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Energy Transmission Competence Hub

RISK and Resilience Day 13 March 2025

Dealing with large-scale offshore wind farm shutdown risk during a severe storm

An adaptive robust optimization approach

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KU Leuven and Etch EnergyVille

Energy Ville

KU LEUVEN

Storm Eunice in February 2022

The Brussels Times

Public transport, air and sea travel disrupted due to storm Eunice

Friday 18 February 2022

By Lauren Walker

INDEPENDENT

Storm Eunice: Schools across UK to close as 'dangerous' weather front approaches

Met Office warns Storm Eunice will be 'one of the most impactful' in years

Emily Atkinson • Thursday 17 February 2022 15:00 GMT • Comments

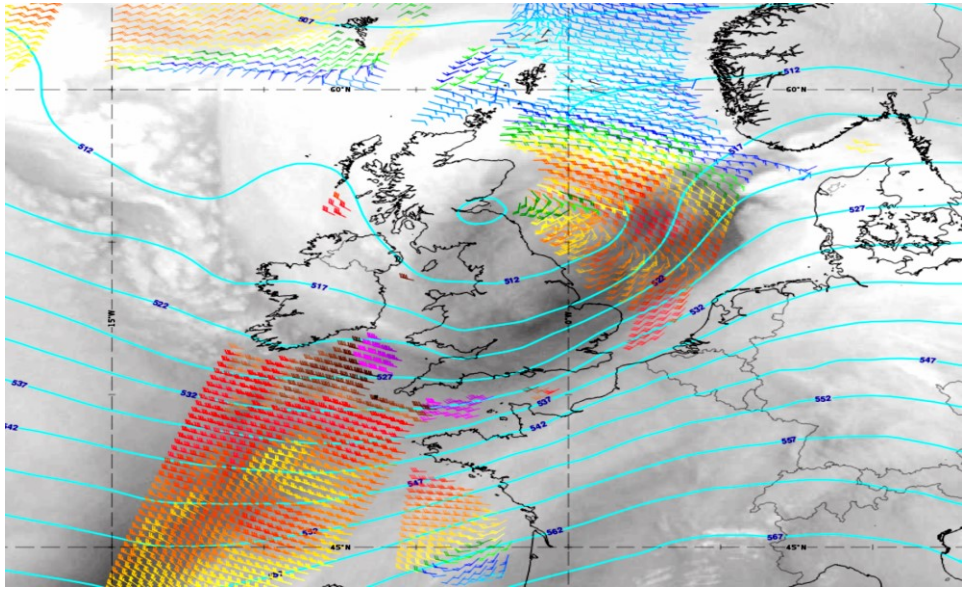
Storm Eunice in February 2022

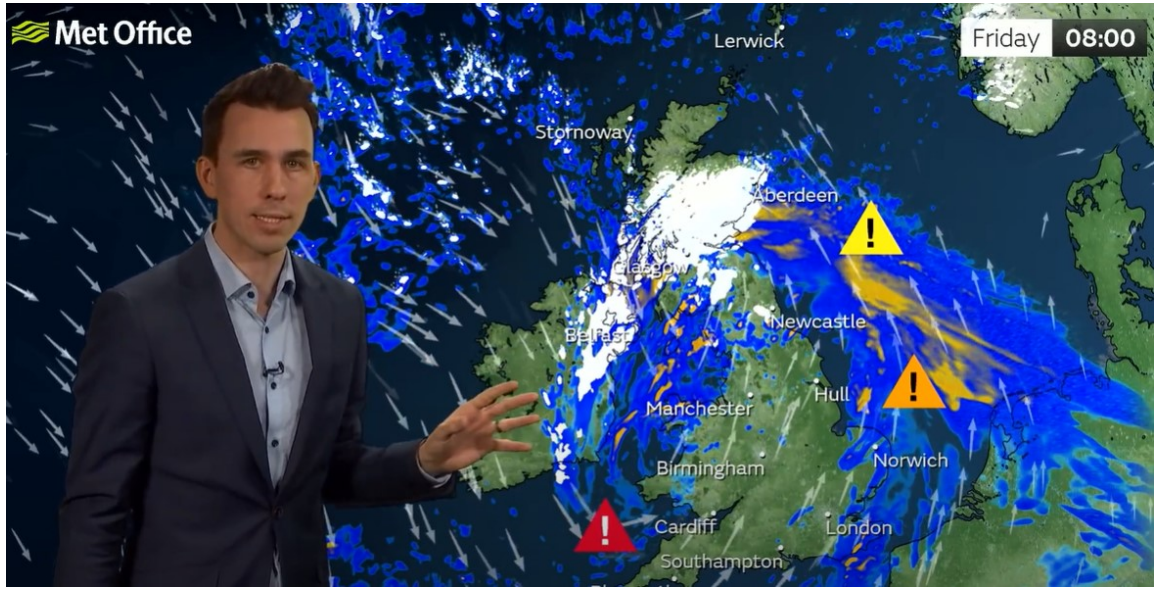
THE STANDARD

NEWS | UK

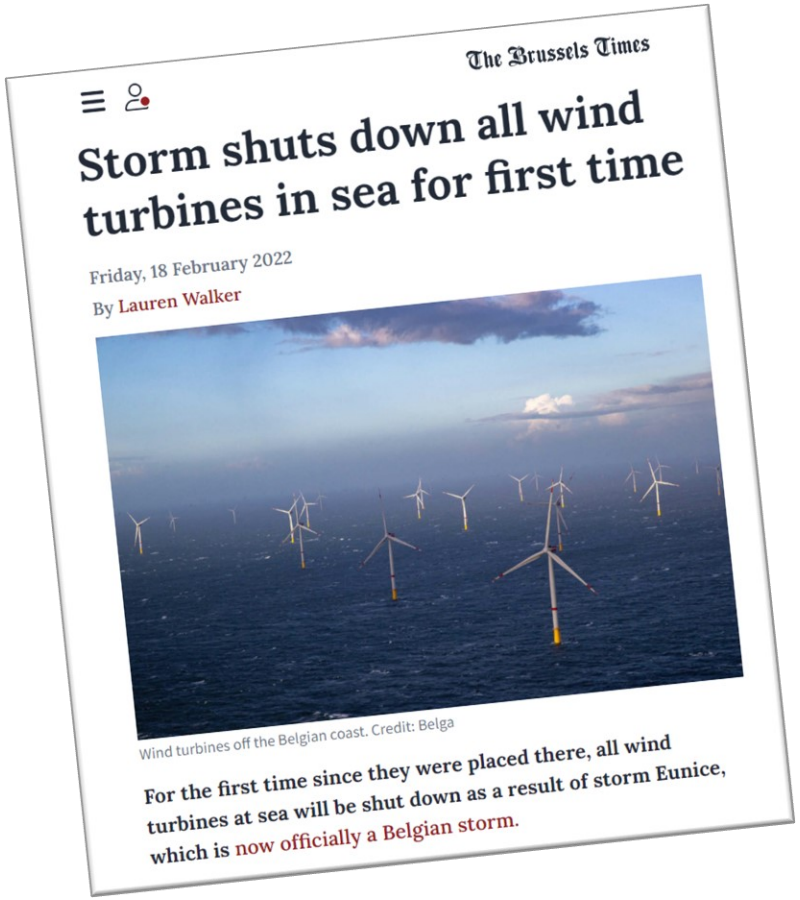
Storm Eunice live: Damage could cost £360m as hundreds of thousands still without power

Storm Eunice in February 2022





Storm Eunice in February 2022



The Brussels Times

Storm shuts down all wind turbines in sea for first time

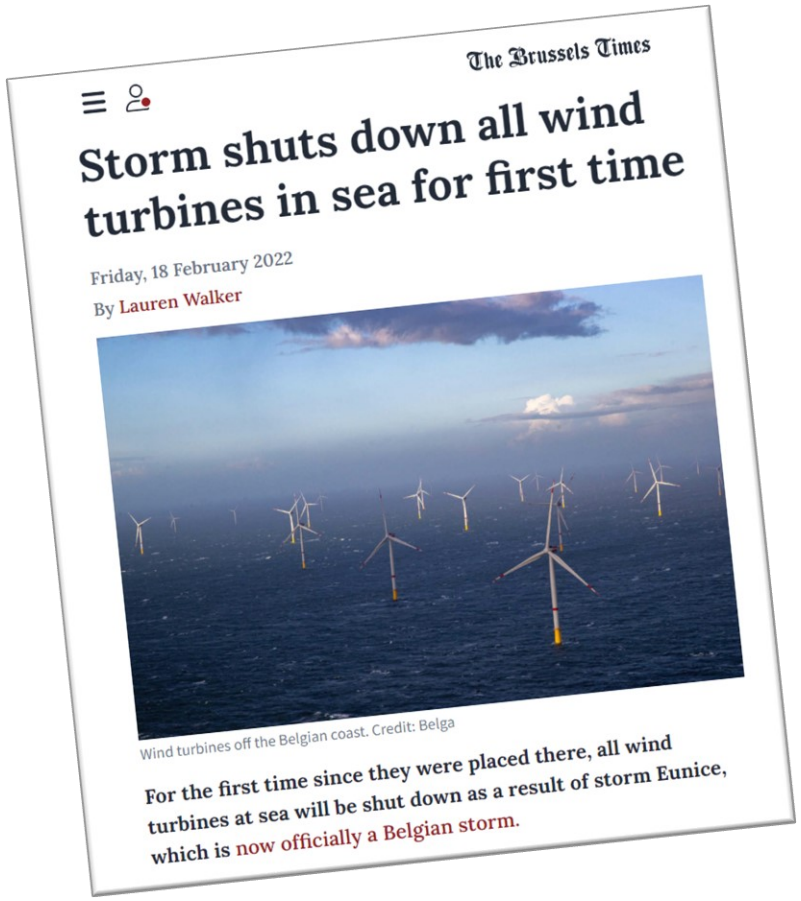
Friday, 18 February 2022

By Lauren Walker

Wind turbines off the Belgian coast. Credit: Belga

For the first time since they were placed there, all wind turbines at sea will be shut down as a result of storm Eunice, which is now officially a Belgian storm.

Storm Eunice in February 2022



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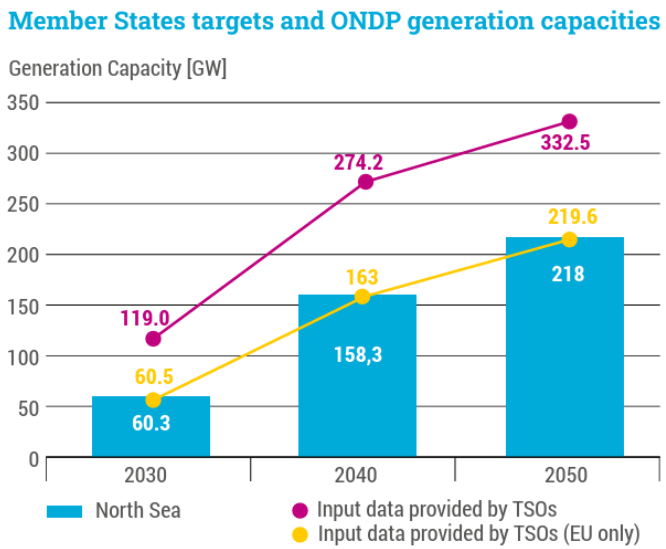
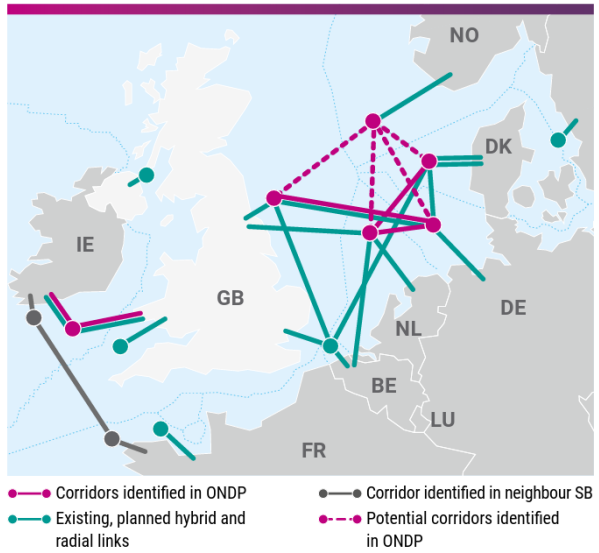
Scheduled shutdown → Curtailment

- Eliminate the risk of massive power fluctuation from the automatic shutdown operation
- Could be too conservative
- Wind energy curtailment

"To curtail or not to curtail—that is the question"

Massive offshore wind farm capacity planned in the North Sea

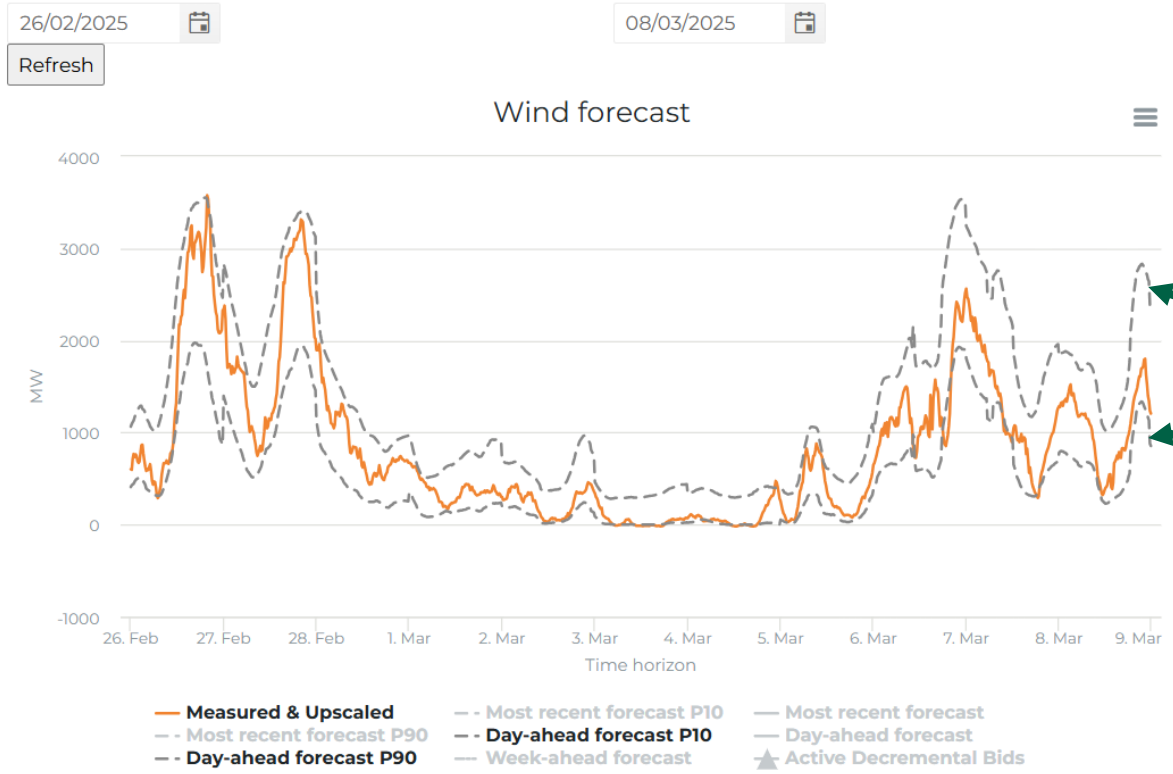




What to do in 2050?

Keep the grid balanced under threat of large-scale offshore wind farm shutdown during a severe storm

Wind forecast

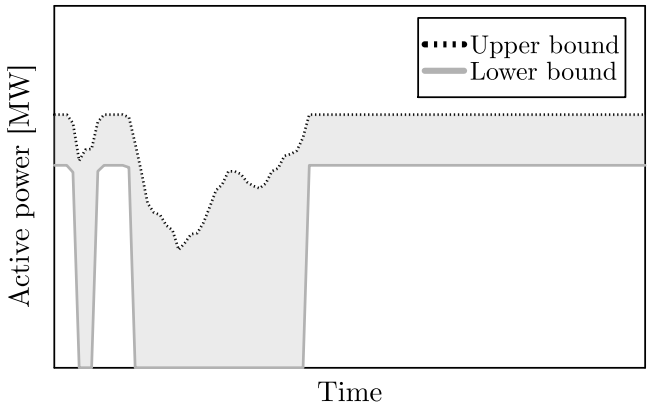


These upper and lower bounds are quite reliable

Our approach

How do we deal with large-scale offshore wind farm shutdown risk?

Wind generation uncertainty intervals considering possible shutdown operation



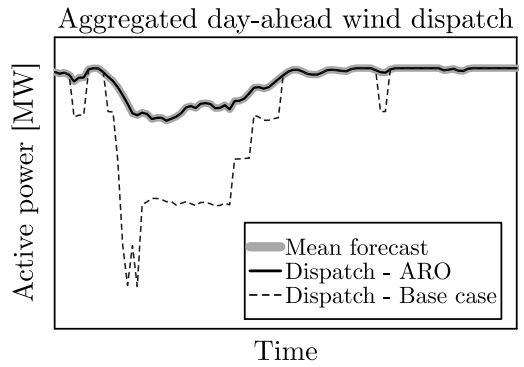
Adaptive robust optimization (ARO) unit commitment model

1st stage — Unit commitment & day-ahead dispatch

2nd stage — Redispatch

Cost efficiency

Offshore wind farm dispatch



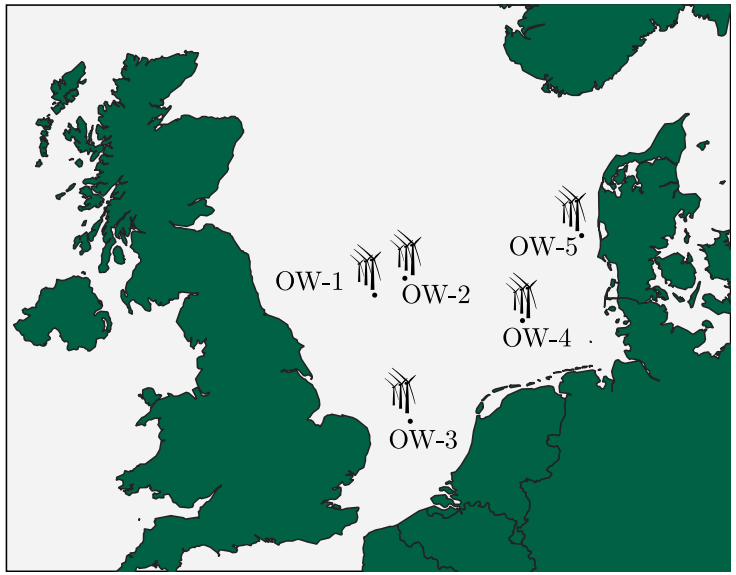
Setup

EVENT

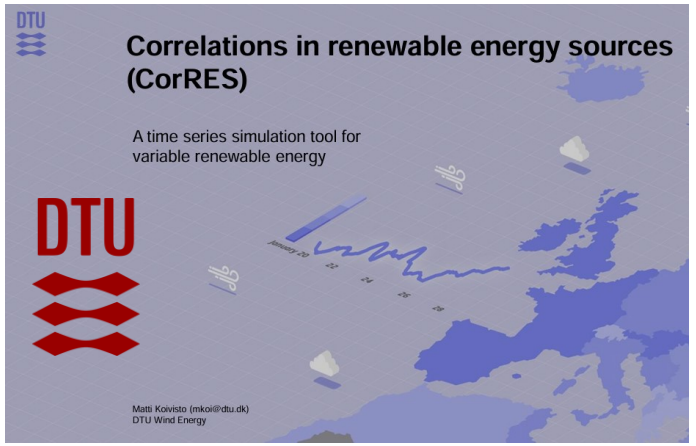
Storm Eunice

16 Feb 2022 18:00
to
17 Feb 2022 17:45

We select 5 coordinates in the North Sea as the locations of the offshore wind farms



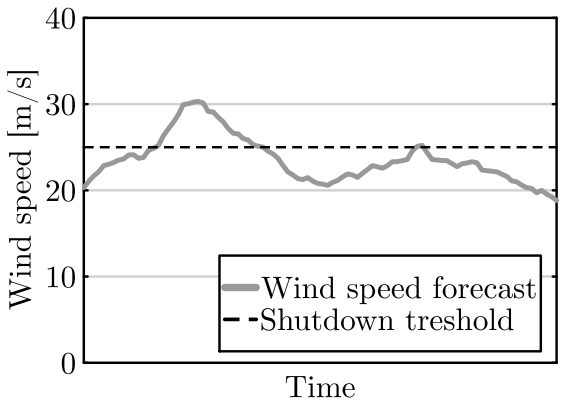
Obtain wind speed and wind power output forecasts using CorRES

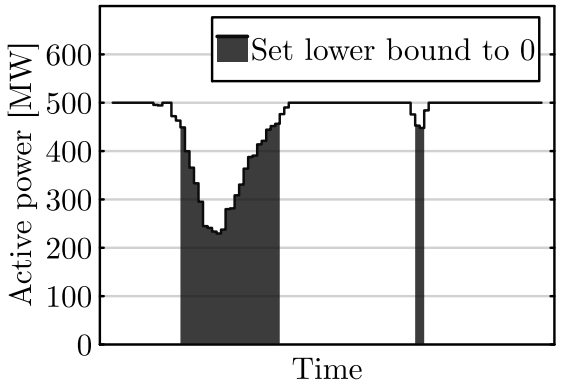


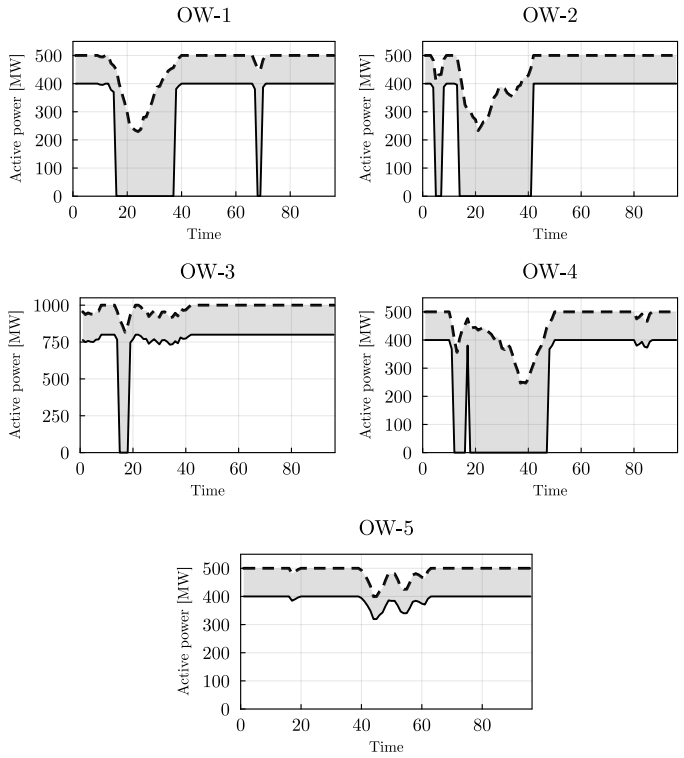
Constructing the uncertainty sets

Define a shutdown threshold wind speed

When the wind speed forecast is higher than the selected shutdown threshold, set the lower bound of the wind power output to 0*

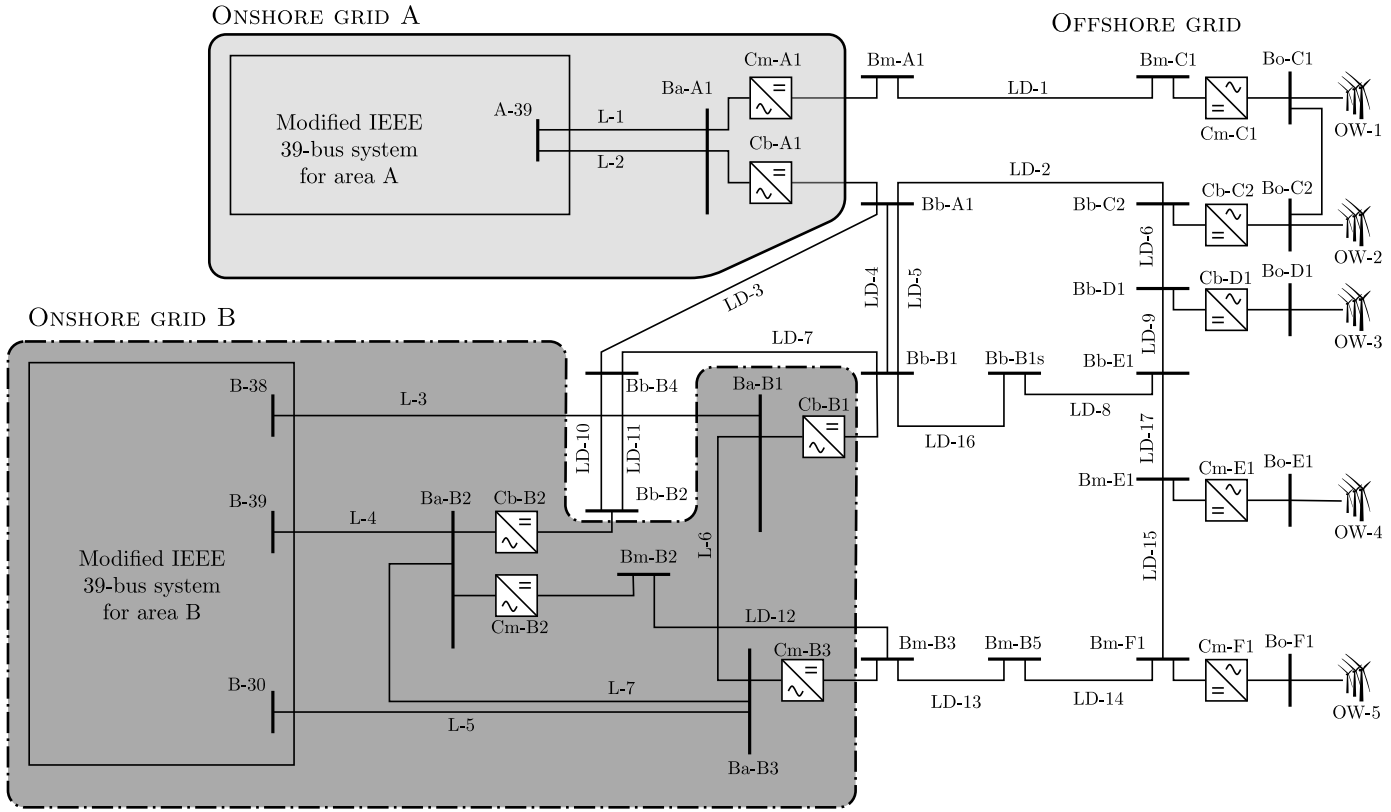


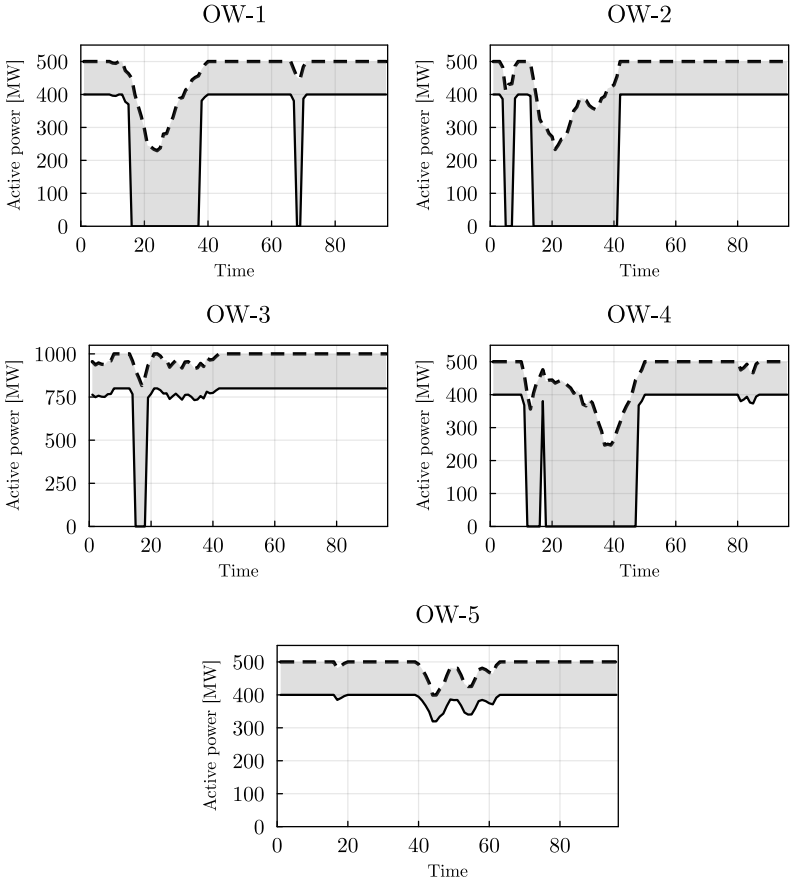




assuming the whole wind farm is shutdown automatically

Test case


Onshore grid A
Modified IEEE
39-bus system
for area A
A-39
L-1
L-2
Ba-A1
Cm-A1
Cb-A1
Bm-A1
Offshore grid
LD-1
Bm-C1
Bo-C1
Cm-C1
OW-1
LD-2
Bb-A1
Bb-C2
Cb-C2
Bo-C2
OW-2
LD-3
LD-4
LD-5
LD-6
Bb-D1
Cb-D1
Bo-D1
OW-3
Onshore grid B
LD-7
Bb-B1
Bb-B1s
Bb-E1
LD-9
LD-8
B-38
L-3
Bb-B4
Ba-B1
Cb-B1
LD-10
LD-11
LD-16
LD-17
Bm-E1
Cm-E1
Bo-E1
OW-4
B-39
L-4
Ba-B2
Cb-B2
Bb-B2
L-6
Modified IEEE
39-bus system
for area B
Bm-B2
Cm-B2
LD-12
LD-15
Cm-B3
Bm-B3
Bm-B5
Bm-F1
Cm-F1
Bo-F1
OW-5
B-30
L-7
L-5
LD-13
LD-14
Ba-B3


OW-1
OW-2
OW-3
OW-4
OW-5
Active power [MW]
Time

Formulation

$$\min_{x_1 \in F_1} \left[\underbrace{\sum_{t \in \mathcal{T}} \left(\sum_{g \in \mathcal{G}} \left(C_g^{on} u_{g,t}^{on} + C_g^{su} u_{g,t}^{su} + C_g^{sd} u_{g,t}^{sd} + C_g^{f} p_{g,t} \right) + \sum_{ow \in OW} C_{ow}^{curt} p_{ow,t}^{curt} \right)}_{\text{Total day-ahead unit commitment and dispatch costs}} + \max_{p_{ow}^{\xi}} \min_{x_2 \in F_2} \underbrace{\sum_{t \in \mathcal{T}} \left(\sum_{g \in \mathcal{G}} C_g^{\Delta\uparrow} p_{g,t}^{\Delta\uparrow} + C_g^{\Delta\downarrow} p_{g,t}^{\Delta\downarrow} + \sum_{ow \in OW} C_{ow}^{\Delta\downarrow} p_{ow,t}^{curt,\xi} \right)}_{\text{Total redispatch costs under the worst-case realization}} \right]$$

$F_1 = \{x_1 \in \mathbb{Z} \times \mathbb{R}$:

- Unit commitment constraints
- AC/DC grid power flow constraints $\}$

$F_2(x_1, \xi) = \{x_2 \in \mathbb{R}$:

- Redispatch constraints
- AC/DC grid power flow constraints $\}$

Solve using a column-and-constraint generation (CCG) algorithm

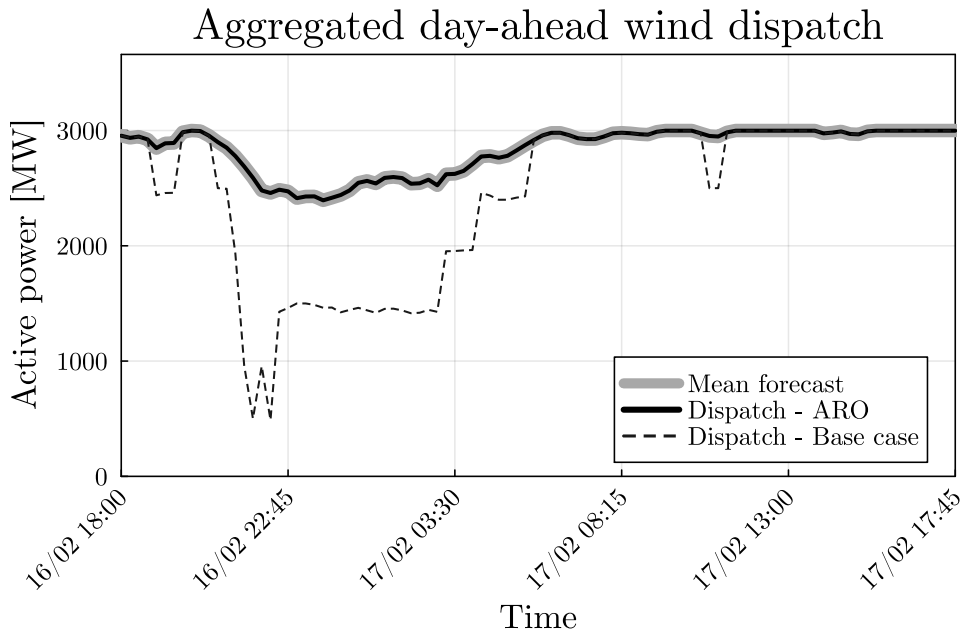
Case study – Results

Base case

Schedule manual shutdown during the storm

ARO approach

Consider uncertainty intervals in the presence of storm



Total day-ahead wind energy dispatch (relative to the base case)

68,029 MWh
(+15%)

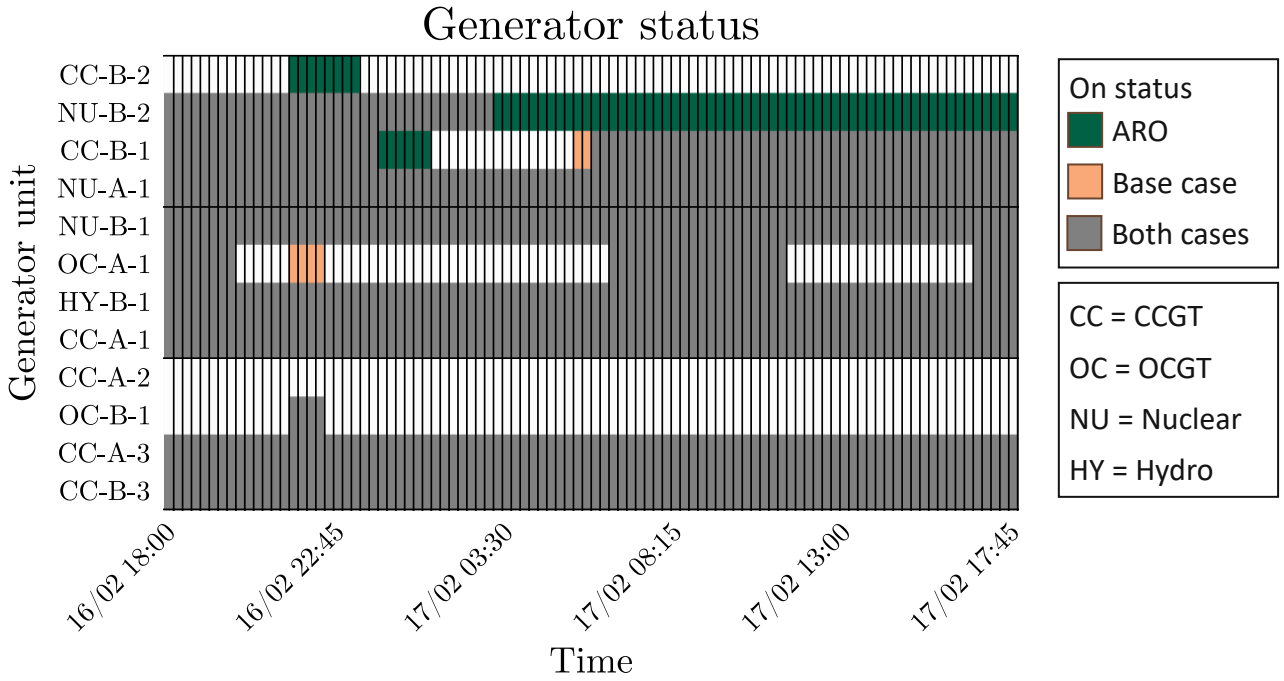
Case study – Results

Base case

Schedule manual shutdown during the storm

ARO approach

Consider uncertainty intervals in the presence of storm



Total day-ahead UC and dispatch costs (relative to the base case)

2,399,320 €

(+3%)

Conclusion

Can we deal offshore wind farm shut down risk during a severe storm?	Yes
What are the consequences?	⇗ More OWF dispatch
	⇗ Secure operation under uncertainty

Further work

- Detailed model of the offshore HVDC grid
  - AC formulation to capture the DC voltage stability
- Refining the weather storm data to wind turbine level

Thank you

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Let's get in touch!