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An integrated market for electricity and natural gas systems with stochastic producers

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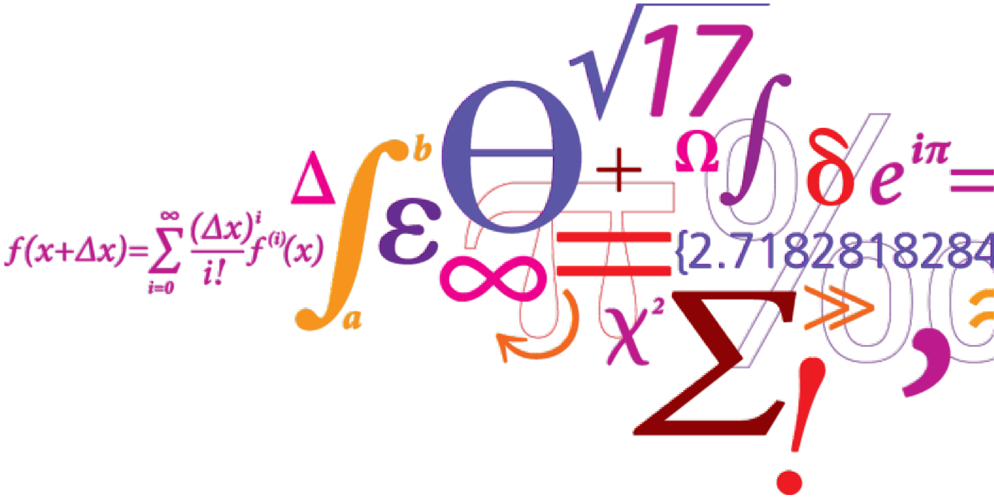

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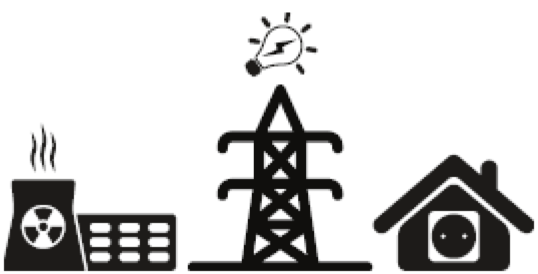
DTU Electrical Engineering
Department of Electrical Engineering

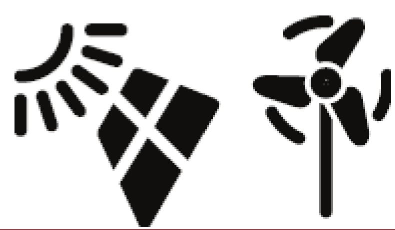
Objective

- Define **existing synergies** among energy systems.
- **Efficiently align** the existing synergies towards **optimal operation** of the energy system.
- New **market** structures that will provide incentives to market participants.
- Manage high **uncertainty** on both supply and demand sides.

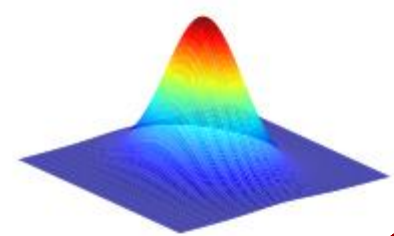
Decision-making in energy markets



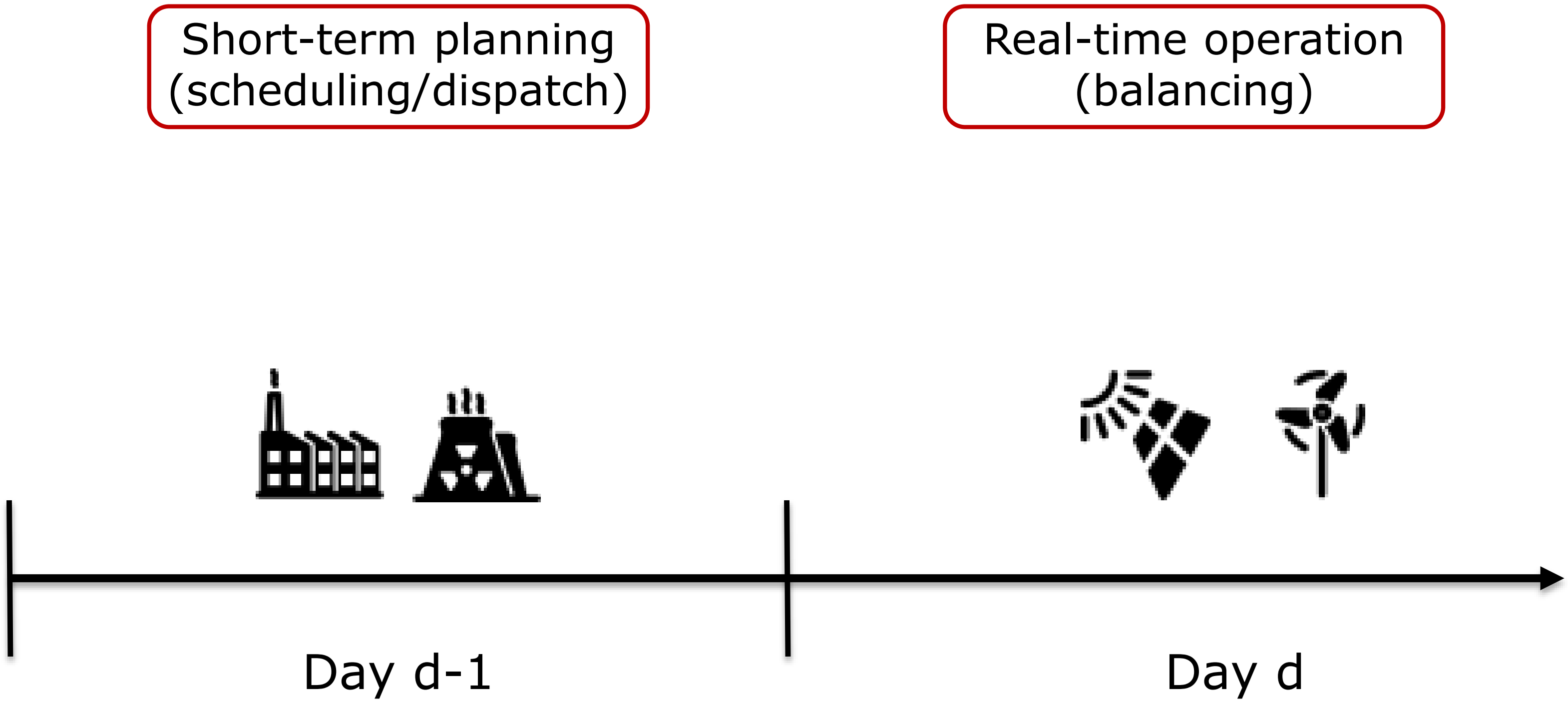
Sources of uncertainty in energy systems



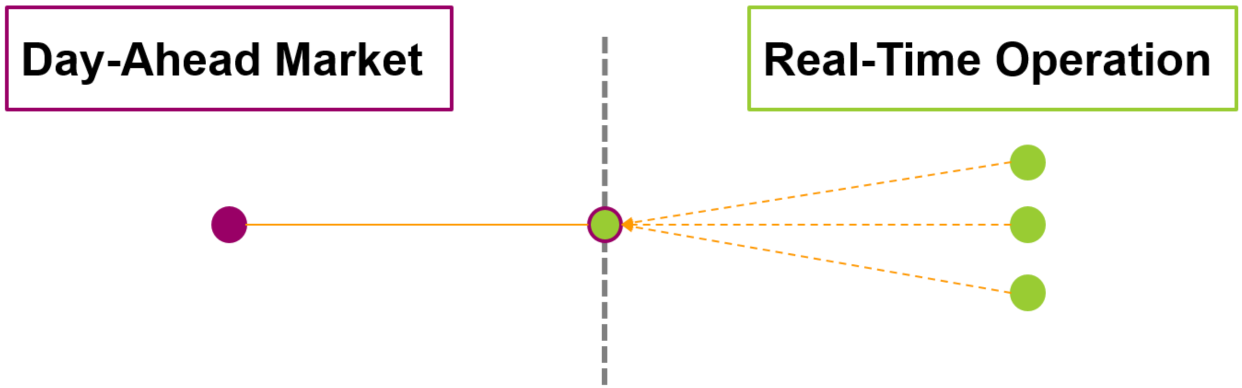
Optimization under uncertainty



System operation



Conventional market-clearing

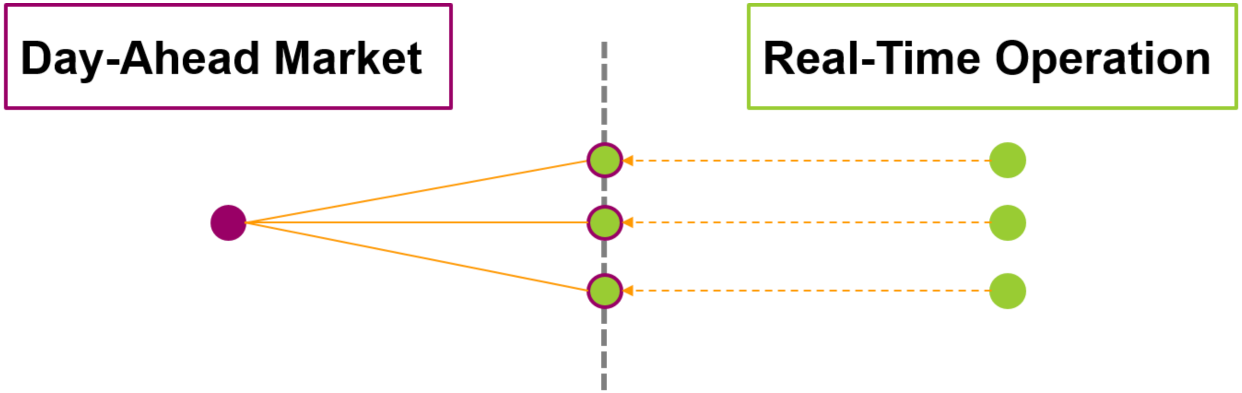


Conventional market clearing

Sequential clearing of two trading floors:

1) Day-ahead market is cleared based on deterministic description of uncertain wind power production.
2) A balancing market is cleared for real-time operation.

Stochastic market-clearing

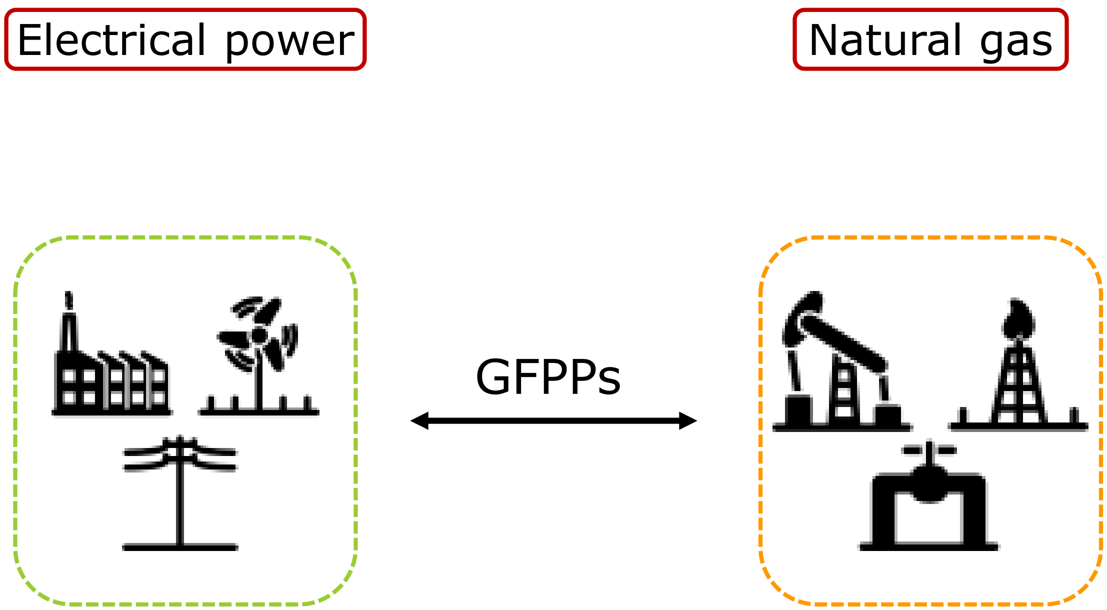


Stochastic market clearing

Co-optimization of two trading floors:

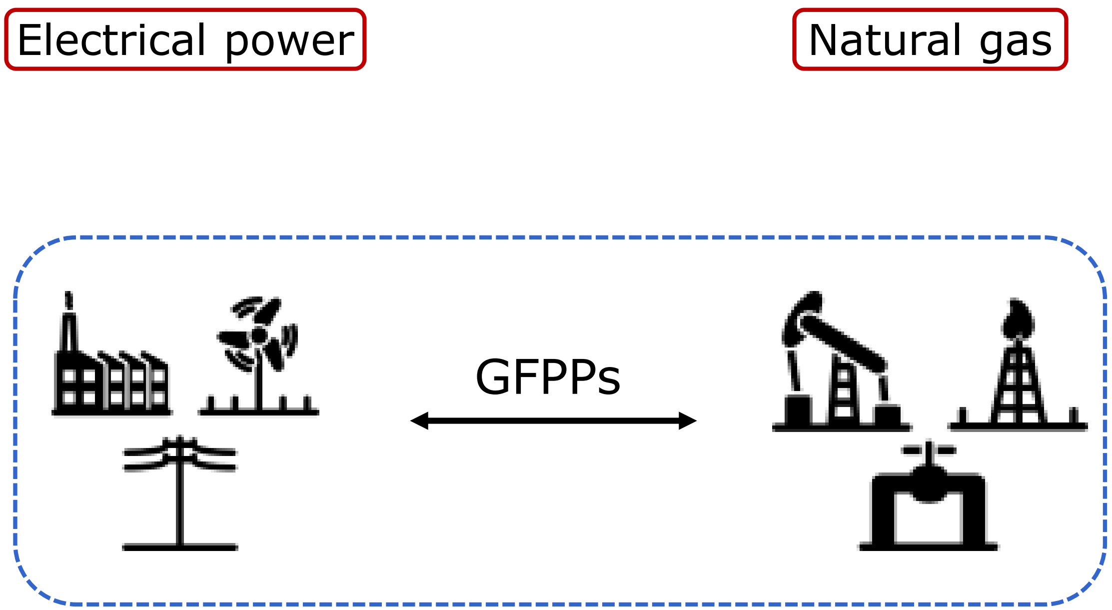
1) Day-ahead dispatch is determined by co-optimizing day-ahead and real-time dispatch, where wind power uncertainty is probabilistically described.
2) A balancing market is cleared for real-time operation.

Electrical power and natural gas systems



Decoupled: 1) Economic dispatch (ED) of electricity system
→ NG consumption for electricity.
2) ED of gas system.

Electrical power and natural gas systems



Integrated: Simultaneously solve the ED of electricity and gas systems.

Market-clearing models for electricity and natural gas systems

Stoch-Coup: Stochastic market-clearing of coupled electricity and natural gas systems.

Conv-Coup: Sequential market-clearing of coupled electricity and natural gas systems.

Conv-Dec: Sequential market-clearing of decoupled electricity and natural gas systems.

Optimization problems – Stoch-Coup

Min. Day-ahead El and NG cost + Exp. {Balancing El and NG cost}

s.t.

Day-ahead El and NG system constraints

Balancing El and NG system constraints (for all wind power scenarios)

DA dispatch
is determined

The following model is solved for
a specific wind power realization

Min. Balancing El and NG cost

s.t.

Balancing El and NG system constraints

Optimization problems – Conv-Coup

Min. Day-ahead El and Gas cost

s.t.

Day-ahead El and Gas system constraints

Wind power is constrained by its expected value

DA dispatch is determined

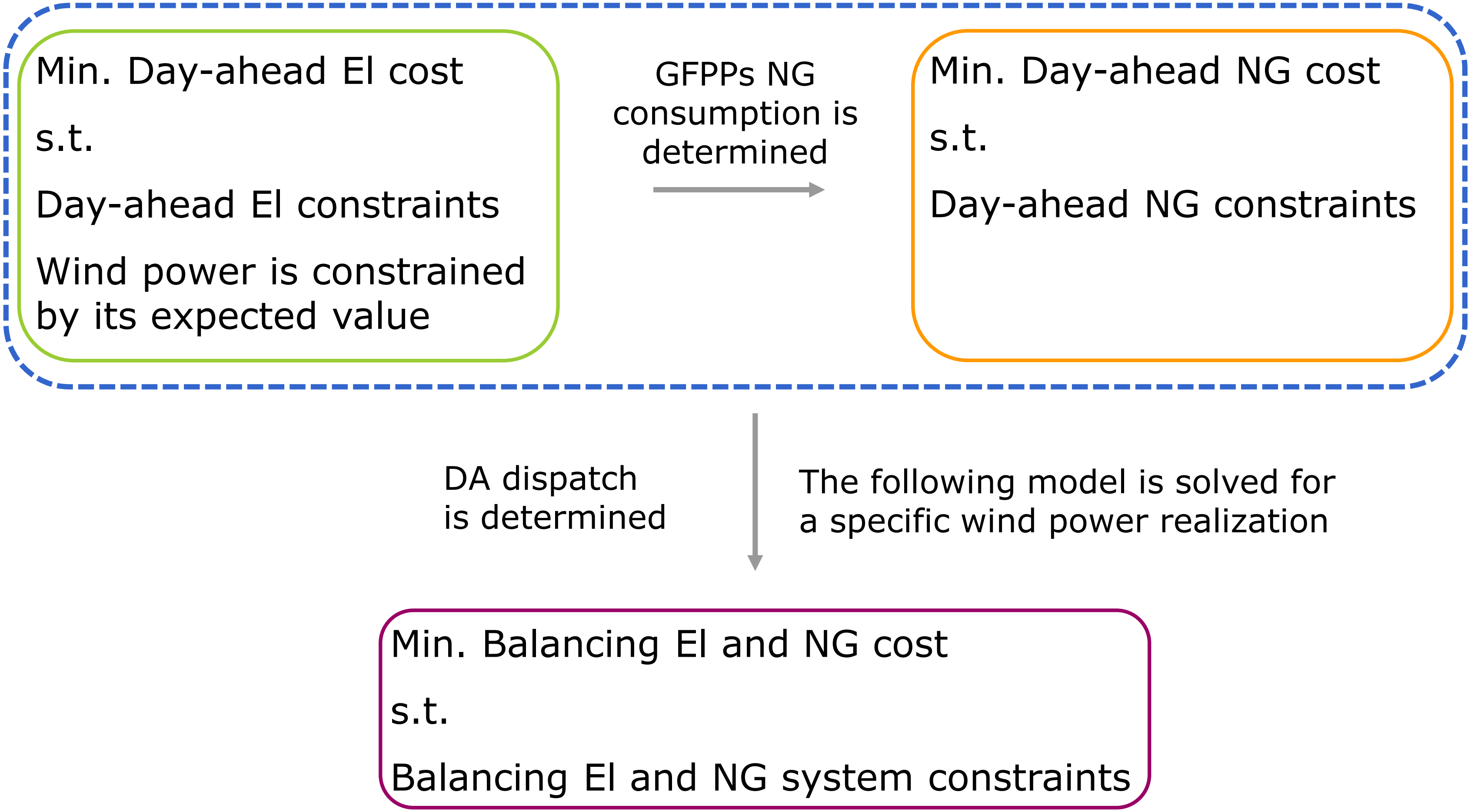
The following model is solved for a specific wind power realization

Min. Balancing El and NG cost

s.t.

Balancing El and NG system constraints

Optimization problems – Conv-Dec



Model details

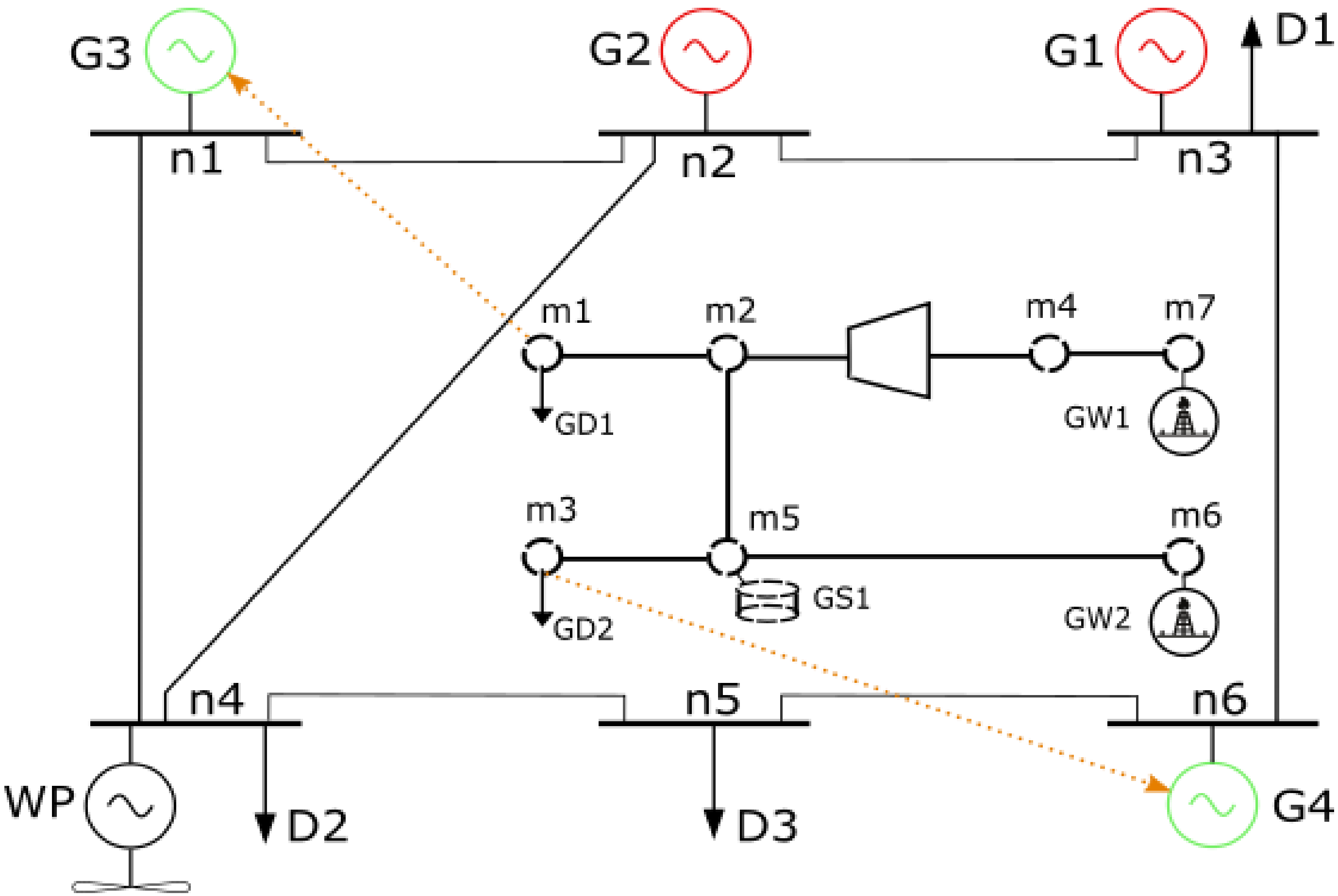
1) The optimization models recast as MILP problems.

2) Power flow is modelled by DC approximation.

3) A Taylor series expansion is used to linearize the constraints related to the natural gas network.

4) A dynamic gas system with line pack is considered.

Test case


G3
G2
G1
D1
n1
n2
n3
m1
m2
m4
m7
GD1
GW1
m3
m5
m6
GS1
GD2
GW2
n4
n5
n6
WP
D2
D3
G4

Test case data

	P_{max} (MW)	$R^{(+/-)}$ (MW)	η (km^3/MW)	C ($/MWh)
G1	100	0	-	20
G2	80	0	-	35
G3	60	60	0.205	-
G4	60	60	0.264	-
WP	200	-	-	0
	G_{max} (km^3)	Initial storage level (km^3)	Max in/outflow rate (km^3/h)	C ($/$km^3$)
GW1	150	-	-	184
GW2	170	-	-	110
GS1	150	75	50	147

Results

Optimization model	Total cost ($) (35%)	Total cost ($) (53%)
Stoch-Coup	576 694	572 483
Conv-Coup	+ 6.25 %	+ 9.91 %
Conv-Dec (k=1.1)	+ 6.29 %	+ 9.97 %
Conv-Dec (k=0.9)	+ 6.92 %	+ 11.05 %

Towards the loose coupling of electric power and natural gas markets

Coordination parameters:

- Total natural gas availability (NGA) for electricity production.
- Natural gas consumption for each GFPP.
- Natural gas prices.

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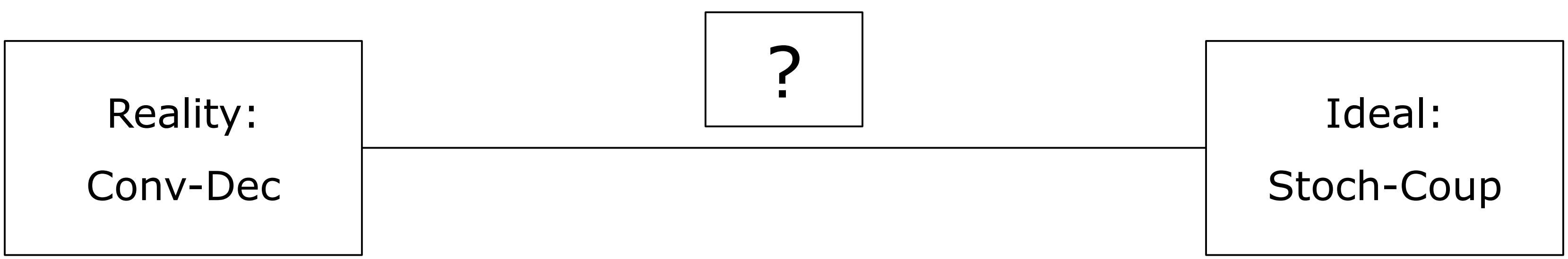


Coupling through proper flexibility price signals

- Increase the available flexibility to handle wind power variability.
- Respect merit-order principle in electricity market.
- Cost-neutral action for the day-ahead stage.

- The problem is formulated as a bi-level model (Imp-Coup):
  - Upper-level: The operator minimizes the expected system cost and decides how to optimally change the natural gas price available for power production.
  - Lower-level: Sequential market clearing.

Coupling through proper flexibility price signals

Optimization model	Stoch-Coup	Imp-Coup	Conv-Coup
Total Expected Cost ($)	194 665.27	195 245.57	196 156.30

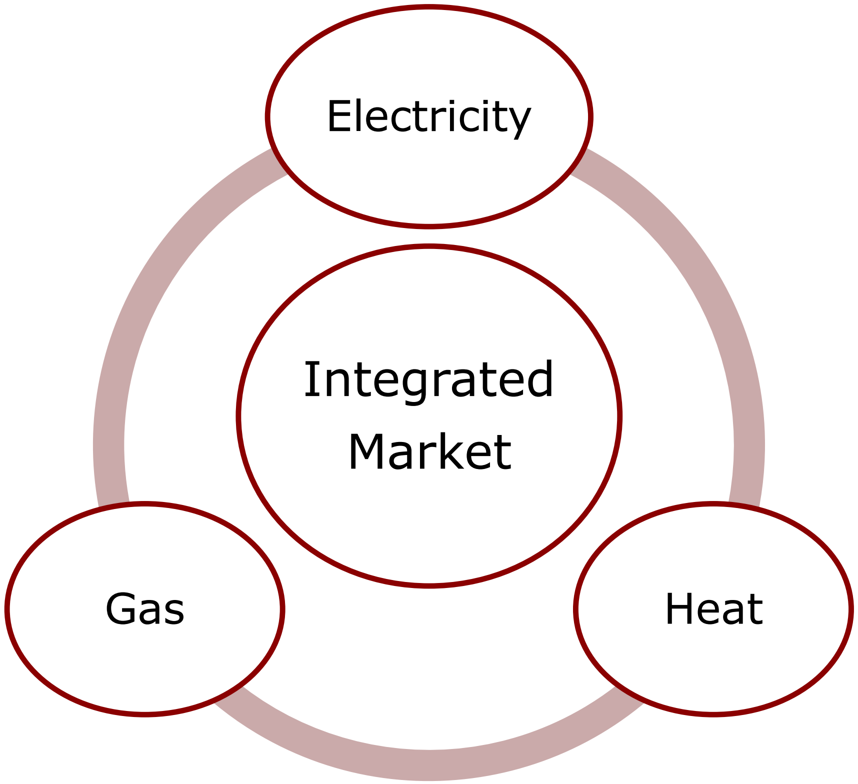
- The expected cost is reduced by $910.73.
- The system operator is expected to pay $75.18.

- The proposed model can be seen as an alternative to capacity payments for power availability in real-time operation.

Future plans

- Evaluate the benefit of NG storage in pipelines.
- Examine cost recovery for market participants and revenue adequacy of the market design for the case of loose coupling the markets.
- Examine the case of NGA as a coordination parameter.

Thank you for your attention !



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