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Chair of Energy Systems & Energy Economics

ROBUST PLANNING OF A EUROPEAN ENERGY SYSTEM UNDER CLIMATE UNCERTAINTY USING IMPORTANCE SUBSAMPLING

OR Karlsruhe 2022, Leonie Sara Plaga, Valentin Bertsch

Overview

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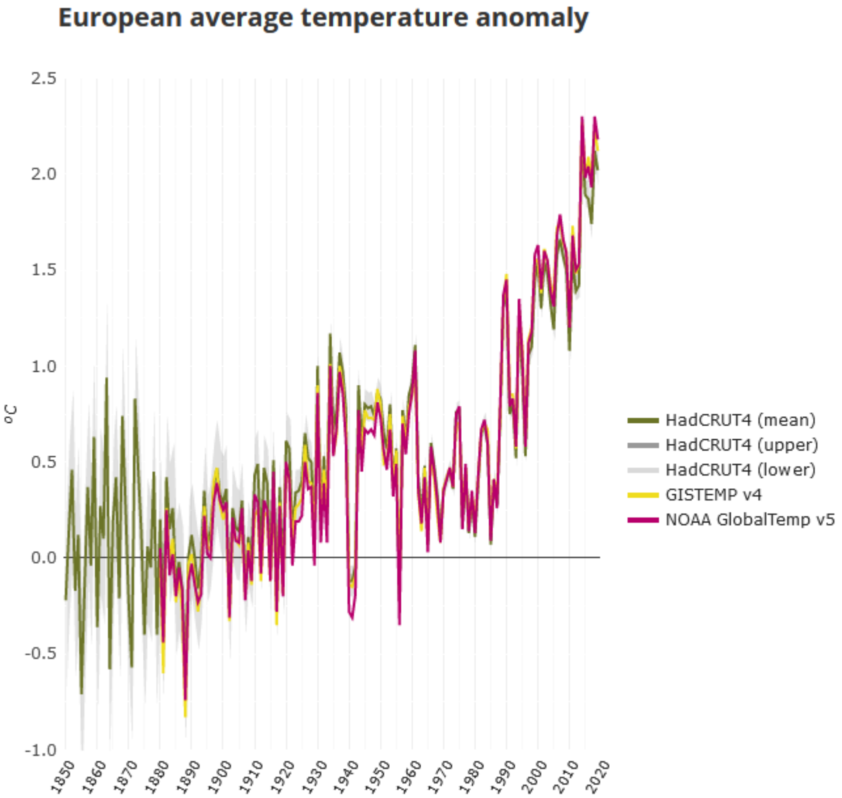
Motivation

- Climate change impacts already visible
- Energy systems depend on climate variables
- Climate projections are highly uncertain
- Many different models for many different years



Source: https://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-10/assessment

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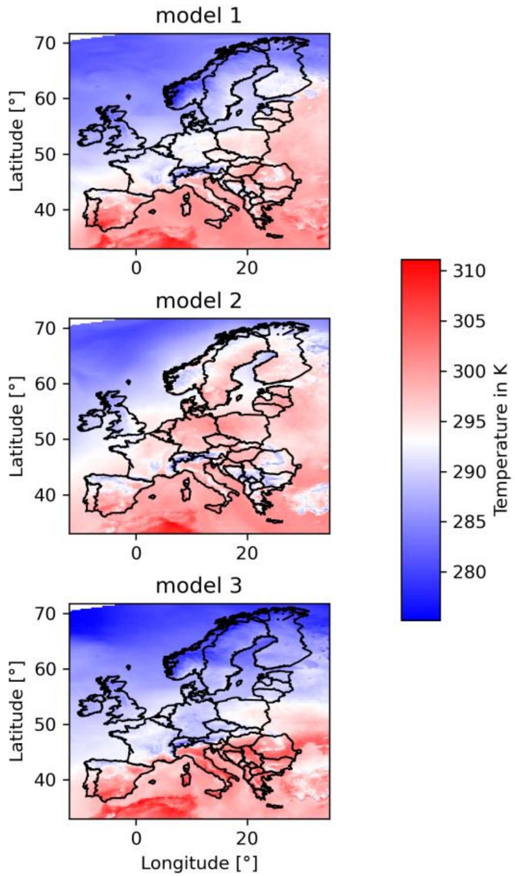
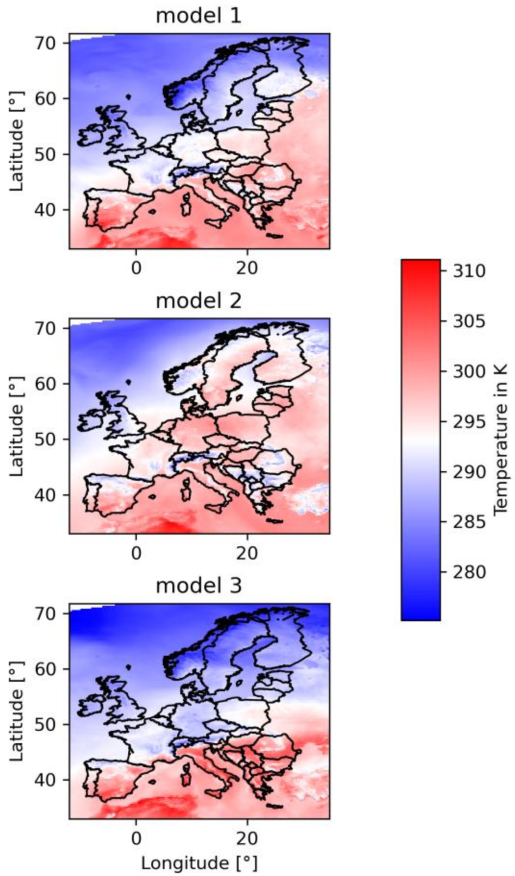


Motivation

- How can one incorporate the different projections into energy system planning?
- How can we reduce the input data to incorporate large numbers of years and models?



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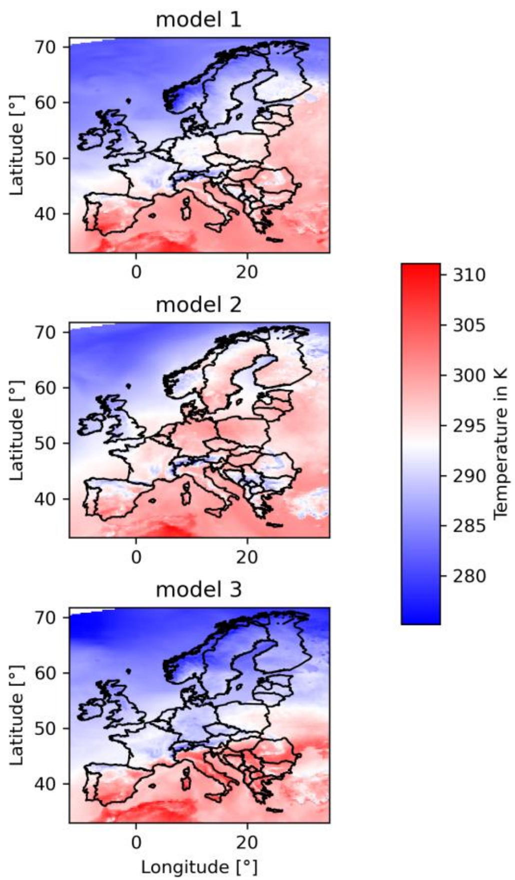
→ **Importance Subsampling**



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Overview

Description of case study

Overview

- Optimization of the European electricity sector for target year 2050
- No coal, oil or gas power plants
- Investment in nuclear power, wind, PV, batteries and hydrogen storage

Description of case study

Data and software

- Analysis in energy system model backbone[1]
- Most power system data from pypsa-eur[2]
- Climate projections from Euro-Cordex
  - >5 different climate models
  - All years from 2006 to 2100

[1] Helistö et. al, 2019, doi.org/10.3390/en12173388
[2] Hörsch et. al, 2018, doi.org/10.1016/j.esr.2018.08.012

Overview

Importance Subsampling

Original Method

- Introduced by Hilbers et. al (2019)*
- Aim: represent a large dataset with a small number of timesteps

* 10.1016/j.apenergy.2019.04.110

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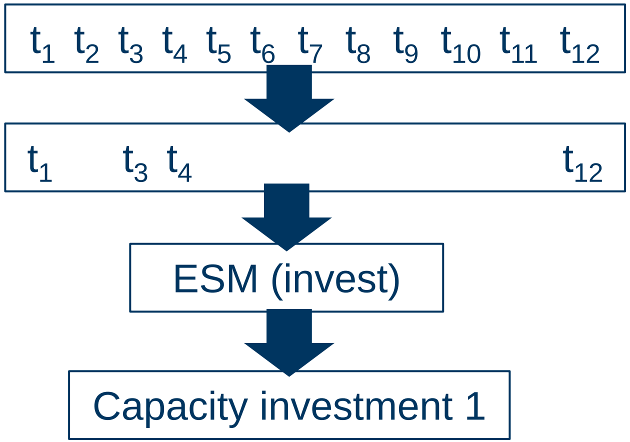
Importance Subsampling

Original Method

- Methodology:
  1. Randomly sample N timesteps from dataset.
  2. Estimate capacity investments based on these datasets.



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Importance Subsampling

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- Methodology:
  1. Randomly sample N timesteps from dataset.
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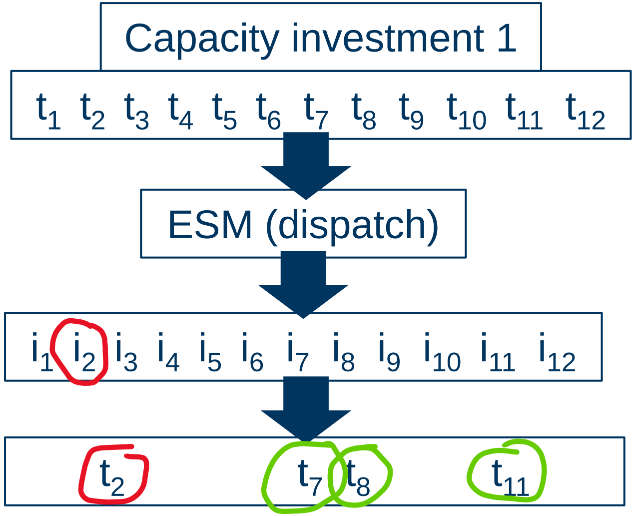
  3. Estimate importance of each dataset based on capacity investment 1.
  4. Construct a dataset of length N consisting of N_i important timesteps and N_r random timesteps.



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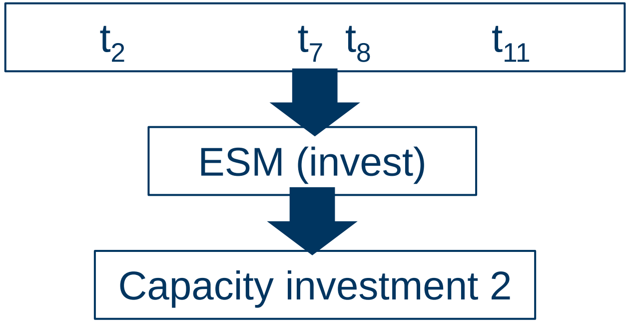
  5. Estimate capacity investment based on this dataset.



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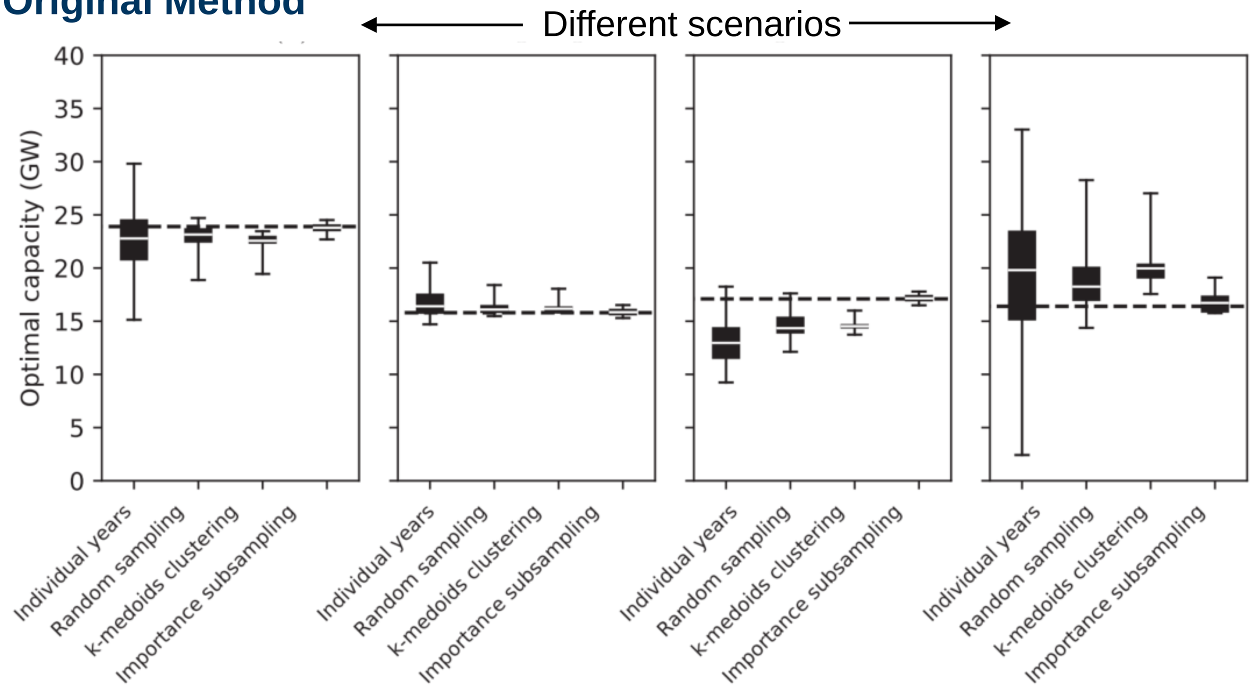

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Importance Subsampling

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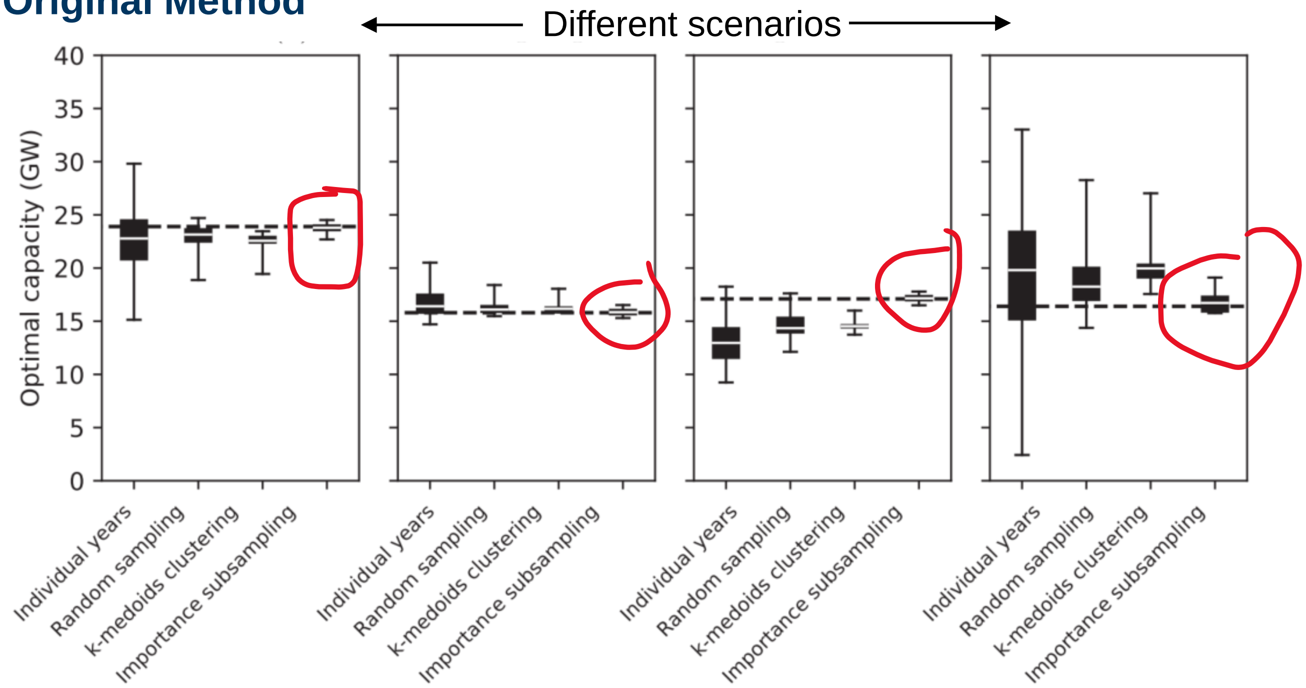

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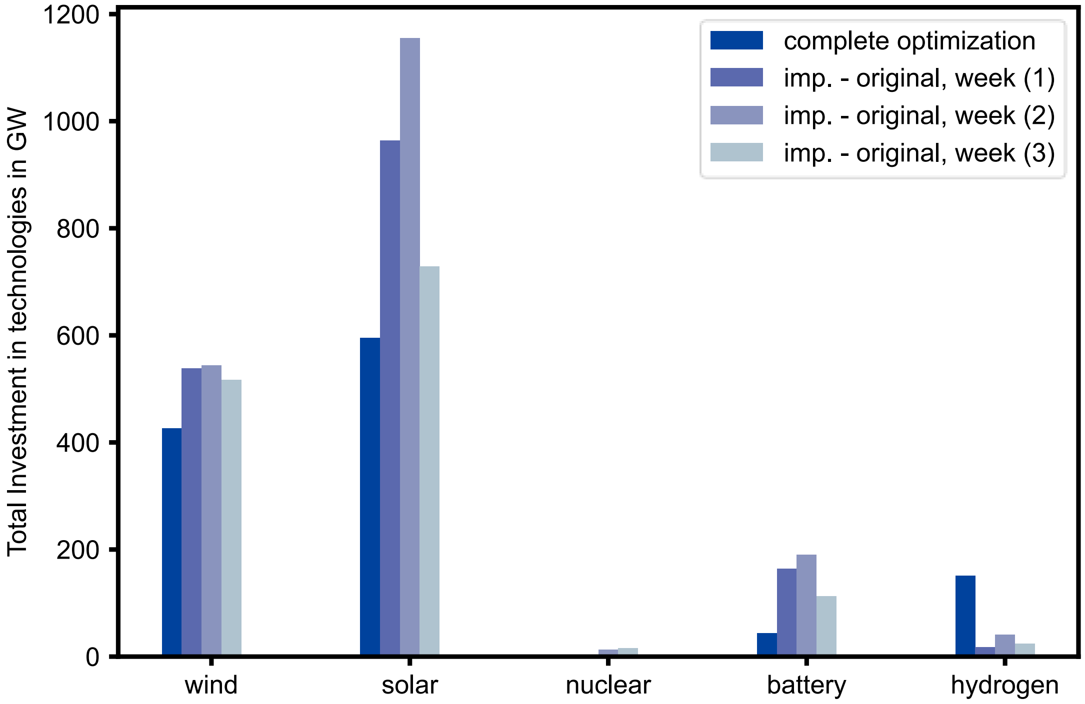
Importance Subsampling

Adaptions for our model

- Length of subsamples at least 24 hours → 1 week (168 h)
- 1 year of data
- $N = 6$ and $N_i = 2$

Importance Subsampling

Results



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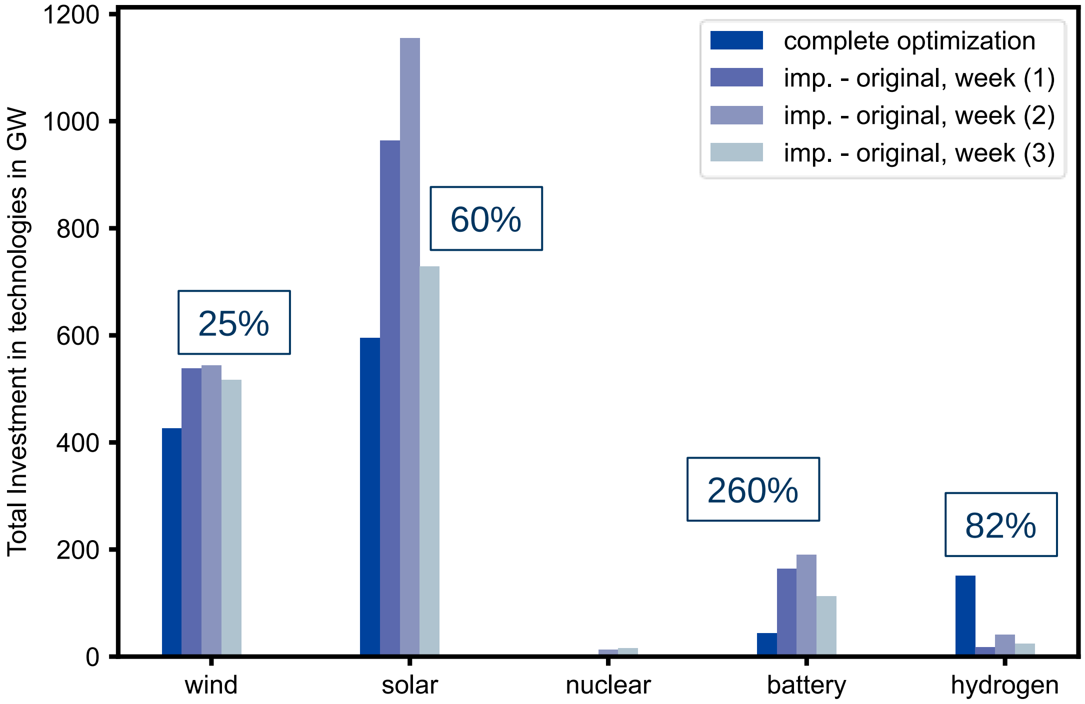

Importance Subsampling

Adaptions for our model

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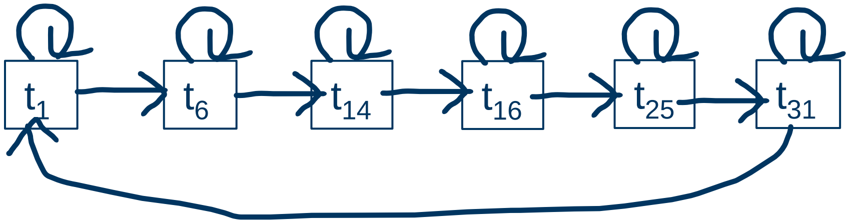
- $N = 6$ and $N_i = 2$
- Is it important to keep the temporal order of the subsamples?



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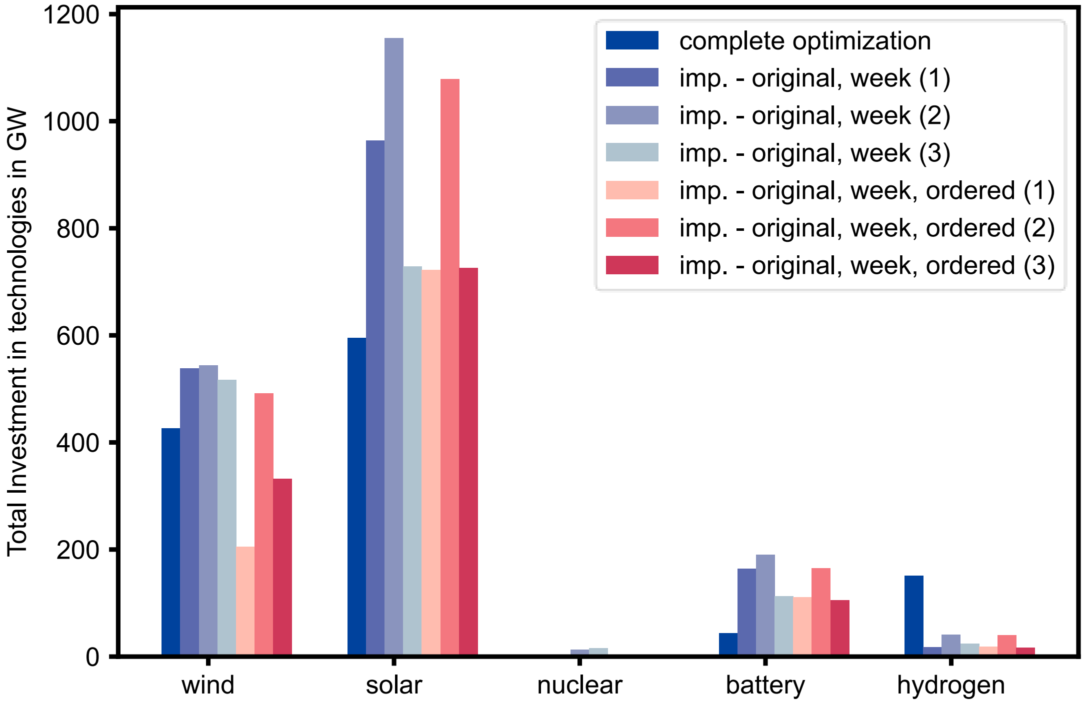

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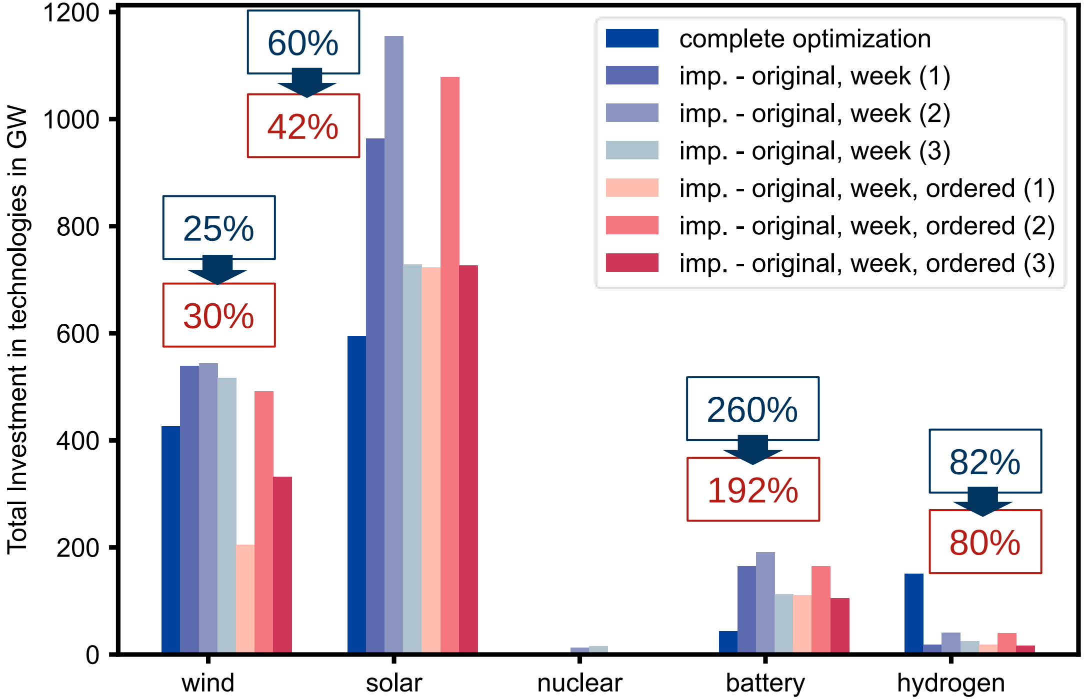


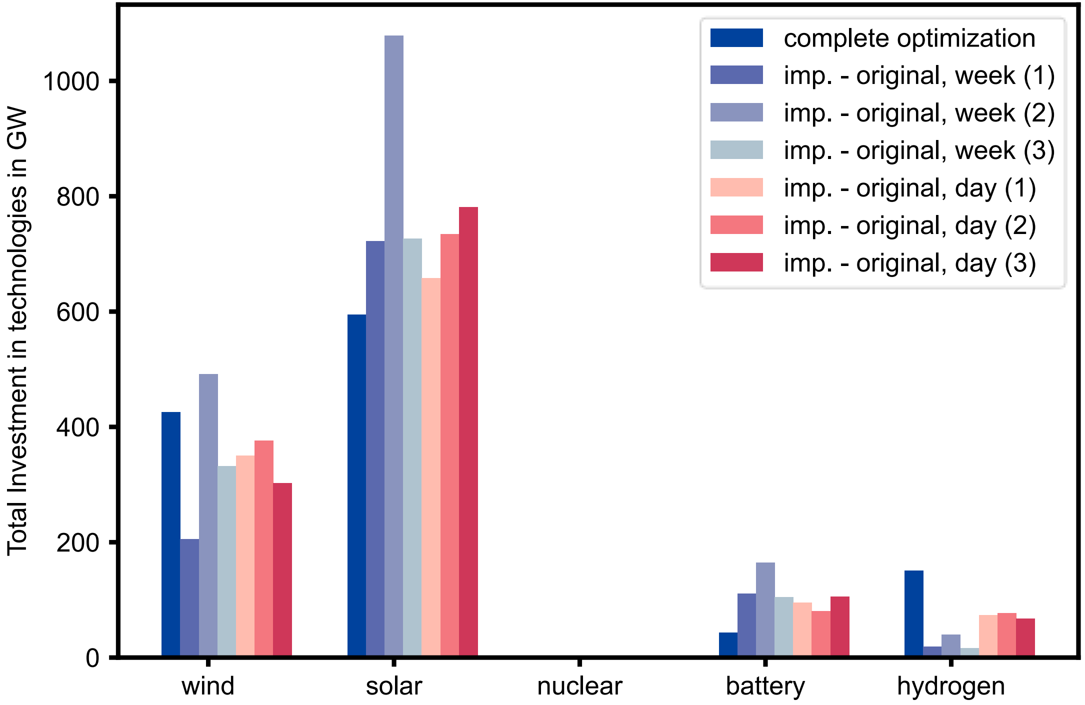
Importance Subsampling

Adaptions for our model

- Length of subsamples at least 24 hours → 1 week (168 h)
- 1 year of data
- $N = 6$ and $N_i = 2$
- Is it important to keep the temporal order of the subsamples?
- What influence has the length of the subsample?
  - Length: 24 h
  - $N = 42$ and $N_i = 14$
  - Same total length as weekly dataset

Importance Subsampling

Results



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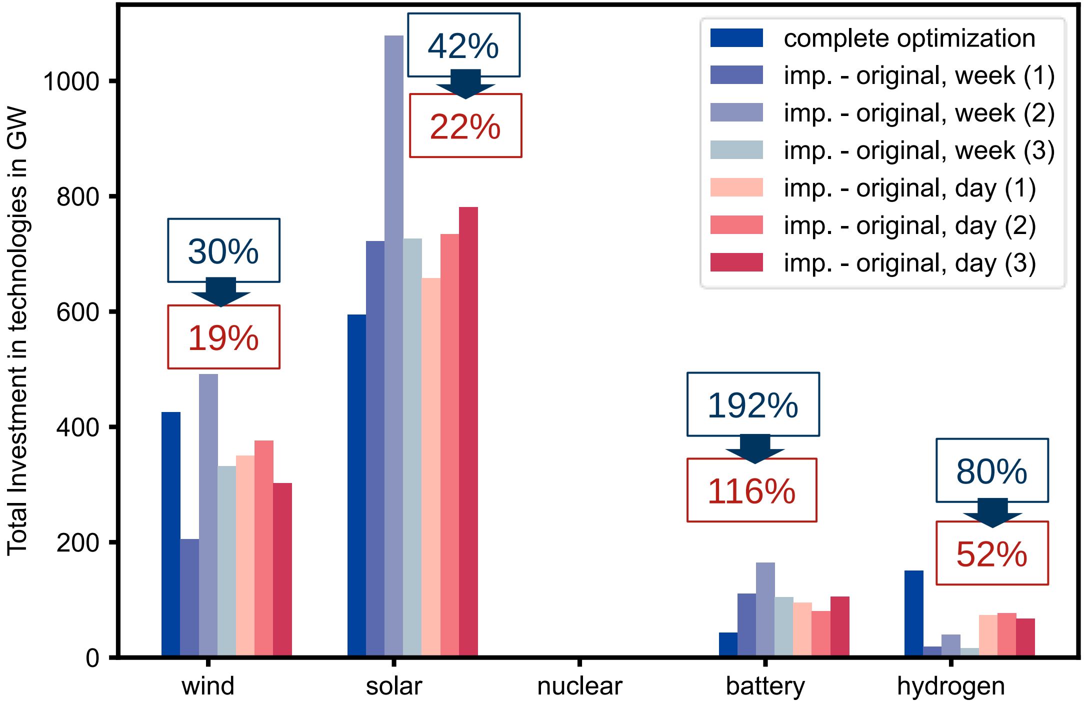
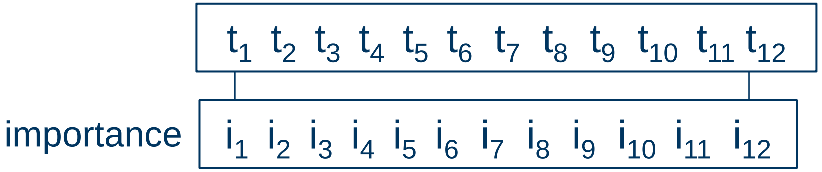


Importance Subsampling

Adaptions for our model

- Deviations still high
- Improve keeping temporal order of timesteps
- Cluster all subsamples into clusters of variable length
- Choose length of clusters aiming to minimize the maximal difference from cluster average



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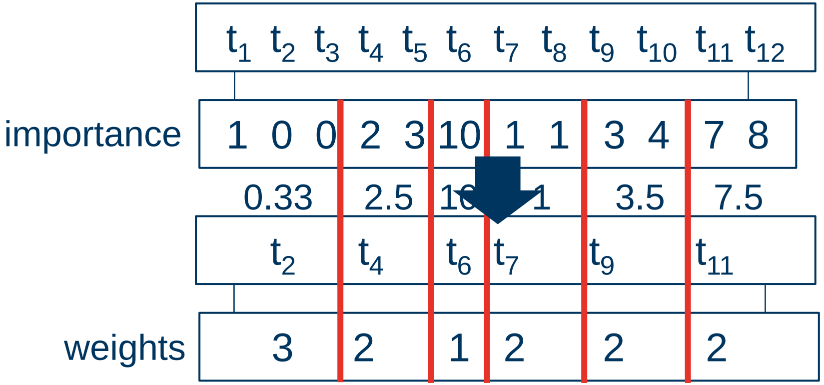

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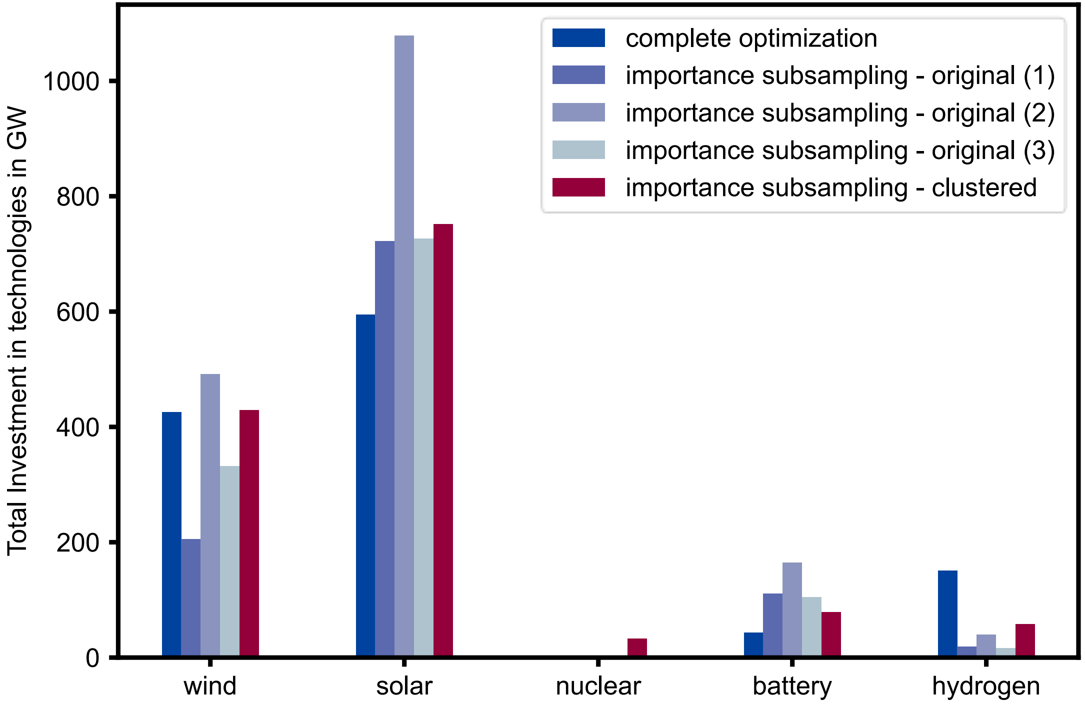
Results after clustering



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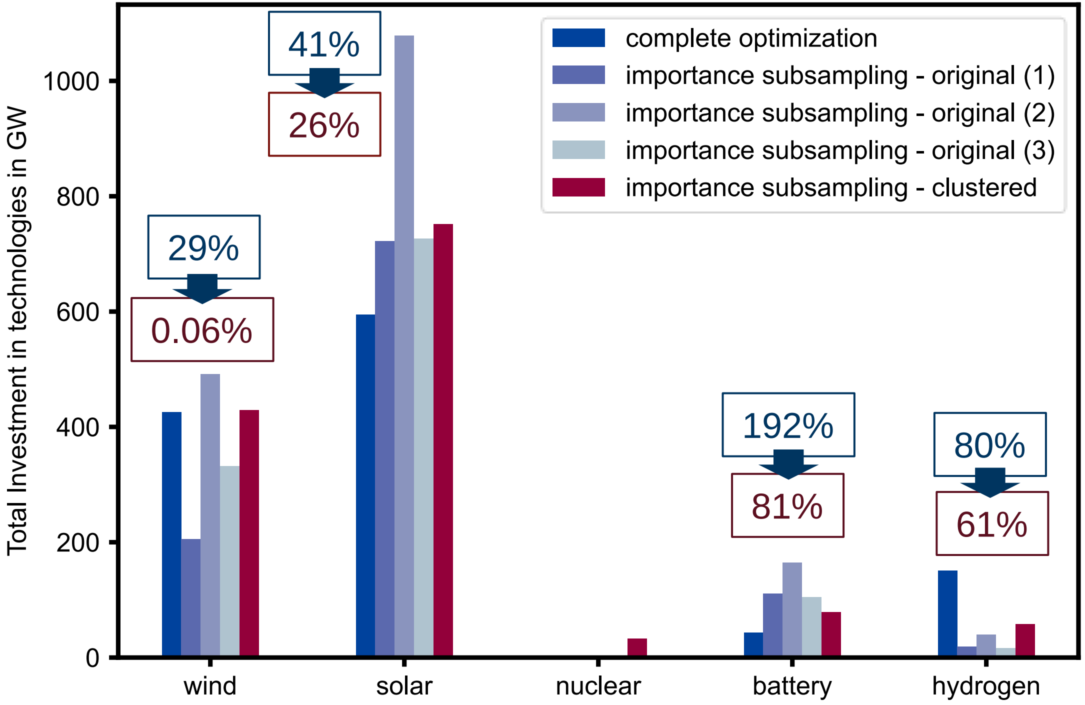

Overview

Conclusion and outlook

Conclusion

- Adaption of importance subsampling for more complicated systems → challenging
- Original method show differences in invest decisions especially for storages
- Choice of appropriate length for subsample necessary
- Clustering all timesteps based on their importance enhances results, but:
  - Leads to higher computational times
  - Deviations still quite high

Conclusion and outlook

Outlook

- Combine daily subsamples with cluster algorithms
- Compare importance subsampling results to other sampling methods
- Use reduced dataset as input in robust optimization

Thank you for your attention!

CONTACT

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Additional Slides

Influence of climate variables on energy systems

- Demand
- Hydro power
- Wind power
- Solar power
- Efficiency of thermal power plants

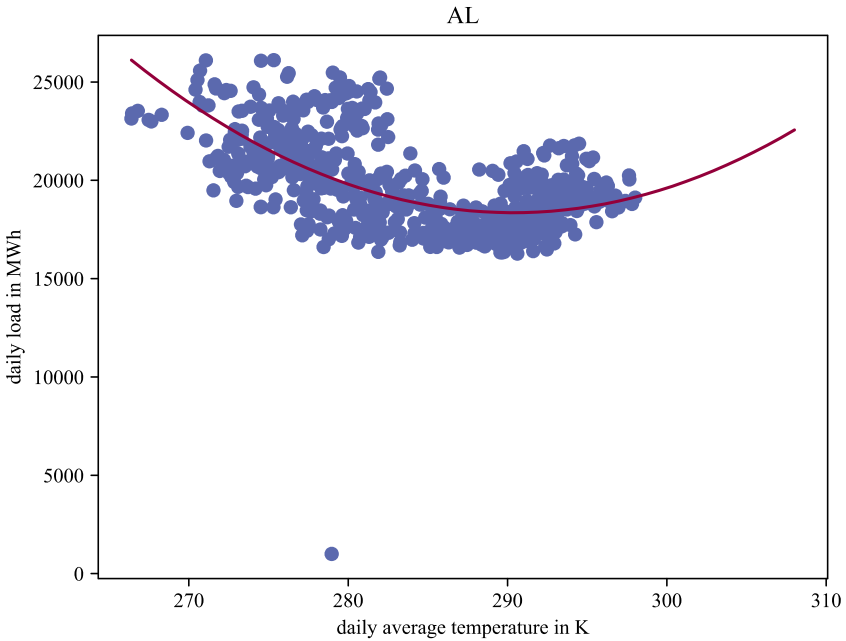
Additional Slides

Influence of climate variables on energy systems

- Demand
  - Temperature influences heating and cooling demand
  - Country-specific regression

Additional Slides

Influence of climate variables on energy systems



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Influence of climate variables on energy systems

- Hydro power
  - River-runoff determines production
  - Site-specific evaluation very costly
  - Europe-wide regression
  - Estimating country-specific hydro production based on European trend

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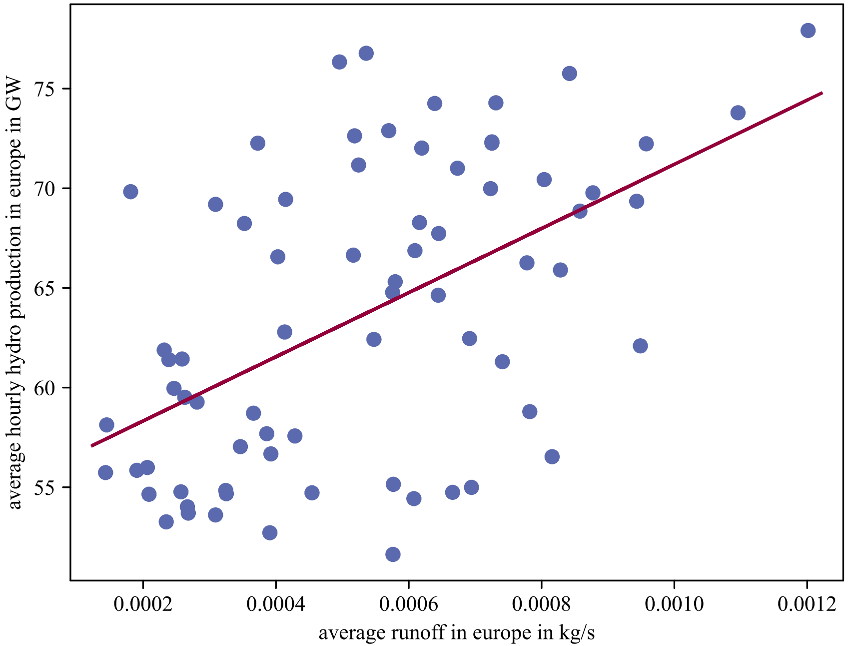
Influence of climate variables on energy systems



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Additional Slides

Influence of climate variables on energy systems

- Wind power
  - Interpolate wind speed to hub height
  - Use standardized production functions
- Solar power
  - Output depends on solar irradiation
  - Rising temperature decreases cell efficiency
  - Temperature of cell rises with outside temperature and irradiation

Additional Slides

Influence of climate variables on energy systems

- Efficiency of thermal power plants
  - Cooling system is depending on temperature
  - Once-through cooling more vulnerable than closed-loop cooling
  - In this study: only closed-loop

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Additional Slides

Influence of climate variables on energy systems

- Wind power
  - Climate models report wind speeds
  - Interpolate to hub height:

$$v(h) = v(h_0) \cdot \left(\frac{h}{h_0}\right)^{1/7}$$

  - Calculate capacity factor:

$$c_\mathrm{f} = \begin{cases} 0, & v < v_\mathrm{in} \\ \frac{v^3 - v_\mathrm{in}^3}{v_\mathrm{r}^3 - v_\mathrm{in}^3}, & v_\mathrm{in} \leq v < v_\mathrm{r} \\ 1, & v_\mathrm{r} \leq v < v_\mathrm{out} \\ 0, & v > v_\mathrm{out} \end{cases}$$

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Influence of climate variables on energy systems

- Solar power
  - Rising temperature decreases cell efficiency:

$$\eta = \eta_{\mathrm{STC}}\left(1 - \beta\left(T_{\mathrm{cell}} - T_{\mathrm{STC}}\right)\right)$$

  - Temperature of cell rises with outside temperature and irradiation:

$$T_{\mathrm{cell}} = T_{\mathrm{am}} + c \cdot G$$

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Influence of climate variables on energy systems

- Efficiency of thermal power plants
  - Cooling system is depending on temperature
  - Once-through cooling more vulnerable than closed-loop cooling
  - In this study, only closed-loop:

$$\eta = \begin{cases} \eta_0, & T \leq T_{\text{health}} \\ \eta_0\big(1 - \rho(T - T_{\text{health}})\big), & T > T_{\text{health}} \end{cases}$$