STRise

Stuttgart Research Initiative on
Integrated Systems Analysis for Energy

Finding realisable & optimal energy systems by coupling simulation and optimisation models

ERAFlex II

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SW

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

https://www.enargus.de/detail/?id=2001065

Motivation

Energy System Modelling

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Optimisation models

- Wide-spread model type
- Deliver cost-optimal systems
- **But:** Assume perfect competition

Agent-based simulations

- Rare type of model
- Can capture market imperfections
- **But:** Do not search for optima

➔ Couple both model types: find optimal systems considering market imperfections

Methodology

E2M2: European Electricity Market Model

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Input	Model	Output

▪ Demand
▪ Renewable feed-in potentials
▪ Available technologies
▪ Techno-economic parameters
  ▪ Fuel prices
  ▪ Efficiencies
▪ Regulatory framework
	Optimisation
	$\min c = c_{inv} + c_{fix} + c_{var}$
	Constraints
	▪ Supply - demand balance
	▪ Upper / lower bounds
	▪ Energy balance
	▪ CO_2 Cap
	▪ Renewable Share
		▪ System cost
		▪ Investments
		▪ Dispatch
		▪ Electricity prices
		▪ CO_2-Prices
		▪ CO_2-Emissions

Methodology

AMIRIS: **A**gent-based **M**arket model for the **I**nvestigation of **R**enewable and **I**ntegrated energy **S**ystems

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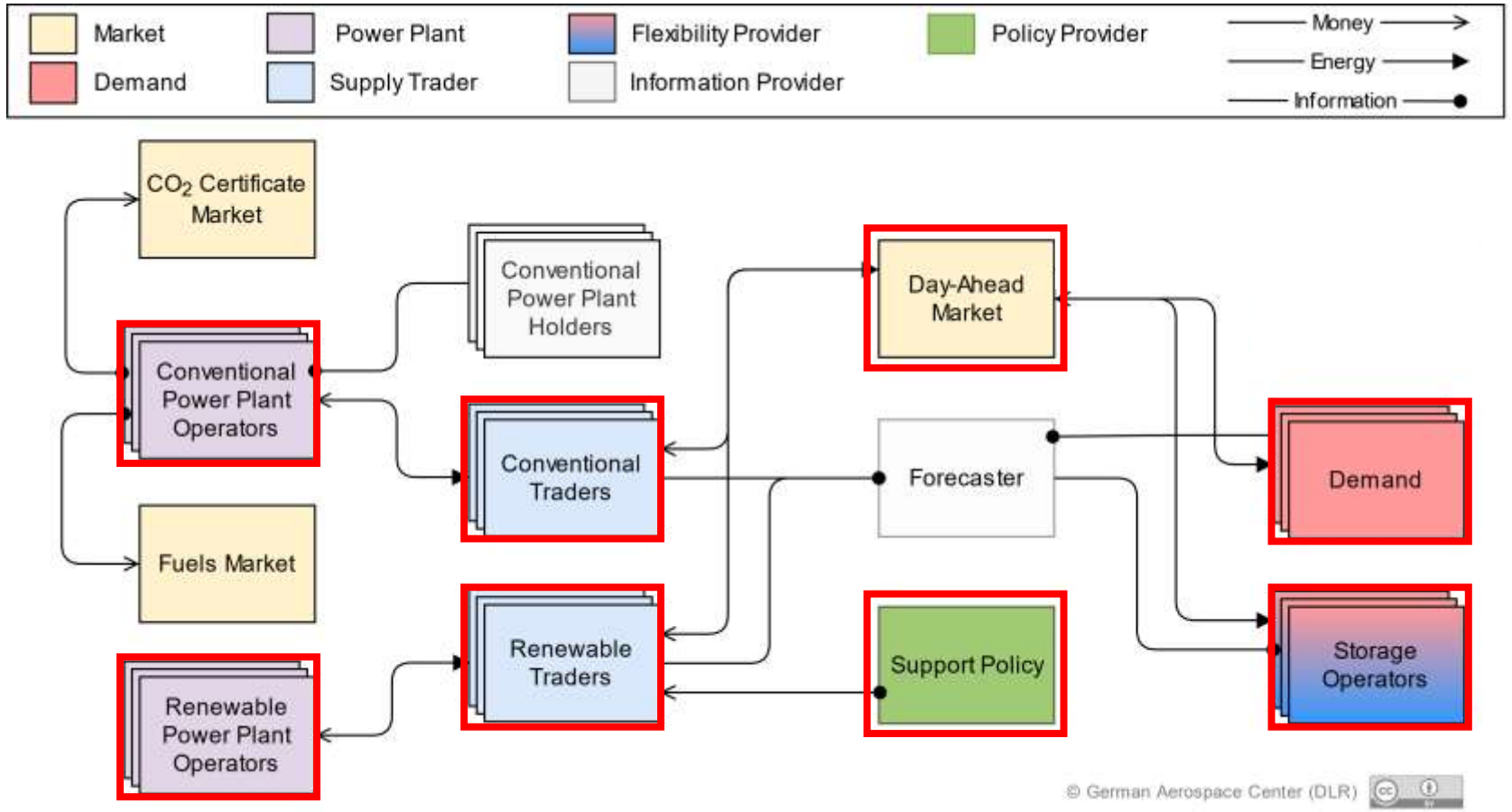
Agents

- Day-Ahead market
- Demand & Supply Traders
- Renewable & conventional power plants
- Flexibility option: storage
- Support Policies

Market Imperfections

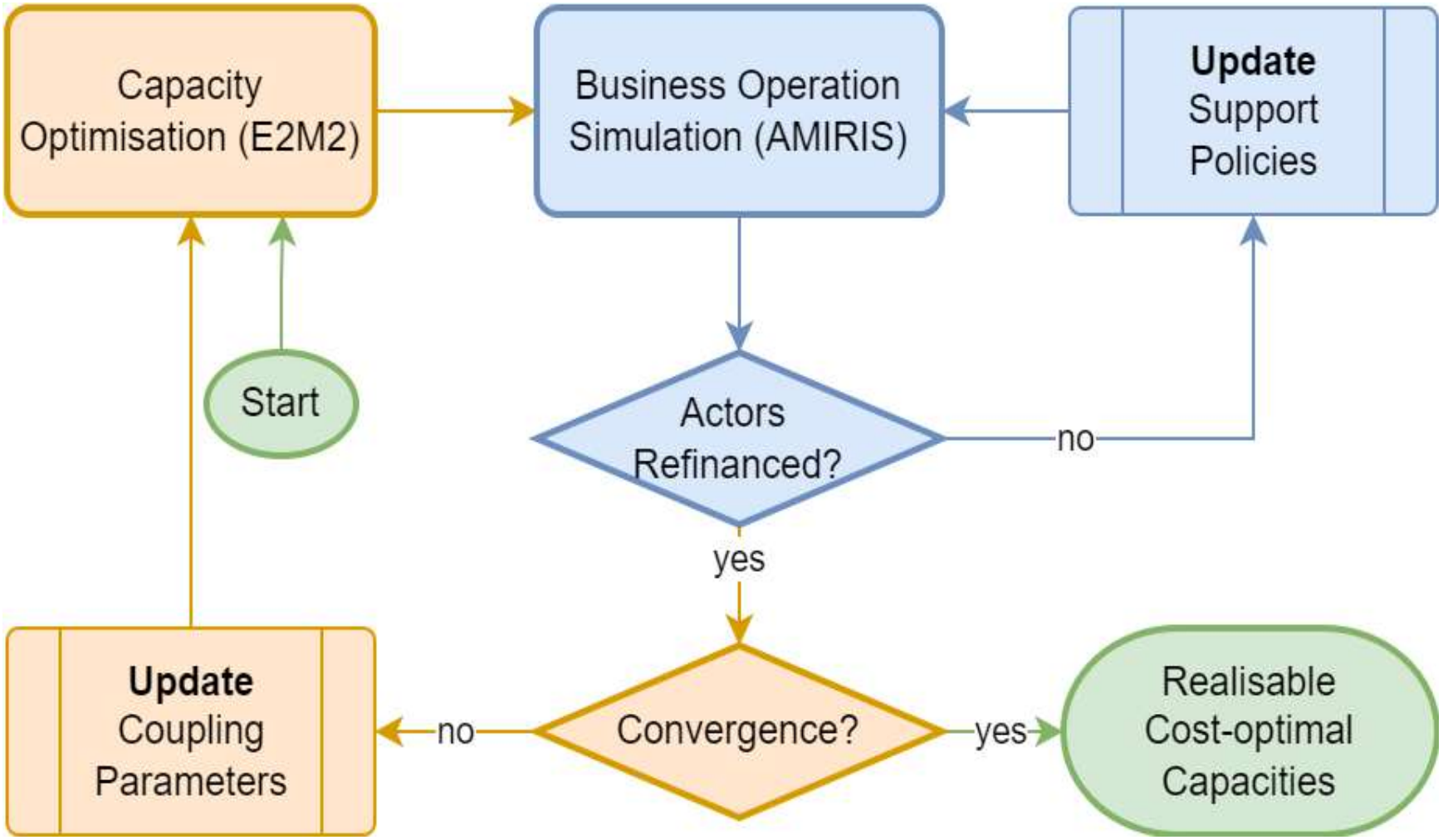
- Imperfect foresight
- Market power
- Strategic bidding



open source available at https://gitlab.com/dlr-ve/esy/amiris/amiris

Methodology

Model Coupling



Methodology

Model Coupling: Automation

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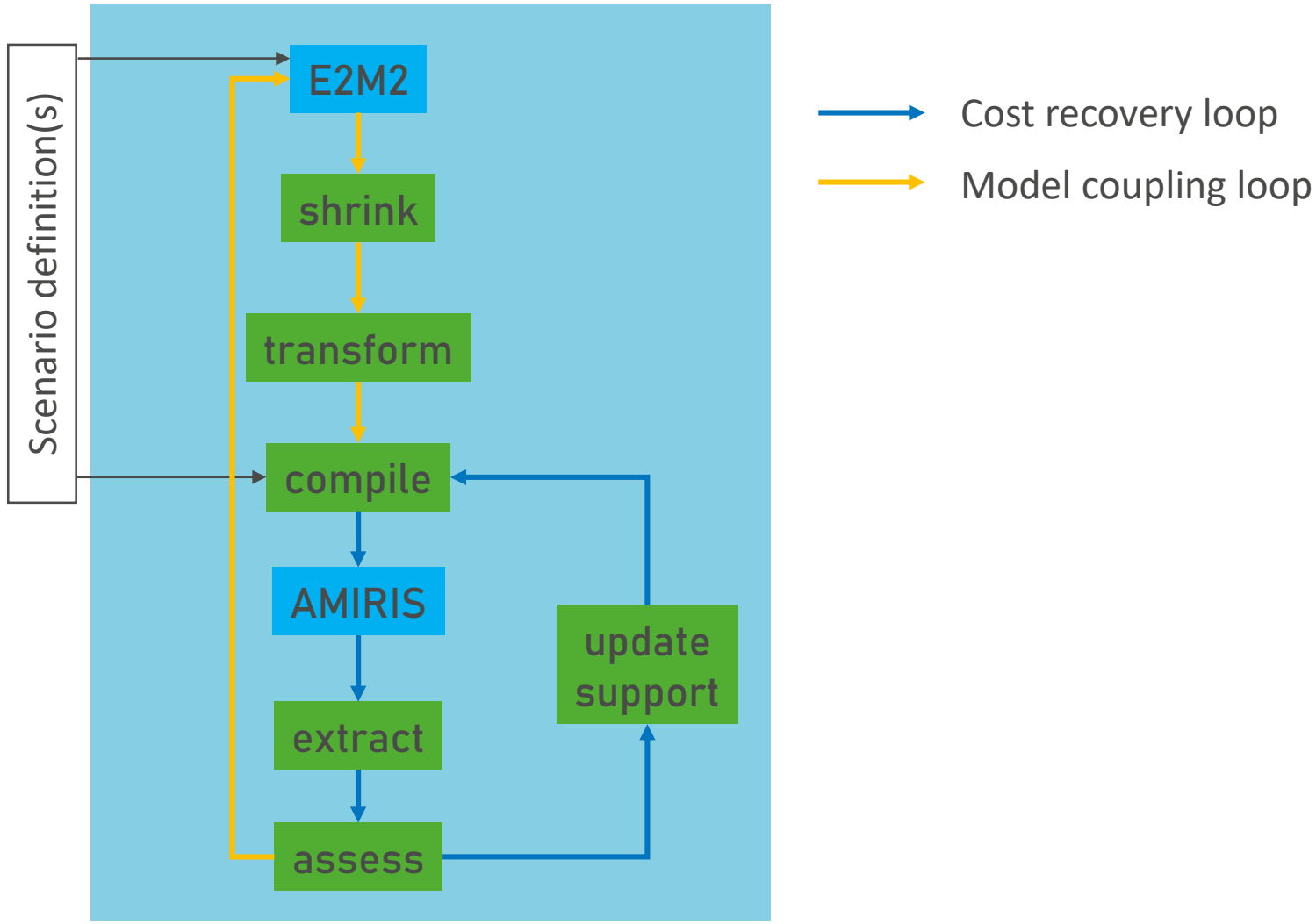
Workflow: Python

- Reduce & transform data: ioProc[1]
- Assess results: pandas
- Fully automated

[1] ioProc: https://pypi.org/project/ioproc/



Methodology

Cost Recovery: Policy Instruments

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Fixed Market Premium

- Monthly payment
- Based on actual generation of agent
- Constant premium, known *ex ante*

→ Impacts bids

Fixed Market Premium
PV
Wind onshore
Wind offshore

Capacity Premium

- Annual payment
- Based on installed capacity of agent
- Constant premium

→ No impact on bids

Capacity Premium
Lignite
Gas Combined Cycle
Gas Turbine
Backup Gas Turbine
Storage: Pumped Hydro

Methodology

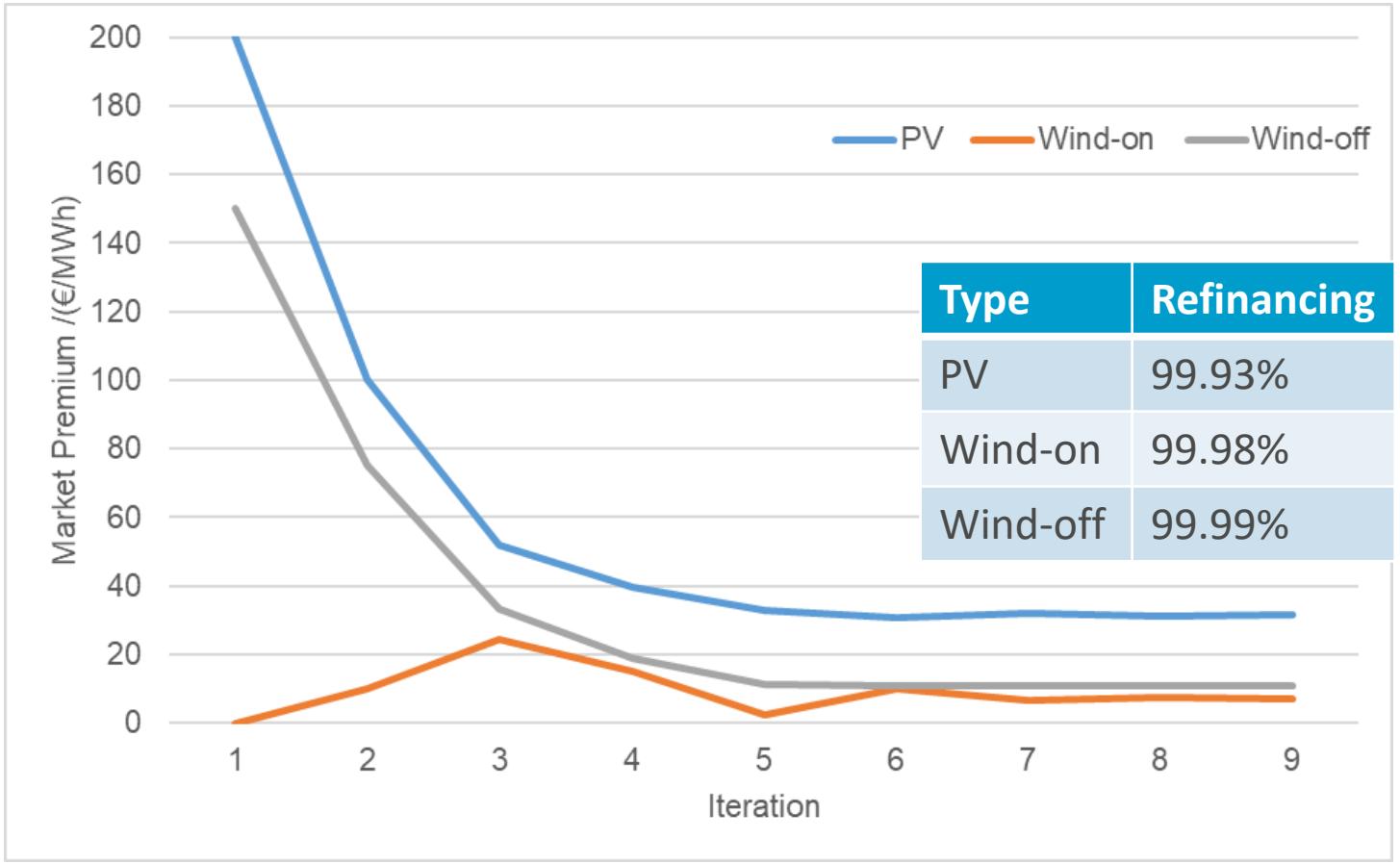
Cost Recovery: Policy Instrument Adaption

Feedback Effect

- Market premia affect bidding
- Bids affect prices
- Prices affect refinancing
- Refinancing affects premia

Iterative approach

1. Guess market premia
2. Run AMIRIS dispatch
3. Evaluate refinancing (revenues / costs)
4. Re-estimate premia
5. Stop if *Cost == Revenues ± 1‰*



Type	Refinancing
PV	99.93%
Wind-on	99.98%
Wind-off	99.99%

Data

Scenario: Simplified Test Bed

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Technologies

- Lignite, Hard-Coal & Natural Gas
- PV, Wind Onshore & Wind Offshore
- Pumped Hydro Storage

Constraints

- Greenfield approach
- CO_2 cap
- Renewable share ≥ 80%
- 2 Stages: Invest + Dispatch

Model Harmonization

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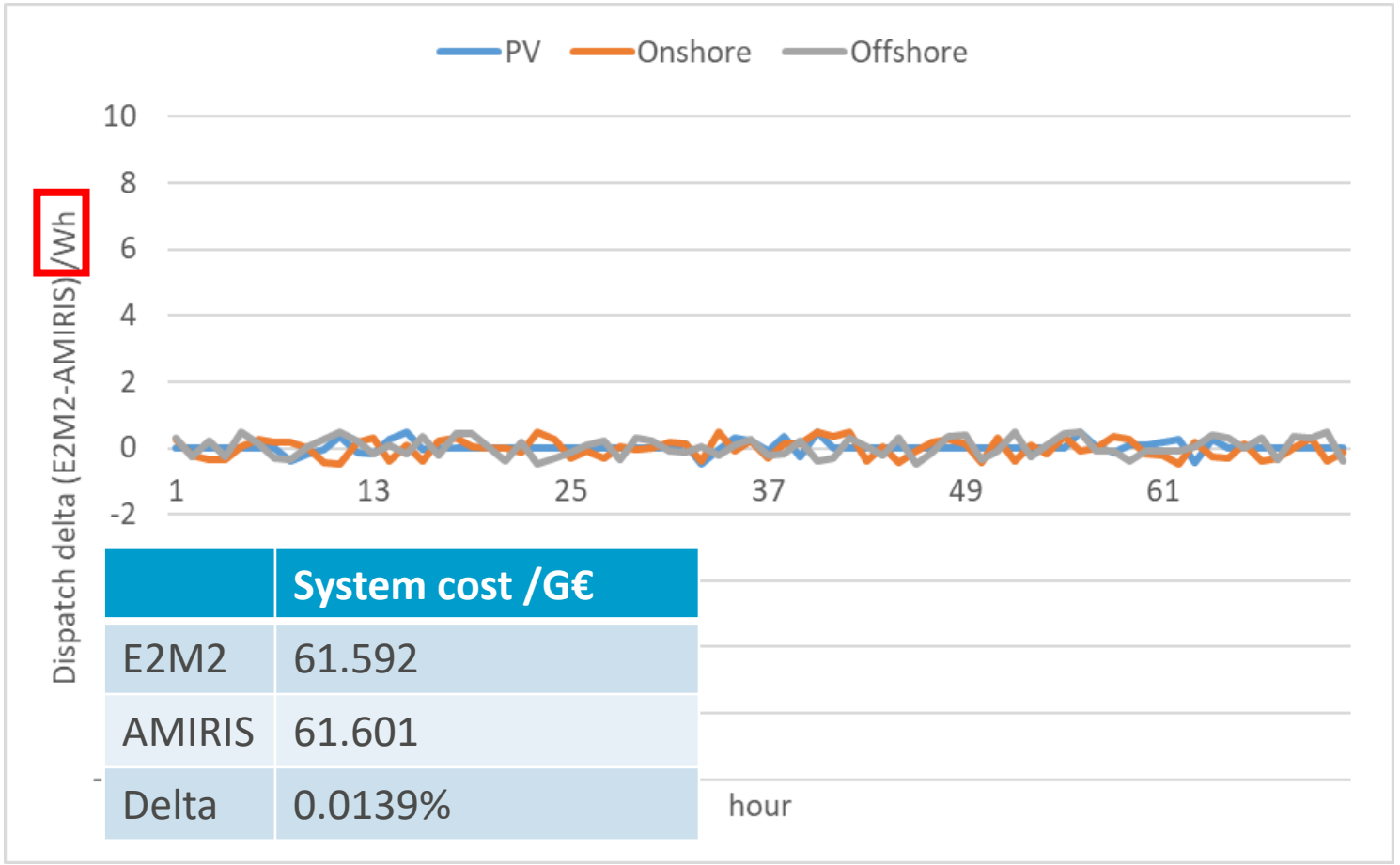
Setup

- *No storage*
- Conventionals: capacity premia
- Renewables: fixed market premium

E2M2 & AMIRIS: Perfect Match

- Dispatch
- System cost



	System cost /G€
E2M2	61.592
AMIRIS	61.601
Delta	0.0139%

Results

Coupling Mechanism: Missing Capacity

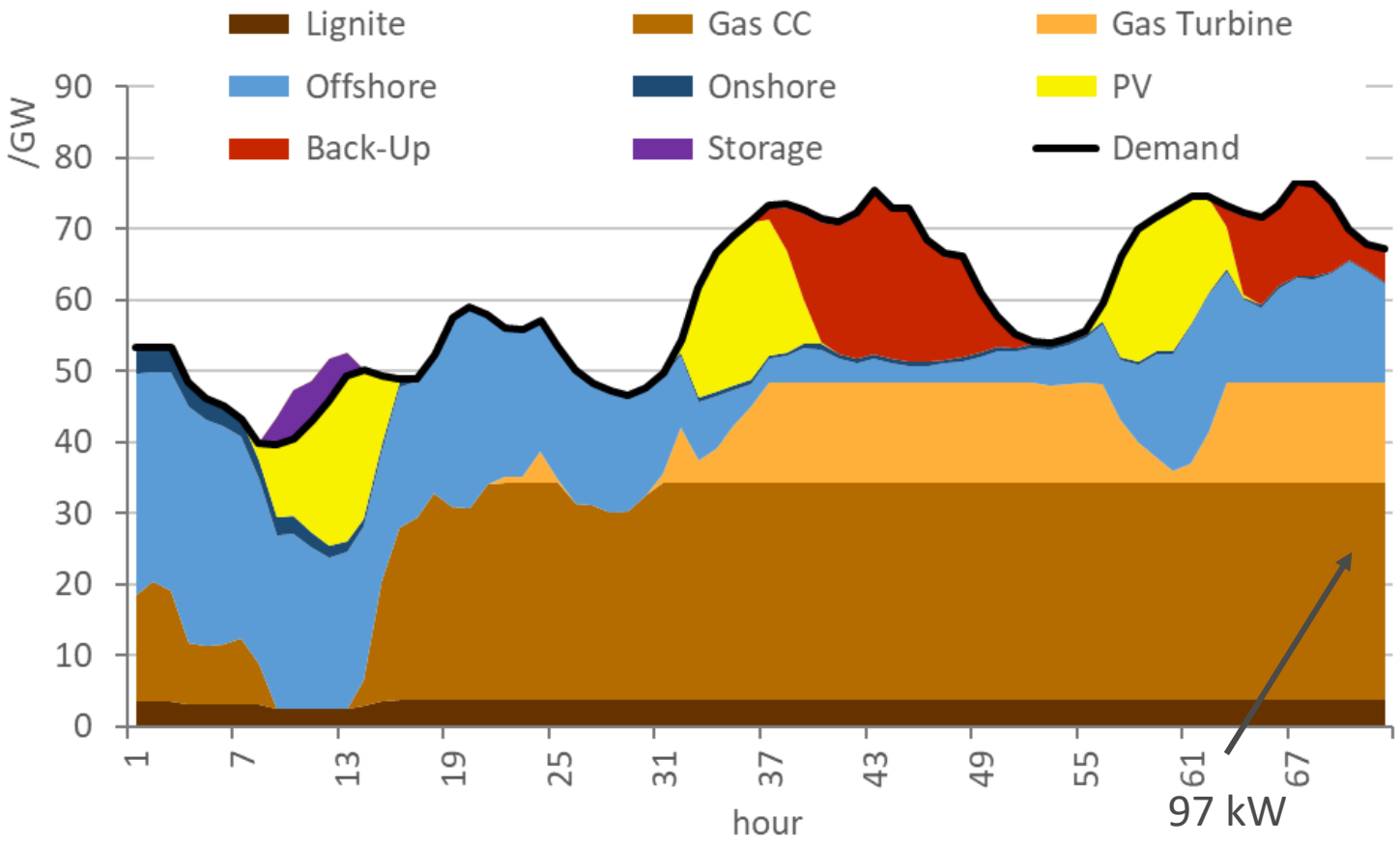
Setup

Storage in AMIRIS: not optimal

→ missing capacity

Model Coupling

- E2M2: add extra conventional plants
- Compensate missing capacity



Results

Coupling Mechanism: Missing Capacity

Setup

Storage in AMIRIS: not optimal

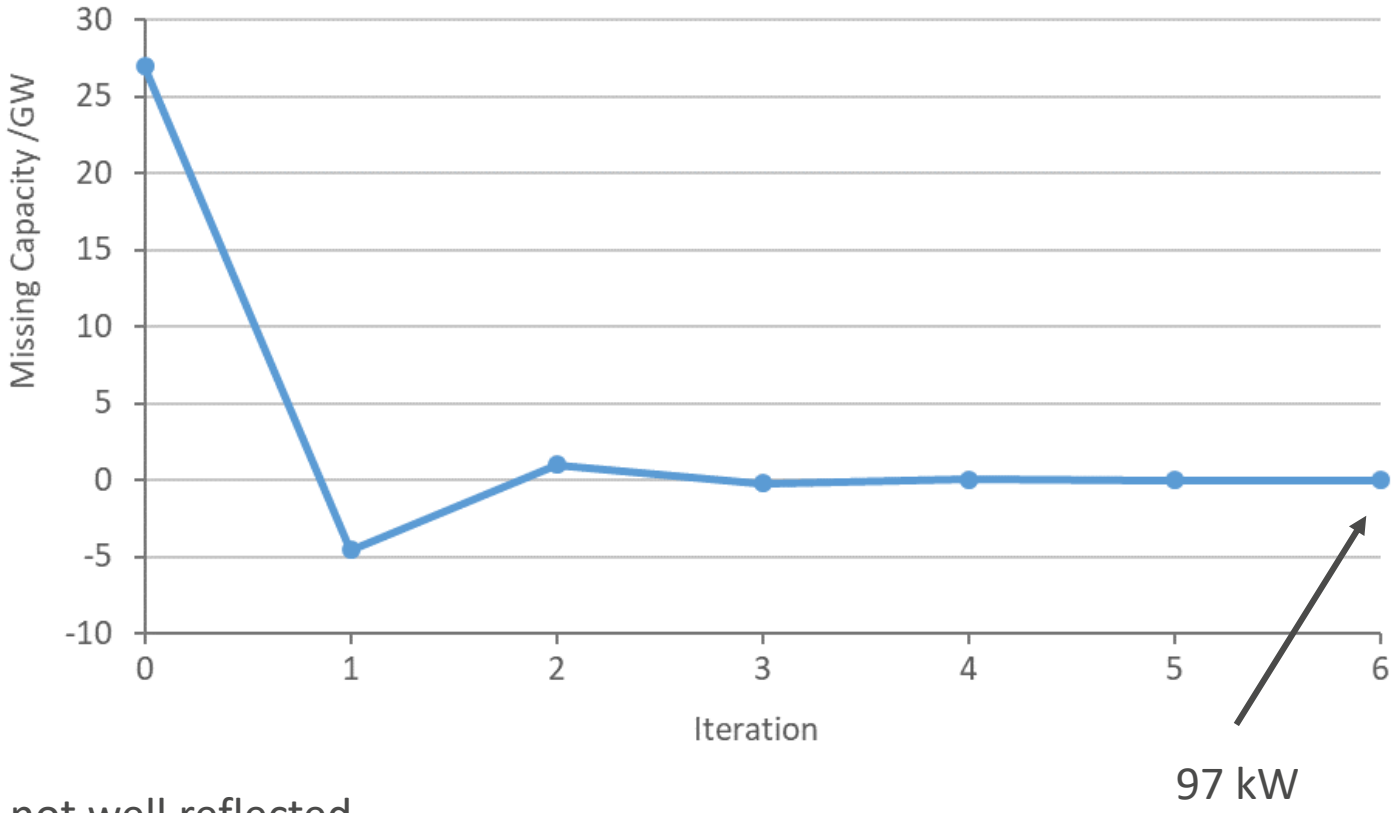
→ missing capacity

Model Coupling

- E2M2: add extra conventional plants
- Compensate missing capacity

Result

Convergence: E2M2 compensates!



Issue: Renewable contribution to firm capacity not well reflected

Results

Coupling Mechanism: Storage Dispatch

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Setup

- Storage causes model differences
  - limited foresight,
  - profit-oriented

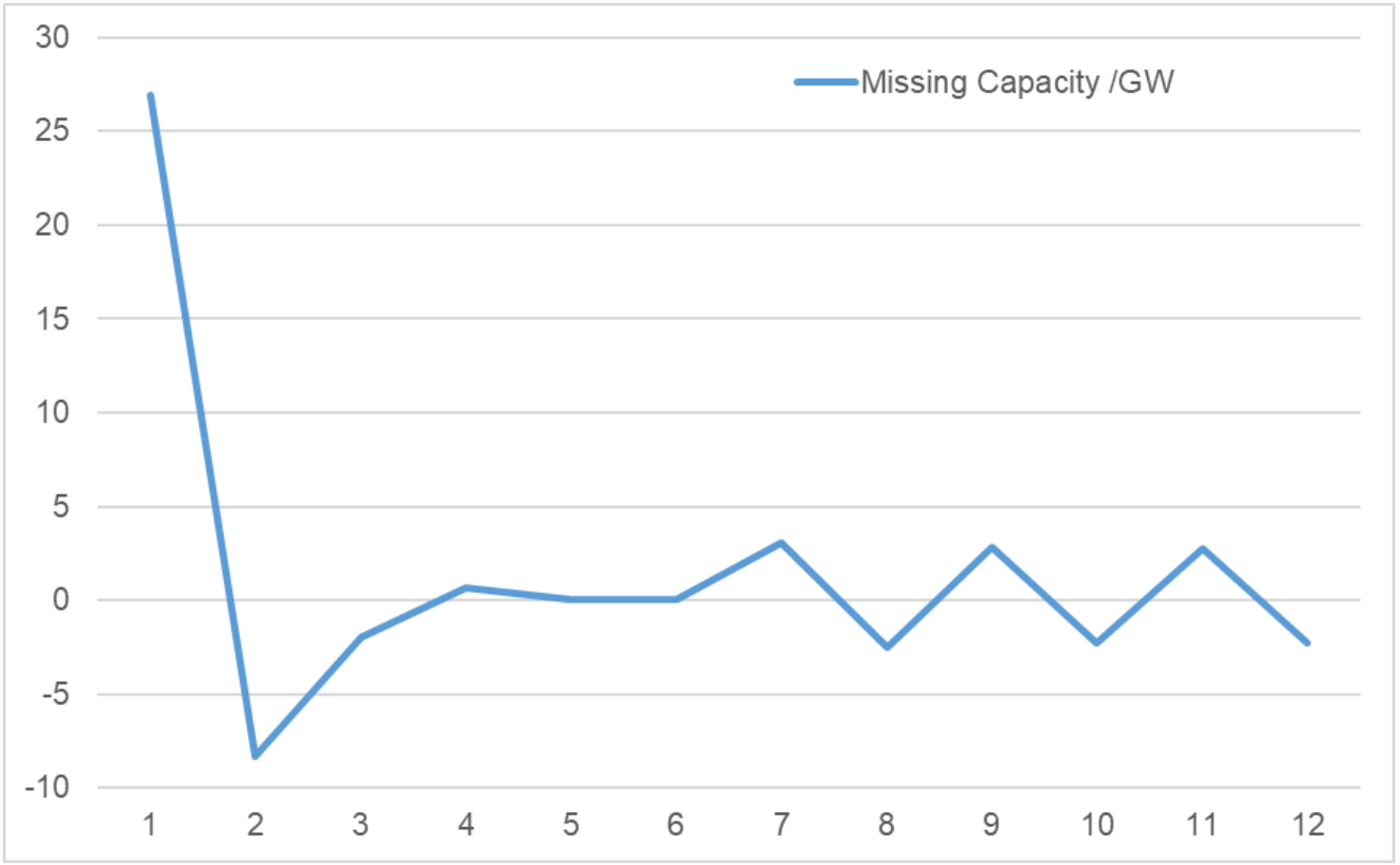
→ Use AMIRIS storage dispatch in E2M2

Result

No Convergence!

Problem

Storage dispatch *unstable*



Method

Unstable Storage Dispatch Strategy: Median Price

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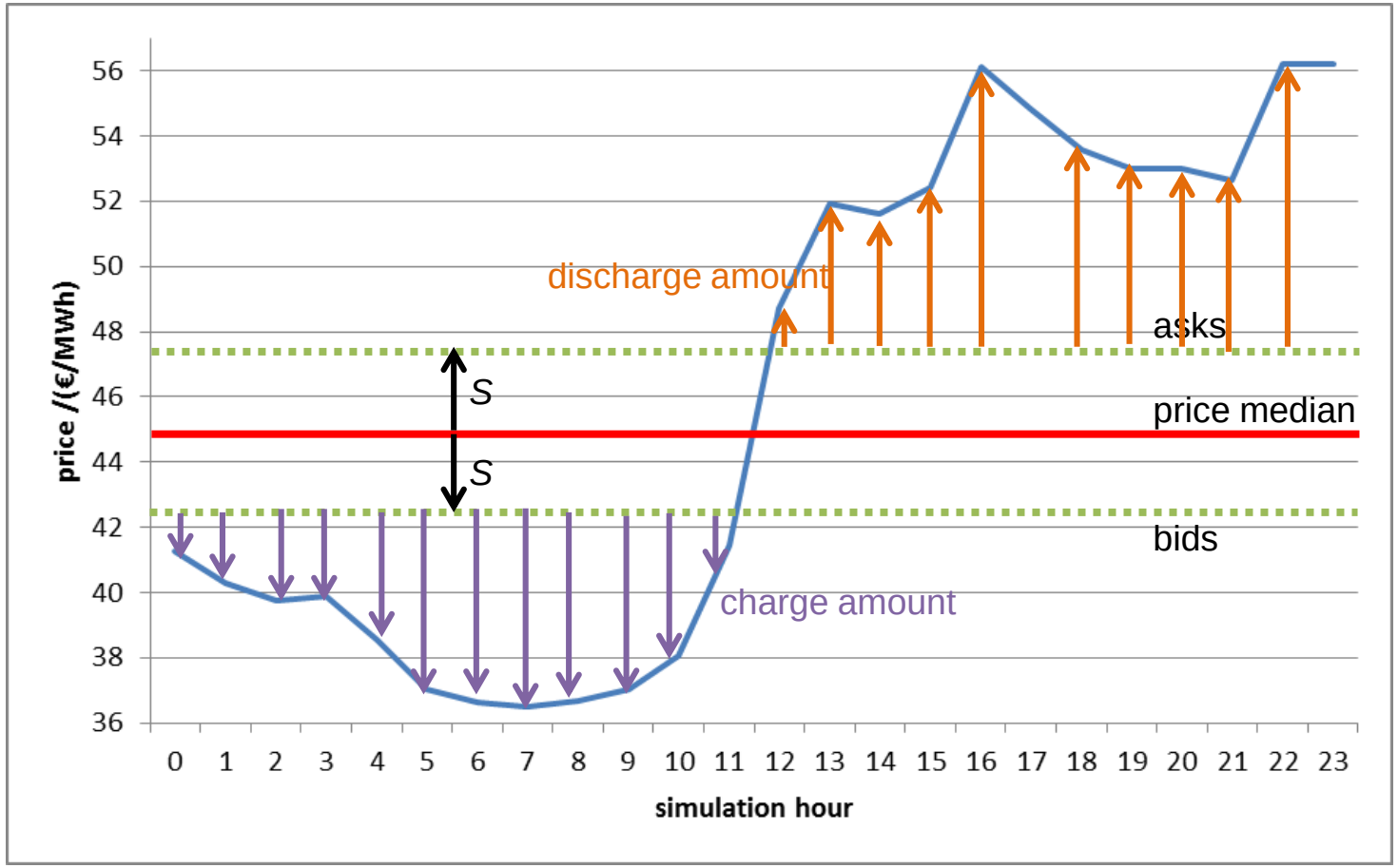
Idea

- Prices lower than average: charge
- Prices higher than average: discharge

Implementation

- Reference: Price median M,
- Losses: safety margin S
- Bidding price: $b = M \pm S$
- Power: polynomial $f_i(p_i)$



Method

Unstable Storage Dispatch Strategy: Median Price

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Implementation

- Reference: Price median M,
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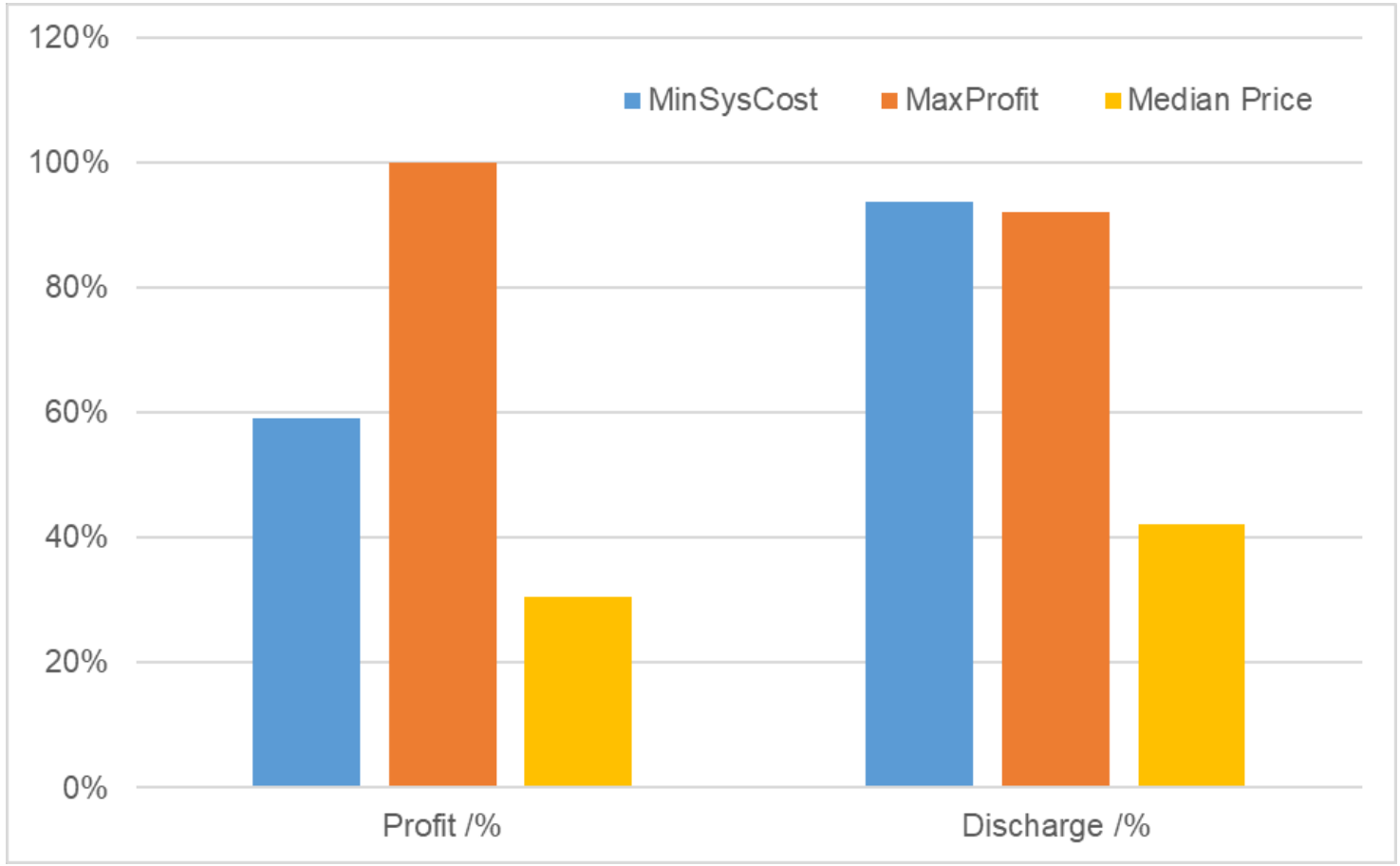
Result

→ Low profits: price impact not regarded
→ Low discharge: dispatch planning failed
→ Low stability: many reschedules



Method Update

New Storage Dispatch Strategy: Price Feedback

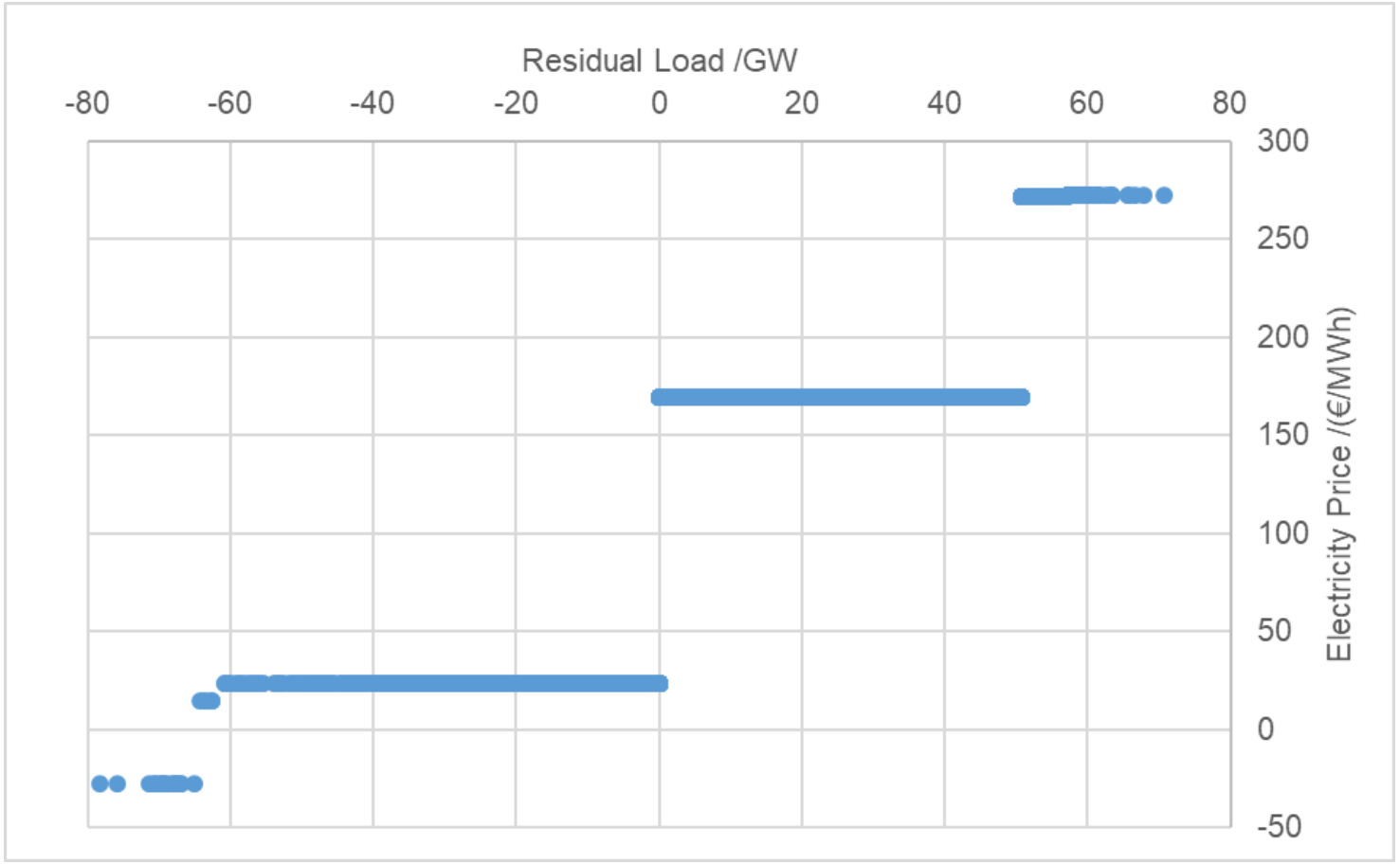
Idea

- Estimate price feedback based on current price & residual load

Problem

- Jumpy merit order

→ Piecewise estimate of price feedback



Method Update

New Storage Dispatch Strategy: Price Feedback

Idea

- Estimate price feedback based on current price & residual load

Problem

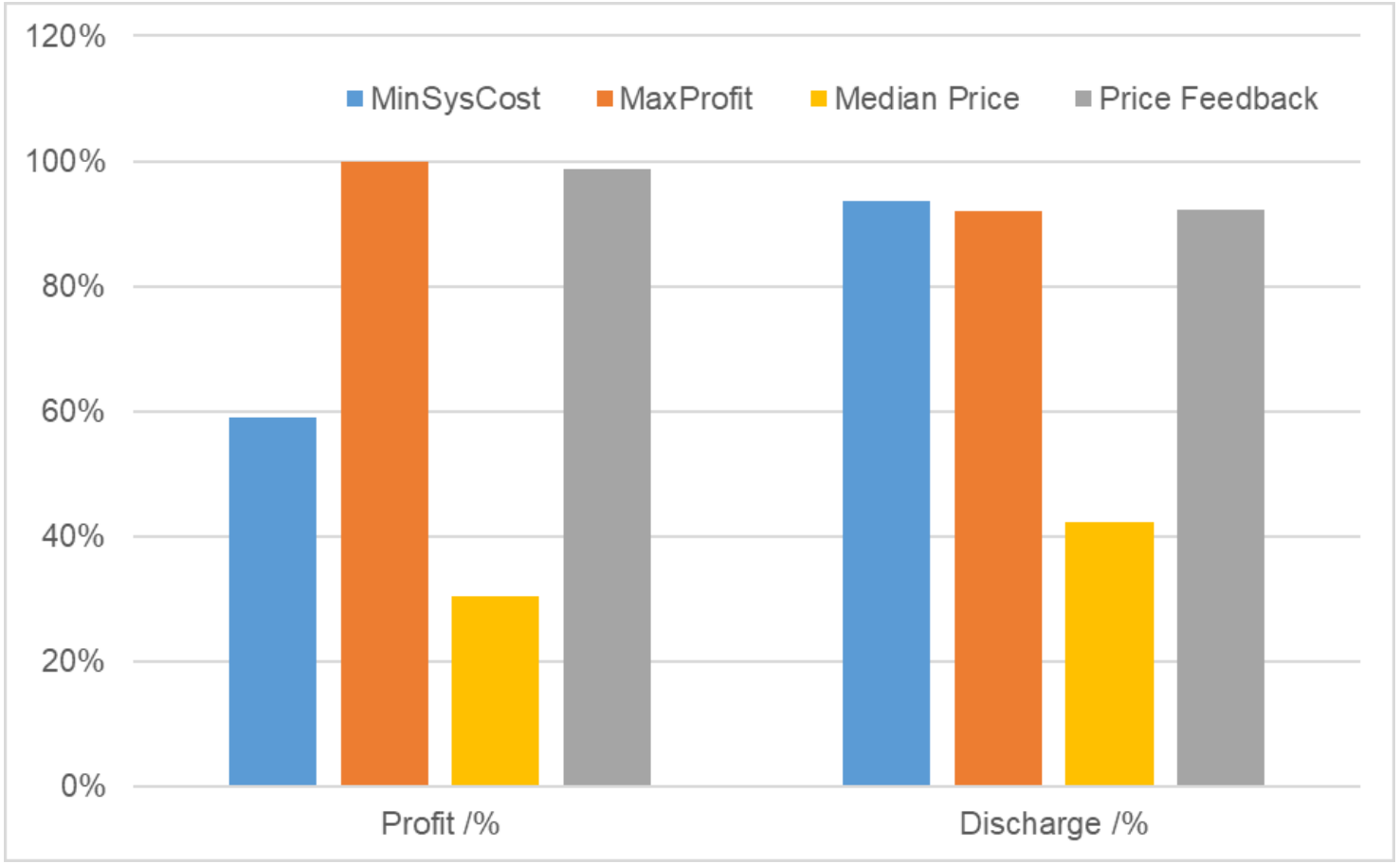
- Jumpy merit order

→ Piecewise estimate of price feedback

Result

→ Good profits: use of market power

→ Stable dispatch across coupling iterations



Data Update

Scenario: Adjusted

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Technologies

- Lignite, Hard-Coal & Natural Gas
- PV, Wind Onshore & Wind Offshore
- Storage

Constraints

- Greenfield approach
- No renewable share constraint
- 1 Stage: Invest + Dispatch

First iteration only

- CO_2 cap

Other iterations

- CO_2 price

Results

Retry Model Coupling with Storage Dispatch

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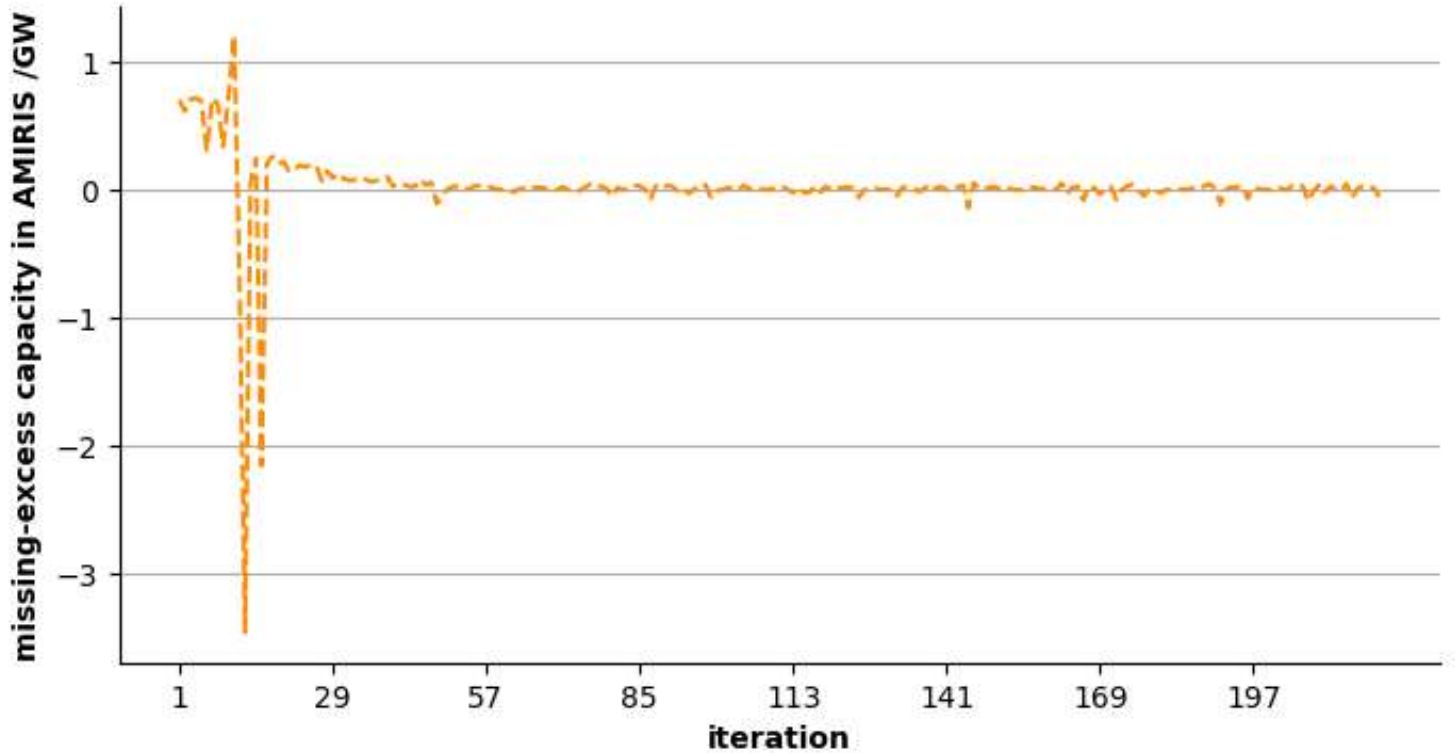
Missing Capacity

- Lower initial amplitude: ± 3 GW
- Converging after ≈ 60 iterations



Results

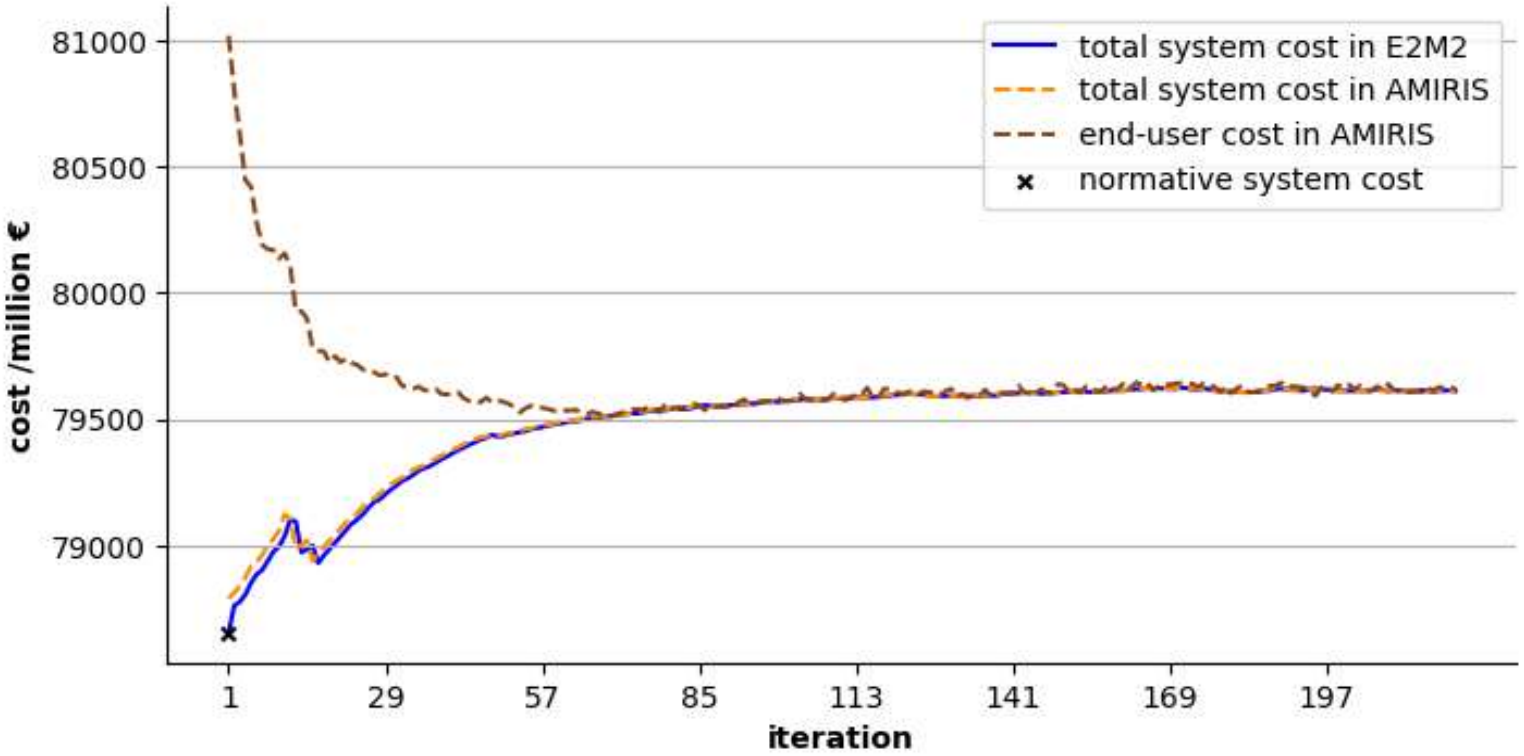
Retry Model Coupling with Storage Dispatch

Missing Capacity

- Lower initial amplitude: ± 3 GW
- Converging after ≈ 60 iterations

System cost

- E2M2 match after AMIRIS ≈ 40 iterations
- End user cost: match after ≈ 70 iterations
- But: model results not stable



Results

Retry Model Coupling with Storage Dispatch

Missing Capacity

- Lower initial amplitude: ± 3 GW
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System cost

- E2M2 match after AMIRIS ≈ 40 iterations
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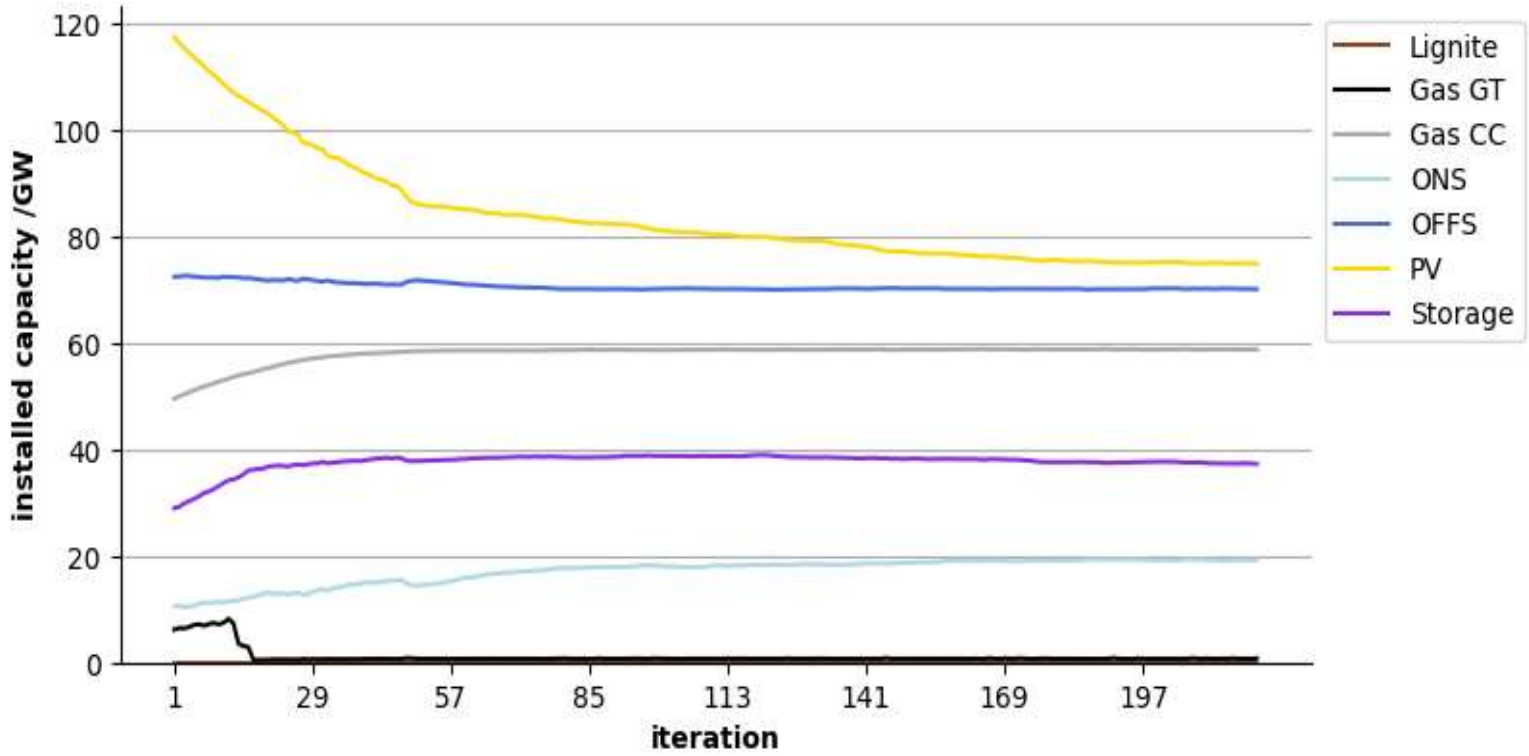
- But: model results not stable

Capacities

- Converging after ≈ 220 iterations
- Reduce PV & Gas GT
- increase Storage, Wind onshore & Gas CC



Analysis

Cost Recovery

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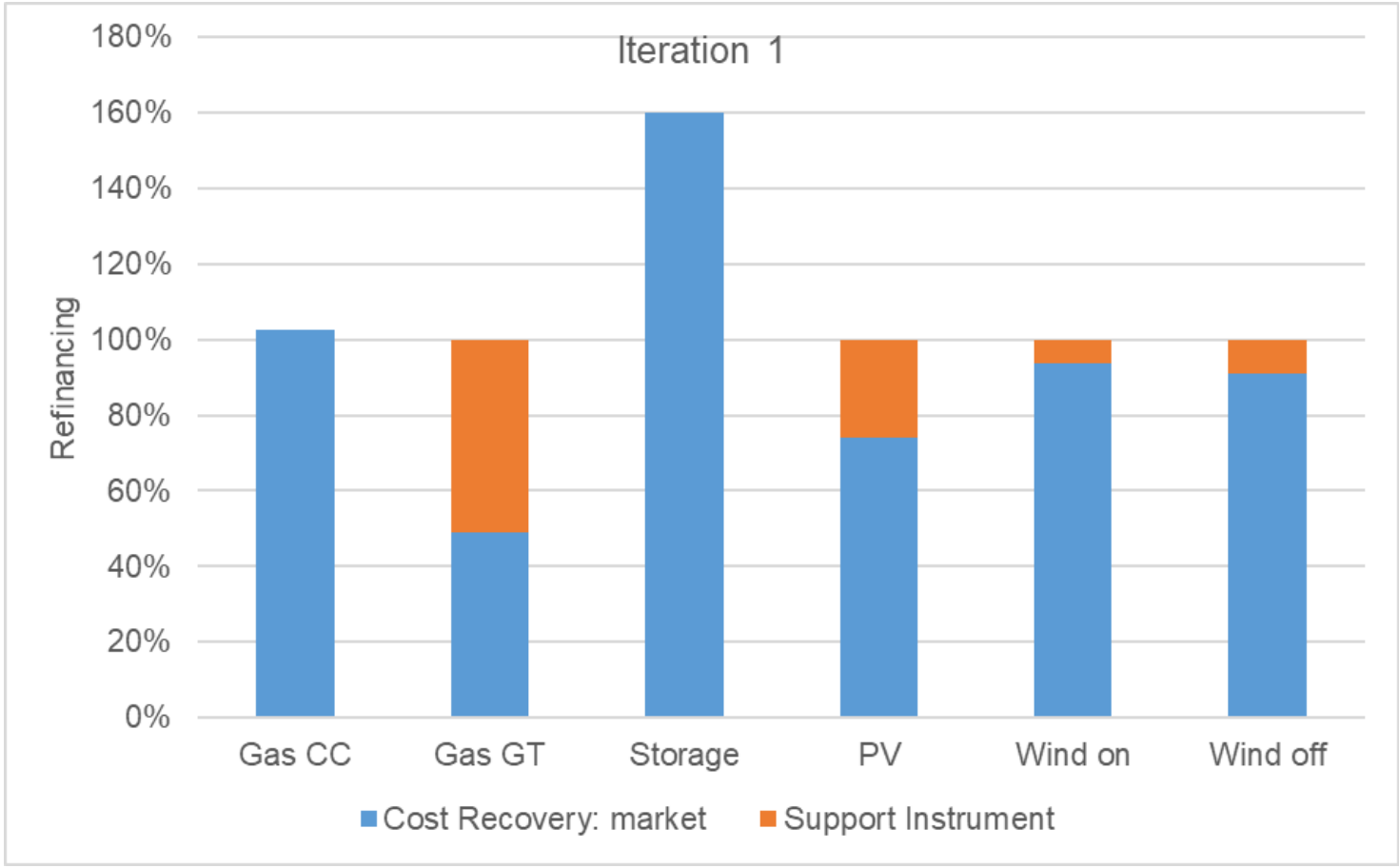
Iteration 1

- Storage utilising market power
- RES & Gas turbines missing money



Analysis

Cost Recovery

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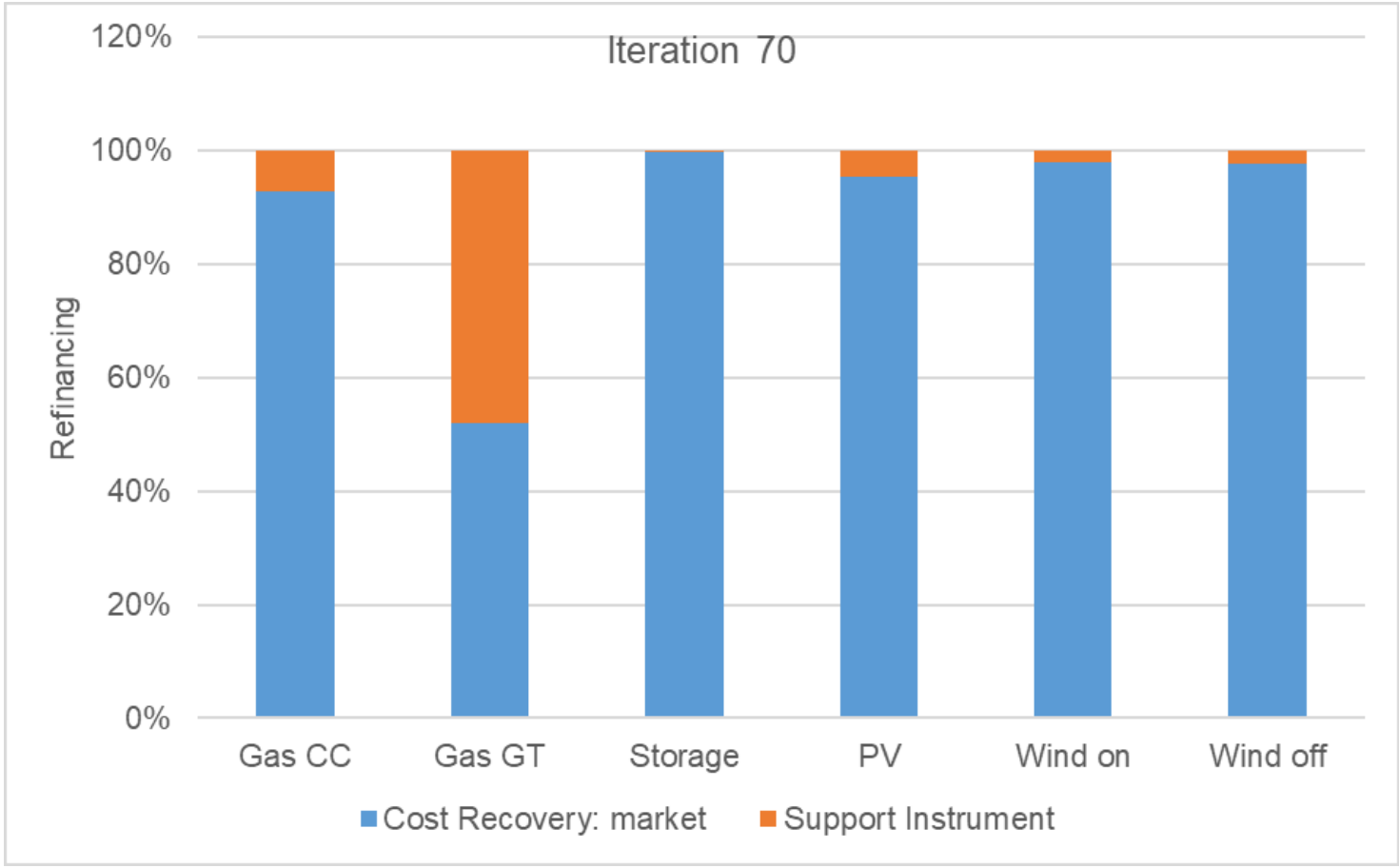
Iteration 1

- Storage utilising market power
- RES & Gas turbines missing money

Iteration 70

- Storage profits cut
- RES need little support
- Gas turbines: < 1 GW



Analysis

Cost Recovery

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Iteration 1

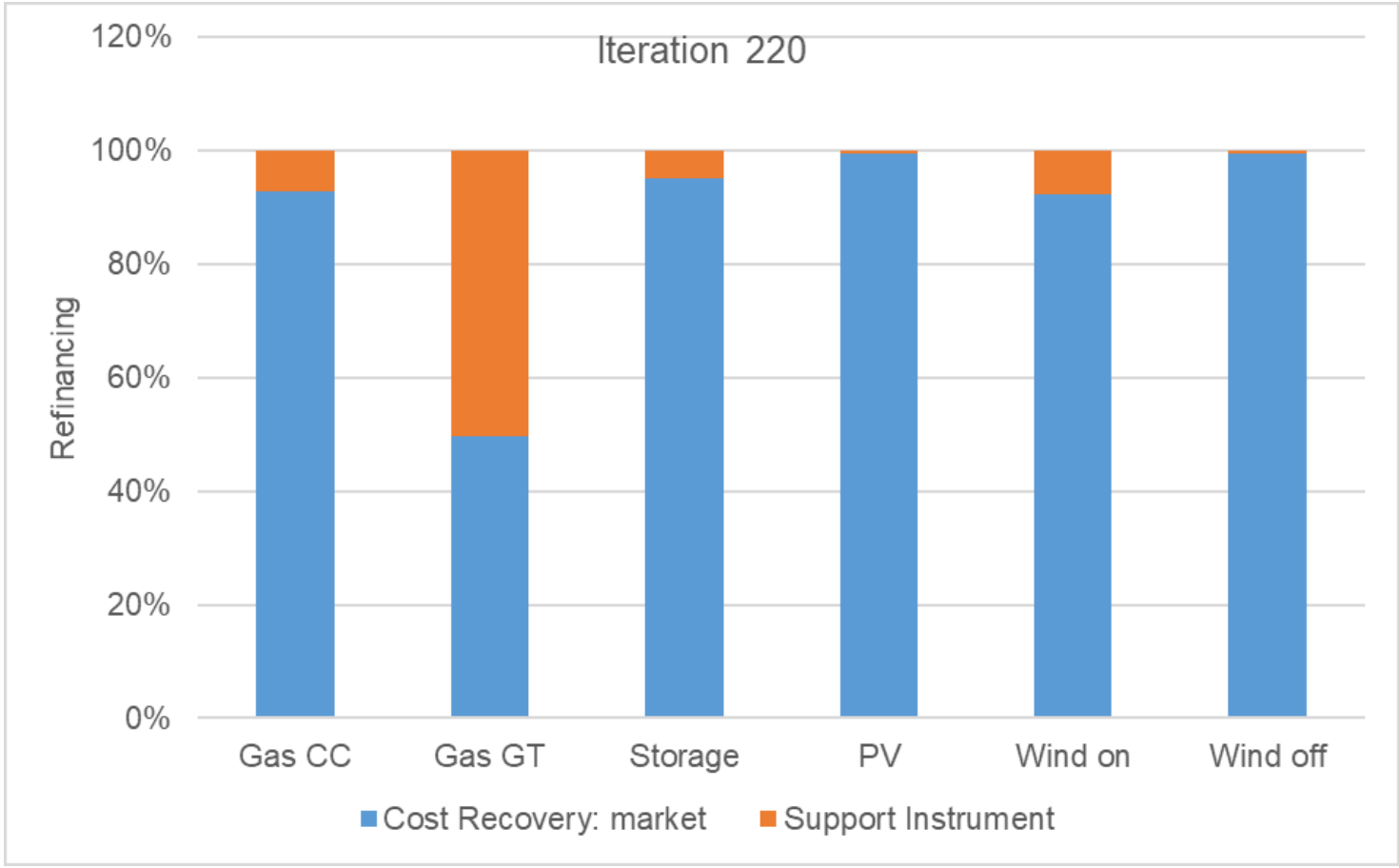
- Storage utilising market power
- RES & Gas turbines missing money

Iteration 70

- Storage profits cut
- RES need little support
- Gas turbines: < 1 GW

Iteration 220

- Storage missing money
- Gas CC & Wind onshore need support

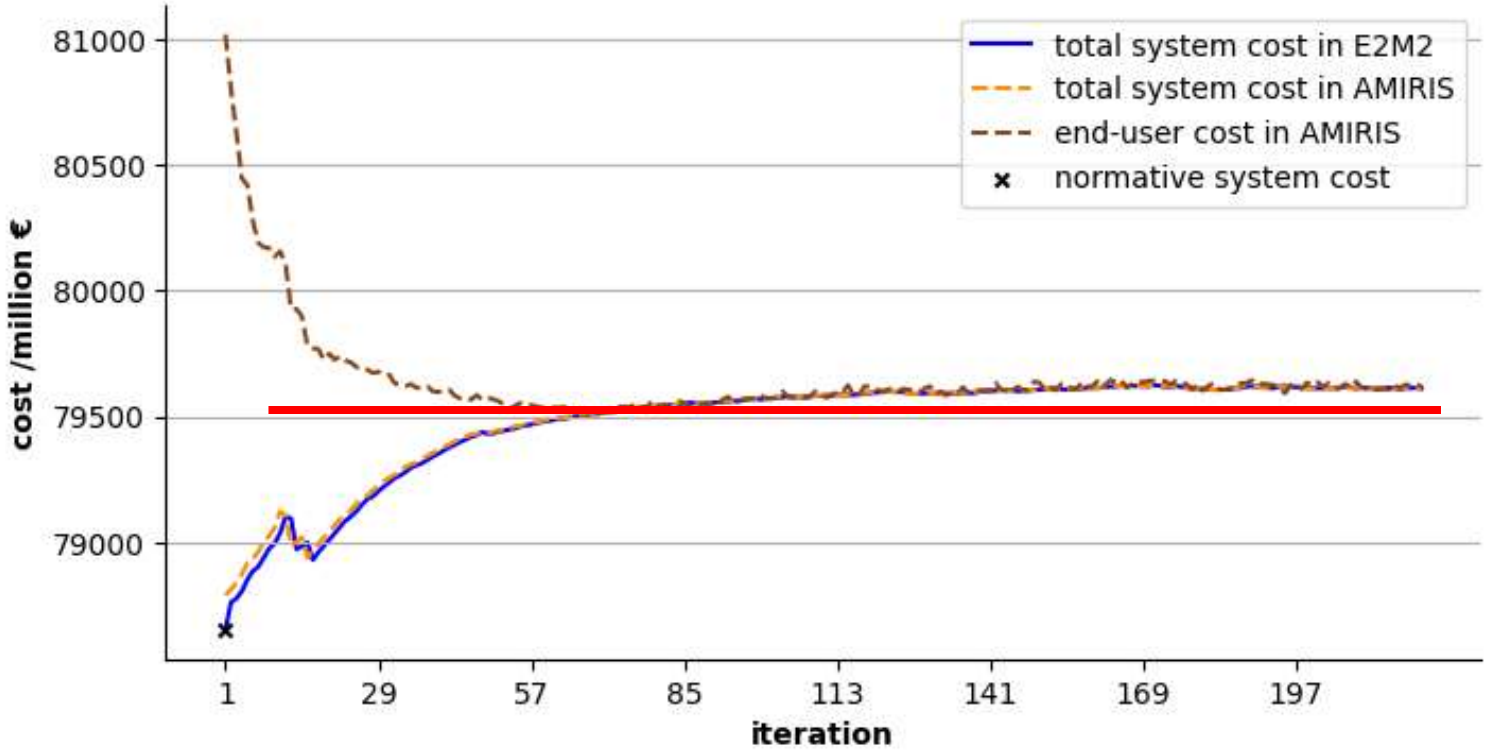


Analysis

Open Questions

Model Convergence after iteration 70

- Why do costs rise?
- Why does the capacity mix change?
- Which is “the best” solution?



Conclusions

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Method

- Harmonised simulation & optimization models
- Fully automated model coupling
- Fully automated support scheme adaptation

Results

- Optimisation model power plants don't recover cost in AMIRIS without additional support
- Convergence of two different coupling methods
- Convergence for different test bed scenarios

Outlook

- Deeper understanding of coupling results
- Assess brown-field scenario path

Imprint

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Topic	Finding realisable & optimal energy systems by coupling simulation and optimisation models
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Images	German Aerospace Center & University of Stuttgart (CC BY-NC-ND 3.0)