Robustness indicators for power systems

Emil Hillberg
Tommie Lindquist
RISE – Research Institutes of Sweden

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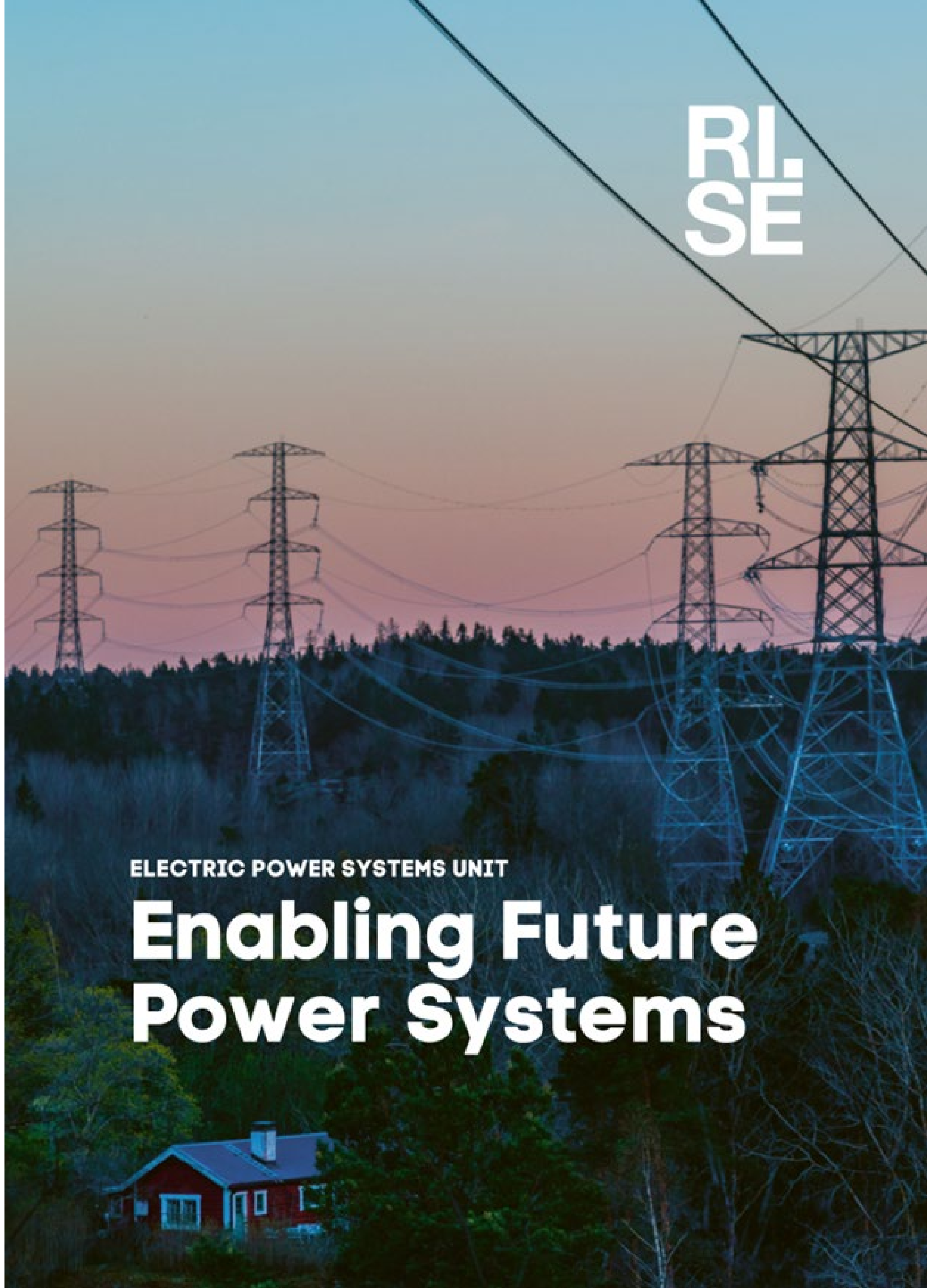

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- We are a **state-owned** company with nearly 3,300 employees who contribute to transforming knowledge from research into new products and services.
- Our mission is to work with our customers and partners to develop **competitive solutions** that drive **sustainable development** forward.
- With our **unique breadth** and collective expertise, we can take a systemic perspective on complex sustainability issues.
- In our more than **130 test beds**, products and processes of the future can be tested and scaled up.

Bioeconomy and health	Digital Systems	Materials and production	Built environment	Safety and transport

Digitalisation

Energy and biobased economy

Sustainable cities and communities

Health and life science

Material transition

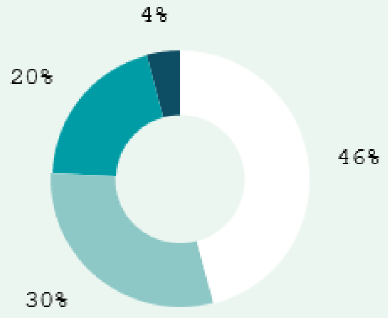
Mobility

3,993

SEK million, net sales

Operating results: 22 SEK million

Operating margin: 0,6%

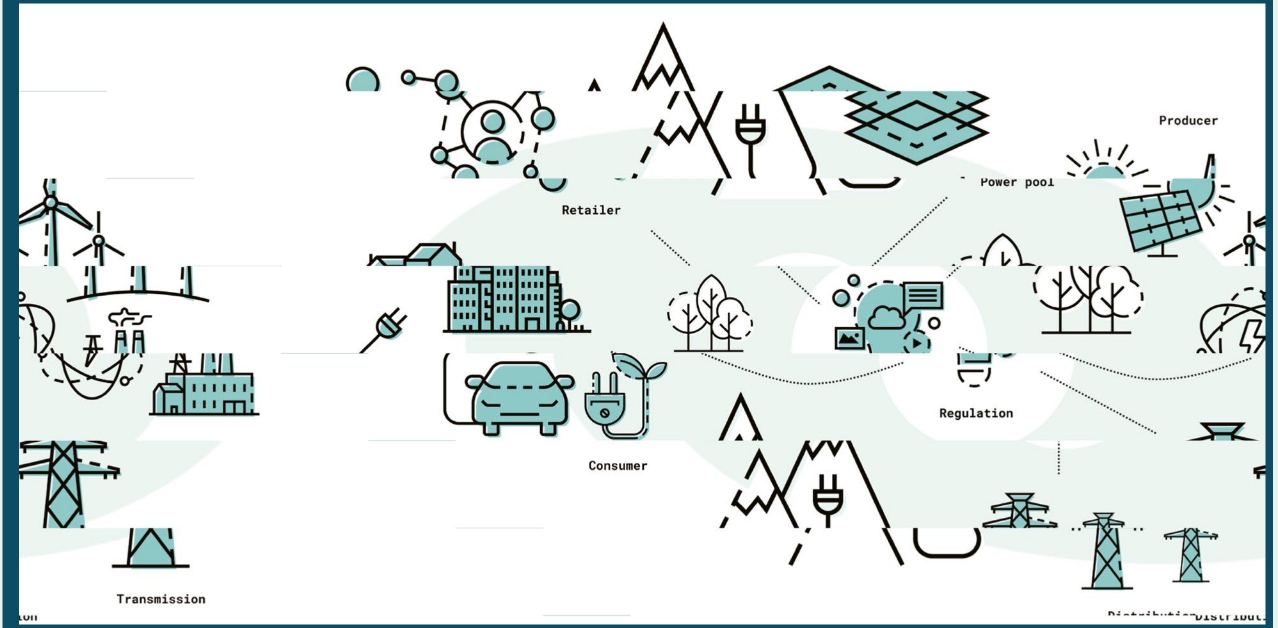


Distribution of net sales

Business sector	1,831 MSEK
Public funds	1,179 MSEK
State funds	812 MSEK
EU funds	171 MSEK

RISE Electric power system unit

Applied Research & Innovation in Techno-Economic perspectives

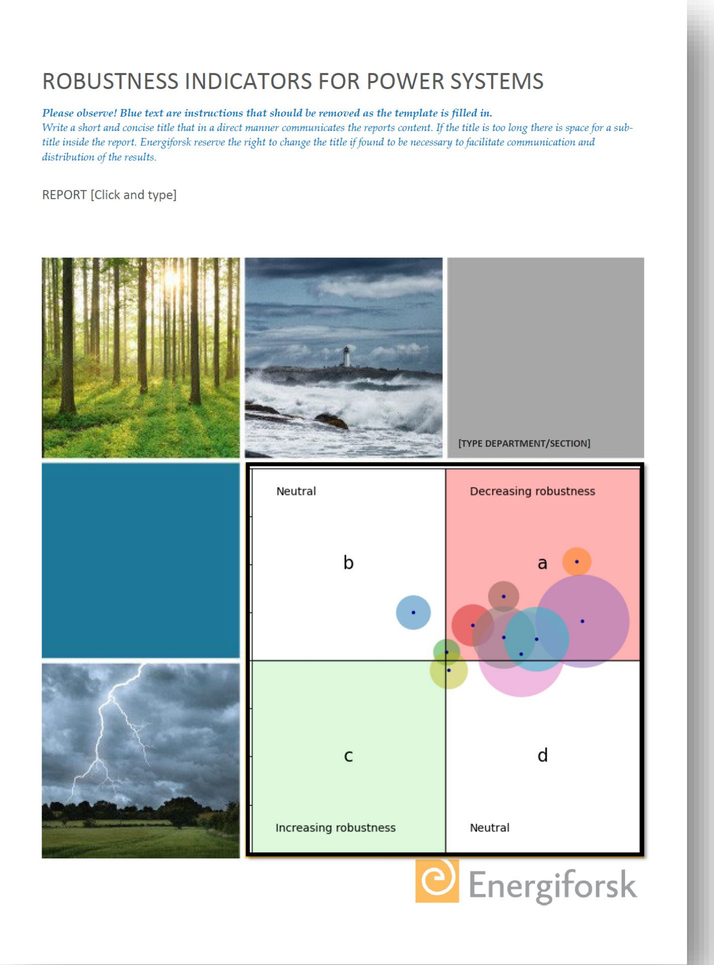


Collaboration:

- Grid owners & system operators
- Universities & Research Institutes
- Consultants
- Industry
- Public actors

Agenda

1. Project background
2. Reliability, Resilience, and Robustness
3. Robustness indicator types
4. Robustness indicator: frequency extremes
5. Robustness indicator: inertia correlation
6. Robustness indicator: transfer corridor unavailability and utilization rate
7. Main conclusions
8. Proposals for future studies


ROBUSTNESS INDICATORS FOR POWER SYSTEMS

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Write a short and concise title that in a direct manner communicates the reports content. If the title is too long there is space for a sub-title inside the report. Energiforsk reserve the right to change the title if found to be necessary to facilitate communication and distribution of the results.

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Project background

Has the ROBUSTNESS of the Nordic power system decreased?

- The Nordic power system is undergoing significant transformation, driven by
  - global energy transition
  - electrification
  - European market integration

  ➔ Escalated strain = decreased Robustness?
- Robustness indicators can provide information of how grid properties develop over time
- Challenge to find indicator to quantify general robustness

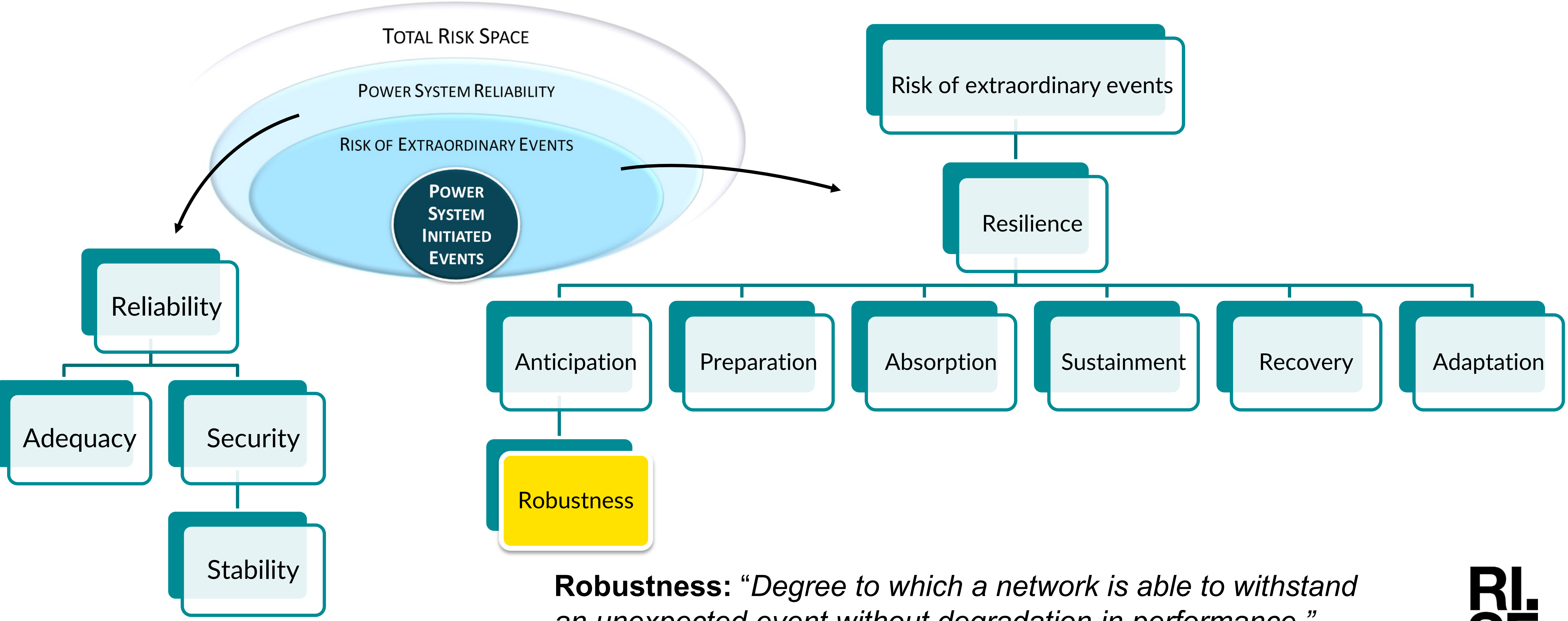
Project background

Has the ROBUSTNESS of the Nordic power system decreased?

- Project focus
  - What is Robustness?
  - How can robustness indicators be developed?
  - Can open data be used to quantify robustness?

Reliability, Resilience, and Robustness

concepts which describe functionalities of the power system

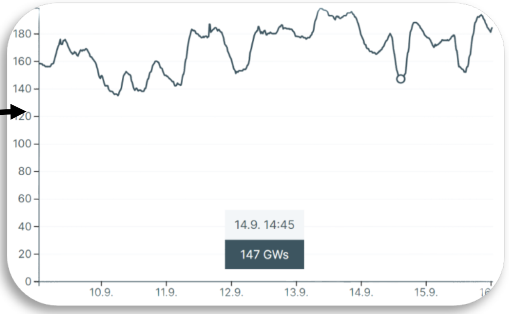


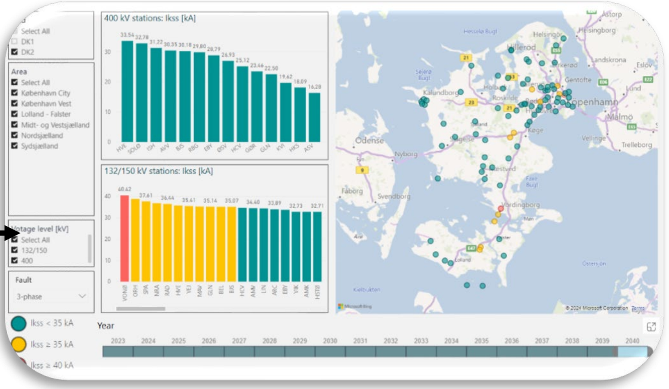
Robustness: "*Degree to which a network is able to withstand an unexpected event without degradation in performance.*"

Robustness indicator types

create robustness indicators based on different categories of data

- **Data availability**
  - Open vs proprietary
- **Time frame**
  - Long term trends / high resolution data
- **Foresight**
  - Lead and lag
- **Locality**
  - Local / regional / global
- **Superposition**
  - Integrating multiple aspects

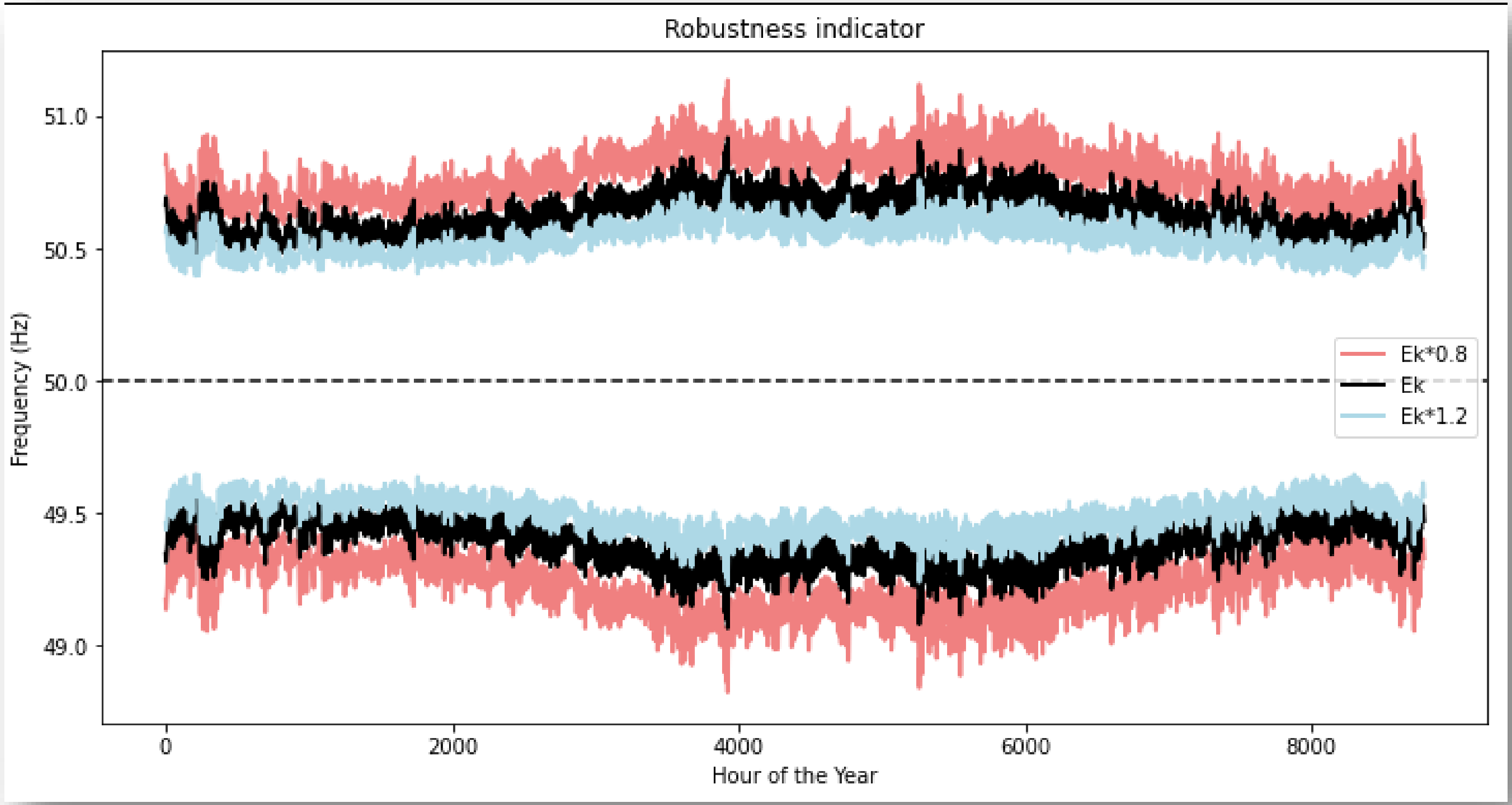




Robustness indicator: frequency extremes

addressing risk of extreme frequencies

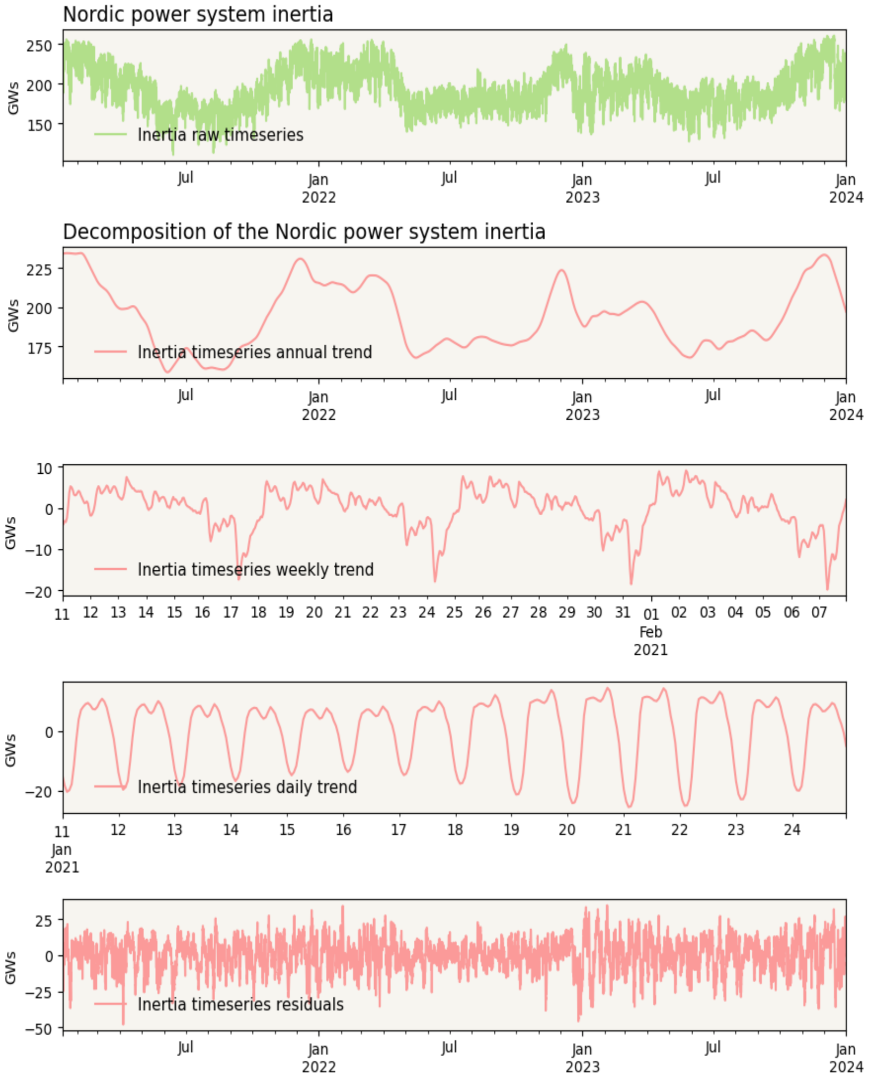
- **Locality:**
  Global
- **Lag:**
  based on historical data
- **Lead:**
  utilising forecasts
- **Existing method:**
  based on inertia



Robustness indicator: inertia correlations

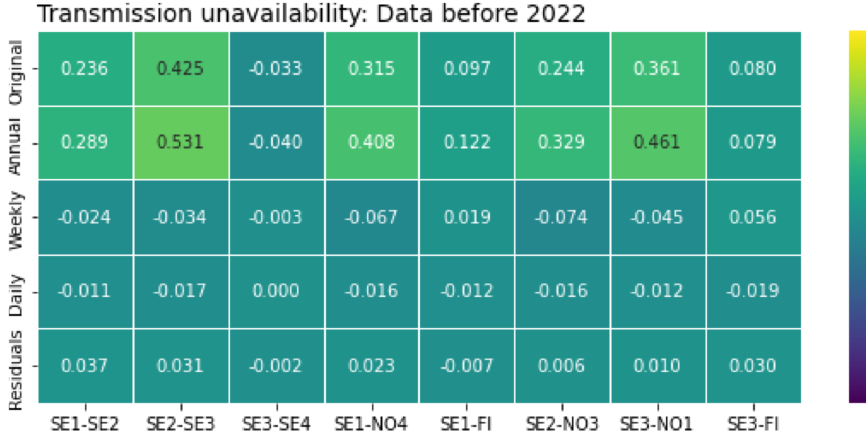
to understand the impact on different variables in various time resolutions

- **Time frame:**
  >years
- **Locality:**
  global and regional
- **Lag:**
  based on historical data
- **Complexity:**
  multifaceted assessment



Correlation parameters:

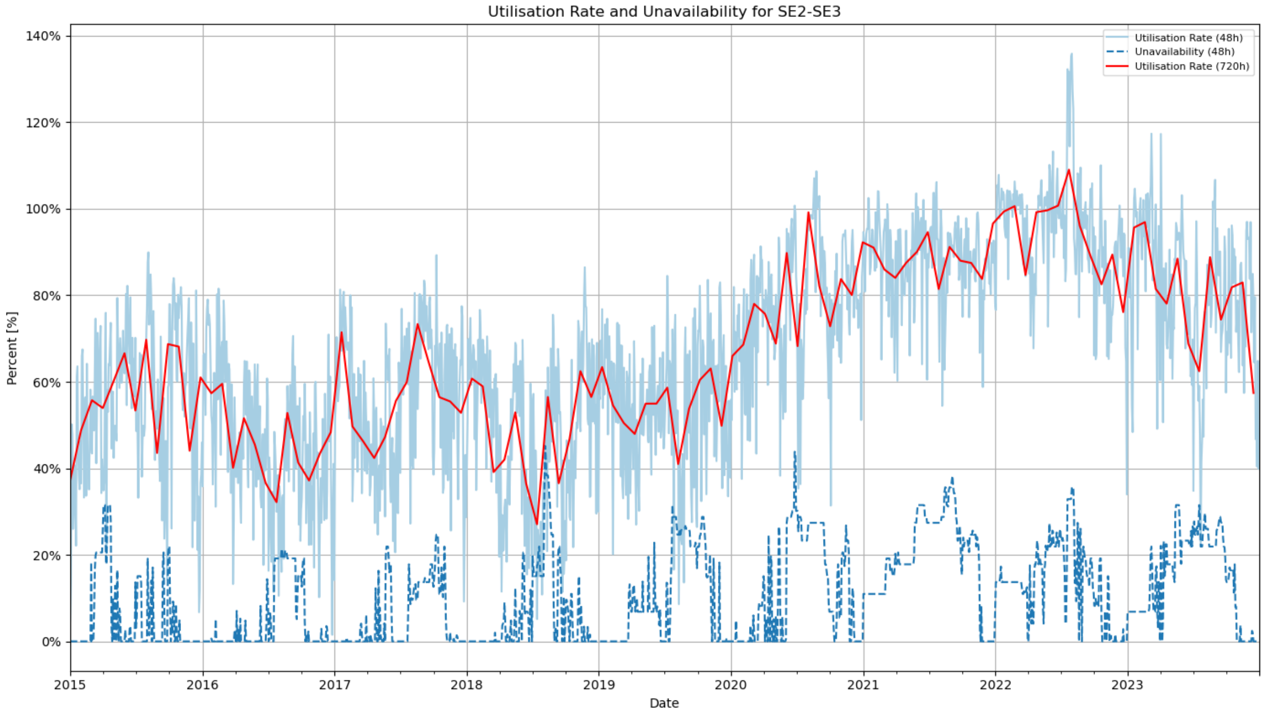
- production per generation type
- actual load
- cross-border flow
- transmission unavailability
- generation unavailability
- day ahead spot price



Robustness indicator: transfer corridor unavailability and utilisation rate

addressing grid adequacy and use

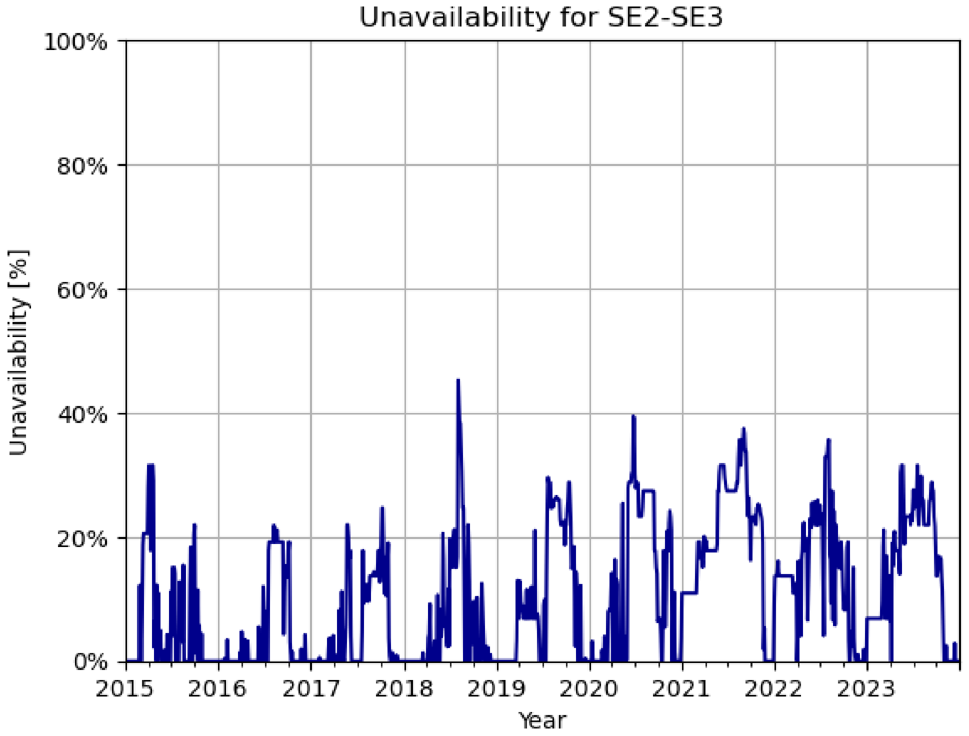
- **Locality:**
  regional
- **Lag:**
  based on historical data
- **Super positioning in two dimensions**

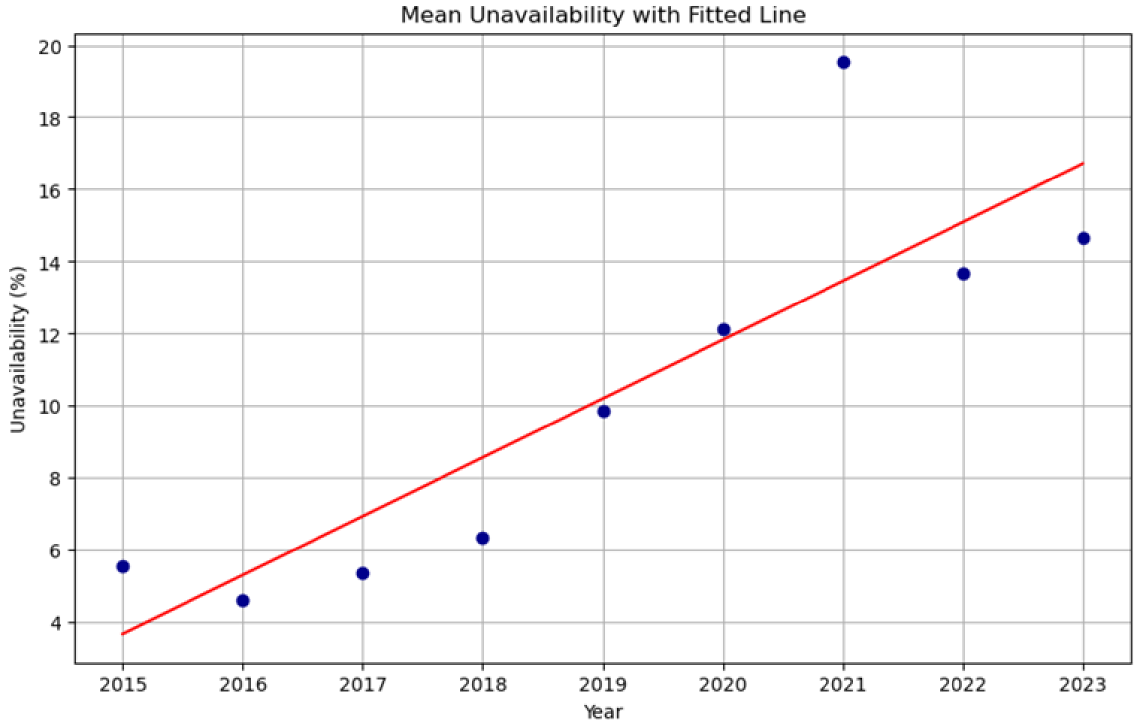


Robustness indicator: transfer corridor unavailability and utilisation rate

Dimension 1: Transfer corridor Unavailability

- **100%: *NTC* = 0 MW all the time**
- **0%: *NTC* = NTC_{max} all the time**

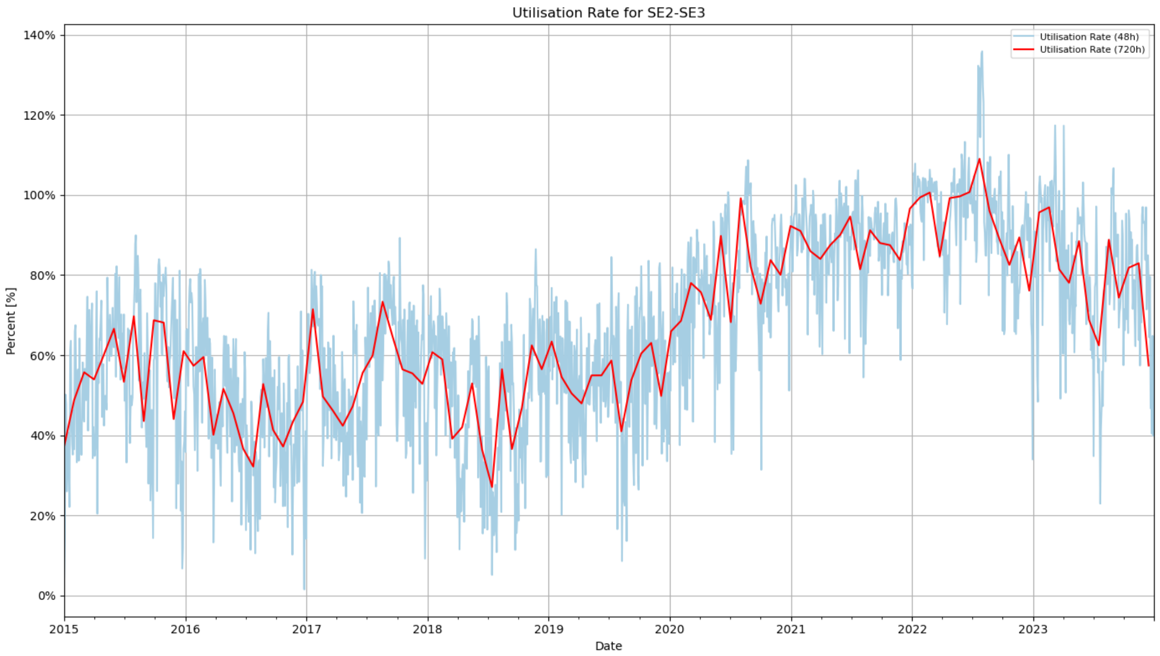


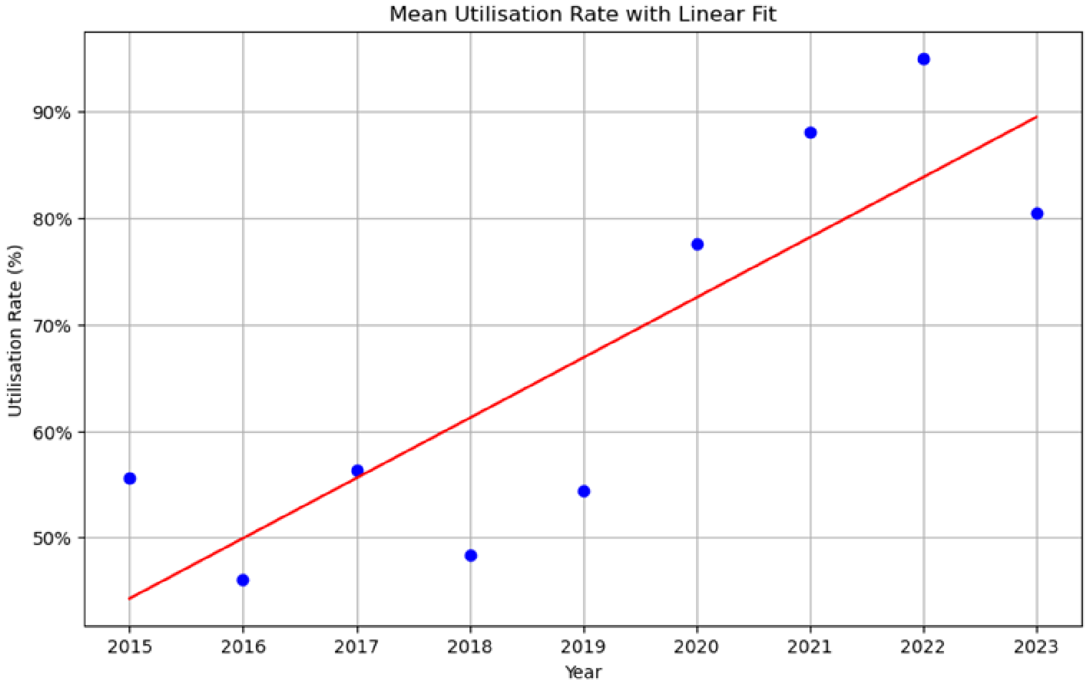


Robustness indicator: transfer corridor unavailability and utilisation rate

Dimension 2: Transfer corridor Utilisation Rate

- **100%: all of the *NTC* is needed, all the time**
- **0%: no power transfer is needed during that time period**

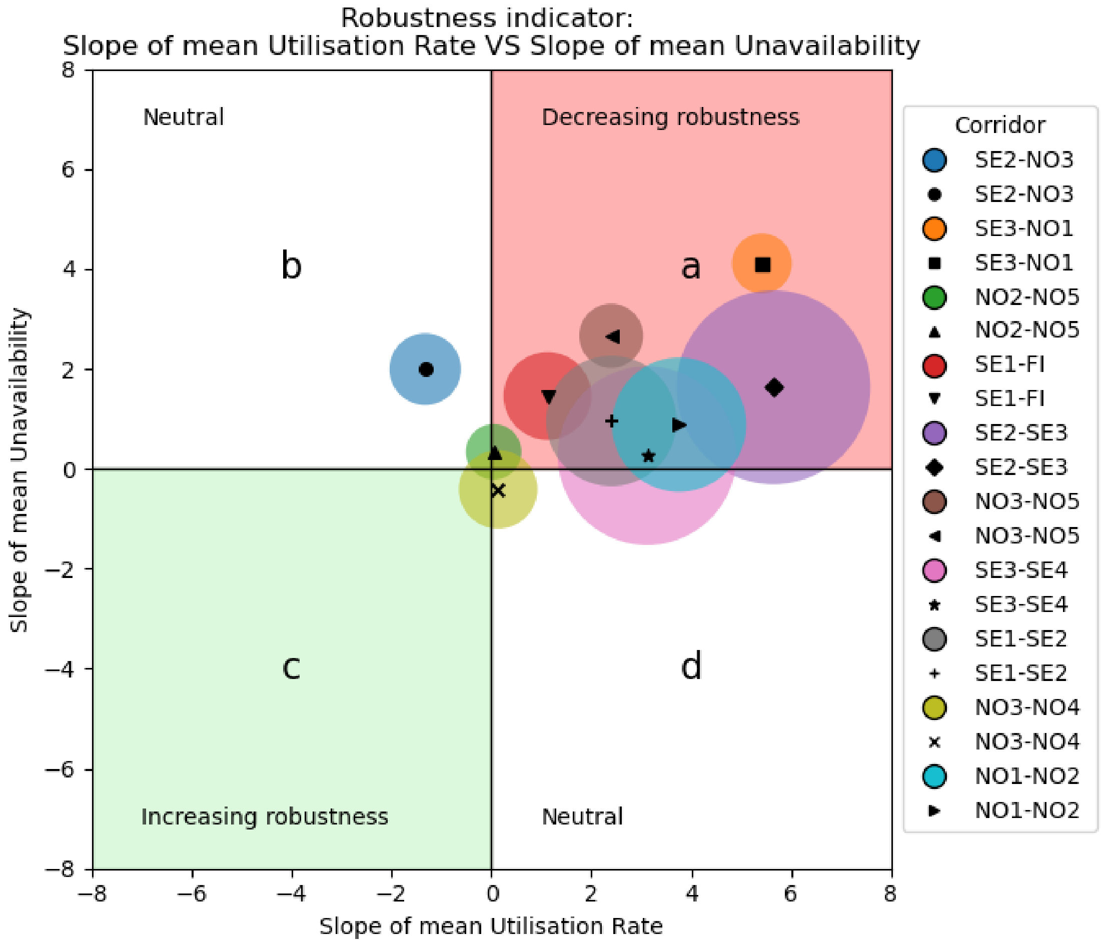




Robustness indicator: transfer corridor unavailability and utilisation rate

Combined robustness indicator

- More than 90% of the transfer corridors in the Nordic Power System (weighted by their respecitve NTC_{max}) are showing signs of decreasing robustness
- No transfer corridor is showing any sign of an increasing robustness
- In summary, the proposed Robustness Indicator clearly shows that the Nordic Power System has on average, become less robust during the studied time period of 2015 – 2023



Main Conclusions

Global and regional robustness indicators using open data, focusing on :

- Frequency
- Inertia
- Transfer corridors

- **Frequency extremes**
  By analysing the relationship between kinetic energy and frequency deviations potential risks may be identified. Frequency robustness is a relevant indicator for anticipating system responses to disturbances, especially in low-inertia situations.
- **Inertia correlation**
  The study of inertia correlations with variables such as power generation, load, cross-border flow, production and transmission unavailability, and electricity spot prices, highlights how system inertia fluctuates over time. This correlation-based approach provides an overview of the factors affecting stability and resilience.
- **Transfer corridor unavailability and utilisation rate**
  Analysing the combined impact of unavailability and utilization rates, a trend toward decreased robustness within the Nordic power system have been identified.
- **Maintenance and cancelled outages**
  The rising trend of cancelled planned outages may signal a maintenance backlog, potentially affecting long-term system reliability. While public data limitations prevent definitive conclusions on this issue, the potential of detrimental impact by delayed maintenance on system robustness could be severe.

Proposals for future studies

Expansion

- Address local robustness indicators
- Requires some proprietary data
- Correlate site-specific statistics with global and local measurements

Further improvement

- **Enhanced Correlation Analysis**
  Time-segmented analyses of time-series data could identify extreme values in correlation factors, which could reveal rapid fluctuations and periods of unavailability
- **Broader Scope of Analysis**
  Expand the analysis to include hydro power generation impact in Norway and assess how mitigation strategies and control unit limitations affect frequency extremes
- **Assessment of Maintenance Backlog**
  Investigating the possibility of a rising maintenance back-log that could affect future grid reliability, by probabilistic methods
- **Refinement of Composite Robustness Indicators**
  Tracing the robustness indicators over time would provide valuable insights. Investigating the uncertainty within these indicators would enhance the reliability of conclusions drawn from robustness assessments

RISE team

Emil Hillberg

Tommie Lindquist

Erik Weihs

Gustaf Bengtsson

RISE Research Institutes of Sweden
Electric Power Systems