Aalto University
School of Science

ACADEMY
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Energy System Response to Future Uncertainties

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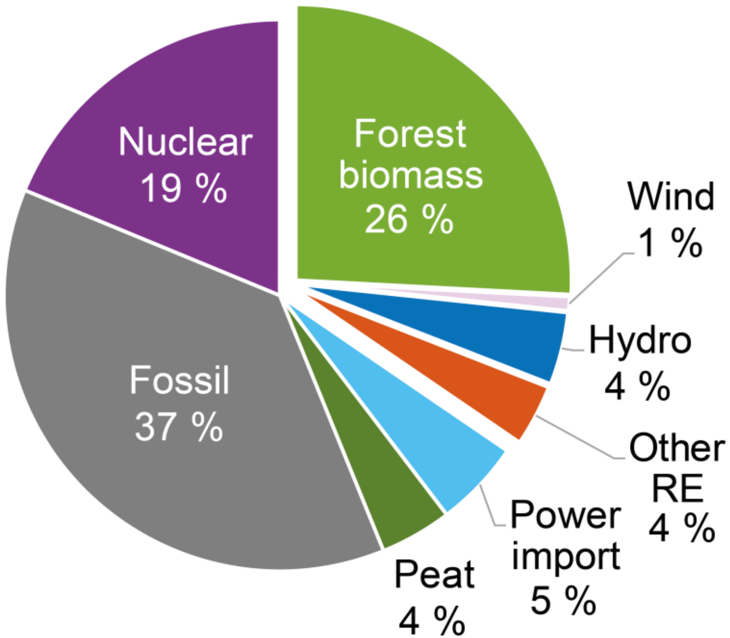
Outline

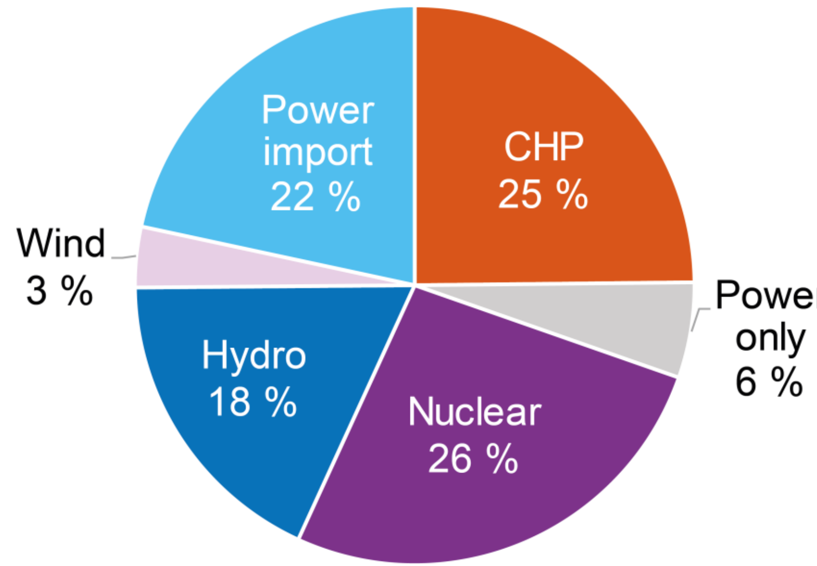
- **Energy in Finland**
- **Motivation and research questions**
- **Methodology: model and analysis**
- **Results**
- **Conclusions**

Energy in Finland

- **Cold climate, very energy-intensive industry**
- **Forest biomass and nuclear**
- **Share of renewables 41% in 2017**
- **Ambitious targets**
  - Banning the use of coal by 2030
  - CO_2 emissions -55% by 2035
  - Carbon-neutrality by 2035
  - Power and heat generation carbon-neutral by 2040

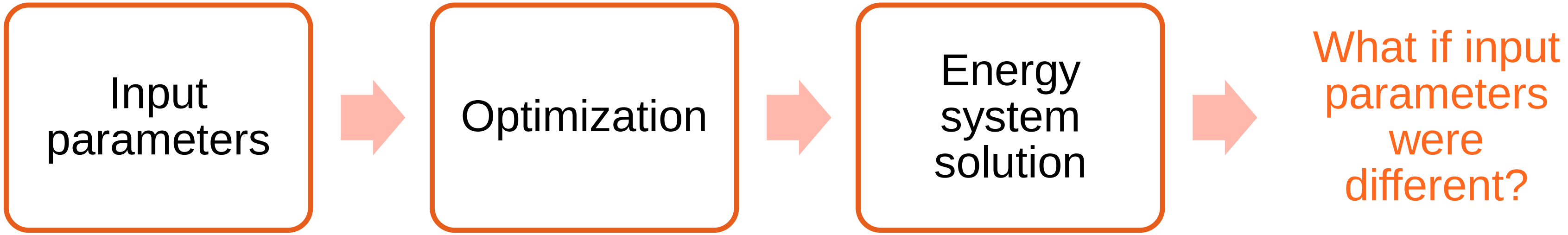
Energy in Finland





Motivation

- **Energy system optimization often based on deterministic values for input parameters**
  - Risk for suboptimal decisions or performance



Research questions

- **To which extent would uncertainties affect the performance of an energy system?**
  - Consumption level, cost and renewable resource uncertainties
  - Existing energy system vs. future low-carbon energy systems
  - Simultaneous sensitivity analysis
  - Which uncertainties are the most significant?

Methodology

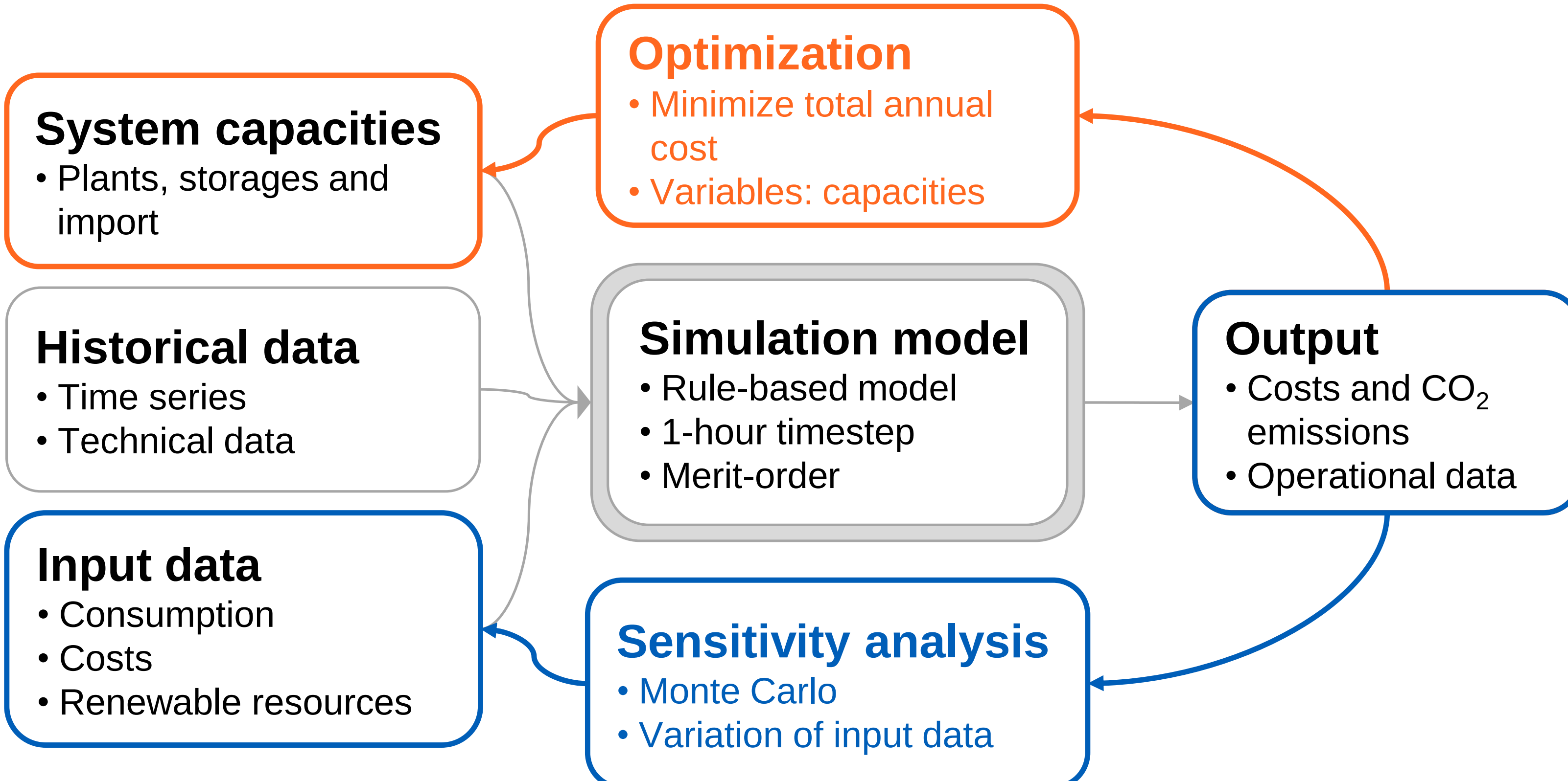
- **National energy system simulation model**
  - Electricity, heat and fuel
  - Hourly merit-order-based heat and power production
  - Also includes P2H, P2G, electric vehicles and storages
- **Reference system: Finland in 2016**
  - Calibrated with historical data
- **Future 2050 low-carbon energy system scenarios**
  - Cost optimization
  - Different levels of nuclear (0 – 6700 MW) and cross-border transfer capacities (3600 – 6800 MW)

Pilpola, S.; Arabzadeh, V.; Mikkola, J.; Lund, P.D. Analyzing National and Local Pathways to Carbon-Neutrality from Technology, Emissions, and Resilience Perspectives—Case of Finland. *Energies* **2019**, *12*, 949.

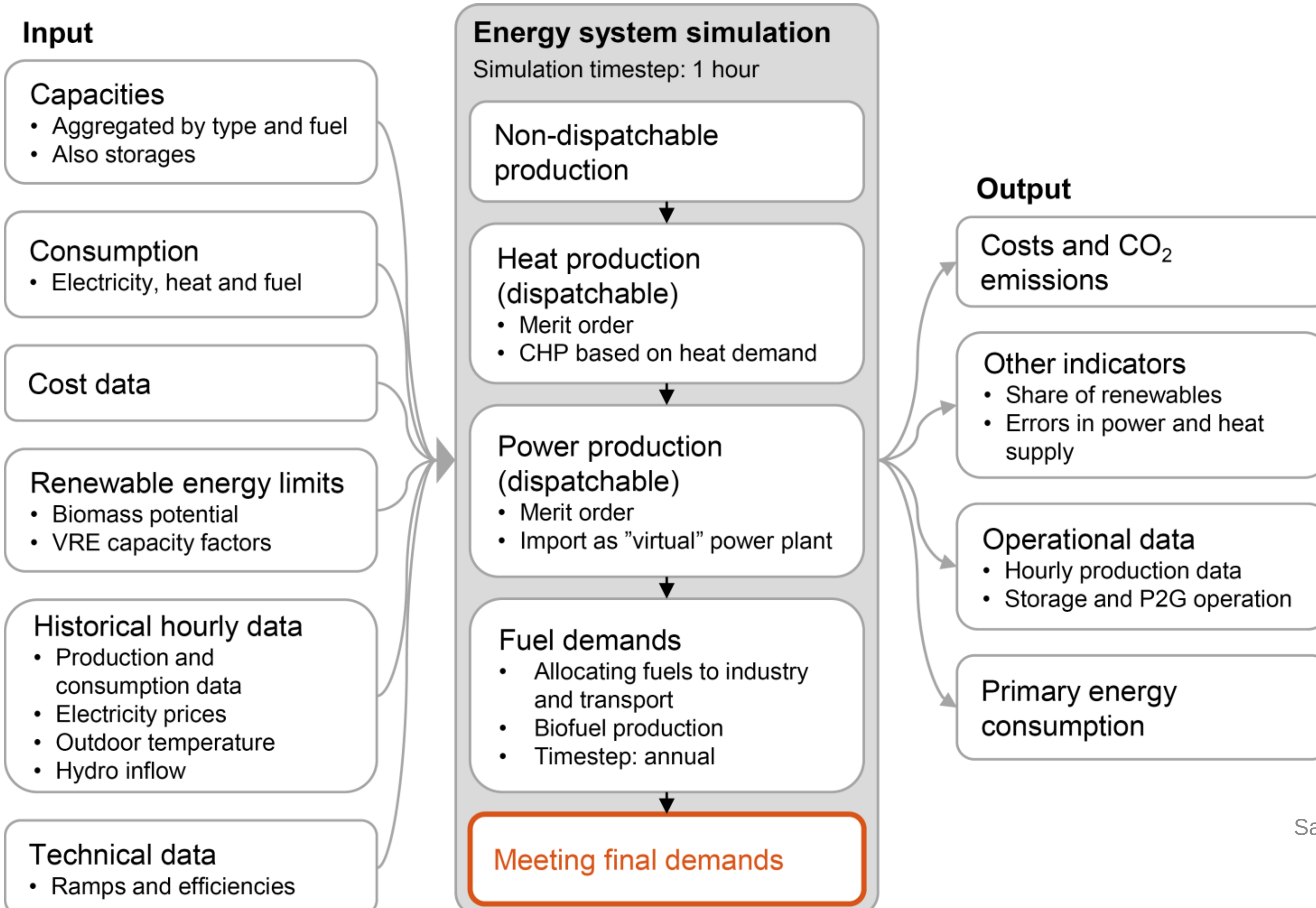
Methodology: sensitivity analysis

- **Monte Carlo uncertainty analysis, N = 10 000**
  - Simulation model is repeatedly evaluated for different samples of the uncertainty
  - Existing energy system (Finland in 2016) and future low-carbon energy system scenarios
- **Uncertainty ranges for costs, consumption and renewable resources in 2050**
  - In total 45 parameters
  - Uniform distribution assumed
- **Most influential parameters determined via correlation coefficients**

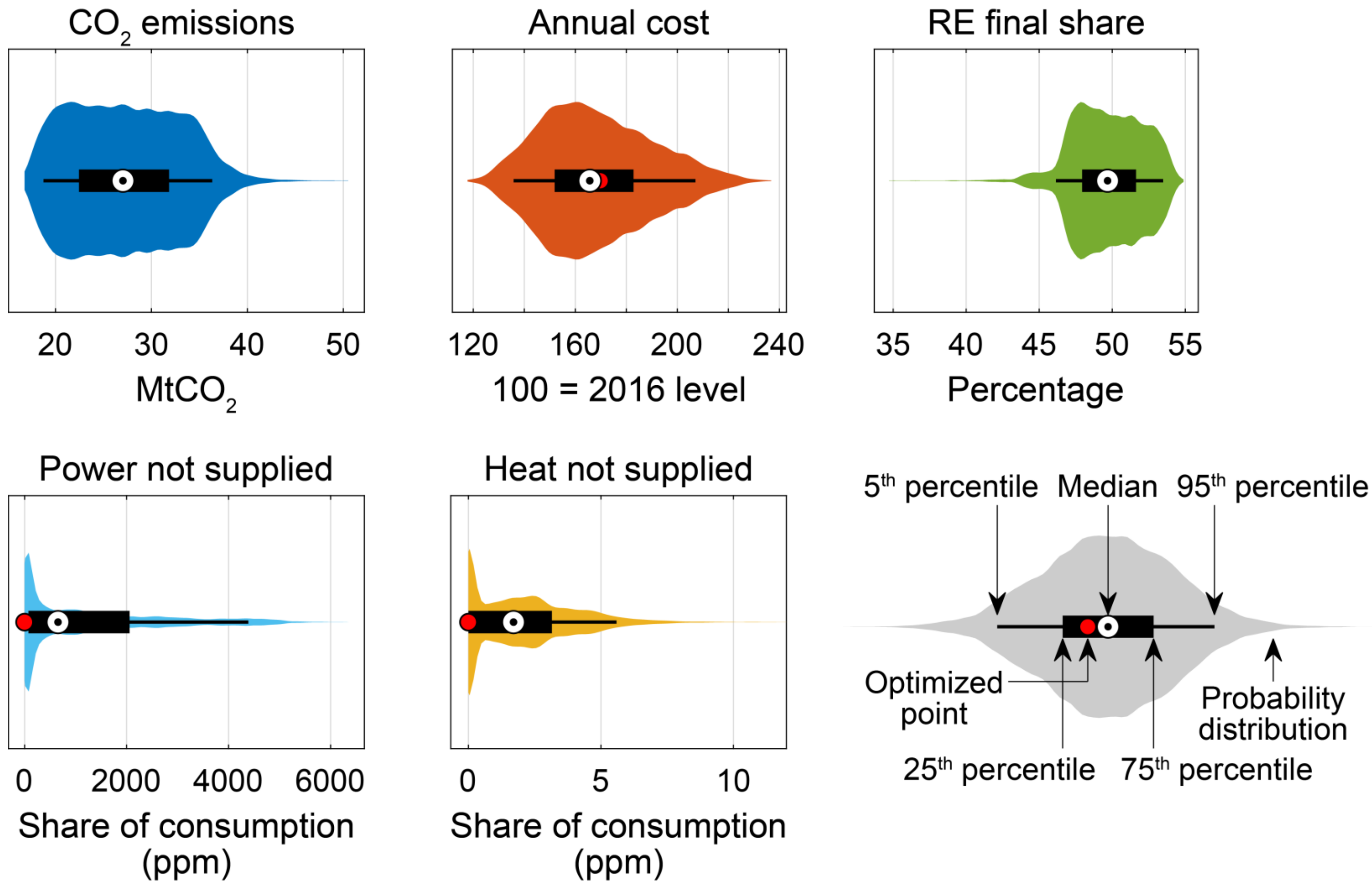
Methodology: schematic of the study



Methodology: simulation model



Results: 2016 system + 2050 uncertainties



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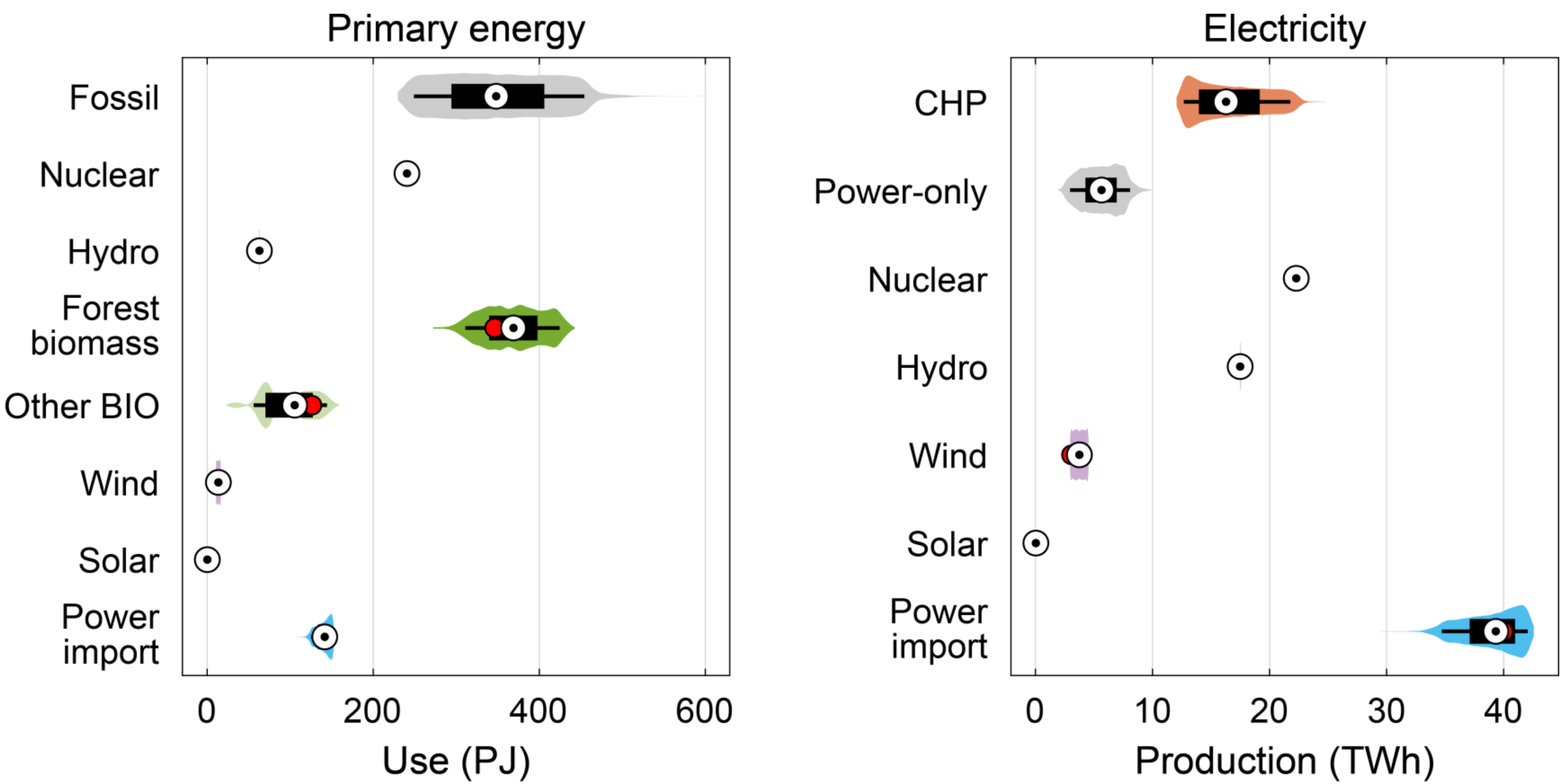
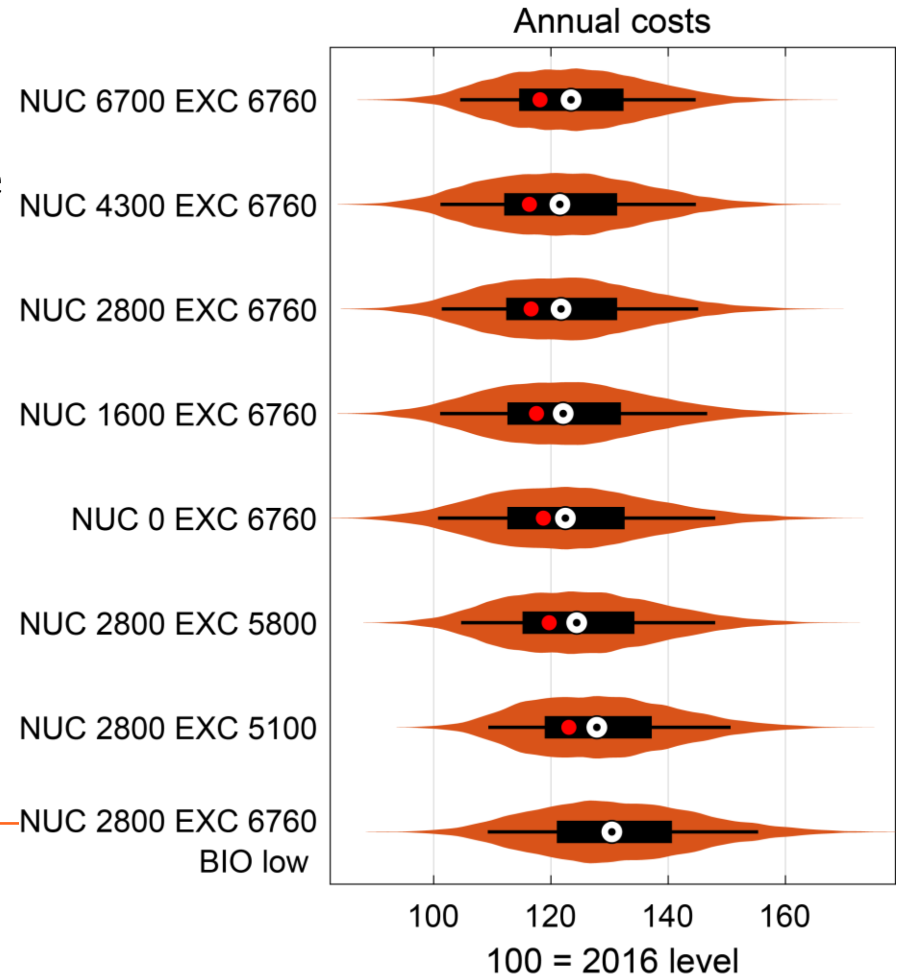


Results: future energy systems

- **8 future scenarios**
  - Different nuclear and exchange capacities
- **Original cost difference 12%**
  - Uncertainties blur out the differences
  - → "Best" scenario ambiguous
- **Similar results for e.g. CO_2 emissions**



Results: final notes

- **Consumption level the most significant factor**
  - Correlation with e.g. CO_2 emissions 0.68-0.93
- **Wind power capacity factor and CO_2 price next significant**
- **Biomass potential affected mainly CO_2 emissions**
- **Uncertainty analysis without consumption variation did not change the results**

Conclusions

- **Level of consumption highly relevant in future energy system optimization**
- **Existing Finnish system not able to fully cope with 2050 consumption**
  - Electricity not supplied 1.1% of the time, annually 0.1% of consumption
- **Fuel-based production more susceptible to variations**
- **Selecting the "best" pathway becomes harder when uncertainties are included**

Thank you for your attention

Questions? Comments?

Justification of N = 10 000