PennState College of Earth and Mineral Sciences

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Stochastic model and techno-economic analysis of integrating large-scale wind power generation with underground hydrogen storage

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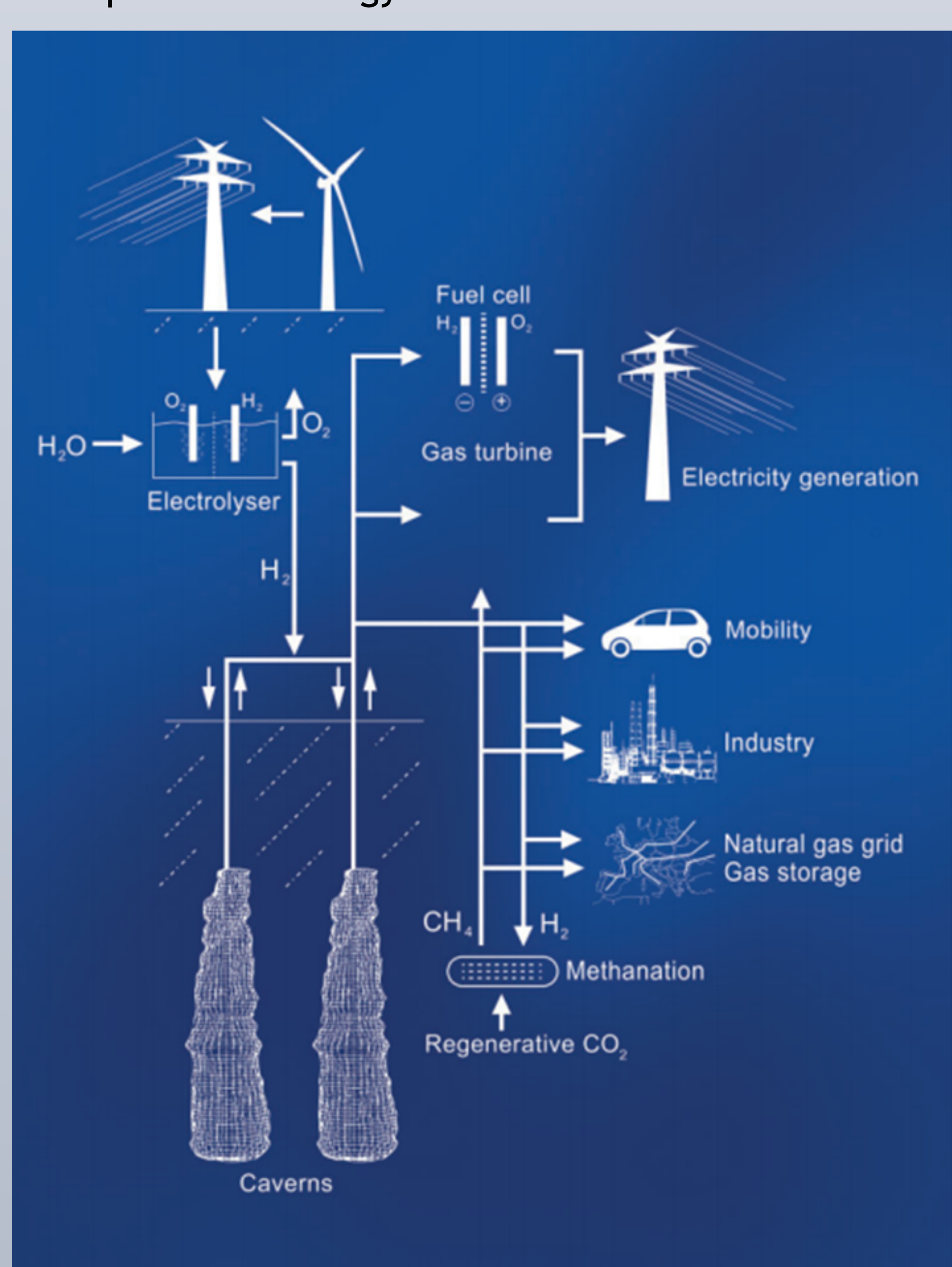
ABSTRACT

- Energy demand fluctuations can be met by large-scale underground energy storage and through maximizing the possibilities of integrated electricity generation system from intermittent wind power [1][2].
- This project analyzes the economic feasibility of power-to-gas using electrolysis technologies in a 1-GW nameplate capacity wind project (500 2-MW wind turbines) and the economic benefits of utilizing salt caverns as underground energy (hydrogen) storage for controlled dispatch.
- We develop a stochastic model using GAMS to calculate different financial parameters (NPV, IRR, B/C ratio) for economic feasibility analysis of 1056 scenarios with ten variables including: cavern installation costs, cost of electrolysis, hydrogen distribution costs, transmission costs, production tax credit, and efficiency (with sensitivity analysis).
- We find that the median increased capacity factor for this 1-GW hypothetical wind project with the installation of salt caverns as hydrogen storage is approximately 0.243.

OBJECTIVES

- To develop a stochastic model that analyzes multiple scenarios with different financial variables to study the economic feasibility of coupling salt cavern hydrogen storage with a hypothetical 1-GW windfarm.
- To propose the most economically reasonable solution to the existing problem of excess renewable energy curtailment.
- To promote the benefits of utilizing green hydrogen gas as a response to energy market demand fluctuations.



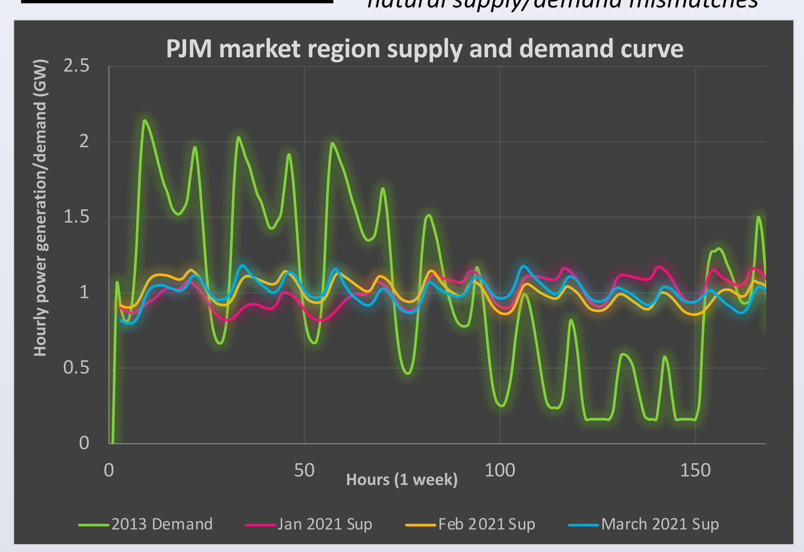
MATERIALS AND METHOD

Stochastic model: Stochastic model is an approach used for estimating probability distributions of potential outcomes which are characterized by a randomizing one or more variables/inputs over time.

GAMS (General Algebraic Modeling System): GAMS is an advanced modeling system for mathematical programming and optimization problems. GAMS modeling language allows the integration of real-world optimization problems into computer code for concise and instantaneous formulation.

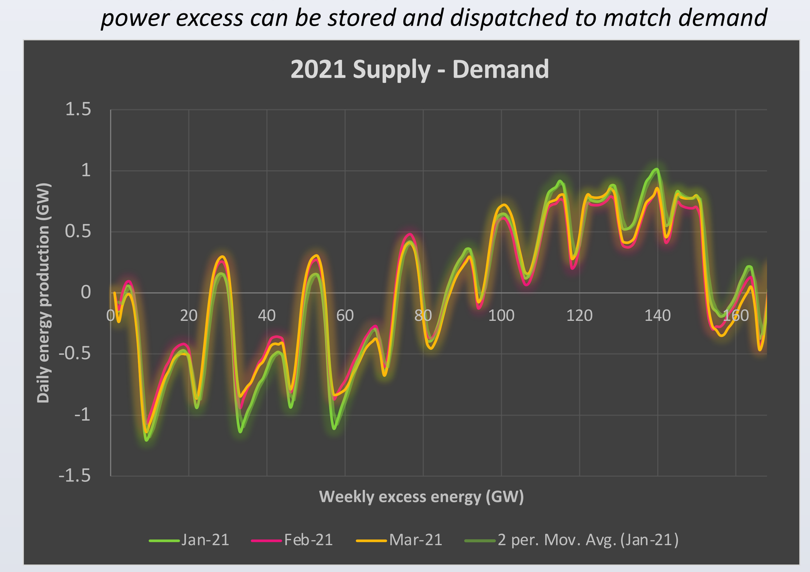
Capacity factor:

Without storage, wind energy creates natural supply/demand mismatches



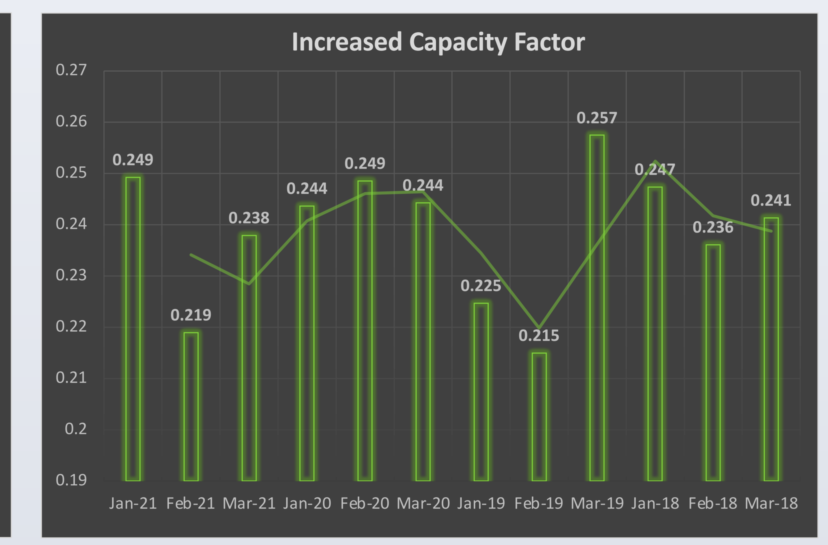
PJM metered load data

Hydrogen storage allows for large-scale wind deployment, as power excess can be stored and dispatched to match demand



Increased capacity factor

Added power output can be measured as increased capacity factor, which historically required decreased power output.



4-years period sample (3 months /year)

Equations and financial inputs:

$$CC\ (S) = Transmission + Wind\ Turbine + Electrolyzer + Compressor + 1.1 * H2production(S) * Storage$$

$$VC\ (S) = Electrolysis + CSD + Storage + Maintenance\ Costs$$

$$H2production(S) = \frac{H2\ conversionfactor * Energy\ produced * Efficiency * 1000 * StorageOpt}{Electrolysis\ energy}$$

$$Electricity\ Sales(S) = Energy\ produced * Efficiency * H2density * \frac{H2production(S)}{1000} * Electricity\ price$$

$$Income\ (S) = Electricity\ Sales\ (S) - VC\ (S) + PTC\ (S) - Tax(S)$$

$$Benefit\ to\ cost\ ratio = \frac{Income(S) * P/A}{CC\ (S)}$$

$$\sum_{t=1}^{T} \frac{Income(S)}{(1+IRR)^T} - CC(S) = 0$$

$$Net\ Present\ Value = -CC(S) + (Income(S) * P/A)$$

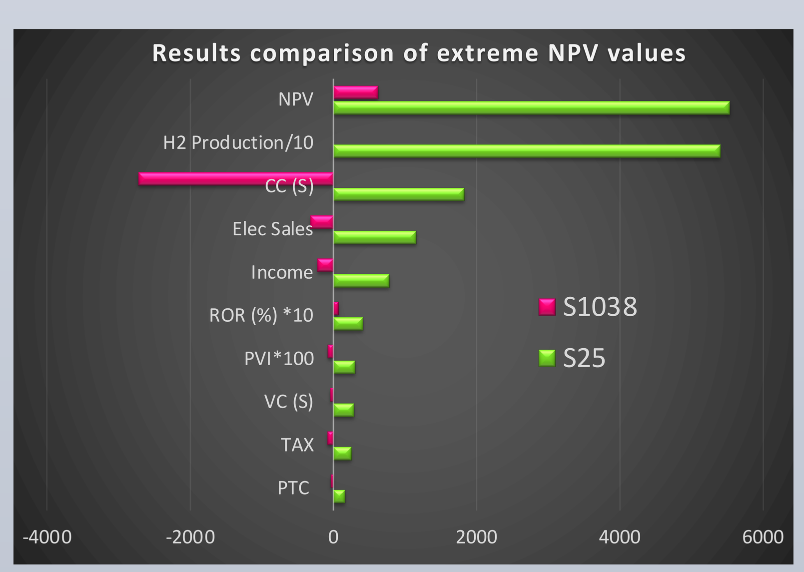
With Storage

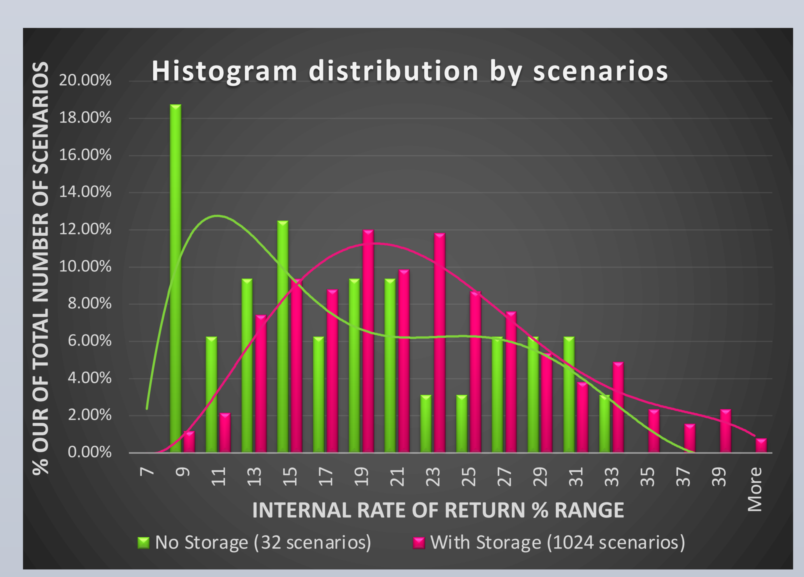
Metric	Units	Low	High
Tax	%	21	31
Electrolysis	$ / kg H2	0	3.1
CSD	$ / kg H2	4.3	5.9
PTC	$ / kWh	1.5	2.5
Efficiency	(-)	0.5	0.74
Transmission	$ MM	370	520
WindTurbine	$ MM	1350	2200
Electrolyzer	$ MM	18.25	27
Compressor	$ MM	18.5	20.5
Storage	$ MM	10	21
Storage CC(S)	$ / kg H2	1.19	

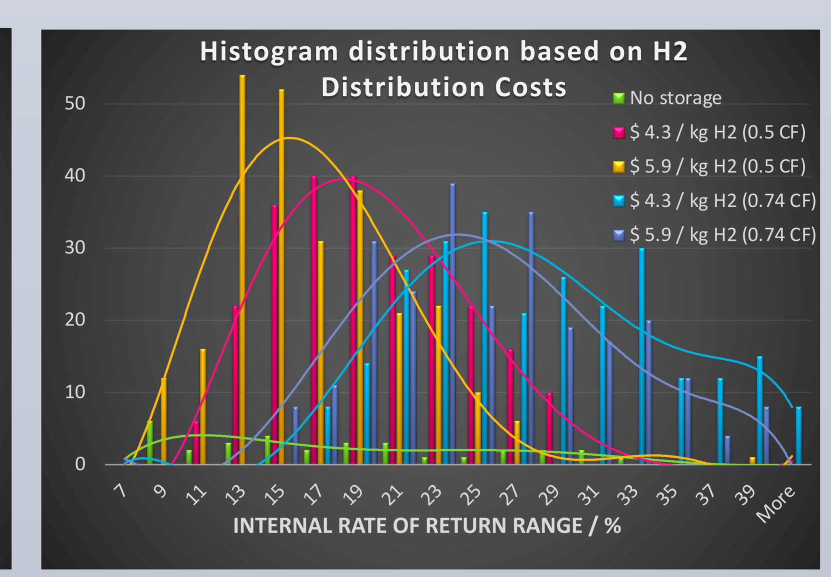
No Storage

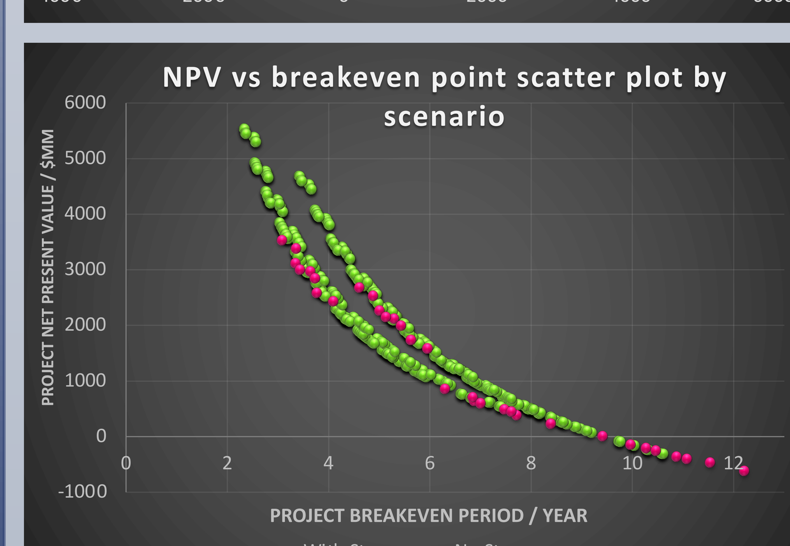
Metric	Units	Low	High
Tax	%	21	31
Electrolysis	$ / kg H2	0	
CSD	$ / kg H2	0	
PTC	$ / kWh	1.5	2.5
Efficiency	(-)	0.26	0.5
Transmission	$ MM	370	520
WindTurbine	$ MM	1350	2200
Electrolyzer	$ MM	0	
Compressor	$ MM	0	
Storage	$ MM	0	
Storage CC(S)	$ / kg H2	0	

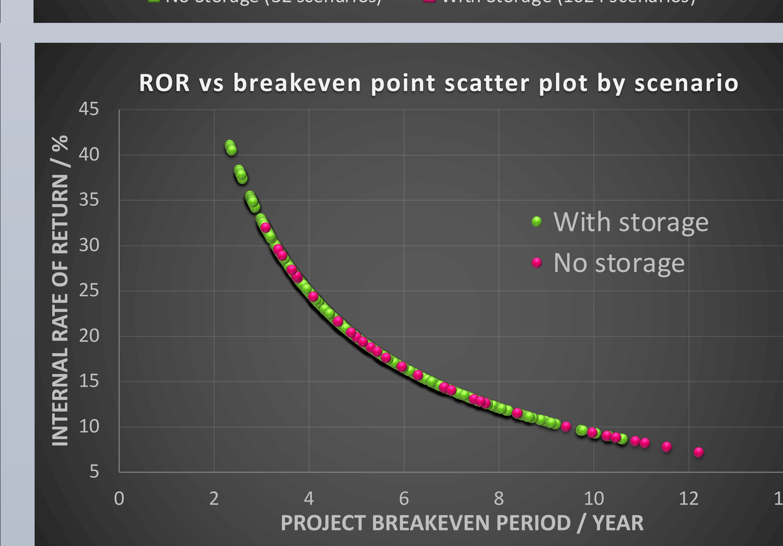
RESULTS ANALYSIS

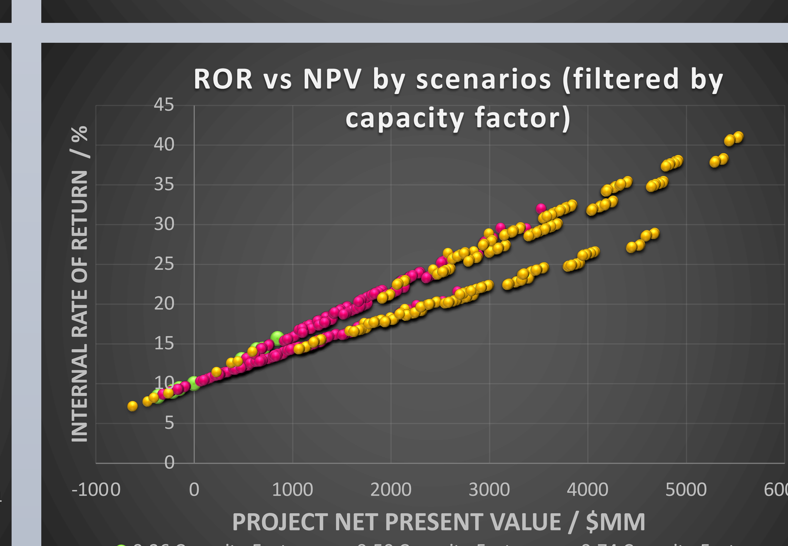












CONCLUSION

- Utilizing salt caverns hydrogen storage increases the Capacity Factor of the 1-GW hypothetical wind project without reducing the power output of the system.
- Since wind pattern can sometimes be unpredictable (there is more wind at non-peak hours), being able to utilize this cheap energy that remains unused for electrolysis processes (to produce Hydrogen for future dispatch) can provide a huge boost in the project revenue [5].
- On the other hand, areas where demand exceeds supply can be managed by conventional power plants such as coal, natural gas, nuclear [5].
- Nevertheless, if the costs of producing Hydrogen gas using renewable energy resources (fixed O&M, production variable, production and CSD costs) can be improved in the nearest future, the benefits of storing Hydrogen for future dispatch will be improved tremendously [4].
- Due to the intermittent nature of wind power and renewable resources in general, the ability to couple large-scale energy storages efficiently with wind turbines will be an excellent feature to help leveling renewable energy with most conventional power plants [5].

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