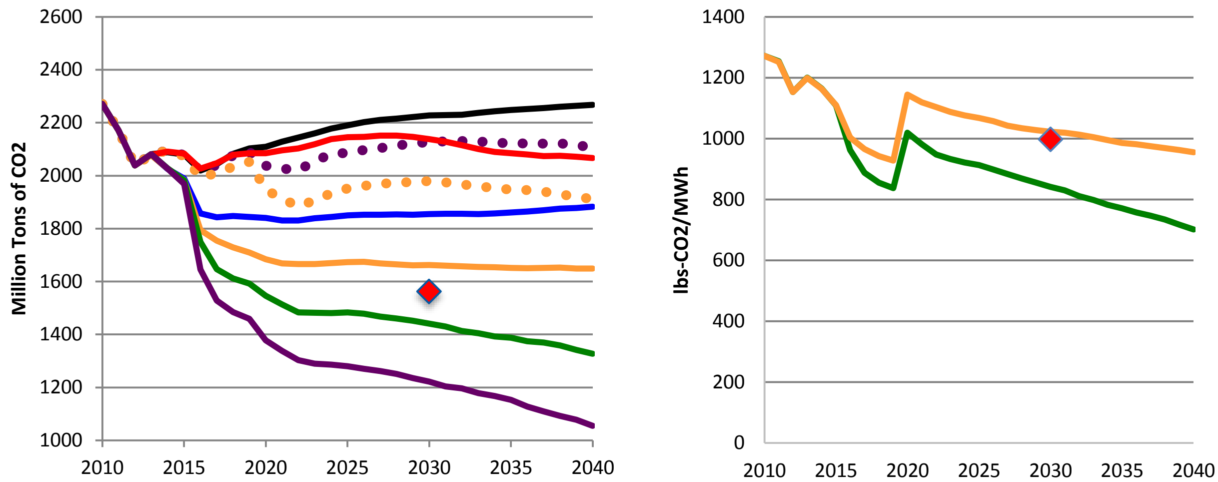
Thus, the CO_2 compliance costs for meeting mass-based goals for existing and new units are higher in the South than in the rest of the U.S. In addition, the rate-based goals appear to be easier to achieve than the mass-based goals for existing and new units. Section 7 considers in greater detail the pros and cons of mass- versus rate-based goals.

Compliance costs appear to vary significantly across the seven NERC regions in the South. The pattern of variation is different, however, when estimating the cost to comply with a mass-based goal rather than a rate-based goal (Figure 8).

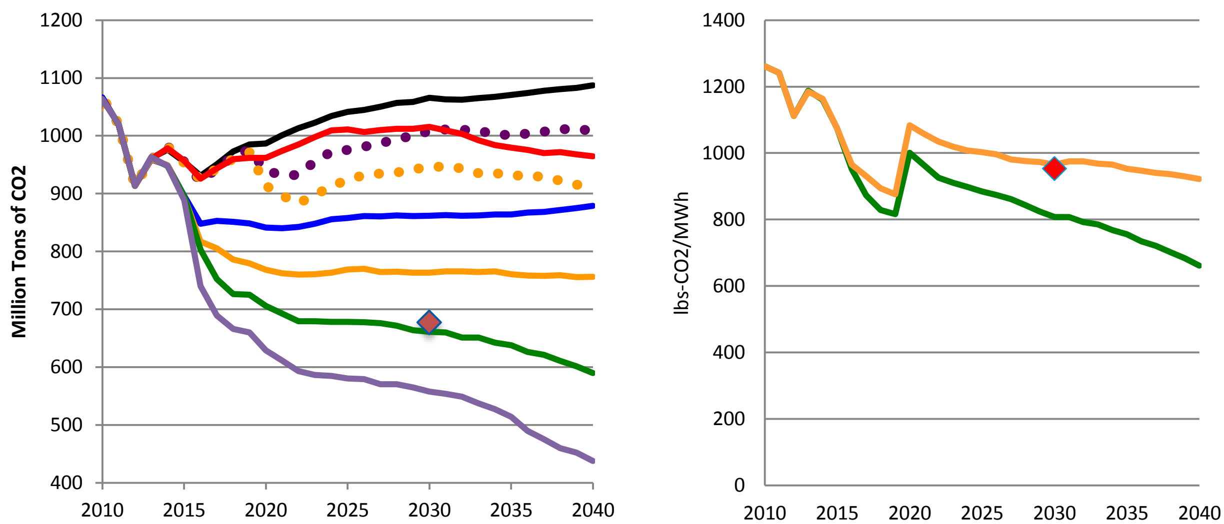
CO_2 Emissions from Existing and New EGUs (Million Tons)

CO_2 Emissions Rates from Existing EGUs (lbs-CO2 per MWh)

The Nation



The South



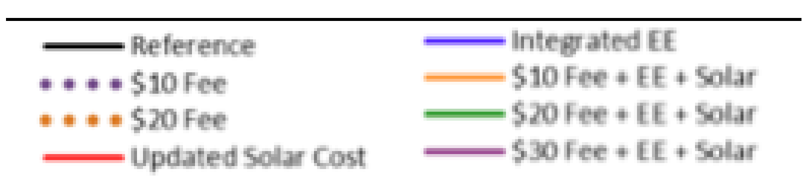


Figure 7. Carbon Mitigation Scenarios in the U.S. and the South

The seven NERC regions in the South can be divided into three types when considering compliance with a mass-based goal:

- SRVC (Virginia-Carolina) and SRCE (Tennessee Valley) could meet regional mass-based goals in 2030 with carbon prices of only $5 per metric ton of CO_2 in combination with energy efficiency and solar.
- FRCC (Florida), SPPS (Southern Plains), and SRDA (Mississippi Delta) could meet regional mass-based goals in 2030 with carbon prices ranging from $12 to $19 per metric ton of CO_2, when combined with energy efficiency and solar.
- TRE (Texas) and SRSE (Georgia-Alabama), on the other hand, would require much higher carbon prices, ranging from $30 to $40 in combination with the same energy efficiency and solar cost approaches (Figure 8).

Interestingly, the three NERC regions that have nuclear units under construction – SRVC, SRCE and SRSE – do not have either universally high or low carbon compliance costs when measured by the proposed mass-based goals. This underscores the complexity of conditions that influence compliance costs, including the composition of fuels each region uses in its electric power sector and its demand growth trajectory.

Considering compliance with a rate-based goal, the seven NERC regions in the South can again be divided into three types:

- SRCE (Tennessee Valley), SRVC (Virginia-Carolina), and SRSE (Georgia-Alabama) would require carbon prices of less than $10 per metric ton of CO_2, when combined with integrated energy-efficiency policies and updated solar costs.
- SRDA (Mississippi Delta), FRCC (Florida), and SPSS (Southern Plains), would meet their goals with carbon prices of between $10 and $20 per metric ton of CO_2, when combined with the same energy efficiency and solar cost approaches (Figure 9).
- As with the mass-based goals, TRE (Texas) would require the highest carbon prices to motivate compliance.

Interestingly, the three NERC regions that have nuclear units under construction – SRVC, SRCE and SRSE – have universally low carbon compliance costs when measured by the proposed rate-based goals.

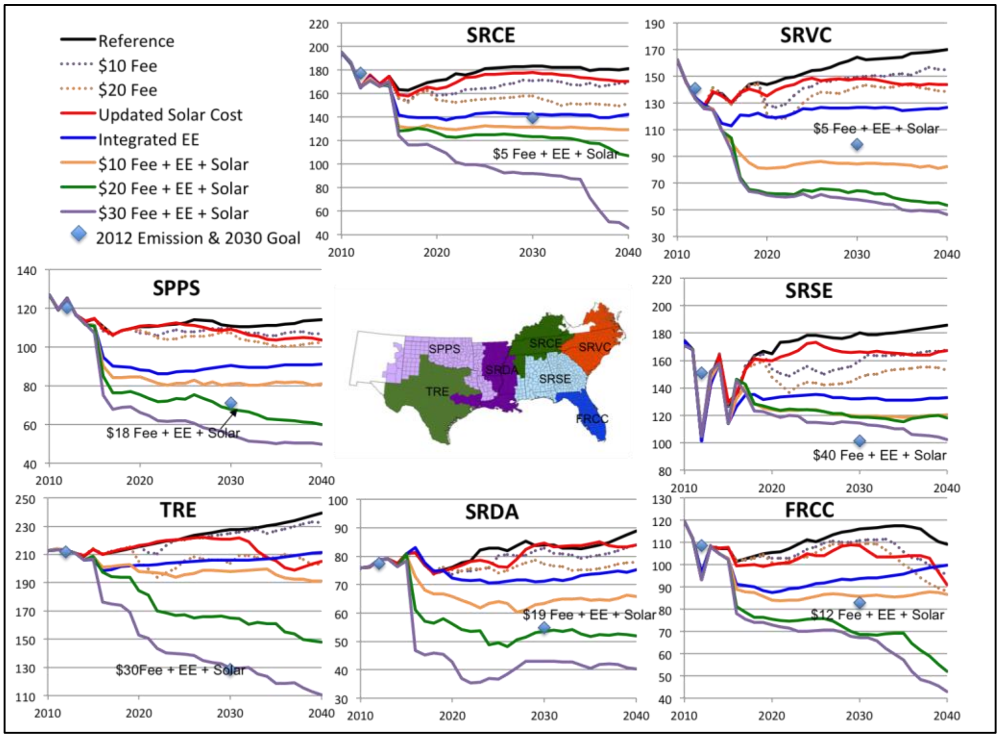


Figure 8. Electric Power Sector CO_2 Emissions and Mass-based Goals by NERC Region
(For Existing and New Sources, in Million Metric Tons of CO_2)

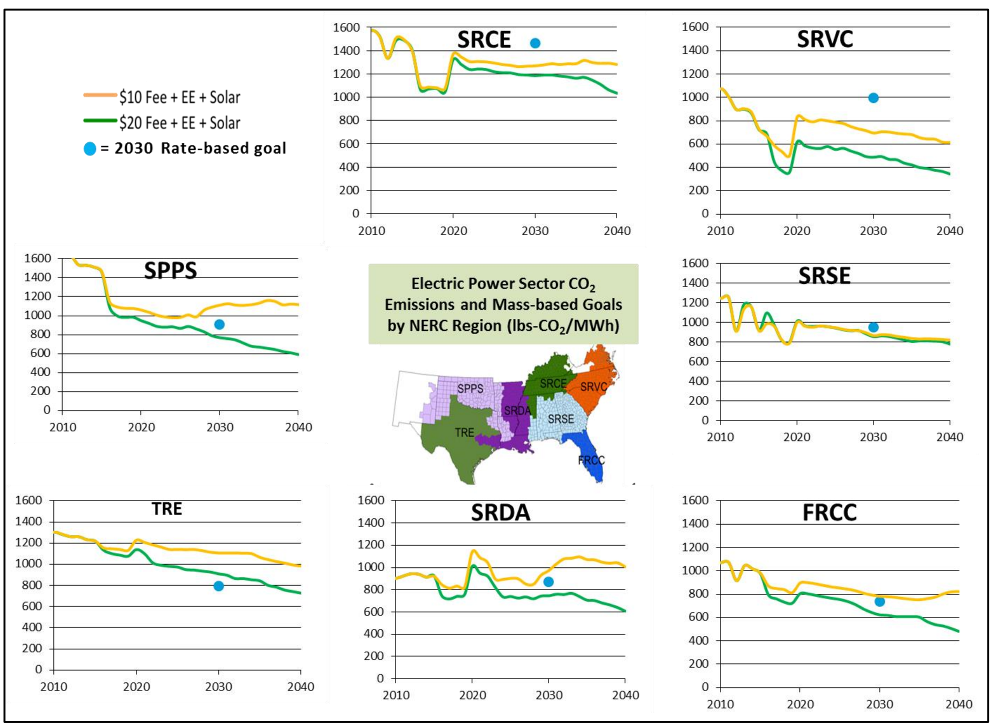


Figure 9. Electric Power Sector CO_2 Emissions Rates and Rate-based Goals by NERC Region
(For Existing Sources Only in lbs-CO_2/MWh)

5.2 IMPACTS ON THE MIX OF ENERGY RESOURCES

Nationwide, the impact of low-carbon pathways on the resources deployed in the electric power sector shows slowed growth or declines in coal-powered generation combined with an overall growth in natural gas, renewable energy, and energy efficiency. The directionality of these impacts in the South is similar, but there are notable differences. For example, consider the impacts of the $10Fee+EE+Solar pathway compared with the Reference case in 2030.

- Coal tends to decline more rapidly in the South (i.e., by 22% vs 20% in the U.S.)
- Natural gas increases less in the South (e.g., it declines by 4% rather than growing by 1% in the U.S.)
- Nuclear power increases more in the South (i.e., by 19% over the Reference case, exceeding the 1% increase in the U.S.)
- The South shows proportionately more growth in renewable energy, increasing by 124% vs 48% nationwide.
- Energy efficiency grows slightly more in the South than in the U.S.

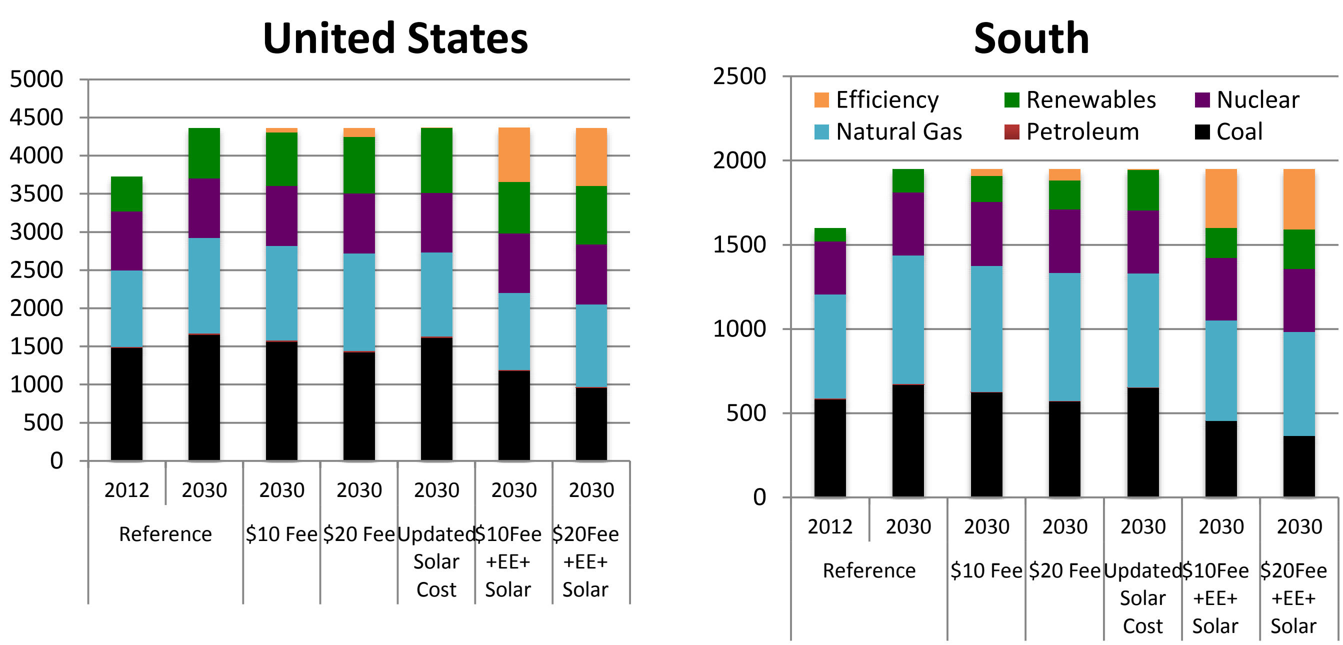


Figure 10. Fuel mix of the U.S. and the South in Multiple Pathways

The impact of compliance on fuel-mixture varies by region and across the low-carbon pathways. More details on the impacts of our compliance pathways on the role of specific fuels in regional fuel mixtures are given in the following sections.

5.2.1 REDISPATCHING FROM COAL TO NATURAL GAS

Some regions would substitute away from coal and toward natural gas, in the low-carbon pathways. Again, consider the impacts of the $10Fee+EE+Solar pathway compared with the Reference case in 2030 (Figure 11). In three of the seven southern NERC regions – SRCE (Tennessee Valley), SRVC (Virginia-Carolinas), and SPPS (Southern Plains), coal power would decline significantly. In each of these regions, energy-efficiency resources grow more than coal generation declines. In addition, natural gas grows significantly to help fill the coal gap in two of these three regions – SPSS and SRCE. In the other region (SRVC), nuclear power and renewables displace much of the coal generation that was forecast in the Reference case.

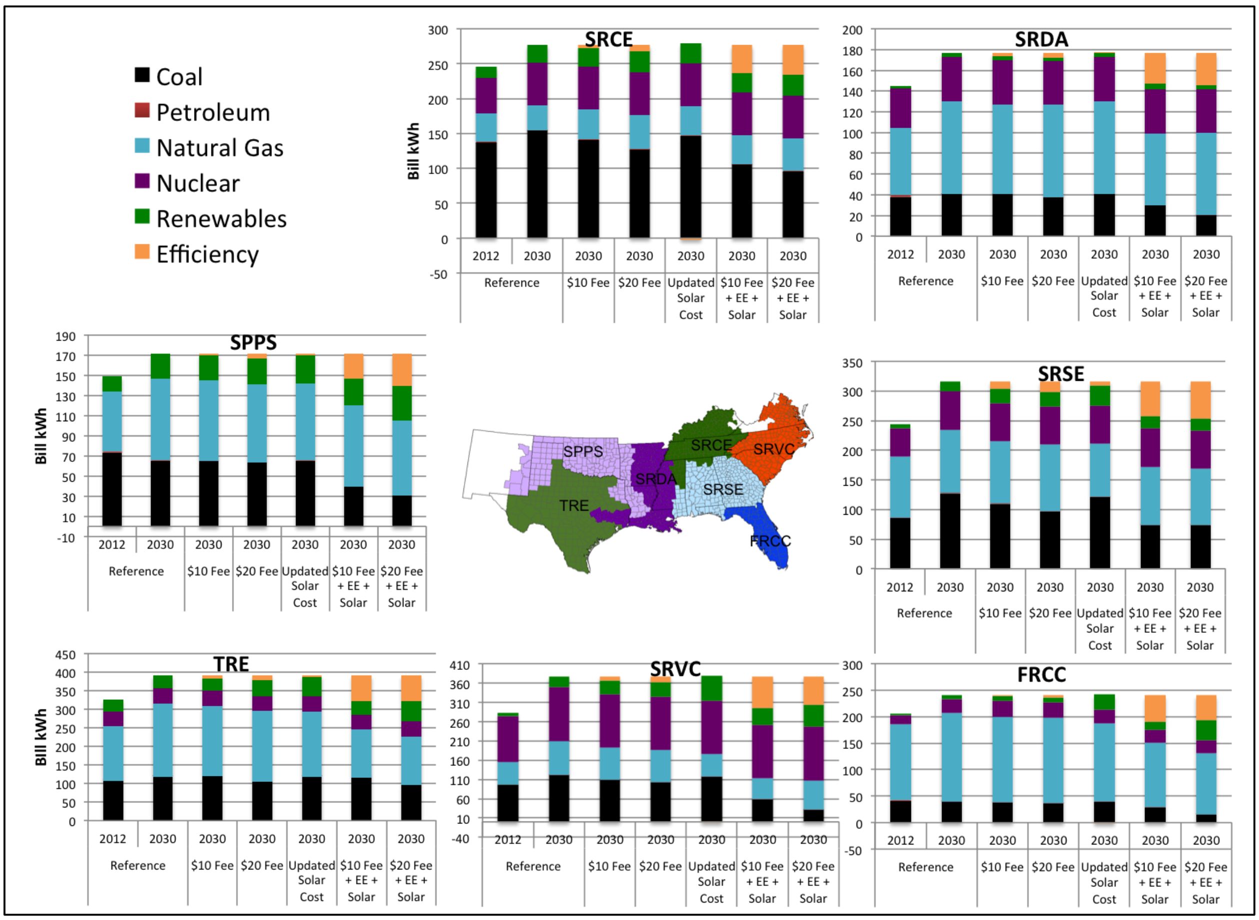


Figure 11. Fuel Mix of NERC Regions in the South Across Multiple Scenarios
(in billion kWh)

In the remaining four regions (SRSE, FRCC, SRDA, and TRE), coal generation declines by just a few percent relative to the Reference case. Small increments in natural gas, nuclear, and renewable energy, along with significant energy-efficiency resources displace the retired coal-fired power.

These regional profiles provide evidence that natural gas and renewables do not always compete in a zero-sum game under our compliance scenarios. SPSS, for example, exhibits a substitution toward natural gas and renewable energy and away from coal generation. That is, renewables and natural gas can act as complements. Conversely, FRCC replace both natural gas and coal with lower-carbon nuclear and renewable energy. In this region, renewable energy is so competitive that it out-competes natural gas and grows along with nuclear energy deployments. Altogether, the regions exhibit great diversity in their least-cost responses to different low-carbon pathways.

5.2.2 DEPLOYMENT OF NUCLEAR POWER

In AEO's Reference case, nuclear energy is forecast to grow by only 1% between 2012 and 2030. Several U.S. nuclear units are expected to retire, others are uprated, and several new units are built. Nuclear generation is forecast to grow by at most 2% in 2030, across the various low-carbon pathways. Nationwide, nuclear power does not displace a significant amount of fossil-fueled generation under the low-carbon pathways investigated here. Figures 10 shows fairly static generation from nuclear units across all scenarios in the U.S., a finding consistent with other research on the Clean Power Plan. Most studies have found that the Clean Power Plan will do little to bring new nuclear generation online (Hopkins, 2015).

The baseline forecast is somewhat different in the South, where nuclear generation is projected in the Reference case to grow by 19% between 2012 and 2030. But the overall impact of the low-carbon pathways on nuclear generation in the South is similar to the national picture: its growth increases to at most 20% across the various low-carbon pathways.

Drilling down to the regional scale uncovers more significant rates of growth of nuclear generation in the Reference case for several southern NERC regions. These NERC regions include SRCE, SRSE, and SRVC, which cover Tennessee where Watts Bar unit 2 is nearing completion, Georgia where two units at Plant Vogtle are being built, and South Carolina where two units at V.C. Summer are under construction. In these three states, coal generation increases in the Reference case, at the same time that nuclear power expands. It is not until the introduction of low-carbon policies that coal generation decreases between 2012 and 2030. The Reference case also projects increased nuclear generation in SRDA and FRCC. In both of these regions, coal generation remains flat between 2012 and 2030 in the reference case despite the growth of nuclear. Again, the introduction of low-carbon pathways in these two regions prompts the reduction of coal use by 2030.

5.2.3 RENEWABLE ENERGY DEPLOYMENT

Renewable energy plays a strong role in the energy mix of the U.S. in the low-carbon pathways. Under the low-carbon scenarios, nearly all regions exhibit growth in either natural-gas-fired power, renewable energy, or both. In some regions, renewables out-compete natural gas, while in other regions natural gas and renewables grow together.

Thus, natural gas and renewables are not always competitors in a zero-sum game, but they do often offset one another.

Figure 12 shows that nearly all compliance scenarios increase the amount of U.S. total renewable electricity generated, with the exception of the Integrated EE scenario due to that scenario's reduction in overall electricity generated. The other compliance scenarios show 2030 renewable electricity increasing by up to 28% over the reference case levels. The $10 carbon price alone increases 2030 renewable electricity by 3%, and the "$30Fee+EE+Solar" scenario increases 2030 renewable electricity by 28%.

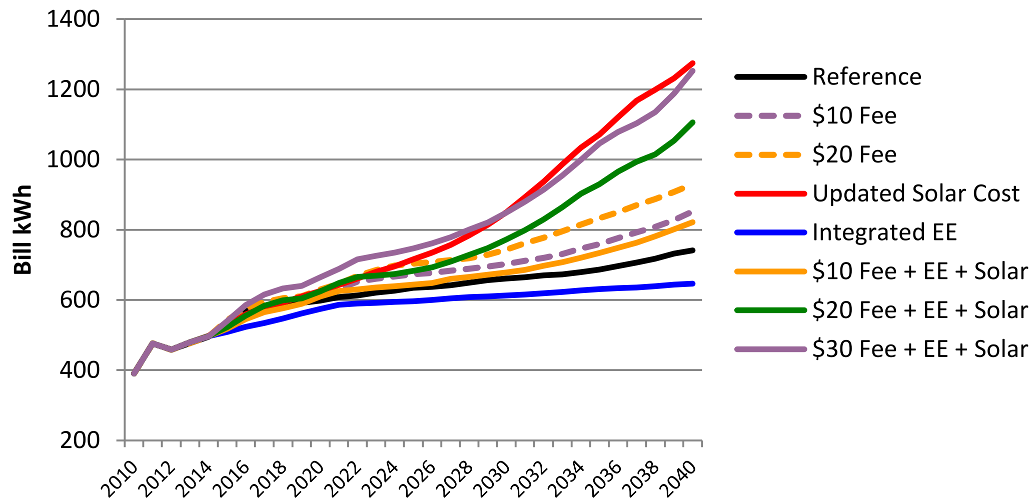


Figure 12. Renewable Energy Generation in the U.S. Electric Power Sector

Studies to date have been inconsistent in characterizing the future role of renewables. Some conclude that the Clean Power Plan will do little to drive growth in renewable sources (Ross, Hoppock and Murray, 2015). Our modeling differs from these studies. By projecting reduced capital costs for renewable sources in combination with penalties to fossil fuels from assuming a price on carbon, our modeling creates a synergistic force for driving growth in renewable energy.

Both the U.S. and the South increase their renewable electricity generation in the Reference case (by 44% in the U.S., and by 76% in the South). The left panel of Figure 13 shows that wind, biomass and geothermal power account for most of this growth across the U.S., while in the South, biomass, hydropower, and wind account for the greatest share of the growth of renewable electricity in the Reference case. The left panel of Figure 13 also shows that the U.S. consistently uses a greater share of hydropower in its renewable portfolio than does the South, but the South is the only region where hydropower would grow in the Reference case, and it does not grow further in the low-carbon pathways. While there are alternative views about the potential for hydro to grow further in the South (Brown, et al., 2012), NEMS is not configured to consider the growth of hydropower at dams in the U.S. that currently are not generating electricity. Geothermal power also grows in the Reference case and does not grow further, to any degree, in the low-carbon pathways. Similarly, none of the low-carbon pathways would show measurable growth of electricity from biogenic municipal waste or solar thermal sources.

In contrast, each of the low-carbon pathways would cause wind, biomass, and solar PV to grow more rapidly than in the Reference case. The U.S. and the South differ in interesting ways in terms of the mixtures of renewable resources that each pathway produces.

- While the Updated Solar Cost scenario increases solar power in both the U.S. and the South, the South's renewable portfolio mixture exhibits a proportionately greater uptake of solar, compared to the U.S., when solar PV costs are reduced.
- In both the U.S. and the South, the growth of solar is subdued with the introduction of the integrated energy-efficiency policies unless a price is included; however, energy efficiency grows along with solar PV when the carbon price is raised to $20 per metric ton of CO_2.
- There appears to be a tipping point between a $10 and $20 price; the higher value significantly accelerates the uptake of solar power.
- Biomass plays a greater role in the South's renewable portfolio under the low-carbon scenarios than it does in the renewable portfolio of the U.S. Biomass rivals the growth of wind in the South, while wind power exceeds biopower in all of the scenarios for the U.S.

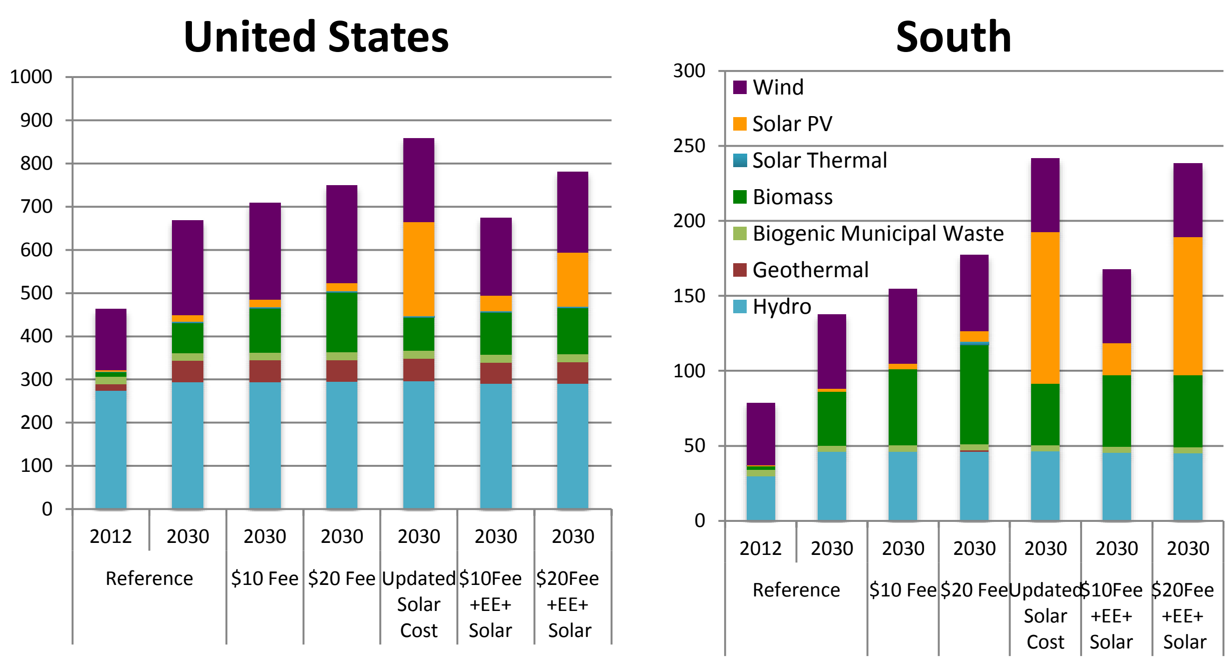
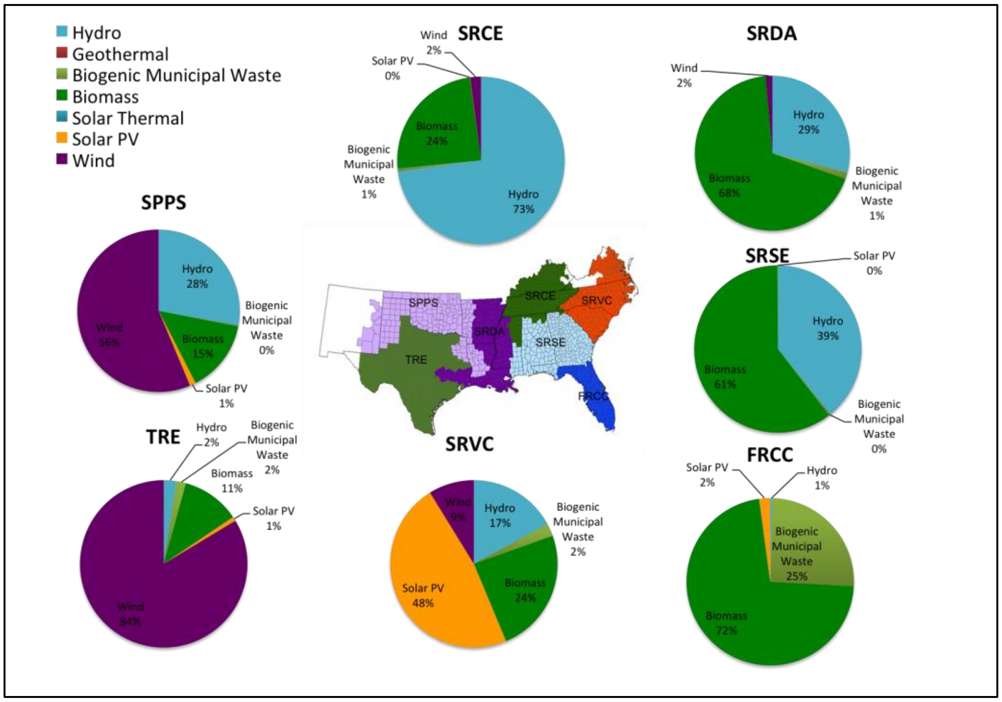
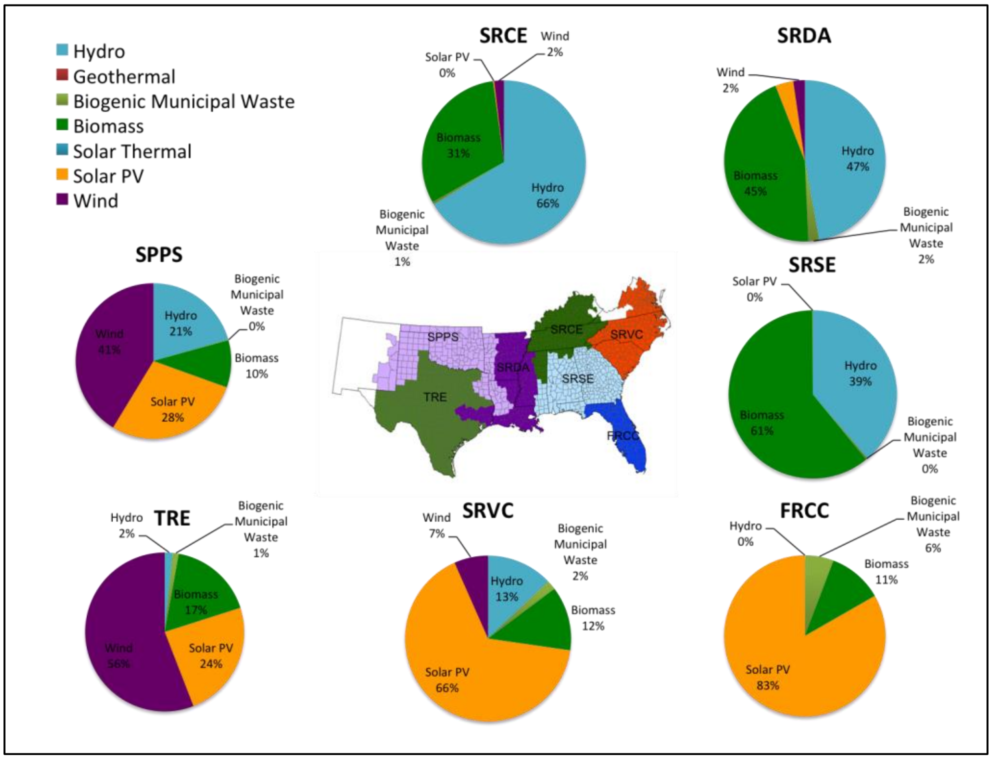


Figure 13. Projected Renewable Generation under Alternative Scenarios



$10Fee+EE+Solar Pathway



$20Fee+EE+Solar Pathway

Figure 14. Projected Renewable Generation in NERC Regions of the South

Within the South, regional renewable electricity portfolios also exhibit diverse mixtures of resources under the various low-carbon pathways. The existence of a tipping point between the $10Fee+EE+Solar and $20Fee+EE+Solar pathways is shown clearly in four NERC regions in the South: FRCC, SPPS, TRE and SRDA. In FRCC, for instance, solar PV's share of renewables mushrooms from 2% to 83% when the carbon price is doubled (Figure 14).

In FRCC (Florida) and SRVC (Virginia-Carolina), solar PV primarily displaces the growth of biomass, while in TRE (Texas) and SPSS (Southern Plains), it primarily displaces wind. While wind is expected to be the dominant 2030 renewable energy resource in TRE and SPPS when the carbon price is set at $10, solar rivals wind as a major renewable resource in SPSS when the carbon price is raised to $20.

5.2.4 DEPLOYMENT OF ENERGY EFFICIENCY

The Reference case forecasts that electric power generation will grow at an annual rate of 0.8% between 2012 and 2030 (EIA, 2014, Table A8). Were this growth rate to materialize, the electric power sector in 2030 would need to generate 17% more power in 2030 than it generated in 2012. Most of the low-carbon pathways examined in this paper produce reductions in electricity use and associated CO_2 emissions relative to the Reference case (Figure 15).

The one exception is the updated solar cost pathway. In the absence of a carbon price or stronger energy efficiency, the low-cost solar trajectory would cause the electricity use in the electric power sector to increase more than in the Reference case. This phenomenon underscores the oversimplification of simply seeking to cut energy consumption. To the extent that the energy consumed is solar or other renewable resources with limited environmental or other externalities, net social welfare would also increase with greater consumption. Indeed, as shown in Figure 7, the updated solar cost pathway decreases CO_2 emissions relative to the Reference case, while at the same time increasing electricity consumption.

The $10 and $20 carbon prices have only a modest impact on electricity consumption, while in all four scenarios in which enhanced deployment of energy efficiency is assumed, total energy consumed by the electric power sector in 2030 remains below 2012 levels. The integrated EE pathway would decrease electricity consumption in 2030 by 13%, which is slightly greater than the 11% decrease in electricity demand that EPA data and Wang and Brown (2014) suggest is cost effective. The $20Fee+EE+Solar pathway could reduce electricity consumption by 17% and CO_2 emissions by 35% in 2030 relative to the Reference case.

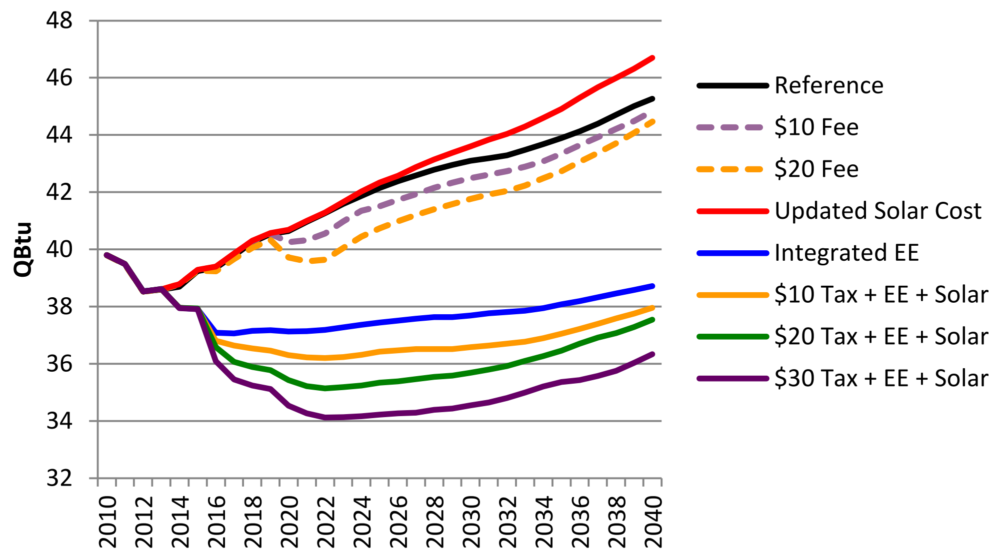


Figure 15. Total Energy Use in the Electric Power Sector

Against that backdrop, Table 1 shows the reductions in electric power generation that could occur with an integrated EE pathway in the U.S., the South, and each of the seven NERC regions in the South.

Table 1. Total Electric Power Generation in the U.S. and the South in 2030 (in Billion KWh) *

NERC Regions	Reference Case	$10 Fee + EE + Solar	% Reduction	$20 Fee + EE + Solar	% Reduction
U.S.	4,368	3,661	-16.2%	3,609	-17.4%
South	1,949	1,600	-18.0%	1,593	-18.3%
TRE	392	325	-17.1%	323	-17.6%
FRCC	2412	193	-20.3%	194	-19.6%
SRDA	177	147	-16.7%	146	-17.6%
SRSE	316	258	-18.6%	254	-19.8%
SRCE	276	236	-14.6%	234	-15.5%
SRVC	376	294	-21.6%	303	-19.5%
SPPS	171	147	-14.2%	140	-18.4%

*Includes plants that only produce electricity and have a regulatory status. Excludes CHP and electricity from on-site generation such as roof-top solar PV.

With either a $10 or $20 price in combination with the integrated EE and updated solar assumptions, the South would reduce its electricity consumption proportionately more than the rest of the U.S. Specifically, the South would achieve an 18% reduction in both cases, while the U.S. reduction is only 16% (in the $20Fee+EE+Solar pathway) and 17% (in the $20Fee+EE+Solar pathway). This contradicts the EPA goal calculations, where building block 4 (energy efficiency) accounts for only 18% of the rate reduction required in the

South, but is allocated 26% of the rate reduction nationwide, suggesting that energy efficiency is less cost-competitive in the South than elsewhere in the U.S.

Across the southern NERC regions, SRVC and FRCC have particularly large reductions in total electric power generation as the result of the two compliance pathways. As might be expected, they also have higher than average electricity prices (Table A.3). But there are exceptions to this correlation between prices and savings. TRE has the second highest electricity prices in the South, but its electricity savings is average at 17.6% in 2030 in the \$20Fee+EE+Solar pathway. Similarly, SRSE has average prices but the second highest electricity reductions in the \$20Fee+EE+Solar pathway in the South.

5.3 IMPACTS ON ELECTRICITY RATES, BILLS, AND CONSUMPTION

Electricity rates are expected to rise over the next several decades, according to the Energy Information Administration's Reference case forecast, increasing from 9.84 ¢/kWh to 10.48 ¢/kWh nationwide (Figure 16). These rates would increase further when a price is placed on carbon emissions: more so with a \$20 price than a \$10 price. Combining carbon pricing with greater energy efficiency and cheaper solar constrains retail rates to their Reference case forecast and lowers both electricity consumption and bills significantly. Other studies of CPP compliance options have concluded that retail prices would rise above the business-as-usual forecast, for example by 6.9% to 13% in the CATF study, NERA, and Rhodium studies described in Hopkins (2015). Energy efficiency did not play as strong a role in the compliance pathways examined in these studies. Indeed, some studies have examined compliance outcomes without using energy efficiency to credit CO_2 reductions (Hopkins, 2015). The differences across these various modeling efforts again confirm that marginal compliance costs are likely to be lower with energy efficiency.

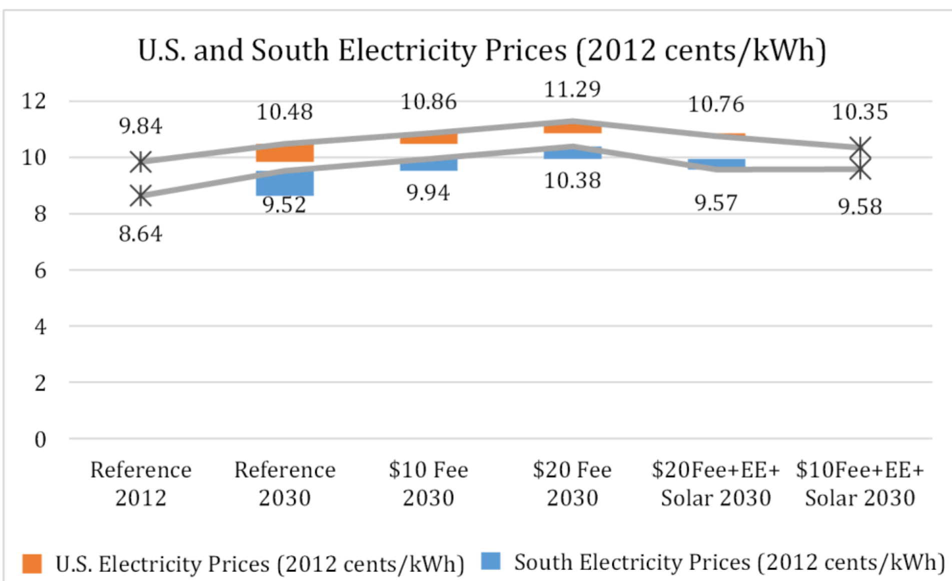


Figure 16. Impact of Low-Carbon Pathways on Electricity Rates (All Sectors)

Since the $10 and $20 Fee+EE+Solar are pathways that meet the compliance requirements in most southern NERC regions in 2030, we examine the impact of these two low-carbon pathways in greater detail, comparing them with the performance of the Reference case in Tables 2 and 3.

In the Reference case, electricity bills per capita for all customer classes are expected to increase by nearly 9% between 2012 and 2030 as the result of environmental regulations, increasing demand, and other factors (Table 2). In the South, electricity prices are expected to increase by slightly more – about 10%. Deploying a compliance pathway that is limited to carbon prices, electricity bills would increase even more between 2012 and 2030.

Table 2. Impact of Low-Carbon Pathways on U.S. Electricity Bills Per Capita in 2030 (in $2012)*

	Households		Businesses		Industry		All Sectors	
Scenario	**U.S.**	**South**	**U.S.**	**South**	**U.S.**	**South**	**U.S.**	**South**
Reference Case 2012	519	629	424	443	207	218	1,153	1,291
Reference Case 2030	538	662	453	482	267	274	1,262	1,913
$10 Fee**	549	677	463	494	276	284	1,292	1,968
$20 Fee	562	695	474	507	285	296	1,326	2,023
Updated Solar Costs	530	650	446	473	263	268	1,242	1,878
Integrated EE	402	493	382	407	237	237	1,025	1,504
$10Fee+EE+Solar	411	505	393	421	247	247	1,055	1,544
$20Fee+EE+Solar	420	517	402	432	255	255	1,081	1,577
$30Fee+EE+Solar	430	531	414	447	265	265	1,112	1,624

* The South is defined by the three Census Division shown in Figure 4.

**The prices in the rows below are for the year 2030.

However, with a carbon price, integrated EE, and updated solar costs, economy-wide electricity prices per capita would increase less than in the Reference case between 2012 and 2030: by only 6% nationwide and by 5% in the South. In summary, compliance with the CPP rate goals can be achieved while curbing the increase in per capita electricity bills forecast by the Reference case – in both the U.S. (by 6 to 8%) and in the South (by 2 to 8%).

The 759 TWh of reduced electricity consumption in the $20Fee+EE+Solar compliance pathway and the 707 TWh reduction in the $10Fee+EE+Solar pathway (see Table 1) are comparable to the 709 TWh energy efficiency limit estimated by Lashof and Yeh (2014) in its full EE case (with average efficiency costs of 2.7 ¢/kWh), the 506 TWh estimated by Eldridge et al. (2008) (with average efficiency costs of 7.8 ¢/kWh), and the 457 TWh estimated by Yu and Brown (2014) (with an average efficiency cost of 0.5 to 8.1 ¢/kWh).

Table 3. Impacts on Residential Electricity Prices, Sales, and Bills in 2030*

		Electricity prices		Electricity consumption		Electricity bills	
Region[a]	Scenario	¢/kWh	% change	Billion kWh	% change	Billion dollars	% change
U.S.	$20Fee+EE+Solar	13.3	4.6%	1,136	-25.5%	150.6	-22.1%
	$10Fee+EE+Solar	12.8	1.3%	1,149	-24.6%	147.5	-23.7%
	Reference 2030	12.7		1,525		193.3	
	Reference 2012	11.9		1,374		163.4	
South	$20Fee+EE+Solar	11.7	4.1%	601	-25.0%	73.1	-21.9%
	$10Fee+EE+Solar	11.3	0.6%	608	-24.1%	71.4	-23.7%
	Reference 2030	11.3		801		93.6	
	Reference 2012	10.7		674		73.7	
Non-south	$20Fee+EE+Solar	14.8	5.3%	536	-26.0%	77.6	-22.2%
	$10Fee+EE+Solar	14.4	2.3%	541	-25.2%	76.1	-23.7%
	Reference 2030	14.0		724		99.7	
	Reference 2012	13.0		700		89.7	

		Electricity consumption per capita		Electricity bills per capita	
Region[a]	Scenario	kWh/ capita	% Change	$2012 /capita[b]	% Change
U.S.	$20Fee+EE+Solar	3,165	-25.5%	420	-22.1%
	$10Fee+EE+Solar	3,200	-24.6%	411	-23.7%
	Reference 2030	4,246		538	
	Reference 2012	4,368		519	
South	$20Fee+EE+Solar	4,247	-25.0%	517	-21.9%
	$10Fee+EE+Solar	4,296	-24.1%	505	-23.7%
	Reference 2030	5,662		662	
	Reference 2012	5,754		629	
Non-south	$20Fee+EE+Solar	2,462	-26.0%	356	-22.2%
	$10Fee+EE+Solar	2,488	-25.2%	350	-23.7%
	Reference 2030	3,326		458	
	Reference 2012	3,546		454	

[a] The South and Non-South regions are based on the Census Divisions of the U.S.

[b] All dollars are in 2012 dollars, and all cents are in 2012 cents. "% Change" is based on the difference between the $10Fee + EE + Solar or $20Fee+EE+Solar scenario in 2030 and the Reference case forecast for 2030.

Our estimates are significantly greater than the 244 TWh of EE gains estimated by Rhodium (with average efficiency costs of 7.8 ¢/kWh), 238 TWh estimated by NERA (with average efficiency costs of 12.5 ¢/kWh), and 325 TWh estimated by EPA (Hopkins, 2015).

The South boasts lower per capita electricity bills in the business and industrial sectors, compared to the rest of the nation. However, households in the South have higher per capita bills (averaging $629 in 2012 compared with $519 across the U.S.) (Table 2). The high residential electricity bills occur in part because of the region's low electricity rates (Figure 16), which make efficiency investments less competitive than elsewhere in the U.S.

Table 3 provides more detailed data on the residential sector. First consider the changes anticipated in the Reference case between 2012 and 2030:

- Residential electricity prices are expected to increase 6.7% from 11.9¢/kWh in 2012 to 12.7¢/kWh in 2030 (in 2012 dollars)
- Residential electricity sales are expected to increase 10.9% from 1,374 billion kWh to 1,525 billion kWh
- The compounding of these two changes, in conjunction with population growth, means that residential electricity bills (the product of prices and quantities) per capita would increase by 4% from $519 in 2012 to $538 in 2030.

Over this same 18-year period, the U.S. population is expected to grow from 315 million to 359 million (14.0%) and real disposable personal income is expected to grow from $10,304 to $15,926 (54.6%) in 2005 dollars. U.S. GDP is expected to grow a similar percentage, from $13.6 trillion in 2012 to $21.1 trillion in 2013, and the value of U.S. industrial shipments are expected to grow from $6.1 trillion to $9.5 trillion over the same period (Figures 19 and 20). Thus, the expected growth in residential bills tracks the population growth rate but is exceeded by faster growth based on various indicators of economic activity. The $20Fee+EE+Solar pathways would have a more profound effect on residential electricity consumption, sales, and bills, with a modest impact on electricity prices.

GT-NEMS modeling indicates that residential electricity rates would increase by only 1.3% with the $10Fee+EE+Solar pathway relative to the Reference case nationwide; rates would rise even less (by 0.6%) in the South. Electricity sales, on the other hand, would decline considerably (by 24.6% in the U.S. and by 24.1% in the South) relative to the Reference case. These reductions occur as the result of price-driven demand decreases and the integrated energy-efficiency policies that motivate households to consume much less electricity by investing in more energy-efficient homes and equipment. The compounding effect is that residential electricity bills per capita would decline substantially: by 23.7% in the U.S. and by 23.7% in the South between 2012 and 2030, relative to the Reference case.

Based on the review article by Hopkins (2015), most studies of the CPP to date project either small cost savings to power consumers or increases of less than $10 billion per year. Our compliance $10Fee+EE+Solar compliance pathway would save residential customers $46 billion in 2030 compared with the bills forecast by the Reference case.

Electricity consumption declines slightly less in the South and electricity prices increase slightly less in the South. Nevertheless, the bottom line is similar – residential electricity bills per capita could decrease significantly – by 22% per capita. Interestingly, the regions with smaller than average rate increases do not always correspond to the regions with high electricity savings. The TRE region in Texas is a good case in point: it is the one NERC region with residential electricity rates that would be expected to decrease relative to the Reference case forecast (only slightly, by -0.2%), but its electricity bill reduction is greater than the national average, at nearly -24% (see Table A.3). At the other extreme, electricity prices increase significantly in the NYCW region of Central New York (12% greater than the Reference in 2030), but electricity bills still drop significantly (-17.7% less than in the Reference case). While the rebound effect may play a role in the rate dynamics – consumers tend to demand more electricity services when rates are low – this is modeled in GT-NEMS, so the declining electricity consumption in the policy pathway is net of rebounding.[11]

Analysis at the NERC region allows further geographic specificity. For instance, the $10Fee+EE+Solar pathway in the SRSE (Georgia-Alabama) region produce significant bill savings compared with a business-as-usual future. Specifically, the average household in that region could reduce its annual electricity bill by $220 in 2020 and by $344 in 2030, with a major push on energy efficiency, natural gas, and solar power compared with the current trajectory.

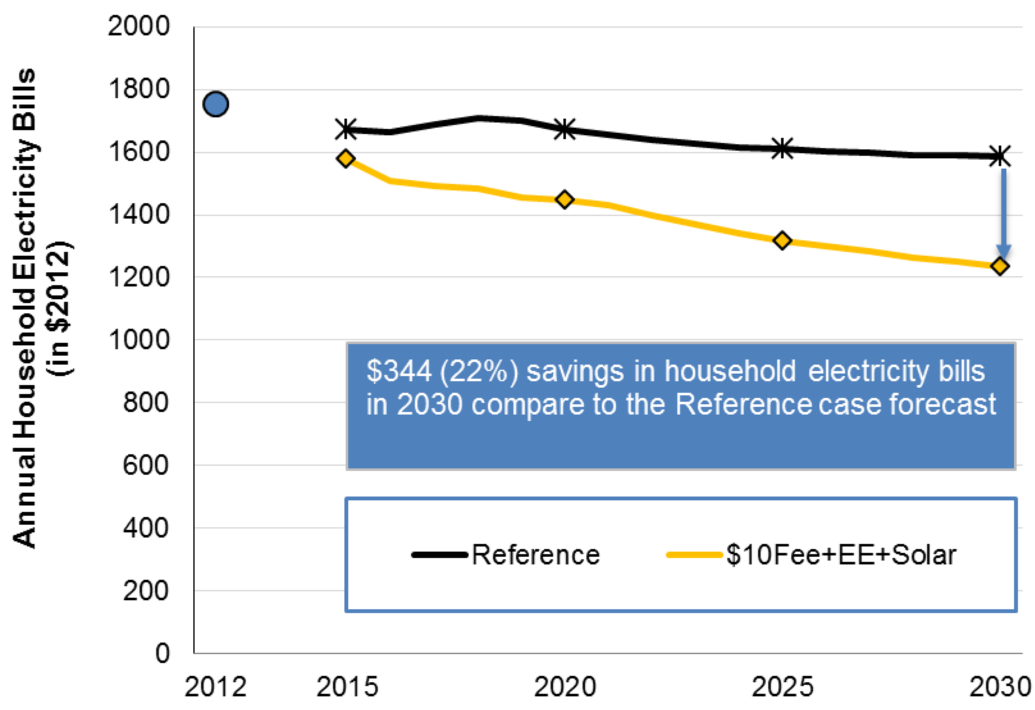


Figure 17. Household Electricity Bills in the SRSE (Georgia-Alabama) Region

[11] Evidence suggests that the rebound effect could partially offset energy savings due to efficiency improvements as households re-spend their savings on other goods and services. However, the impact is generally found to be modest and diminishing with time (Sorrell, Dimitropoulos, & Sommerville, 2009).

To achieve the bill savings of the $10Fee+EE+Solar pathway, increased levels of investment are needed to improve heating and cooling equipment, appliances, lighting, and other end-use technologies as well as insulation and windows to improve the thermal integrity of homes. Cumulatively, by the year 2020 of the $10Fee+EE+Solar pathway, the residential buildings sector spends approximately $297 billion more than under the Reference case; by 2030, the residential sector spends approximately $832 billion more.

The financing to enable such investments can come from a variety of sources. Households may increase their expenditures on such improvement, electing to pay the additional "efficiency premium" required to purchase more energy-efficient equipment when their existing systems need to be replaced. Funding for these purchases could come from traditional sources such as personal savings, loans from banks, or mortgages that enable homeowners to add energy-efficiency features to new or existing housing as part of their home purchase or refinancing mortgage. Subsidies may be available from cities (e.g., with property assessed clean energy programs), states (e.g., with revolving loan funds or qualified energy conservation bond programs), and the federal government (e.g., with tax rebates). Utilities may offer on-bill financing programs and energy-service companies may provide energy-saving performance contracts. Financing options for energy efficiency are numerous and diverse (Brown and Wang, 2015).

Figure 18 shows that electricity total resource costs are less under the two compliance pathways. GT-NEMS measures these costs in cumulative net present value terms, in 2012$. We report these in cumulative terms through 2030.

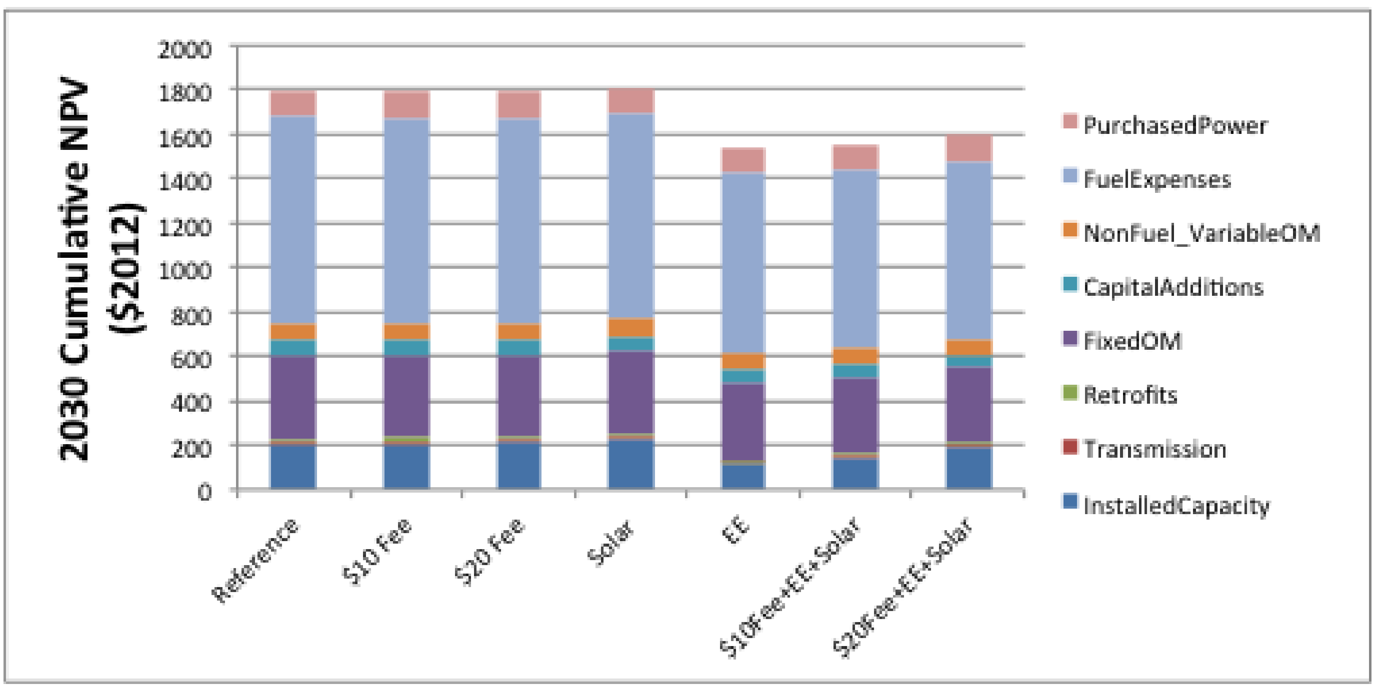


Figure 18. Electricity Total Resource Costs Across Low-Carbon Pathways

The cost savings associated with the compliance pathways are likely due to the lower electricity sales resulting from greater energy efficiency. The fact that the $20Fee+EE+Solar pathway exhibits slightly greater total resource costs than the $10Fee+EE+Solar pathway may be a function of its larger utility investment in solar power.

5.4 IMPACTS ON ECONOMIC ACTIVITY

Updating solar PV costs and strengthening the deployment of energy efficiency produces economic synergies with Clean Power Plan compliance. When solar PV costs are updated, or when energy-efficiency deployment is enhanced, the economic outcomes are superior to those of the Reference case.

Figure 19 shows that the value of U.S. industrial shipments in 2030 under the Updated Solar and the Integrated EE cases both surpass the value of shipments in the Reference case. Figure 20 shows that the GDP projections for the Updated Solar and the Integrated EE case also surpass those of the Reference case.[12] While the $10 and $20 prices shrink value-of-shipment and GDP results below the reference case, the 2030 value-of-shipment and 2030 GDP results for both the $10Tax+EE+Solar case and the $20Tax+EE+Solar cases far surpass the Reference case. Thus, the pathways that achieve Clean Power Plan compliance produce greater economic activity. Analysis of the GT-NEMS macro-economic results suggests that the two compliance pathways benefit from greater exports and lower imports, consistent with their lower levels of energy consumption.

Corroborating these results, the CPP analyses by EIA and Energy Ventures Analysis find similar levels of impact to GDP. EIA finds the macroeconomic impacts of the CPP to be in the hundreds of billions of dollars, "equivalent to changes of a few tenths of one percent from baseline given the magnitude of GDP" (EIA 2015, pp. 63). Energy Ventures Analysis finds that 2020 GDP under a compliance scenario would be $19,681 billion (real) but does not offer a comparison with the 2020 BAU GDP (EVA 2014, pp.34). Most other studies of the CPP do not analyze impacts to GDP (CSIS 2015).

[12] The higher equipment investments prompted by the integrated EE policies would divert capital that could have been invested in other economic activities. Results from GT-NEMS suggest that this reallocation of capital resources would affect the national GDP, albeit to a small extent. In addition, the policies would reduce energy consumption and production, which also has GDP impacts. GT-NEMS models the macroeconomic consequences of energy policy using the Global Insight's model. Both energy demand and supply sides interact through a Cobb–Douglas production function to calculate the national GDP. The Global Insights model assumes that the US economy has a 0.07 energy elasticity, which means that a 1% decrease in energy supply decreases potential GDP by 0.07% (EIA, 2012).

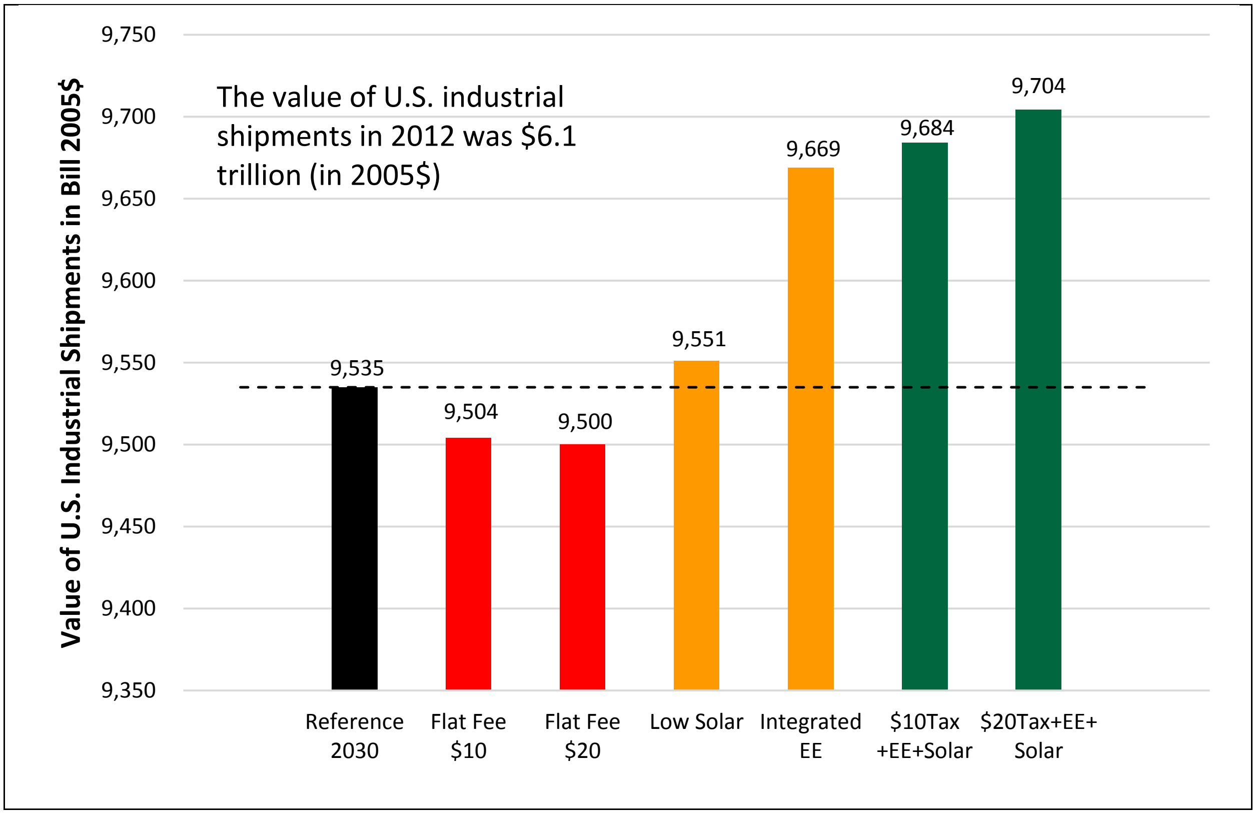


Figure 19. Value of U.S. Industrial Shipments in 2030 under Alternative Scenarios

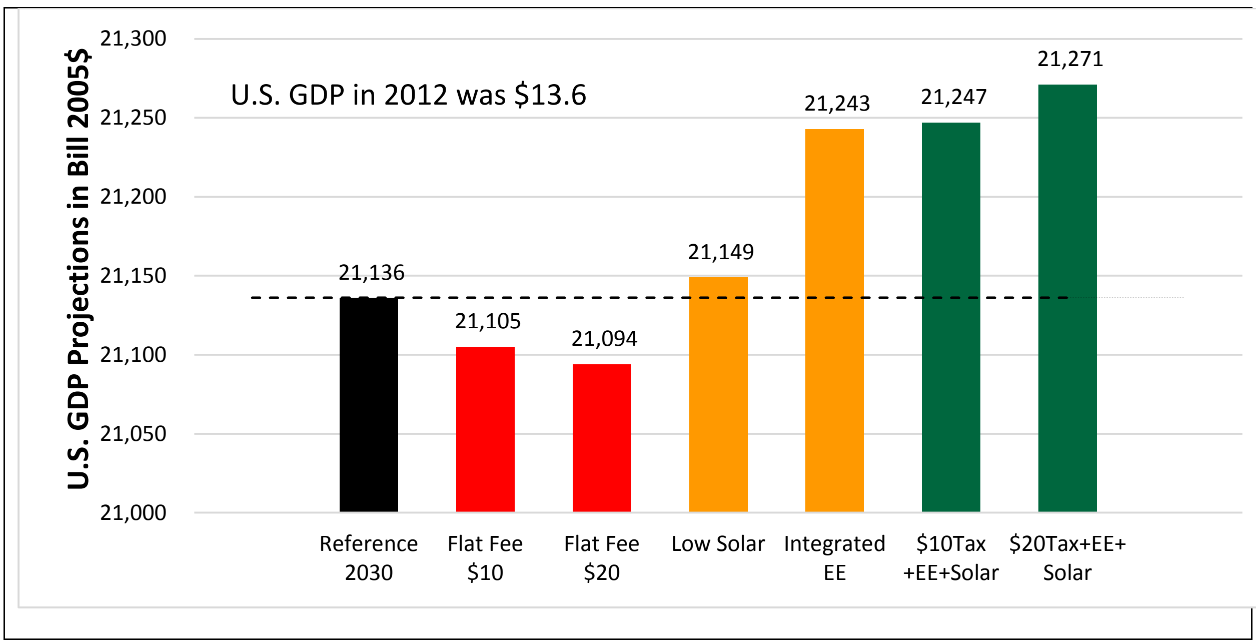


Figure 20. U.S. GDP in 2030 under Alternative Scenarios

6. STATE VS. REGIONAL APPROACHES

In complying with the proposed Clean Power Plan, the cost implications of using a regional approach versus a using state approach are difficult to predict. When compliance costs vary across states, regional trading offers the potential to reduce compliance costs overall. Indeed, Ross, Murray, and Hoppock (2015) conclude that compared to individual state implementation plans, a regional approach would lower national generation costs by approximately 20 to 30% between 2015 and 2030. Regional approaches require political trust, and they can be undermined by high transaction costs, but they also offer the potential for economies of scale in addition to the ability to trade emissions credits. In the South where large utility holding companies serve multiple states, regional approaches would appear to be particularly workable.

Regional approaches are more or less complex depending on whether the region adopts a mass-based goal or a rate-based goal. Mass-based goals at the regional scale are similar to mass-based goals at the state level: a single pound of CO_2 begets the same contribution toward a regional mass-based goal as it does toward a state mass-based goal. Mass-based goals make it easy to trade CO_2 emissions reductions. Conversely, regional rate-based goals present significant complexity in comparison to state rate-based goals. Exactly what unit of compliance would be traded across state borders is unclear. Moreover, since the rate goal for each state differs, the value of an improvement in one state's emissions rate may not be the same as the value of an improvement in another state's emissions rate. The efficient price of rate-improvements will be difficult to determine.

Rather than having each state participating in a regional compliance plan to maintain its own rate-based goal, EPA has recommended that regions calculate an average rate-based goal reflecting the rate-based goals of constituent states. Using a regional-average rate-based goal would enable planners to treat the regional rate-based goal much like a state-level rate-based goal. Forming a regional rate that is the average of the rates of participating states could increase the feasibility of regional approaches, but presents its own challenges, including the likelihood that greater negotiation and coordination across states would be required (Litz and Macedonia, 2015). There is little experience with rate-based regional trading arrangements, and limited experience with situations where collaborating states have adopted different types of goals. Thus, coordination between states in the choice of goals could be valuable.

Coordination with compliance programs that have "common elements" would also appear to be valuable under most circumstances (Monast, et al., 2015). This would include common definitions of tradable units across state plans and the use of common tracking systems that prevent double counting. Such approaches would facilitate regional coordination while not requiring agreement on compliance plan specifics, a mandatory compliance market, or the specification of state partners.

Our NEMS analysis suggests that the U.S. and the South can meet their rate- and mass-based goals with a $10Fee+EE+Solar scenario. This holds whether the mass-based goals consider either (1) existing EGUs or (2) existing and new units (Figure 21 and Table 4).

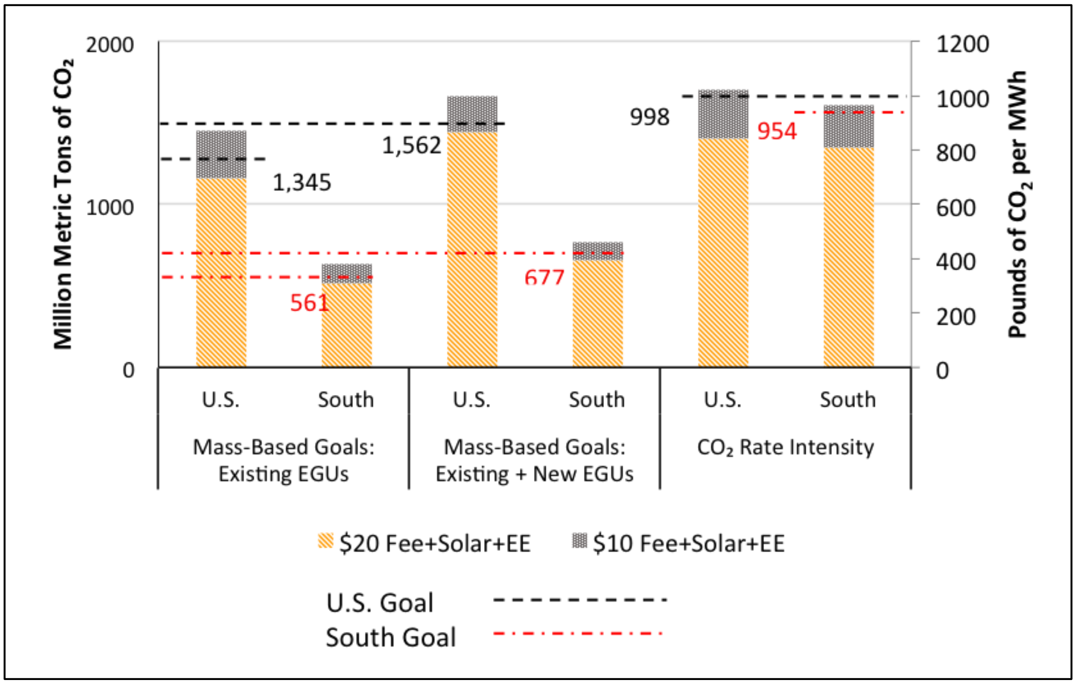


Figure 21. Achievement of Rate- vs. Mass-Based Goals with Under Alternative Policy Pathways

While the $10Fee+EE+Solar scenario achieves both the rate-based goal and the mass-based goal for the U.S. and the South, both rate-based goals and mass-based goals are slightly less costly to meet in the U.S. than in the South.

Rate-based goals appear to be less expensive than mass-based goals to comply with in both the U.S. and the South. This may be because of the differential way each treats the growth of demand over time. Demand growth typically requires new capacity and hence more CO_2 mass emissions if natural gas is used to meet the additional demand, putting pressure on the region's goals. In contrast, with a rate-based goal, some new natural-gas-fired generation can typically be accommodated without escalating carbon emission rates.

States need to consider other factors, as well. For example, high levels of electricity imports benefit mass-based goals because the recipient state is not penalized for the CO_2 associated with the imported electricity; states could reduce their generation, which would reduce their emissions. High levels of exports would penalize a state for associated emissions; therefore, rate-based goals would be easier for compliance purposes.

Large energy-efficiency programs can perhaps more simply be used to offset CO_2 mass emissions because of the more straight-forward measurement and verification techniques. The proposed Clean Power Plan will allow states to count energy efficiency in the denominator of the rate calculation, and if demand reduction is used to idle or retire coal plants more rapidly, energy efficiency would reduce carbon emission rates. However, energy efficiency may not improve CO_2 emissions rates if demand reductions are proportionate across all fuels.

Within the South, differences in compliance feasibility appear at the regional level as well. Table 4 shows where the compliance outcome falls at varying levels of carbon price for the NERC regions in the South, as well as the overall compliance for the South and the Nation.

The NEMS analysis indicates that most regions within the South track similarly in terms of meeting the rate-based goals than the mass-based goals. SRVC and SRCE have lower than average compliance costs for both rate- and mass-based goals. TRE has higher-than-average compliance costs for meeting both mass- and rate-based goals from existing units and new sources.

The one exception is SRSE (Georgia-Alabama), where meeting a rate-based goal appears to be considerably less costly than meeting a mass-based goal.

Table 4. Performance of Compliance Pathways in the U.S., the South, and its Regions*

Performance with respect to CPP goals for 2030		**CO_2 Fee+EE+Solar Required to Meet the Proposed Mass-Based Goals (Existing & New Units)**		
		≤$10/metric ton	**$10-$20/metric ton**	**>$20/metric ton**
CO_2 Fee+EE+Solar Required to Meet the Proposed Rate-Based CPP Goals (Existing Units Only)	**≤$10/metric ton**	SRCE, SRVC		SRSE
	$10-$20/metric ton		U.S., South, SRDA, FRCC, SPSS	
	>$20/metric ton			TRE

*FRCC = Florida; SRCE = Tennessee Valley; SRDA = Mississippi Delta; SRSE = Georgia-Alabama; SRVC = Virginia-Carolina; SPPS = Southern Plains; TRE = Texas

8. OTHER ELECTRIC SECTOR POWER EMISSIONS

Beyond achieving compliance with the goals of the Clean Power Plan, the low-carbon electricity pathways modeled here offer additional environmental benefits. The low-carbon pathways not only reduce CO_2 emissions, but they also accelerate the reduction of sulfur dioxide (SO_2), nitrogen oxide (NOx), and mercury emissions in the U.S. Table 5 shows the emissions of these important criteria pollutants in 2012 and 2030, as well as how those pollutant levels change over the scenarios.

Table 5. Electric Power Sector Emissions in the U.S. in 2012 and 2030

	Carbon Dioxide		Sulfur Dioxide		Nitrogen Oxide		Mercury	
Scenario	**Million Metric Tons**	**% Change**	**Million Short Tons**	**% Change**	**Million Short Tons**	**% Change**	**Short Tons**	**% Change**
Reference Case:								
2012	2,039		3.35		1.68		26.48	
2030	2,227		1.58		1.60		6.69	
Low-Carbon Pathways (2030):								
$10 Fee	2,128	-4.4%	1.45	-8.2%	1.51	-5.6%	6.33	-5.4%
$20 Fee	1,979	-11.1%	1.32	-16.5%	1.37	-14.4%	5.75	-14.1%
Updated Solar Costs	2,139	-4.0%	1.52	-3.8%	1.55	-3.1%	6.53	-2.4%
Integrated EE	1,854	-16.7%	1.19	-24.7%	1.30	-18.8%	5.61	-16.1%
$10Fee+EE+Solar	1,662	-25.4%	0.98	-38.0%	1.10	-31.3%	4.77	-28.7%
$20Fee+EE+Solar	1,440	-35.3%	0.78	-50.6%	0.90	-43.8%	3.84	-42.6%
$30Fee+EE+Solar	1,221	-45.2%	0.61	-61.4%	0.66	-58.8%	2.91	-56.5%

"% Change" is based on the difference between the low-carbon pathways in 2030 and the Reference case forecast for 2030.

9. SUMMARY AND CONCLUSIONS

Since the release of the Clean Power Plan, stakeholders across the U.S. have vigorously debated the pros and cons of different options for reducing CO_2 emissions from existing power plants. States have an array of options to meet their carbon-reduction goals, including both demand- and supply-side resource investments. Administratively, states need to choose between adhering to an emissions intensity goal or an equivalent CO_2 mass-based goal; politically, they can also prepare an individual state or a multistate implementation plan. Using GT-NEMS, we offer the following policy-relevant findings about the effectiveness, costs and benefits of these various compliance alternatives.

Our modeling suggests that CPP compliance can be achieved cost effectively with a combination of renewable and energy-efficiency policies plus a modest price on carbon that could be expected to result from the Plan's implementation.

In combination, these policies could significantly curb the increase in per capita electricity bills forecast by EIA to occur over the next 15 years. In addition to transitioning to a low-carbon power system, a compliance pathway that combines these three policies would produce substantial collateral benefits including greater GDP growth and increased industrial shipments, as well as household utility bill savings and significant reductions in SO_2, NOx, and mercury emissions.

Nationwide, the compliance pathways would reduce the use of coal in the electric power sector, curb the growth of natural gas, and accelerate the use of energy efficiency and renewable energy. The details of this fuel mix transformation are quite interesting:

- Without the addition of low-carbon policies such as those proposed by the CPP, the least-cost Reference case would not decrease coal generation between 2012 and 2030
- The low-carbon pathways cause little additional uptake of nuclear power
- The low-carbon pathways would cause increases in wind, biomass, and solar PV (but not geothermal or hydro)
- Wind power exceeds each of the non-hydro renewable resources in all of the scenarios except the pathway that is limited to updating solar costs, where solar PV is larger
- The uptake of solar PV appears to benefit from a tipping point between the $10Fee+EE+Solar and $20Fee+EE+Solar compliance cases; with the higher price signal, solar PV becomes transformational in many region of the U.S.
- The growth in solar PV mostly displaces wind and natural gas
- The growth of solar is subdued when the low-carbon policy is limited to integrated energy efficiency; however, solar PV grows along with energy efficiency when a carbon price is added.

Our analysis suggests several differences between national and southern fuel mix responses to low-carbon policies. Specifically, compared with the least-cost national response,

- Coal tends to decline more rapidly in the South
- Natural gas increases less, and nuclear power increases more in the South
- The South shows proportionately more growth in renewable energy and slightly more growth in energy efficiency
- Biomass plays a greater role in the South's renewable portfolio, rivaling the role of wind

Our analysis identifies some differential responses to the low-carbon policies across the seven NERC regions that comprise the South:

- The three NERC regions in the South with nuclear units under construction would require lower carbon prices to achieve their rate-based goals.
- The solar PV price tipping point is shown clearly in four southern NERC regions; in FRCC, for instance, solar PV's share of renewables mushrooms from 2% to 83% when the carbon price is doubled.
- In three of the seven southern NERC regions, coal power would decline significantly. Energy efficiency and renewables grow to fill the gap in SRVC and SPPS, and natural gas also grows in SRCE.

The variation in compliance costs across the nation and within the South suggests that regional approaches to compliance would cost less than individual state approaches. In addition, our modeling of U.S. compliance costs suggests that rate-based goals are less costly than mass-based goals, particularly in the South.

In conclusion, combining a $10 to $20 carbon price with the enhanced deployment of energy efficiency and reduced solar costs could achieve EPA's carbon reduction goals nationwide and in the South. The impact of this low-carbon pathway would vary across regions of the country with different resources investments being chosen. The overall result would produce a low-carbon power system and an array of collateral benefits including lower electricity bills across all customer classes, greater GDP growth, lower household utility bills, and significant reductions in SO_2, NOx, and mercury emissions.

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Table A.1. Estimated Regional CO_2 Reduction Goals in Tons and Rates: in 2030 vs 2012

	CO_2 Mass-based Goals, Existing and New Plants (Million Metric Tons of CO_2)			CO_2 Mass-based Goals, Existing Plants Only (Million Metric Tons of CO_2)			Emissions Rate-based Goals (lbs-CO_2/MWh)		
	2012 Emissions	2030 Goal	% Reduction	2012 Emissions	2030 Goal	% Reduction	2012 Emissions	2030 Goal	% Reduction
U.S.	1,980.78	1,561.91	21%	1,980.78	1,344.72	32%	1,521	998	34%
South	850.83	677.33	20%	850.83	561.31	34%	1,517	954	37%
1.TRE	179.54	128.45	28%	179.54	110.02	39%	1,300	793	39%
NM	28.62	13.34	53%	28.62	135.94	39%	1,586	1,048	34%
TX	222.12	158.78	29%	222.12	30.89	34%	1,298	791	39%
OK	46.75	35.13	25%	46.75	67.82	36%	1,387	895	35%
2. FRCC	105.21	82.77	21%	105.21	68.22	36%	1,200	740	38%
FL	105.83	83.26	21%	105.83	46.05	39%	1,200	740	38%
12.SRDA	75.34	54.91	27%	75.34	20.10	41%	1,488	870	42%
AR	34.27	23.53	31%	34.27	26.82	38%	1,640	910	45%
LA	42.96	32.84	24%	42.96	16.45	28%	1,466	883	40%
MS	22.95	18.92	18%	22.95	135.94	39%	1,130	692	39%
TN	36.34	32.99	9%	36.34	81.97	32%	1,903	1,163	39%
TX	222.12	158.78	29%	222.12	50.27	23%	1,298	791	39%
14. SRSE	120.67	101.53	16%	120.67	68.22	36%	1,445	950	34%
AL	65.33	59.21	9%	65.33	31.68	42%	1,444	1,059	27%
FL	105.83	83.26	21%	105.83	16.45	28%	1,200	740	38%
GA	54.75	42.39	23%	54.75	115.02	24%	1,500	834	44%
MS	22.95	18.92	18%	22.95	50.27	23%	1,130	692	39%
15. SRCE	151.56	139.39	8%	151.56	20.10	41%	1,933	1,462	24%
AL	65.33	59.21	9%	65.33	70.20	17%	1,444	1,059	27%
AR	34.27	23.53	31%	34.27	55.79	22%	1,640	910	45%
GA	54.75	42.39	23%	54.75	16.45	28%	1,500	834	44%
KY	84.42	81.95	3%	84.42	30.89	34%	2,158	1,763	18%
MO	71.82	60.17	16%	71.82	22.84	37%	1,963	1,771	10%
MS	22.95	18.92	18%	22.95	78.96	35%	1,130	692	39%
NC	55.67	45.17	19%	55.67	36.92	34%	1,646	992	40%
OK	46.75	35.13	25%	46.75	15.82	51%	1,387	895	35%
TN	36.34	32.99	9%	36.34	18.92	24%	1,903	1,163	39%
VA	24.84	24.49	1%	24.84	52.64	20%	1,297	810	38%
16. SRVC	122.26	99.24	19%	122.26	61.47	36%	1,596	942	41%
KS	30.11	26.70	11%	30.11	20.10	41%	1,940	1,499	23%
NC	55.67	45.17	19%	55.67	24.08	20%	1,646	992	40%
SC	32.61	22.01	32%	32.61	26.82	38%	1,587	772	51%
VA	24.84	24.49	1%	24.84	55.79	22%	1,298	810	38%
WV	65.86	54.57	17%	65.86	10.39	64%	2,019	1,620	20%

Table A.1. Estimated Regional CO_2 Reduction Goals in Tons and Rates: in 2030 vs 2012 (continued)

	CO_2 Mass-based Goals, Existing and New Plants (Million Metric Tons of CO_2)			CO_2 Mass-based Goals, Existing Plants Only (Million Metric Tons of CO_2)			Emissions Rate-based Goals (lbs-CO_2/MWh)		
	2012 Emissions	2030 Goal	% Reduction	2012 Emissions	2030 Goal	% Reduction	2012 Emissions	2030 Goal	% Reduction
18. SPPS	96.25	71.04	26%	96.25	30.89	34%	1,404	910	35%
AR	34.27	23.53	31%	34.27	135.94	39%	1,640	910	45%
KS	30.11	26.70	11%	30.11	1,344.72	32%	1,940	1,499	23%
LA	42.96	32.84	24%	42.96	561.31	34%	1,466	883	40%
MO	71.82	60.17	16%	71.82	110.02	39%	1,963	1,771	10%
NM	28.62	13.34	53%	28.62	135.94	39%	1,586	1,048	34%
OK	46.75	35.13	25%	46.75	30.89	34%	1,387	895	35%
TX	222.12	158.78	29%	222.12	67.82	36%	1,298	791	39%

* Sources: 2012 Emissions - EPA State CO_2 Emissions, http://epa.gov/statelocalclimate; 2030 Goals - EPA Fact Sheet, http://www2.epa.gov/carbon-pollution-standards/fact-sheet-clean-power-plan-technical-support-document#print)

Table A.2. Impact of Low-Carbon Pathways on Electricity and Natural Gas Prices: All Sectors

	Electricity Prices (2012 cents/kWh)		Natural Gas Prices (2012 $/MMBtu)	
	U.S.	South Average	U.S.	South Average
Reference 2012	9.84	8.64	5.38	3.32
Reference 2030*	**10.48**	**9.52**	**8.51**	**6.55**
$10 Fee	10.86	9.94	8.63	6.97
$20 Fee	11.29	10.38	8.75	7.43
Updated Solar Costs	10.32	9.38	8.27	6.20
Integrated EE	9.92	9.12	8.01	5.87
$10 Fee + EE + Solar	10.35	9.58	8.15	6.38
$20 Fee + EE + Solar	10.76	9.57	8.23	6.34

*The prices in the rows below are for the year 2030.

Red: Higher price compared to the Reference case in 2030; Green: Lower price compared to the Reference case in 2030

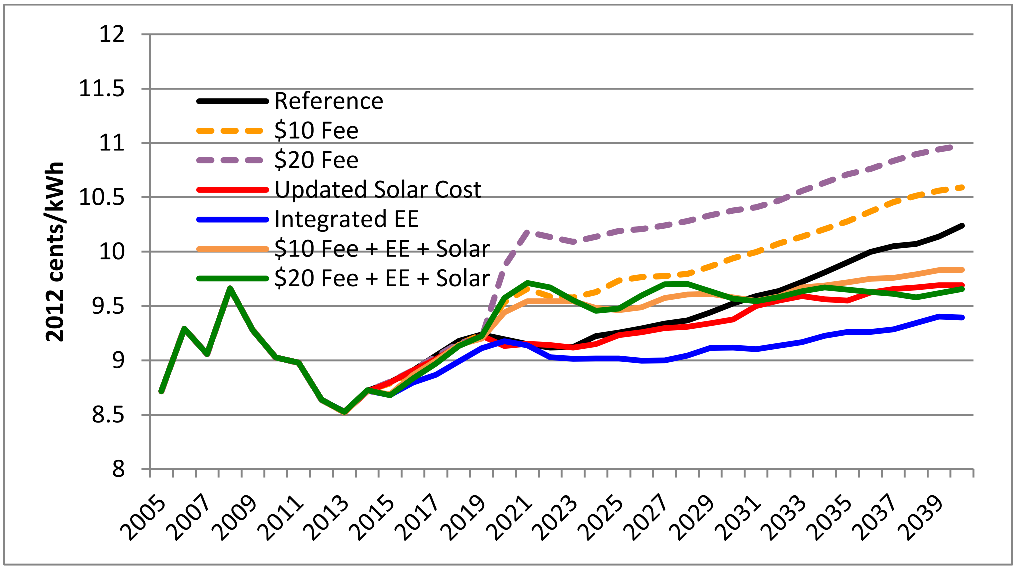
Table A.3. Impact of Policy Pathway on Residential Electricity Prices, Sales, and Bills in 2030*

		Electricity prices		Electricity sales		Electricity bills	
Region	Scenario	¢/kWh	% Change	Billion kWh	% Change	Million dollars	% Change
South							
TRE	$20 Fee + EE + Solar	12.7	-0.2%	113.3	-13.3%	15,069	-23.8%
	Reference	12.7		130.6		19,772	
FRCC	$20 Fee + EE + Solar	13.2	6.6%	88.3	-16.3%	11,937	-21.9%
	Reference	12.4		105.5		15,284	
SRDA	$20 Fee + EE + Solar	11.9	4.2%	35.2	-13.3%	5,447	-20.3%
	Reference	11.4		40.6		6,837	
SRSE	$20 Fee + EE + Solar	11.8	6.1%	71.8	-15.4%	9,254	-20.7%
	Reference	11.1		84.9		11,674	
SRCE	$20 Fee + EE + Solar	9.0	4.1%	54.5	-13.5%	6,564	-19.8%
	Reference	8.6		62.9		8,185	
SRVC	$20 Fee + EE + Solar	12.5	6.2%	109.0	-16.3%	12444	-22.2%
	Reference	11.8		130.3		15985	
SPPS	$20 Fee + EE + Solar	10.9	6.1%	44.0	-13.4%	5031	-19.1%
	Reference	10.3		50.8		6222	
Non-South							
MORE	$20 Fee + EE + Solar	15.9	8.4%	7.4	-17.0%	665	-17.2%
	Reference	14.7		8.9		803	
MROW	$20 Fee + EE + Solar	11.5	3.5%	54.0	-13.2%	5636	-20.2%
	Reference	11.1		62.3		7064	
NEWE	$20 Fee + EE + Solar	17.9	7.5%	39.1	-14.5%	5895	-22.4%
	Reference	16.7		45.8		7598	
NYCW	$20 Fee + EE + Solar	41.8	12.0%	34.5	-14.0%	4292	-17.7%
	Reference	37.4		40.1		5217	
NYLI	$20 Fee + EE + Solar	22.2	3.2%	8.9	-14.0%	1574	-24.2%
	Reference	21.5		10.4		2076	
NYUP	$20 Fee + EE + Solar	18.9	2.9%	23.8	-14.0%	3668	-24.4%
	Reference	18.4		27.7		4850	
RFCE	$20 Fee + EE + Solar	14.9	0.1%	100.3	-15.0%	10941	-26.5%
	Reference	14.9		118.0		14882	
RFCM	$20 Fee + EE + Solar	15.6	7.1%	31.7	-17.0%	3599	-18.1%
	Reference	14.6		38.3		4396	
RFCW	$20 Fee + EE + Solar	14.9	6.4%	136.4	-16.6%	18968	-19.5%
	Reference	14.0		163.6		23551	
SRGW	$20 Fee + EE + Solar	12.2	8.2%	30.7	-14.7%	3975	-16.8%
	Reference	11.3		36.0		4777	
SPNO	$20 Fee + EE + Solar	12.2	6.3%	24.3	-12.9%	2254	-18.0%
	Reference	11.5		27.9		2750	
AZNM	$20 Fee + EE + Solar	13.9	2.3%	49.0	-15.6%	6080	-27.5%

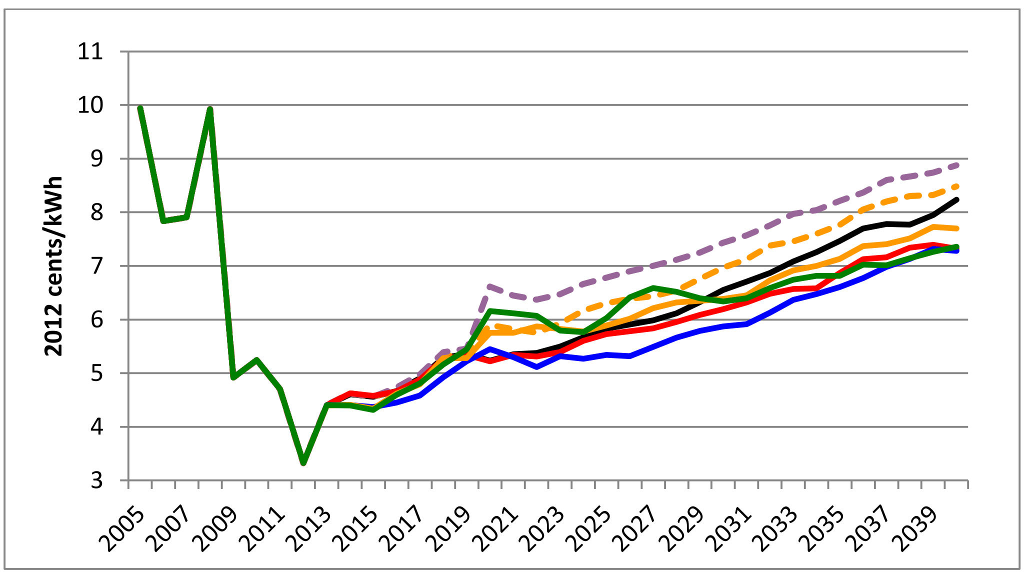
	Reference	13.6		58.0		8387	
CAMX	$20 Fee + EE + Solar	15.3	6.0%	129.0	-11.9%	9260	-23.2%
	Reference	14.5		146.4		12064	
NWPP	$20 Fee + EE + Solar	9.4	2.2%	77.4	-13.4%	5704	-26.7%
	Reference	9.2		89.4		7786	
RMPA	$20 Fee + EE + Solar	12.9	4.6%	24.0	-15.8%	2244	-25.9%
	Reference	12.3		28.5		3027	
South	$20 Fee + EE + Solar	11.7	4.7%	552.0	-24.9%	65,747	-21.7%
	Reference	11.2		734.8		83,960	
Non-south	$20 Fee + EE + Solar	16.6	6.0%	580.3	-26.0%	84,752	-22.4%
	Reference	15.7		784.2		109,227	
U.S.	$20 Fee + EE + Solar	13.3	4.6%	1136.6	-25.5%	150,623	-22.1%
	Reference	12.7		1525.0		193,282	
t statistic		0.675		0.174		0.235	

*The Policy Pathway is the $20Tax + EE + Solar. All dollars are in $2012.

Integrated energy efficiency and updated solar costs cause electricity and natural gas rates to drop below the Reference case forecast in 2030. Carbon fees, on the other hand, cause electricity and natural gas rates to increase more rapidly than in the Reference case (Figure A.1).



a. Electricity Rates in the South



b. Natural Gas Rates in the South

Figure A.1. Electricity and Natural Gas Rates Under Alternative Pathways in the South

Electricity bills per capita are lower with energy efficiency and updated solar costs, and are higher with carbon fees (Figure A.2). In combination with energy efficiency and updated solar costs, a carbon fee of $30 per metric ton of carbon still allows electricity bills to decline relative to the Reference case forecast.

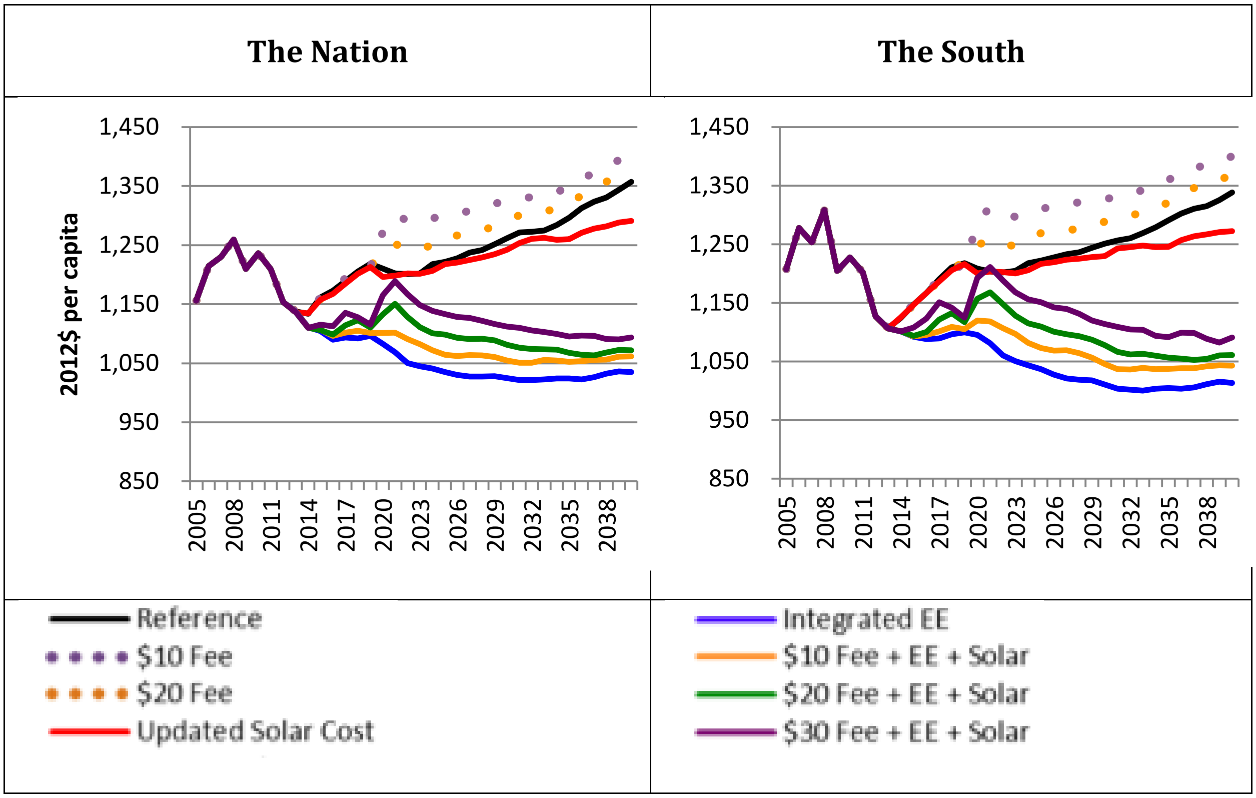


Figure A.2. Electricity and Natural Gas Bills Per Capita Under Alternative Pathways

Brown, et al. (2014) provide evidence that delivered electricity intensity in the South is high in each of the three sectors of the economy, compared with rest of the U.S.[13] In 2012, the industrial sector in the South (which includes manufacturing, agriculture, mining and construction) used 42% more electricity than the national average to generate one dollar of GDP. This is partly due to the region's higher-than-average share of electricity-intensive industries such as primary metals, textiles, paper and other wood products, and chemicals.[14] The commercial and residential sectors in the South are also more electricity-intensive than the rest of the nation, by 33% and 27%, respectively. This is partly because buildings in the South rely more on electricity and less on natural gas for space

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[13] These intensities are lower when Texas and Oklahoma data are included (the drop in industrial intensity is particularly notable), but the South is still more electric intensity than the rest of the country even with these two states included.

[14] Brown, et al. (2014) details the composition of electricity-intensive industries in the US and their share in southern states' Gross State Production (GSP).

heating than the rest of the nation as a whole. Southern states also experience warmer temperatures – as reflected in their larger cooling degree days (CDDs) – and as a result consumers use more electricity for space cooling than the rest of the nation as a whole. Considering all of the states in the South with significant cooling loads and electric home heating, residential electric intensity is particularly high in Alabama and South Carolina (with intensities of 0.16) and Mississippi (at 0.17), compared with Texas (at 0.09). Further evidence of high residential electricity intensity in the South is illustrated by Arizona with CDDs exceeding 5,000 in 2012 and 58% electric home heating, but with a residential electricity intensity of only 0.12. Brown, et al (2014) provides evidence that the high electricity intensities in the South also reflect inefficient end-use equipment, systems, and practices as well as the absence of key energy-efficiency policies.

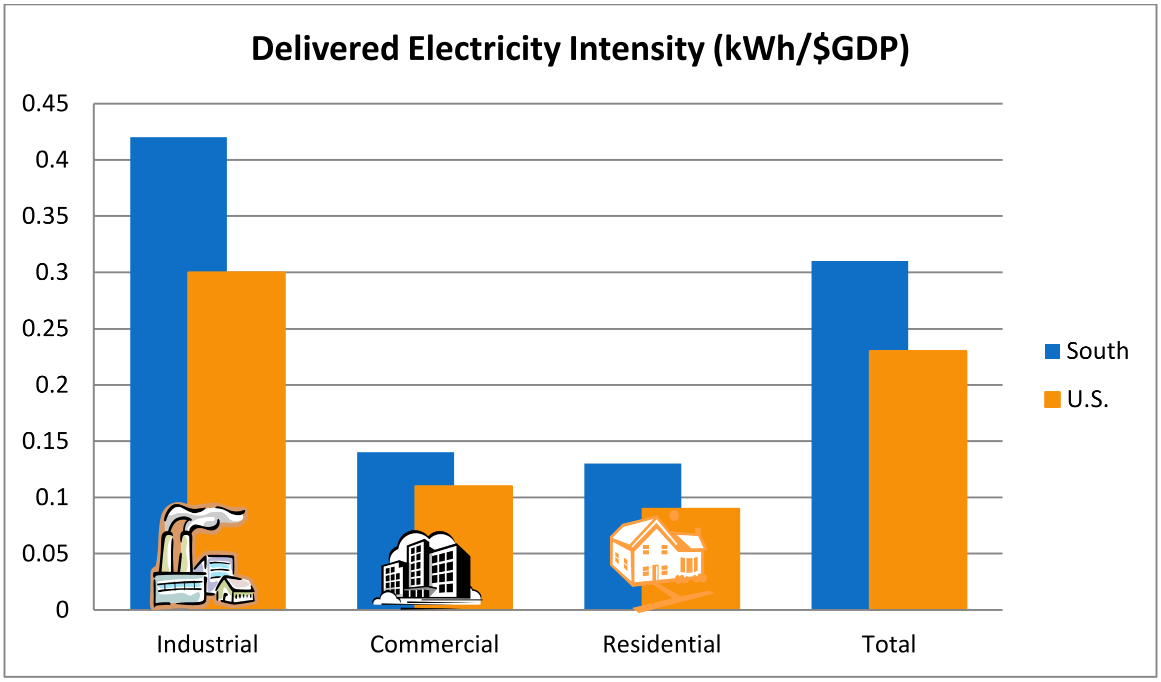

Figure A.3. Electricity Intensity by Customer Class in the South and the US in 2012
(Source: Brown, et al., 2014. Note: The definition of the South used to construct this figure excludes TX and OK.)[15]

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[15] The gross regional product (GRP) of the South (excluding TX and OK) was approximately $3.90 trillion in 2012. Most of this GRP was affiliated with the commercial sector ($3.1 trillion), which is defined as the South's GRP minus the sum of the economic activity associated with the industrial and transportation sectors. $0.75 trillion of economic activity was affiliated with industrial activity, defined as agriculture, construction, manufacturing, and mining. The economic activity associated with the residential sector is assumed to be the total GRP of the South (Bureau of Economic Analysis: Gross Domestic Product by State, http://www.bea.gov/regional/). Electricity intensity is calculated as the delivered electricity consumed by each sector divided by the economic activity associated with that sector. The electricity consumption and economic activity data come from:

http://www.eia.gov/state/seds/seds-data-complete.cfm?sid#Consumption
http://www.bea.gov/iTable/iTable.cfm?reqid=70&step=1&isuri=1&acrdn=1#reqid=70&step=1&isuri=1.

APPENDIX B: DESCRIPTION OF DATA SOURCES USED BY THE GT-NEMS ELECTRICITY MARKET MODULE:

EIA Form 860: This survey collects information about boilers, reactors, and other electricity generating units at US power plants with a total nameplate capacity greater than or equal to 1 MW. These data include financial data such as the owner/operator and the utility served by the plant, spatial data such as the state in which the plant lies and the portion of the US electric grid to which the plant is connected, and technical data such as the fuels used by the plant and the pollutant emissions control technologies applied to each generator at the plant. Data from this survey form and further description are available online at: http://www.eia.gov/electricity/data/eia860/.

EIA Form 861: This survey collects information about utility systems' performance with variables such as total energy sales, summer and winter peak demand, number of customers, and deployment of distributed resource programs such as net metering. This form also includes business information such as mergers between utility firms. Data from this survey form and further description are available online at: http://www.eia.gov/electricity/data/eia861/

EIA Form 923: This survey collects data monthly and annually on US power plants. The data collected include the type of "prime mover" used (e.g. a steam turbine versus a combustion turbine), the amount of fuel stockpiled at the power plant site, the costs of fuel delivered to the power plant if and when fuel purchases are made, and power consumption by the plant itself. Data from this survey form and further description are available online at: http://www.eia.gov/electricity/data/eia923/

NERC (North American Electric Reliability Corporation) Load Projections: The NERC (North American Electric Reliability Corporation) is a not-for-profit corporation responsible for developing and enforcing reliability standards. In carrying out this responsibility, NERC performs analyses called LTRAs (Long Term Reliability Assessments) in which load growth is forecast. In addition to incorporating these load growth forecasts, GT-NEMS' EMM also makes use of the regional definitions provided by NERC in defining the EMM regions. More description of the NERC LTRAs can be found online at: http://www.nerc.com/pa/rapa/Pages/default.aspx. An example LTRA from 2013 is available online at: http://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/2013_LTRA_FINAL.pdf.

FERC Form 1: This survey collects data from major electric utilities on a vast number of different variables, including plantlevel operating data, system-level performance, and data on the utilities' financial structure. While some of these data (e.g. total system sales) are duplicated in EIA surveys, other data (e.g. number of rate classes offered and sales by rate class) are not. Data from this survey and further description are available at: http://www.ferc.gov/docs-filing/forms/form-1/data.asp.

APPENDIX C: METHODOLOGY FOR PROJECTING HOUSEHOLD UTILITY BILLS IN THE 22 NERC REGIONS[16]

This appendix describes the methodology developed to estimate the impact of low-carbon electricity pathways on the utility bills of households. GT-NEMS provides the data necessary for estimating household utility bills for the nine U.S. Census divisions. It also estimates residential energy consumption and prices by fuel type for smaller geographic units – the 22 North American Reliability Corporation (NERC) regions shown in Figure C.1. While the GT-NEMS code incorporates population estimates for these regions in its macroeconomic model, it does not provide these population estimates as outputs. It also does not generate per capita utility bill estimates at the resolution of the 22 NERC regions. As a result, additional work by users of GT-NEMS is required to estimate utility bills on a per capita or per household basis at the scale of these NERC regions. Our supplemental spreadsheet approach is described below.

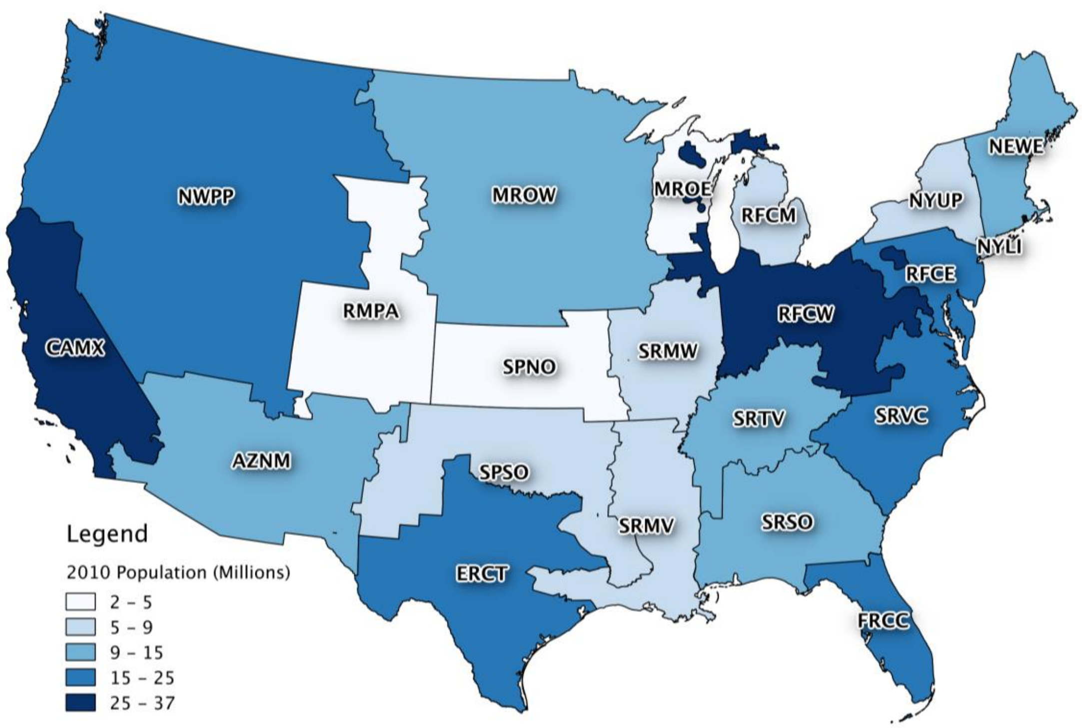

Figure C.1. The Electricity Market Module's NERC Regions and their Populations in 2010
(Source: Benjamin Staver, Georgia Institute of Technology)

[16] The methodology described in this appendix was developed in large part by Ben Staver and Jeff Hubbs working with the Georgia Institute of Technology's Climate and Energy Policy Lab.

While not a perfect method for downscaling to states, the 22 NERC regions can inform state statistics. The 22 NERC regions were developed and implemented by the Energy Information Administration in the Electricity Market Module (EMM) module of the *Annual Energy Outlook 2011*. They correspond to the North American Reliability Corporation regions that were in place in 2011. In some cases they are divided into sub-regions (EIA, 2015).

Some of the 22 regions correspond approximately to states, such as FRCC (Florida), ERCT (Texas), and CAMX (California). Others are aggregations of states, such as NEWE (New England), or are parts of states that can be aggregated (New York). Still others cut across state boundaries, reflecting the territories overseen by power coordinating entities or power marketing authorities such as the Northeast Power Coordinating Council and the Southeast Reliability Corporation. In some cases these are divided into the subregions served by entities such as utility holding companies. For example, the Georgia-Alabama NERC region is served by the Southern Company and is abbreviated SERC-Southeast or SRSE. Because of the influence these holding companies and power marketing authorities have over power planning, they provide useful insights into energy rates, consumption, and bills at the state level.

Four data transformations are necessary to forecast household utility bills for these 22 geographic regions. First, we need to identify the counties that comprise each NERC region. Second, we need to identify the baseline population of each region based on county populations. Third, we need to identify the population growth rate of each region so that we can estimate its population in each year between 2010 and 2040. Finally, the average household size of each region must be estimated so that the number of households in each region can be estimated for the 2010-2040 time period.

C.1 THE COUNTIES THAT COMPRISE EACH NERC REGION

We began by deploying data that linked zip codes to NERC regions. We then cross-referenced the county data with a zip code to county data set (ZIP Codes To Go, 2011). The calculations for linking counties to NERC regions are contained in the file NERC-to-CNTY CALC, which produced a table showing the NERC region location of each county. A fragment of this is shown in Table C.1; the entire file can be found at http://cepl.gatech.edu/drupal/node/88.

Table C.1. Linking Counties to NERC Regions

	State	NERC Region	County	CNTY_STATE
1	NY	NYLI	Suffolk	Suffolk, NY
2	MA	NEWE	Hampden	Hampden, MA
. . .				
3140	AK	AKMS	Ketchikan Gateway	Ketchikan Gateway, AK
3141	AK	AKMS	Prince Wales Ketchikan	Prince Wales Ketchikan, AK

In turn, this information was condensed to a unique list of counties by State and NERC region. Any counties located in multiple NERC regions were assigned to one region based on where the largest portion of its land area was located, based on a map of the NERC regions produced by the U.S. Environmental Protection Agency (EPA). EPA uses the same NERC regions in its eGRID database (EPA, 2014).

C.2 THE BASELINE POPULATION OF EACH NERC REGION

The aggregation of the 2010 population from counties and states to NERC regions is shown in the file named NERC_POP CALC, which can be found at http://cepl.gatech.edu/drupal/node/88.

Each county was coded with its 2010 census population based on data from the National Historical Geographic Information System (NHGIS, 2013). This allowed for state population growth projections to be broken down based on the population weighting of each county.

C.3 THE POPULATION GROWTH RATE OF EACH NERC REGION

Population projections used within NEMS are based on proprietary data from IHS Global Insight's Model of the U.S. Economy. They account for migration among Census divisions as described in the documentation of NEMS' macroeconomic activity module (MAM) model, which can be found at: http://www.eia.gov/forecasts/aeo/nems/documentation/macroeconomic/pdf/m065(2014).pdf.

Because the population forecasting data is not publicly available from IHS Global Insights, we developed an alternative approach to forecasting population growth by Census division and NERC region. It uses population forecasts published by state agencies or their representatives. An illustration of these forecasts is shown in Figure C.2.

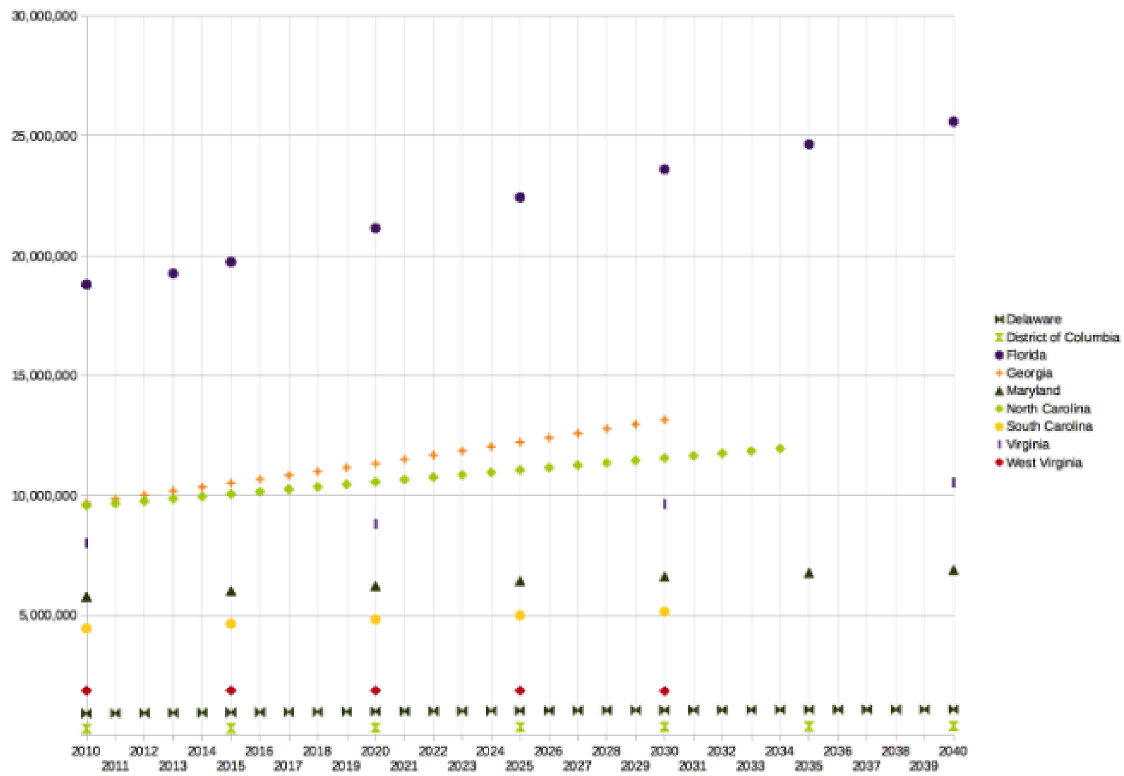

Figure C.2. Population Projections for States in the Southeast

As can be seen for these states in the South, state population forecasts are generally linear with flat to rising slopes based estimates for each year, every five years, or every decade between 2010 and 2040. Regression analysis of these projections produced an annual increment of population growth that could be applied to each NERC region for each year in the 30-year timeframe. This then allowed for the summation of population and population growth across the counties of each NERC region, where counties are incremented by the rate of population of their state. The results are summarized in Table C.2.

Table C.2. Population Growth Rates for NERC Regions

NERC Region Labels				Population in 2010	Annual Population Growth: 2010-2040
Number	Geographic Name*	eGRID	NEMS		
1	Texas	ERCT	ERCT	21,926,489	335,820
2	Florida	FRCC	FRCC	17,737,979	222,936
3	Eastern Wisconsin	MROE	MROE	2,463,739	157
4	Northern Plains	MROW	MROW	12,265,621	57,952
5	New England	NEWE	NEWE	14,444,865	28,565
6	New York City	NYCW	NYCW	8,175,133	3,611
7	Long Island	NYLI	NYLI	2,832,882	1,251
8	Upstate New York	NYUP	NYUP	8,370,087	3,697
9	Mid-Atlantic	RFCE	RFCE	24,919,722	105,001
10	Lower Michigan	RFCM	RFCM	9,415,466	11,892
11	Great Lakes	RFCW	RFCW	37,386,227	116,845
12	Mississippi Delta	SRMW	SRDA	8,641,966	58,034
13	Mississippi Basin	SRMV	SRGW	7,417,047	48,672
14	Georgia-Alabama	SRSO	SRSE	14,781,887	201,852
15	Tennessee Valley	SRTV	SRCE	13,905,143	119,605
16	Virginia-Carolina	SRVC	SRVC	20,298,216	159,695
17	Central Plains	SPNO	SPNO	3,809,001	19,828
18	Southern Plains	SPSO	SPPS	6,868,658	55,590
19	Southwest	AZNM	AZNM	11,030,359	188,530
20	California	CAMX	CAMX	36,996,232	295,969
21	Northwest	NWPP	NWPP	17,095,654	165,786
22	Rocky Mountains	RMPA	RMPA	5,487,768	94,842

*Geographic names are approximately descriptive.

The resulting population estimates and forecasts are shown in Table C.3.

Table C.3. Population Projections for NERC Regions (in millions)

	ERCT	FRCC	MROE	MRO W	NEW E	NYC W	NYLI	NYUP	RFCE	RFCM	RFC W
2010	21.93	17.74	2.46	12.27	14.44	8.18	2.83	8.37	24.92	9.42	37.39
2011	22.26	17.96	2.46	12.32	14.47	8.18	2.83	8.37	25.02	9.43	37.50
2012	22.60	18.18	2.46	12.38	14.50	8.18	2.84	8.38	25.13	9.44	37.62
2013	22.93	18.41	2.46	12.44	14.53	8.19	2.84	8.38	25.23	9.45	37.74
2014	23.27	18.63	2.46	12.50	14.56	8.19	2.84	8.38	25.34	9.46	37.85
2015	23.61	18.85	2.46	12.56	14.59	8.19	2.84	8.39	25.44	9.47	37.97
2016	23.94	19.08	2.46	12.61	14.62	8.20	2.84	8.39	25.55	9.49	38.09
2017	24.28	19.30	2.46	12.67	14.64	8.20	2.84	8.40	25.65	9.50	38.20
2018	24.61	19.52	2.46	12.73	14.67	8.20	2.84	8.40	25.76	9.51	38.32
2019	24.95	19.74	2.47	12.79	14.70	8.21	2.84	8.40	25.86	9.52	38.44
2020	25.28	19.97	2.47	12.85	14.73	8.21	2.85	8.41	25.97	9.53	38.55
2021	25.62	20.19	2.47	12.90	14.76	8.21	2.85	8.41	26.07	9.55	38.67
2022	25.96	20.41	2.47	12.96	14.79	8.22	2.85	8.41	26.18	9.56	38.79
2023	26.29	20.64	2.47	13.02	14.82	8.22	2.85	8.42	26.28	9.57	38.91
2024	26.63	20.86	2.47	13.08	14.84	8.23	2.85	8.42	26.39	9.58	39.02
2025	26.96	21.08	2.47	13.13	14.87	8.23	2.85	8.43	26.49	9.59	39.14
2026	27.30	21.30	2.47	13.19	14.90	8.23	2.85	8.43	26.60	9.61	39.26
2027	27.64	21.53	2.47	13.25	14.93	8.24	2.85	8.43	26.70	9.62	39.37
2028	27.97	21.75	2.47	13.31	14.96	8.24	2.86	8.44	26.81	9.63	39.49
2029	28.31	21.97	2.47	13.37	14.99	8.24	2.86	8.44	26.91	9.64	39.61
2030	28.64	22.20	2.47	13.42	15.02	8.25	2.86	8.44	27.02	9.65	39.72
2030	28.64	22.20	2.47	13.42	15.02	8.25	2.86	8.44	27.02	9.65	39.72

NEMS	SRDA	SRG W	SRSE	SRCE	SRVC	SPNO	SPSO	AZN M	CAM X	NWP P	RMP A
2010	8.64	7.42	14.78	13.91	20.30	3.81	6.87	11.03	37.00	17.10	5.49
2011	8.70	7.47	14.98	14.02	20.46	3.83	6.92	11.22	37.29	17.26	5.58
2012	8.76	7.51	15.19	14.14	20.62	3.85	6.98	11.41	37.59	17.43	5.68
2013	8.82	7.56	15.39	14.26	20.78	3.87	7.04	11.60	37.88	17.59	5.77
2014	8.87	7.61	15.59	14.38	20.94	3.89	7.09	11.78	38.18	17.76	5.87
2015	8.93	7.66	15.79	14.50	21.10	3.91	7.15	11.97	38.48	17.92	5.96
2016	8.99	7.71	15.99	14.62	21.26	3.93	7.20	12.16	38.77	18.09	6.06
2017	9.05	7.76	16.19	14.74	21.42	3.95	7.26	12.35	39.07	18.26	6.15
2018	9.11	7.81	16.40	14.86	21.58	3.97	7.31	12.54	39.36	18.42	6.25
2019	9.16	7.86	16.60	14.98	21.74	3.99	7.37	12.73	39.66	18.59	6.34
2020	9.22	7.90	16.80	15.10	21.90	4.01	7.42	12.92	39.96	18.75	6.44
2021	9.28	7.95	17.00	15.22	22.05	4.03	7.48	13.10	40.25	18.92	6.53
2022	9.34	8.00	17.20	15.34	22.21	4.05	7.54	13.29	40.55	19.09	6.63
2023	9.40	8.05	17.41	15.46	22.37	4.07	7.59	13.48	40.84	19.25	6.72
2024	9.45	8.10	17.61	15.58	22.53	4.09	7.65	13.67	41.14	19.42	6.82
2025	9.51	8.15	17.81	15.70	22.69	4.11	7.70	13.86	41.44	19.58	6.91
2026	9.57	8.20	18.01	15.82	22.85	4.13	7.76	14.05	41.73	19.75	7.01
2027	9.63	8.24	18.21	15.94	23.01	4.15	7.81	14.24	42.03	19.91	7.10
2028	9.69	8.29	18.42	16.06	23.17	4.17	7.87	14.42	42.32	20.08	7.19
2029	9.74	8.34	18.62	16.18	23.33	4.19	7.92	14.61	42.62	20.25	7.29
2030	9.80	8.39	18.82	16.30	23.49	4.21	7.98	14.80	42.92	20.41	7.38

C.4 THE NUMBER OF HOUSEHOLDS IN EACH REGION

The population of each region was divided by an estimated household size in order to estimate the number of households in 2010 through 2040. We used the average household size of each of the 9 Census Divisions that comprise the U.S. as shown in Table C.4.

Table C.4. Average Household Size in 2010
(Source: Day, 1996, Table F)

U.S. and Census Division in 2010	Household Size
US	2.58
New England	2.46
Middle Atlantic	2.55
East North Central	2.5
West North Central	2.45
South Atlantic	2.52
East South Central	2.49
West South Central	2.67
Mountain	2.62
Pacific	2.8

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