IAM COMPACT

Expanding Integrated Assessment Modelling:
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for Sustainable, Co-Created Climate Action

Responsive science in support of climate policymaking
IAM COMPACT Final Conference, Athens, 29 August 2025

# Security, flexibility, and resilience in the EU

**Dr. Rasmus Magni Johannsen, Aalborg University**

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**Are renewable energy systems inherently less secure and resilient than traditional energy systems?**

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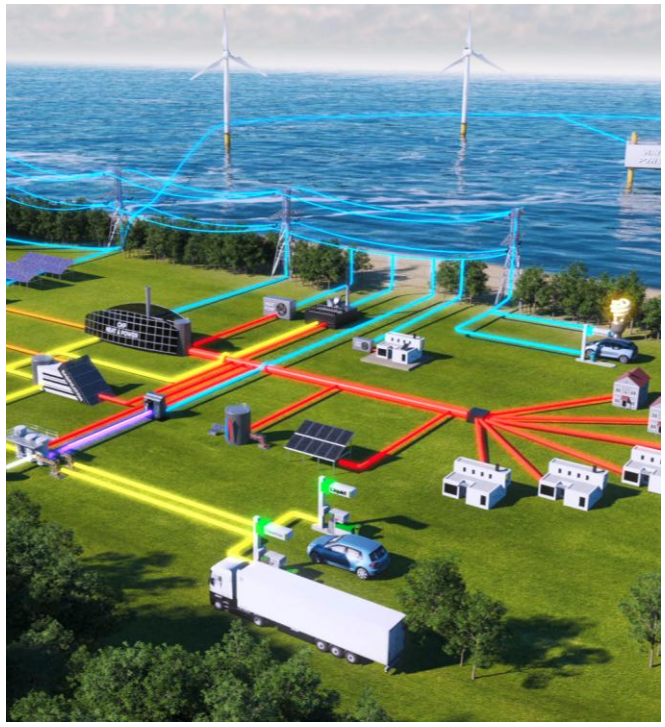
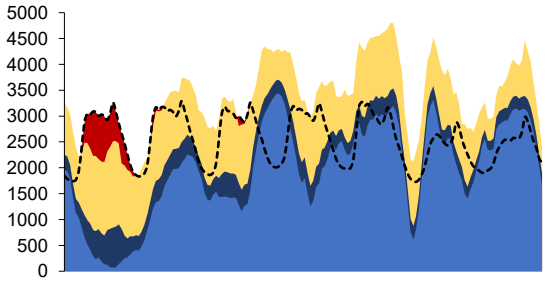
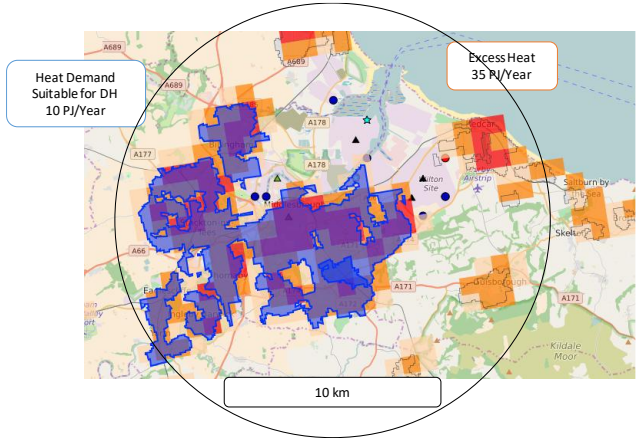
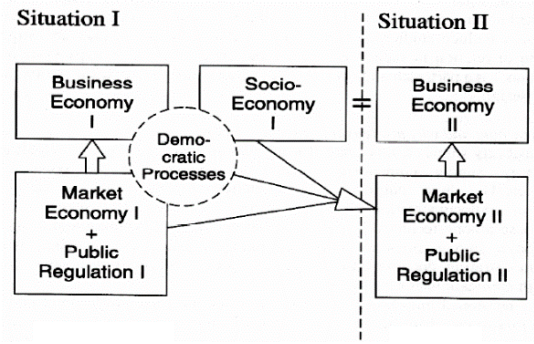
## What do we do?

- Energy System Analysis
- Energy & Geographical Information Systems (GIS)
- Feasibility studies
- Public regulation, ownership models



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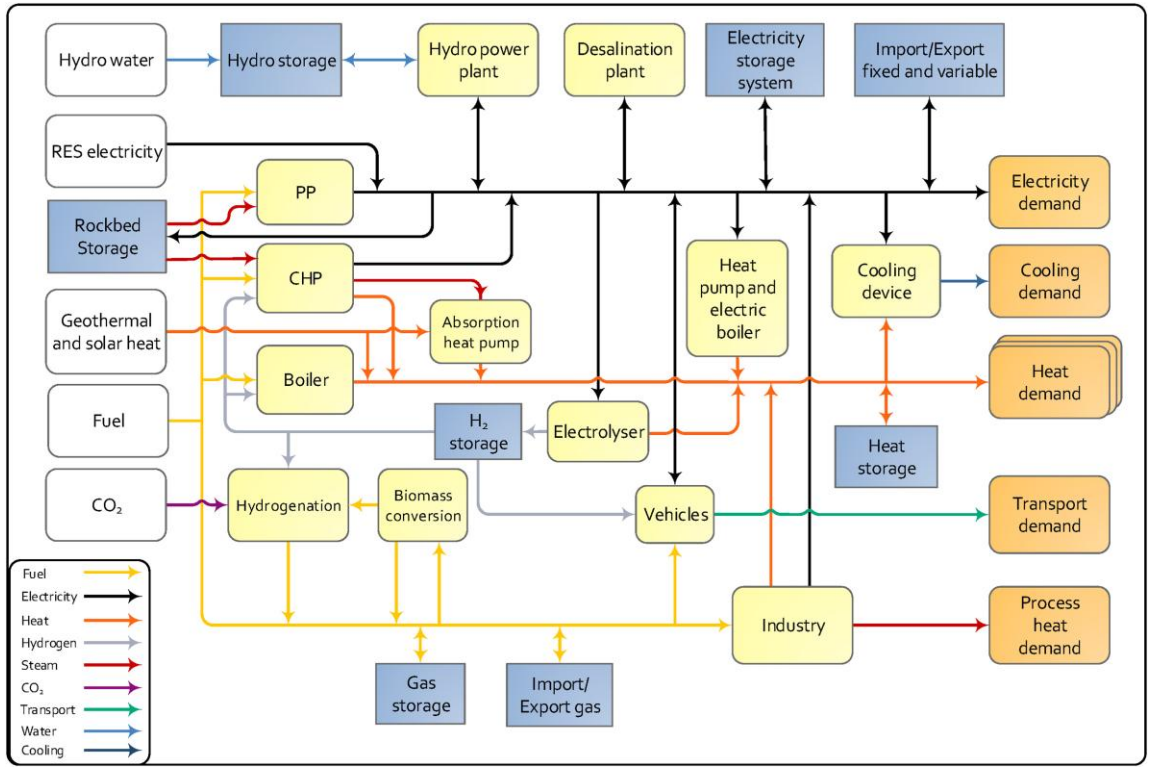
## EnergyPLAN

- Developed since 1999
- Freely available online including documentation, videos, and training material

## Model characteristics

- Deterministic model
- Hourly simulation
- Aggregated system design
- Optimises *operation* rather than investments
- Analyses 1-year steps
- Fast computation time (seconds)




https://energyplan.eu/

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With this study, we explore **energy security, resilience**, and **flexibility** in the context of European **renewable** energy systems, specifically:

- **Security** measured through degree of system diversification
- **Resilience** in disruptive events evaluated through system shock scenarios
- **Flexibility** as the ability of the system to integrate large amounts of variable renewable electricity

See related policy brief: "Enhancing Renewable Energy System Metrics: Security, Flexibility, and Sustainability"

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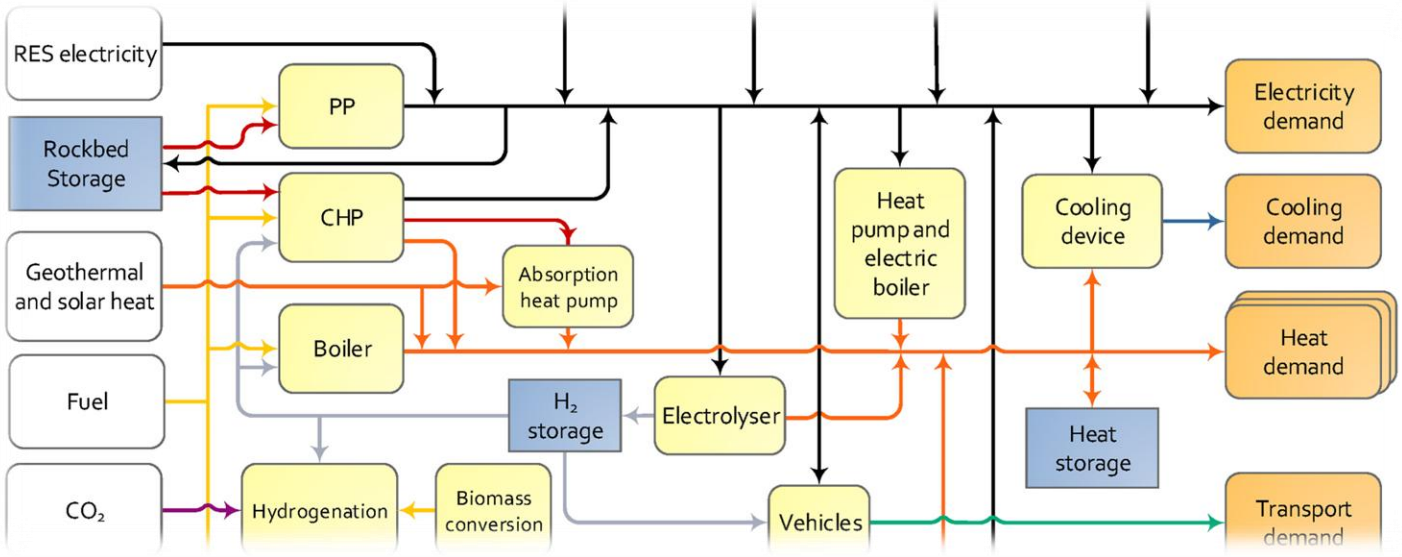
## EU scenarios

- **"Baseline 2050":** Current trajectory reflecting agreed policies, and macro-economic projections, fuel price projections, and technology assumptions.
- **"1.5 TECH 2050":** Climate-neutral scenario with emphasis of electrification, hydrogen, nuclear energy, and VRE.
- **"Smart Energy Europe 2050":** A 100% renewable energy system based on Smart Energy System principles, emphasizing energy efficiency, district heating and VRE expansion




See more also in the publication *"Beyond sector coupling: Utilizing energy grids in sector coupling to improve the European energy transition"* https://doi.org/10.1016/j.segy.2023.100116

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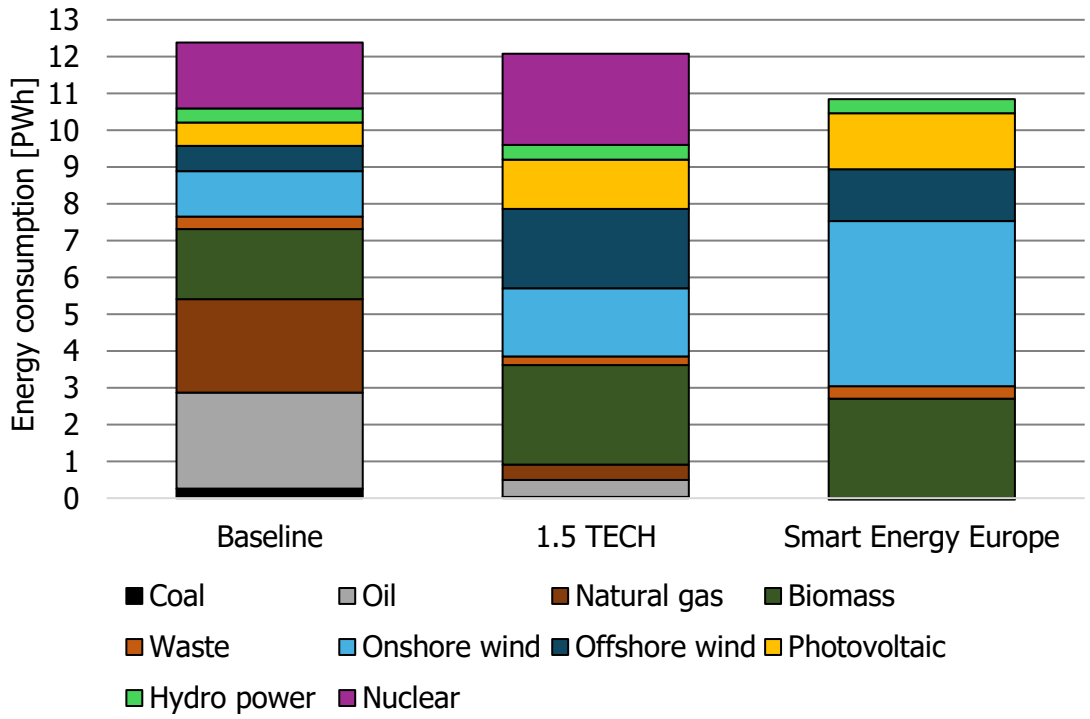
- **Smart Energy Europe** uses the least energy due to strong efficiency measures.
- Smart Energy Europe achieves **100% renewable energy**, omitting nuclear and fossil fuels.
- **1.5 TECH** achieves **90% $CO_2$ reduction**, but retains nuclear and some fossil fuels—mainly for transport.

## Modelled 2050 energy system scenarios

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# Energy system security through diversity

***"Don't put all your eggs in one basket!"***

**Why it matters:**

- Imports can fail
- Weather can disrupt
- Supply chains can break
- Infrastructure can be attacked

**Diverse, decentralised technologies = stronger, more resilient systems.**

Traditional metrics (e.g., Shannon-Wiener index) miss the unique strengths of renewable energy systems.

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# Diversity Evaluation Results

**Decentralisation adjusted diversity index:**

- A diversity index metric considering not only **technological diversity** but also **degree of decentralization**

**Baseline**

- Benefits from retaining fossil fuels (increased technological diversity)

**Smart Energy Europe**

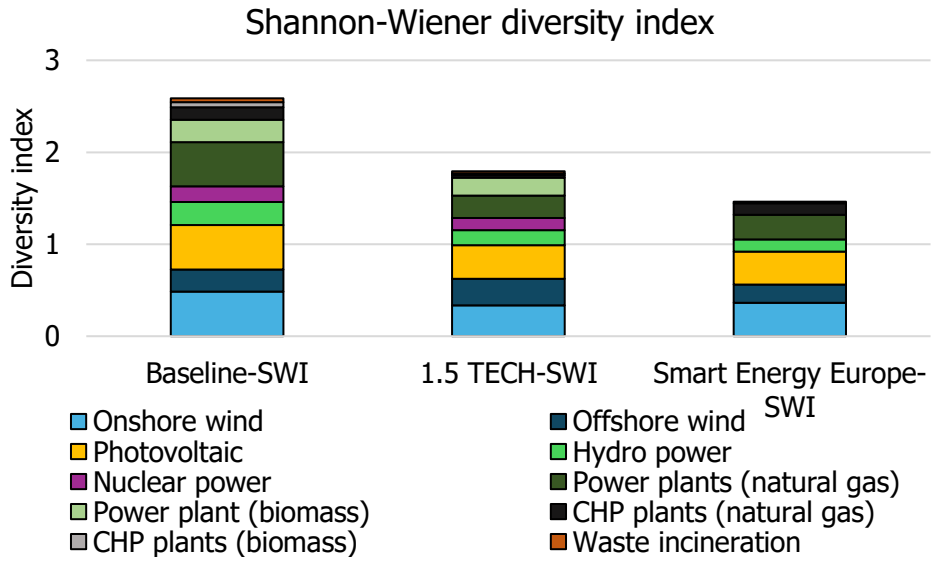
- High unit count from onshore wind
- Limited diversity gain due to dominance of one tech
- SWI underrepresents value of decentralised renewables
- DADI better reflects system structure

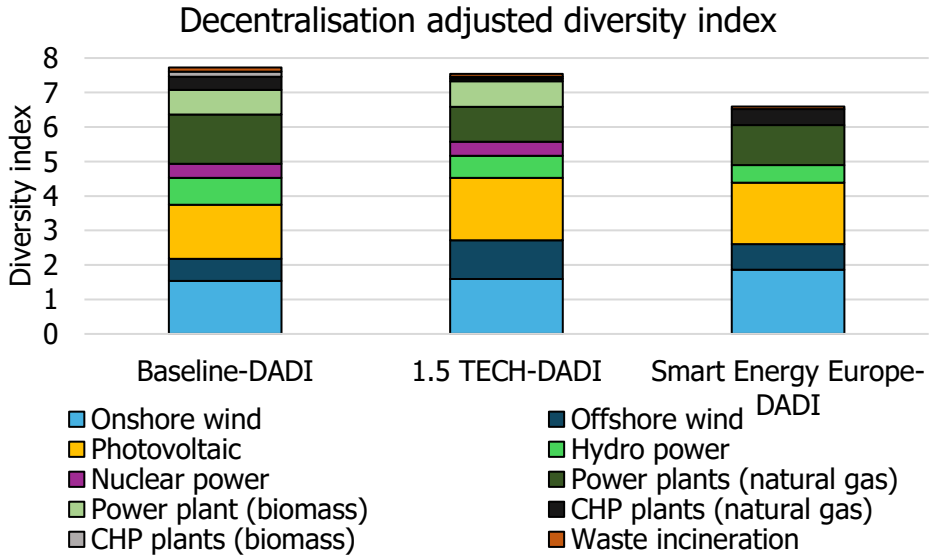
**1.5 TECH Scenario**

- Balanced mix of wind, PV, CHP, and nuclear
- Higher diversity scores (SWI & DADI)

**Takeaway**

- Diversity was not a design goal - but matters for security
- Advanced diversity metrics are essential for future planning

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## Disruption types

- Nuclear outages
- Adverse wind conditions

## System impacts

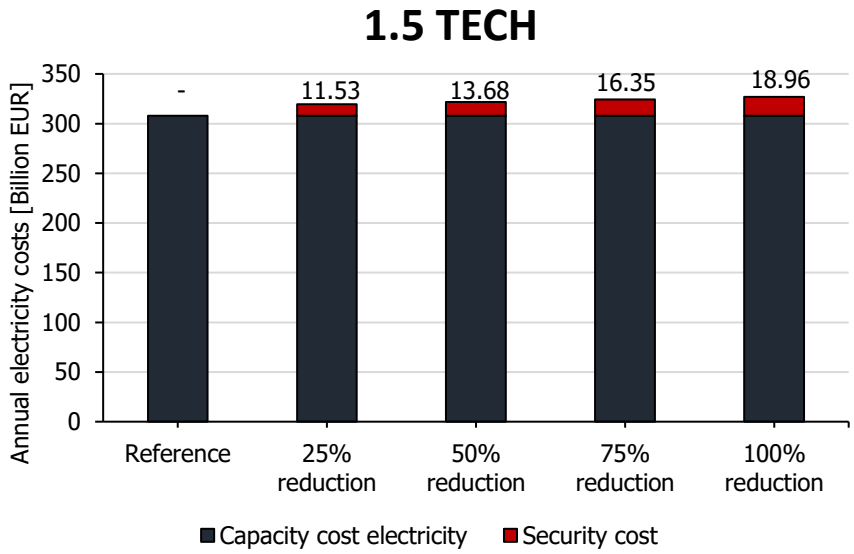
- 300-400 GW reserve capacity needed
- Active only 70–200 hours/year

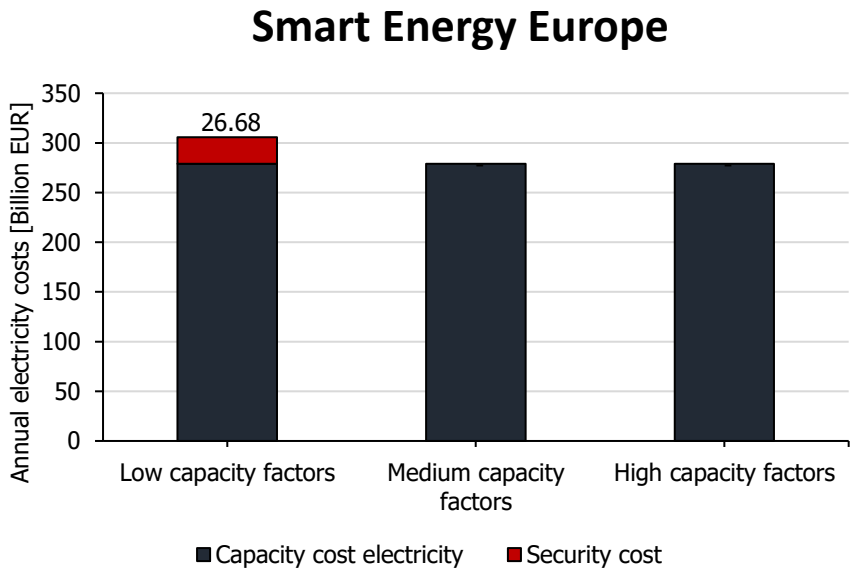
## Adaptation options

- Peak power plants, demand flexibility, curtailment, imports

## Policy Insight:

Extreme disruptions require large reserve capacity but minimal operation time. Flexible alternatives are likely to be more cost-effective.

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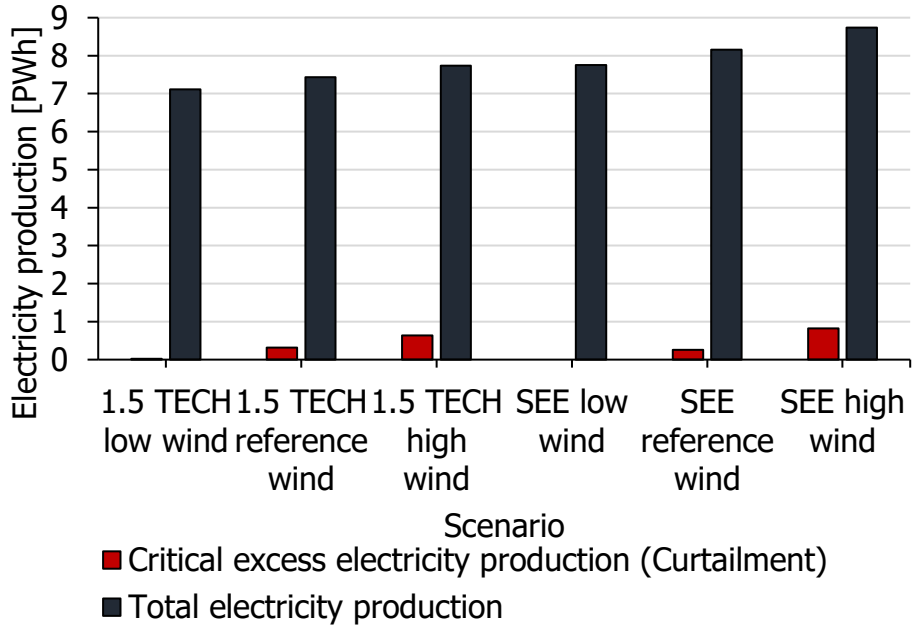
**What is CEEP?**

**Critical Excess Electricity Production** = Unused electricity due to system limits (no use, storage, or export)

**Key Insights:**

CEEP stays **below 10%**, even with high wind output

High wind shares are **manageable** without major losses or nuclear cutbacks




**Efficiency Drivers:**

- Smart sizing of renewables
- Flexible backup systems
- Integration tech: **PtX, power-to-heat, thermal storage, EVs, smart charging**

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**Incorporate resilience & security** into energy system modelling - not just cost & emissions.

**Use advanced diversity metrics** (e.g., DADI) to reflect decentralisation and renewable technologies.

**Maintain dispatchable capacity** (e.g., biogas, CHP) to support system robustness.

**Plan for extreme disruptions** with peak-load plants and flexible backup strategies.

**Support integration technologies** like PtX, district heating, EV smart charging, and storage.

**Prioritise strategic diversification** of technologies and fuels in scenario design.

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# Thank you!

**Rasmus Magni Johannsen**

rmj@plan.aau.dk

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