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Cost-benefit analysis of grid-connected wind–biogas hybrid energy production, by turbine capacity and site

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The impacts of a recently launched community feed-in tariff (COMFIT) scheme on renewable energy production, with energy prices differentiated by renewable energy technology type, have not been adequately understood. The knowledge gap is addressed by applying the Hybrid Optimization Model for Electric Renewables (HOMER) decision tool to investigate the economic feasibility and effects of selected energy policy schemes on wind–biogas hybrid energy production, by taking into consideration geographic location (Greenwood, Sydney, Caribou Point), and wind turbine capacity (including 20, 35, and 50 kW). The biogas energy production component reflected a representative Nova Scotia, Canada dairy farm with 100 cows. Wind–biogas hybrid energy systems were generally not economically feasible without COMFIT scheme financial incentives. Locating the hybrid energy system one km away from a utility grid increased cost of energy produced by about $0.06 per kWh. Under current government COMFIT scheme with guaranteed energy prices, economic feasibility improved relative to a base scenario, with NPV per kWh increasing from -$0.51 to $0.83 for a system with the 50 kW turbine at Caribou Point, compared with -$0.51 to -$0.14 for a similar 50 kW turbine at Sydney. Wind–biogas power production was economically viable under COMFIT scheme prices only for Caribou Point.

1. Introduction

Power intermittency and the associated uncertainty in electricity availability are major drawbacks to wind energy production [1,2]. Options for addressing such complications with wind power variability include grid-connection to smoothen fluctuations in wind power production [3], storage of wind energy produced for use during peak demand [4,5], and wind-hybrid systems with other energy sources (e.g., biogas, hydro, and photovoltaic systems) [6–8]. Grid distance from the wind energy source, and alignment of the energy produced with utility company transmission and power distribution networks can complicate using the utility grid as a storage option [9]. Battery storage systems, on the other hand, are particularly useful for stand-alone wind power systems, and have been piloted for rural and remote urban residential areas in some regions of the world [10,11]. However, current storage technologies have limited cost-efficiency [12], typically require frequent (re) charging, and tend to be oversized [13]. In addition, frequent charging and discharging tend to reduce the useful life of storage batteries [14]. Furthermore, the high initial capital cost of storage components substantially reduces cost-efficiency of the resulting wind power system [12,15].

Wind hybrid power systems can be grid-connected and/or linked to a battery storage system. However, the design and capacity of the resulting hybrid systems are influenced by technical or engineering factors such as size of the hybrid system components [16], electricity load requirements [17], and site-specific characteristics [12], as well as economic factors such as cost of system components [13], relative prices of energy types, and incentive schemes [18]. Studies have investigated the optimal sizing of hybrid systems by taking into account alternative combinations of hybrid component sizes [19], and alternative wind turbine capacities to meet given energy load requirements [20]. In general, the studies suggest that technical and economic factors, and overall economic viability differ according to geographic location. Potential power production and energy cost are also influenced by wind turbine capacity, energy storage options and capacity, distance of energy source from utility grid, and overall system efficiency linked to

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location-specific meteorological conditions. Nandi and Ghosh [8], for example, reported in a study for Bangladesh that beyond 10 km from a grid, on-site battery storage systems had lower cost of energy produced than a grid-connected system.

In a recent study of the economic feasibility of on-farm biogas energy production in Nova Scotia (NS), Canada, Brown et al. reported that livestock farm size substantially constrained financial viability mainly because of limited biomass feedstock (i.e., manure) from the representative dairy farm sizes considered [21]. As with other farming regions in Canada, availability of livestock manure for biogas energy production varies across agricultural regions in the province. Thus, site selection can be critical to optimizing power production from wind–biomass hybrid energy systems. Various studies have investigated the economics of wind and biogas systems [22–26]. Crawford [24], for example, reported that wind turbines with a rated capacity of 850 kW generated 4036 kWh m^{-2} of energy, compared with an alternative turbine with 3000 kW rated capacity which generated 4675 kWh m^{-2}. On the other hand, Amr et al. [25] reported that larger turbines with low rated wind speeds at selected sites in Jordan reduced overall cost of energy produced. As with wind energy, Walla and Schneeberger [27] found that the average cost of producing electricity decreased with increasing biogas digester size. Other factors that affect the cost of biogas/wind energy production include initial capital cost, electricity price [15], and economic incentives [23,28].

The provincial government of NS (Canada) is encouraging renewable energy production under its feed-in tariff (FIT) and community feed-in tariff (COMFIT) programs, to meet renewable energy targets of 25% by 2015, and 40% by 2020 [29]. Various NS government initiatives have been designed to encourage participation in renewable energy projects. Net metering, for example, allows power producers to generate eligible renewable energy for own use. However, such projects are currently limited to wind turbines with capacity to meet power consumption of up to 1.0 MW.

Technologies such as wind, small scale in-stream tidal, combined heat and power from biomass, and run of the river hydroelectricity are currently eligible under the COMFIT scheme. Under current regulations, wind turbines with a rated capacity of less (greater) than 50 kW are guaranteed a retail price of $0.499 ($0.131) per kWh of electricity produced [30]. The guaranteed price is for a 20-year contract under which Nova Scotia Power Incorporated (NSP Inc.) will purchase all such "green" electricity produced. However, to produce wind energy under the COMFIT scheme, participants (who may or may not be farmers) must be members of an established cooperative with a minimum of 25 members. As with wind energy, the current guaranteed price offered for electricity produced from biomass through combined heat and power (CHP) operation is $0.175 per kWh. Participation in these schemes also requires connection to the NSP Inc. utility grid.

Electricity use constitutes a substantial proportion of production cost on farms. Thus, development of on-farm wind–biogas energy systems has the potential to enhance power supply in agricultural regions of Atlantic Canada, where power distribution from conventional grid-connected power utilities often poses problems [23]. For example, utility and fuel expenses in NS, together, accounted for about 11% of total farm operating cost in 2009 [31]. In a study for the US, Potter reported that electricity cost accounted for almost half of total farm cash production costs [32]. In addition, recent studies for NS reported that dairy farmers are seeking economically viable renewable energy options not only to meet on-farm energy requirements [33], but also as part of strategies to manage environmental problems from livestock manure produced [23].

Under existing Nova Scotia government renewable energy policies and guidelines, individuals and community groups can establish small capacity wind turbines (or other eligible small renewable electricity sources) to generate power for own electricity consumption, or for sale to the electricity grid. Under a previous provincial net metering system referred to as the "all or nothing" net metering system in this study, customers could produce electricity (of 100 kW or less) from eligible renewable sources (e.g., wind power), while also being able to draw power from the grid of NSP Inc. to meet power shortfalls. Any unused or surplus power was fed to the grid, and producers did not receive payments from such electricity fed to the grid (although they could receive a credit up to the value of power consumed). In 2011, the Nova Scotia Utility and Review Board (NSURB) approved an enhanced net metering system under which qualified power producers receive a credit payment for all power produced (up to 1 MW) from eligible renewable energy sources (e.g., wind). Producers are paid for any surplus power produced (beyond the producer's power consumption needs) on a yearly basis [34].

The purpose of this study was to assess the economic performance of a grid-connected wind–biogas hybrid energy system at the farm level, for a fixed size biogas digester and varying capacity of the wind energy component. A wind–biogas hybrid energy system allows for increased renewable energy production, while also enabling farmers to reduce negative externalities associated with excess livestock manure. The wind–biogas hybrid system considered in this study is a proposed innovation, with potential to address inherent limitations of the two power systems noted earlier. Although power production from stand-alone wind energy systems is eligible under existing COMFIT scheme in NS, energy produced by using biogas and biogas-based hybrid power systems (e.g., biogas-wind hybrid energy system) are currently not eligible. Given that livestock manure to feed the biogas digester is constrained by dairy farm size in NS thereby limiting the amount of power produced by a representative farm, the farm-based biogas energy component investigated was coupled with a wind energy component. The resulting wind–biogas hybrid system will have the potential to produce sufficient electricity to meet on-farm energy demand of an average or representative NS dairy farm, as well as help improve economic viability of the biogas-wind hybrid energy system by taking advantage of COMFIT wind energy rates.

The first objective was to assess the economic viability of a grid-connected wind–biogas hybrid system required to meet the on-farm energy requirements of a representative 100-cow dairy operation in NS, with annual electricity consumption requirements of 77,375 kWh. The analysis took into consideration varying wind turbine capacities (i.e., 25 kW, 35 kW, and 50 kW), in combination with the biogas energy production. In an initial or base scenario, the analysis considered a stand-alone hybrid energy system, without a limit on level of (potential) production. In addition, the analysis was extended to address potential power intermittency problems by considering connection of the micropower systems to a utility grid. The second objective was to analyze the effect of COMFIT scheme policies on the economic feasibility of the grid-connected wind–biogas hybrid system. Since biogas energy is not an eligible renewable energy technology for the existing COMFIT scheme in NS, it was assumed that all electricity produced from biogas digestion was used on-farm, while electricity produced from the wind power component can be sold to the utility company. A sensitivity analysis focused on the wind power component of the wind–biogas hybrid system, with three wind turbine power ratings (i.e., 25 kW, 35 kW, and 50 kW). The analysis then investigated the effects of: (i) changes in COMFIT rates per kWh (i.e., $0.20, $0.30, $0.499, and $0.60); and (ii) varying distance of the utility grid from source of the wind turbines (i.e., 0.25 km, 0.5 km, 0.75 km, and 1 km). To allow for tractability in the sensitivity analyses, the biogas component of the wind–biogas hybrid system was fixed in all