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Hydrogen storage for wind parks: A real options evaluation for an optimal investment in more flexibility

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HIGHLIGHTS

- Economic analysis of investing in H_2 storage for excess wind power production.
- Use of real options analysis to account for uncertainty and managerial flexibility.
- Hourly profits are simulated for profit-maximizing operation of the storage device.
- Revenues by load factor increase, offering minute reserve, temporal arbitrage, H_2 sale.
- Power-to-power is unprofitable under current techno-political conditions in Germany.

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ABSTRACT

In this paper, we investigate the economic viability of hydrogen storage for excess electricity produced in wind power plants. For the analysis, we define two scenarios (50 MW system with and without re-electrification unit) and apply Monte Carlo simulation and real options analysis (ROA) to compute hourly profits under uncertainty regarding wind speed, spot market electricity prices, and call of minute reserve capacity. Hydrogen as a storage medium helps to either (1) increase capacity utilization of the wind park in case of grid disconnection; (2) to offer minute reserve; or (3) to exploit temporal price arbitrage at the electricity spot market; additionally, hydrogen can also be directly sold as a commodity. We find that power-to-power operation is highly uneconomical under current framework conditions in Germany, irrespective of potential energy efficiency gains. Interestingly, due to counterbalancing effects, offshore wind parks are found to have only a modest economic advantage compared to onshore ones. The power-to-fuel plant can be operated profitably (at hydrogen prices of more than 0.36 € m^{-3} and a 100% utilization of the electrolyzer) if hydrogen is directly marketed instead of used to store and re-generate electrical energy. The ROA recommends investment in a storage device without re-electrification unit beyond an expected project value that is about twice the investment cost of the storage device, a figure which is reduced markedly as conversion efficiency rises, assuming technical change to come at no cost for the investor, i.e. as being exogenous.

1. Introduction

Due to their political promotion over the last years, the (new) renewable energies have developed into important energy sources for the liberalized electricity market in Germany. Among these renewables, wind power currently provides the largest share at about 7.3% of the total energy supply, and a further increase of this share is expected for the future [1].

The integration of the renewables into the electric grid, however, creates some challenges. Many of them deliver a strongly fluctuating supply of energy, leading to bottlenecks in the transmission grid when transporting electricity from the wind-rich regions in the north of Germany to the demand centers in the south. Due to the special characteristics of electrical energy, especially its limited storability, this brings up some new challenges regarding the maintenance of grid stability since supply and demand have to be in equilibrium at any one moment in time. Beyond a share of volatile renewables of about 20% [2, p.34], supply fluctuations have to be smoothed with technical equipment to safeguard a secure supply.

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Nomenclature

Symbols
A (m s^{-1}) Weibull scale parameter
A_i (–) form factor in the real options model
α (–) drift parameter
β (–) parameter in the real options model
c_{FC} (€ MW h^{-1}) specific operating costs of the fuel cell
C_{FC} (€) operating cost of the fuel cell
C_{MC} (€) pro rata maintenance cost of the storage device
δ (–) minute reserve status
E (–) expected value
ε (–) mathematical error
η (–) conversion efficiency
F (–) option value
h_W (–) frequency distribution of the wind
I (€) investment costs
k (–) Weibull shape parameter
M_{H_2} (m^3) pro rata maintenance cost of the storage device
μ (–) mean value
p_{EEG} (€ MW h^{-1}) feed-in tariff according to EEG
p_{H_2} (€ m^{-3}) price for hydrogen
p_{SM} (€ MW h^{-1}) spot market price for electricity
P_i (MW) power of the plant component i = {WT, WF, EL, Comp, FC}
π (€) profit
φ (–) unused share of wind power
ϱ (–) interest rate of the investor
σ (–) standard deviation
t (s) time
T (a) project duration
v (m s^{-1}) wind speed
V (€) time-dependent project value
W (MW h) amount of energy

Abbreviations
AV average value
BC base case
CAES compressed air energy storage
Comp compressor
DC demand charge
EB economic benefit
AV average value
EEG German act for priority to renewable energies (Erneuerbare-Energien-Gesetz)
EL electrolyzer
EnWG German act for electricity and gas supply (Energiewirtschaftsgesetz)
EC energy charge
FC fuel cell
FINO research and development platforms in the North and East Sea
MC maintenance costs
MRC minute reserve capacity
NPV net present value
OC operating costs
PSHP pumped storage hydro power
PT profit threshold
RE renewable energy
ROA real options analysis
SD standard deviation
SM spot market
St storage
TSO transmission system operator
WF wind farm
WT wind turbine

Subscripts
el electrical
neg negative
pos positive
tot total

Energy storage plants are seen as a key technology for the increasing integration of renewable energies in the German electricity mix. Their use enables a better match of the fluctuating supply of wind power to the variable energy demand and an avoidance of grid overloads. The use of energy storage devices can also be seen as an economic optimization problem in a liberalized electricity market. However, note that geographical dispersion of wind power plants can help to flatten this variability as uncorrelated wind profiles balance out each other [3].

In this paper, we analyze the investment in a hydrogen storage device as an expansion of a wind farm. Economic benefits can be achieved through the following aspects:

1. *Load factor increase of the wind farm*: due to the storage possibility, a wind farm operator can still produce energy even if the wind farm is disconnected from the grid, e.g., due to system-related measures (grid overload, securing grid stability).
2. *Temporal arbitrage*: There is also the possibility to purchase electrical energy in times of low spot market prices in order to produce hydrogen, which is then re-electrified in times of high spot market prices.
3. *Supply of system services*: By means of the storage unit it is possible for the investor to offer system services to the grid operator in the form of reserve capacity (minute reserve).

Note that the first two economic advantages have load-smoothing characteristics. Through its application, supply peaks are balanced out.

In our study, the economic valuation is conducted with real options analysis (ROA) based on Dixit and Pindyck [4] and Trigeorgis [5]. ROA takes into account the irreversible character of the investment, and allows the investor some flexibility with respect to the choice of the investment timing. He can either invest immediately or wait, in order to learn more about the future and decide about the investment later. Furthermore, with ROA, it is possible to account for the investor's uncertainty, and changes thereof over time. In our analysis, the risks of fluctuating wind speed, fluctuating spot market prices, and fluctuating call of minute reserve capacity are stochastically taken into account. Uncertain time states are simulated with Monte Carlo simulation (MCS), the results of which are fluctuating cash flow streams, which are used as input parameters in the ROA. Furthermore, technical uncertainty is taken into consideration by a sensitivity analysis regarding the plant efficiency.

The original contribution of this paper is threefold. First, to the best of our knowledge we are the first to apply ROA to a hybrid wind power and hydrogen storage system. Second, we show that various economic benefit components that arise from the feasible combinations of operating modes interfere with each other and sometimes reduce the overall benefit. Third, from a policy perspective, we demonstrate that fuel cells cannot be operated