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Integrated electricity and gas market modelling – accounting for uncertainty.

Iegor Riepin, Thomas Möbius and Felix Müsgens

Seminar Energiemodelle
IER, Uni of Stuttgart, 20.06.2018

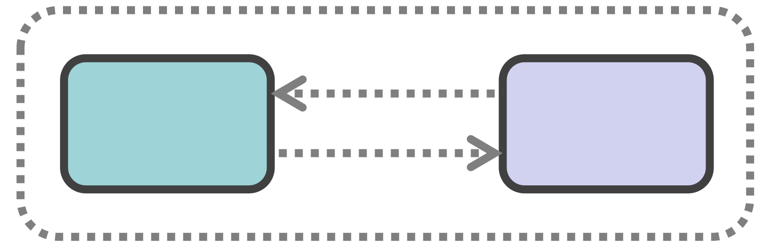
Contents

- **Gas- and electricity markets are linked:**
  - Gas price patterns have a significant impact on the competitiveness of gas-fired power technologies
  - European policy focus on emission reduction and renewable energies in turn affects power sector demand
  - Gas and coal cost levels drive investment substitution effects
- Nonetheless, many quantitative models (and studies) of European energy markets focus on single energy sectors, such as electricity <u>OR</u> gas.

Model integration approaches

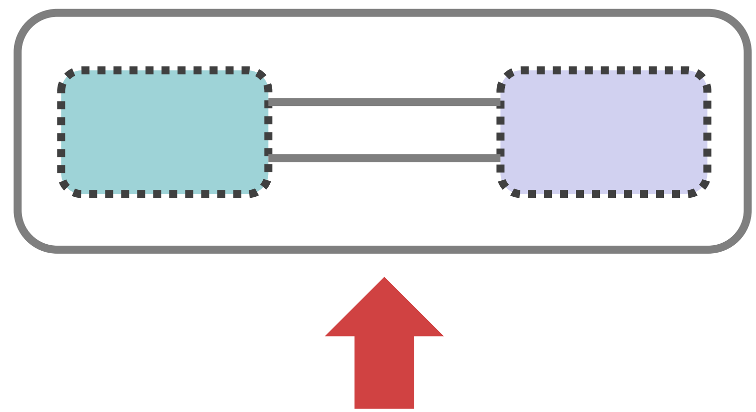
1) Separated models

3) "Hard-linked" models



2) "Soft-linked" models

4) Integrated models



Integrated models – what was the focus of the previous research?

Electrical Power and Energy Systems 34 (2012) 99–113

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

The importance of market interdependencies in modeling energy systems – The case of the European electricity generation market

Martin Lienert [a], Stefan Lochner [b,*]

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[b] Institute of Energy Economics at the University of Cologne (EWI), Vogelsanger Str. 321, 50827 Cologne, Germany

Selected conclusion:

> "The effects of integrating the models were found to be substantial implying that models not considering interdependencies between electricity and natural gas markets produce results with systematic deviations from a more realistic joint optimization."

Integrated models – what was the focus of the previous research?

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J. Abrell and H. Weigt, **“The Short and Long Term Impact of Europe’s Natural Gas Market on Electricity Markets until 2050,”** *The Energy Journal*, vol. 37, 2016.

Selected conclusions:

[On long-term interaction] “The results of the two long term sensitivities show that spatial developments on the natural gas market can indeed have significant impact on the electricity market. Naturally, the main driving force are price impacts.”

[On short-term interaction] “The results of the short term sensitivity analysis shows how direct feedback effects of short term gas supply interruption can lead to distortions on the European electricity market.”

Integrated models – what was the focus of the previous research?

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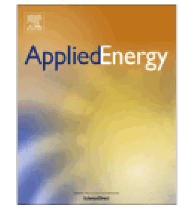
Applied Energy 193 (2017) 479–490

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy



ELSEVIER

An integrated gas and electricity model of the EU energy system to examine supply interruptions

J.P. Deane *, M. Ó Ciaráin, B.P. Ó Gallachóir

MaREI, Environmental Research Institute, University College Cork, Ireland

CrossMark

Selected results:

"[...] interruption of Russian gas supply lead to a rise in average gas prices of 28% and 12% in electricity prices."

"With all gas storages removed for the whole year, average gas demand for the power sector fell by 4% and average gas prices rose by 4% relative to the reference scenario. Across Europe, electricity prices rose by 6% on average and the yearly capacity factor of CCGT plants fell by 16% on average owing to the higher cost of gas."

Contents

World Energy Issues monitor (2017), Wolrd Energy Council

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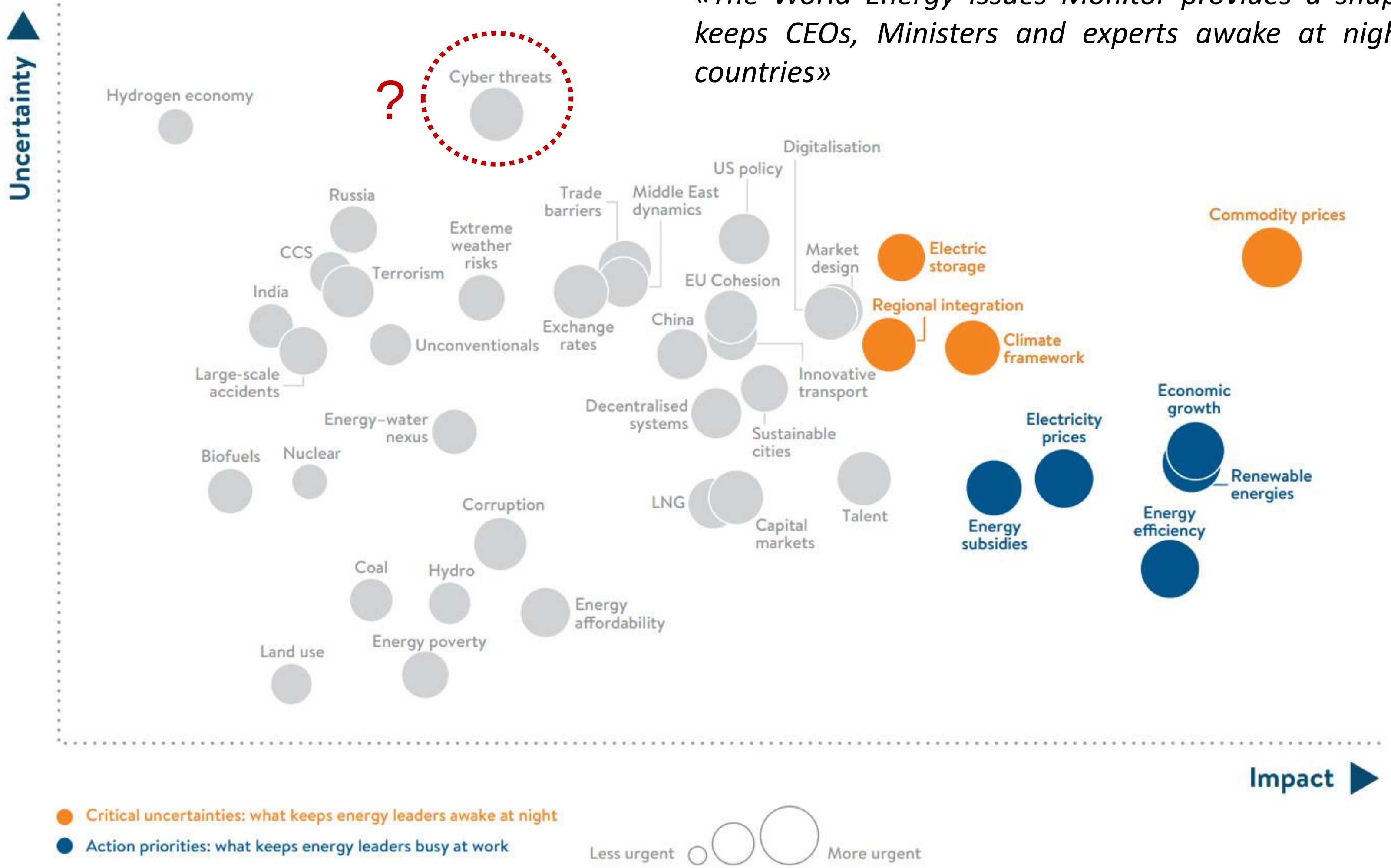
«The World Energy Issues Monitor provides a snapshot of what keeps CEOs, Ministers and experts awake at night in over 90 countries»



Focusing on a single circle: gas demand

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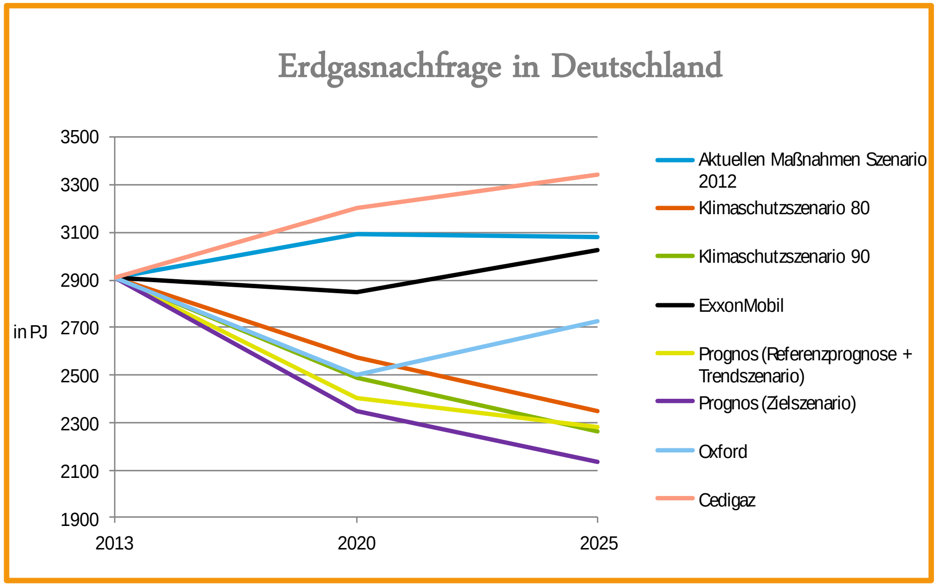
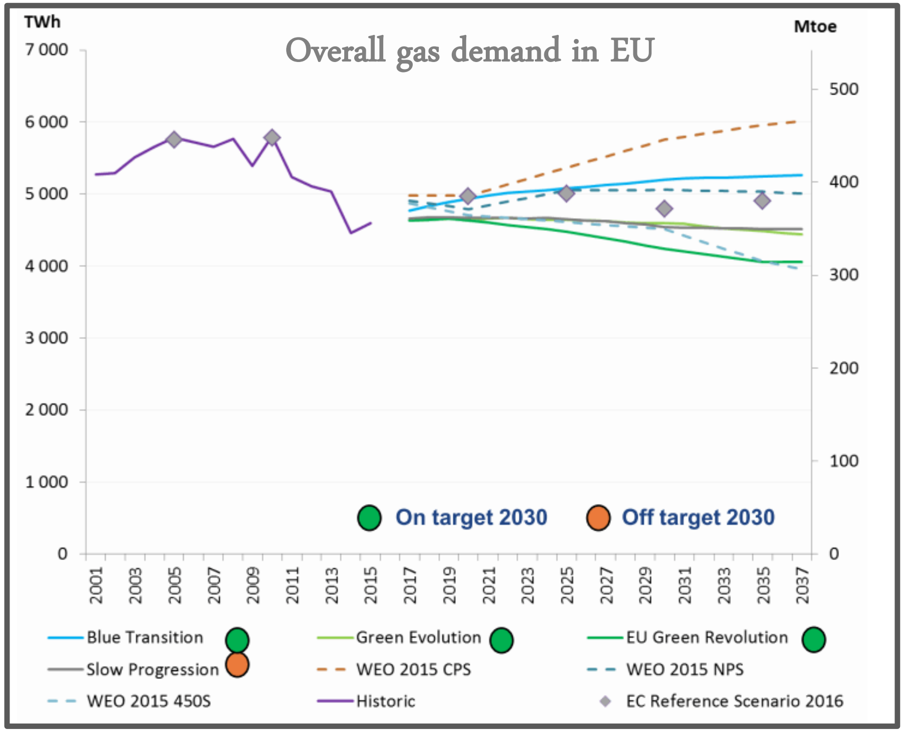
German and European gas demand uncertainty in 2 charts:



Source: Hans Von Soest, illustration from internal project with a gas trade utility, Jan 2016



Source: ENTSO-G (2017)

Numerous studies used energy system models with uncertain parameters – the studies, again, mostly focus on single markets.

(selected studies)

Electricity markets

A. H. van der Weijde and B. F. Hobbs, "**The economics of planning electricity transmission to accommodate renewables: Using two-stage optimisation to evaluate flexibility and the cost of disregarding uncertainty**," *Energy Economics*, vol. 34, no. 6, pp. 2089–2101, 2012.

P. Seljom and A. Tomasgard, "**Short-term uncertainty in long-term energy system models - A case study of wind power in Denmark**," *Energy Economics*, vol. 49, no. 0, pp. 157–167, 2015.

Gas markets

M. Fodstad, R. Egging, K. Midthun, and A. Tomasgard, "**Stochastic Modeling of Natural Gas Infrastructure Development in Europe under Demand Uncertainty**," *The Energy Journal*, vol. 37, no. Sustainable Infrastructure Development and Cross-Border Coordination, 2016.

T. Baltensperger and R. Egging, "**Stochastic modeling of imperfect markets**," *Nova Science Publishers*, 2017

Research focus

Our research focus general:

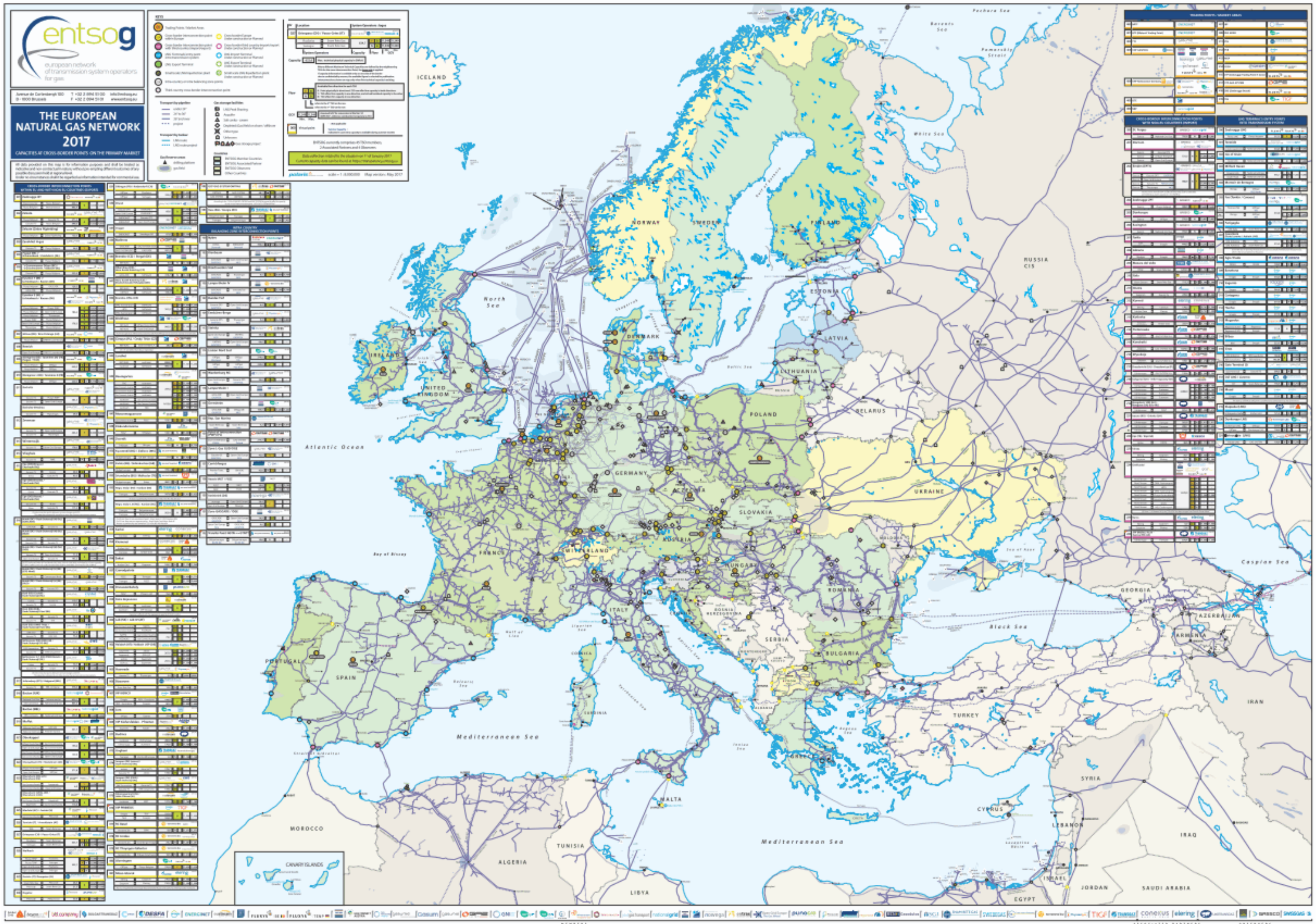
- Evaluate economic impacts of uncertainty drivers on the integrated energy system (including the feedback effects across the gas and electricity markets).

More specific focus (today):

- Evaluate effects of uncertain gas demand on electricity generation investments.

Contents

Gas market
ENTSO-G gas infrastructure map (2017)



Nodes representing gas market
(gas infrastructure for year 2017)

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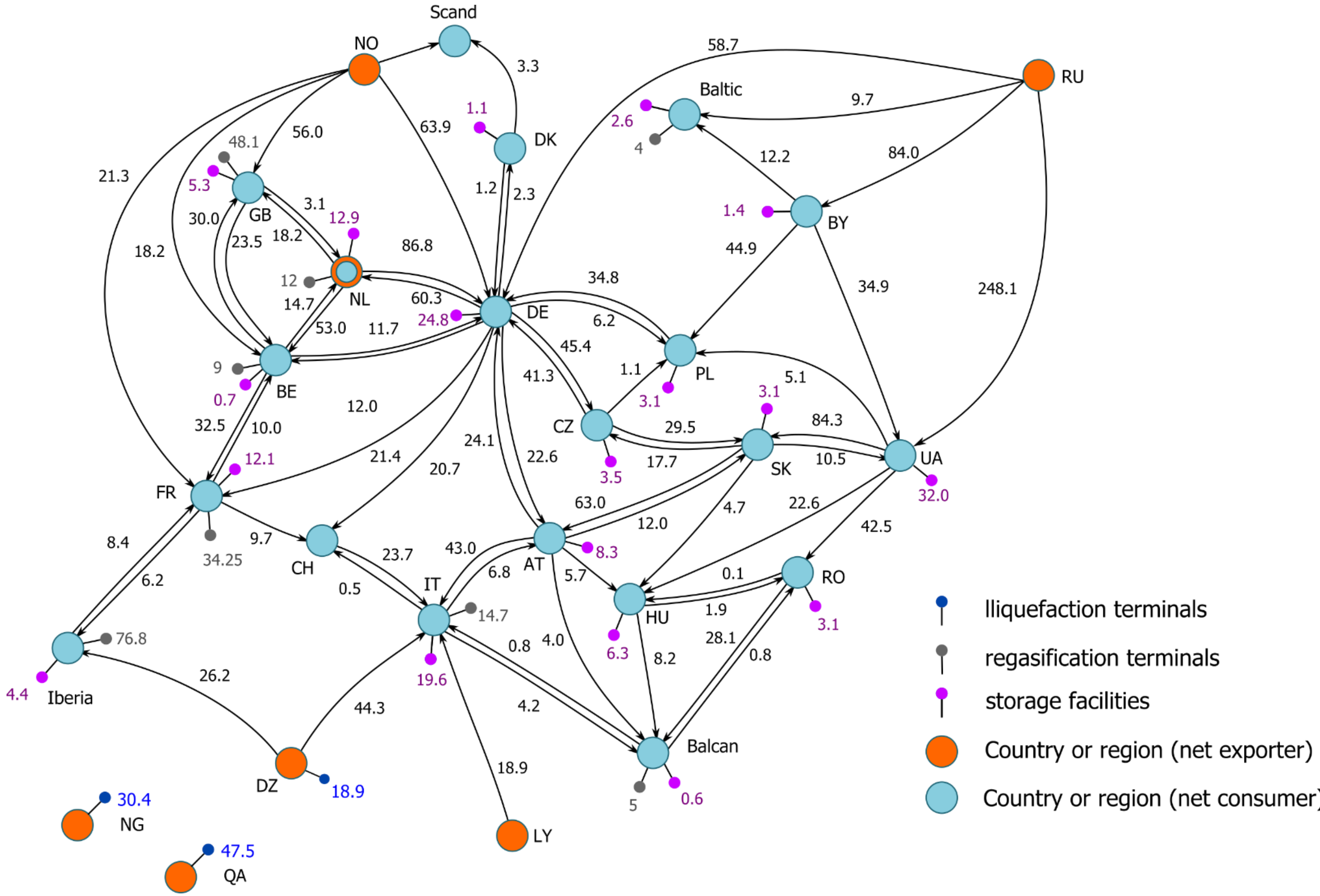

Nodes representing electricity market

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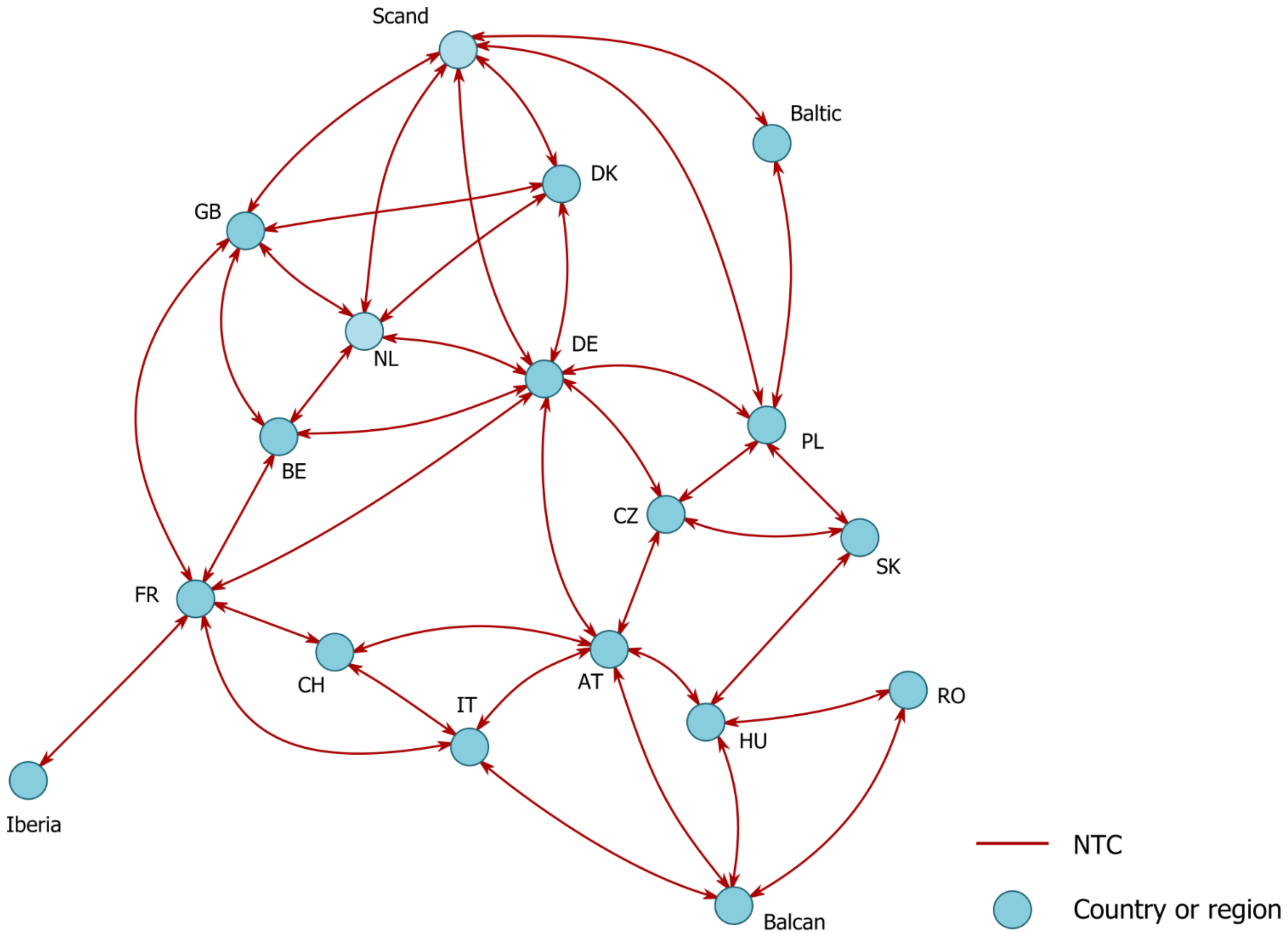
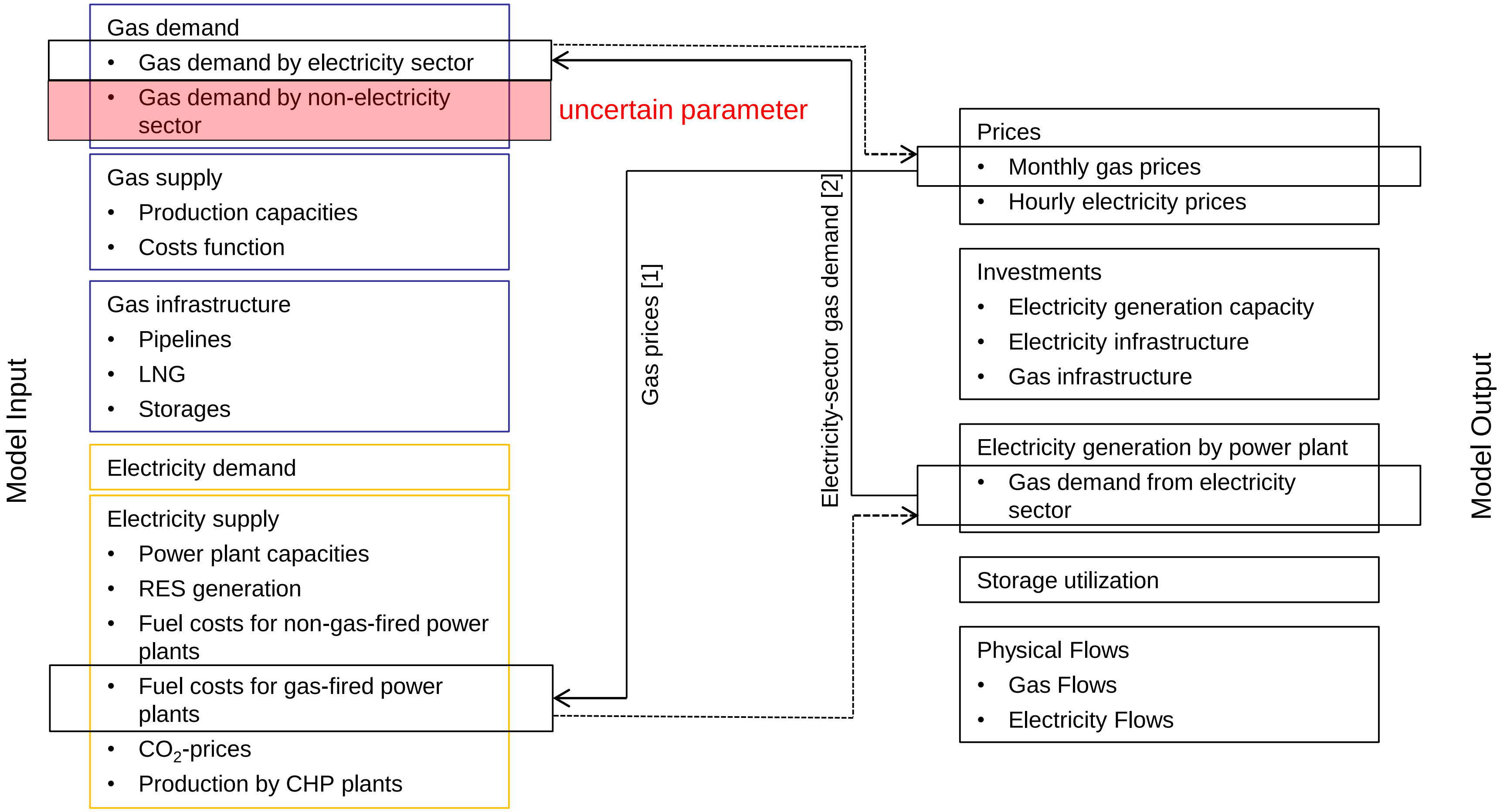


Model integration (fuel link)



[1] Marginal cost estimators
[2] Aggregated production of gas-fired technologies

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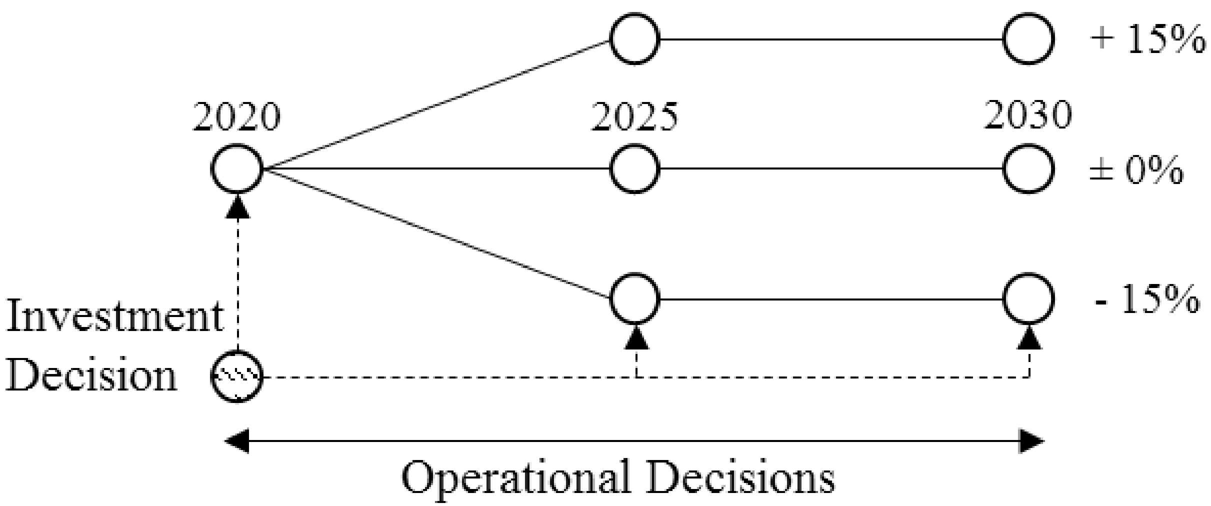
We represent uncertain gas demand from non-electricity sectors by a discrete realization probabilities (two-stage scenario tree).



The 'stochastic solution' defines the optimal endogenous capacity extension plan (that has to hold for all scenarios), as well as scenario-dependent optimal dispatch decisions.

(Simplified) objective function

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$$\text{TOTAL\_COST} =$$

$$\left\{ \sum_{n,t,y,s} \rho_s * df_y * \left(\sum_{i \in I \setminus G} (fc_{i,y} + c_{i,y}^{CO2}) * G_{i,n,t,y,s} + \sum_{g \in G} c_{g,y}^{CO2} * G_{g,n,t,y,s} \right) \right\}$$

Power dispatch costs

$$\left\{ + \sum_{i,n,y} df_y * ic_{i,y} * INV_{i,n,y} \right\}$$

Investment costs (power generation capacity)

$$\left\{ + \sum_{m,y,s} \rho_s * df_y * \left(\sum_{p} pc_p * PR_{p,m,y,s} + \sum_{p,n,nn} tc_{n,nn} * TR_{p,m,y,n,nn,s} + \sum_{n} (sc^{in} * ST_{m,y,n,s}^{in} + sc^{out} * ST_{m,y,n,s}^{out}) \right) \right\}$$

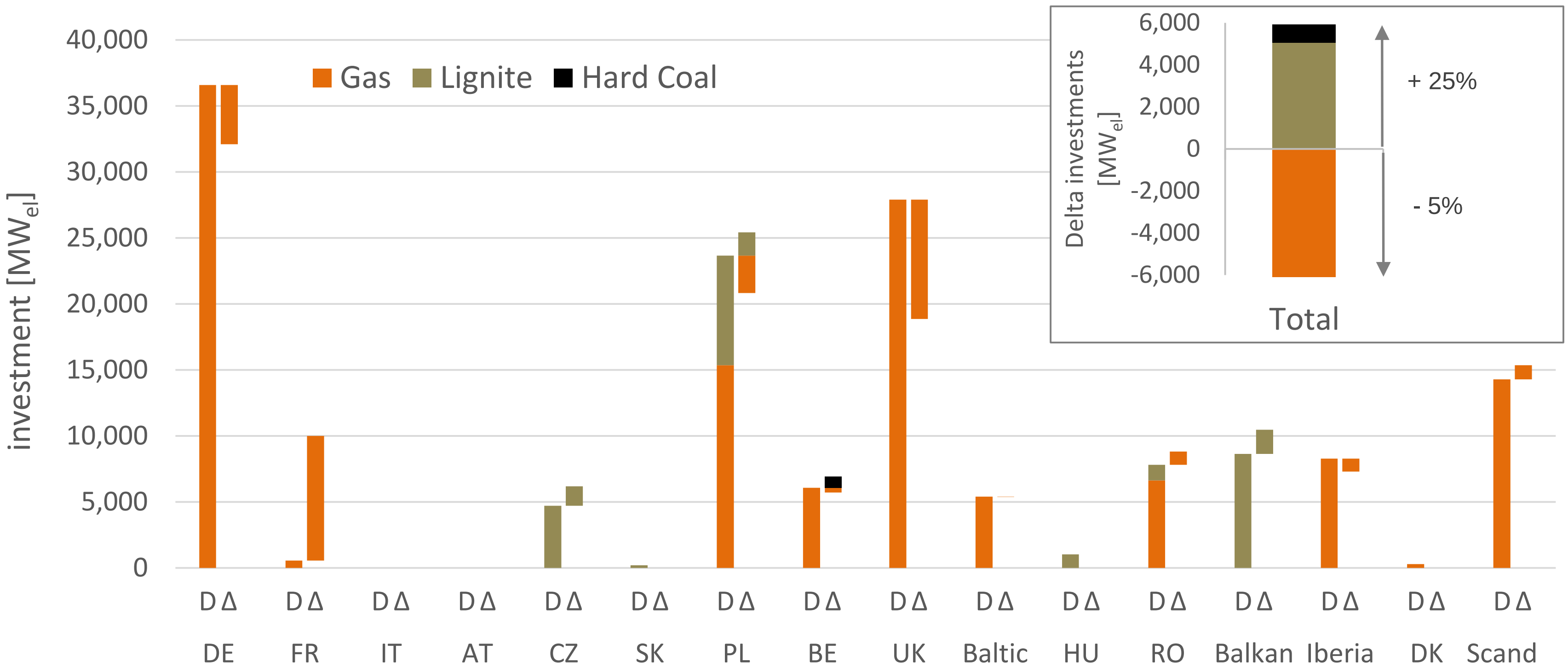
Gas dispatch costs

$$\sum_{g \in G} \sum_{t \in m} \frac{G_{g,n,t,y,s}}{eff_{g,t,y}} = Psector\_gas\_demand_{n,m,y,s}$$

- The magnitude of temporal and spatial changes in gas price is determined endogenously by a set of constraints in the gas market model.
- Hence, electricity generators investing and utilizing gas-fired power plants face expected values for the gas price depending on time and location.

Contents

Cumulative investments in power generation capacities until 2030



I. Majority of investments into gas-fired technologies

II. Overall, amount of investments into gas-fired technologies decrease in the stochastic solution

Gas price differences as a driver for changes in optimal investment decisions

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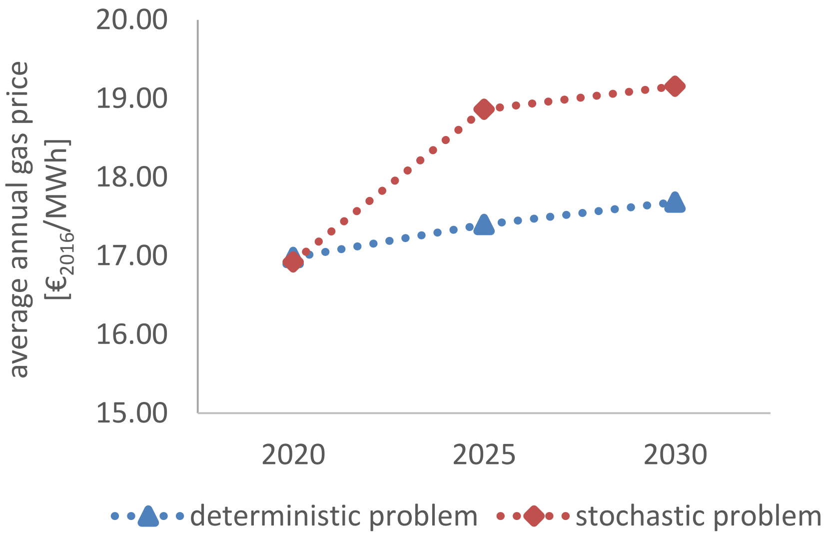
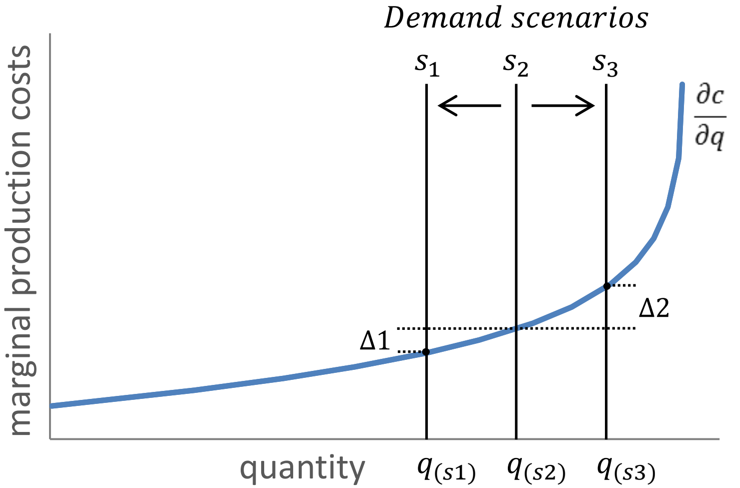
In the stochastic problem the average expected European annual gas price increases by 1.47 €/MWh in 2030

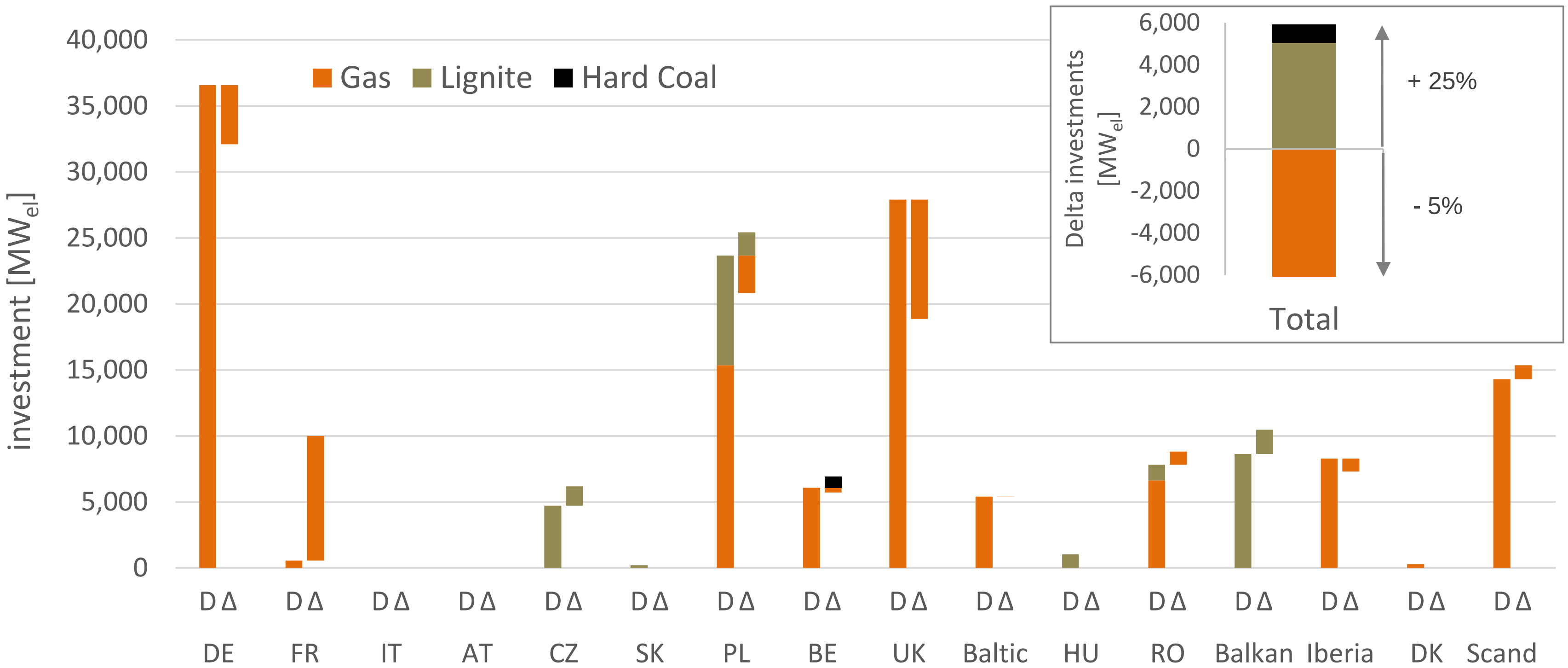


This increase can be explained by the incremental slope of the logarithmic gas production cost functions.



$$\Delta 2 > \Delta 1, \quad \forall\, x \in \frac{\partial c}{\partial q}$$

Cumulative investments in power generation capacities until 2030



I. Majority of investments into gas-fired technologies

II. Overall, amount of investments into gas-fired technologies decrease in the stochastic solution

III. Overall, amount of investments into lignite and hard coal increase in the stochastic solution

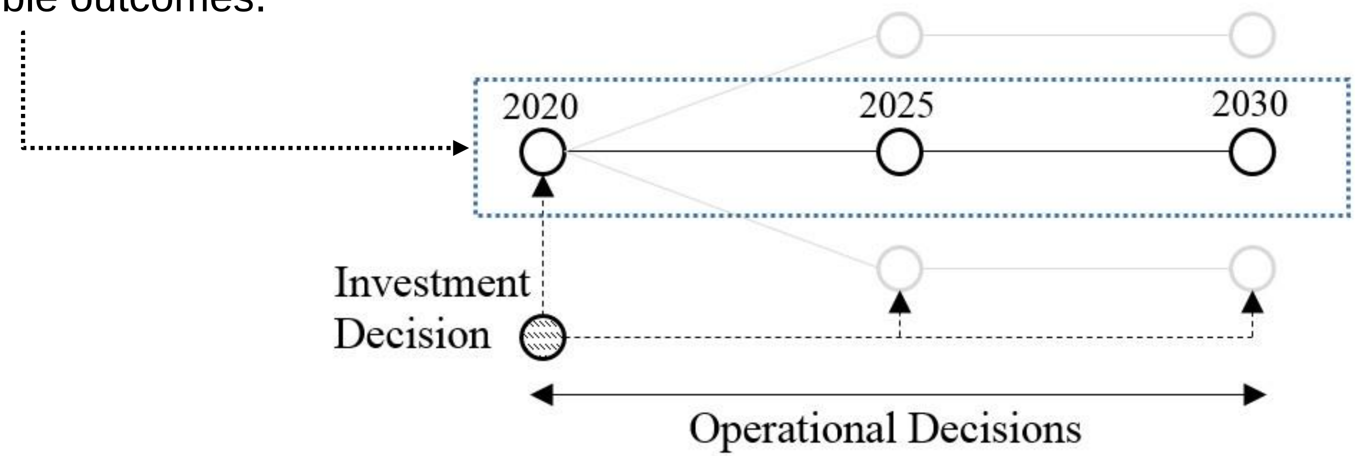
IV. Reallocation of power generation investments

Contents

Value of stochastic solution (VSS)

or expected cost of ignoring uncertainty

Imagine a situation in which a central planner in the first stage naively plan for one specific scenario, even though that scenario in only one from several possible outcomes.



I. Define one scenario as the 'naïve' scenario that is assumed to occur in the future;
II. 'Naïve' scenario is solved with a probability of 1;
III. The vector of the first-stage investment decisions is imposed into the stochastic model;
IV. The VSS is calculated as:

$$VSS = f^{stoch}_{\text{inv}(determ)} - f^{stoch}$$

Value of stochastic solution (VSS)

or expected cost of ignoring uncertainty

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	Total costs	Expected costs of ignoring uncertainty
Stochastic	€ 247,078 M	
Stochastic(inv_determ)	€ 247,143 M	
VSS		€ 65 M
VSS (% of total costs)		**0.026%**

A. H. van der Weijde and B. F. Hobbs, "The economics of planning electricity transmission to accommodate renewables: Using two-stage optimisation to evaluate flexibility and the cost of disregarding uncertainty", 2012

Uncertainty: economic, technologic, and regulatory drivers

System: electricity market of GB

VSS (%) = 0.08%

M. Fodstad et. al., "Stochastic Modeling of Natural Gas Infrastructure Development in Europe under Demand Uncertainty", 2016

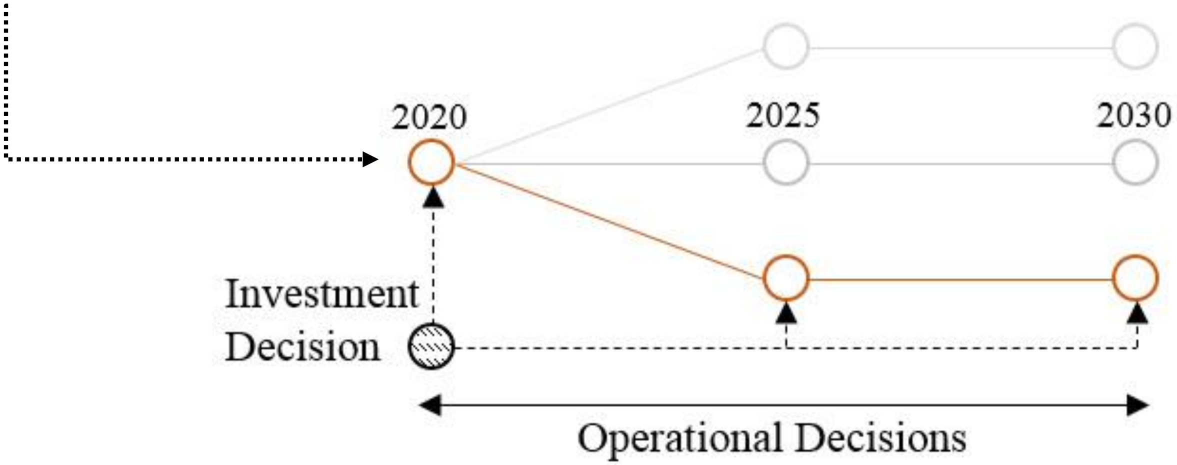
Uncertainty: gas demand

System: natural gas market for Europe (+ rest of the world on highly aggregated level)

VSS (%) < 0.01%

Expected value of perfect information (EVPI)

Imagine a situation in which a central planner in the first stage knew exactly which scenario would happen.



I. Solve each scenario separately as a deterministic model;

II. EVPI is the difference between the expected costs of the stochastic solution and the probability-weighted average of the scenarios' deterministic costs:

$$EVPI = f^{stoch} - \sum_{s} \rho_s \cdot f_s^{determ}$$

Expected value of perfect information (EVPI)

	Total costs	Saving resulting from a perfect information
Stochastic	€ 247,078 M	
Deterministic		
Scenario 1 (Low dem)	€ 223,432 M	€ 23,646 M
Scenario 2 (Ref dem)	€ 245,533 M	€ 1,545 M
Scenario 3 (High dem)	€ 271,125 M	-€ 24,047 M
EVPI		€ 381 M
EVPI (%)		**0.154%**

A. H. van der Weijde and B. F. Hobbs, "The economics of planning electricity transmission to accommodate renewables: Using two-stage optimisation to evaluate flexibility and the cost of disregarding uncertainty", 2012

Uncertainty: economic, technologic, and regulatory drivers

System: electricity market of GB

EVPI (%) = 3.02%

M. Fodstad et. al., "Stochastic Modeling of Natural Gas Infrastructure Development in Europe under Demand Uncertainty", 2016

Uncertainty: gas demand

System: natural gas market for Europe (+ rest of the world on highly aggregated level)

EVPI (%) = 0.012%

Conclusions

I. We develop an integrated stochastic model considering both gas and electricity sectors.

II. We focus on effects of gas demand uncertainty on the integrated system.

III. Gas demand uncertainty leads to (i) an overall decrease and (ii) a reallocation of investments in gas-fired technologies.

IV. We quantify and compare the VSS and EVPI metrics. The findings support the hypothesis that the economic impact of uncertainty should be evaluated using an integrated modelling approach.

V. Further research should be conducted to fully understand the impact of different uncertainty drivers on all the planning decisions across the integrated energy system.

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References

Prognos AG, final report "Current Status and Perspectives of the European Gas Balance", January 2017. Available at: https://www.prognos.com/uploads/tx_atwpubdb/20170406_Prognos_study_European_Gas_Balance_final_1_01.pdf

A. H. van der Weijde and B. F. Hobbs, "The economics of planning electricity transmission to accommodate renewables: Using two-stage optimisation to evaluate flexibility and the cost of disregarding uncertainty," Energy Economics, vol. 34, no. 6, pp. 2089–2101, 2012.

M. Fodstad, R. Egging, K. Midthun, and A. Tomasgard, "Stochastic Modeling of Natural Gas Infrastructure Development in Europe under Demand Uncertainty," The Energy Journal, vol. 37, no. Sustainable Infrastructure Development and Cross-Border Coordination, 2016.