Efficient Acquisition of Generation Reserves to Back-Up Wind

Possible Improvements in Dutch Electricity Markets

Robin Broder Hytowitz[1], Özge Özdemir[2], Paul Koutstaal[2], Benjamin Hobbs[1]

[1]*Johns Hopkins University*

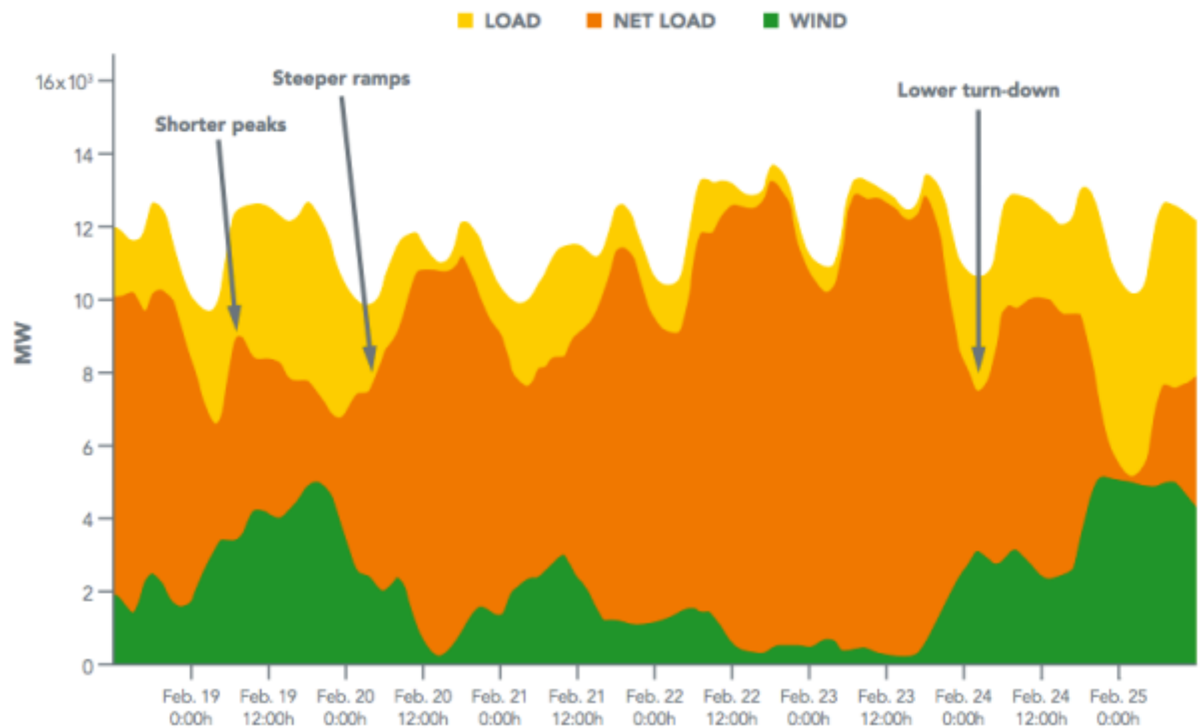
[2]*Energy Research Centre of the Netherlands (ECN)*

The views expressed are solely those of the presenters.

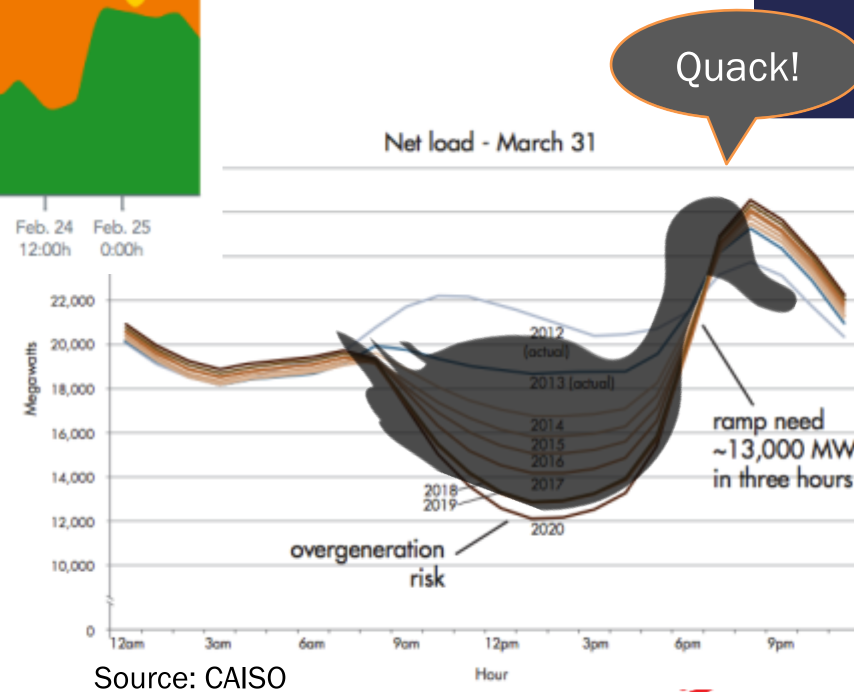
Outline

- Background & Motivation
- Reserve Modeling Framework
  - Types of improvements
  - COMPETES simulations
- Results

Challenges Arising from Wind



Source: Flexibility in 21st Century Power Systems, NREL Report

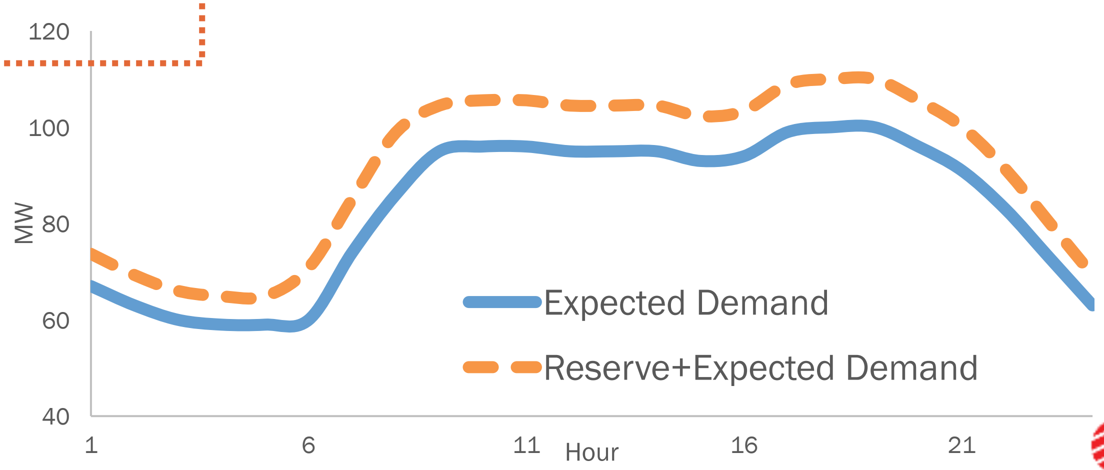


Source: CAISO

Reserve

- **Operating Reserve** is extra capacity (MW) needed in case of contingency
  - Loss of a generator
  - Loss of a transmission line
  - Sudden change in load
  - *Now*: change in renewable energy

Frequency restoration (mFRR), not automatic frequency response

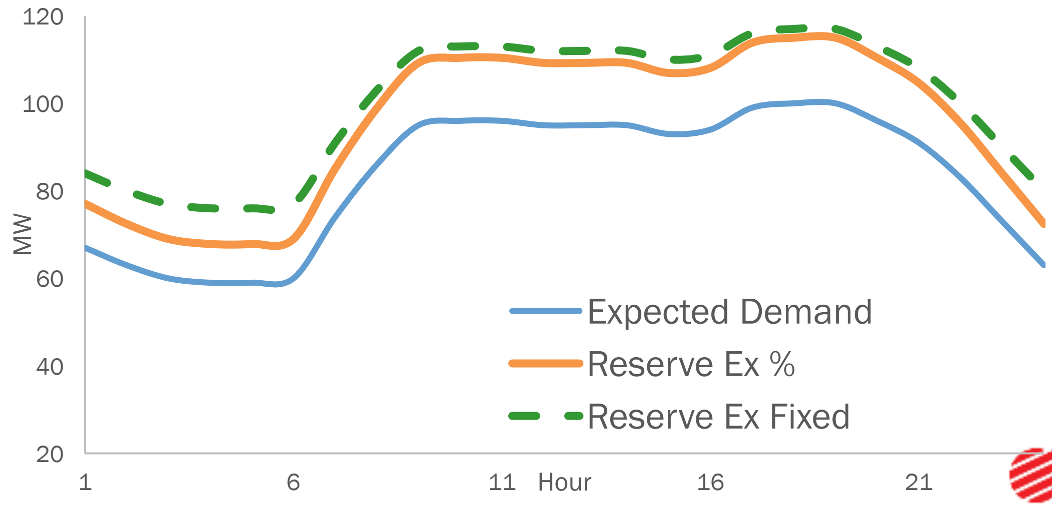


Operational Reserve

1. Size / Procure
   - How much do we need?
   - E.g., extra 30 MW on-line in every hour
2. Allocate
   - Who will be scheduled?
   - Generator B & C will each provide 15 MW
3. Activate
   - Who will provide the energy if actually needed?
   - Deliverability in real time market

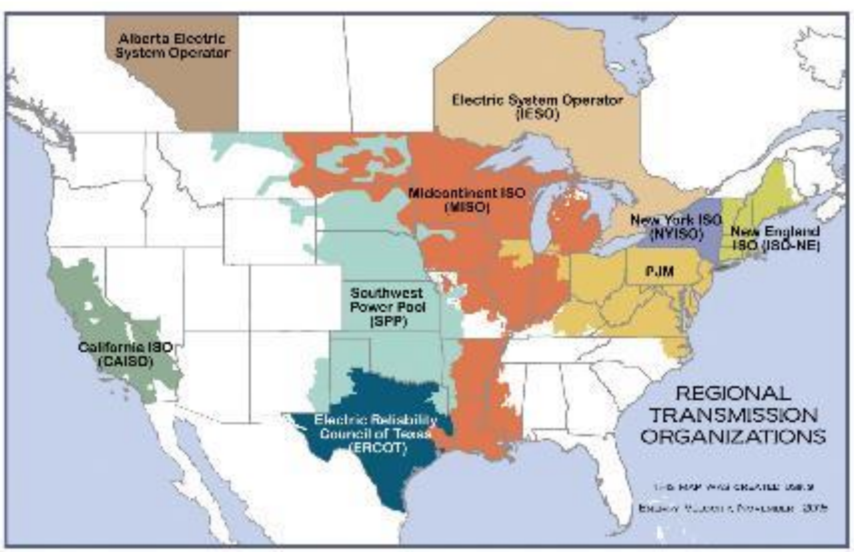
Procurement

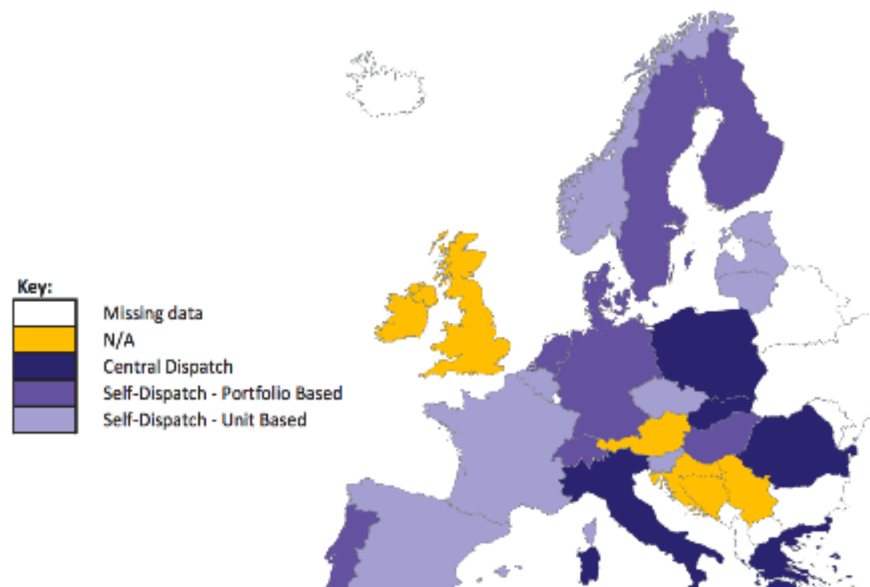
- How much do we need?
  - Often called ’reserve requirement’
  - Examples
    - Capacity of largest generator or transmission line
    - *X*% of demand and *Y*% of renewables for …
      - One day
      - One season



Allocation *Who will be scheduled?*

- Most US markets
  - Market based
    - Primary
    - Secondary
    - Tertiary
  - Determined in zones
- Most European markets
  - Long-term contracts
    - Portfolio based
    - Unit based
    - Some dispatch
  - Determined by country





Source: ENTSO-E

Activation

- Who will actually provide reserves if needed?
  - Generators change energy output level in balancing
    - Contract-based
      - TSO can call on contracted generators to provide reserve in real time
    - Market-based (US)
      - System operator calls on generators selected in the day-ahead for reserve
  - Energy must be deliverable
    - Transmission constraints might limit deliverability within and between countries

ECN-JHU Current Research Question

What changes to market design will most enhance efficiency in procuring/allocating/activating reserve?

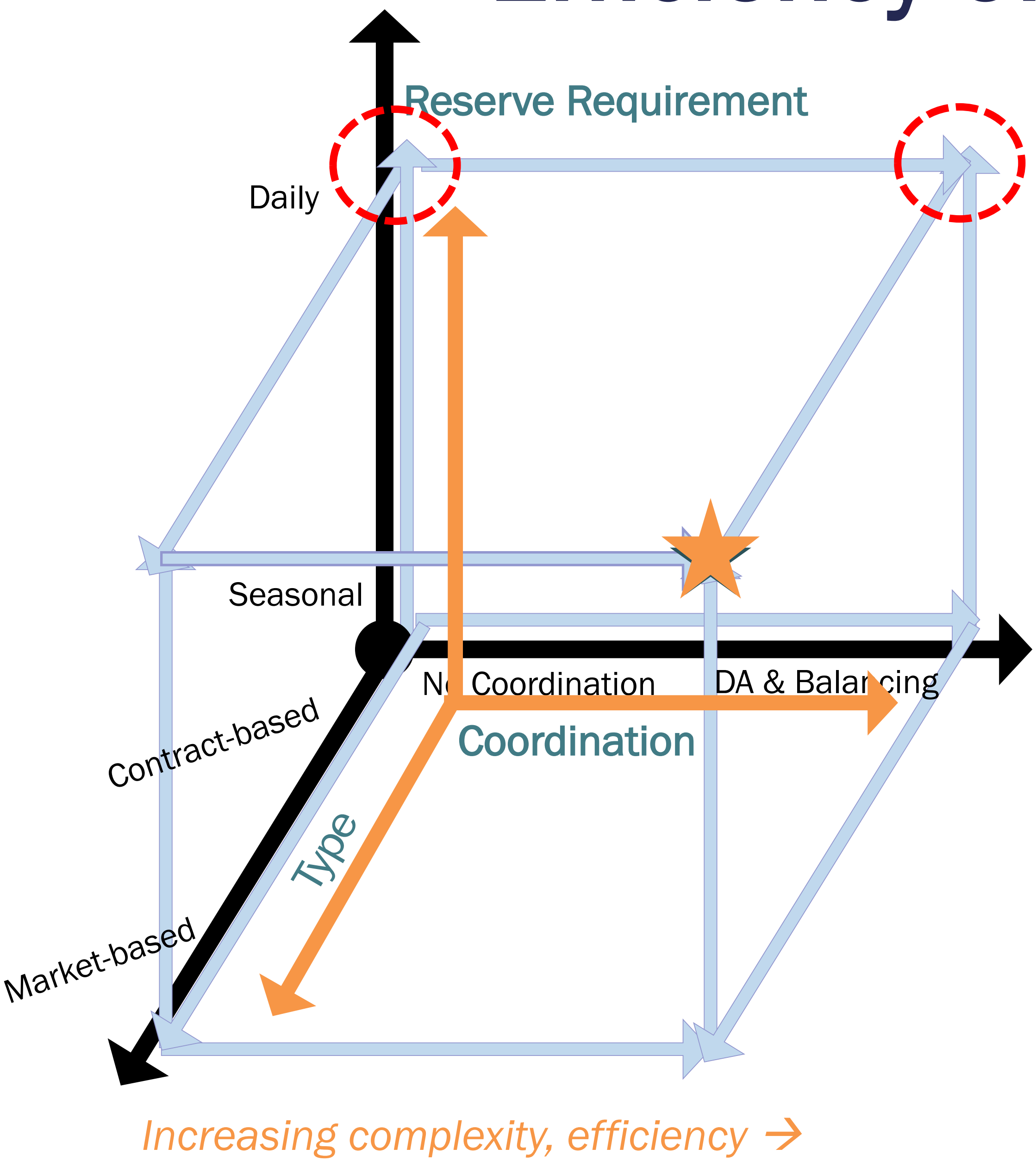
Types of Improvements

- <u>Reserve requirement procurement period</u>
  - Seasonal
    - Current practice, four seasonal periods assessed
  - *Enhancement*: Daily
    - Requirement determined daily
- <u>Allocation type</u>
  - Contract-based
    - Current practice
    - Bi-lateral contracts between TSO and generators
  - *Enhancement:* Market-based
    - Procured through co-optimization with energy market
- <u>Amount of coordination</u>
  - Independently determined, current practice
  - *Enhancement:* Northwest Europe coordinates

Example requirement:
3% of demand and
5% of renewable generation

ECN

Efficiency of Reserve

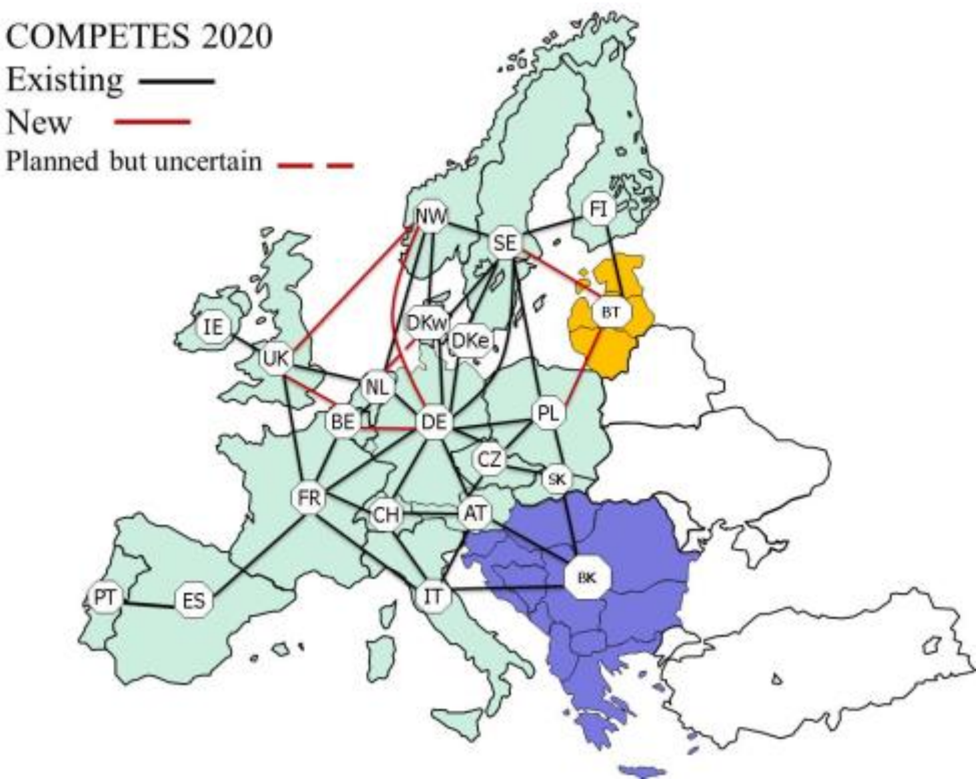


- Each axis shows a different improvement to reserve
- Increasing complexity and efficiency moving away from origin
- Star ★ = hypothetical ideal
- Dot ● = worst case

Thanks to Qingyu Xu

COMPETES Network

- 33 node pan-European network
- Transmission mimics integrated EU network with capacity limited by NTC
- Future generation + potential energy storage
- Renewable scenario based on ENSTO-E 2030 Vision 4 of "European Green Revolution"



Model Formulation: Unit Commitment

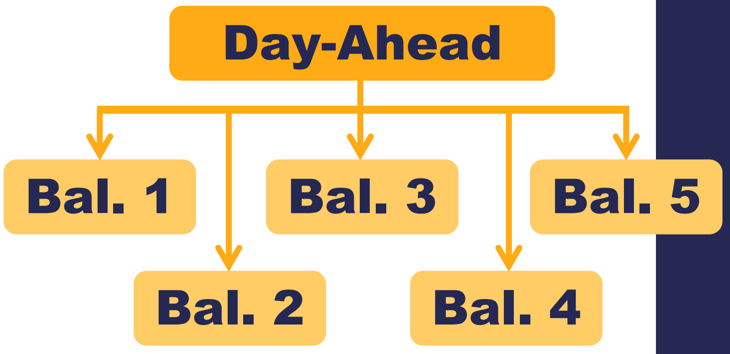
- Min Operating Cost
- Subject to
  - Generator min & max capacity
  - Ramp limits
  - Min up & down times
  - Transmission line capacity & flow (Net Transfer Capacity)
  - Startup & no-load binary constraints / relaxed formulation

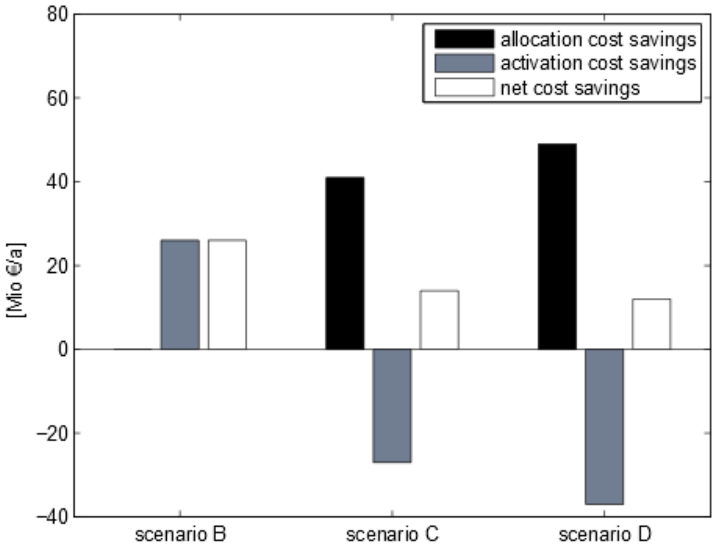
Operational Markets

- Day Ahead
  - Schedules generation for the following day
  - Inputs: bids & offers, forecast for load and wind, reserve sizing
  - Outputs: prices, schedule (on/off), dispatch
  - → Reserve allocation phase
- Balancing
  - Updates schedule to reflect new information
  - Inputs: new bids & offers, updated forecast
  - Outputs: prices, fast start schedule, dispatch
  - → Reserve activation phase
    - Was the right amount procured?
    - Was it allocated to those who could deliver it?

Simulations & Sensitivity Analysis

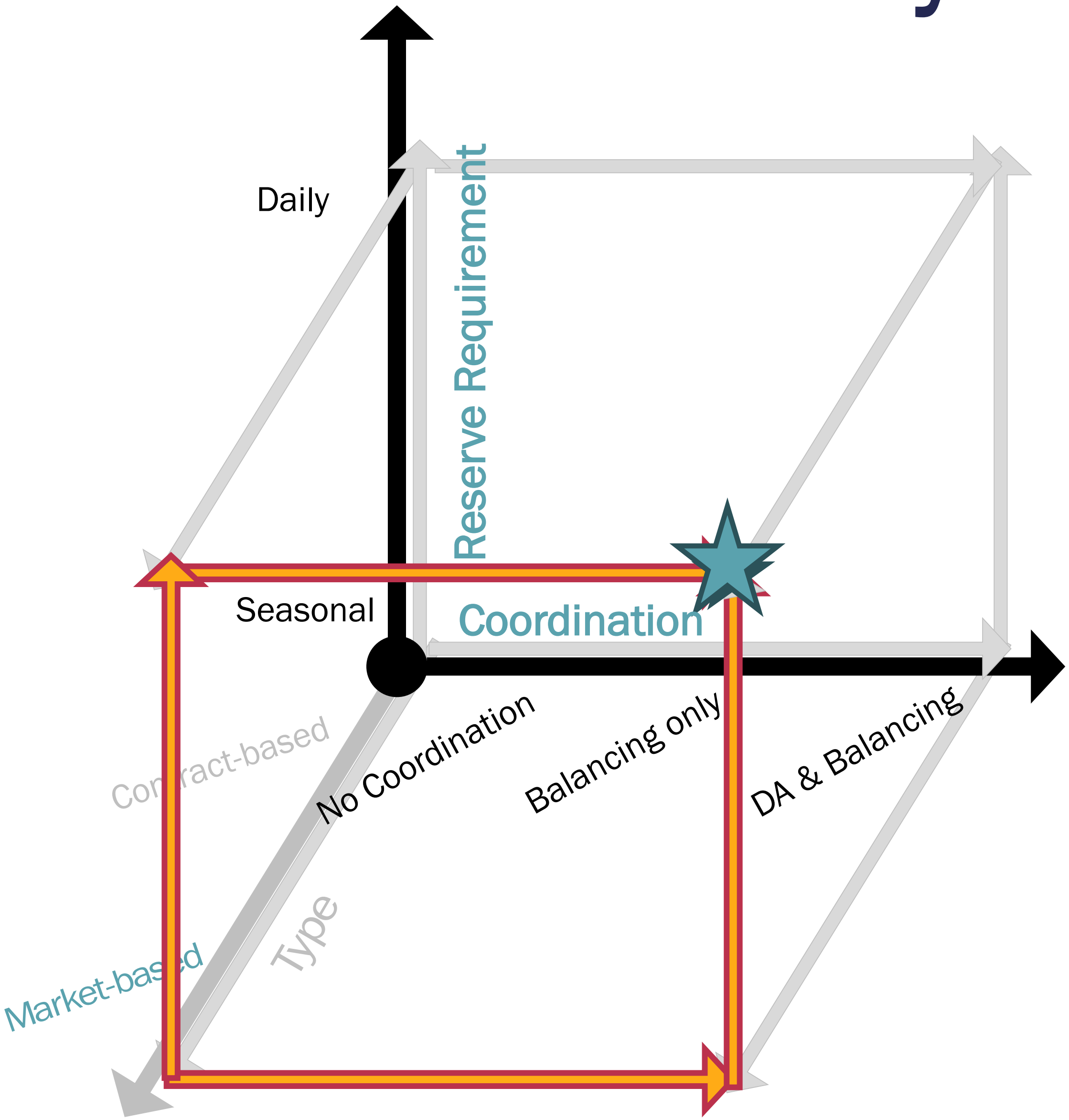
- Simulations
  - Simulated one day-ahead forecast
  - Followed by 5 real-time ”actual” wind realizations
- Results show mean of 5 simulations
  - Error bars show minimum and maximum deviations
- Added an extra coordination component
  - Due to results found by K. van den Bergh in [4], we consider coordination in balancing alone with no coordination in day-ahead





K. van den Bergh, [4]

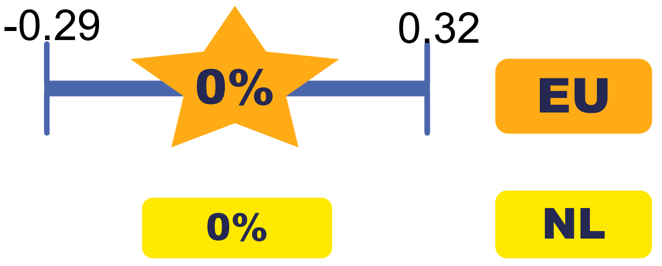
Efficiency of Reserve



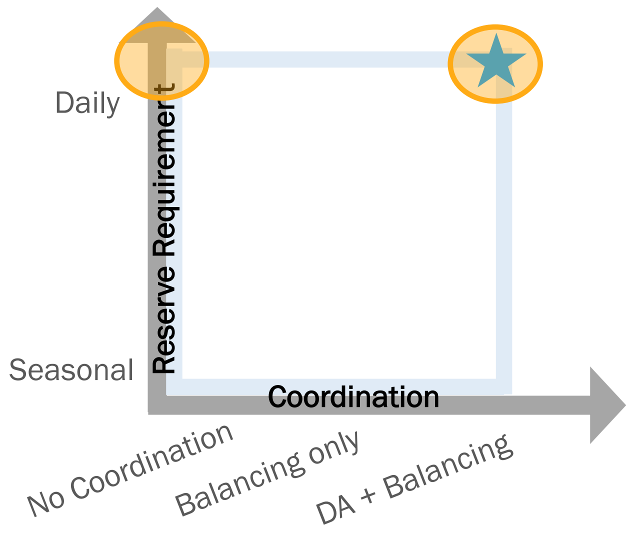
- Each axis shows a different improvement to reserve
- Increasing complexity and efficiency moving away from origin
- Star ★ = hypothetical ideal
- Dot ● = worst case

Operating Costs

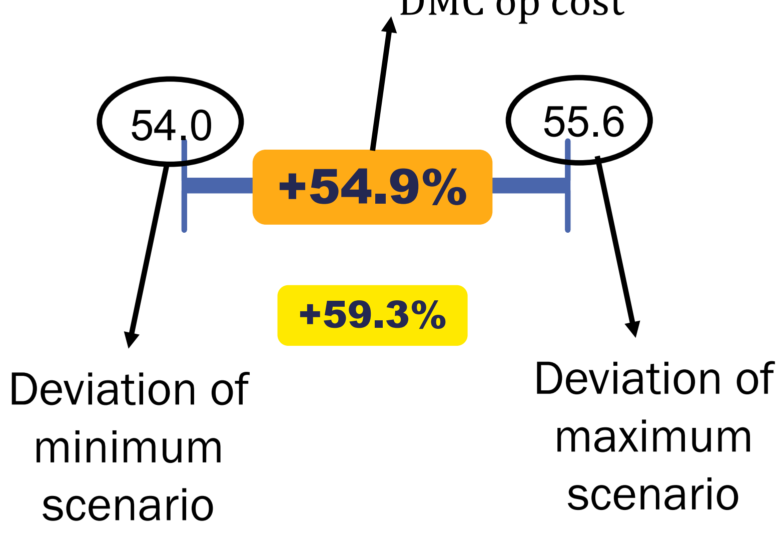
- Example results comparing
  - Star, 'ideal case' (DMC)
    - Reserve size based on daily average
    - Market-based allocation
    - <u>Coordination in day-ahead and balancing</u>
  - Rectangle (DMN)
    - Reserve size based on daily average
    - Market-based allocation
    - <u>No coordination</u>



$$54.9\% = \frac{\text{DMN op costs} - \text{DMC op cost}}{\text{DMC op cost}}$$

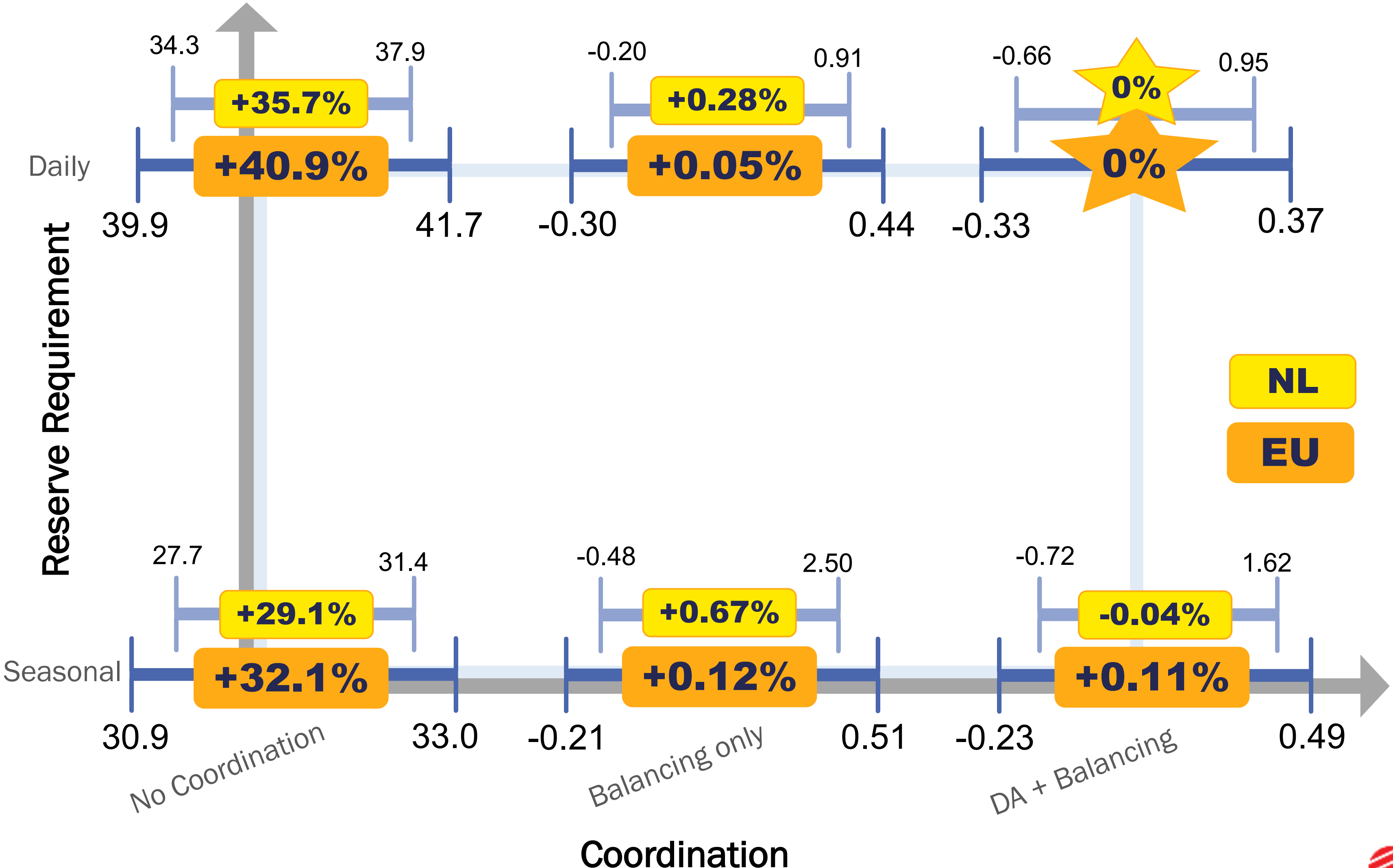


<u>54.9%</u>:
20% load shedding
80% generation deviations



Results – operating cost

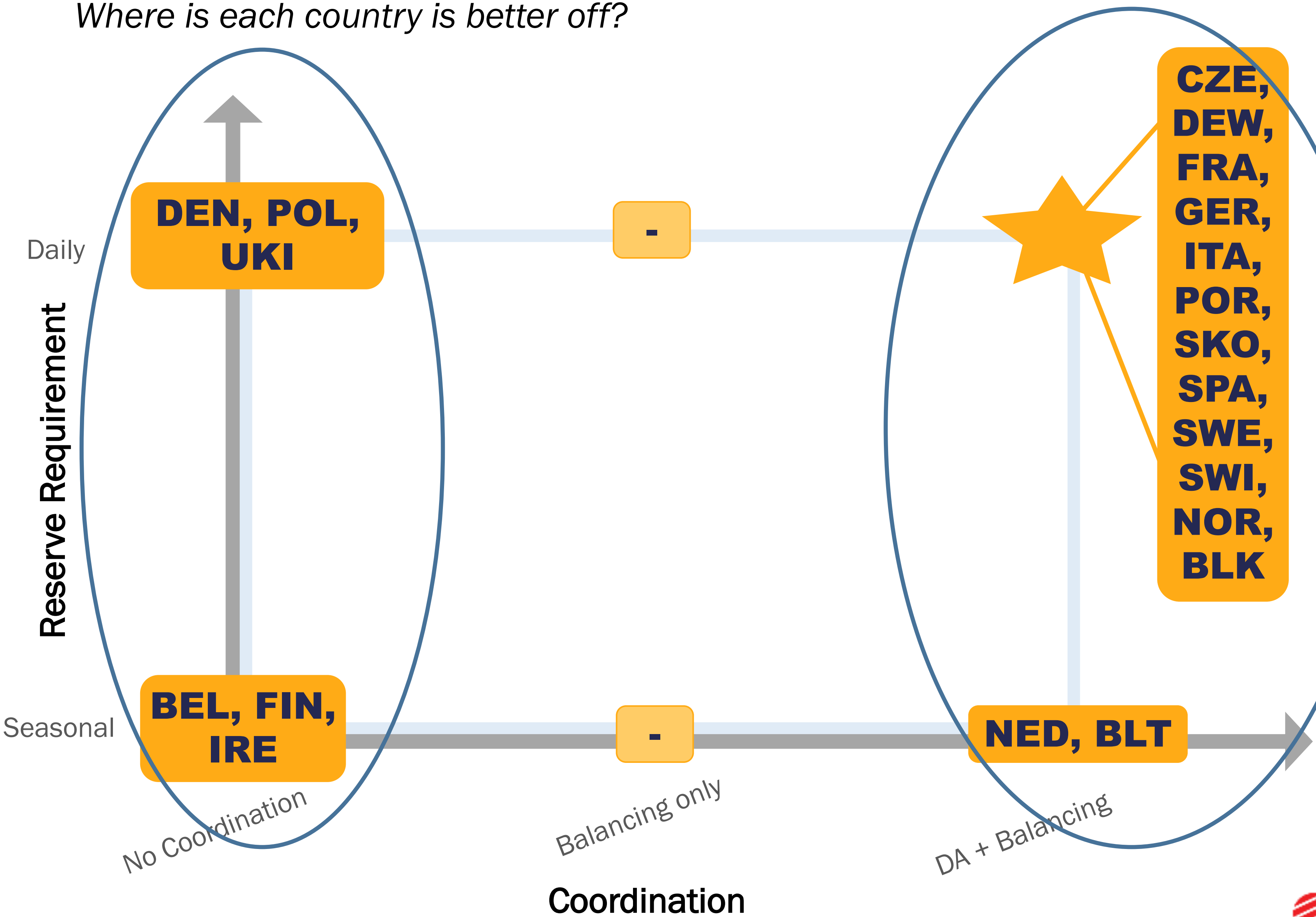
% deviations from 'ideal' case *without load shedding*



ECN

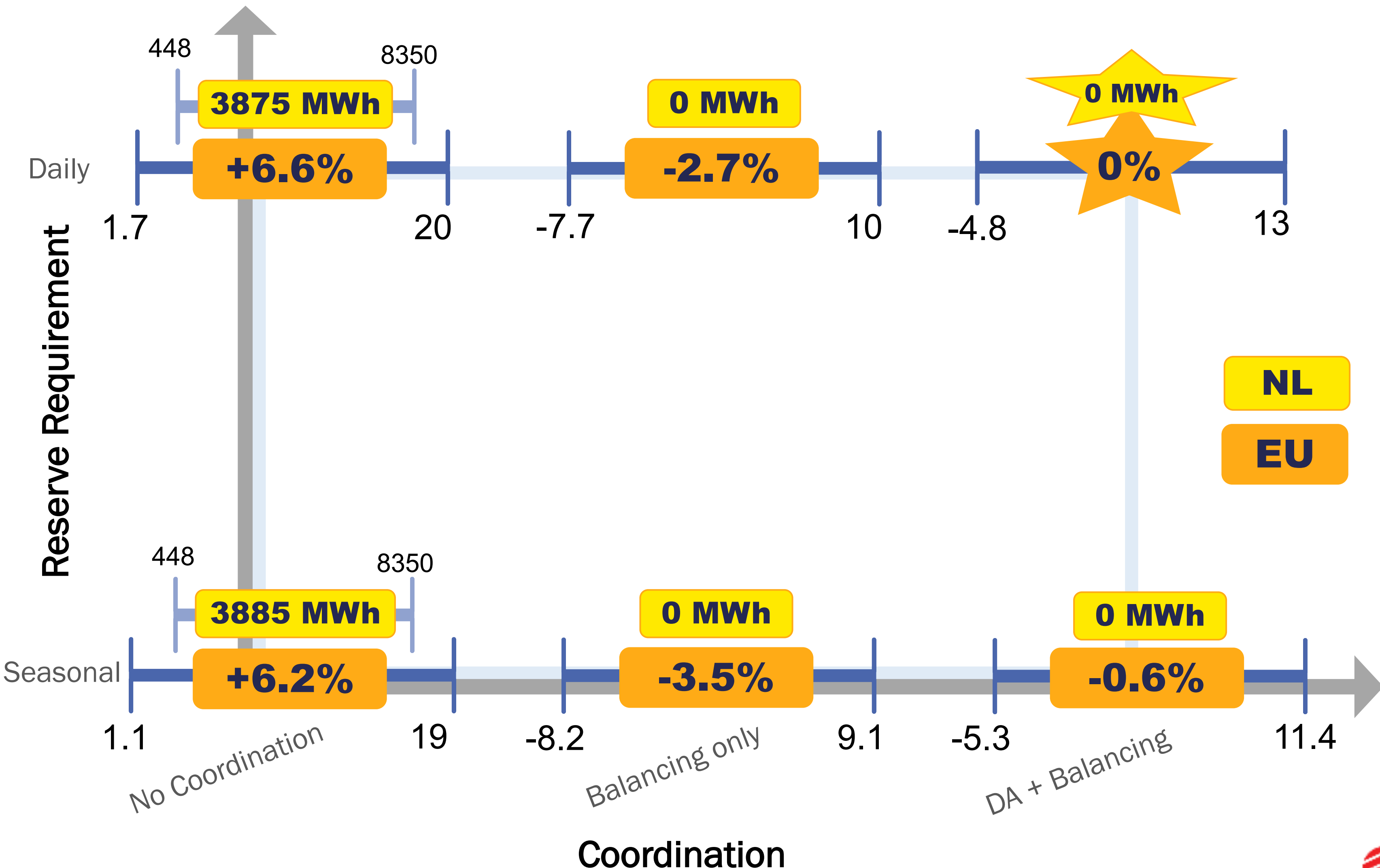
Lowest Cost Solution by Country

Where is each country is better off?



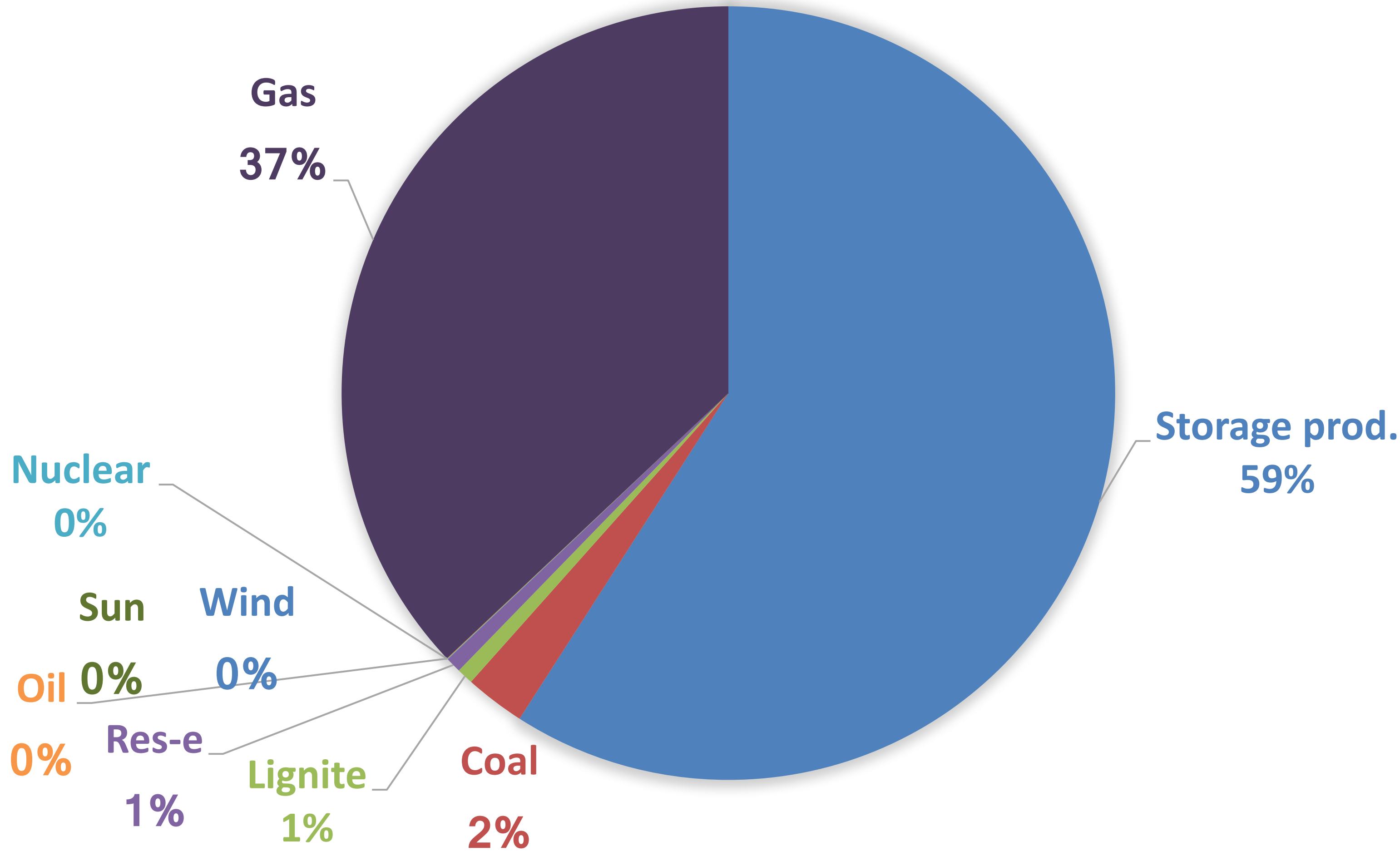
Results – wind curtailed

% deviations from 'ideal' case, NL data in MWh



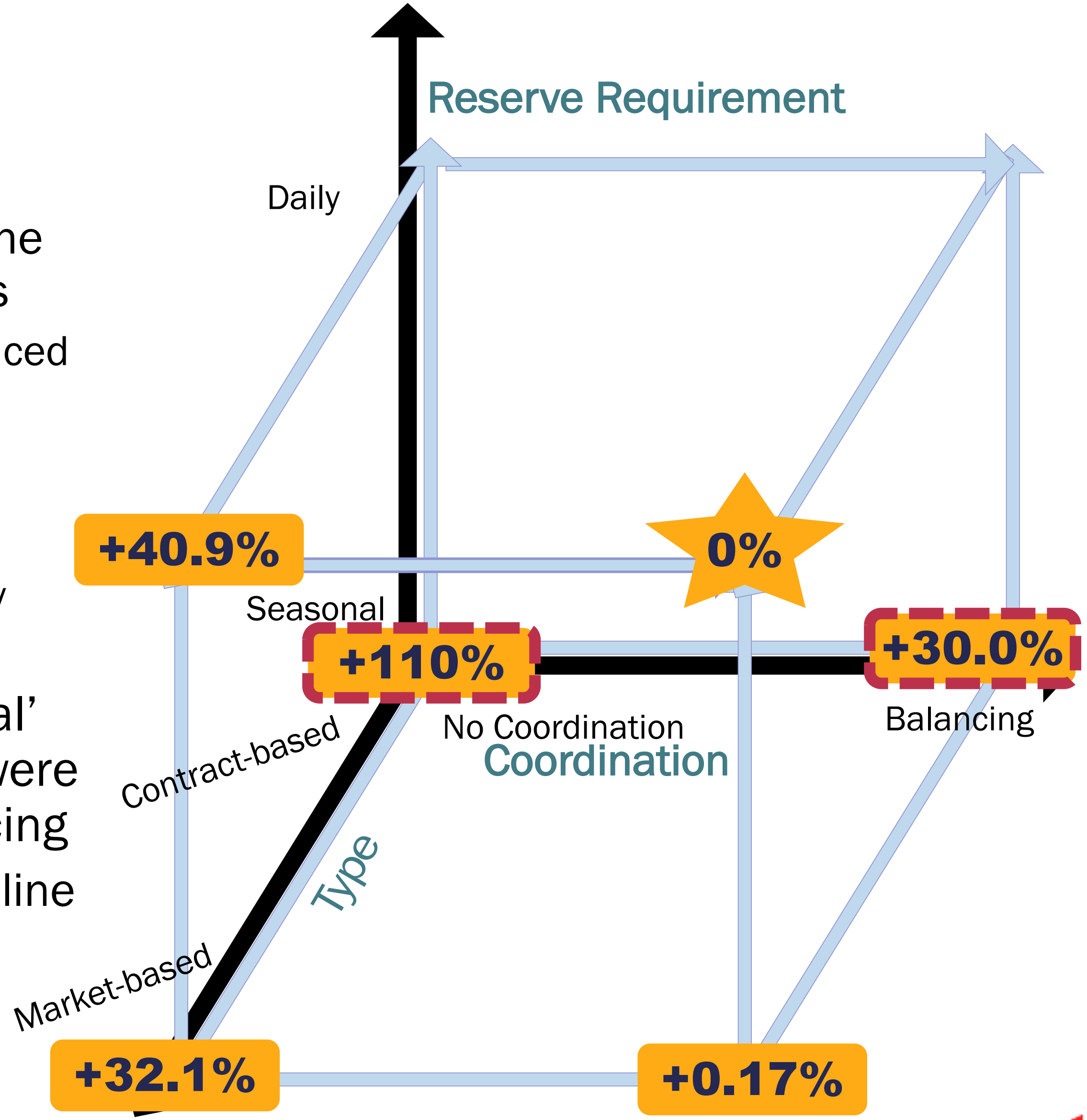
Reserves: Source Fuel

All market based simulations showed similar percentages



Contracted Reserve Cases

- All contracted cases showed **higher costs**
  - Some cases were double the cost of the market-based cases
    - Some countries faced significant load shedding
    - Wide difference in operating costs country by country
- Fewer MWh of **wind curtailment** than ‘ideal’ case when reserves were coordinated in balancing
  - Additional plants online meant lower curtailment



Conclusions

Three Suggested Improvements:

1. Difference between daily vs. seasonal requirement is minimal
2. Coordination in balancing achieves almost all benefit, or can produce better solution
3. Naïve contracts for reserves produce least efficient solution compared to market
   - Coordination in reserve allocation & balancing might make up for higher costs

Other Observations

- More coordination may lead to more wind curtailment
  - Possibly due to location of reserve within country
  - Consideration of forecast uncertainty and wind farm location can reduce curtailment
- Storage can provide a significant amount of reserve

ECN

References

[1] S. Kasina, S. Wogrin, and B.F. Hobbs, “A comparison of unit commitment approximations for generation production costing,” Working Paper, Johns Hopkins University, 2014.

[2] Ö. Özdemir, F. Munoz, J. Ho, and B.F. Hobbs, “Economic Analysis of Transmission with Demand Response and Quadratic Losses by Successive LP,” *IEEE Trans. Power Syst.*, DOI: 10.1109/TPWRS.2015.2427799, in press.

[3] J. Cochran, M. Miller, O. Zinaman, M. Milligan, D. Arent, B. Palmintier, M. O’Malley, S. Mueller, E. Lannoye, A. Tuohy, B. Kujala, M. Sommer, H. Holttinen, J. Kiviluoma, and S. K. Soonee, “Flexibility in 21st Century Power Systems,” Golden, CO, 2014.

[4] K. van den Bergh, R. B. Hytowitz, K. Bruninx, E. Delarue, W. D'haeseleer, and B.F. Hobbs, "Benefits of coordinating sizing, allocation and activation of reserves among market zones," *Electric Power Systems Research*, 143: 140–148, Feb. 2017.

ECN

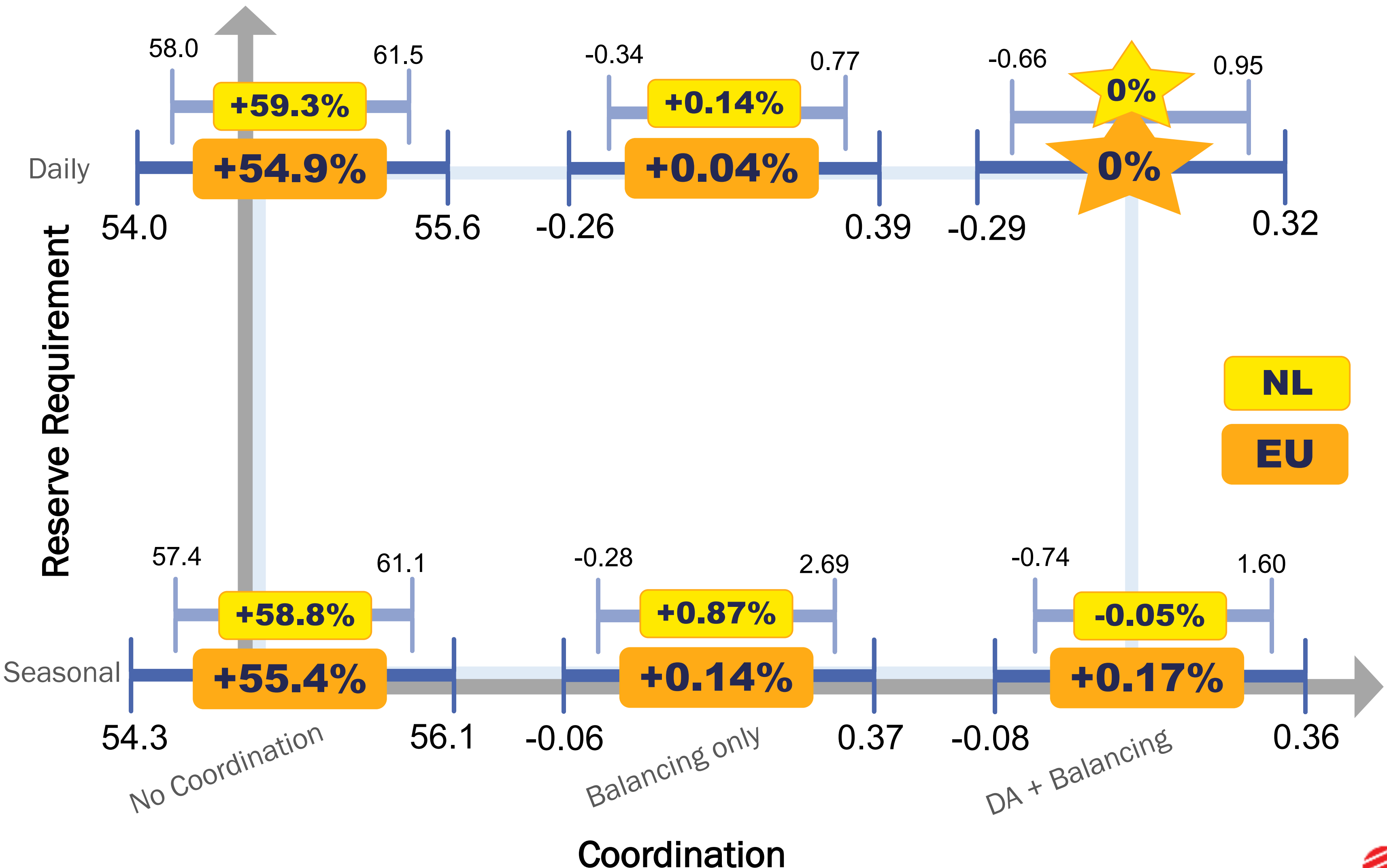
Thank you!
Questions?

Email: hytowitz@jhu.edu

Backup slides

Results – operating cost

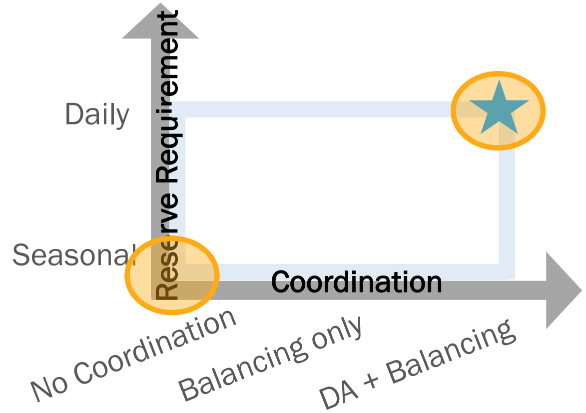
% deviations from 'ideal' case



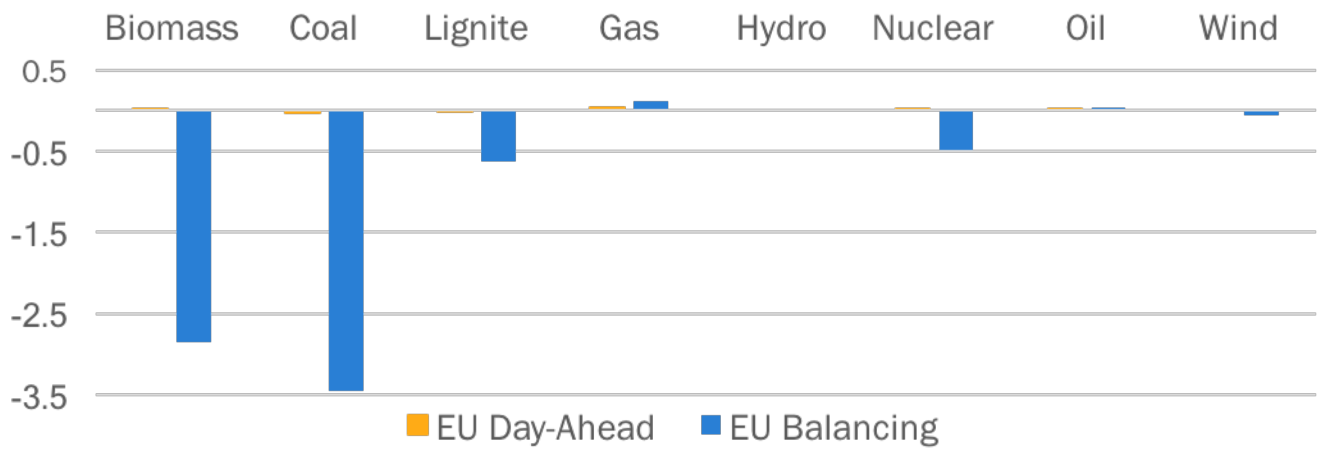
ECN

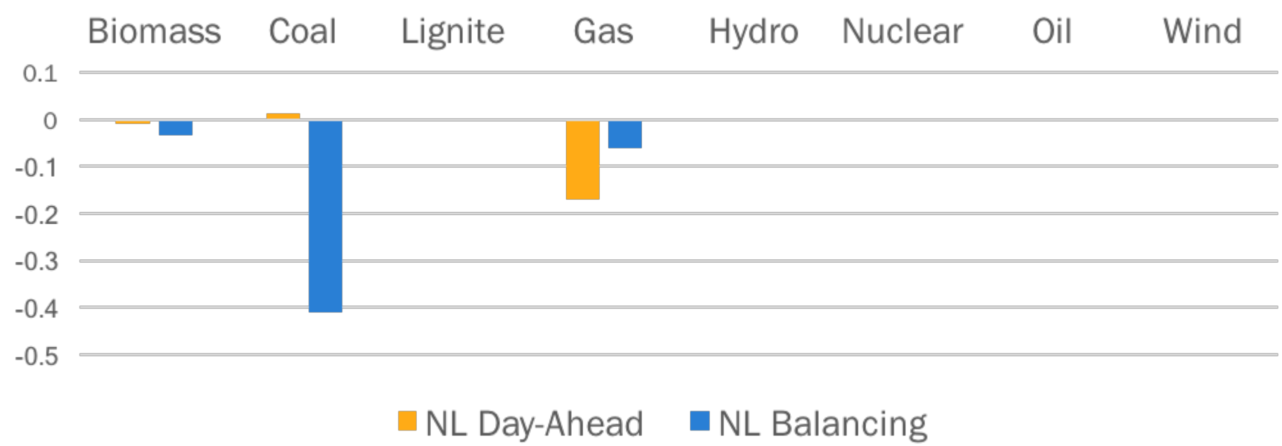
Generation Mix

TWh difference between (Seasonal/Market/No Coordination) - (Daily/Market/Coordination)



More in S/M/NC case ⟶





⟵ More in 'ideal case'

Net Trade (Imports)

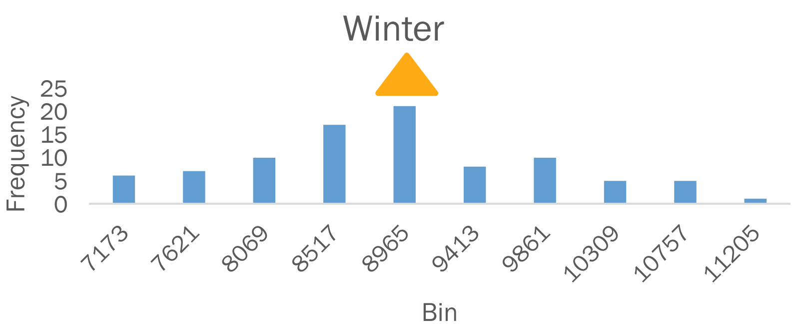
for market based simulations, (+) = fewer imports, (-) = more imports

	Daily Requirement		Seasonal Requirement	
	Day-ahead & Balancing Coordination	No or Only Balancing Coordination	Day-ahead & Balancing Coordination	No or Only Balancing Coordination
BEL	0%	0.07%	0.06%	-0.01%
CZE	0%	0.15%	0.23%	0.14%
DEN	0%	0.15%	0.07%	0.12%
DEW	0%	0.47%	0.01%	0.64%
FIN	0%	0.34%	-0.05%	0.04%
FRA	0%	0.16%	0.07%	0.19%
GER	0%	0.03%	0.26%	0.04%
IRE	0%	0.20%	0.26%	0.19%
ITA	0%	-0.05%	-0.09%	-0.02%
NED	0%	1.27%	-0.08%	1.90%
POL	0%	-0.06%	-0.04%	-0.08%
POR	0%	0.45%	0.60%	0.65%
SKO	0%	0.06%	-0.58%	-0.50%
SPA	0%	-0.21%	-0.19%	-0.62%
SWE	0%	-0.02%	0.13%	0.07%
UKI	0%	0.55%	-0.04%	0.55%
SWI	0%	0.31%	0.29%	0.34%
NOR	0%	-0.40%	0.41%	-0.31%
BLK	0%	-0.04%	-0.08%	-0.19%
BLT	0%	-0.13%	-0.09%	-0.14%
AUS	0%	0.32%	0.09%	-0.03%
Total Energy Traded		**0.15% less trade**	**0.07% less trade**	**0.15% less trade**

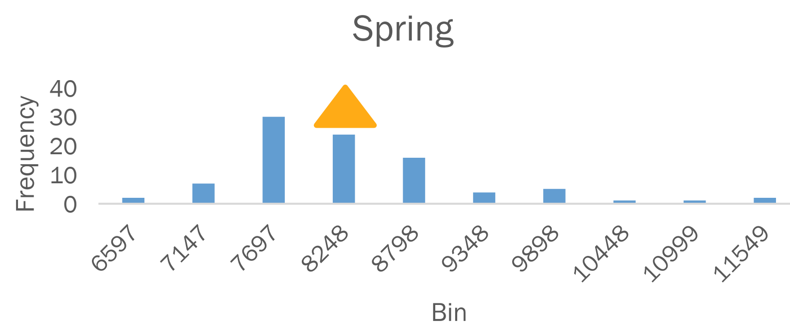
ECN

Reserve Requirement

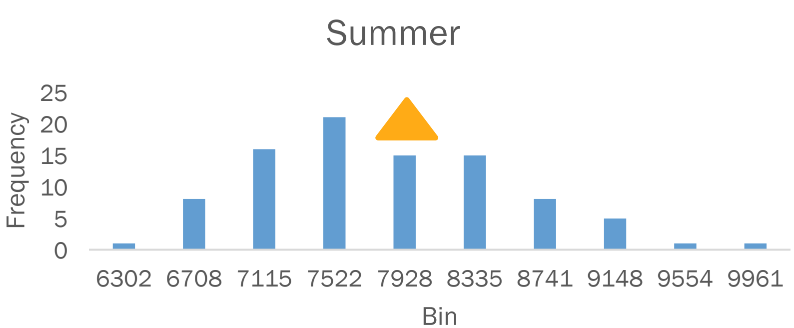
Seasonal: 8675 MW



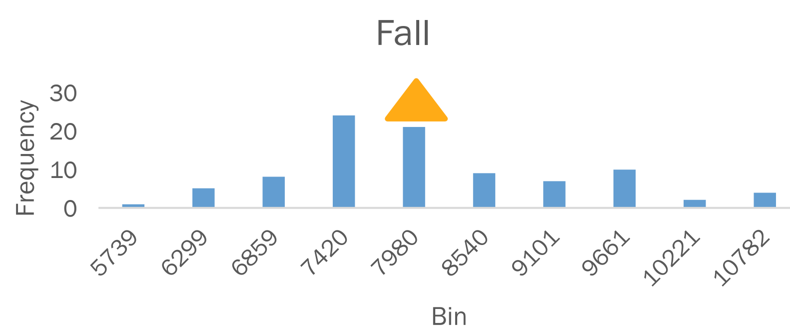
Seasonal: 8032 MW



Seasonal: 7625 MW



Seasonal: 7870 MW

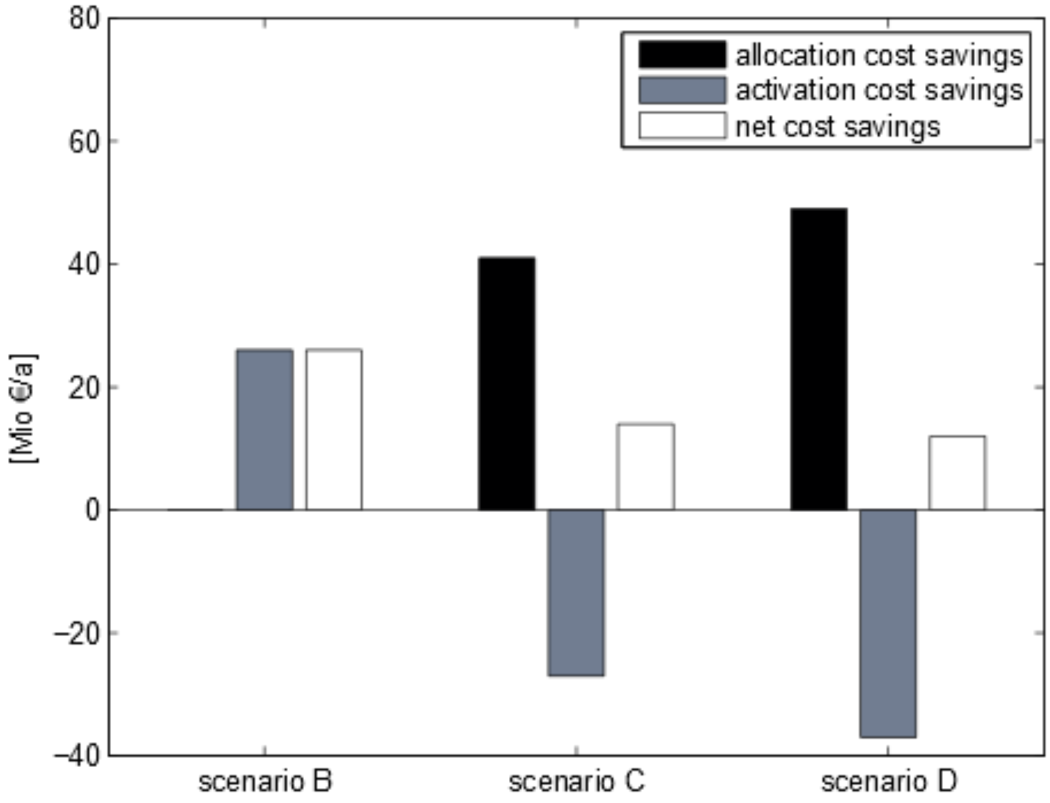


Four different scenarios (A↔D) considered

	A	B	C	D
Sizing	-	-	-	+
Allocation	-	-	+	+
Activation	-	+	+	+

"+" = coordinated　　"-" = uncoordinated

(3) Activation of reserves (real-time)



Allocation, activation and net cost savings relative to scenario A.

Conclusions

1) Coordinating real-time reserve activation is always beneficial
2) Coordinating reserve sizing & allocation can lead to suboptimal results (possibly even deteriorated) if network constraints are neglected
3) Further research deals with including network constraints in (deterministic) reserve sizing and allocation rules

KU LEUVEN

Model Formulation

Day-Ahead

Commitment within the Netherlands

continuous variables

$$\begin{bmatrix} \vdots \\ x_i \\ \vdots \end{bmatrix}$$

binary variables

$$\begin{bmatrix} \vdots \\ u_i \\ \vdots \end{bmatrix}$$

ECN

Model Formulation

Day-Ahead

Commitment outside the Netherlands

continuous variables

$$\begin{bmatrix} \vdots \\ x_i \\ \vdots \end{bmatrix}$$

relaxed

~~binary~~ variables

$$\begin{bmatrix} \vdots \\ u_i \\ \vdots \end{bmatrix}$$

Model Formulation

Balancing

Commitment only
within the Netherlands

continuous variables

$$\begin{bmatrix} \vdots \\ x_i \\ \vdots \end{bmatrix}$$

binary variables
fast start units

$$\begin{bmatrix} \vdots \\ u_i \\ \vdots \end{bmatrix}$$

Fixed variables:
line flows,
slow units

$$\begin{bmatrix} \vdots \\ x_i \\ \vdots \end{bmatrix} \begin{bmatrix} \vdots \\ u_i \\ \vdots \end{bmatrix}$$