University of Stuttgart
IER Institute of Energy Economics
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Multistage Modeling Approach to Optimize Investment and Operational Decisions in Electricity Markets with a High Level of Detail

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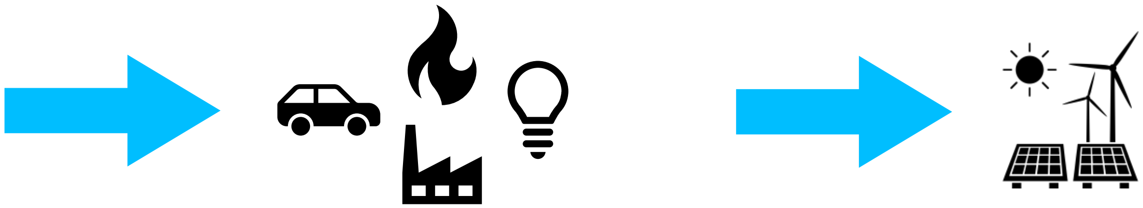
Background and motivation

Increasing energy system complexity

- One of the **most prominent strategies** to achieve **climate neutrality** in the energy system is its **electrification**.
- Shifting from **fossil fuel-based technologies to electricity-based technologies** makes it possible to take advantage of **RES** to reduce **GHG emissions** across all energy sectors but bears the disadvantage of adding **complexity** to the system.



Background and motivation

Bottom-up capacity expansion models

Inputs	Model	Outputs
Unit commitment ▪ Demand ▪ RES deployment ▪ Power plant fleet **Capacity expansion** ▪ Investment options **Scenario framework** ▪ Techno-economic parameters ▪ Regulatory restrictions	**Objective function** $\min c = c_{inv} + c_{fix} + c_{var}$ **Restrictions** ▪ Supply-demand balance ▪ Storage energy balance ▪ Upper/lower bounds ▪ Operational processes	**Objective function** ▪ System costs ▪ Dispatch ▪ Fuel consumption ▪ CO_2 emissions ▪ Investment decisions ▪ Electricity prices ▪ CO_2 certificate prices

European Electricity Market Model – E2M2

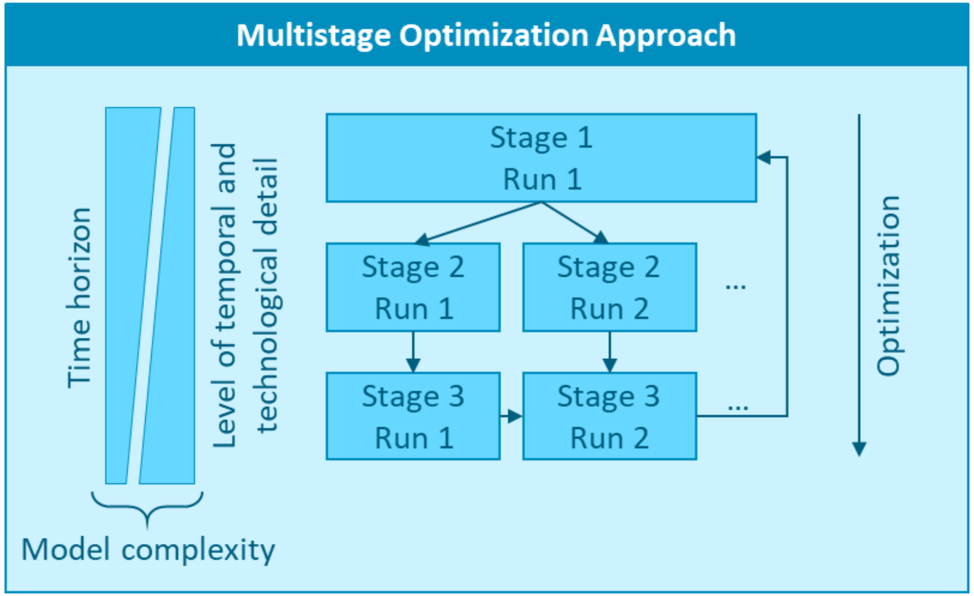
- Fundamental linear (mixed-integer) European electricity market model
- Identification of normative cost-optimal energy system configurations
- Simultaneous optimization of investment and operational decisions
- Detailed depiction of conversion, storage, transport and end-use technologies

- The **increasing complexity of the energy system** is making the underlying mathematical problem of bottom-up capacity expansion models nearly intractable by **drastically increasing the computational effort**.

Method

Multistage optimization approach

- To overcome computational limitations, the optimization of investment and operational decisions can be carried out **hierarchically**.



- **Which is the most suitable temporal and technological configuration at each stage?**

- **How do different simplifications on the temporal and technological dimensions affect the model performance?**

Method

Complexity Reduction Efficiency Coefficient (CREC)

- Indicator of the efficiency of model complexity reduction techniques:

$$CREC_{mr} = \frac{Result\ deviation_{mr}}{Complexity\ reduction_{mr}}$$

- CREC for deviations in investment decisions:

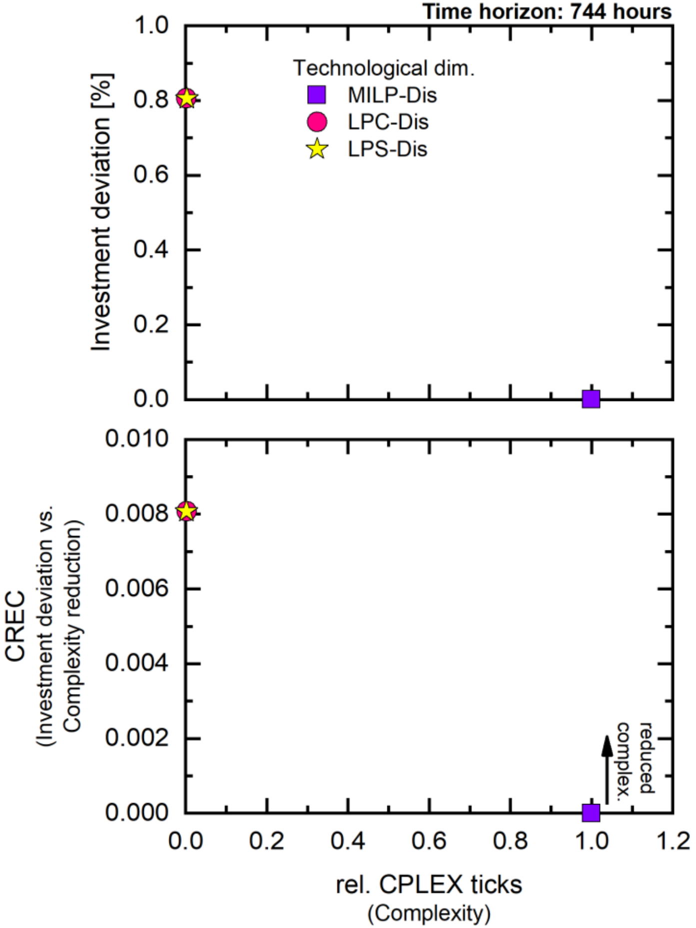
$$CREC_{mr}^{inv} = \frac{Investment\ deviation_{mr}}{Complexity\ reduction_{mr}}$$

CREC	CPLEX ticks	Efficiency
++	Decrease	Low efficiency
+	Decrease	High efficiency
-	Increase	Low inefficiency
--	Increase	High inefficiency

Detail level of thermal power plants

Method and key findings

Technological dimension			
Thermal power plants			
Detail level			
Features	**MILP**	**LPC**	**LPS**
Integral variables	X		
Maximum generation	X	X	X
Minimum generation	X		
Partial efficiencies	X	X	X
Start-up constraints and costs	X	X	
Load change constraints and costs	X	X	
Minimum operating time	X		
Minimum down time	X		

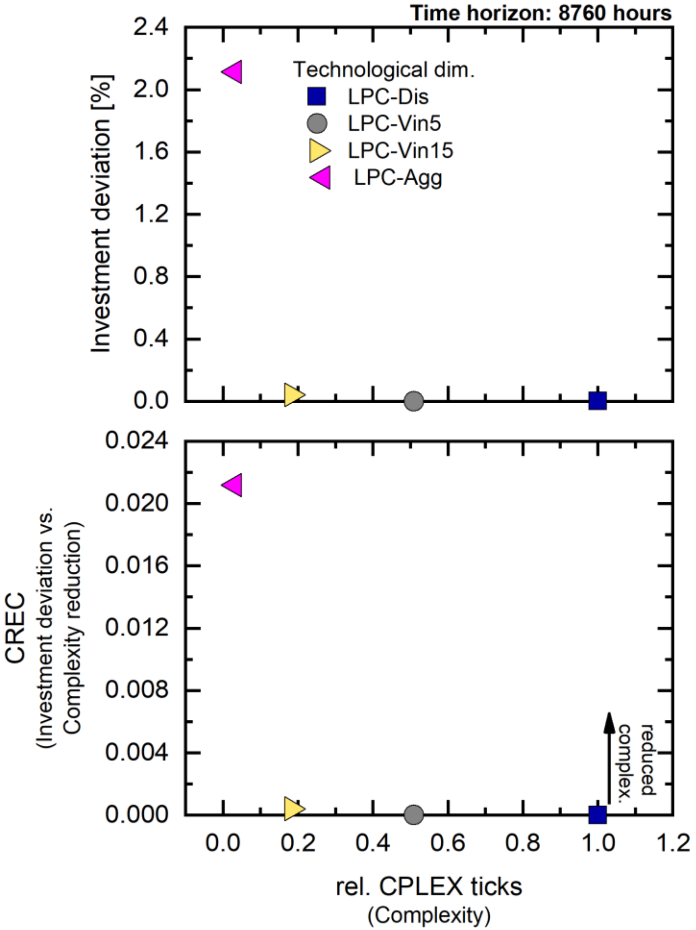


- MILP approach is computationally very intensive → CPLEX ticks more than 450 times higher.
- Investment deviations resulting from the linearization of thermal power plants are minor → <1%.

Aggregation level of thermal power plants

Method and key findings

Technological dimension	
Thermal power plants	
Aggregation level	
Aggregation level	Definition
Dis	Disaggregation in typical power plant sizes
Vin5	Aggregation based on commissioning year in 5-year steps
Vin15	Aggregation based on commissioning year in 15-year steps
Agg	Aggregation based on primary energy and technology type (e.g., CCGT, OCGT, ST, Offshore, Onshore)

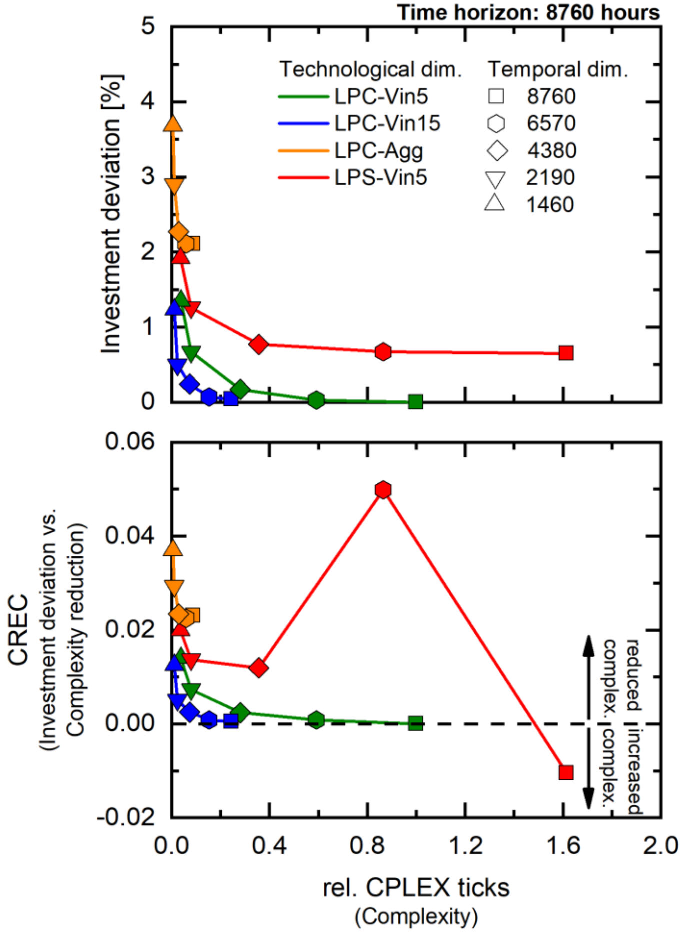


- By aggregating existing thermal power plants with similar techno-economic characteristics, it is possible to achieve very low CREC values.

Combination of temporal and technological simplifications related to thermal power plants

Method and key findings

Temporal dimension
Segmentation
Number of yearly time steps
8760
6570
4380
2190
1460



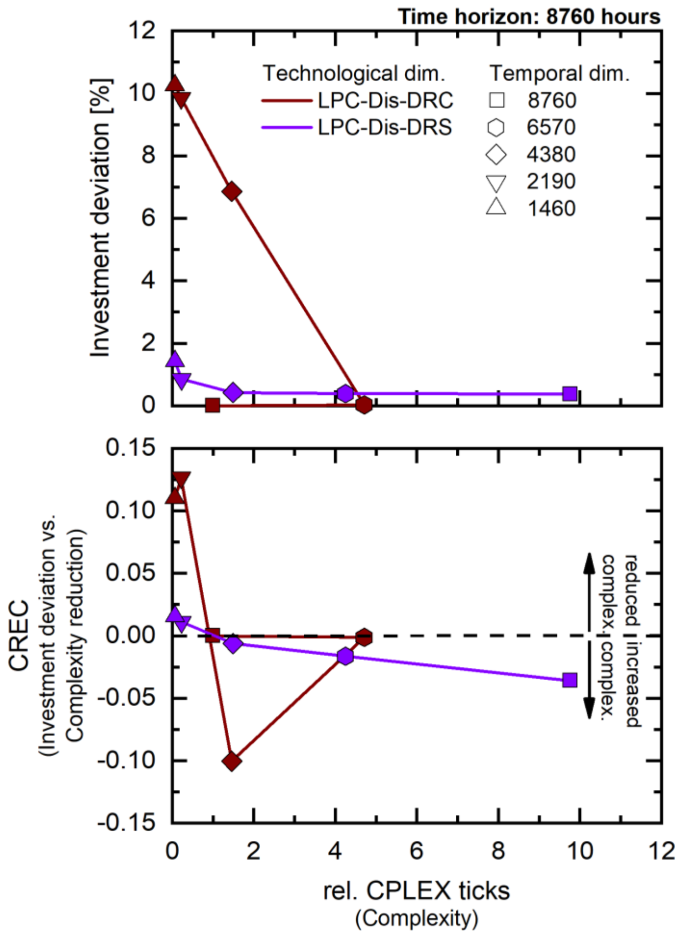
- Not considering start-up or load change processes for thermal power plants can increase CPLEX ticks → By increasing tightness.

- The combination of low aggregation levels in both model dimensions shows lower CREC values, than larger aggregations in only one dimension.

Combination of temporal and technological simplifications related to demand response (DR)

Method and key findings

Technological dimension	
Demand response	
Detail level	
Detail level	Definition
DRC	Formulation as compensation variables with two time-related indices [1]
DRS	Formulation as fictitious storage units [2]



- The model performance is more robust to reductions in temporal resolution if DR technologies are considered as fictitious storage units.
- When decreasing the temporal resolution, the formulation as compensation variables:
  - Greatly overestimates their flexibility.
  - Increases tightness.
- The formulation as fictitious storage units also increases tightness but has the opposite effect on the flexibility.

Conclusions and outlook

Conclusions

- It is not possible to consider MILP simultaneously to long-term investment decisions, because such an approach is computationally very intensive.
- The tightness of the problem and not only its compactness (size) determine its solving time.
  - To further decrease the computational effort, neglecting start-up and load change processes should be avoided.
- Low aggregation levels in multiple model dimensions show lower investment deviations and higher CPLEX tick reductions, than larger aggregations in only one dimension.
- The impact of simplifying a certain model dimension is highly dependent on the configuration of the other dimensions, e.g.:
  - Temporal resolution vs. Formulation of demand response technologies

Outlook

- Establishment of a suitable configuration of the multistage approach based on this comprehensive analysis
- Comparison of the multistage approach with established methods, such as a myopic foresight
- Application of the multistage approach to facilitate the linkage with other energy models, e.g., with an agent-based model → **ERAFlex II**

Literature

[1] A. Zerrahn, W.-P. Schill, *On the representation of demand-side management in power system models*, Energy 84 (2015) 840–845. https://doi.org/10.1016/j.energy.2015.03.037.

[2] M. Steurer, *Analyse von Demand Side Integration im Hinblick auf eine effiziente und umweltfreundliche Energieversorgung*, Ph.D. thesis, University of Stuttgart, Germany (2017). http://dx.doi.org/10.18419/opus-9181.

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Thank you!

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