

# DISSERTATION DEFENSE

## **Managing Wind-based Electricity Generation and Storage**

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Among the many issues that profoundly affect the world economy every day, energy is one of the most prominent. Countries such as the U.S. strive to reduce reliance on the import of fossil fuels, and to meet increasing electricity demand without harming the environment.

Two of the most promising solutions for the energy issue are to rely on renewable energy, and to develop efficient electricity storage. Renewable energy—such as wind energy and solar energy—is free, abundant, and most importantly, does not exacerbate the global warming problem. However, renewable energy is inherently intermittent and variable, and thus can benefit greatly from coupling with electricity storage, such as grid-level industrial batteries. Grid storage can also help match the supply and demand of an entire electricity market. In addition, electricity storage such as car batteries can help reduce dependence on oil, as it can enable the development of Plug-in Hybrid Electric Vehicles, and Battery Electric Vehicles. This thesis focuses on understanding how to manage renewable energy and electricity storage properly together, and electricity storage alone.

In Chapter 2, I study how to manage renewable energy, specifically wind energy. Managing wind energy is conceptually straightforward: generate and sell as much electricity as possible when prices are positive, and do nothing otherwise. However, this leads to curtailment when wind energy exceeds the transmission capacity or when prices are negative, and possible revenue dilution when current prices are low but are expected to increase in the future. Electricity storage is being considered as a means to alleviate these problems, and also enables buying electricity from the market for later resale. But the presence of storage complicates the management of electricity generation from wind, and the value of storage for a wind-based generator is not entirely understood.

I demonstrate that for such a combined generation and storage system the optimal policy does not have any apparent structure, and that using overly simple policies can be considerably suboptimal. I thus develop and analyze a triple-threshold policy that I show to be near-optimal. Using a financial engineering price model and calibrating it to data from the New York

Independent System Operator, I show that storage can substantially increase the monetary value of a wind farm: If transmission capacity is tight, the majority of this value arises from reducing curtailment and time-shifting generation; if transmission capacity is abundant this value stems primarily from time-shifting generation and arbitrage. In addition, I find that while more storage capacity always increases the average energy sold to the market, it may actually decrease the average *wind* energy sold when transmission capacity is abundant.

In Chapter 3, I examine how electricity storage can be used to help match electricity supply and demand. Conventional wisdom suggests that when supply exceeds demand, any electricity surpluses should be stored for future resale. However, because electricity prices can be negative, another potential strategy of dealing with surpluses is to destroy them. Using real data, I find that for a merchant who trades electricity in a market, the strategy of destroying surpluses is potentially more valuable than the conventional strategy of storing surpluses.

In Chapter 4, I study how the operation and valuation of electricity storage facilities can be affected by their physical characteristics and operating dynamics. Examples are the degradation of energy capacity over time and the variation of round-trip efficiency at different charging/discharging rates. These dynamics are often ignored in the literature, thus it has not been established whether it is important to model these characteristics. Specifically, it remains an open question whether modeling these dynamics might materially change the prescribed operating policy and the resulting valuation of a storage facility. I answer this question using a representative setting, in which a battery is utilized to trade electricity in an energy arbitrage market.

Using engineering models, I capture the dynamics of energy capacity degradation and efficiency variation explicitly, evaluating three types of batteries: lead acid, lithium-ion, and Aqueous Hybrid Ion—a new commercial battery technology. I calibrate the model for each battery to manufacturers' data and value these batteries using the same calibrated financial engineering price model as in Chapter 2. My analysis shows that: (a) it is quite suboptimal to operate each battery as if it did not degrade, particularly for lead acid and lithium-ion; (b) reducing degradation and efficiency variation have a complimentary effect: the value of reducing both together is greater than the sum of the value of reducing one individually; and (c) decreasing degradation may have a bigger effect than keeping the efficiency constant.