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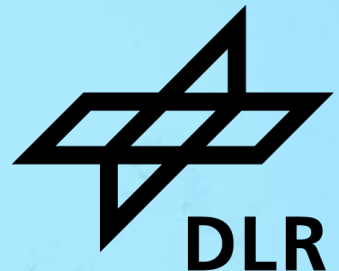


on the basis of a decision
by the German Bundestag

A MULTI-PERSPECTIVE APPROACH FOR EXPLORING THE SCENARIO SPACE OF FUTURE POWER SYSTEMS

OR2022, 6.-9. September 2022, Karlsruhe

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Jan Buschmann¹, Kai von Krbek¹ and Aileen Böhme³





Source: ZDF Mediathek, ZDFzoom, Gaskrise - Heißer Herbst vor kaltem Winter?
<https://www.zdf.de/dokumentation/zdfzoom/zdfzoom-gaskrise---heisser-herbst-vor-kaltem-winter-100.html>, accessed: 06.09.2022

“[...] wie könnte die weitere Entwicklung der Gasversorgung sein?

Die [Bundesnetzagentur] haben allein 18 Szenarien berechnet [...], verschiedene, weil einfach die Variablen zu groß sind [...].

Wie geht es mit der Gasversorgung aus Russland weiter? [...]

Wie hart wird der Winter? Wieviel [Gas] können wir [...] in den Transit bringen? [...]

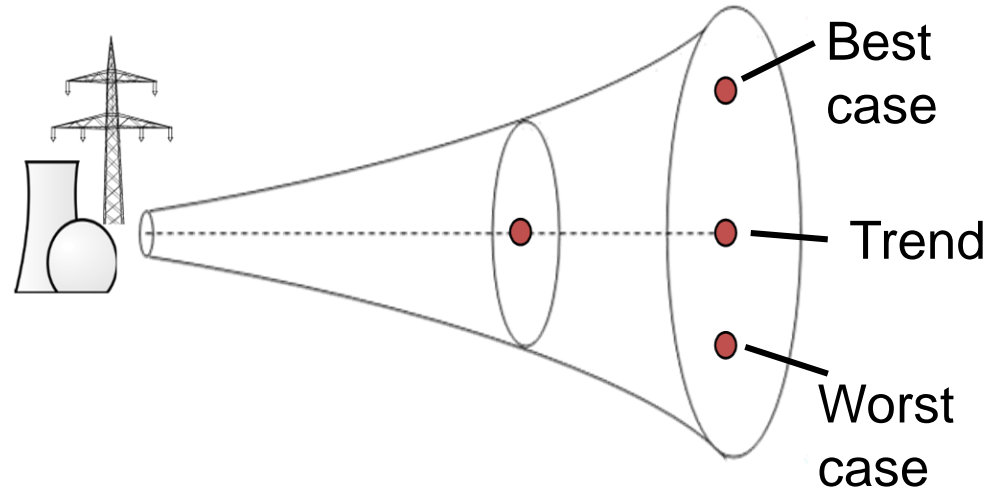
Das sind alles ungewisse Faktoren [...].

Das bringt unglaubliche Unsicherheit in unsere Unternehmen hinein.“

"[...] what could be the further development of gas supply? The [Bundesnetzagentur] has already calculated 18 scenarios [...], different ones, because simply the variables are too many [...]. What will happen with gas supply from Russia? [...] How hard will the winter be? How much [natural gas] can we [...] transmit? [...]. These are all uncertain factors [...]. This brings incredible uncertainty into our companies".

Exploring the Scenario Space

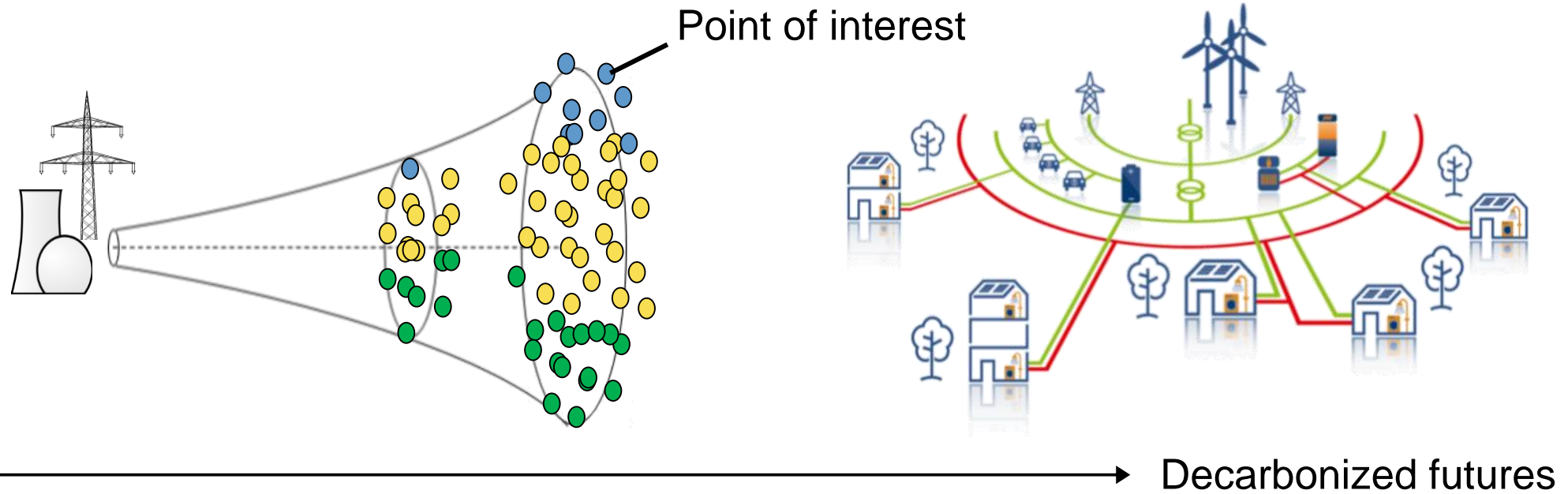
The state of the art



Decarbonized futures

Exploring the Scenario Space

The objective



The Challenges



Scenario
Assumptions

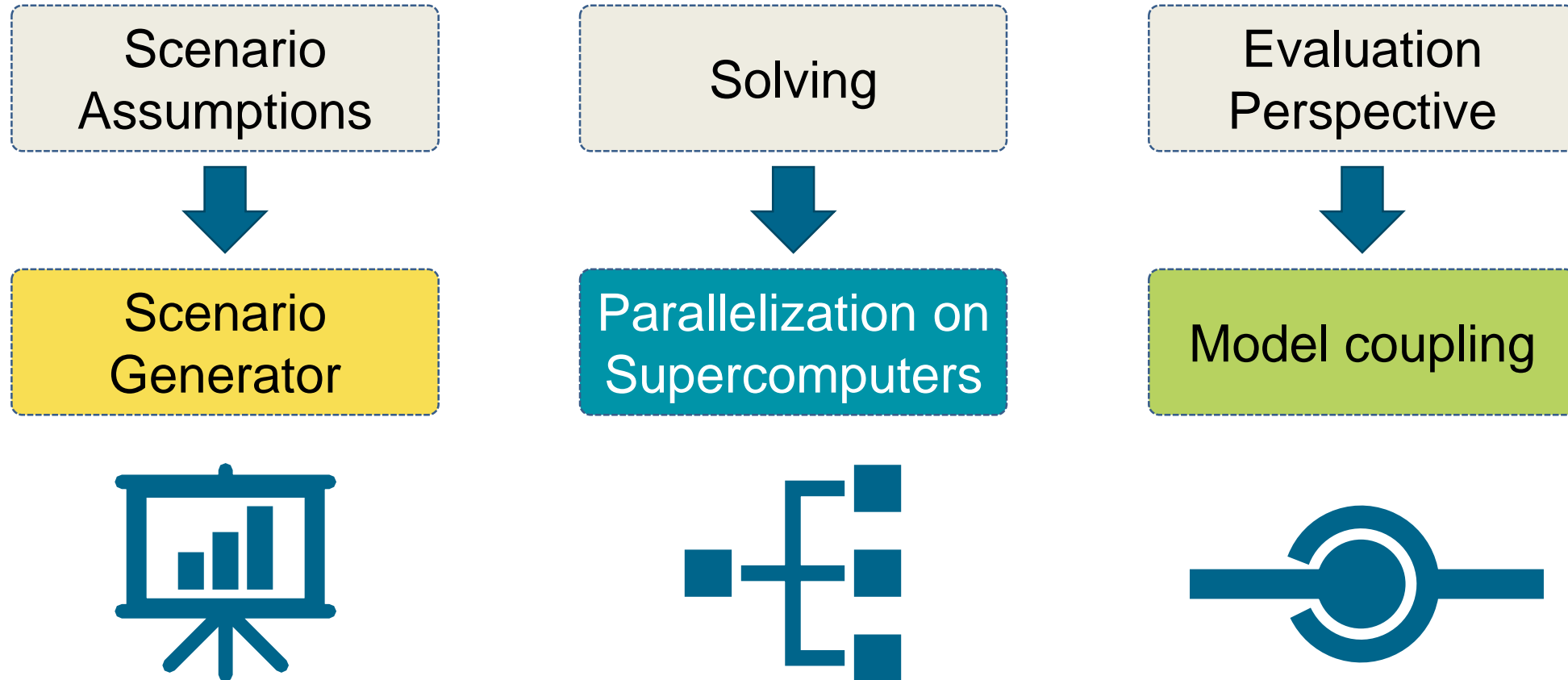
Solving

Evaluation
Perspective

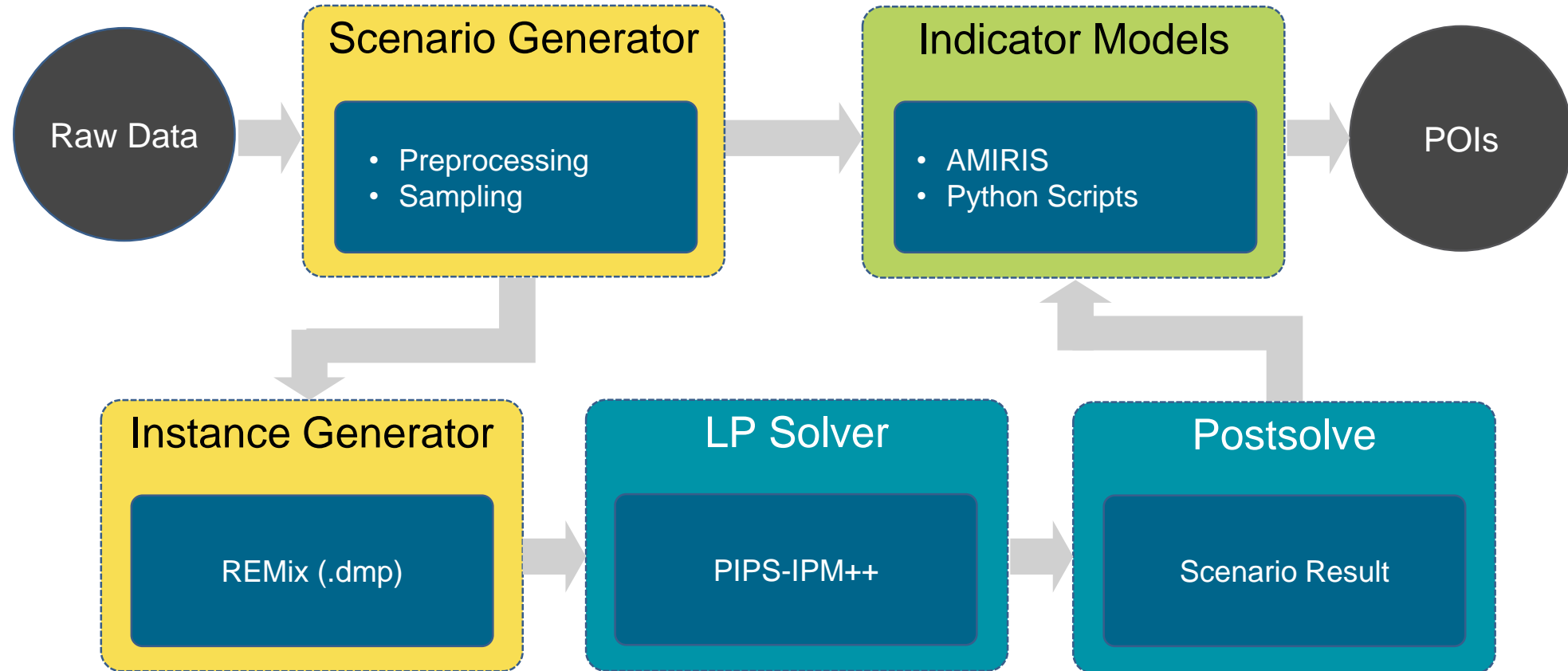
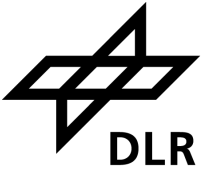


METHODOLOGY

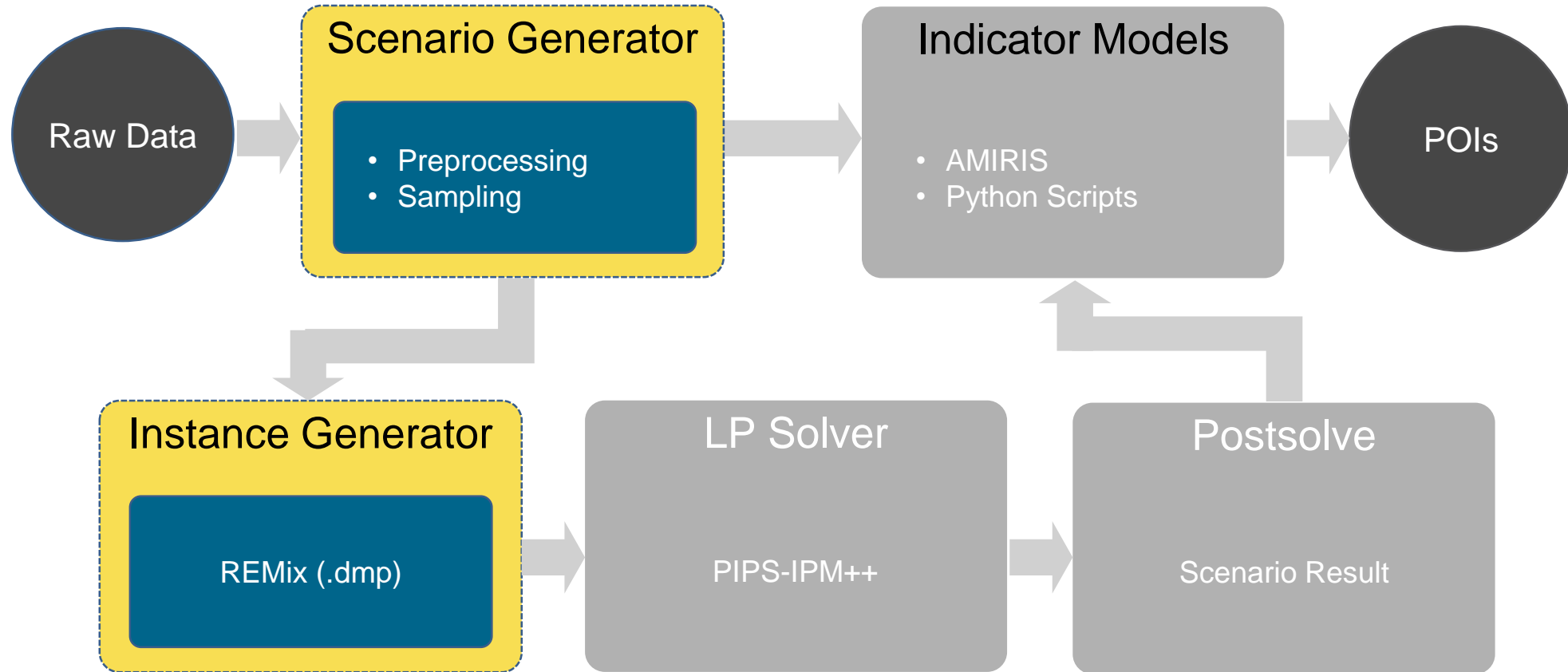
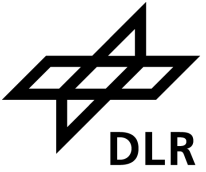
The Solution



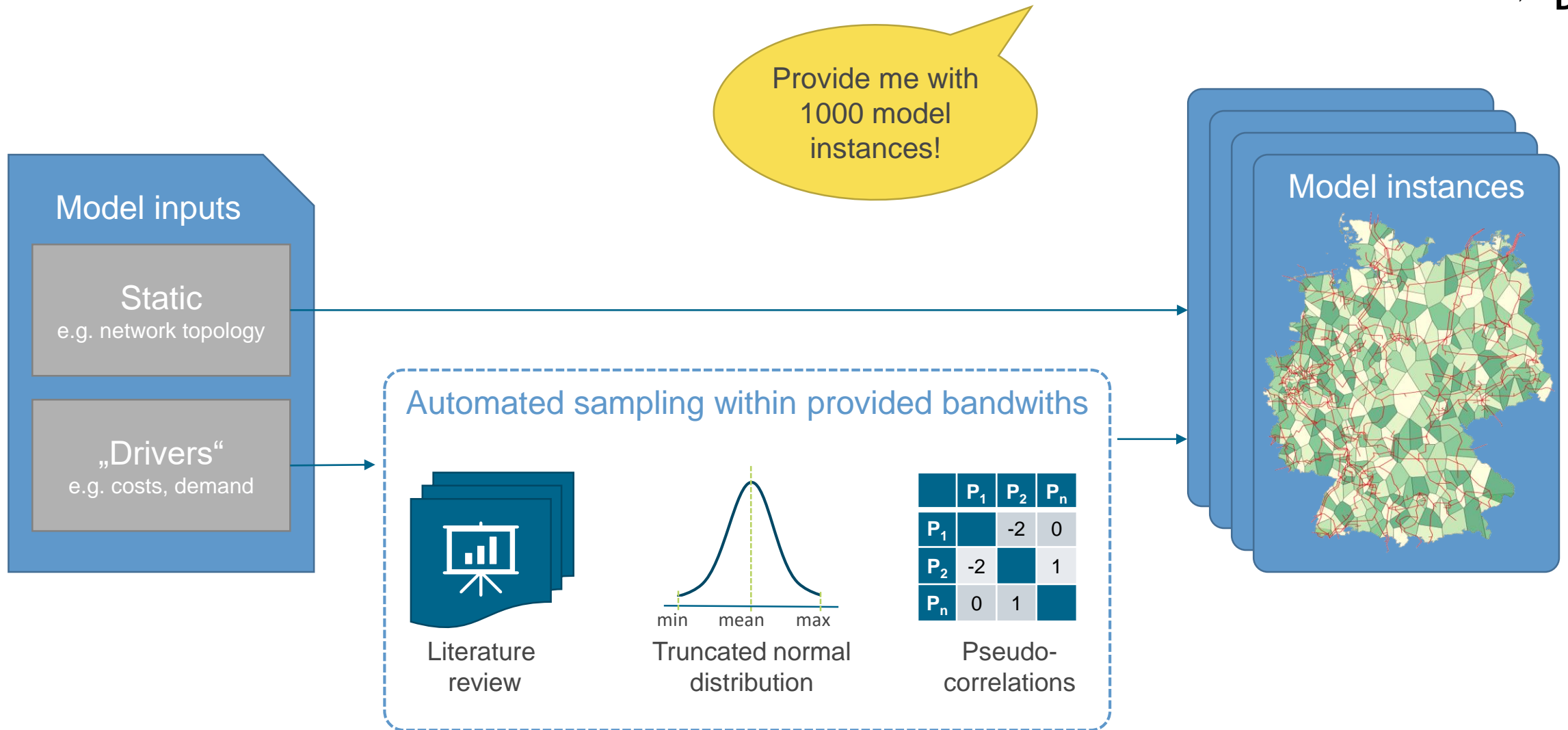
The Solution



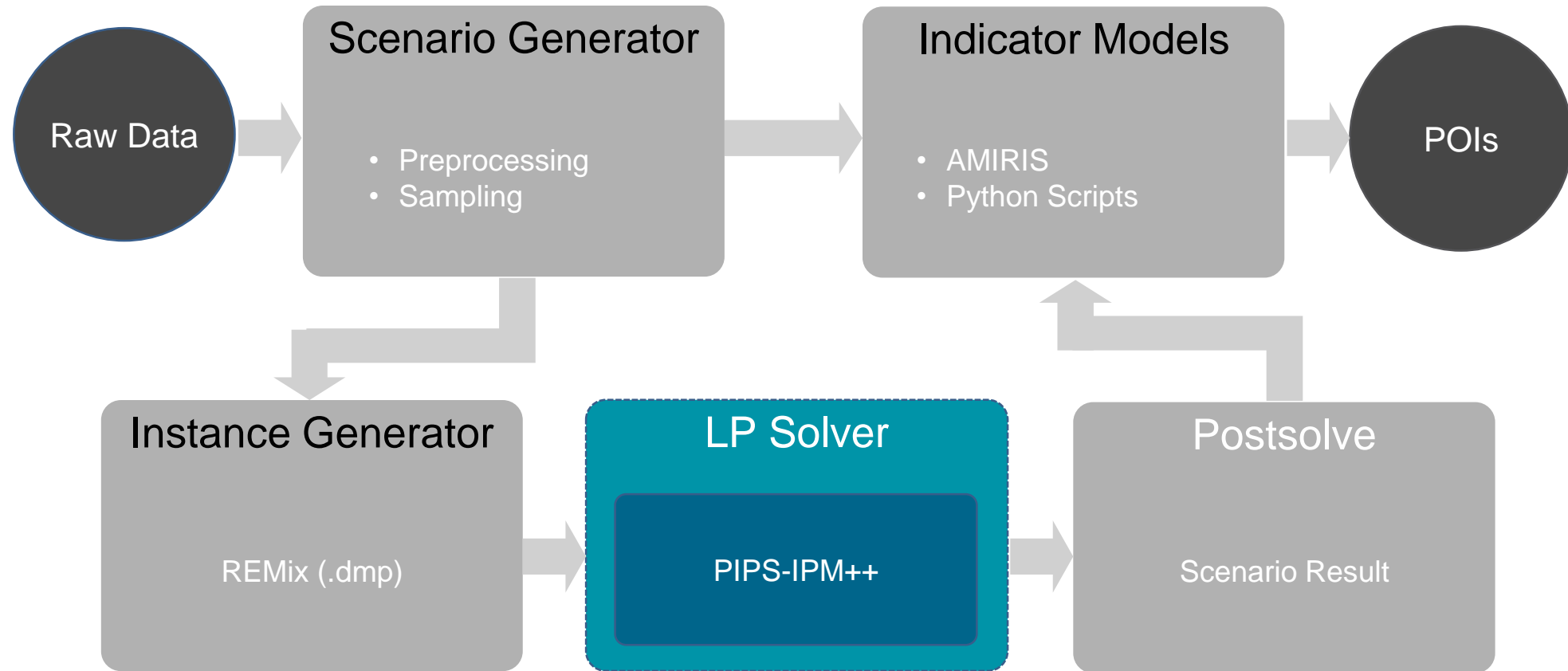
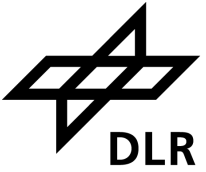
The Solution



Generation of multiple model instances



The Solution

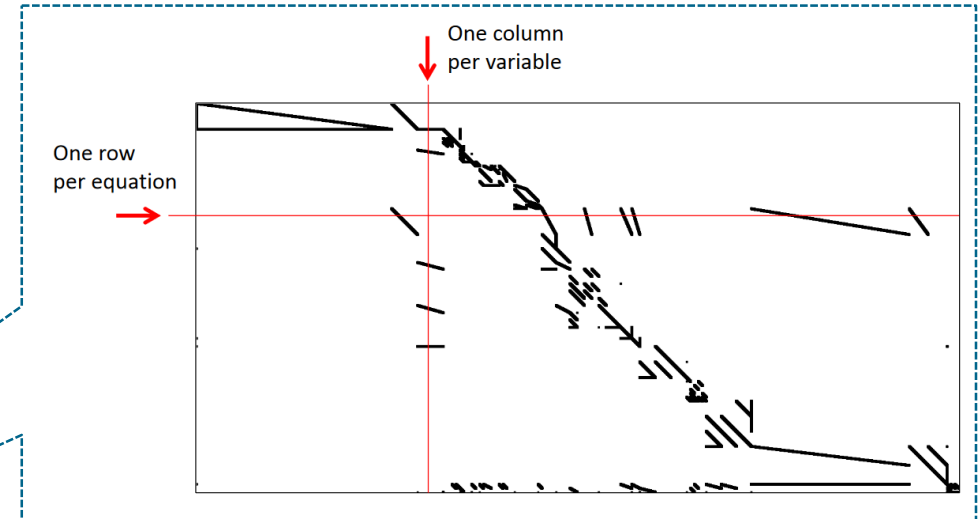


Model generation

Transform model instance into
mathematical optimization problem:

$$\begin{aligned} \min \quad & c^T x \\ \text{s.t.} \quad & Ax = b \\ & x \geq 0 \end{aligned}$$

where $c \in \mathbb{R}^n$, $b \in \mathbb{R}^m$, $A \in \mathbb{R}^{m \times n}$.



LP solver

Problem characteristics

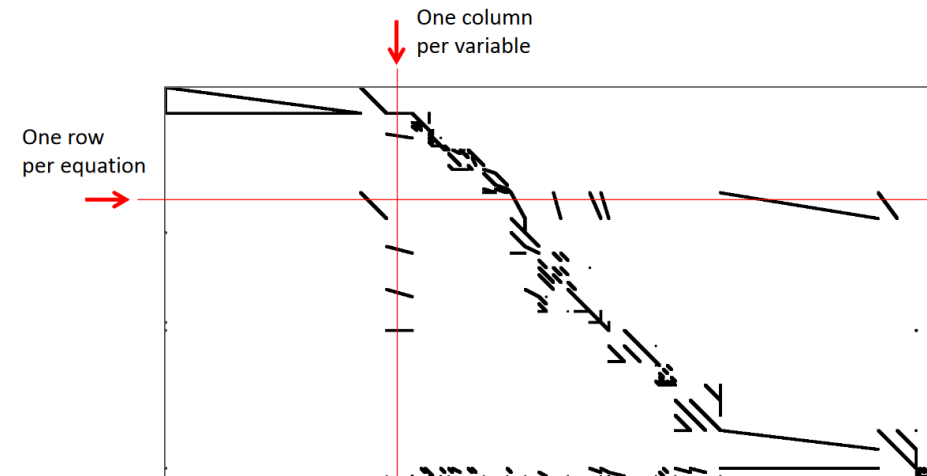
- 94.6M variables (3713 locally and 3356 globally linking)
- 91.2M constraints (367k locally and 693 globally linking)

PIPS-IPM++¹

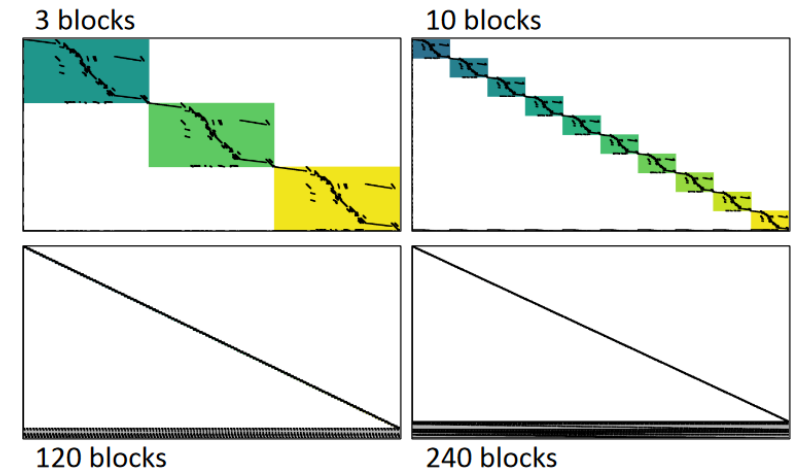
- Open source, parallel interior point solver
- Initially developed for stochastic problems by C. Petra
- Extended to treat linking constraints

Solver config

- 730 blocks annotated by time
- Hierarchical approach

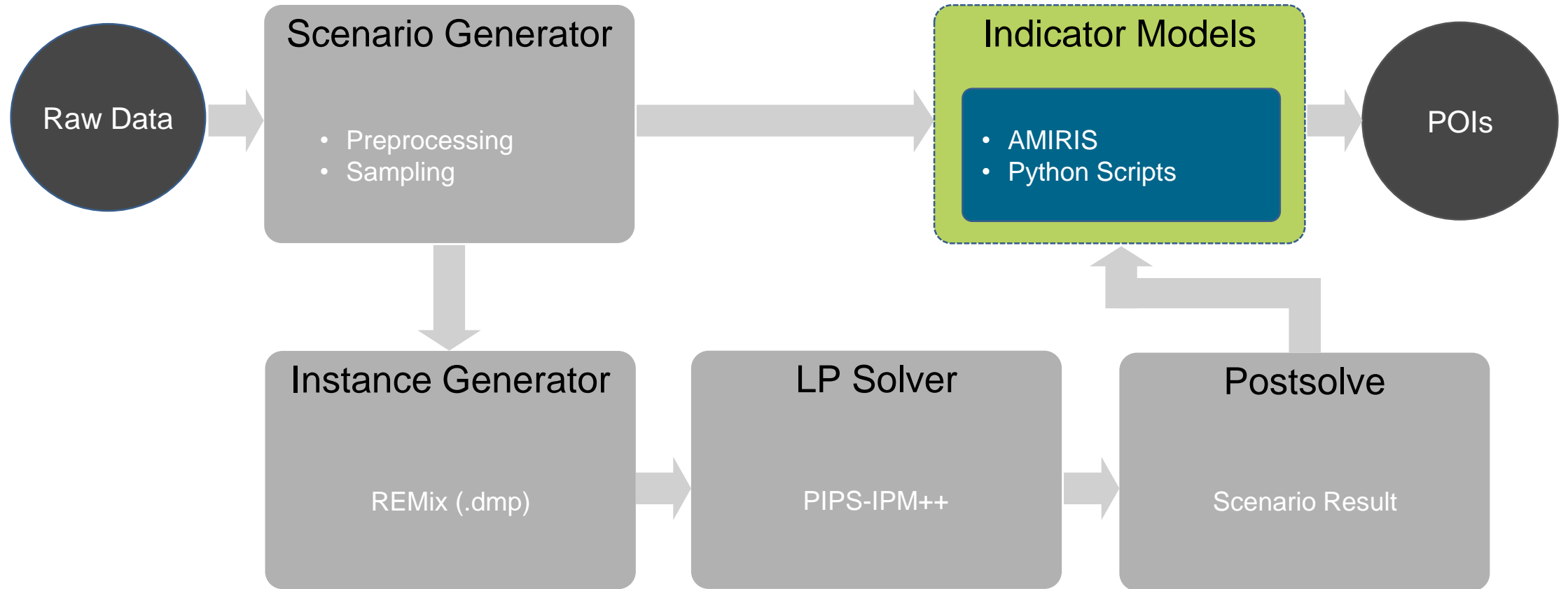
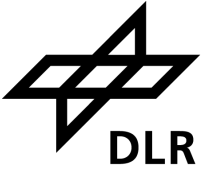


Original non-zeros entries of a coefficient matrix

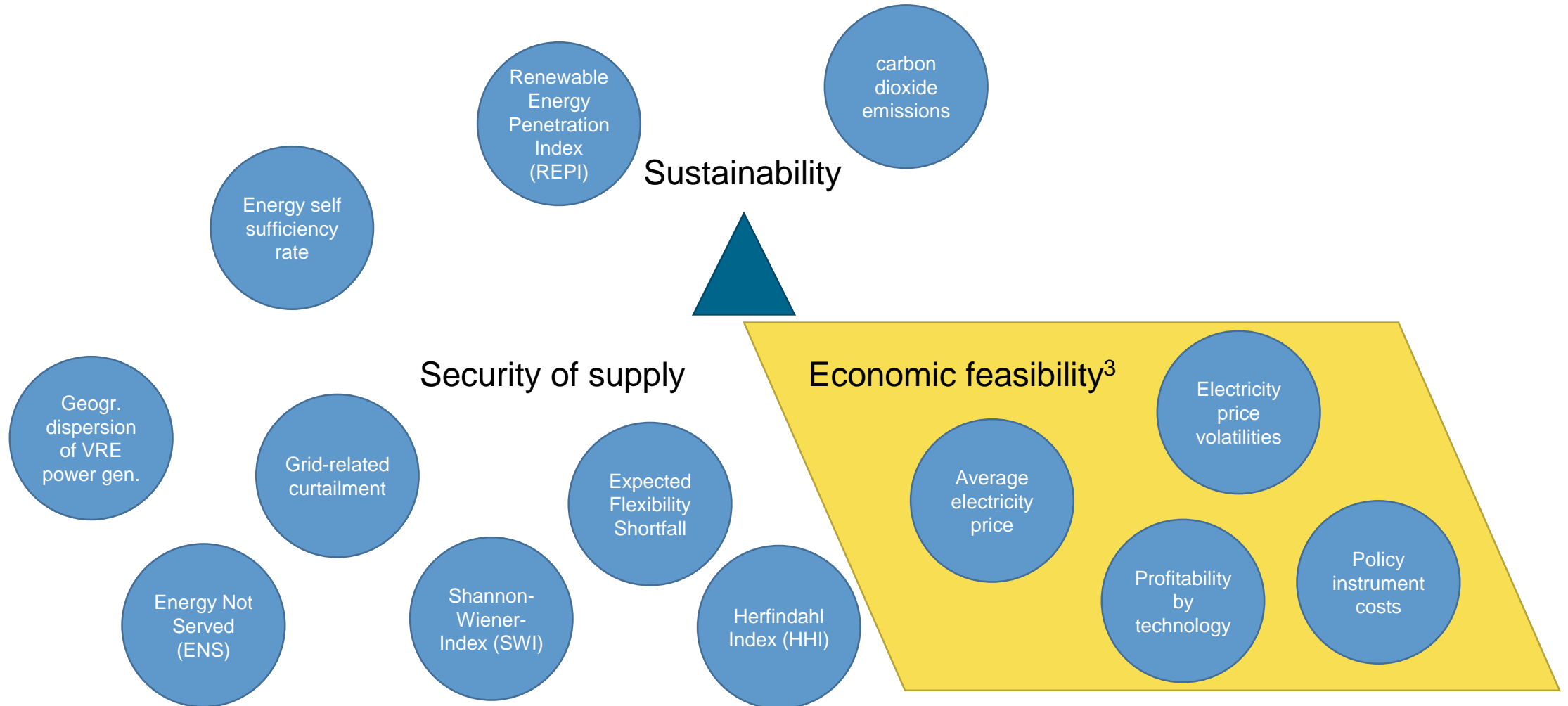
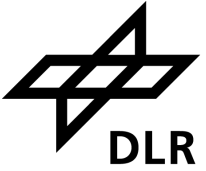


Annotated and permuted coefficient matrix

The Solution



27 Scenario assessment indicators²



² Buschmann, J., von Krbeke, K., Schimiczek, C. "Energy System Indicators", doi: 10.23728/b2share.fe70b138419243c0817425a0d2d5ae32, 2022

³ Deissenroth, M., et al. Assessing the plurality of actors and policy interactions: agent-based modelling of renewable energy market integration. Complexity 2017 (2017)

PRELIMINARY RESULTS

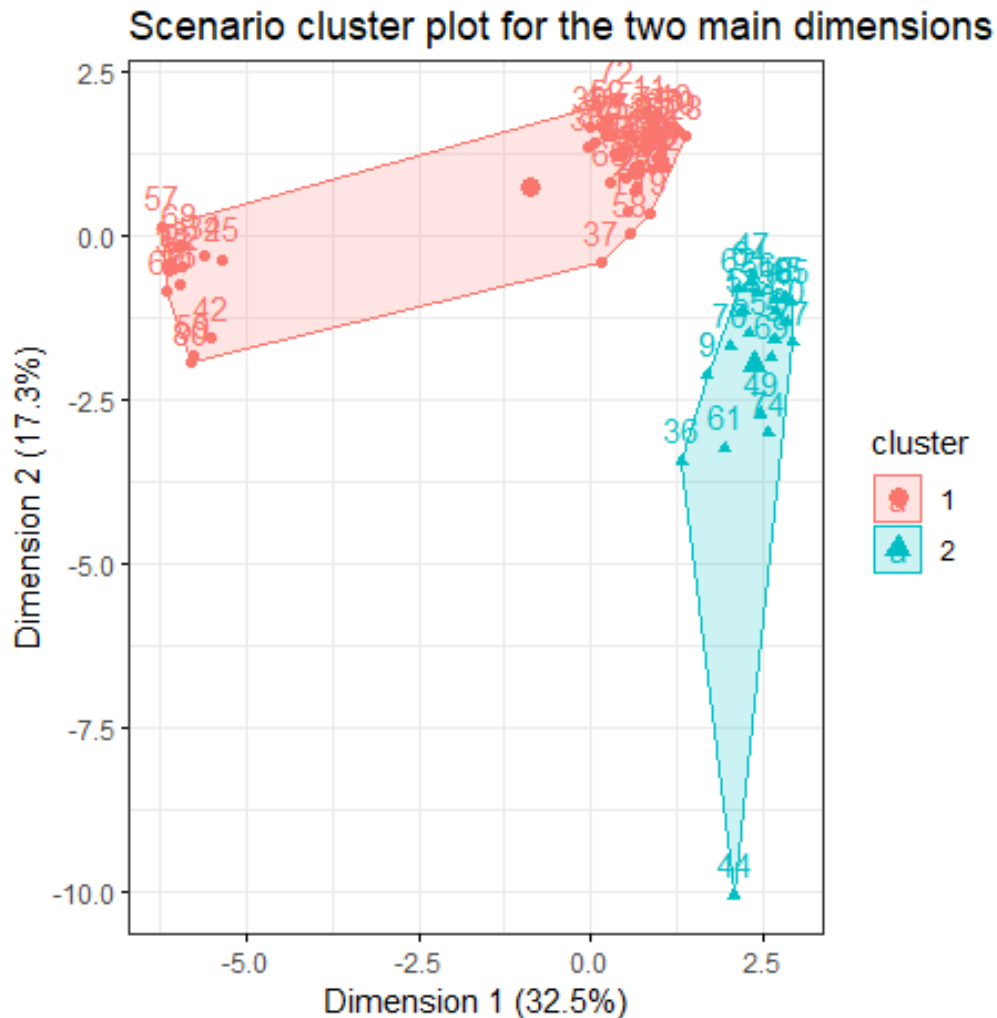
Evaluation 1: Scenario groups



- Target: Identifying clusters of scenarios
- 2 methods*:
 1. K-means
 2. K-medoids
- Automatic determination of optimal number of clusters
- Different number of indicators /inputs used to see if cluster numbers differs
- Result: Yes, but max. 3 clusters

*to ensure robustness, but no differences

Scenario groups: Results



C1: n=59; C2: n=22 (inverse of C1)

Exemplary Indicators	
RE-share	↑
CO ₂ -emissions	↓
Energy not served	↓
Geogr. dispersion of VRE power gen.	↓
Expected Flexibility Shortfall	↑
Power demand	↓
Reserve inadequacy	↓
Grid related curtailment	=
System costs	=

Evaluation 2: Points-of-Interest



- Define boundaries: ± 1 standard deviation
- Sort indicators: low/high | “good”/”bad”
- Point-of-Interest: Scenario with ≥ 10 “good” indicators*

Indicators	
I1	↑
I2	↓
I3	↓
I4	↓
I5	↑
I6	↓
I7	↓
I8	↓
I9	↓
I10	↓
I11	↓
...	

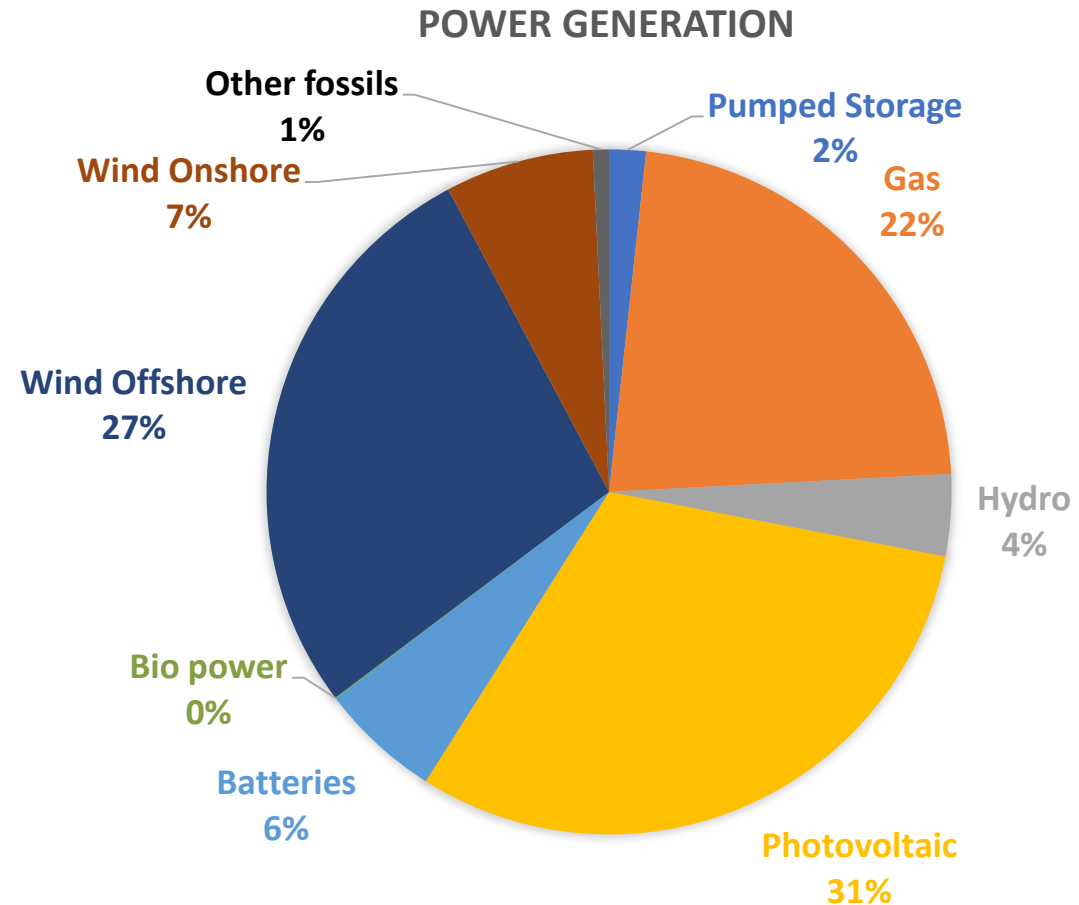
* 1 standard deviation better than population

Points-of-Interest: Results



Top Scenarios

- 13 of 27 indicators are “good”
- Example: Scenario No. 85
 - @555 TWh power demand



Limitations and Discussion

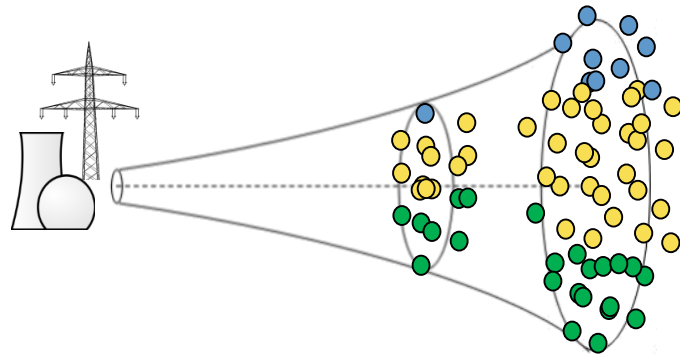


- Less ambitious mitigation scenarios
- Still LP
- Power sector only
- Cluster number is different, i.e. not stable
 - Group comparisons (t-tests between "good" and "normal") yield no significant results
 - No clusters for 1000 scenarios with small-sized models
 - 3 clear clusters for 50 scenarios with large-sized models
- What to do?
 - Sample other parameters – what / where to optimize?
 - Change evaluation methods – looking for pareto-fronts? / change indicators?
 - Change model – MIP? / resolution? / [sectoral coverage]?

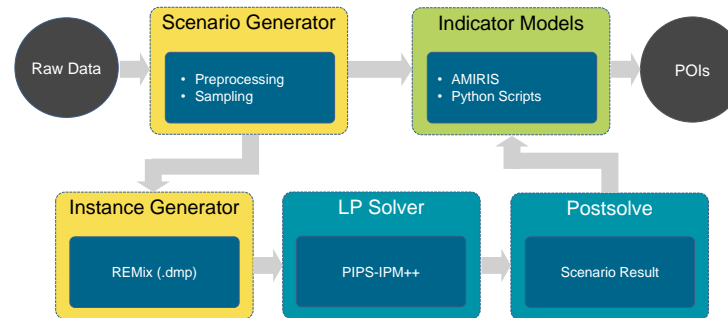
Conclusions

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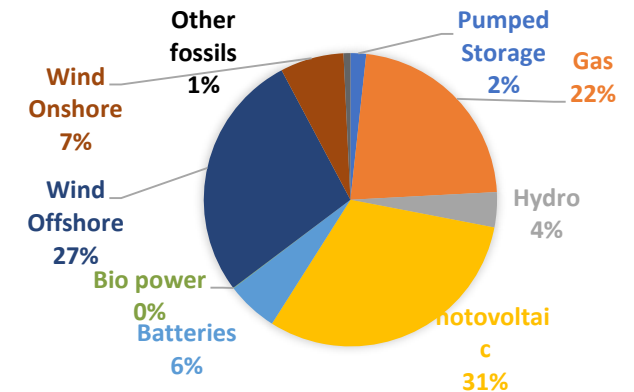
Motivation: The „possibility space“



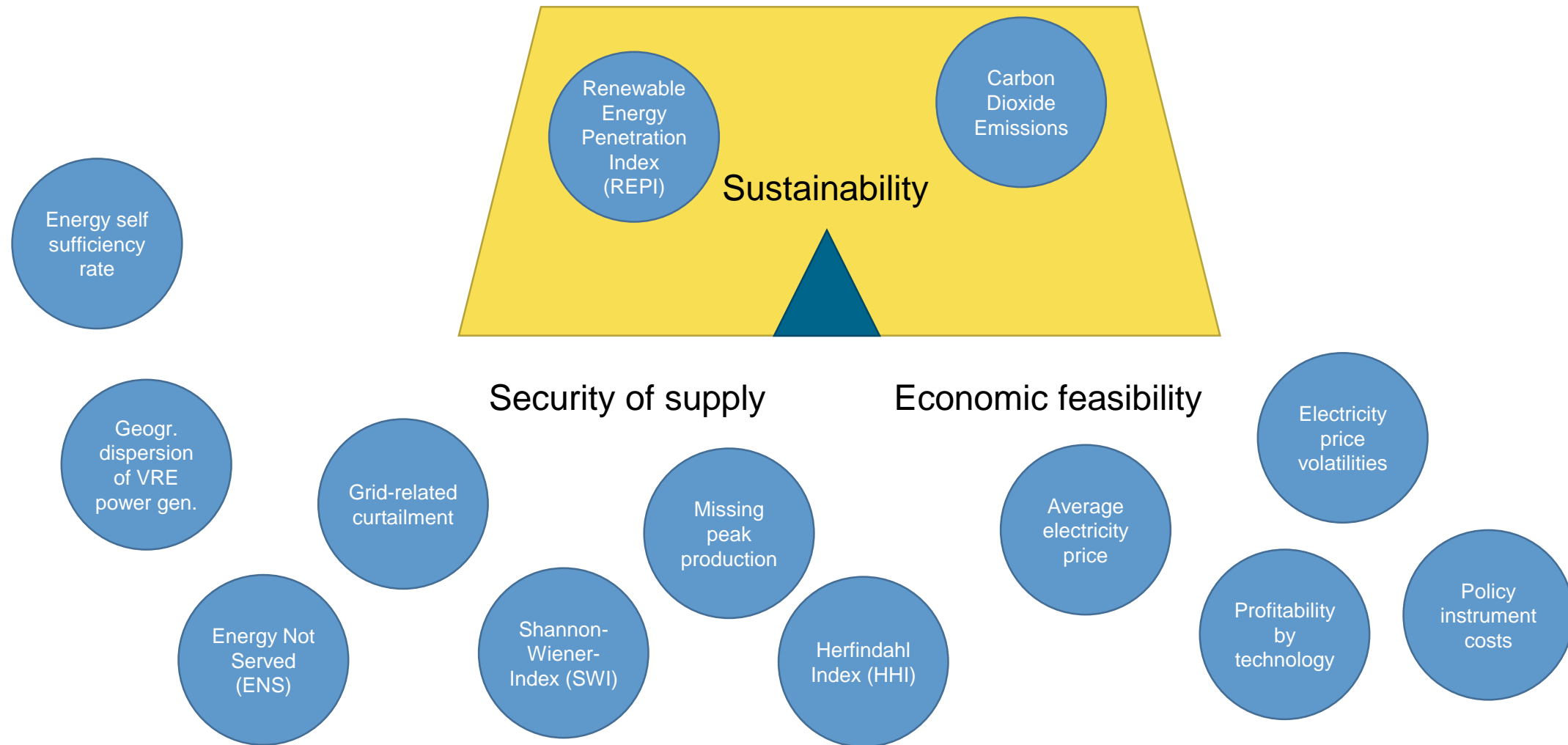
Method: Workflow on Supercomputers



Results: Best-performing scenarios



Outlook



THANK YOU!

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