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A Levelized Cost of Energy (LCOE) model for wind farms that include Power Purchase Agreements (PPAs)

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ABSTRACT

The Cost of Energy is a major concern for the electric power industry. Customers are sensitive to the cost of renewable energy, which is typically more expensive than conventional energy generation due to the variability and uncertainty associated with their sources. Power Purchase Agreements (PPAs) are developed to balance the energy price and associated risks with poewr gerneation and transmission. The energy delivery limits imposed by current PPAs impact the Levelized Cost of Energy (LCOE) in ways that are not accomodated by existing LCOE models. In this work, a new cost model is developed to evaluate the LCOE from a wind power source under a PPA contract. The application of the model to real wind farms demonstrates that the actual LCOE depends on the defined minimum/maximum energy purchase limitations within a PPA contract. The developed cost model can be used as a basis for setting appropriate PPA terms, such as a price schedule and performance metrics. Hence, it can help the Seller to negotiate penalties and energy price within their PPAs.

1. Introduction

Cost of Energy (*COE*) becomes a major concern for the public and utilities as the demand for power from renewable energy sources, such as wind, increases. Utilities may become reluctant to purchase more renewable energy than they are required to purchase if the *COE* is too high. *COE* is the actual cost to buy energy while Levelized Cost of Energy (LCOE) is the break-even cost to generate the energy. The LCOE is a commonly accepted calculation of the Total Life-Cycle Cost (*TLCC*) for each unit of energy produced in the lifetime of a project [1].

In addition to the increase in the use of renewable energy sources, there is an increase in the use of Power Purchase Agreements (PPAs) for all sources of energy. PPAs are Performance-Based Contracts (PBCs) that aim to create a “fair” and risk-controlled agreement for the purchase and sale of energy between a utility (the Buyer) and a generator (the Seller). The use of PPAs has been increasing around the world and they are commonly used in Europe, the U.S., and in Latin America. In Germany alone, wind projects with PPAs totaled over 1.2 GW in capacity in 2013 [2]. Berkeley Lab produced a dataset with a total of 34,558 MW of capacity in 387 signed or planned PPAs in the U.S. for 2016–2017 [3]. Between 2008 and 2016, 650 MW of new capacity was signed in the U.S. and in 2015 the use of PPAs in the U.S. grew up to 1.6 GW [4]. Unlike the U.S. or Europe, in Latin America the national governments typically award PPAs to energy generators. In 2014, the government of Peru awarded PPAs to projects with a total of 232 MW of capacity [5]. Within the U.S., PPAs have gained more prominence as State governments set Renewable Portfolio Standards (RPS). RPS laws mandate the level of renewable energy that a State is required to consume. Utilities must then purchase renewable energy at the levels required by the RPS [6]. Because renewable energy is typically more expensive than gas or coal (at the current time in the U.S.), utilities will utilize a maximum energy purchase limit, so they do not have to purchase more of the expensive renewable energy than required. In other parts of the world, minimum energy purchase limits may be preferred to maximum limits due to energy policies, as is the case in some Latin American countries. Government policies shape the preferences by using a minimum, maximum, minimum and maximum, or no energy purchase limitation in PPAs. Even within regions, such as Europe or Latin America, because each country has different energy or environmental policies, energy purchase limitation preferences vary.

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Nomenclature

CBI	Capacity-based incentive
CF	Capacity factor
CfD	Contract-for-Differences
COE	Cost of Energy
CPE	Cost to produce energy
CRF	Capital recovery factor
D	Depreciation
E	Quantity of generated energy
EIA	U.S. Energy Information Administration
F	Fuel cost
I	Initial investment
IBI	Investment-based incentive
ITC	Investment tax credit
LCOE	Levelized Cost of Energy
Max_{lim}	Threshold for maximum energy delivery penalty (fraction)
Min_{lim}	Threshold for minimum energy delivery penalty (fraction)
n	Number of years the LCOE applies
N	Number of turbines in the wind farm
NREL	National Renewable Energy Laboratory
O&M	Operation and maintenance
OM	Operation and maintenance cost
OREC	Offshore Renewable Energy Credit
P_{exp}	Annual expected power production
PPA_{term}	Fraction of the *COE* paid for energy above the maximum energy delivery limit
PBC	Performance-based contract
PBI	Production-based incentive
Pen	Total penalty cost
PL	Production loss
PN	Minimum penalty cost
PPA	Power Purchase Agreement
PTC	Production tax credit
PVOM	Present value of operation and maintenance costs
r	Weighted average cost of capital (discount rate)
R	Royalties or land rents
RP	Rated power
SAM	System Advisor Model
T	Tax levy
TC	Tax credit
TLCC	Total life-cycle cost

However, the basic concept of a PPA does not change between countries.

PPAs use an LCOE models to determine a fair price of energy, similar to a standard retail energy contract. However, Buyers in a PPA can create terms that limit the annual purchase of energy, thereby affecting the actual LCOE. Buyers can create a limit for the minimum annual amount of energy that needs to be delivered and/or a maximum amount that energy will be bought at full price. The PPA contract limits create penalties; a penalty is incurred when the Seller does not fall within the energy delivery requirements. In a normal energy contract (such as a standard retail contract, a market retail contract, and in a PPA), the LCOE is calculated over the period of the contract and energy is purchased as it arrives at the agreed upon point of delivery. PPAs are used to share and reduce the risks of additional costs, however, in some cases the costs are not accounted for within LCOE models. The term cost refers to a flow of money, while the term risk refers to the combination of uncertainty in generation and transmission, and the cost consequences that it carries. Electricity and PPA price are defined as the value energy is purchased at. The specific risks managed by PPAs differ depending on the country and market the energy is sold into. In a PPA, the risk of additional costs is negotiated between the Buyer and Seller. By taking on more risk, the Buyer reduces the LCOE of the wind farm by taking on extra costs. In doing so, the PPA price is reduced as it is negotiated around the actual LCOE of the wind farm. A PPA is used to allocate risk between the Seller and the Buyer; additional costs to the Buyer that arise from the allocated risks are reflected in the energy purchase limits as well as the PPA price. The risks that are allocated to the Buyer reduce the LCOE of the wind farm because the Buyer accepts the risk of those costs. Additional costs to the Buyer outside of the terms of the PPA do not affect the LCOE of the wind farm.

Conventional LCOE models consider all the capital costs and annual operational costs that are expected to be incurred in an energy project. PPAs address the capital costs, operational costs over the lifetime of the project, the energy produced, tax credits, and the weighted average cost of capital (WACC) of the project. The National Renewable Energy Laboratory (NREL) and others have developed and used LCOE models that typically consider all or most of these parameters [7–12]. The terms of the PPA are important because they create costs that affect the actual LCOE. However, current LCOE models do not include the effects of the energy delivery limits and their penalty costs imposed by PPAs as a cost to the wind farms. If the LCOE does not reflect the break-even cost, the Seller risks the project's failure and the Buyer risks a loss in profit from not providing enough energy to its end-use consumers. A more accurate LCOE could prevent the failure in financing a wind farm and benefit the Seller, the Buyer, and consumers.

In this paper, a new LCOE model is proposed to address energy delivery limits defined by a PPA. These energy delivery limits are referred to as penalties in this paper. Although the application of penalties as a cost appears to be straightforward (because of their direct and indirect costs to the Seller), the penalties are more complex to analyze when uncertainties in energy generation are introduced. The difference between the LCOE with and without penalties can be significant (see the Wind farm case study later in this paper). The effect of penalties on the LCOE can vary depending on the capacity factor (*CF*), as well as the limits on the purchase of energy. Determining the best limits in a PPA depends on the needs (including governmental mandates) of the Buyer in conjunction with a desire for a *COE* that reflects the actual LCOE for the Seller within the contract.

2. Power Purchase Agreements (PPAs) and Levelized Cost of Energy (LCOE)

PPAs can define every aspect of the project including: the terms for the entire project's construction, operation and maintenance (O&M), insurance, the interconnection and grid, government involvement in the project, the delivery of energy, and any other third party involvement in the project [13]. Each of these aspects is a responsibility of the Seller that affects the cost of the wind farm. Normally, PPAs are viewed as just the relationship between the utility (Buyer) and the generator (Seller), however, this paper views the PPA as a plan with specific features defined for the success of the wind farm and all the parties involved, such as the cost of energy and energy delivery limits.