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Uncertainty in Integrated Electricity and Gas Markets – Analyzing the Economic Impact

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Motivation & Research idea

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- Many quantitative models (and studies) focus on single energy sectors, such as electricity OR gas
- Many large-scale state-of-the-art optimization models remain deterministic

We evaluate the economic impacts of different uncertainty drivers on the integrated electricity and gas system

Our analysis includes feedback effects across the markets

Model integration (fuel link)

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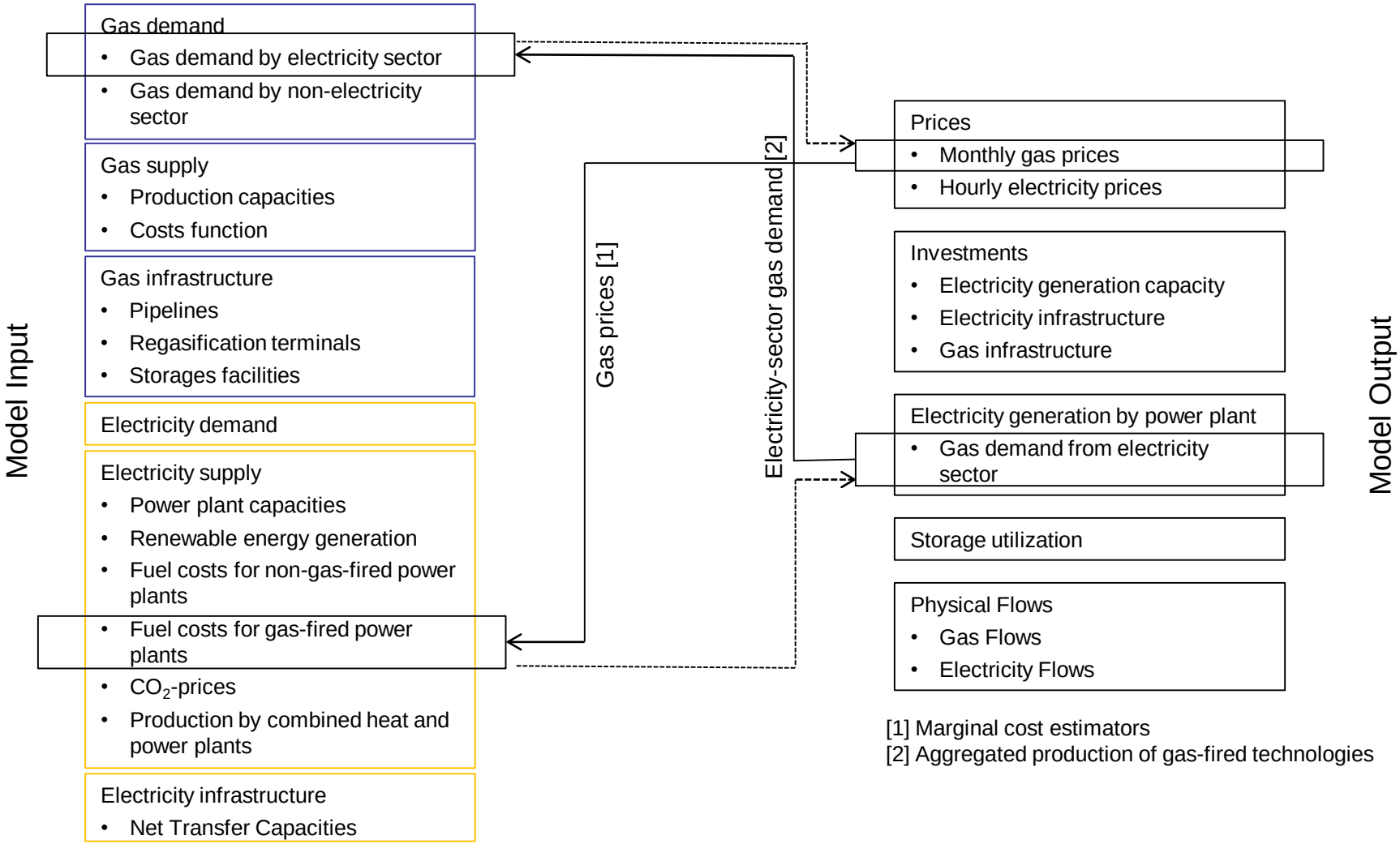

[1] Marginal cost estimators
[2] Aggregated production of gas-fired technologies

Model integration (fuel link)

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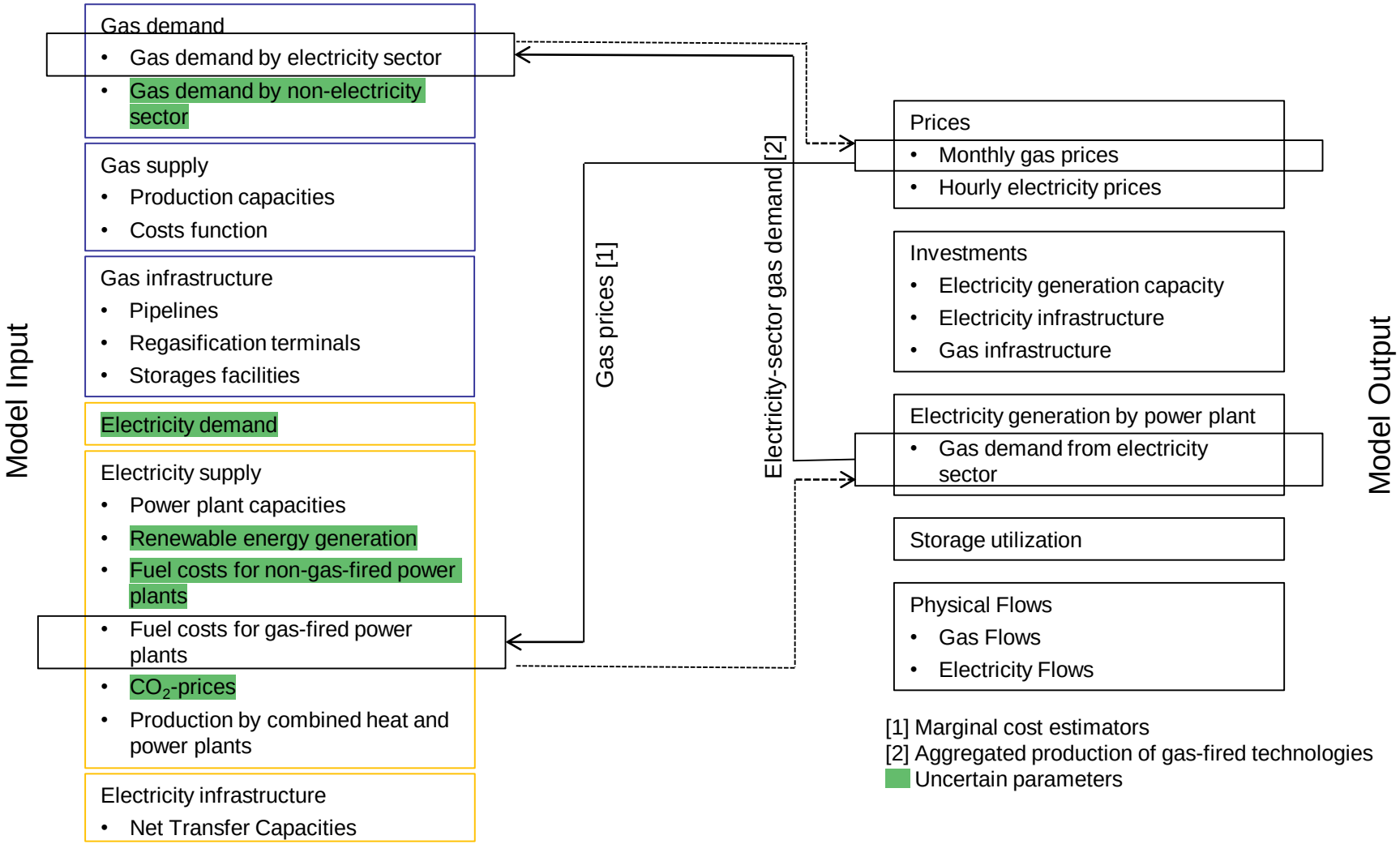
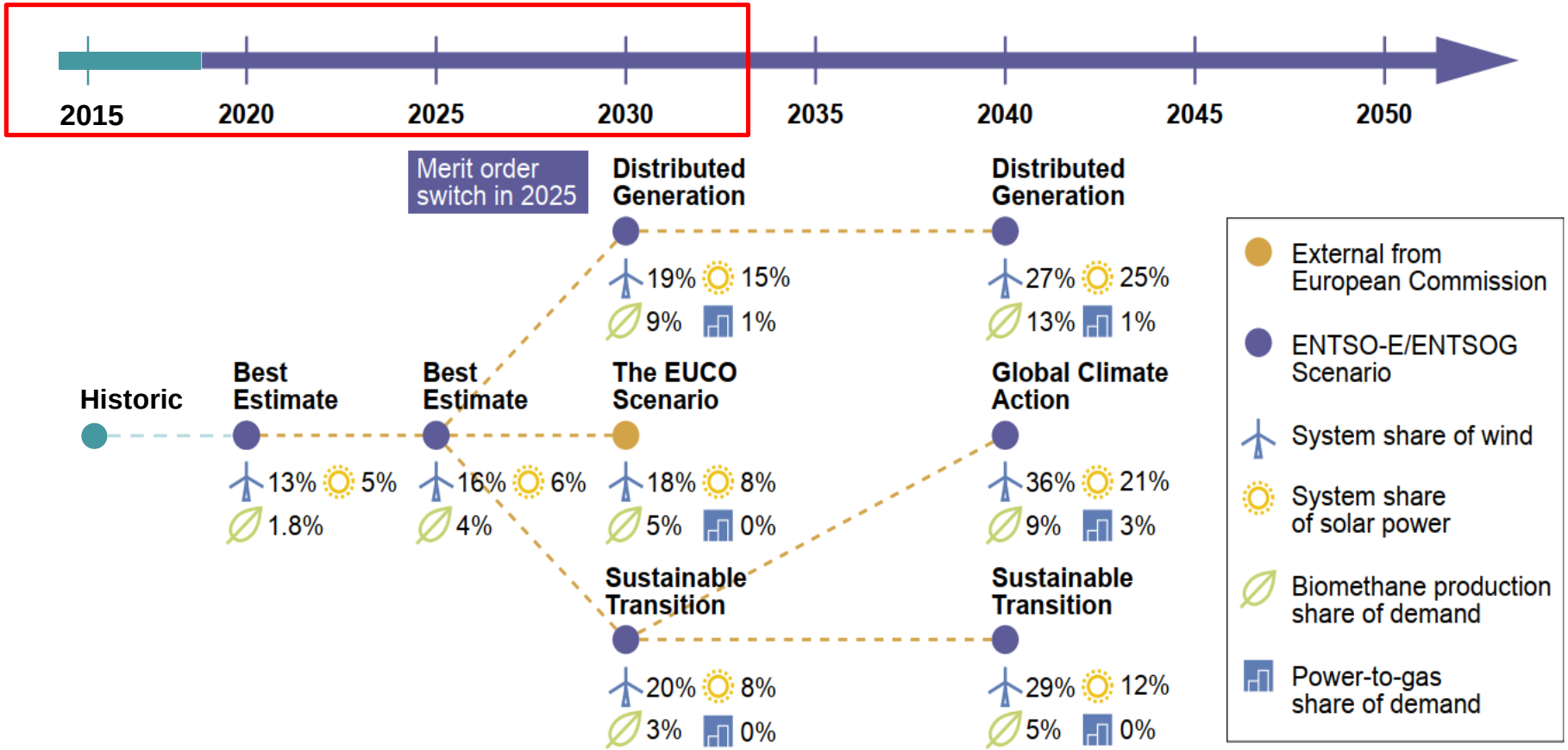


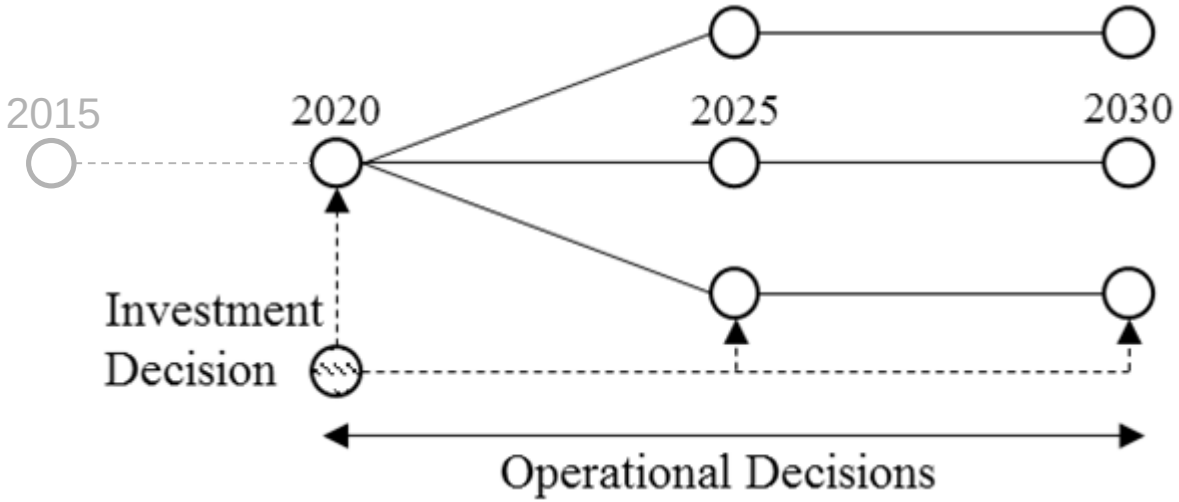
[1] Marginal cost estimators
[2] Aggregated production of gas-fired technologies
Uncertain parameters

Implementing uncertainty



Source: The TYNDP 2018 scenarios for 2030 and 2040

Implementing uncertainty



i. Each branch is represents one of the three TYNDP 2018 scenarios
ii. Stochastic two-stage model is formulated as a linear optimization model
iii. The 'stochastic solution' (in the sense of minimization of expected total costs) defines:
   - the optimal endogenous capacity extension plan (that has to hold for all scenarios)
   - scenario-dependent optimal dispatch decisions

The Expected Cost of Ignoring Uncertainty (ECIU)
or the value of the stochastic solution

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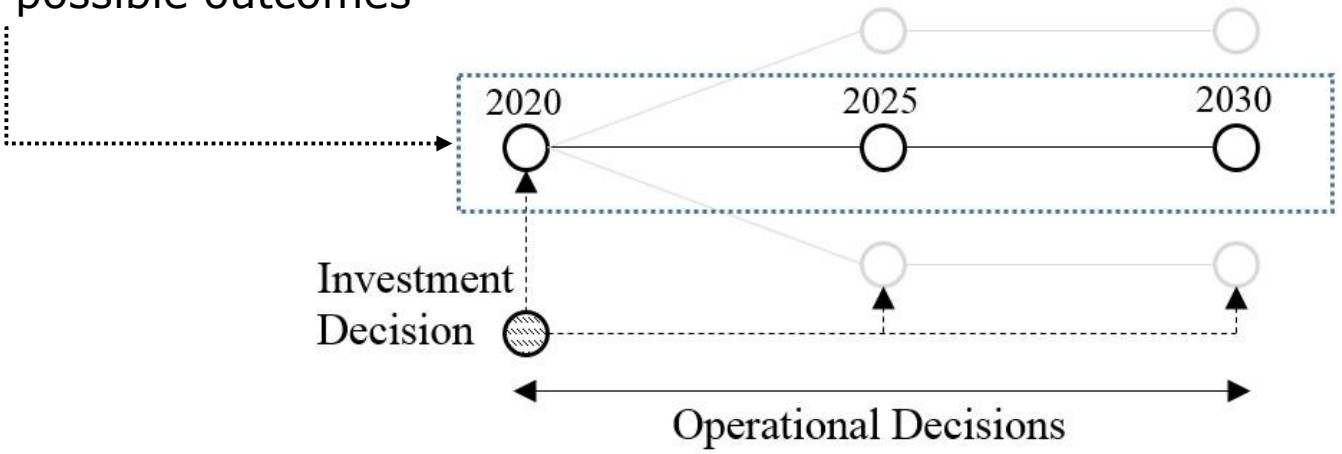
Imagine a situation in which a central planner in the first stage naively plans for one specific scenario, even though that scenario in only one from several possible outcomes



$$ECIU = F^{stoch}_{\text{inv}(fix(EVP))} - F^{stoch}$$

The ECIU describes the value of considering the full range of uncertainties in a stochastic model, rather than using a less realistic deterministic model

The Expected Cost of Ignoring Uncertainty (ECIU)
or the value of the stochastic solution

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Parametric uncertainty	Expected costs of ignoring uncertainty[1] [Million Euro$_{2015}$]	Expected costs of ignoring uncertainty [% of total costs]	Expected costs of ignoring uncertainty[1] [Million Euro$_{2015}$]	Expected costs of ignoring uncertainty [% of total costs]
	1st stage decisions are based on EUCO30		1st stage decisions are based on EVP	
Gas demand[2]	€ 51 M	0,02%	€ 2 M	0,00%
Electricity demand	€ 1.101 M	0,40%	€ 533 M	0,19%
Installed RES capacity	€ 154 M	0,06%	€ 43 M	0,01%
Fuel price[3]	€ 163 M	0,06%	€ 1 M	0,00%
CO_2 price	€ 463 M	0,16%	€ 9 M	0,00%

1) Costs are computed for four representative years (2015, 2020, 2025, 2030)
2) Scenario reflects uncertainty in non-power sector of gas demand
3) Fuel price scenario reflects uncertainty in lignite, hard coal and oil prices

Preliminary results
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The Expected Cost of Ignoring Uncertainty (ECIU)
or the value of the stochastic solution

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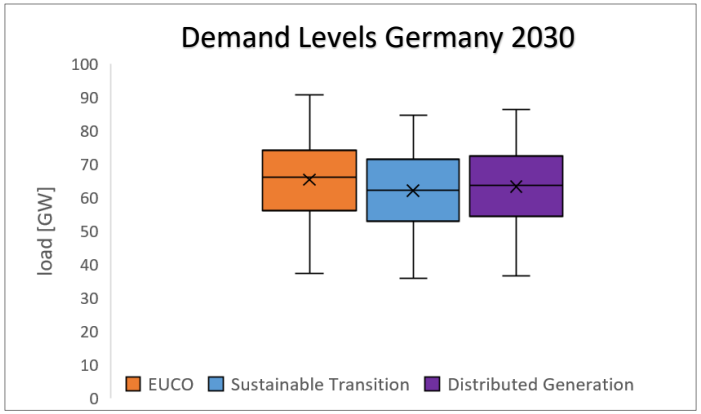
Electricity demand uncertainty shows highest impact

- Uncertainty in future electricity demand either leads to overcapacities or supply shortages
  - In case of overcapacities, we observe to high investment payments
  - In case of supply shortages, we observe increased amount of times with scarcities



- Higher investments in the stochastic solution, in particular in open cycle gas turbines
  - Higher capacity investments prevent from load shedding and scarcity hours
- The stochastic model identifies an efficient trade-off between costs in scarcity times and investment costs

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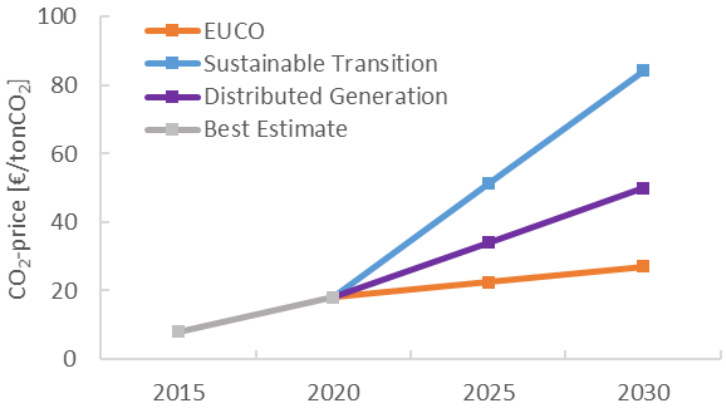
Insights to a relatively low impact of CO_2 price uncertainty



- TYNDP 2018 energy future settings show a broad forecast variation for CO_2-prices
  - Nevertheless, the expected costs of ignoring uncertainty are rather low
- Investments shift from OCGT to CCGT
  - Increase in CCGT investments by 8.1 % (4.7 GW)
  - Decrease in OCGT investments by 9.5 % (4.9 GW)
- The effects balance each other
  - The model aims to reduce electricity generation costs by increasing the utilization of CCGT
  - Each additional unit of gas consumed by the electricity sector leads to an increase in the marginal costs of natural gas production

Conclusion

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- The added value of incorporating uncertainty (ECIU) strongly depends on which scenario is chosen as the reference:
  i. Applying expected values, the ECIU is low for all parameters tested except for electricity demand uncertainty
  ii. Applying EUCO30, the ECIU is high for electricity demand uncertainty and moderate for CO2 price uncertainty
- Under the TYNDP 2018 energy future settings, the impact of uncertainty in gas demand by the non-power sector is negligible
- The impact of uncertainty in the future electricity demand strongly depends on the costs of managing supply shortages
- The impact of CO_2-price uncertainty is limited to the trade-off between savings in electricity production and increasing gas production costs

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Thank you very much
Questions?

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ECIU vs EVPI

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Both ECIU and EVPI compare the expected value of the (investment) decision with another decision made without uncertainty.

- For ECIU an investment decision is made when the uncertainty is ignored (although it is there).
- While for EVPI an investment decision is made after the uncertainty is removed by obtaining perfect information about the future.

To sum up:

- The ECIU is the additional expected cost of assuming that future is certain.
- The EVPI is the expected cost of being uncertain about the future.

Expected value of perfect information (EVPI)

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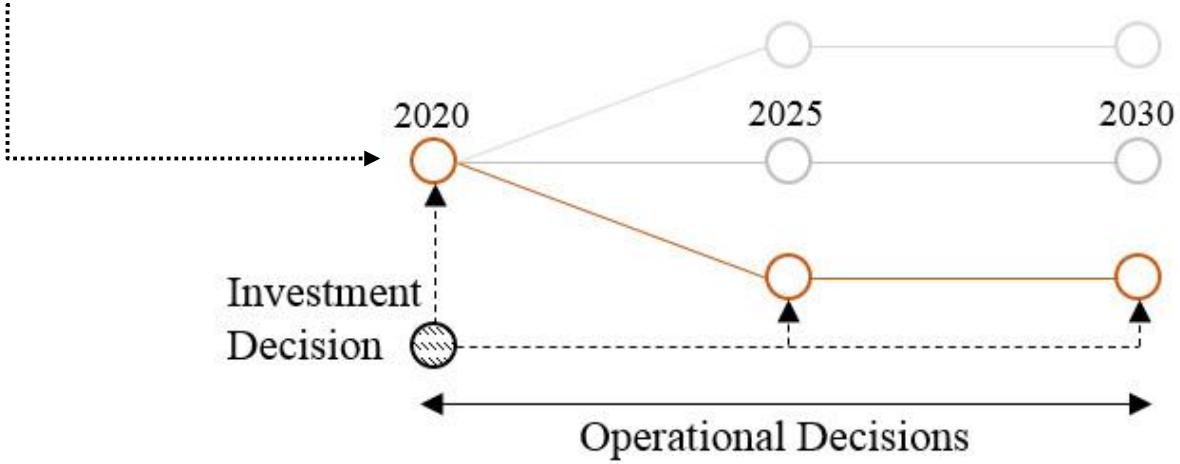
Imagine a situation in which a central planner in the first stage knew exactly which scenario would happen.



$$EVPI = F^{stoch} - \sum_{s} \rho_s \cdot F_s^{det}$$

The EVPI measures the maximum amount a decision maker would be ready to pay in return for complete (and accurate) information about the future.

Expected value of perfect information (EVPI)

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Parametric uncertainty	Total (expected) costs [Million Euro$_{2015}$]	Saving resulting from a perfect information [% of total costs]
Gas demand - Stochastic	€ 285.432 M	
TYNDP 2018 ST	€ 291.963 M	-€ 6.531 M
TYNDP 2018 EUCO30	€ 279.153 M	€ 6.280 M
TYNDP 2018 DG	€ 285.149 M	€ 283 M
EVPI		**€ 11 M**
EVPI (%)		0,004%
Electricity demand - Stochastic	€ 285.759 M	
TYNDP 2018 ST	€ 281.427 M	€ 4.332 M
TYNDP 2018 EUCO30	€ 284.288 M	€ 1.471 M
TYNDP 2018 DG	€ 290.733 M	-€ 4.974 M
EVPI		**€ 276 M**
EVPI (%)		0,097%
Installed RES capacity - Stochastic	€ 285.960 M	
TYNDP 2018 ST	€ 287.854 M	-€ 1.895 M
TYNDP 2018 EUCO30	€ 291.791 M	-€ 5.832 M
TYNDP 2018 DG	€ 277.765 M	€ 8.195 M
EVPI		**€ 156 M**
EVPI (%)		0,055%
Fuel price - Stochastic	€ 285.274 M	
TYNDP 2018 ST	€ 284.721 M	€ 553 M
TYNDP 2018 EUCO30	€ 286.339 M	-€ 1.065 M
TYNDP 2018 DG	€ 284.721 M	€ 553 M
EVPI		**€ 14 M**
EVPI (%)		0,005%
CO_2 price - Stochastic	€ 284.924 M	
TYNDP 2018 ST	€ 297.390 M	-€ 12.465 M
TYNDP 2018 EUCO30	€ 272.576 M	€ 12.348 M
TYNDP 2018 DG	€ 283.714 M	€ 1.210 M
EVPI		**€ 364 M**
EVPI (%)		0,128%

Preliminary results
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The Expected Cost of Ignoring Uncertainty (ECIU)
or the value of the stochastic solution

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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 investment decisions is imposed into the stochastic model;
IV. The VSS is calculated as:

$$VSS = f_{\mathrm{inv}(determ)}^{stoch} - f^{stoch}$$

	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

ECIU (%) = 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)

ECIU (%) < 0.01%

Expected value of perfect information (EVPI)

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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:

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

	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%

Marginal Production Costs

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