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ANALYSIS

Examining the relationship between shale gas production and carbon capture and storage under CO_2 taxes based on the social cost of carbon

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ABSTRACT

One of the major challenges of the U.S. energy policy is to achieve greenhouse gases emissions reductions at low cost. Economists tend to prefer policies that effectively establish a price of emissions. This paper examines the impacts of carbon taxes that are equal to the social costs of carbon on the U.S. energy system in the long-term future under different assumptions on the potential of shale gas development and with respect to carbon capture and storage deployment.

The analysis shows how the mutual effects of substitution within both the supply and demand-side play an important role in constraining or enabling the penetration of shale gas into the energy mix. The study discusses multiple scenarios and helps guide policy making by identifying areas where, and the extent to which, climate policy can reinforce energy objectives in the U.S.

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1. Introduction

The Obama Administration has proposed an ambitious national goal for managing CO_2 and other greenhouse gases (GHG) emissions, calling for these emissions to be reduced 80% by 2050. This CO_2 emissions reduction target is alternately defined as an 83% reduction from of 2005 levels (or an 80% reduction below 1990 levels) [1,2]. In addition, President Obama's Climate Action Plan, released on June 25, 2013, looks to reduce GHG emissions and provides steps to implement it. Importantly, the President is committing the U.S. to meet its target of reducing GHG by 17% below 2005 levels by 2020 [3]. CO_2 emissions reduction at power plants is the focus of a climate-change plan that will also involve new federal funds to advance renewable energy technology and new regulations by the U.S. Environmental Protection Agency (EPA). EPA and other U.S. federal agencies use the social cost of carbon (SCC) to estimate the climate benefits of rulemakings. The SCC is an estimate of the economic damages associated with a small increase in CO_2 emissions and represents the value of damages avoided for a small emission reduction or the benefit of a CO_2 reduction. The SCC is a comprehensive estimate of climate change damages and includes changes in net agricultural productivity, human health, and property damages from increased flood risk. However, given current modelling and data limitations, it does not include all possible damages [4,5].

To achieve reductions in GHG emissions at low cost, economists tend to prefer policies that effectively establish a price of emissions, in the form of either carbon taxes or emission allowance prices under cap and trade. Many analysts suggest that a carbon tax will produce the most efficient carbon reductions throughout the economy, as a uniform price on CO_2 emissions regardless of source of the emissions [6–11]. The objective of a tax on carbon is to set a price that reflects the "real" costs of emissions that account for the damages from global warming, including effects on agricultural productivity and human health, coastal inundation, and other changes [12]. This paper examines the impacts of the carbon taxes that are equal to SCC on the U.S. energy system in the long-term future under different assumptions on the shale gas development potential.

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Escalating natural gas prices in the early 2000s after deregulation offered new economic incentives to develop unconventional gas resources including shale gas [13]. Advances in the cost effectiveness of horizontal drilling, new mapping tools, and hydraulic fracturing technologies, enabled in part by investments in research and development from the Department of Energy and its national labs, have led to the dramatic increase in U.S. shale gas resources that can be economically recovered [14]. Despite these advancements, there are still major uncertainties related to the quantity of shale gas that is available and its implications on energy policy [13]. Given that knowledge of the shale gas resource size and its associated production cost are two key requirements for shale gas development, our scenario analysis reveals the way in which these and other variables interact with the energy system, and their impact on the distribution of gas, demand and prices.

A series of reports and papers have been recently released on the U.S. shale gas revolution and possible environmental challenges due to the extraction of shale gas [15–20]. However, there is lack of quantitative analyses of the potential impacts of shale gas based on energy system models with only few papers available in the peer-reviewed journals (see, for example, [21–26]). The paper aims to provide the analysis that shows how the mutual effects of substitution within both the supply and demand-side play an important role in constraining or enabling the penetration of shale gas into the energy mix under different scenarios.

Energy scenarios provide a framework for exploring future energy perspectives, including various combinations of technology options and their implications. Many scenarios in the literature illustrate how energy system development will affect the environment and describe energy futures that are compatible with sustainable development goals, such as improved energy efficiencies or the adoption of advanced energy supply technologies [24,27,28]. Some scenarios describe how environmental constraints affect energy system and new energy technologies deployment [29,30]. The approach, which makes use of the MARKAL energy system model, allows exploring future perspectives of the U.S. energy system if the shale gas boom is a long-term phenomenon through different scenarios in order to assist in understanding the complex behaviour of the energy system by identifying the key variables and the synergies and trade-off between them. The study discusses multiple scenarios and will help guide policy making by identifying areas, and the extent to which, climate policy can reinforce energy objectives in the U.S.

The remainder of this paper is structured as follows: the next section gives a brief overview on the methodology and scenarios definitions. The third and fourth sections presents modelling results. The last section discusses the results and also layouts some of the key conclusions.

2. Methodology and scenarios definitions

2.1. MARKAL and the EPA database

We use the MARK et AL location (MARKAL) energy system model that allows policy instruments to be examined quantitatively in a dynamic energy system context. MARKAL is a least-cost optimization bottom up linear programming energy systems model that determine the optimal fuels and technologies to achieve the lowest energy system cost while meeting the demands and constraints. The model has energy production, conversion and usage sub-modules. The user specifies energy demand and model distributes this demand to the lowest energy system cost over time. Energy sector capacities are result of capacity limits, constraints and various policy considerations [31–33].

In this paper we adopt a MARKAL nine regions database (EPAUS9r2012) representing the U.S. energy system by the nine U.S. Census divisions that was readily available [34,35]. The EPAUS9r2012 the implementation of existing policies and standards including the Clean Air Interstate Rule (CAIR), renewable portfolio standards (RPS) aggregated to each region from existing state RPS, and Corporate Average Fuel Economy (CAFE) standards [36]. We modify the original EPAUS9r2012 database according to the scenarios' objectives.

We use BASE (the EPAUS9r 2012's reference case scenario) as a base case. The EPA developed energy demand in BASE scenario for the entire forecast horizon (2005–2055) based on exogenous regional economic and demographic projections that are consistent with the Energy Information Administration's (EIA) Annual Energy Outlook 2012 (AEO 2012) [37]. The model satisfies these demands in each time period by using the existing capacity or by implementing new capacity for energy production and end-use technologies. These demands are set only for the base case, but are endogenously determined in alternate scenarios where the prices of energy services vary from the base case prices. For example, a scenario causing the cost of electricity generation to rise relative to the base case and, *ceteris paribus* electricity demand could decline relative to the base case. An increase in the electricity cost relative to the base case would also affect investment decisions. Over time, as the stock of equipment turns over, more efficient demand technologies may be chosen, tending to lower the cost of service, thus increasing service demand.

We generate two sets of scenarios – 7and High Gas Supply Cases. In the Base Gas Supply Case, natural gas supply curve was not changed. In the High Gas Supply Case, natural gas supply curve was modified and includes "shale boom" assumptions. The subsection below provides more details.

2.2. "Shale boom" and gas supply curve modification

Technological advancements are helping the U.S. to unlock major sources of natural gas trapped in dense rock, known as tight and shale gas, dramatically altering the energy landscape [38]. The best-known examples of shale gas plays are the Barnett in Texas, the Marcellus in eastern U.S. and tight gas plays prolific examples include the Bakken field [38]. Currently the EIA's estimate for Marcellus Shale gas is roughly a third of the total technically recoverable resources available in the entire country [39]. Although a survey of the Marcellus by the U.S. Geological Survey has raised doubts over the extent of gas reserves [40], the issue will not be resolved until more details on the survey methodology are released.

The outlook for U.S. gas production is highly dependent upon the production profile of individual wells over time, in addition to the drilling and operating costs. Every year, EIA re-estimates initial production (IP) rates and production decline curves, which determine estimated ultimate recovery (EUR) per well and total technically recoverable resources (TRR). A common measure of the long-term viability of U.S. natural gas is the remaining technically recoverable resource, consisting of proved reserves and unproved resources. Estimates of TRR are highly uncertain, especially in emerging plays. Early estimates tend to vary and shift significantly over time as new geological information from additional drilling activities and better management practices. TRR estimates used by EIA for each AEO (more than 900 MMBtu in the latest AEO report) are based on the latest available well production data [41].

However, TRR do not necessarily have an implication on projected natural gas production, which depends on economic assumptions and environmental constraints. Economically recoverable resources (ERR) are a subset of TRR that can be produced at a profit. The recoverability of shale gas resources depends greatly on technological improvement and, combined with the effects of variations in demand and prices, the line between economically recoverable and uneconomical shale gas resources is constantly shifting [28].

Thus, while there remains disagreement about the exact size of the shale resource base, the estimates of shale gas resources are increasing