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The economic costs of reducing greenhouse gas emissions under a U.S. national renewable electricity mandate

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ABSTRACT

The electricity sector is the largest source of greenhouse gas emissions (GHGs) in the U.S. Many states have passed and Congress has considered Renewable Portfolio Standards (RPS), mandates that specific percentages of electricity be generated from renewable resources. We perform a technical and economic assessment and estimate the economic costs and net GHG reductions from a national 25 percent RPS by 2025 relative to coal-based electricity. This policy would reduce GHG emissions by about 670 million metric tons per year, 11 percent of 2008 U.S. emissions. The first 100 million metric tons could be abated for less than $36/metric ton. However, marginal costs climb to $50 for 300 million metric tons and to as much as $70/metric ton to fulfill the RPS. The total economic costs of such a policy are about $35 billion annually. We also examine the cost sensitivity to favorable and unfavorable technology development assumptions. We find that a 25 percent RPS would likely be an economically efficient method for utilities to substantially reduce GHG emissions only under the favorable scenario. These estimates can be compared with other approaches, including increased R&D funding for renewables or deployment of efficiency and/or other low-carbon generation technologies.

1. Introduction

The largest source of greenhouse gas (GHG) emissions in the U.S. is electric power generation, accounting for about 35 percent of total GHGs in 2008 (Environmental Protection Agency (EPA), 2010a). If U.S. GHGs are to fall substantially, emissions from generating electricity will need to considerably decline. One policy option for reducing GHG emissions is to impose a mandate, such as a Renewable Portfolio Standard (RPS), on electric power providers to generate a specified share of their electricity from renewable sources such as wind and biomass.[1]

A number of scholars have analyzed the economic costs of using an RPS to reduce GHG emissions and have arrived at differing conclusions. Wiser et al. (2007) concluded that RPSs yield "mixed-results." Nogee et al. (2007) found RPSs generated "important economic and environmental benefits." Michaels (2008) concluded they induce "inefficient" and in some cases "pernicious" outcomes. Some studies argue that using a diverse portfolio of low-carbon sources of energy could achieve targeted reductions in GHG emissions at lower cost than the more rigid technological mandates incorporated into RPSs (Dobesova et al., 2005; Apt et al., 2008). Chen et al. (2009) estimated the anticipated effects of an RPS on retail electricity rates, finding expected increases would be small.

In this paper we estimate the net benefits from imposing a national RPS mandate in terms of reductions of GHGs and the corresponding economic costs relative to coal-based electricity.[2] Following on an earlier study by Toman et al. (2008), we set a target of generating 25 percent of U.S. electricity from renewable sources by 2025.[3] We identify which sources of renewable energy are most economical for achieving such a mandate. We also assess the economic costs and net GHG benefits of the 20 percent Renewable Electricity Standard (RES) included in the American Clean Energy and Security Act (ACES) (HR 2454; Waxman-Markey) passed by the House of Representatives in 2009 (ACES, 2009).

The paper is organized as follows. In Section 2, we outline the methodology we use to estimate the costs and quantities of electricity generated by prospective renewable energy sources and associated reductions in GHG emissions. We also introduce scenarios to consider uncertainty in technological developments and costs. Section 3 presents details on the costs and emissions

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[1] For a review of RPS designs and a survey of early implementation, see Berry and Jaccard (2001). For an additional discussion of RPS design, see Espey (2001).

[2] Note that in this analysis we consider the production of electricity in pulverized coal (PC) plants *without* the use of carbon, capture, and sequestration (CCS).

[3] We examine the GHG benefits and economic costs of a 25 percent mandate for renewable motor vehicle fuels by 2025 in another forthcoming paper.

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associated with each of the renewable technologies we analyze: hydropower, wind, biomass, solar thermal, and geothermal. We present our results in Section 4. In Section 5, we discuss the implications of our analysis for recent proposals for legislation to reduce GHGs.

2. Methods

2.1. Estimating costs and quantities

We first estimate the additional cost of replacing electricity generated by coal-fired electric power plants with renewable sources of energy. For each source of renewable energy, we estimate the cost of producing electricity, factoring in the availability of sites or resources. All sources exhibit increasing marginal costs. The cost estimates are based on the full economic costs of substituting renewables for coal, and we do not incorporate subsidies into the analysis. Details of these estimates and underlying assumptions can be found in the Electronic Annex in the online version of this article.

We use these estimates of quantities and costs of renewable fuels to construct supply curves for renewable electricity, employing the lowest cost sources first. To estimate the additional cost of renewable electricity, we compare the costs of renewables to the dispatch costs in 2009 of electricity generated by coal-fired power plants, electricity that we assume new renewable sources would replace. Then we compare the costs of renewables with the cost of additional coal-fired generating capacity that would be needed to meet the EIA's Reference Case projection for U.S. demand for electricity in 2025.[4]

We chose to compare the cost of electricity generated by renewables with that generated from coal-fired power plants as one plausible scenario. As substantial amounts of variable renewable generation are added to the electricity grid, actual fossil resources displaced will depend on relative cost of fuels, local supply and demand characteristics, and other factors. In a recent National Renewable Energy Laboratory (NREL) analysis, they posit that baseload coal could be displaced with high penetration of wind, as more flexible generation assets are preferred to address modeled day-ahead forecast error (NREL, 2010). Wind or solar power could be dispatched to meet peak needs if storage technologies were available and affordable, but currently such technology is not widely used (see Electronic Annex). The comparison with coal-fired power plants is also useful because coal-fired electric power generates the most GHG emissions per kWh relative to other technologies. As one purpose of the RPS is to reduce GHG emissions, the comparison with coal is pertinent.[5]

This analysis does not include externalities, such as health impacts from air pollution, in the calculation of the relative costs of coal-based versus renewable electricity production. These can be significant (NRC, 2010a; Barr and Dominici, 2010).

2.2. Estimating potential net reductions of GHG emissions

We calculate the net reductions in life cycle GHG emissions that would result from substituting renewables for coal to generate electricity. All renewables generate a low level of GHG emissions when the full life cycle (i.e., constructing, operating, and decommissioning) of these technologies are taken into consideration. We calculate life cycle GHG emissions/kWh for each renewable technology and then subtract this total from life cycle GHG emissions of coal-fired electric power to derive a net reduction in GHG emissions for each technology. We then calculate the cost per metric ton of carbon dioxide equivalent (CO_2e) from reduced GHG emissions using the cost and net emission estimates above.

2.3. Scenarios

To account for broad uncertainty in changes in technological options and costs, we employ three scenarios: (1) Reference Scenario; (2) Favorable Technology Scenario, where technological development is assumed to be relatively rapid; and (3) Unfavorable Technology Scenario, where technological development is assumed to be relatively slow.

We develop the Favorable and Unfavorable Technology Scenarios by identifying the key components of each renewable technology that are most likely to determine the pace at which technologies improve or costs fall. We then evaluate the likely speed at which these technological advances could occur and the extent to which current expectations about improvements and cost reductions may fail to materialize. In these scenarios, we also take into account how rapidly the technologies are likely to be deployed. Detailed discussions of the assumptions in our technology analysis can be found in the Electronic Annex.

3. Costs and GHG emissions of renewable sources of electricity

The electric power industry is capital-intensive. Generating plants are expensive and operate for decades. Obtaining site approvals, constructing a plant, and bringing it to full operation is a lengthy process, generally taking years to complete. Therefore, a substantial dramatic shift from generating electricity from fossil fuels to using renewable energy would take a considerable amount of time as renewable capacity is constructed.

If the U.S. were to set a goal of generating 25 percent electricity from renewable sources by 2025, planning and construction of large amounts of renewable generating capacity would have to begin shortly to meet such a target. Consequently, we assume that only currently commercial renewable generating technologies would be available to meet such a mandate by 2025. Technologies that are not yet at this stage would be highly unlikely to be widely adopted at scale by that date. Accordingly, we confine our analysis to the following technologies: (1) Hydropower; (2) Wind; (3) Biomass; (4) Geothermal; and (5) Solar.

Some renewable technologies, like hydropower, are mature; significant reductions in cost or improvements in productivity and efficiency are less likely. Some, like emerging solar thermal technologies, could see rapid improvements in efficiency or large reductions in cost. Other technologies, like wind power, fall in-between. Here we briefly describe our estimates of the costs and GHG emissions for these five technologies. To calculate net GHG reductions, we compare emissions from electricity generated from renewable sources with that from baseload coal-fired power plants. Coal-fired power is assumed to have a life cycle emissions factor of 1.021 kg CO_2e/kWh (Wang et al., 2007). For a more detailed discussion, see the Electronic Annex.

3.1. Hydropower: technologies, quantities and prices, and net GHG emissions

There are two categories of hydroelectricity: conventional and emerging hydrokinetic. The deployment of hydrokinetic power technologies, including wave and tidal energy, is likely to remain

[4] CCS would simultaneously lower emissions and raise the cost of coal-fired power, but the technology is still being developed and demonstrated. Consequently, we do not consider it in this analysis.

[5] Note that we have not considered other factors in this analysis, such as potential siting difficulties, criteria pollutants, and water use, which may influence the type of technologies in the electricity generation portfolio in 2025.