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Quantifying the value of investing in distributed natural gas and renewable electricity systems as complements: Applications of discounted cash flow and real options analysis with stochastic inputs

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HIGHLIGHTS

- Natural gas and renewable electricity can be viewed as complements.
- We model hybrid natural gas and renewable electricity systems at the hourly level.
- We incorporate variable renewable power output and uncertain natural gas prices.
- Hybrid natural gas and renewable electricity systems can be valuable investments.

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ABSTRACT

One energy policy objective in the United States is to promote the adoption of technologies that provide consumers with stable, secure, and clean energy. Recent work provides anecdotal evidence of natural gas (NG) and renewable electricity (RE) synergies in the power sector, however few studies quantify the value of investing in NG and RE systems together as complements. This paper uses discounted cash flow analysis and real options analysis to value hybrid NG-RE systems in distributed applications, focusing on residential and commercial projects assumed to be located in the states of New York and Texas. Technology performance and operational risk profiles are modeled at the hourly level to capture variable RE output and NG prices are modeled stochastically as geometric Ornstein-Uhlenbeck (OU) stochastic processes to capture NG price uncertainty. The findings consistently suggest that NG-RE hybrid distributed systems are more favorable investments in the applications studied relative to their single-technology alternatives when incentives for renewables are available. In some cases, NG-only systems are the favorable investments. Understanding the value of investing in NG-RE hybrid systems provides insights into one avenue towards reducing greenhouse gas emissions, given the important role of NG and RE in the power sector.

1. Introduction

Although natural gas (NG) and renewable electricity (RE) have traditionally competed for market share in the United States power sector, there is growing potential for the two to be used synergistically as complements. Both NG and RE benefit from abundant domestic resource bases, and for electricity generation, they exhibit different but complementary cost and operational risk profiles. Power from RE technologies hedges fuel price risk that is introduced by NG-fired generation given its zero fuel costs (and thus low and stable operation and maintenance (O&M) costs), but it requires higher upfront capital expenses. On the other hand, NG-fired generation requires lower capital costs and has the ability to rapidly ramp output in response to variable output from some RE sources, particularly solar and wind. The alignment of NG and variable RE (VRE) operational and cost profiles suggests that NG and VRE have potential to work as complements as opposed to competitors.

While recent work provides anecdotal evidence of NG-RE synergies in the power sector (e.g., see Lee et al. (2012) and Cochran et al. (2014)), few studies in the literature quantify the value

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proposition of project-level end-use applications comprised of both NG and RE. Some analyze the complementary nature of NG and RE at the grid level, take a portfolio optimization approach to analyze an electricity portfolio, or analyze single-technology distributed generation applications, but to our knowledge, these studies do not examine project-level case studies that consider the use of both RE and NG in harmony. The purpose of this paper is to fill this gap by quantifying the value of investing in hybrid NG-VRE relative to their single technology alternatives or business-as-usual in distributed applications. We focus on stand-alone configurations for single homes and critical services buildings composed of NG microturbines and solar photovoltaics (PV), two technologies that are commercially available today and which have sufficient public data to enable valuation of these systems while also allowing hourly operations to be modeled. We implement two different methodologies, traditional discounted cash flow (DCF) and real options analysis (ROA) frameworks. This provides robustness to the findings, showing that the conclusions are constant despite which method is used. It also provides insight about the implications of fuel price volatility and electricity rate structure for valuation. Lastly, we focus on project economics in New York and Texas, two states that offer comparative investment conditions given their distinct energy resource bases, market conditions, and climates.

The remaining of this paper is organized as follows. Section 2 provides motivation for our choice of applying both DCF and ROA methodologies. Section 3 summarizes existing research in this area and highlights the gaps in the literature that we hope to narrow. Section 4 identifies cash inflows and outflows for DG systems and describes how DCF and ROA are applied. Section 5 details the natural gas price modeling methodology, as it is the main source of uncertainty captured in this analysis and is characterized by a stochastic process. The business case designs and assumptions are provided in Section 6, and Section 7 summarizes results. The paper concludes in Section 8 with an overview of policy implications and areas ripe for future research.

2. Methodology overview

From the consumer's perspective, or the system owner end-user's perspective, investment decisions concerning distributed generation (DG) units theoretically involve some assessment of uncertainty in electricity and fuel prices. The former are considered relatively fixed for utility customers (either through standard or time-of-use (TOU) rate structures), but the latter introduce significant uncertainty, which has implications when considering cash flows from energy investments. While DCF analysis provides tractable and easily interpretable investment decision-making support, it ignores characteristics inherent to power generation investments, namely uncertainty and irreversibility, and it assumes that the underlying conditions are stationary and definite throughout project life.[1]

This can be a costly assumption when cash flows are actually uncertain, which is the case for many energy investments. The value of power generation technologies is a function of the system's expected lifetime, investment costs, financing structure, and discounted cash flows, the last of which comprises several underlying uncertain and often volatile system attributes related to operations and output, the price of fuel, technological efficiency, technology costs, and the price of electricity. Traditional DCF assumes predefined and constant discount rates even though risk varies depending on technology, performance, and the other aforementioned risks.[2] Uncertainty in DCF can be handled in a risk-adjusted discount rate, but this is still a static treatment of uncertainty that does not account for the dynamic variation of cash flow risk through time.

On the other hand, more advanced methodologies have been developed to account for uncertainty, such as probabilistic DCF as well as DCF within a portfolio of scenarios. Rather than taking this approach, we focus on modeling the uncertainty of input prices (stochastic NG prices and the hourly variability of RE output) given their implications for the relative risk profiles of NG and RE, which are then projected into DCF over time and expressed in NPV terms. This allows us to capture the complementary risk profiles of NG and RE at the hourly level in our valuations.

An alternative valuation tool to overcome some of the limitations of DCF is the stochastic modeling approach of Real Options Analysis (ROA), which incorporates uncertainty directly into the investment model. Options analysis originated in the field of finance (Myers, 1984) and has been developed for use of management and budgeting decisions since the early 1990s (Dixit and Pindyck, 1994; Trigeorgis, 1996; Copeland and Antikarov, 2001).

The intuition behind ROA is this: having options allows for gains on the upside of uncertainty and reductions on downside potential. Thus, the ability to make decisions in reaction to risk skews the distribution of possible outcomes towards the upside, increasing the overall value of the project. When investments are characterized by uncertainty and irreversibility, the traditional NPV rule can be wrong (Pindyck, 2008) and valuation grounded in pricing options is sometimes viewed as superior (Dixit and Pindyck, 1994; Sick, 1995; Trigeorgis, 1996; and Abadie and Chamorro, 2009). Ultimately, ROA allows for better treatment of volatility relative to DCF so that the extent of uncertainty and its implications are not underestimated.

Energy investments are particularly suitable for ROA, exhibiting unique characteristics that distinguish them from many other investments. First, they are at least partially (if not completely) irreversible. Second, they are subject to significant uncertainty as they face price volatility, technological change, and policy and regulatory uncertainty, and ROA explicitly reflects the impact of volatile input prices on investments. Power generation investments face many sources of risk that change throughout time, and assets consisting of both NG and RE technologies add even more uncertainty to the investment decision relative to single-technology assets since both fuel price volatility and RE output variability impact returns. In general, when uncertainty is high, there is greater value in the option to invest, and thus there is a greater incentive to keep options open (Pindyck, 2008).

Any decision that involves sunk costs can be viewed in a ROA framework, such as opening or closing a mine, installing scrubbers on a coal-burning power plant, or signing a long-term fuel contract. When the “investor” is a homeowner or firm considering distributed energy solutions, one can imagine ROA applications in the context of having the option to invest in a DG project beyond a business-as-usual (BAU) case of purchasing electricity and NG from local utilities. This “option to expand” is the case explored here, as it is possible to wait for more information before exercising the option since there exists an opportunity cost associated with investing now rather than waiting.

This paper focuses on the option to expand given *a priori* that the investment decision-maker is considering a DG system relative to BAU, implementing both a traditional DCF analysis and a ROA

[1] This is only one construct of DCF, however. One could project variable prices (as we do in this analysis) into DCF over time and then express this in NPV terms.

[2] It is important to note that although DCF techniques assume constant discount rates, the net present value method can easily accommodate the term structure of interest, which makes it an advantage over the internal rate of return method.