The EPSRC Supergen Energy Networks Hub Risk and Resilience Day
Birmingham, United Kingdom
March 13th, 2025

Balancing-aware Redispatch Actions Under Uncertainty

Accurate uncertainty quantification using Polynomial Chaos Expansion

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With the support of Energy Transition Fund

Power System Operation Under Uncertainty

The goal is to manage the *operational* and *topological uncertainties* effectively, ensuring ***reliability*** and ***efficiency***.

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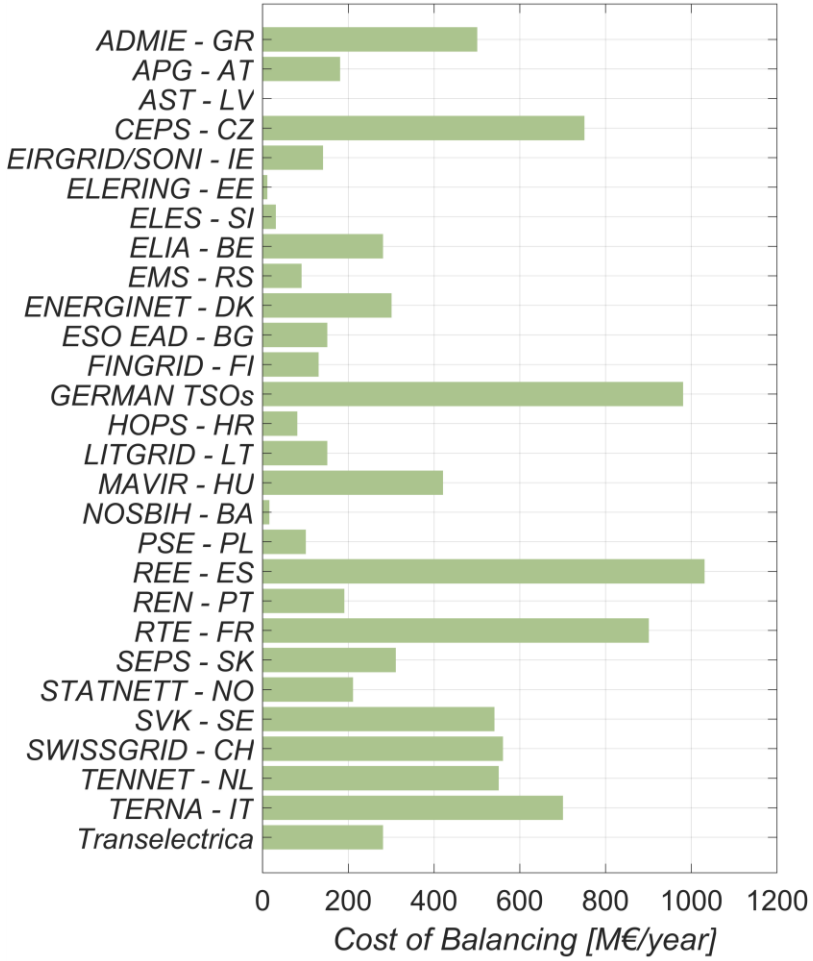
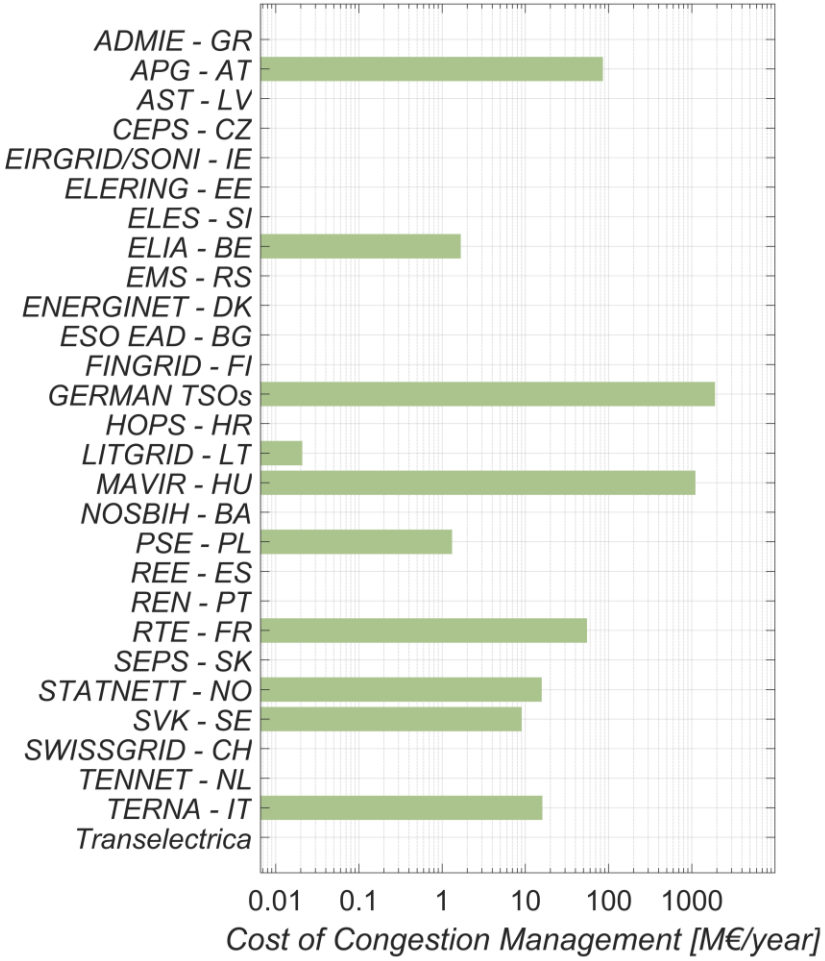
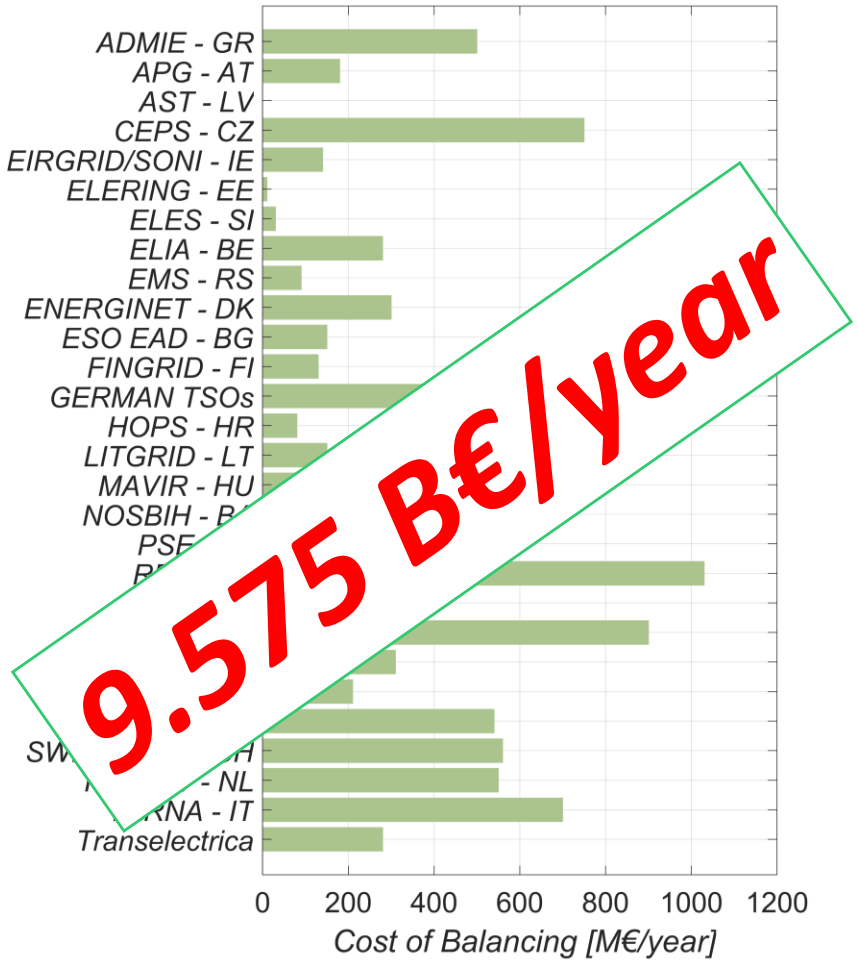
Consequences of Operational and Topological Uncertainty

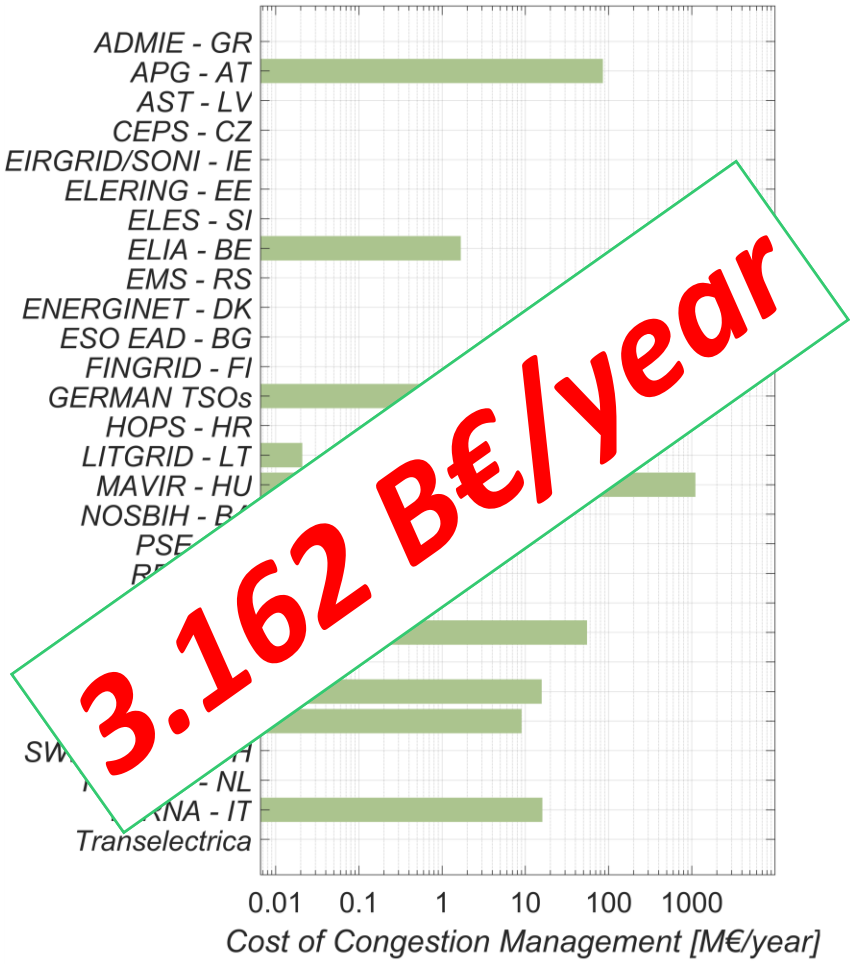




Data Sources: ENTSO-E Balancing Report 2024 and ENTSO-E Transparency Platform

Consequences of Operational and Topological Uncertainty



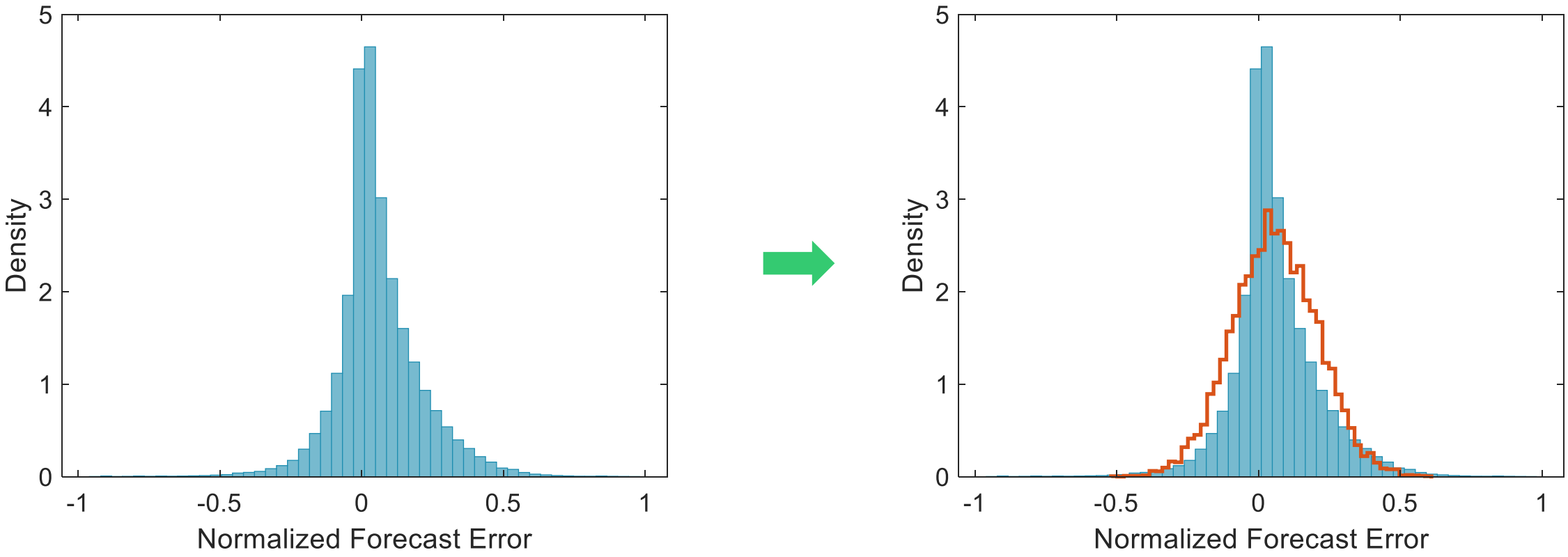


Failing to manage uncertainty effectively leads to ***significant congestion management*** and ***balancing costs***.

Data Sources: ENTSO-E Balancing Report 2024 and ENTSO-E Transparency Platform

Operational Uncertainty Characteristics

Gaussian or *Non-Gaussian*?

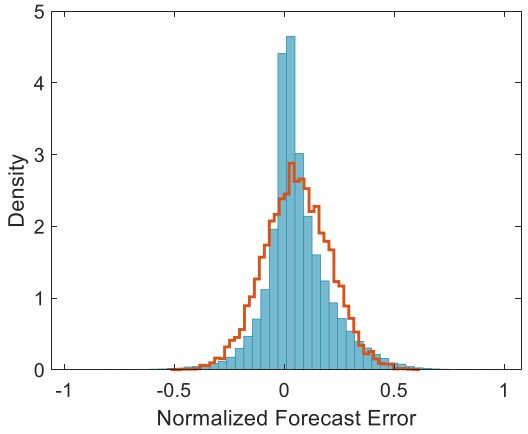


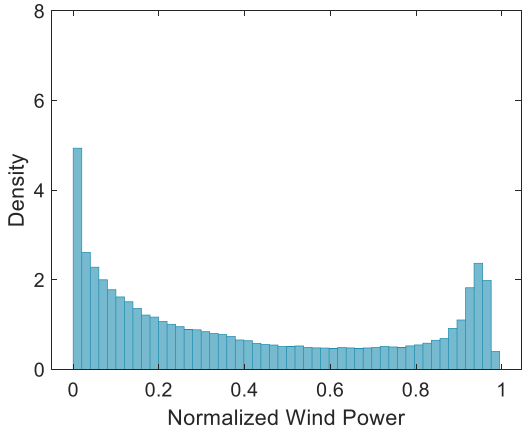
The forecast error itself can be described by a Gaussian distribution. ***However,*** …

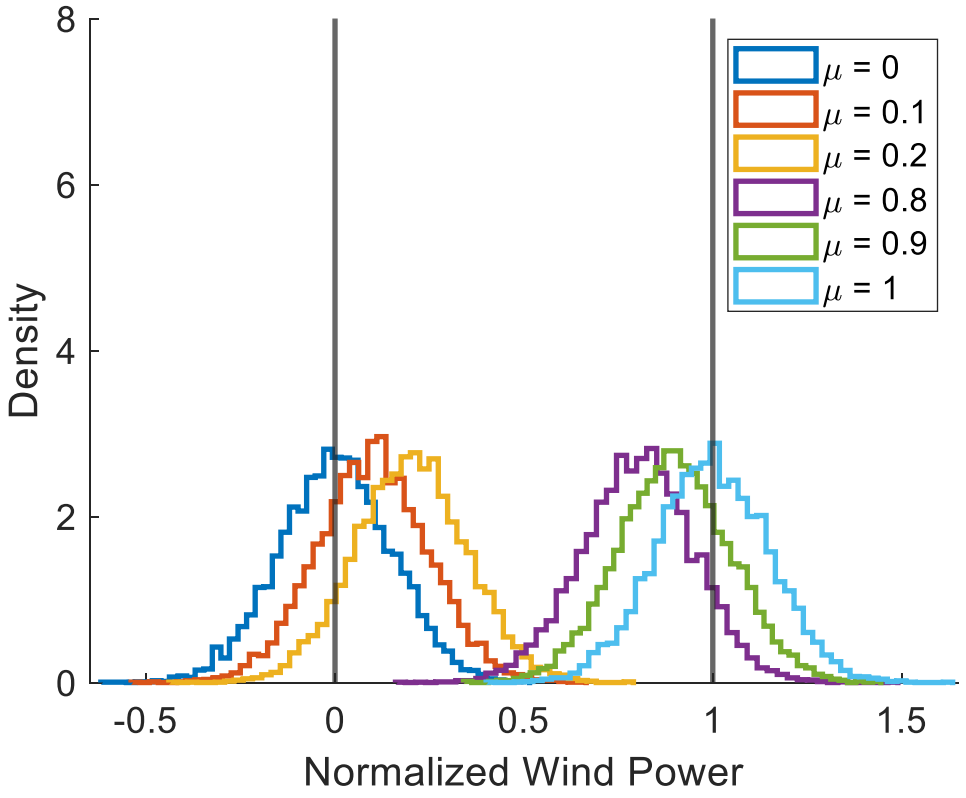
Data Source: https://www.elia.be/en/grid-data/open-data

Operational Uncertainty Characteristics

Gaussian or *Non-Gaussian*?





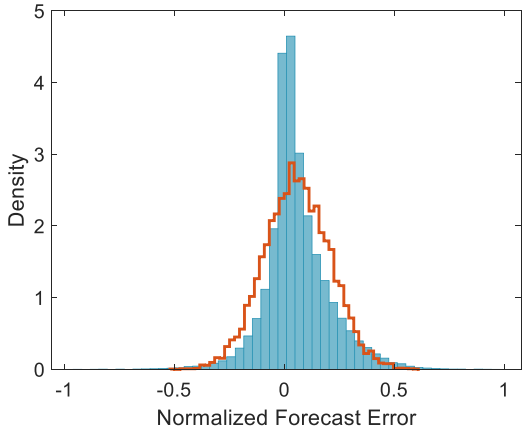


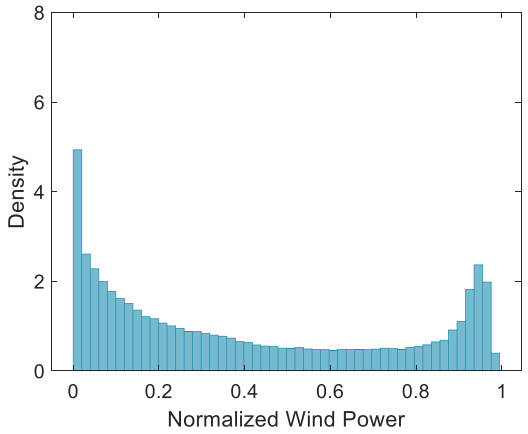
The forecast errors in wind (or RES) power generation ***CANNOT*** be described by Gaussian distributions.

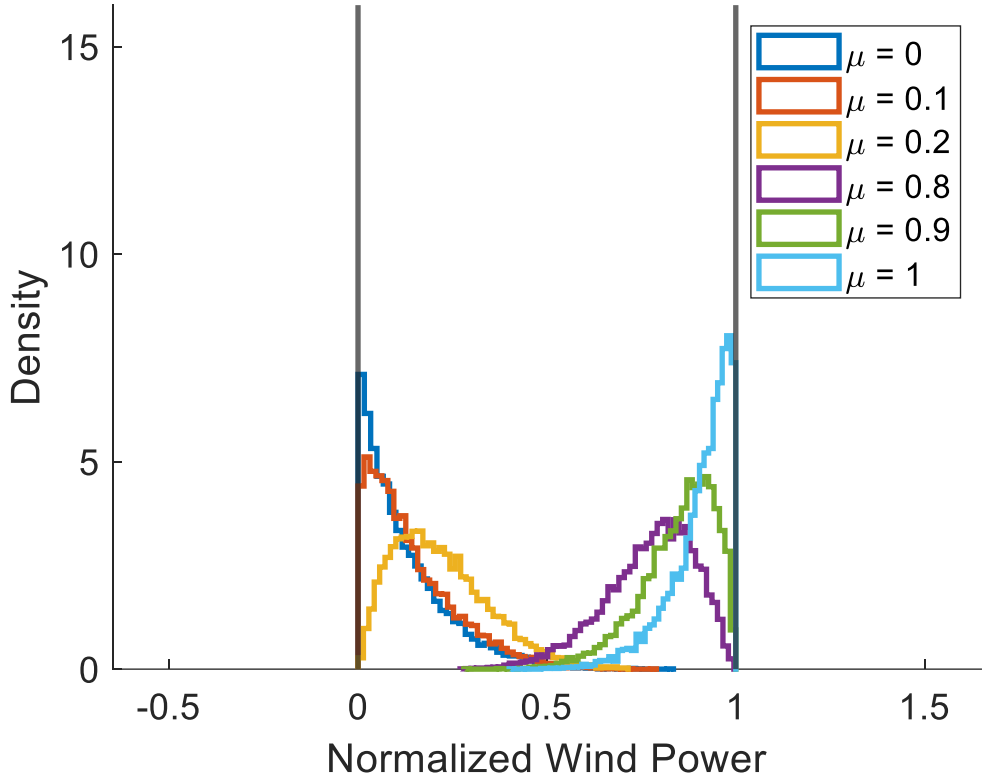
Data Source: https://www.elia.be/en/grid-data/open-data

Operational Uncertainty Characteristics

Gaussian or *Non-Gaussian*?







The forecast errors in wind (or RES) power generation ***CAN*** be described by ***BETA*** distributions[1, 2].

[1] Xu, Y., Dong, Z. Y., Zhang, R., & Hill, D. J. (2017). Multi-timescale coordinated voltage/var control of high renewable-penetrated distribution systems. *IEEE Transactions on Power Systems*, *32*(6), 4398-4408.
[2] Fabbri, A., Roman, T. G., Abbad, J. R., & Quezada, V. M. (2005). Assessment of the cost associated with wind generation prediction errors in a liberalized electricity market. *IEEE Transactions on Power Systems*, *20*(3), 1440-1446.
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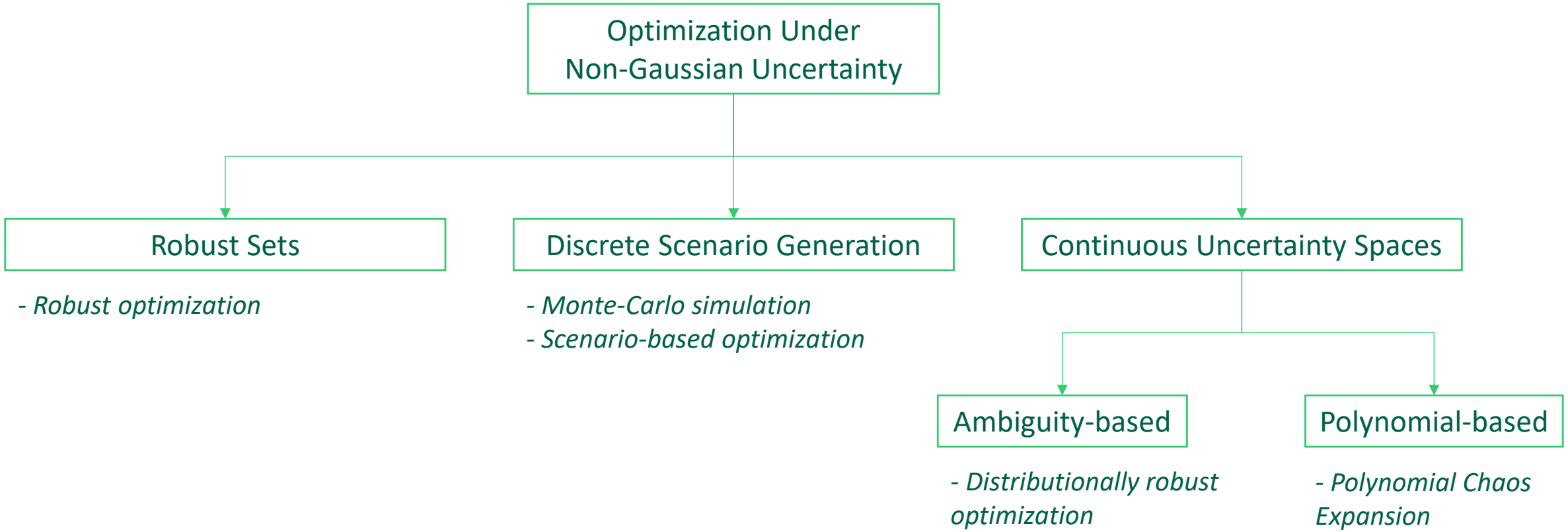
How to Handle Non-Gaussian Uncertainty?



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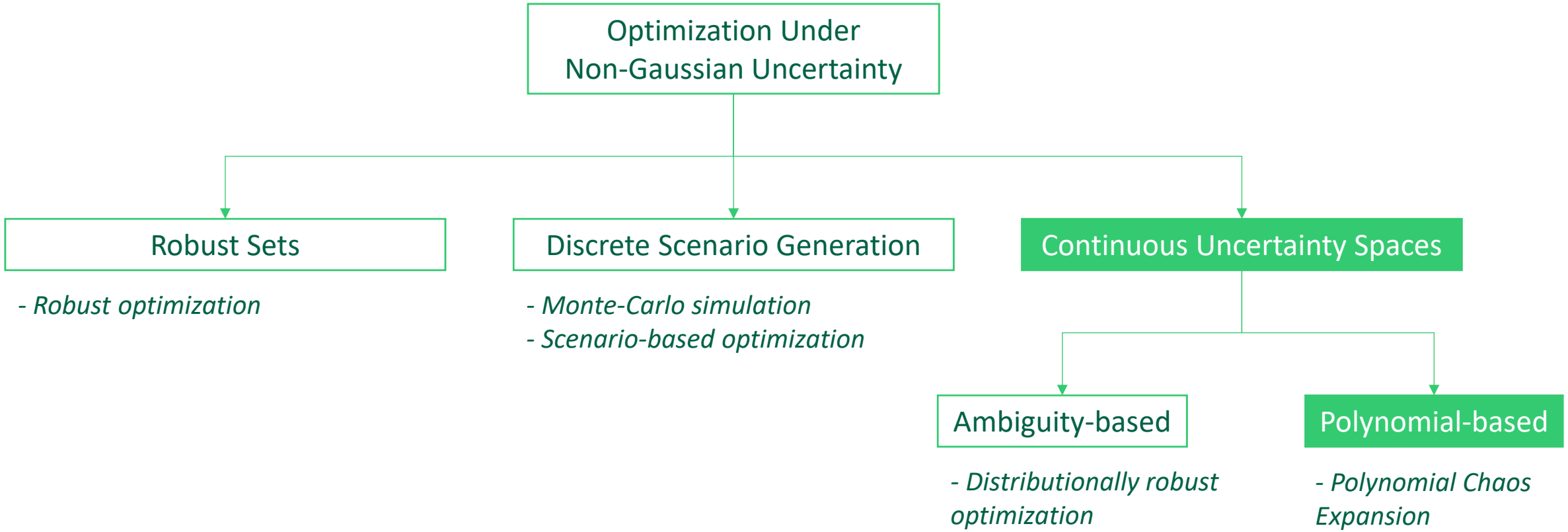
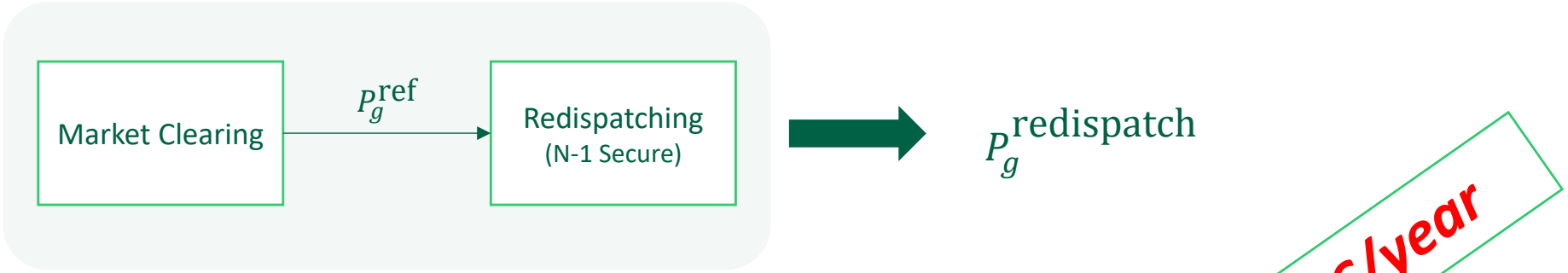


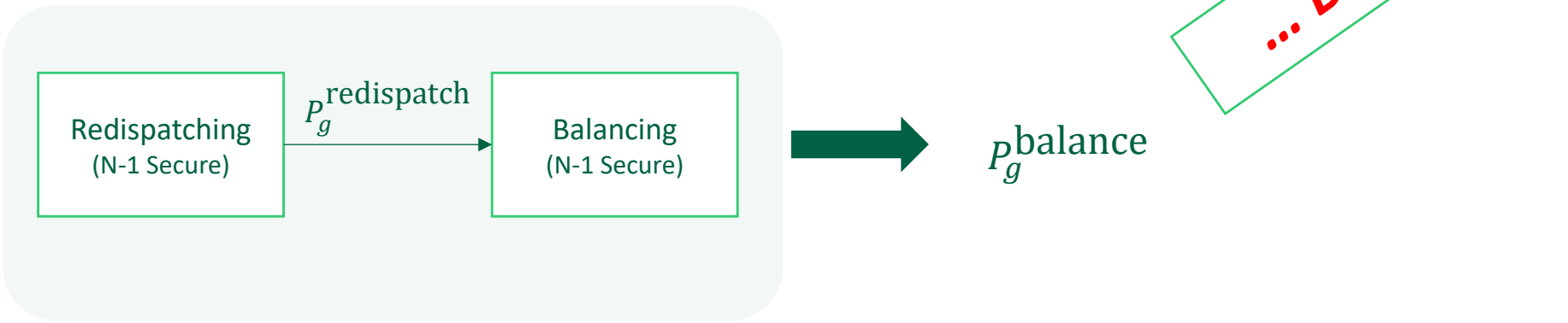
Multi-Stage Model Structure

Traditional Approach

1st Analysis



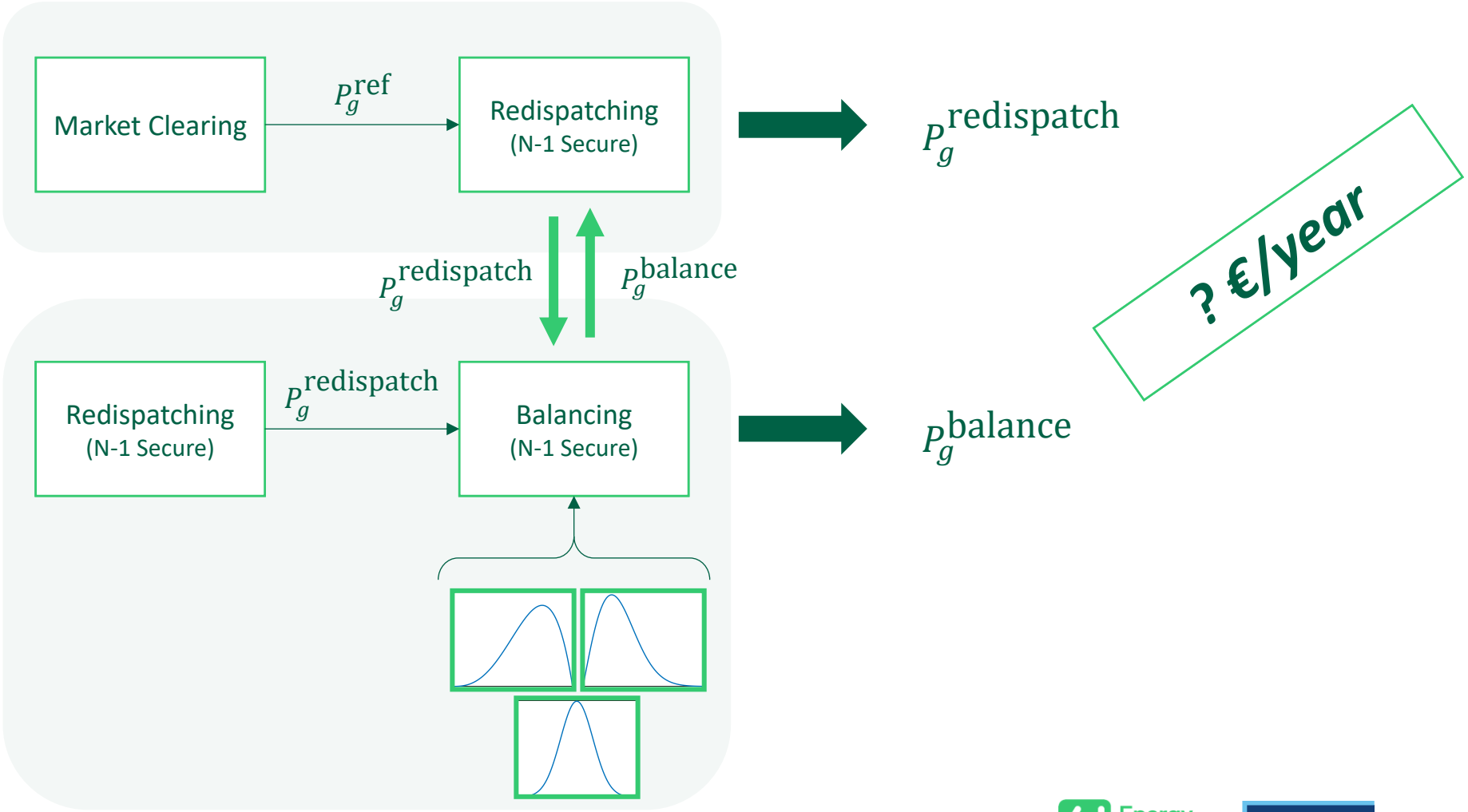
2nd Analysis



Multi-Stage Model Structure

Proposed Model

1st Analysis



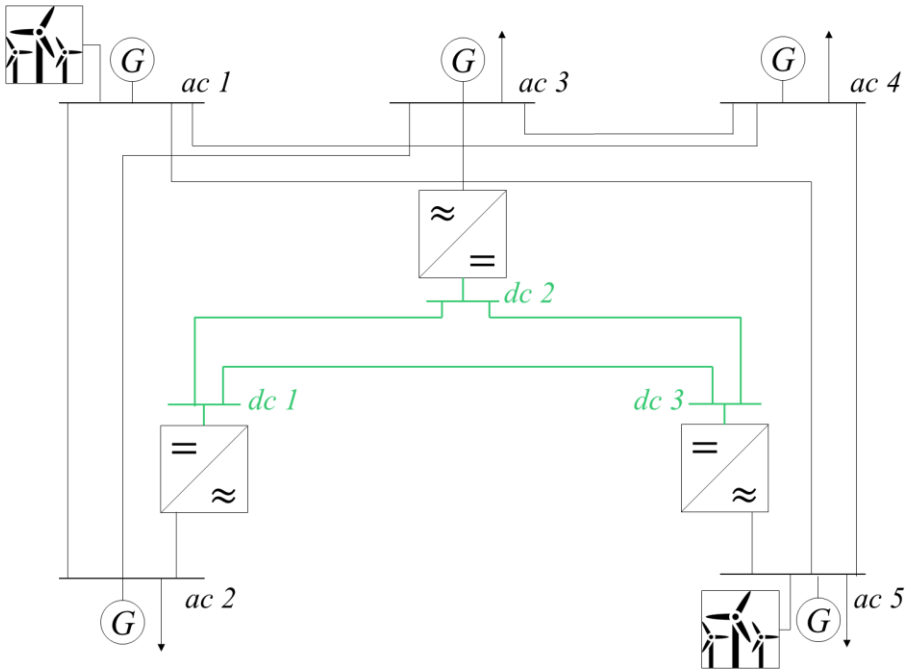
Problem at Hand

Load Uncertainty

RES Uncertainty

Balancing-aware Security-constrained Stochastic Optimal Power Flow for hybrid AC/DC Grids

- The effect of balancing-aware redispatch actions on total cost
- The importance of being able to describe non-Gaussian uncertainty
- The advantages gained by HVDC flexibility



Preliminary Results

The effect of balancing-aware redispatch actions on total cost

	Traditional Approach	Proposed Model	
Expected Redispatch Cost	119.328 M€/year	120.791 M€/year	+1%
Expected Balancing Cost	24.440 M€/year	14.997 M€/year	-39%
Total Expected Cost	143.768 M€/year	135.788 M€/year	**-6%**

The proposed model ***reduces total cost*** without compromising ***N-1 security***.

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Preliminary Results

The importance of being able to describe non-Gaussian uncertainty

	Simplified Gaussian Model	Proposed Model	Mismatch
Expected Redispatch Cost	118.636 M€/year	120.791 M€/year	2%
Expected Balancing Cost	22.697 M€/year	14.997 M€/year	34%
Total Expected Cost	141.333 M€/year	135.788 M€/year	4%

The ***approximation*** of non-Gaussian input random variables as ***Gaussian*** leads to ***significant errors***, resulting in ***inefficient generation dispatch*** and ***inaccurate risk assessment***.

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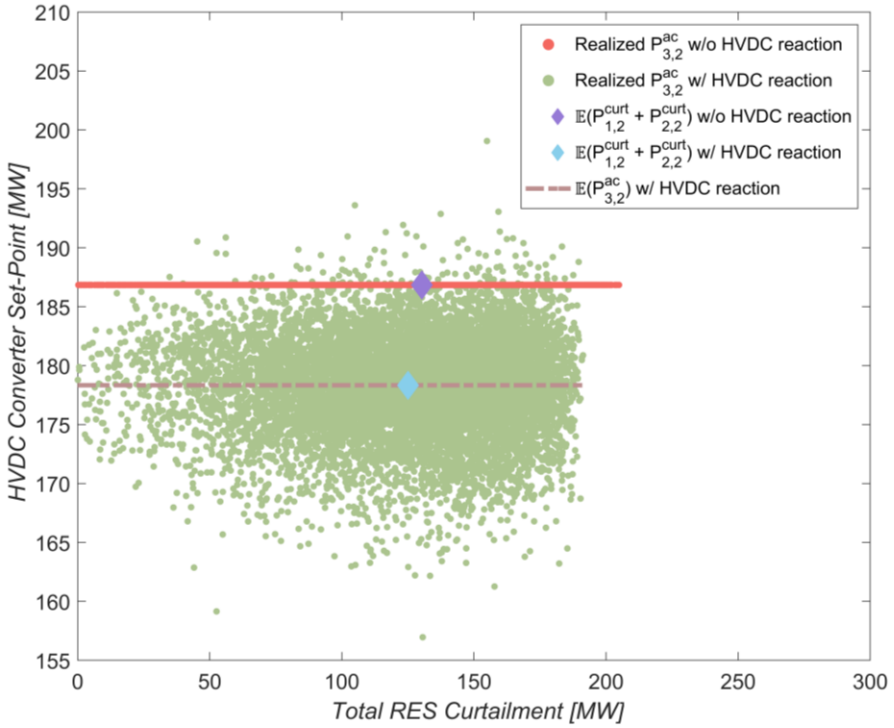
Preliminary Results

The advantages gained by HVDC flexibility



Utilizing HVDC to react to forecast uncertainty leads to:

4.1% reduction in the ***expected*** total ***RES curtailment***.

6.6% reduction in the ***range*** of the probability distribution function of ***total RES curtailment***.

The ***HVDC flexibility*** not only ***lowers the expected RES curtailment*** but also ***mitigates*** the associated ***risks***.

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Conclusion and Future Work

The proposed ***PCE-based*** balancing-aware redispatching tool paves the way for ***tailoring congestion management*** and ***balancing*** strategies of TSOs on ***hybrid AC/DC grids***.

Future extensions of this work involve developing ***more tractable formulations*** and using the tool on ***the Belgian transmission grid***.

An ***open-source*** implementation of the proposed framework will be provided in ***StochasticPowerModels.jl***[1] which is developed on top of the structure of *PowerModels.jl*

[1] https://github.com/Electa-Git/StochasticPowerModels.jl

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Thank you for your attention!

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