Future inertia needs from a system split perspective

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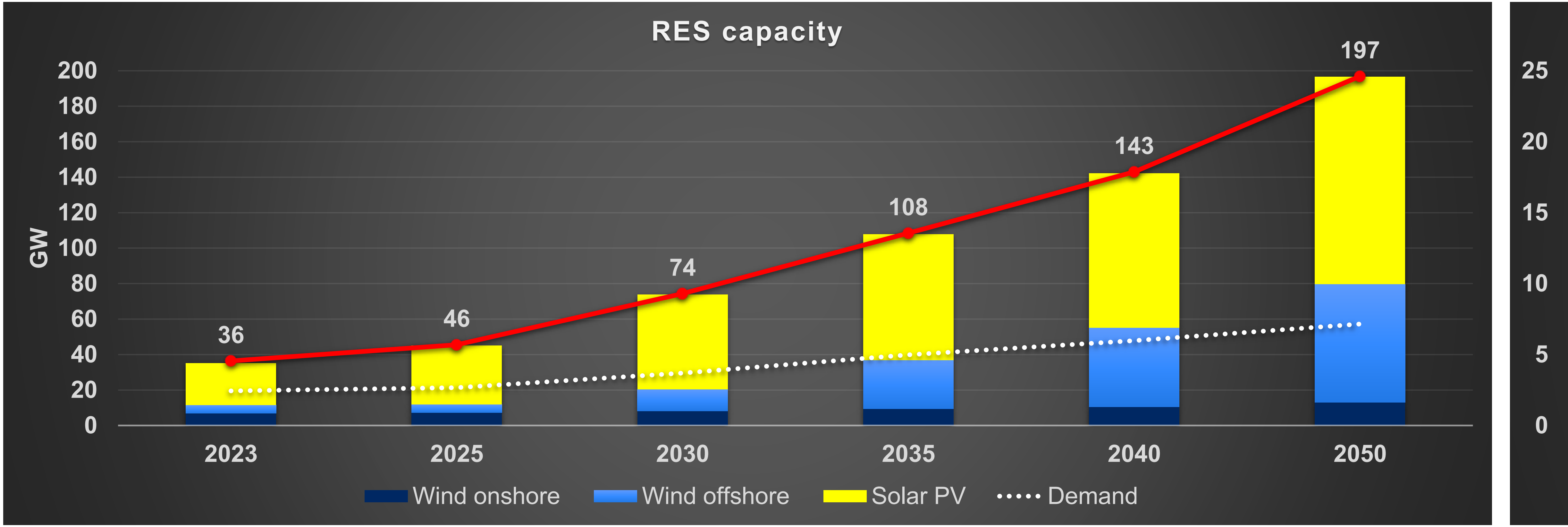
Agenda

1. Changing generation mix
2. System challenges – inertia
3. Inertia from Continental European perspective
4. Inertia developments in the Netherlands

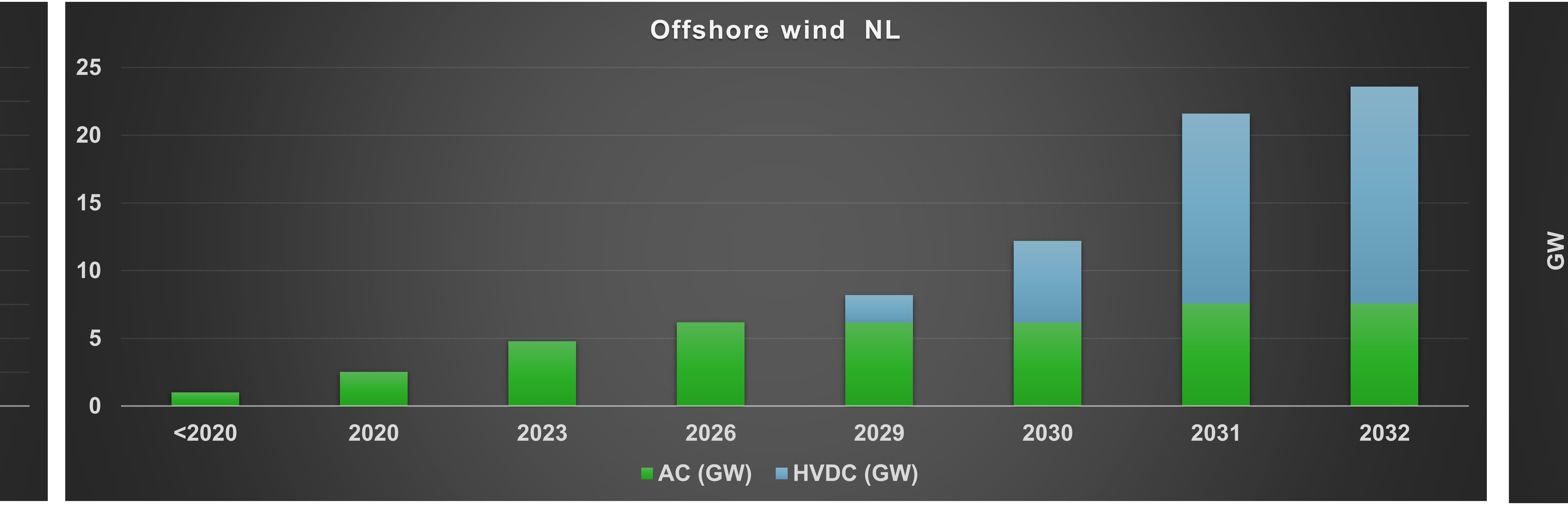
Changing generation mix

Installed capacity in the Netherlands



Graph based on data from TenneT IP2026 – KM scenario

Installed capacity in the Netherlands



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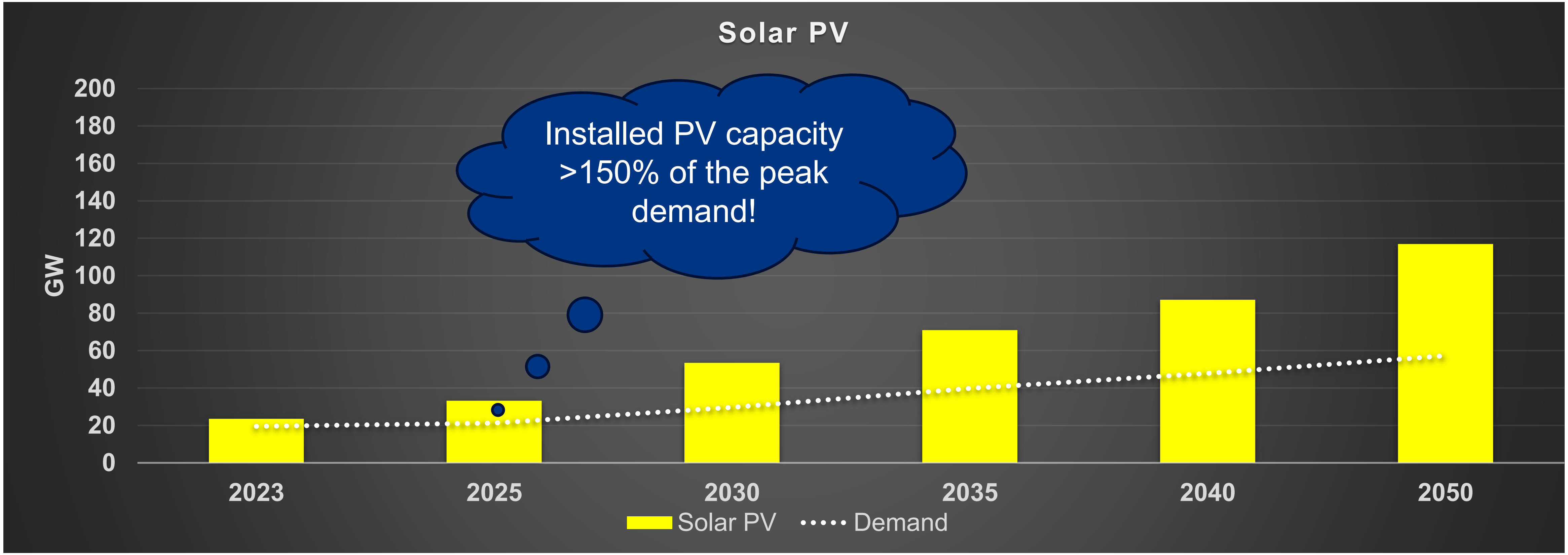

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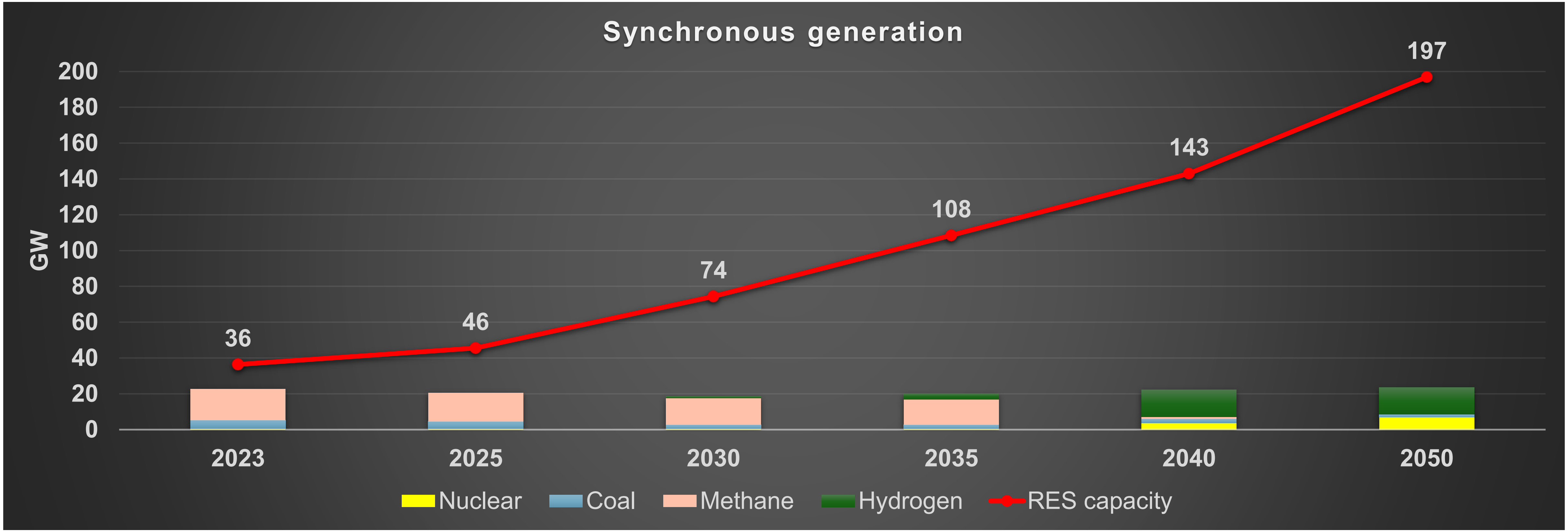
Installed capacity in the Netherlands



Graph based on data from TenneT IP2026 – KM scenario

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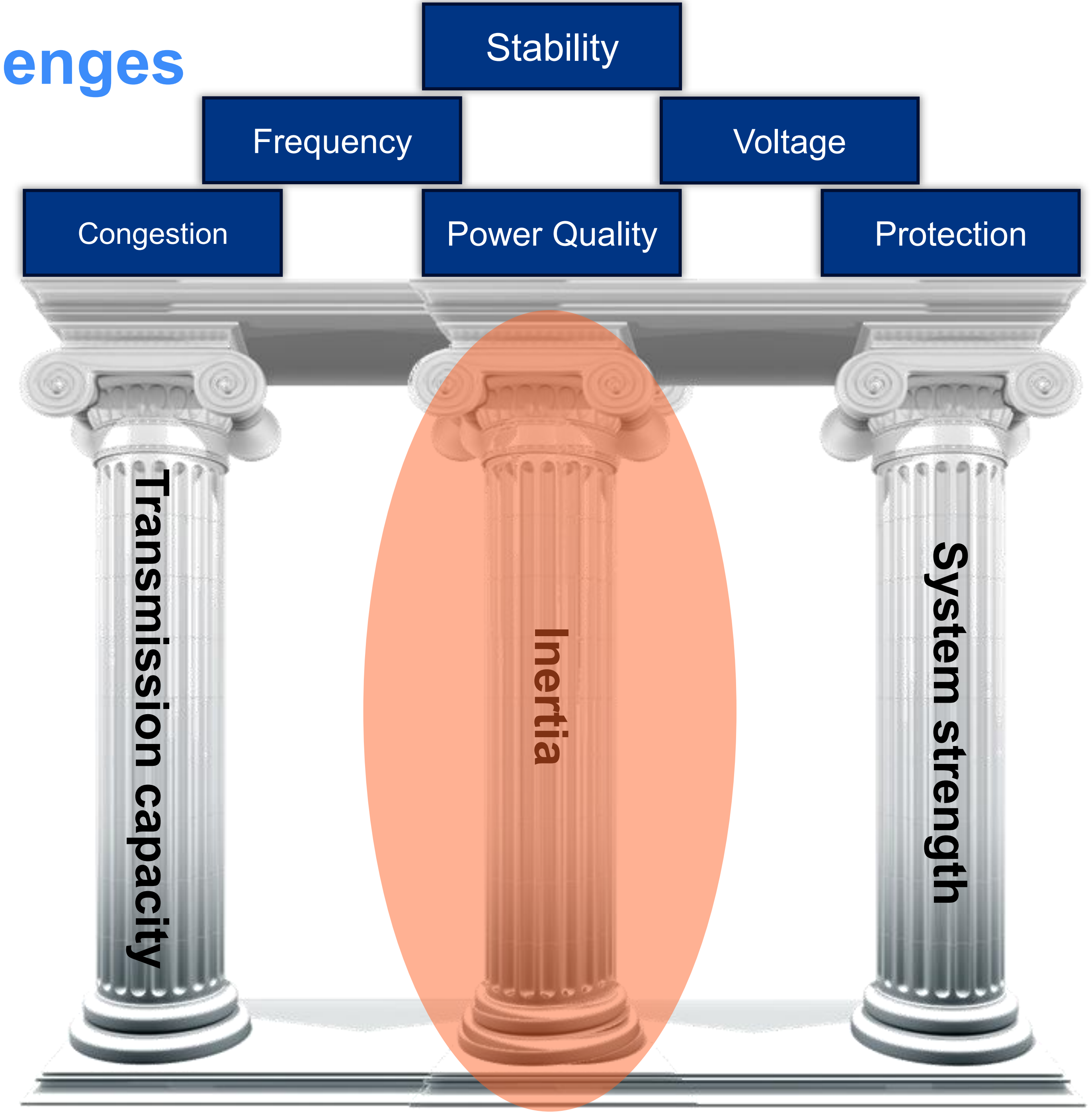
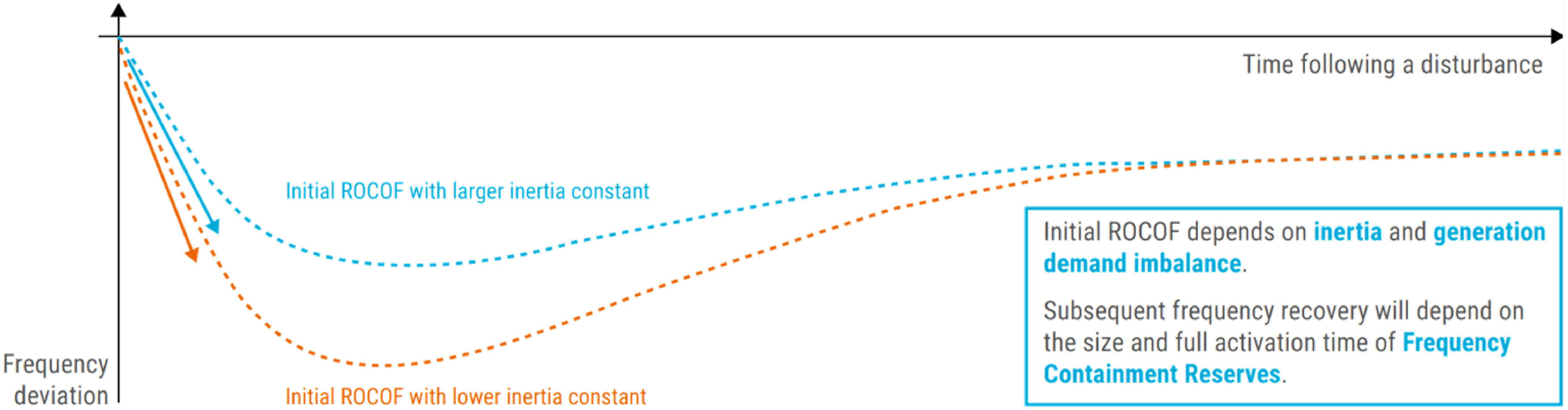
System challenges - Inertia

System challenges

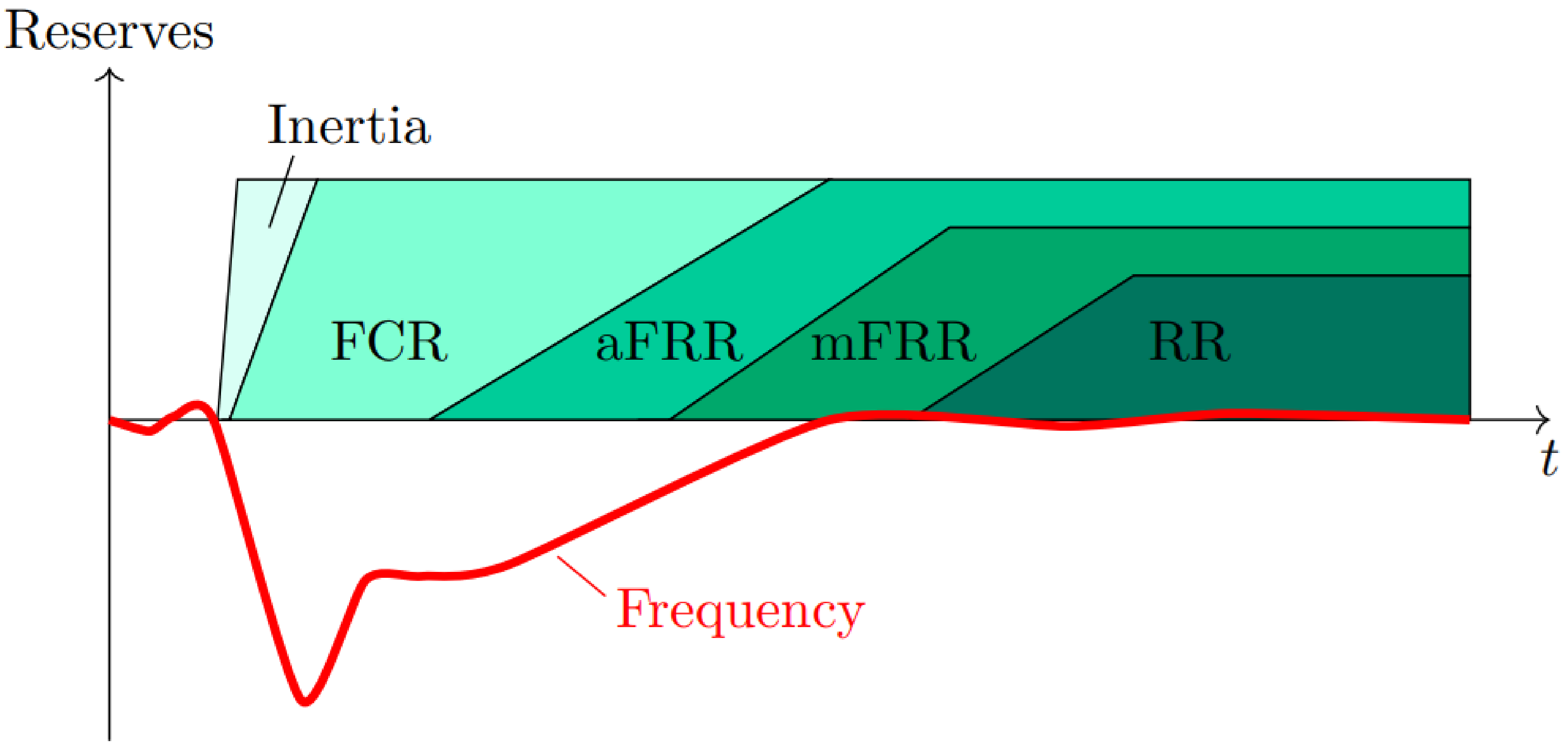


Inertia – Why do we need it?

Inertia limits the speed at which the frequency changes; **RoCoF**
(Rate of Change of Frequency)



Inertia and frequency reserves - timescales



Reserve	Response time
Inertia	Instantaneous
Frequency Containment Reserves (FCR)	after 2 seconds
Automatic Frequency Restoration Reserves (aFRR)	30 seconds
Manual Frequency Restoration Reserves (mFRR)	5 min
Replacement Reserves (RR)	12,5 min

Risks of increasing RoCoF

Current operational **RoCoF limit is 1 Hz/sec**[1]

- **Mechanical stress in synchronous machines**
  - Resulting in failures/breakages
- **Misfunctioning low frequency demand disconnection (LFDD)**
  - Acts between 49-48Hz
  - Load is being shed in 6-10 tranches
  - Response time ~ 200 ms
  - → Risk of undershedding in case high RoCoF
- **Cascading effects risks,** leading to a possible blackout

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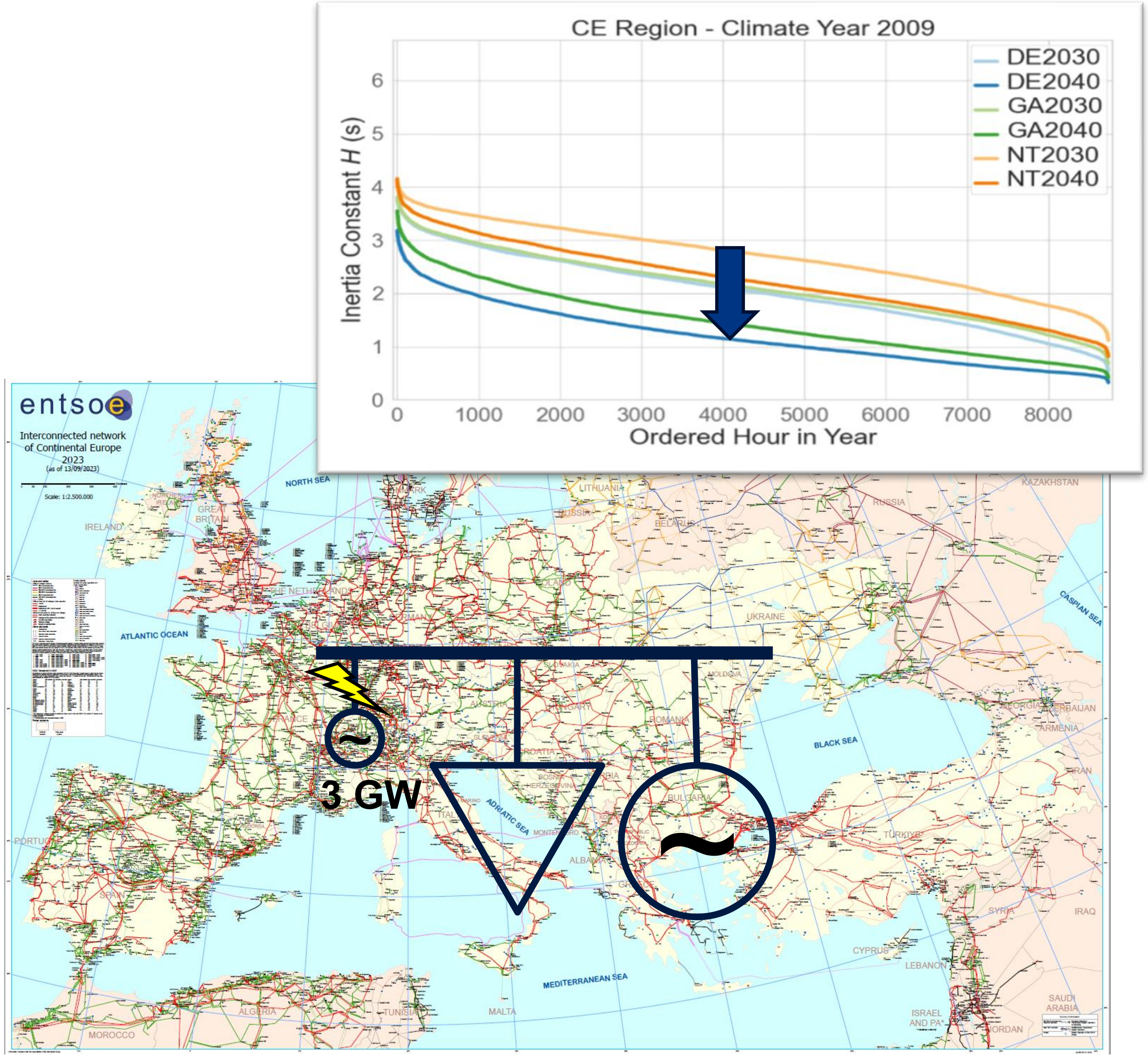
[1] ENTSO-E (2020-12-16), Inertia and rate of change of frequency (RoCoF). https://eepublicdownloads.entsoe.eu/clean-documents/SOC%20documents/Inertia%20and%20RoCoF_v17_clean.pdf

Inertia from Continental European perspective

Inertia - normal situation
Interconnected system

- Reference-incident 3000 MW:
  - Frequency should stay >49,8 Hz
  - No load disconnection
  - ‘Automatic’ recovery (primary control)

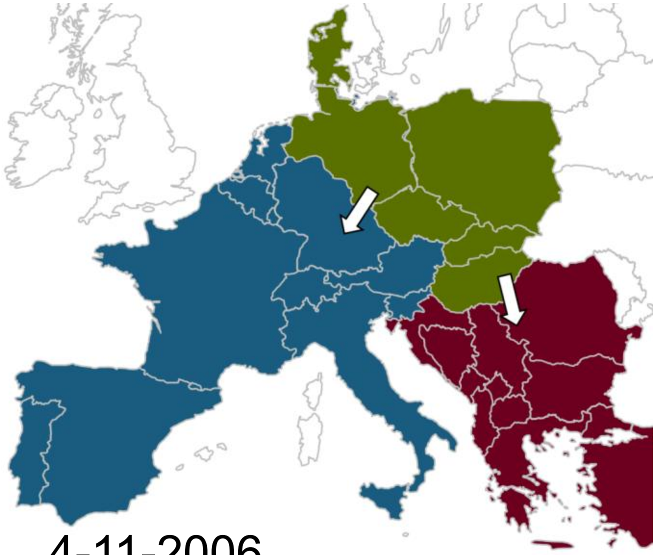
- Sum of inertia
  - Natural spread
  - Still ‘quite some’ inertia on system level
  - NL part of the big system



ENTSO-E = European Network for Transmission System Operators (-Electricity)

Inertia - system splits

examples



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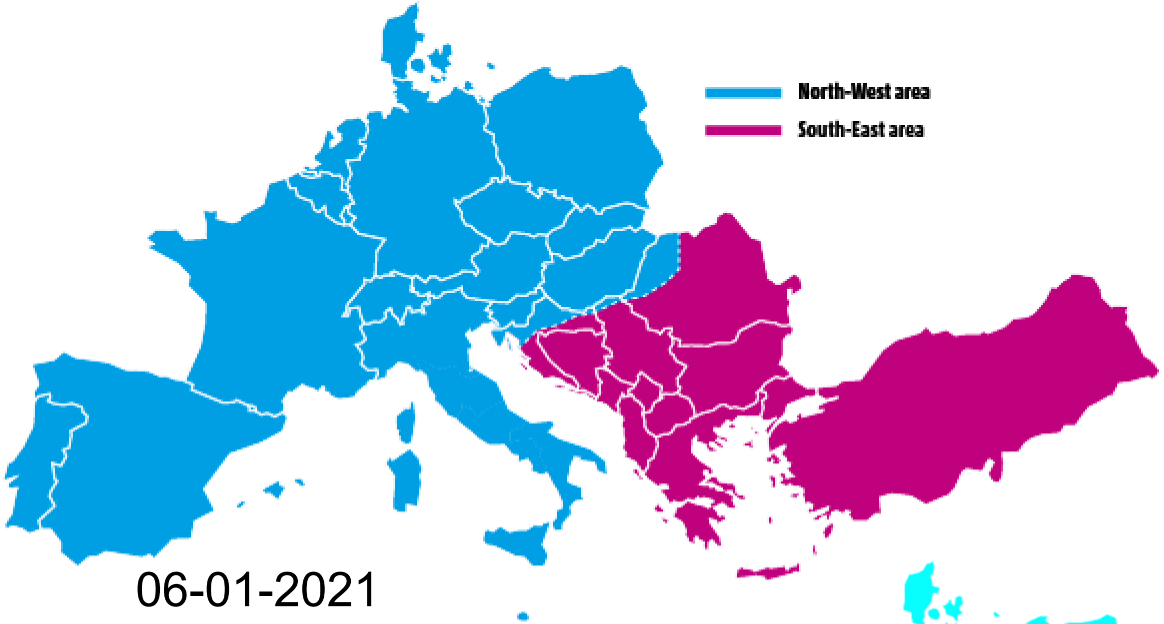

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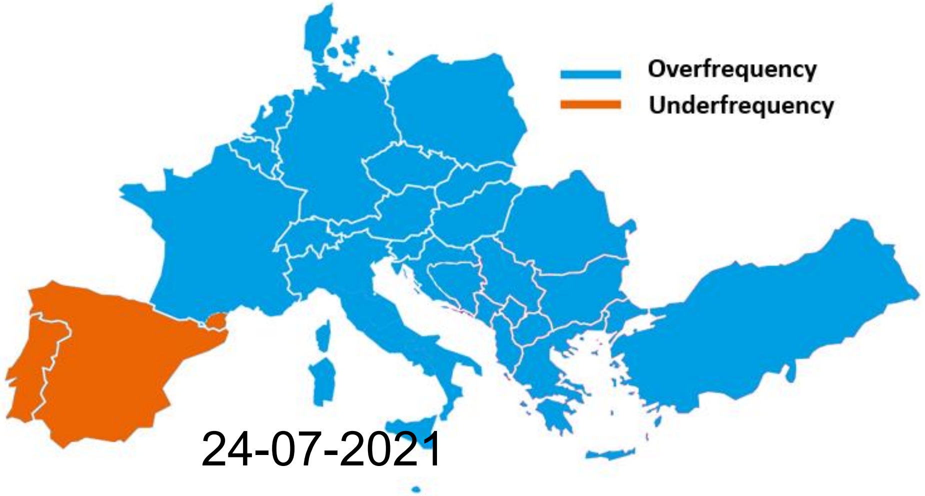
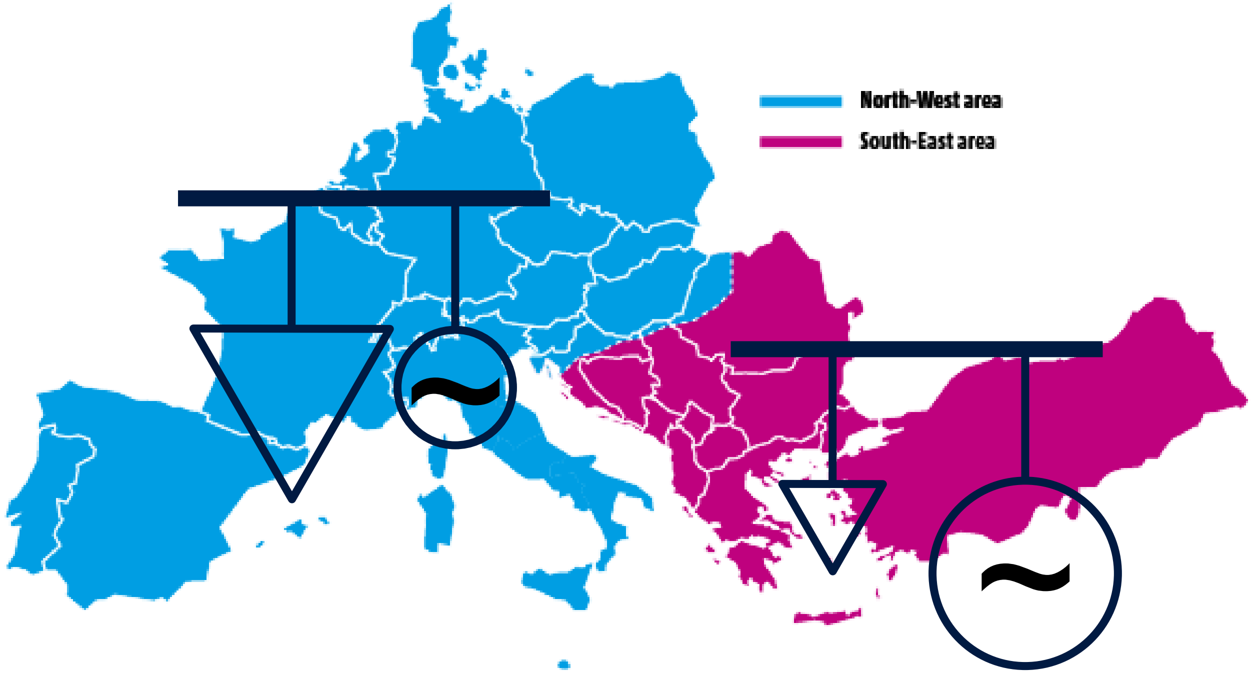


24-07-2021

28-04-2025

Inertia - system splits (2)

- Possible unbalance larger than reference-incident
  - Risk of black-out due to large unbalance and low inertia
- Theoretically every split possible
- In practice very low probability of NL island
- ENTSO-E 'project inertia'[1]
  - Identify inertia need per country



[1]https://eepublicdownloads.azureedge.net/clean-documents/Publications/ENTSO-E%20general%20publications/211203_Long_term_frequency_stability_scenarios_for_publication.pdf

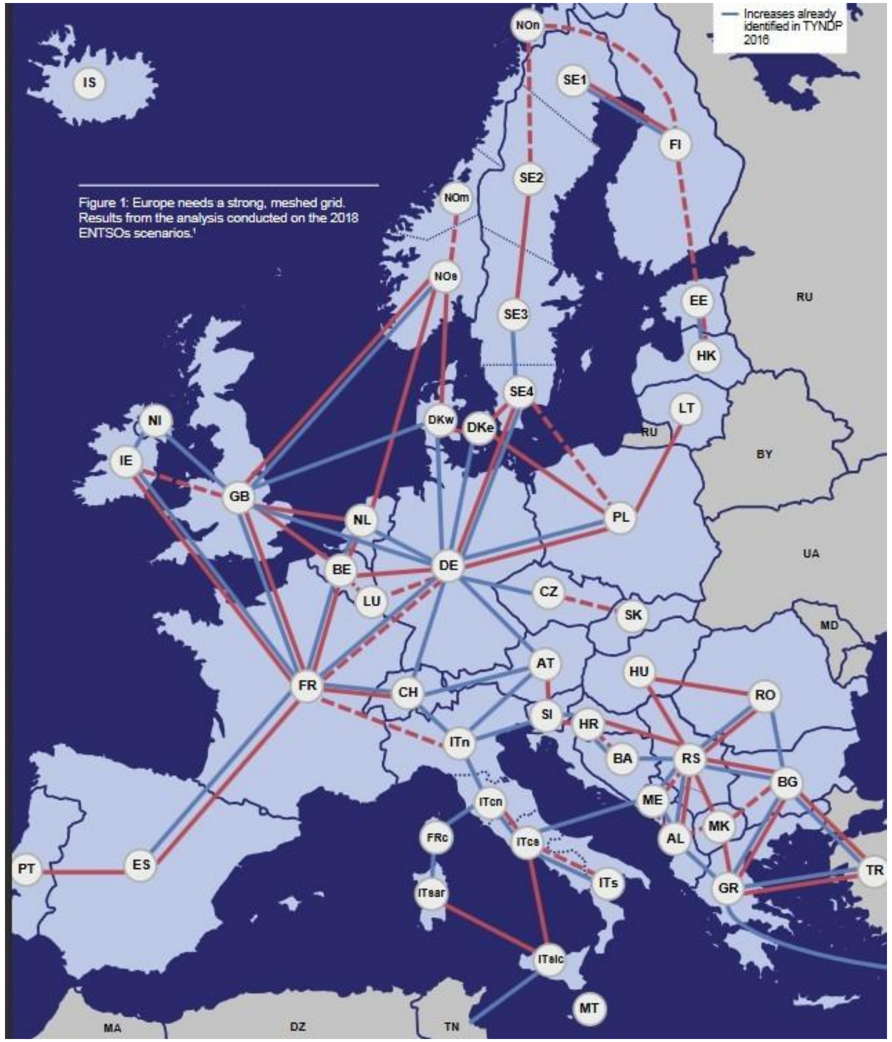
ENTSO-E project inertia

Calculation methodology and assumptions

- **Objective,** to calculate for system splits:
  - RoCoF (R)
  - Frequency response (F)

- **Inputs** from market simulations
  - Ten Year Network Development plan (TYNDP) 2022

- **Simplified model** of European grid:
  - one node per market zone, no impedance
  - Hourly data of generation mix and flows between market zones
  - 6 scenarios
  - Generic inertia data per fuel type and country



Overview possible blackout cases

- Assessment of RoCoF and frequency nadir/zenith
- Assumed blackout in case:
  - f < 47,5 Hz
  - f > 51,5 Hz
  - |RoCoF|>1Hz/s

Total blackout

RR
Both areas:
|RoCoF|>1Hz/s

FF
Both areas:
f< or f>

RF
One area:
|RoCoF|>1Hz/s
Other area:
f< or f>

Partial blackout

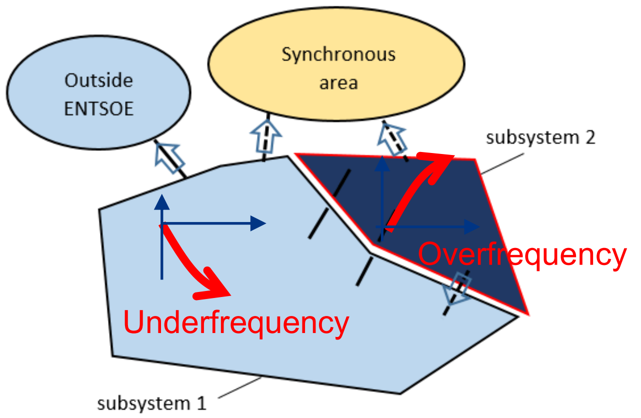
R
One area:
|RoCoF|>1Hz/s

F
One area:
f< or f>

Calculation of the RoCoF (R)

- No grid model
- Imbalance is assumed instantaneous
- RoCoF derived from rotating masses equation:

$$\underbrace{\frac{df}{dt}}_{RoCoF(Hz/s)} = \frac{\overbrace{f_0}^{50Hz}}{2H_{eq}} \frac{\overbrace{\Delta P}^{Imbalance\ (MW)}}{\underbrace{\sum Smax_{gen}}_{generation\ running\ capacity(MVA)}}$$

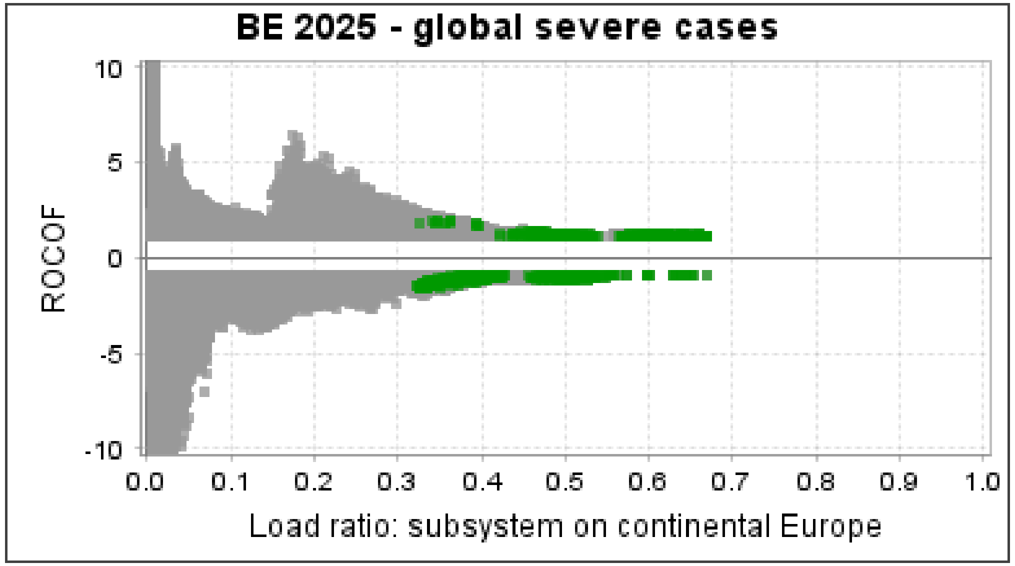


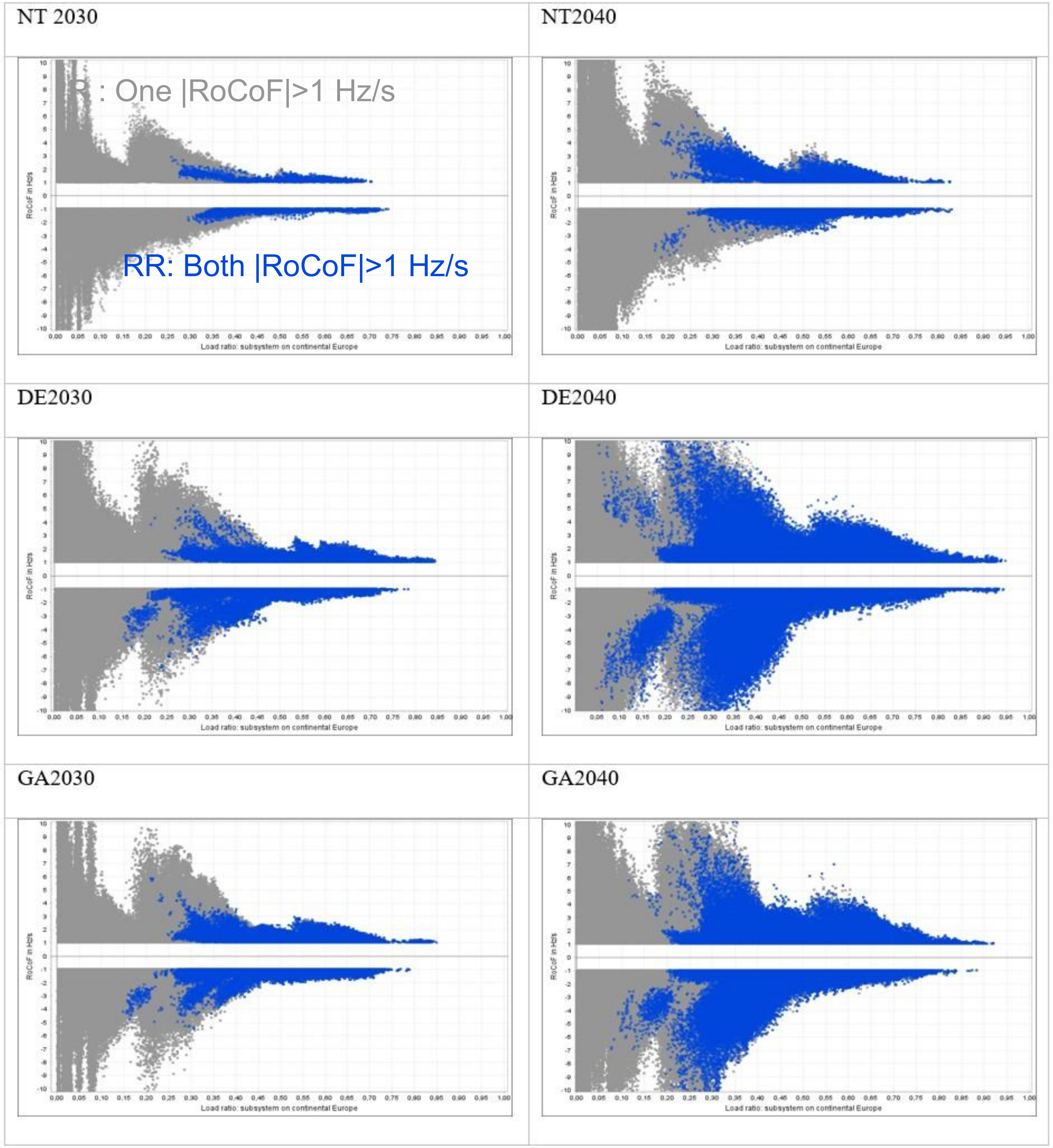
- RoCoF calculated at centre of inertia: $H_{eq} = \frac{\sum H_{gen} Smax_{gen}}{\sum Smax_{gen}}$

Focus on 'global severe splits'

- |RoCoF|>1Hz/s in both islands
- Beyond 1Hz/s frequency stability is not guaranteed
- Risk of blackout of the whole synchronous area

Results RoCoF (R)



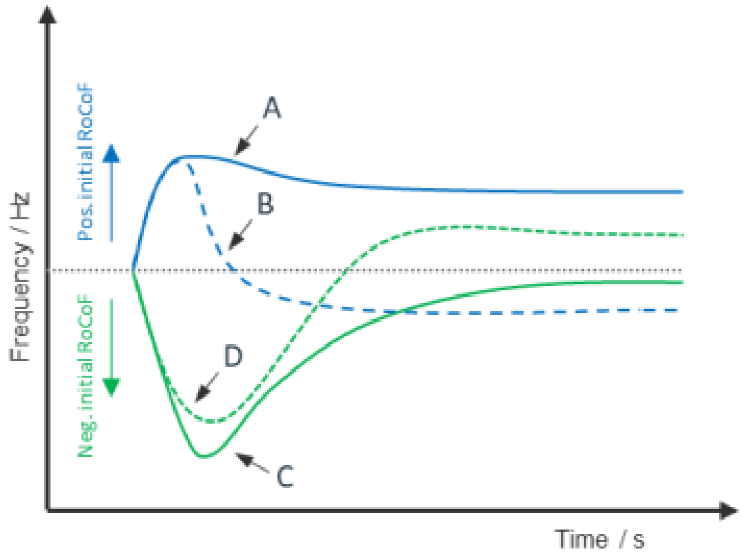


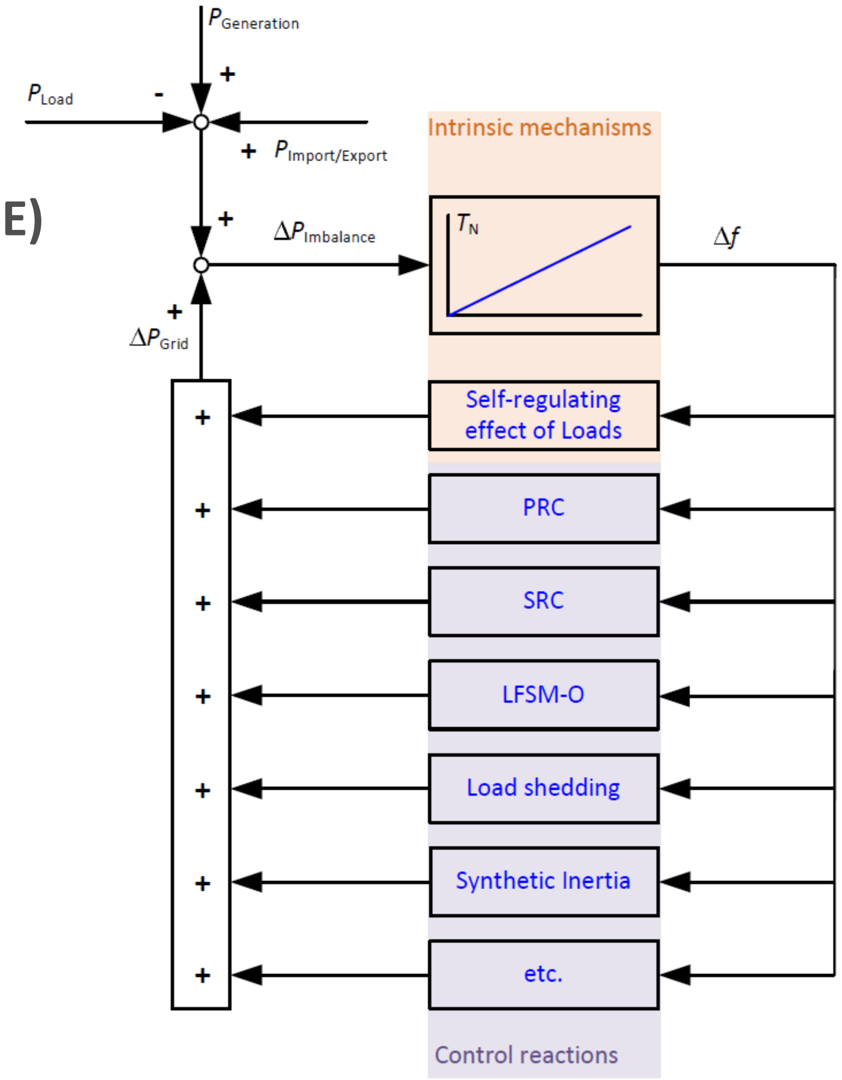
A clear degradation of the resilience of the system

Calculation of frequency response (f)

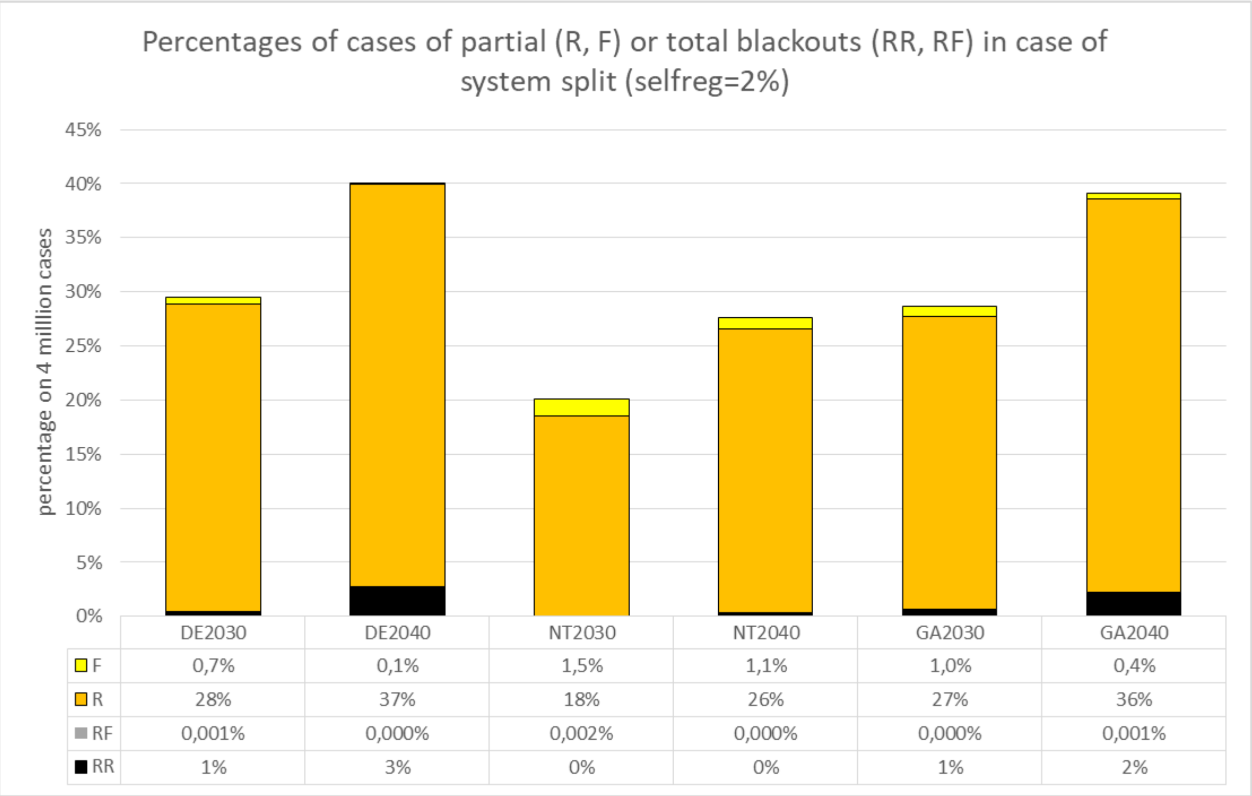
Single Busbar model in MatLAB/Python (developed by ENTSO-E)

- Inputs per hour, split and island:
  - Imbalance (MW),
  - Inertia (MWs/MVA)
- Outputs:





Results: algebraic RoCoF (R) and time domain simulation (f)



	DE2030	DE2040	NT2030	NT2040	GA2030	GA2040
F	0,7%	0,1%	1,5%	1,1%	1,0%	0,4%
R	28%	37%	18%	26%	27%	36%
RF	0,001%	0,000%	0,002%	0,000%	0,000%	0,001%
RR	1%	3%	0%	0%	1%	2%

RR
Both areas:
|RoCoF|>1Hz/s

RF
One area:
|RoCoF|>1Hz/s
Other area:
f< or f>

Total blackout

R
One area:
|RoCoF|>1Hz/s

F
One area:
f< or f>

Partial blackout

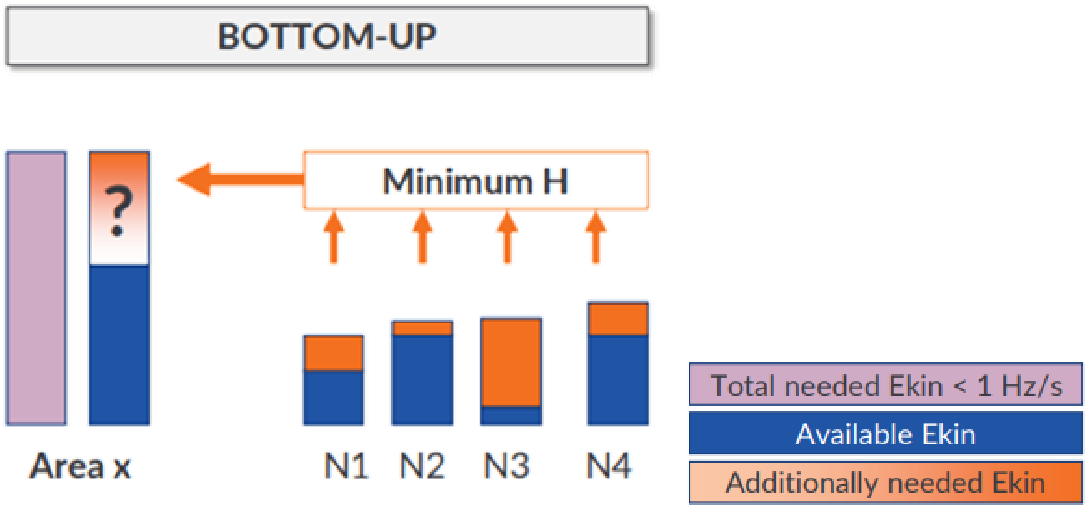
- In cases with |RoCoF|<1 Hz/s, only few issues with frequency (RF and F cases)
- **Conclusion**:
  - RoCoF is the main issue

➔ Need to limit instantaneous RoCoF ➔ need for foundational measures

Determination of mitigation measures

- Mitigation measures based on RoCoF limitation
- Calculate additionally needed kinetic energy to keep the |RoCoF| < 1 Hz/s:

$$E_k = \frac{f_0}{2} |\Delta P|$$ *in GWs by hour, split and island*



- H_{min} of **2 sMW/MVA** proposed as requirement, provides good performance:
  - # of splits satisfied
  - cost–benefit aspects

Limitations and advantages of the approach

- In real life:
  - System splits never follow borders of market zones
  - Potentially local RoCoF >> central RoCoF
  - Impact of system split does not only depend on instantaneous response
  - Probability of system split (very low) is not considered here
- Advantages of simplified approach
  - Broad view on the phenomenon and its evolution
  - Main drivers of phenomenon captured

Conclusion: A proper approach to assess recovery of system resilience and guarantee a good future inertia distribution

Minimum inertia levels

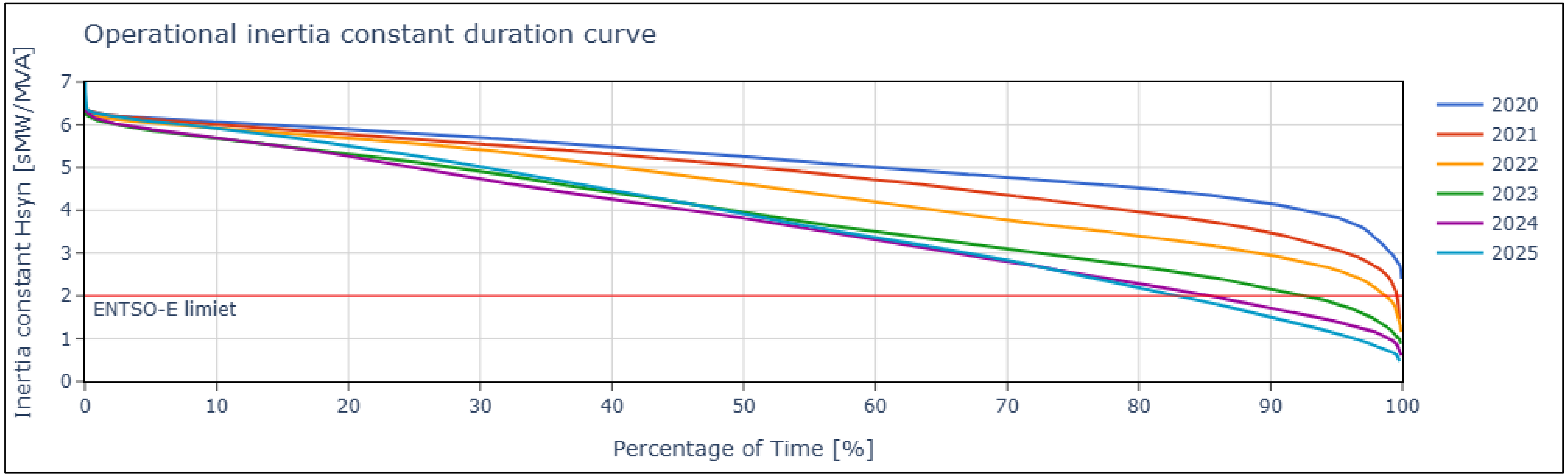
- Based on ENTSO-E Project Inertia position paper[1]:
    - Minimum inertia level needed per country
    - Recommended system equivalent inertia constant $\mathbf{H_{min}} \geq$ **2 sec** to be ensured:
        - By **2035** (short/medium term): **50% of time** in a year
        - **Long term: 90% of time** in a year (subject to reassessment)

- On national level:
    - Absolute minimum inertia level throughout the year (GWs)
    - Threshold for the Netherlands under investigation and to be determined
        - Based on local RoCoF

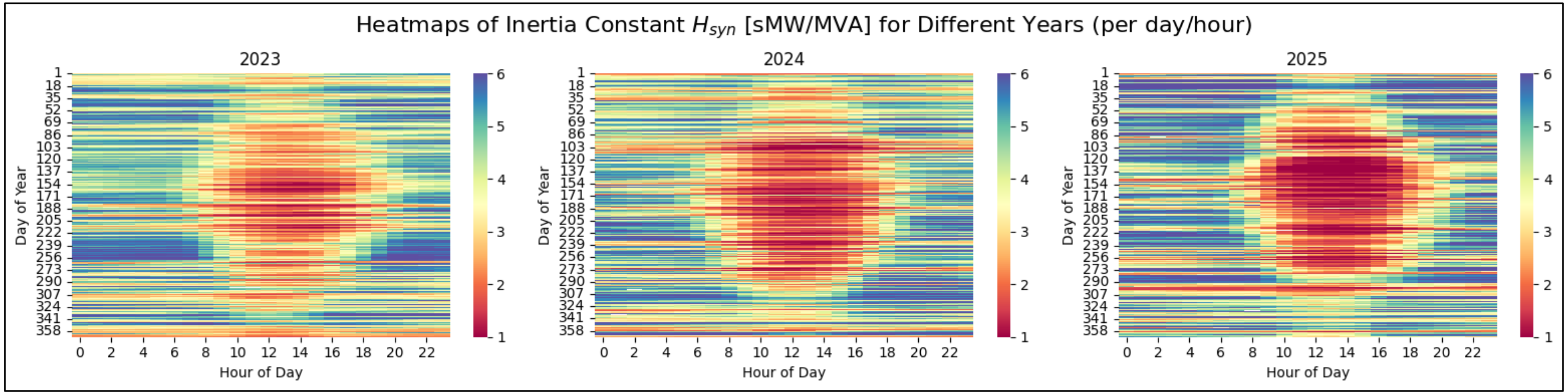
[1] ENTSO-E releases the latest work from Project Inertia, which studies the evolution of the inertia levels in the long-term horizons in the Continental Europe Synchronous Area and the challenges emerging from their decrease.

Inertia developments in the Netherlands

Historical inertia constant for NL

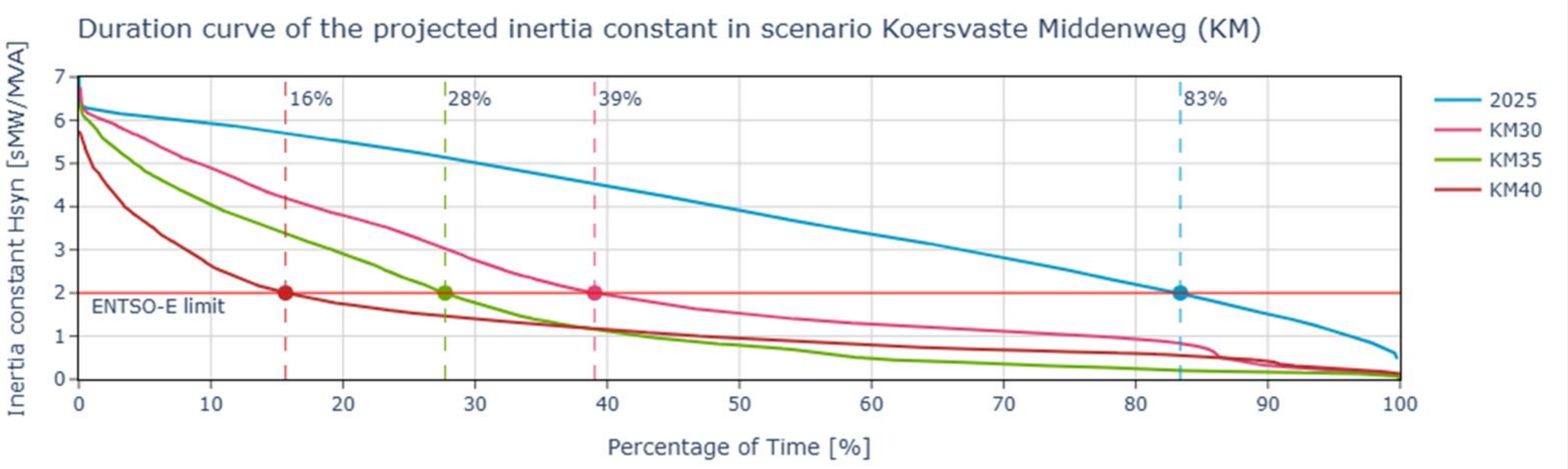


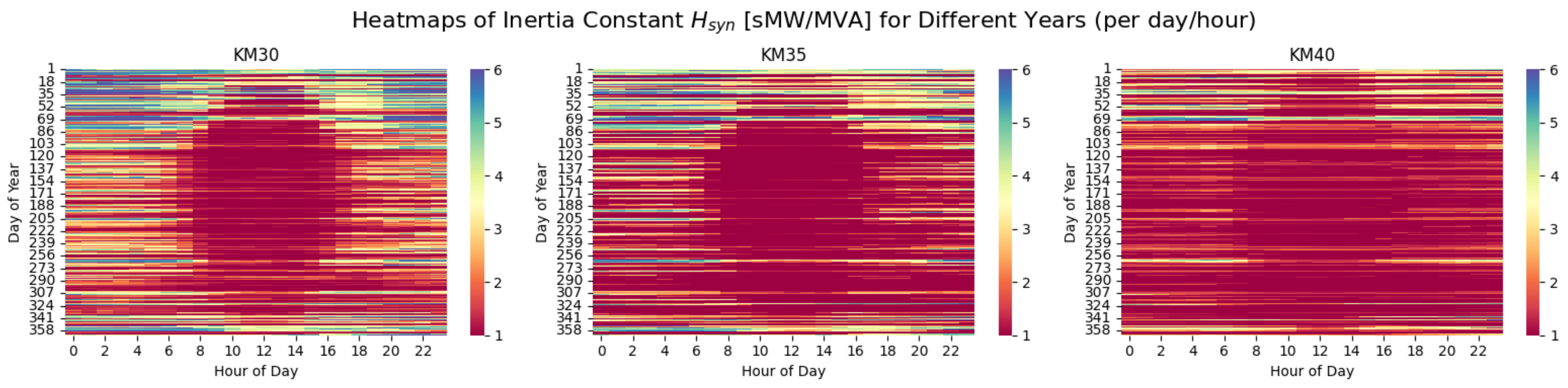
- Inertia levels are decreasing
- Still above ENTSO-E limit of $\mathbf{H_{min} \geq 2s}$ limit >80% if the time



- Lowest inertia levels in summer, mid-day

Projected future inertia constant for NL



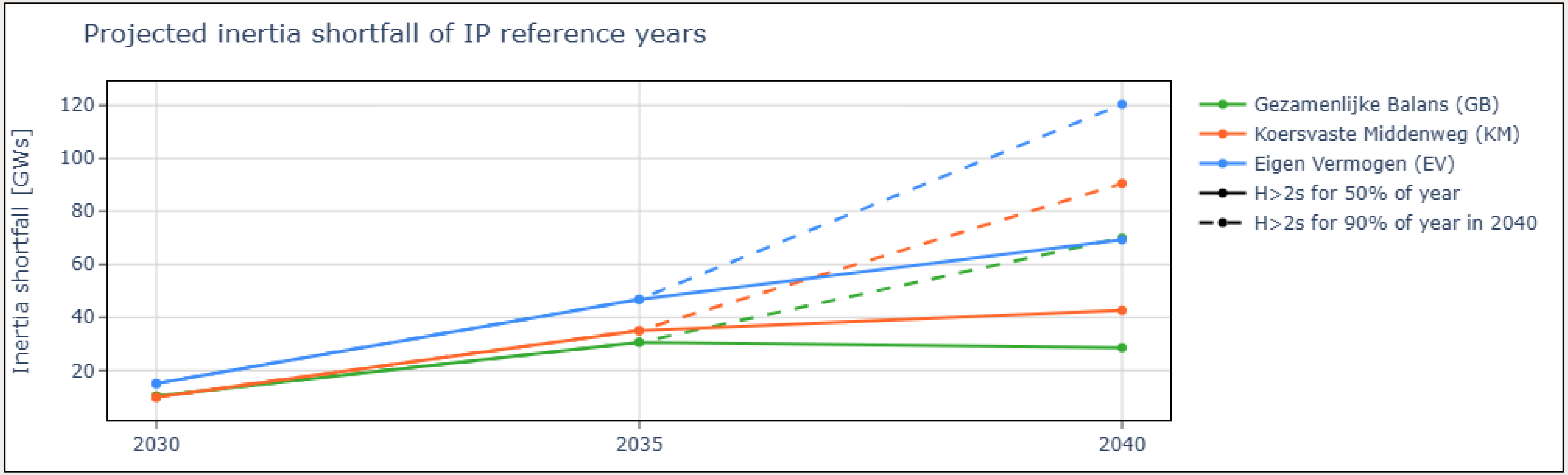


- Inertia levels are further decreasing
- Expected to drop **below** ENTSO-E limit of **H_{min} ≥ 2s** for 50% of the time by 2030

- Lowest inertia levels no longer only in summer, mid-day

Inertia shortfall development

- Shortfall increases over the years
- Bandwidth and uncertainty increases further into the future

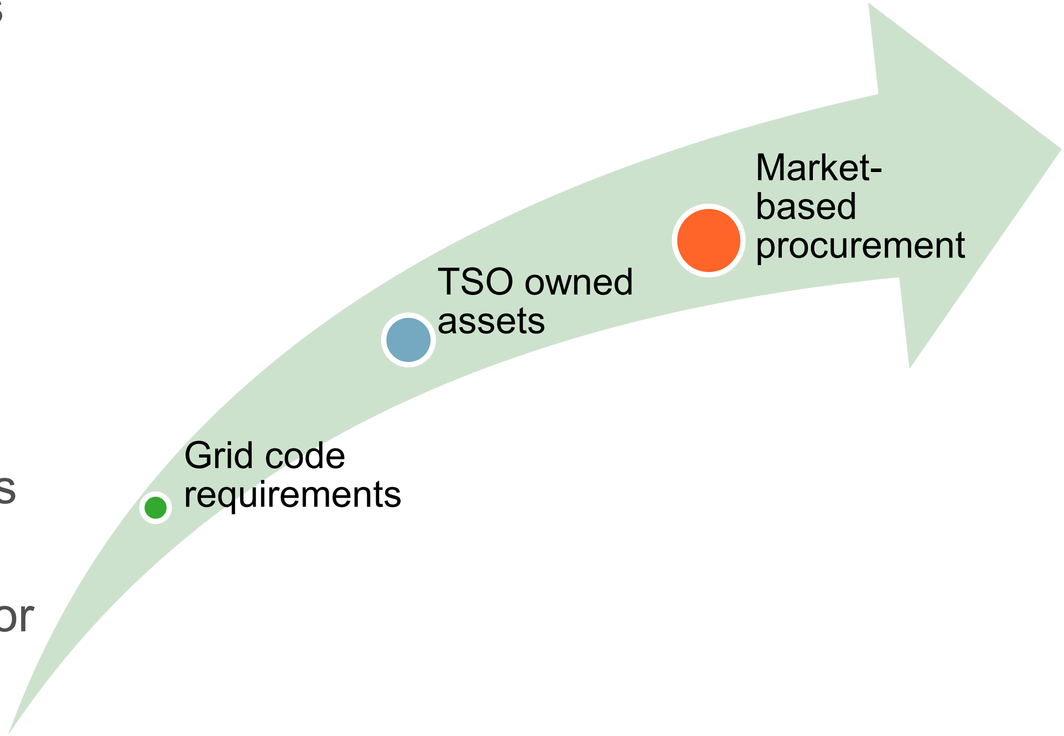


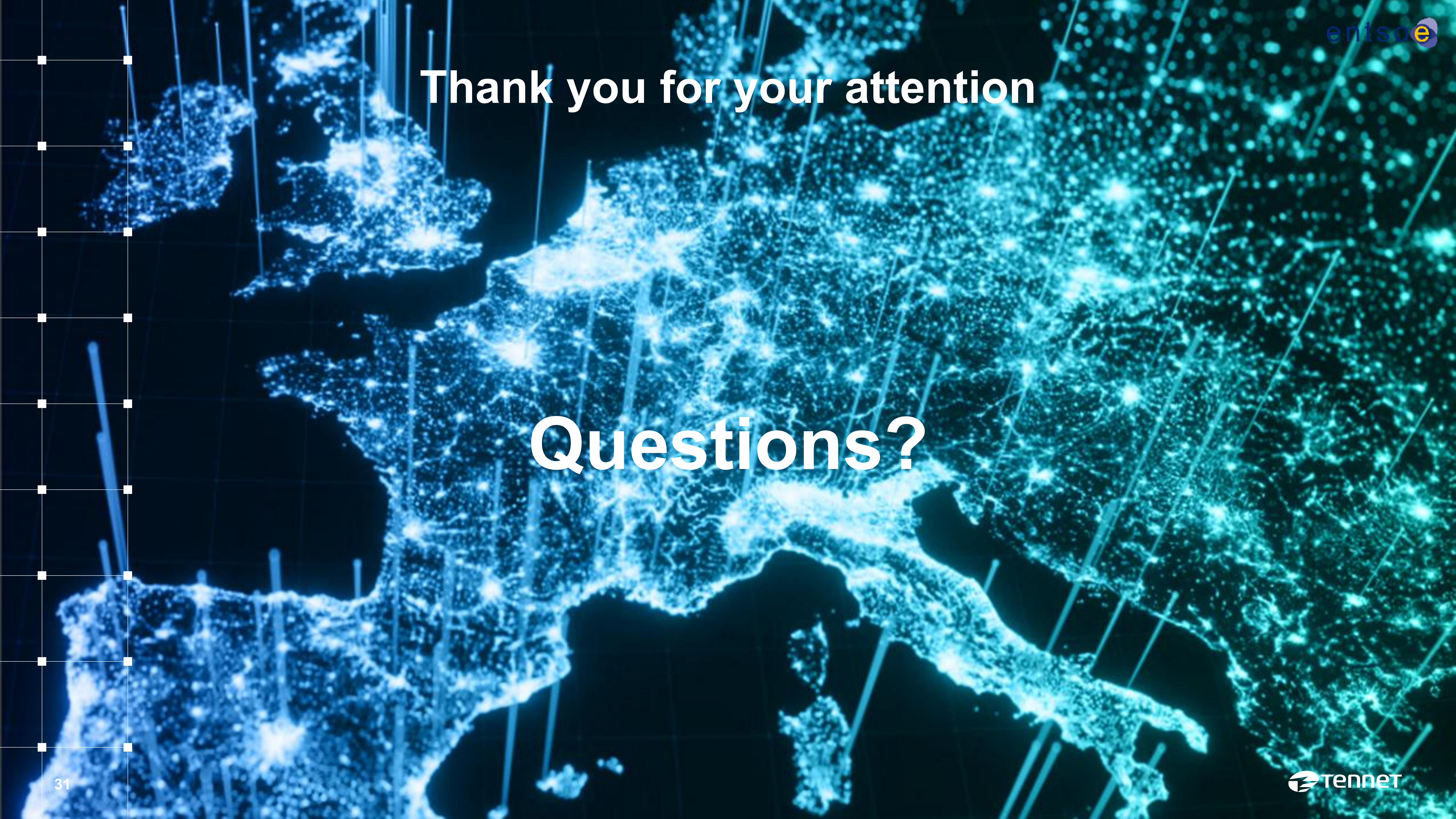
Based TenneT investmentplan 2026-2040 (IP2026) scenarios

Currently foreseen mitigation measures

Hybrid approach

- **Grid code requirements** to enable grid forming as a basis (inertia capability)
- **TSO owned assets**
  - ➢ Project to install three synchronous condensers
    - Improve local system strength
    - Cover part of mid-term inertia needs
  - ➢ Future project for additional 2-4 new TSO owned assets (E-STATCOM or synchronous condenser)
  - ➢ TSO owned assets only fulfill part of the inertia needs for 2035 and beyond
- **Market-based procurement**
  - ➢ Required to meet large future inertia needs





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Thank you for your attention

Questions?

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