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Integrated electricity and gas market modelling – effects of gas demand uncertainty

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EEM2018

Lodz, 28.06.2018

Motivation for integrated modelling

- **Gas- and electricity markets are linked:**
  - Gas price patterns determine 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.

Motivation for incorporating uncertainty

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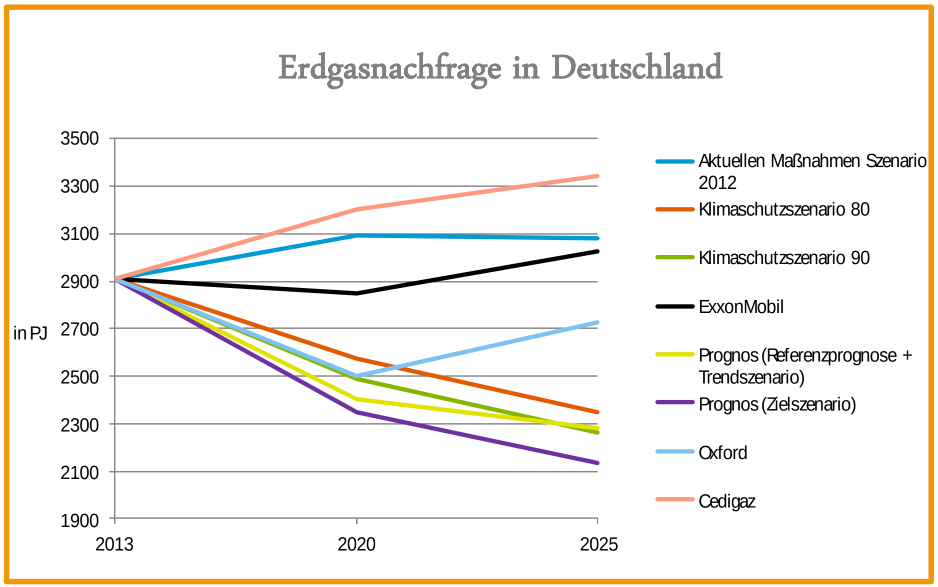
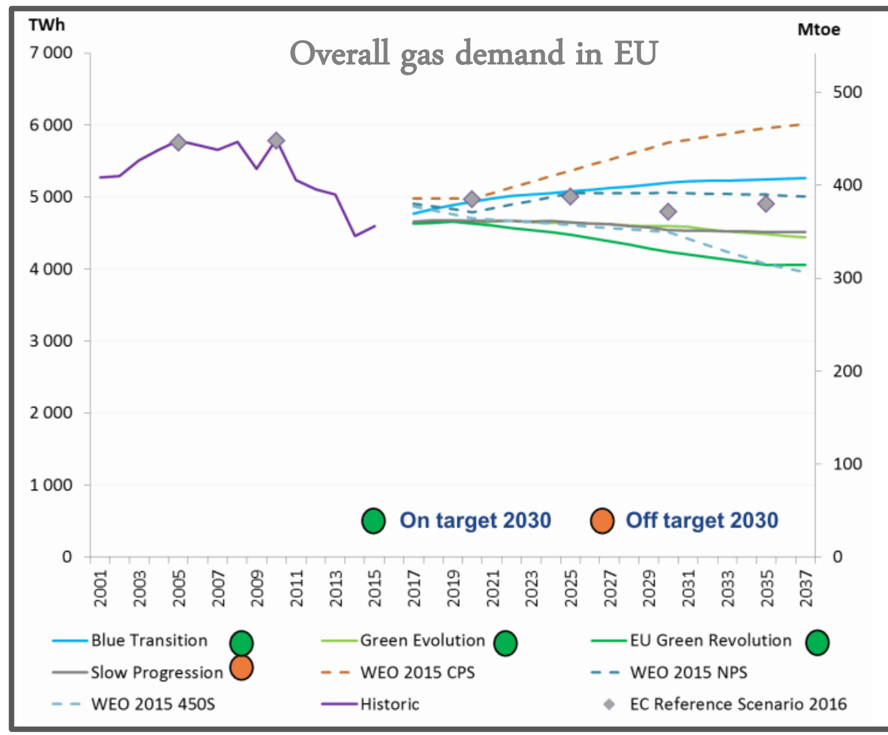
German and European gas demand uncertainty in 2 charts:



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



Source: ENTSO-G (2017)

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:

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

Model integration (fuel link)

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Model Input

Gas demand
- Gas demand by electricity sector
- Gas demand by non-electricity sector

Gas supply
- Production capacities
- Costs function

Gas infrastructure
- Pipelines
- LNG
- Storages

Electricity demand

Electricity supply
- Power plant capacities
- RES generation
- Fuel costs for non-gas-fired power plants
- Fuel costs for gas-fired power plants
- CO_2-prices
- Production by CHP plants

Electricity infrastructure
- Net Transfer Capacities

Model Output

Prices
- Monthly gas prices
- Hourly electricity prices

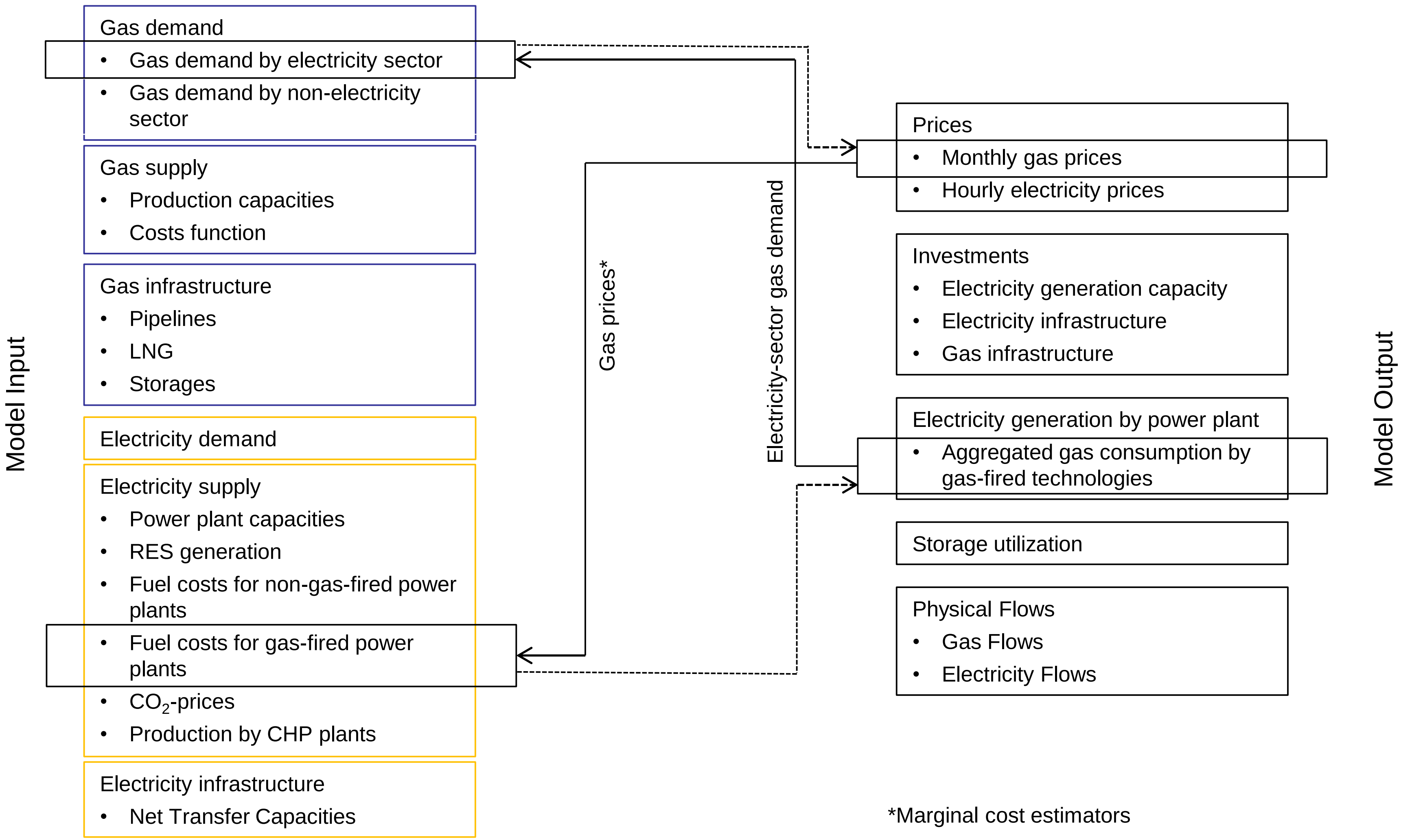
Investments
- Electricity generation capacity
- Electricity infrastructure
- Gas infrastructure

Electricity generation by power plant
- Aggregated gas consumption by gas-fired technologies

Storage utilization

Physical Flows
- Gas Flows
- Electricity Flows

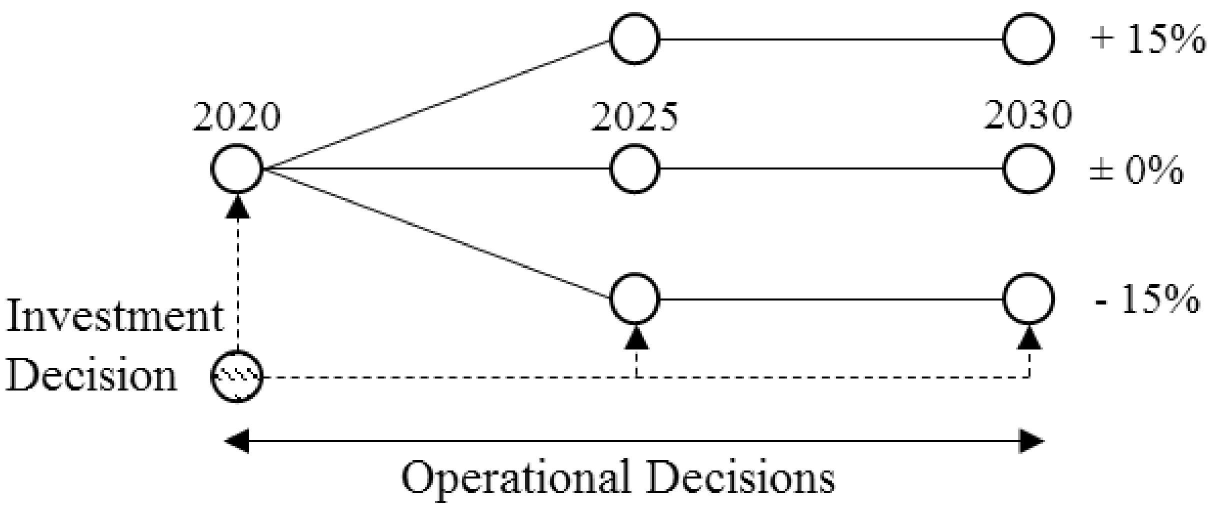
Model integration (fuel link)



*Marginal cost estimators

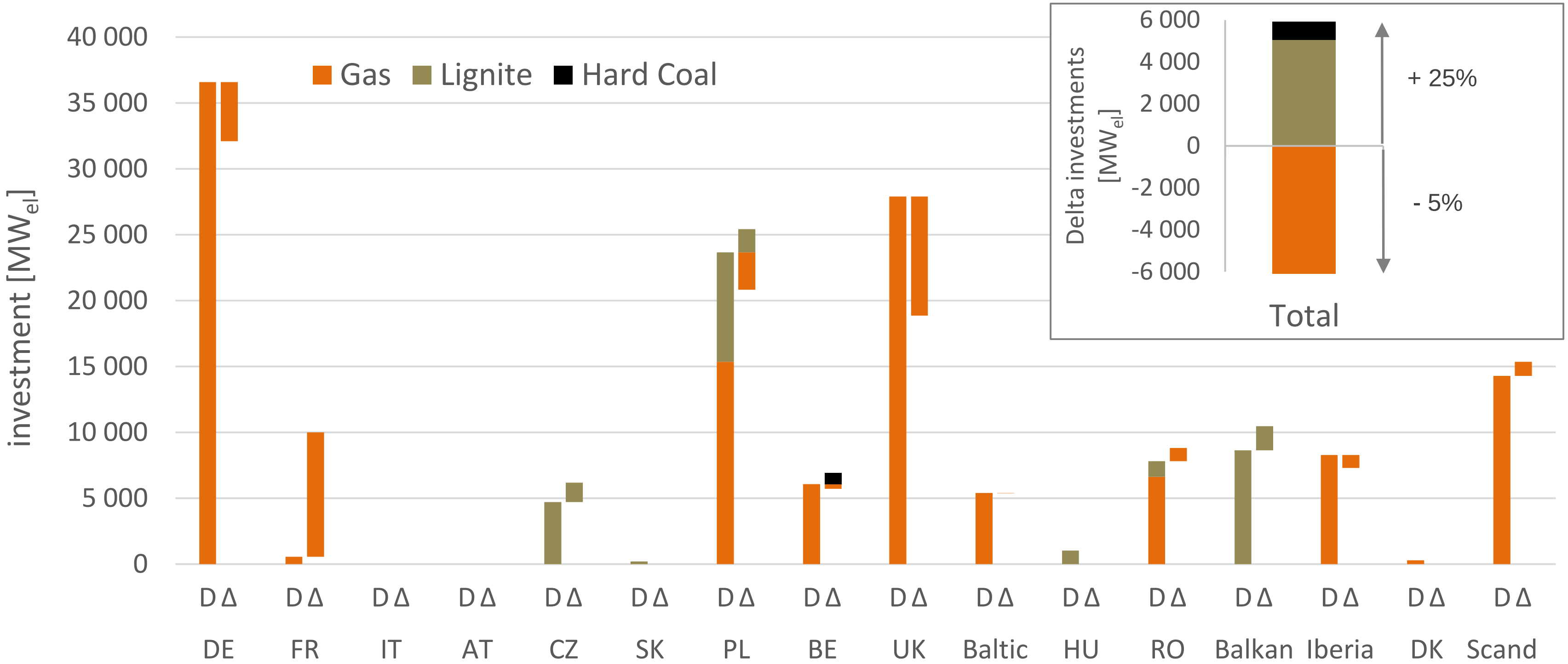
Implementing uncertainty

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.

Cumulative investments in power generation capacities until 2030

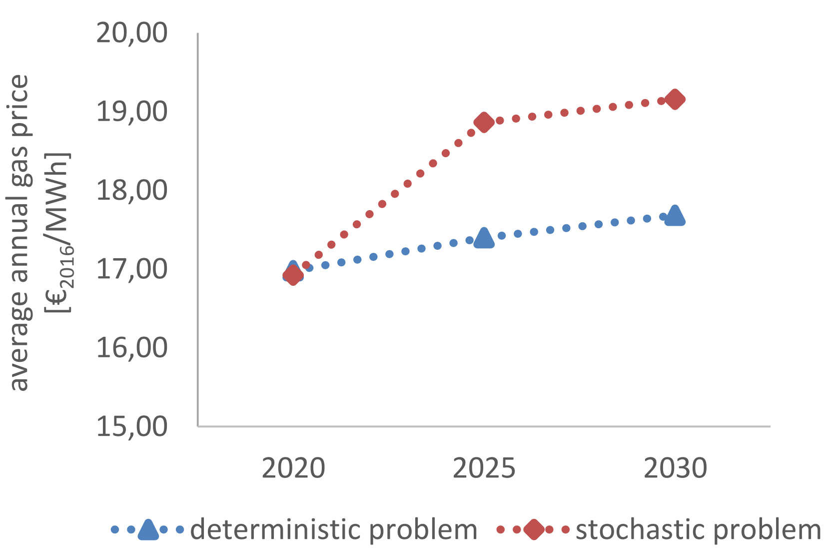


I. Majority of investments into gas-fired technologies

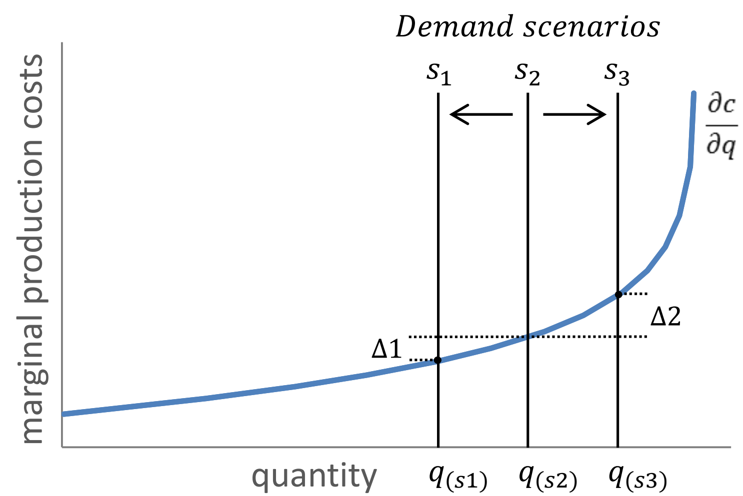
II. Overall, amount of investments into gas-fired technologies decrease in the stochastic solution

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

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.



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

Cumulative investments in power generation capacities until 2030

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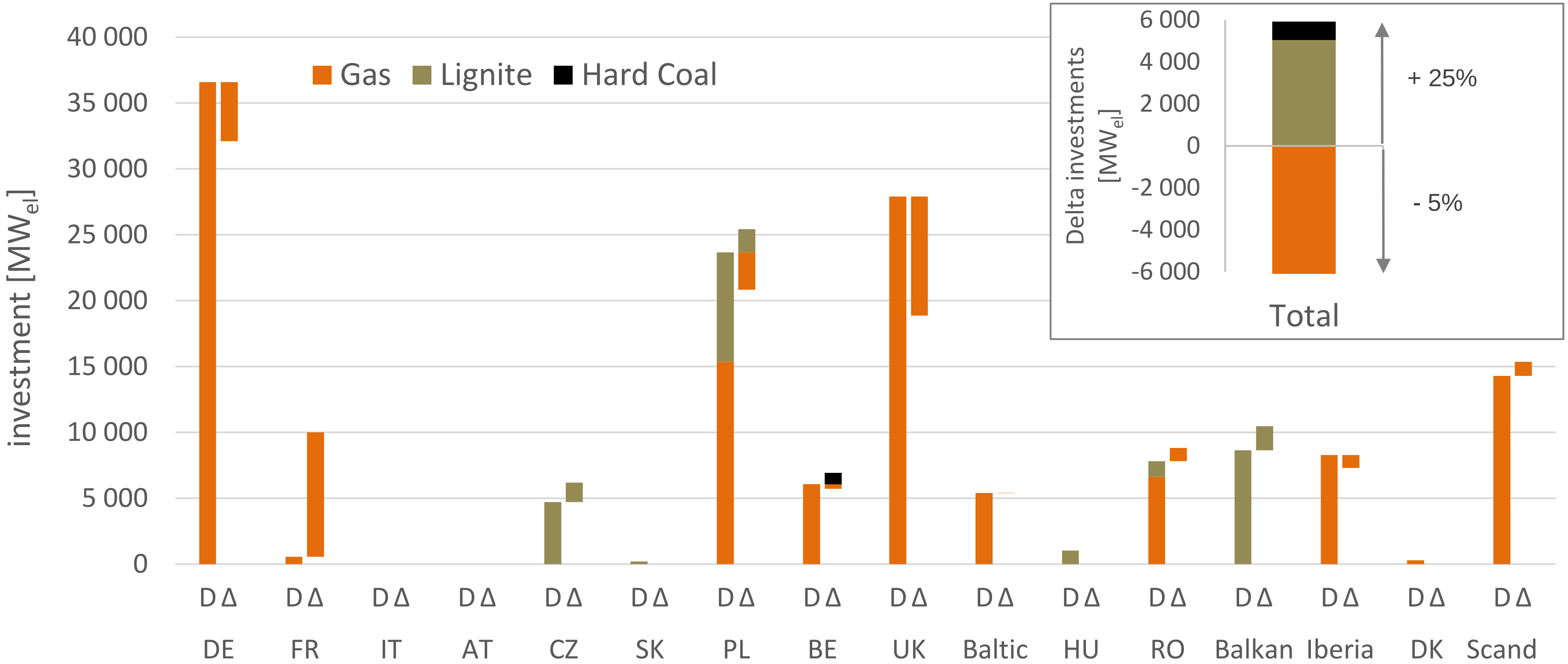

I. Majority of investments into gas-fired technologies

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

Value of stochastic solution (VSS)

or expected cost of ignoring uncertainty

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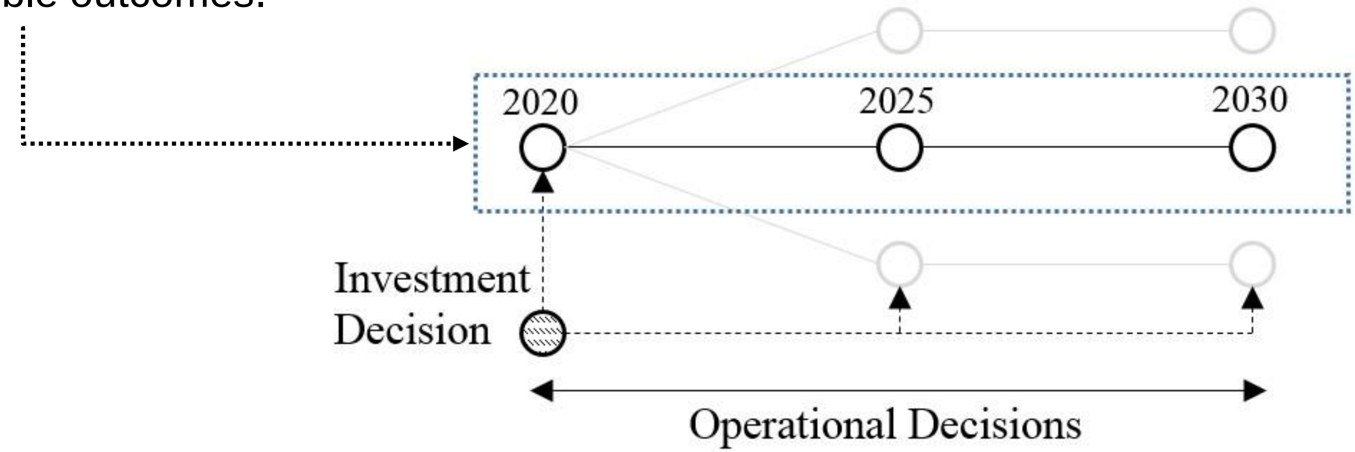
Imagine a situation in which a central planner in the first stage naively plan for one specific scenario, even though that scenario in only one from several possible outcomes.



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%**

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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%

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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