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# Exploring revenue-driven wind turbine design

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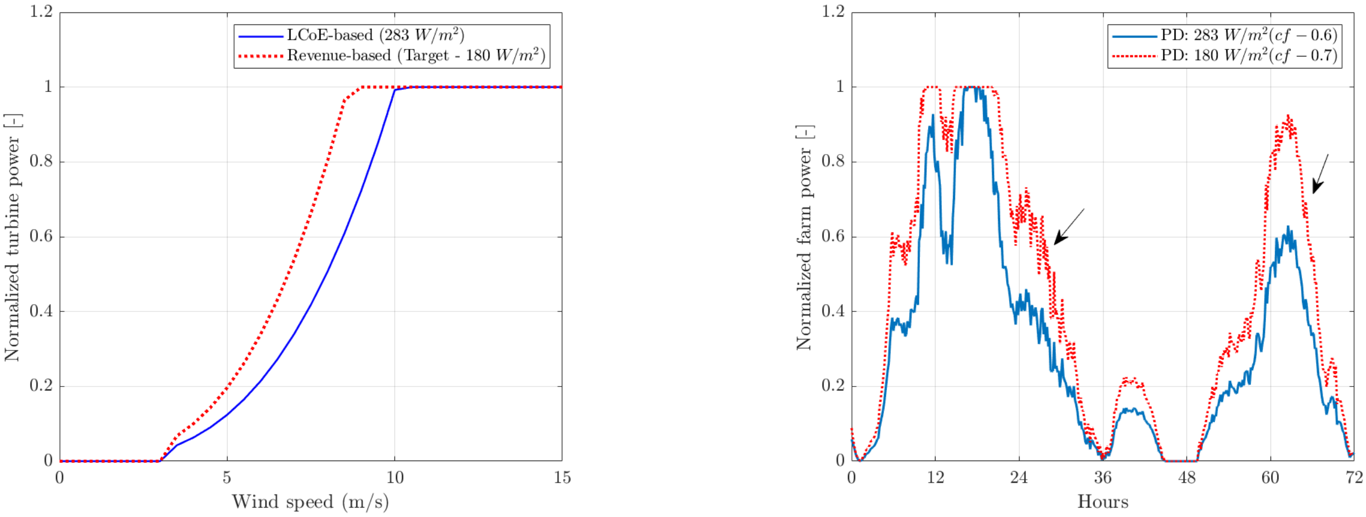
## Abstract

Traditionally, wind turbine and wind farm designs have been optimized to minimize the cost of energy. Such a design would make sense when bidding in price-based auctions. However, in a future with a high share of renewables and zero subsidies, the wind farm developer could be completely exposed to the volatility of market prices, where the price paid per kWh of energy would not be a constant anymore. The developer might then have to maximize the revenue earned by participating in different energy, capacity, or ancillary services markets. In such a scenario, a turbine designed for maximizing its market value could be more profitable for the developer compared to a turbine designed for minimizing the Levelized Cost of Electricity (LCoE). This study is in line with this paradigm shift in the field of turbine and farm design. The goal is to optimize the design for a new set of objective functions and constraints, and analyze the impact of these new designs on the system as a whole.

The power density of the turbine is optimized to maximize the Internal Rate of Return (IRR) and is compared to the turbine design optimized for LCoE. A multivariate model is developed to derive the spot price from the existing nationwide wind power and demand forecast. For the future years, the forecasts are scaled up w.r.t the increase in installed wind turbine capacity and demand derived from trends/government targets. Various scenarios are simulated wherein the installed wind turbine capacity and demand are varied. A gradient-free optimization is performed by using the rotor diameter as a design variable while keeping the machine rating constant. Using IRR as an objective function results in larger rotor sizes enabling the turbine to produce a higher power at lower wind speeds, corresponding to times with higher spot prices. The result of a scenario (Target) where the installed wind turbine capacity follows government targets and demand is extrapolated linearly, is shown in Figure 1a. Here, the power density of a 5 MW baseline turbine is optimized for IRR, where the revenue from the Dutch day-ahead market is considered along with the turbine costs.

Results for a single (onshore) turbine will be compared with a similar IRR optimization of power density of a turbine in a sample offshore wind farm. At a wind farm level, the effects of power density variations on the farm layout, wake losses, cabling costs, etc. are also included. Moreover, insights into the consequences of optimizing the turbines on 'system-friendliness' are provided. Figure 1b illustrates a comparison between the farm capacity factor and farm power ramps. It is observable that while the capacity factor of the farm with a revenue-driven turbine is higher, the power ramps are steeper as well. A system-level trade-off is apparent as higher capacity factors ensure a better supply of demand at lower wind speeds while higher ramps need further compensation. This shows how moving beyond LCoE, by only considering energy markets, might not necessarily produce the most system-friendly turbines. To avoid negative implications, this study emphasizes the need to examine the consequences of selecting a revenue-based objective function on the system as a whole.



(a) Power curve of the different turbine configurations

(b) Sensitivity of ramps w.r.t power density of the turbine

Figure 1

***Keywords: Wind turbine optimization; beyond LCoE; wind farm; ramp rates; capacity factor***