NREL
Transforming ENERGY

Wind Bidding in Regulation Markets Accounting for Forecast Uncertainty

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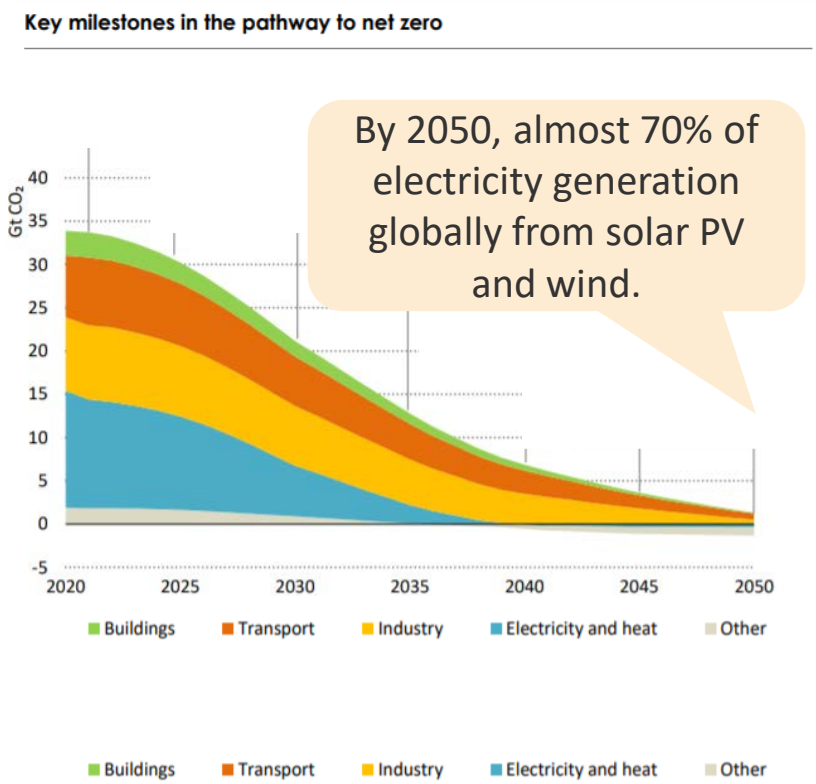
ESIG Meteorology & Market Design for Grid Services Workshop
Session 7: Impacts of Forecasting on Operations – An Operations Perspective

Background: Clean Energy Future

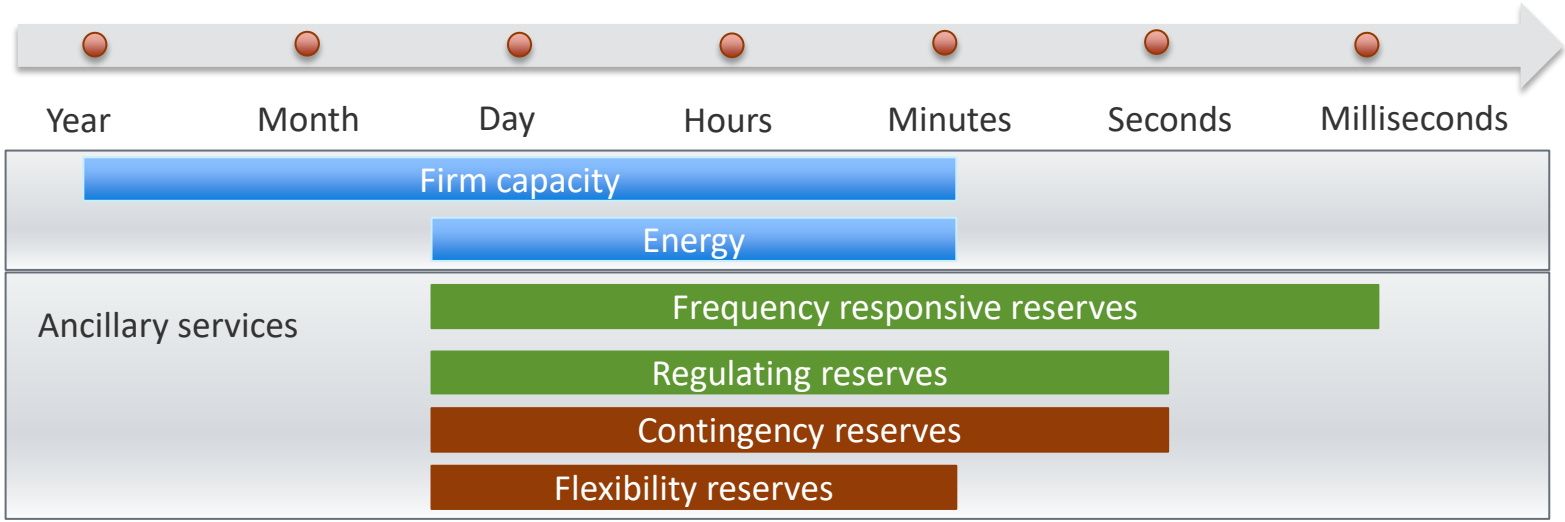
Wind and solar photovoltaics:

- Will play a major role in the future electricity resource mix!
- Are variable energy resources.



Source: International Energy Agency. 2021. "Net Zero by 2050 A Roadmap for the Global Energy Sector."

Timeline from procurement to deployment for products in organized electricity markets



Graphic adapted from P. Denholm, Y. Sun, and T. Mai. 2019. *An Introduction to Grid Services: Concepts, Technical Requirements, and Provision from Wind*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-72578. https://www.nrel.gov/docs/fy19osti/72578.pdf.

Ancillary services are procured for reliable operations

Ancillary services help manage:

- the variability and
- uncertainty

of electricity supply and demand.

How could variable energy resources supply ancillary services?

So far, only a handful of variable energy resources provide ancillary services.

Source: I. Chernyakhovskiy, S. Koebrich, V. Gevorgian, and J. Cochran. 2019. *Grid-Friendly Renewable Energy: Solar and Wind Participation in Automatic Generation Control Systems.*" Greening the Grid Program: A Joint Initiative by USAID/India and Ministry of Power.

Uncertainty management → "near-certain" offers

- Low quantiles from interval forecasts
- Hybridization with storage
- Regional aggregation.

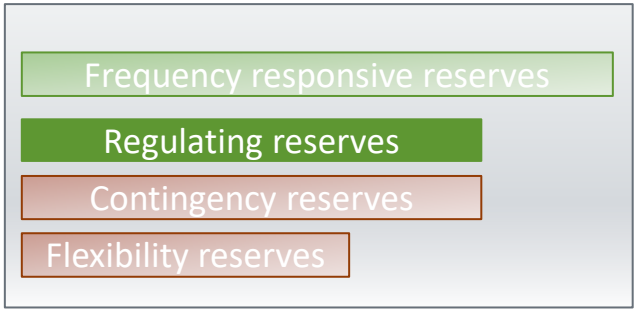
Variability management → controllable output

- Control plant, e.g., pitch or yaw of wind power plant
- Hybridization with storage.

DISCLAIMER: The list of solutions for uncertainty and variability management includes examples but it is by no means comprehensive.

Overarching Question and Scope

Considering available probabilistic forecasts, what **quantity** can be offered as regulation capacity by variable energy resources and at what **price**?



Regulating reserves:

- ✓ Highest in pricing hierarchy
- ✓ Demonstrations of control capabilities in pilots.

Uncertainty management → "near-certain" offers

- Low quantiles from interval forecasts
- Hybridization with storage
- Regional aggregation

Interval ("probabilistic") forecasts:

- ✓ Existing infrastructure
- ✓ Existing contractual agreements.

Regulating Reserves

Power System Operator’s Rules Relevant for Imperfect Delivery

Disqualification rules determine what constitutes acceptable performance.

- Lower bound on Type I metric → upper bound on probability of "default"
- Lower bound on Type II metric→ upper bound on expected relative shortfall.

Resource disqualifies when..

Metric	Below	During	
Type I: Frequency of intervals with acceptable performance	85%	Calendar month	ERCOT
Type II: Average precision score	85% (10% booster)	Calendar month	NYISO
	75%	Calendar month or five best tests	SPP
	25% (accuracy)	Calendar month	CAISO
	40%	100 hours	PJM

DISCLAIMER: The summary of current practice is based on our understanding of tariffs, manuals, and publicly available material and has not been reviewed by U.S. operators.

Settlement schemes encourage near-perfect delivery of regulation capacity.

When delivery of regulation capacity is imperfect, payment for regulation capacity to supplier is:

Pro rata	Proportional to performance score	CAISO, NYISO
All or nothing	Rescinded if performance is below a threshold	SPP, MISO
Hybrid	Proportional to performance score if score is above a threshold	PJM, ISO-NE
Over-/under-generation penalties	Incurring same penalties for deviations as energy but stricter tolerance	ERCOT

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Regulating Reserves from Variable Energy Resources

Considering available probabilistic forecasts and **operators' rules**, what **quantity** can be offered as regulation capacity by variable energy resources and at what **price**?

PREVIEW OF KEY FINDINGS

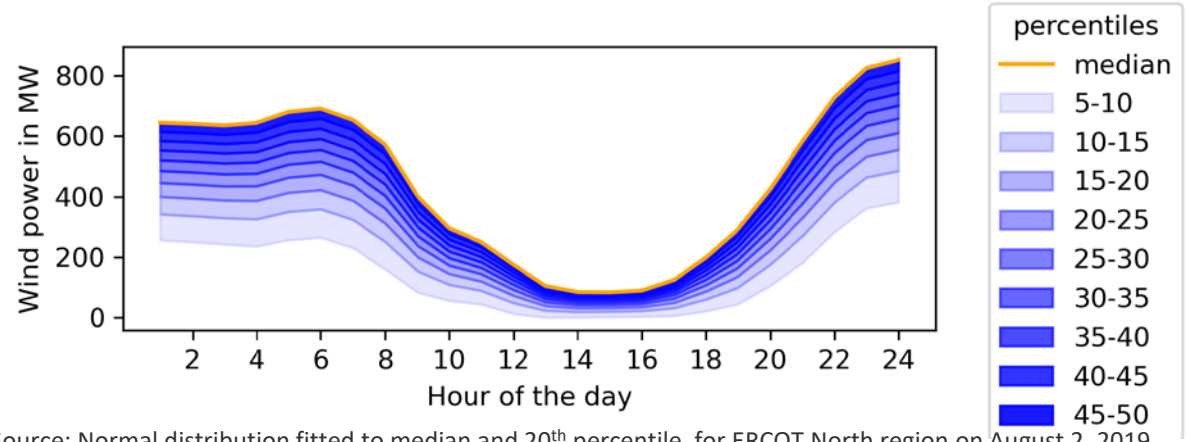
1

Variable energy resources that consider operator's disqualification rules should offer ***lower than the median**** percentiles of their forecast as regulation capacity.

**analytical formulas for determining the exact percentile derived*

2

When settlement schemes encourage near-perfect delivery by adjusting payments for imperfect delivery of regulation capacity, ***opportunity costs should reflect expected performance*** or resources might offer lower percentiles than the ones derived based on disqualification rules.



Source: Normal distribution fitted to median and 20th percentile for ERCOT North region on August 2, 2019.
[Wind Power Production - Hourly Averaged Actual and Forecasted Values by Geographical Region]

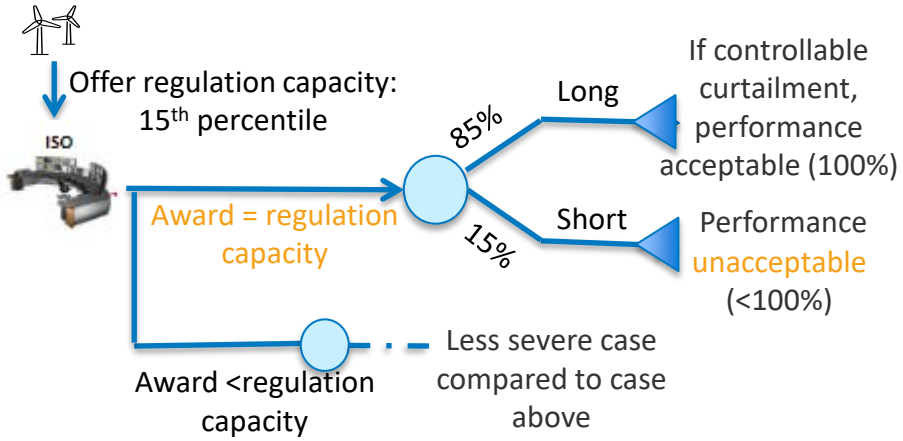
Example of probabilistic forecast

1

Probabilistic forecasts are useful for deciding on regulation offers

Disqualification rules suggest an upper bound on offer of regulation capacity, which is a rule-dependent percentile of the *true* probabilistic forecast.

Example of correspondence of lower bounds on performance metrics (disqualification rules) to upper bounds for offers of regulation capacity.



Under conservative assumptions, an offering of 15th percentile would yield at least:
- 85% of intervals with acceptable performance (Type I Metric)
- 85% average precision score (Type II Metric).

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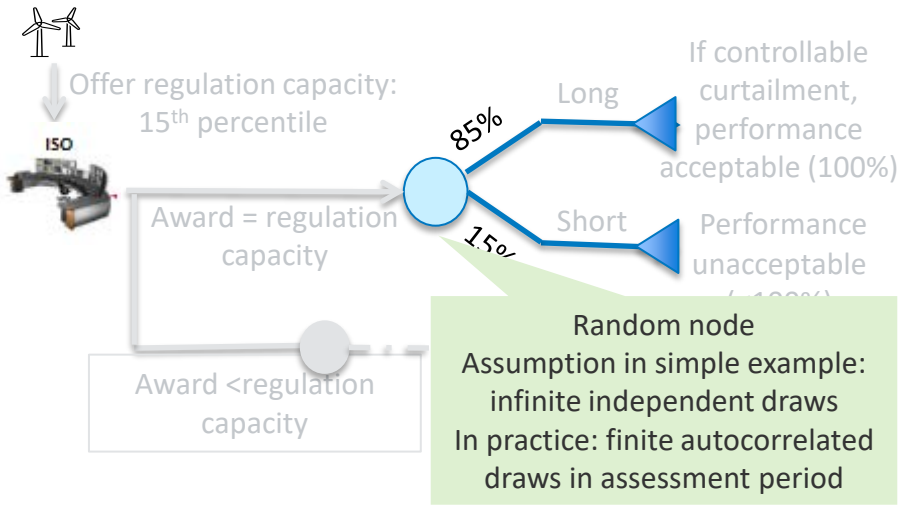

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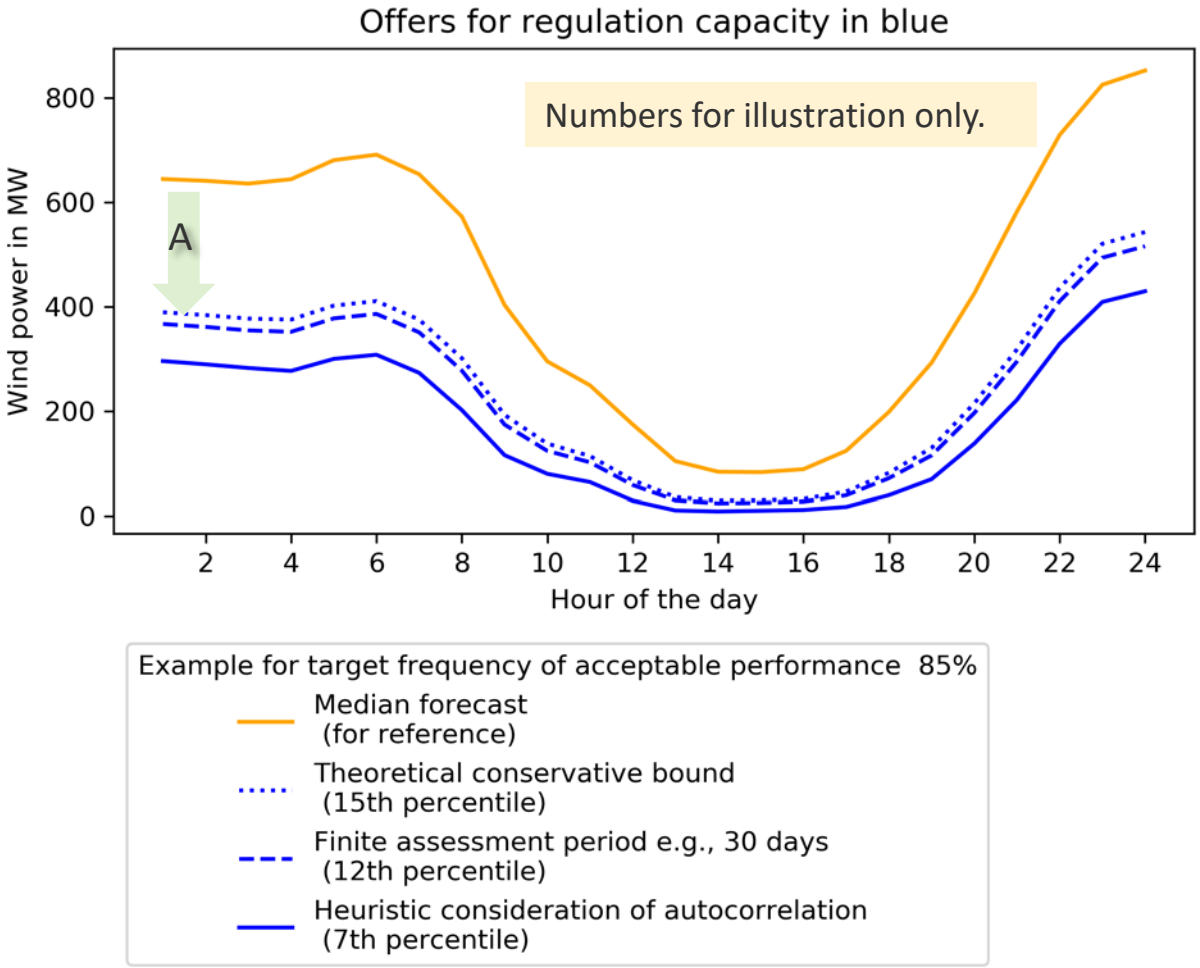
- 85% average precision score (Metric Type II).

1

Offering at lower than the median quantiles as a result of:

A. Disqualification rules



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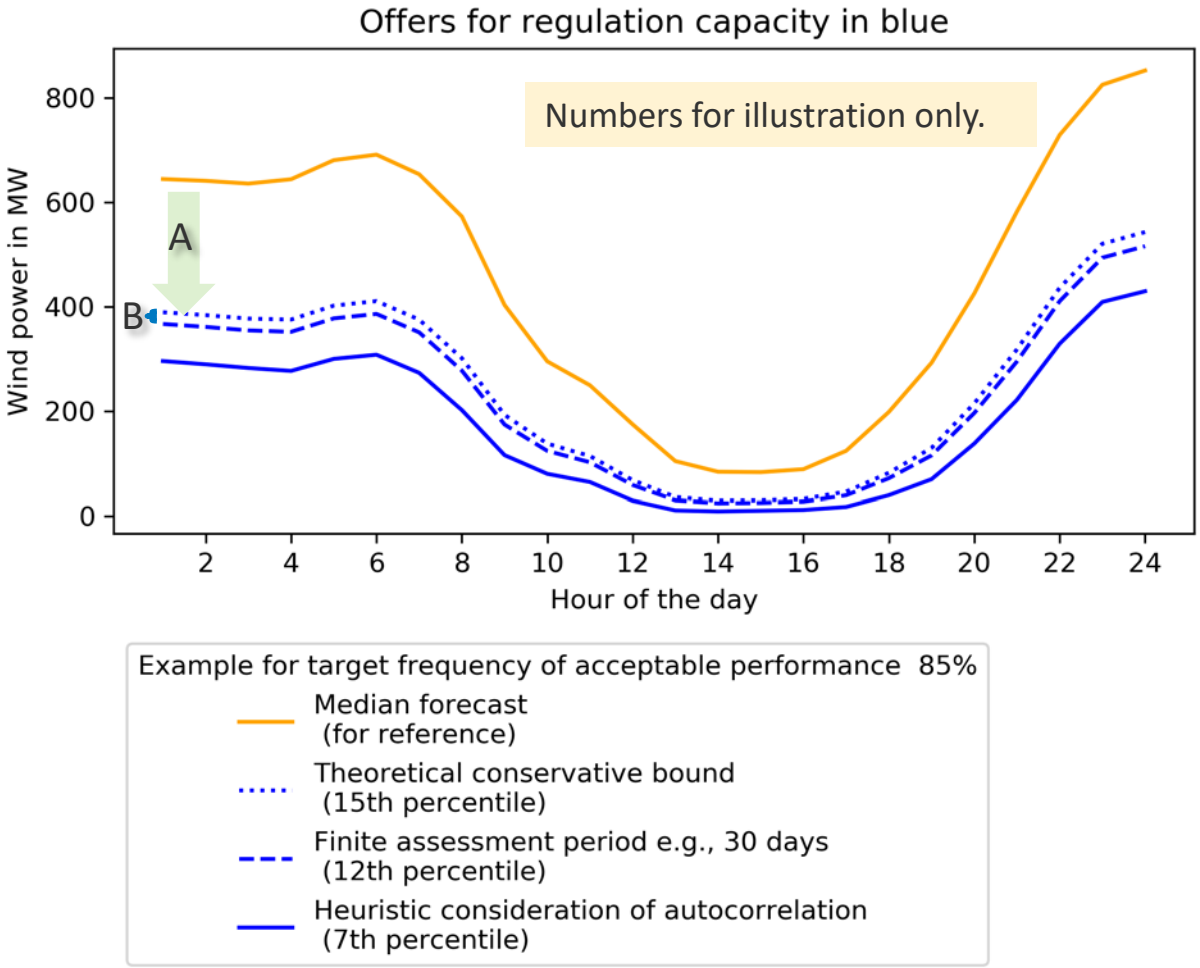
Wind Power Production - Hourly Averaged Actual and Forecasted Values by Geographical Region

1

Offering at lower than the median quantiles as a result of:

A. Disqualification rules

B. Finite assessment period



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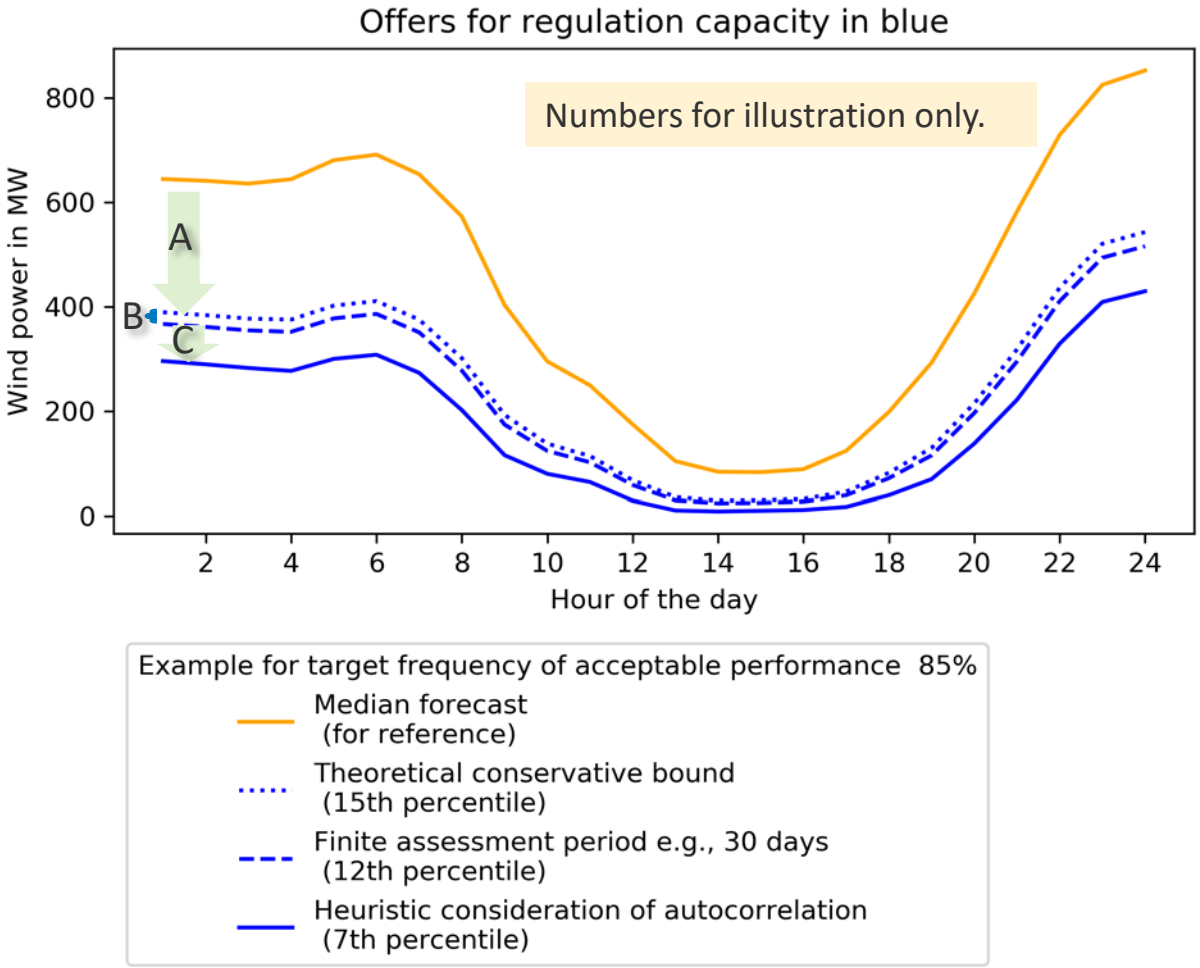
1

Offering at lower than the median quantiles as a result of:

A. Disqualification rules

B. Finite assessment period

C. Autocorrelation of forecast errors.



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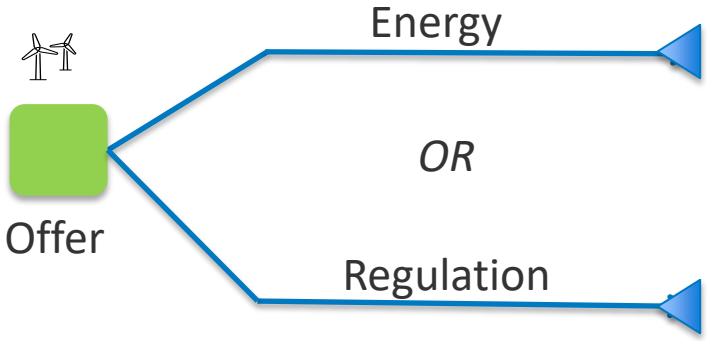
2 THE CERTAIN SUPPLIER'S DILEMMA:



$\boldsymbol{\pi_{EN}}$: profit from energy

$\boldsymbol{p_{REG} - c_{REG}}$

$\boldsymbol{c_{REG}}$: regulation cost

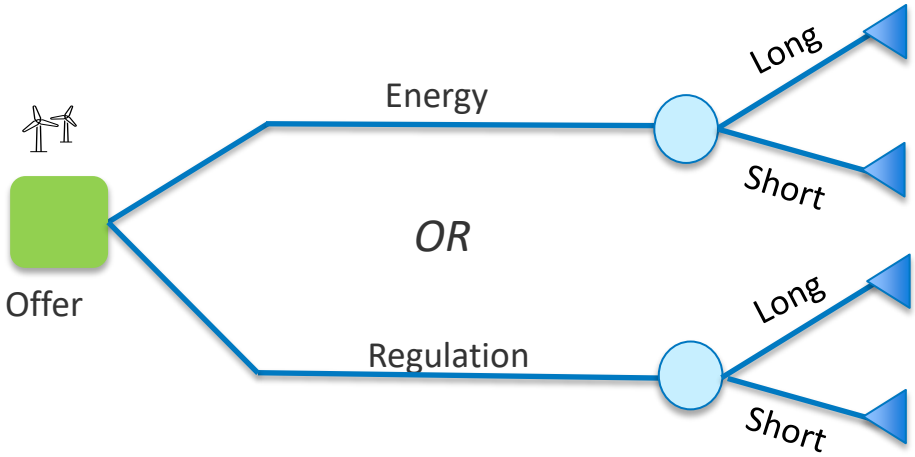
$\boldsymbol{p_{REG}}$: regulation price

Opportunity costs when delivery is *perfect*.

Resource indifferent (no dilemma) between energy and regulation when:

$$p_{REG} = \pi_{EN} + c_{REG}$$

2 THE NEAR-CERTAIN SUPPLIER'S DILEMMA:



If controllable curtailment, $\boldsymbol{\pi_{EN}}$

Energy imbalance penalties

If controllable curtailment, $\boldsymbol{p_{REG} - c_{REG}}$

Adjustment to payments for imperfect delivery of regulation capacity

Opportunity costs when delivery is *imperfect*.

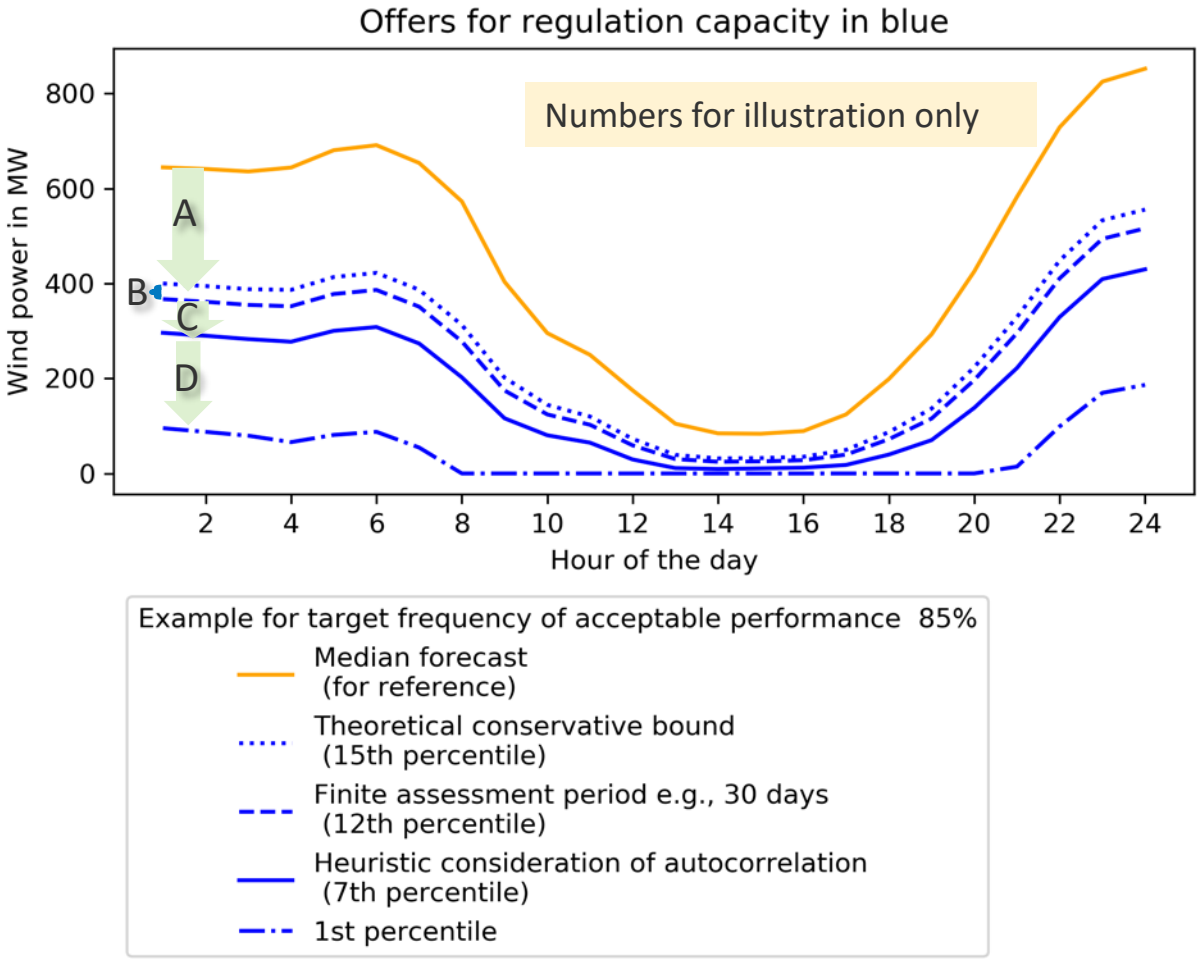
Higher regulation price is necessary for the resource to be indifferent (no dilemma) between energy and regulation:

- $\frac{\boldsymbol{\pi_{EN}}}{\alpha} + \boldsymbol{c_{REG}}$, where $\alpha \leq 1$ reflects expected performance
- $\boldsymbol{\pi_{EN}} + \boldsymbol{c_{REG}} + \boldsymbol{f(\varepsilon)}$, where $f(\varepsilon) \geq 0$ and $\boldsymbol{\varepsilon}$ reflects difference in tolerance.

Analytical formulas for α and $f(\varepsilon)$ respectively derived for (pro-rata, all or nothing, hybrid) and over-/under-generation settlement schemes.

2

If variable energy resources cannot include opportunity costs reflecting expected delivery, they might offer even lower regulation capacity (D).



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Key findings

1 Variable energy resources that consider operator's disqualification rules should offer ***lower than the median**** percentiles of their forecast as regulation capacity.

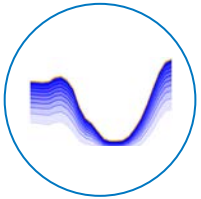
2 When settlement schemes encourage near-perfect delivery of regulation capacity, ***opportunity costs should reflect expected performance**** or resources might offer lower percentiles than the ones derived based on disqualification rules.

**analytical formulas derived*

Future Research

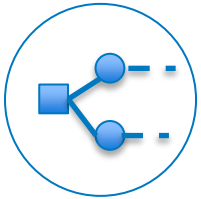
- Study alternative participation schemes, such as hybrid resources or clusters of variable energy resources.
- Consider control performance and imperfection in forecasting system to decide on offering.
- Relax current conservative assumptions, e.g., on awarded amount.
- Offer recommendations for product design and study correlation of regulation deployment with availability of variable generation.

Ongoing and future research under a three-year project: Integrating Atmosphere to Electrons to Grid Research & Tools to Increase the Value Streams of Wind Power Plants



Probabilistic forecasting of atmospheric conditions and wind power

Control algorithms



Decision analysis for offering of ancillary services

Case studies	Assess profitability and reliability for individual wind power plants offering ancillary services using historical or simulated prices and historical atmospheric conditions.
Open-source tool	Release software platform that advises on offers for energy and ancillary services and implements controls to deliver contracted energy and ancillary services.

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Thank you

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