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Transition to sustainability with natural gas from fracking

Kangqian Wu *, Gokulram Paranjothi, Jana B. Milford, Frank Kreith

Department of Mechanical Engineering, University of Colorado Boulder, Boulder, CO 80309, United States

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A B S T R A C T

This paper analyzes the energy requirements and cost of constructing a renewable energy system with the excess energy available from natural gas obtained by hydraulic fracturing. Using U.S. Energy Information Administration estimates of the future availability of natural gas and estimates from the literature of the energy required to build a wind power and photovoltaic (PV) electricity generation system, we develop a scenario for constructing a sustainable electricity system for the United States. A preliminary analysis is made of the cost of the renewable system. Net reductions in emissions of greenhouse gases and oxides of nitrogen are also estimated. The analysis suggests that it would be possible to build a sustainable electricity system from the excess natural gas from fracking in less than 30 years. After that, the energy produced from the renewable system is sufficient to replace obsolete equipment and construct new generation technology as required by growth in demand. Even after accounting for the emissions associated with its construction and operation, the sustainable system would reduce greenhouse gas (GHG) and nitrogen oxides emissions compared to continued use of a fossil fuel system.

Introduction

The impacts of anthropogenic greenhouse gas emissions on the earth's climate are of growing concern. Fossil fuel combustion in the electric power sector accounted for 31% of U.S. greenhouse gas emissions in 2013 [1]. In addition, emissions of sulfur and nitrogen oxides and other pollutants from fossil fuel burning cause health and environmental damage on local to regional scales. These problems have grown especially acute in developing countries such as China and India.

According to the U.S. Energy Information Administration, after 2008 the wide application of horizontal drilling and hydraulic fracturing (fracking) significantly increased the proven oil and natural gas reserves in U.S. shale formations. From 2008 to 2014, natural gas production increased from 20 trillion cubic feet to 26 trillion cubic feet, mostly as a result of horizontal drilling in tight formations that were previously inaccessible [2]. Fracked natural gas is an unexpected new energy source. But it is still a fossil fuel. To speed the transition to sustainable energy, we consider whether this resource could be used to build renewable systems to replace traditional fossil fired power plants. The major assumption underlying the analysis is that natural gas can replace all forms of energy that are used in manufacturing and building wind and solar PV plants.

Wind and PV are the fastest growing renewable technologies. The cost of the electricity from these sources is close to that from fossil fuel plants. But wind and solar vary with time and location. This is perceived as a major problem in employing these abundant resources. But on average, wind blows more at night when solar is not available. Thus, a combined wind and PV system with hydro storage could provide a relatively stable electricity source. According to Short and Diakov [3], 83% of the total U.S. electricity demand can be provided by a combination of wind and solar PV with about 40 GW of hydro storage. Other recent studies have examined prospects for a high percentage of renewable electricity worldwide. Edenhofer et al. [4] explored the possibility of achieving high levels of renewable electricity penetration and found that government policy, the declining cost of many RE technologies, changes in the prices of fossil fuels and other factors have supported the continuing increase in the use of RE. Cochran et al. [5] provided a meta-analysis of several recent analytical studies that evaluate the possibility, operability, and implications of high levels of renewable sources of electricity in the power system. Mai et al. conducted the Renewable Electricity Futures study for the National Renewable Energy Laboratory [6], which examined the implications and challenges of renewable electricity generation levels (from 30% up to 90) in 2050. Aitken [7] argued that policies now in existence, and economic experience gained by many countries to date, should be sufficient stimulation for governments to adopt aggressive long-term actions that can accelerate the widespread applications of renewable energy, and to get on a firm path toward a worldwide "renewable energy transition". The World Economic

* Corresponding author at: 431 Wright St. Unit 204, Lakewood, CO 80228, United States. Tel.: +1 720 369 0658.

E-mail address: kangqianwu@gmail.com (K. Wu).

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Forum's Energy Vision 2013 [8], provided a framework for understanding the potential for changed in the energy mix. It looked at how energy transitions have unfolded in the past and the factors that brought about these transitions.

This study complements the prior work by focusing on the energy requirements for such a transition in the U.S. The analysis in this paper shows that over a period of 30 years, the available natural gas energy from fracking could be used to build a wind, water, and solar PV (WWS) system that provides 83% of U.S. electricity demand with the optimal ratio of wind to PV capacity. We assumed the remaining 17% of demand would have to be met by energy conservation or dispatchable electricity generators such as solar thermal or geothermal energy.

Although transition to a renewable electricity system is expected to provide environmental benefits relative to continued reliance on fossil fuels, production of natural gas made economically viable through hydraulic fracturing has raised environmental concerns. These concerns include, but are not limited to, methane contamination of drinking water, spills of toxic drilling fluids, and flow back of produced water with natural salts, heavy metals, hydrocarbons and radioactive materials [9,10]. There have also been concerns that in some areas, hydraulic fracturing or associated water reinjection can stimulate earthquakes [10,11]. Earthquakes linked to the hydraulic fracturing process itself have been below the threshold associated with structural damage; however, larger earthquakes have apparently been caused by disposal of oil and gas-associated wastewater in deep strata or basement formations [12]. Furthermore, the U.S. Environmental Protection Agency estimates that natural gas and petroleum production account for approximately 30% of U.S. emissions of methane, a potent greenhouse gas [1]. Natural gas production operations also release volatile organic compounds and oxides of nitrogen, which contribute to ground-level ozone formation, and hazardous air pollutants such as benzene and formaldehyde [13].

However, most of the adverse environmental impacts of unconventional gas production can be mitigated through careful engineering, operations, and regulatory oversight [9]. This includes induced earthquake risk, which could be reduced by careful monitoring for low-level seismic activity with changes in wastewater injection volumes or pressures mandated if set thresholds are exceeded [12]. Nevertheless, the tradeoffs involved in using unconventional natural gas to provide energy for a transition to a renewable electricity system warrant careful consideration. To begin to examine these tradeoffs, we estimate net greenhouse gas and nitrogen oxides emissions associated with the scenario of using fracked natural gas to build out the WWS system.

Methods

Energy analysis

The Energy Return On Energy Invested (EROI) method is widely used in large-scale energy analysis. EROI is defined as the net energy output during the lifetime of the system (E_{out}) divided by the energy required to build, operate, and decommission the system (i.e., energy investment E_{inv}) [14]. For a power plant, E_{out} is equal to the product of the plant capacity (Ca), the capacity factor (CF) and the system lifetime (L). Thus, the EROI for wind and PV are:

$$\mathrm{EROI}_{wind} = \frac{\mathrm{Ca}_{wind}(t) \times \mathrm{CF}_{wind} \times L_{wind}}{E_{inv,wind}(t)} \tag{1}$$

$$\mathrm{EROI}_{PV} = \frac{\mathrm{Ca}_{PV}(t) \times \mathrm{CF}_{PV} \times L_{PV}}{E_{inv,PV}(t)} \tag{2}$$

where Ca(t) is the capacity built in year t and $E_{inv}(t)$ is the energy invested to build sustainable systems in year t. Values of EROI, Ca, and L for wind and PV are available from the literature [15–26].

Short and Diakov developed a linear optimization model to design a WWS system that meets all the U.S. load demands while minimizing the energy from dispatchable resources and the curtailed energy from renewable resources [3]. According to their model, the optimal ratio of wind and PV generation to meet the electricity demand is:

$$\frac{\mathrm{Ca}_{wind}(t)}{\mathrm{Ca}_{PV}(t)} = \frac{100}{71} \tag{3}$$

For this analysis, we assumed that all the available fracking natural gas in year t, $E_{ava}(t)$, is used to provide energy for construction of wind and PV plants,

$$E_{inv,wind}(t) + E_{inv,PV}(t) = E_{ava}(t) \tag{4}$$

until 83% of the electricity demand is met. Using Eqs. (1)–(4), wind and PV capacity built in year t can be calculated. We further assumed the plants' construction period is one year. Then the electricity generated in year (t + 1), $E_{ele}(t+1)$, from all the plants built in year t is:

$$E_{ele}(t+1) = \mathrm{Ca}_{wind}(t) \times \mathrm{CF}_{wind} + \mathrm{Ca}_{PV}(t) \times \mathrm{CF}_{PV} \tag{5}$$

After 83% of the electricity demand is met, energy is only needed to meet the sum of increased electricity demand and the replacement of the wind and PV systems that have reached their useful life. Hence, the newly increased demand $A(t)$ is:

$$A(t) = E_{demand}(t+1) - E_{ele}(t) \tag{6}$$

where E_{demand} is obtained from the U.S. Energy Information Administration (EIA) [27].

As some renewable plants reach their lifetime ($t > L$), the electricity generated by these plants in a given year, $B(t)$, is:

$$B(t) = \mathrm{Ca}_{wind}(t - L_{wind}) \times \mathrm{CF}_{wind} + \mathrm{Ca}_{PV}(t - L_{PV}) \times \mathrm{CF}_{PV} \tag{7}$$

while the capacity that needs to be built is:

$$\mathrm{Ca}_{wind}(t) \times \mathrm{CF}_{wind} + \mathrm{Ca}_{PV}(t) \times \mathrm{CF}_{PV} = A(t) + B(t) \tag{8}$$

Using Eqs. (3) and (8), we can calculate wind and PV capacity built in year t after 83% of the U.S. electricity demand is matched. To calculate the electricity generation, the capacity factors for wind and PV were assumed to be 35% and 25%, respectively. The lifetime of both wind and solar systems was assumed to be 25 years. The equations above were implemented in Microsoft Excel to calculate energy requirements and output.

According to EIA's Energy Outlook 2013 [27], the annual growth rate of fracked natural gas production is expected to be 2.64% for the next 30 years. Since all the natural gas currently produced is under contract to be sold, we assumed that only the difference between future production and current production can be used for the construction of the sustainable energy system. Using 2013 as the base year, the natural gas energy available for construction in year t (Fig. 1) is the production of natural gas from fracking in year t minus that in year 2013.

The EROI method was used in this paper to calculate the energy output during the plants' lifetime. Tables 1 and 2 show EROIs of wind and PV from the literature. The results of any EROI analyses depend on the assumptions used by the investigators. Different assumptions, such as the lifetime of the system, will lead to a difference in the energy output of a sustainable energy system. To compare EROI values, it is necessary to standardize the original values to similar operating parameters and boundary conditions [28]. The Standardized EROI columns in Tables 1 and 2 show the results of standardization. For the analysis in this paper, the average EROI