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Efficient fuel conversion for power generation under distributed solar generation and carbon emission regulations

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ABSTRACT

A new framework allows one to examine how likely a traditional power producer is to switch to more efficient fuel under various relevant price risk factors. The results show that the carbon emission price and natural gas price stand out as the two most important determinants for an economically justifiable fuel conversion strategy. The impact of coal and electricity prices is less significant.

1. Introduction

Greenhouse gas emissions from the power sector are a cause for concern for both the developed and the developing countries. Power sector accounts for nearly one-third of the emissions in the United States, and forms a sizeable share of emissions for many other countries across the globe (Zhou et al., 2012). With the growing concern over global warming and the consequent tightening of emission regulations, there is increasing pressure for the power sector to transition to cleaner fuels. As for overall emission compliance control of emissions from the power sector is crucial.

Due to abundant supply and low cost, coal has historically been the preferred fuel for power plants in the United States. While improvements have been made in coal technology over the years, these improvements are not commensurate to the necessary carbon emission standards, thus triggering a pressing need for power plants to consider alternatives to coal, such as natural gas, wind energy, solar energy, and other renewable or clean energy sources. As seen in Fig. 1, natural gas usage for power production has steadily increased in the past 15 years, while coal has steadily declined. Natural gas is an attractive alternative to coal owing to lower capital costs, higher efficiency, better environmental characteristics and a continued outlook for low gas prices for the foreseeable future. Another alternative emerging is the utilization of photovoltaic devices by consumers for the purpose of solar power generation, as seen in Panel b. of Fig. 1. Solar power has shown an average year-on-year annual increase of almost 60% in the past 7 years, while wind power enjoys an average year-on-year growth of approximately 30%. In the past 7 year, wind power growth shows a declining trend, while solar power displays a sharp rise.

Solar power has several advantages over other forms of electricity generation, including matching peak output with peak demand, distributed scalability, and versatility. Since installations at consumer locations, whether industrial, commercial or household consumers, are possible, it reduces investment in production transmission and distribution from remote generators. Moreover, government incentives such as (i) net metering laws that allow on-grid end users to sell electricity back to the grid at retail prices, (ii) direct subsidies to end users to offset costs of photovoltaic equipment and installation charges, (iii) low interest loans for financing solar power systems and tax incentives; are also providing impetus to development and deployment of clean photovoltaic (PV) technologies. However, transition to clean energy resources is likely to face long lead times and uncertainty caused by the volatility in the price of electricity, coal, natural gas, carbon emissions, and indeed, photovoltaic devices.

While the existing literature analyzes the impact of most of these factors on the fuel-transition path for power plants, there are significant gaps from perspective of clean energy adoption. In particular, incentives like net metering have gained special importance in recent years for clean energy adoption. Rapid, sustained rates of installation of photovoltaic devices, as seen in Fig. 1, could become an important factor affecting the total output

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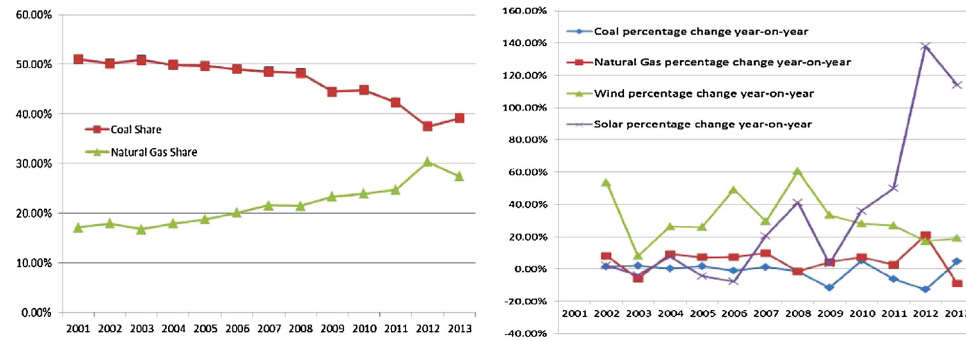

Fig. 1. Fuel usage for Power Production in the 14 years. Panel a: trends in usage of coal versus natural gas for power production in United States (2001–2013) (Source: EIA.gov). Panel b: Year-on-year change in fuel type usage for power production in the United States (2000–2013) (Source: EIA.gov).

of power plants. Adoption and successful implementation of any carbon policy makes it imperative to analyze the collective impact of all these factors and examine the rubric in which fuel transition for power plants should be guided.

In this paper, we analyze the dynamic transition of coal-based power production to natural gas-based power production, in presence of trends in solar power adoption by end users. The key question we investigate is, in presence of all the risk factors, to what extent does solar adoption by end users reduce or affect the need for power producers to migrate to cleaner energy. A comparative assessment of this fuel transition strategy is conducted in a dynamic fuel portfolio optimization framework. A long-term fuel transition strategy is examined under different carbon policies and clean energy adoption scenarios, and the relationship between fuel transition strategy and features of carbon policy are investigated.

We find that the most crucial risk factors in this analysis are the fuel prices, especially natural gas price, and carbon emission parameters. While renewable energy investment has some impact, in the range of plausible deployments it doesn't obviate efficient fuel transition. Therefore, for efficient fuel transition the degree of stringency of carbon allowance becomes truly significant, as does the presence of a market to trade carbon credit to lend some flexibility to power producers to respond to carbon controls.

Rest of the paper is organized as follows. Section 2 presents a brief review of relevant literature. Section 3 develops the models to construct the framework for evaluating fuel transition strategies, while in Section 4, we analyze fuel transition under different carbon policies and clean energy adoption. Results are presented and discussed for all the significant risk factors, and finally, Section 5 summarizes the key conclusions.

2. Literature review

The idea of improving or replacing an existing power plant with new technology to create a more economical and environment-friendly plant is not new. The advantages of repowering are attractive (Popov, 2011), for instance, in a conventional plant, the benefits of improving a steam turbine with a combination of steam and gas turbine is significant. On the other hand, aging facilities are retired under multiple considerations, including assessing the impact of retiring a local generation plant on the transmission network (Li, 2005).

There is a growing body of literature that focuses on the feasibility of de-carbonizing the power plants through carbon capture techniques. Chen et al. (2010) studied the introduction of carbon capture systems in power plants, where by examining the operations mechanism of a carbon capture system, a simplified bi-state operations pattern for the system is identified. The "flexibilities" of carbon capture system are taken as a series of "call options", evaluated using a real options approach. Zhang et al. (2009) conducted a life-cycle analysis of fossil-fuel fired power plants with carbon capture systems, identifying important gaps in parts of the supply chain, alternative technologies and potentially important impact categories. The limitation of carbon capture systems is that these systems are not economically viable yet for large scale adoption. Recent EPA rules regulating greenhouse gas emission from new power plants are tilting the balance against coal-fired plants, which will further obviate deployment of carbon capture systems.

After the deregulation of electricity markets, researchers have worked on mutual-incentive mechanism between emission policy and fuel efficiency, and carbon trading and its related investment decisions have also emerged (Laurikka and Koljonen, 2006). Portfolio analysis of power generation under carbon emission constraints have been considered in the literature. Doherty et al. (2005) analyzed how the generation portfolio in the all-Ireland system may evolve by 2020 under the emission constraint and fuel price uncertainty. A limitation of this study was its focus on a static portfolio analysis. Choi et al. (2007) used linear programming techniques to analyze the best generation mix achievable under constraints on fuel, load growth, reliability, air pollution, and cost minimization. While researchers have investigated the long-term self-scheduling of fuel for power generation under uncertainty (Kazempour et al., 2009; Kim et al., 2009; Fortes et al., 2008; Vithayasrichareon et al., 2009; Catalao et al., 2007), the scope has been limited with the carbon trading variable only serving as a constraint instead of being part of the objective. Moreover, tactical simulation of optimal technology transition process for a power plant towards cleaner fuels has also been missing in the existing literature.

Policy implications of the transition of power plants to cleaner alternatives have been investigated using rigorous mathematical models. Santhoshkumar and Lakshmi (2012) proposed a multi-objective formulation to handle the generation scheduling problem with conflicting profit maximization and emission control objectives. The pricing and allocation rules in each market effectively motivate generator to mitigate its emission while maximizing its profit. Yogyong (2011) proposed the concept of fuel optimization for a power plant meeting both generator constraints and fuel resource constraints using a genetic algorithm. A key objective of this allocation is the efficient use of fuel, while maintaining the ability to serve all load demand and have enough spinning reserve to provide acceptable security buffers.

In incorporating the impact of carbon policies on power production, Yang et al. (2008) used a real options approach for analyzing the effects of governmental climate policy uncertainty on private investors' decision-making in the power sector. Chappin and Dijkema (2009) investigated the long-term fuel portfolio shift of power generators under carbon credits trading, and concluded