UNIVERSITETET
I OSLO

DEPARTMENT OF TECHNOLOGY SYSTEMS
TEK5410 ENERGY MARKETS AND REGULATION:
MODELLING AND ANALYSIS

Geopolitical Threats: Impact on the German Energy Transition

Hans Kristian Haraldseth

University of Oslo

December 2023

Agenda

- Introduction
  - Research question
- Methodology
  - Mathematical formulation
  - Model parameters
- Results
  - Cost-optimal installed capacities
  - Cost-optimal variable generation
  - Total system costs
  - Sensitivity analysis
- Discussion
  - Most important take-away!
  - Concluding remarks
- References

Introduction

- In response to the climate crisis, energy transitions are initiated
- Simultaneously, geopolitical tensions are rising!

- *“How can Geopolitical Threats affect the German Energy Transition?”*

Methodology

Methodology

- Scenario-based modelling approach with varying degree of geopolitical tensions:

Scenario Element	"Harmony Horizon"	"Turbulent Times"	Base Scenario
Energy Consumption	Low	High	Unevenly distributed
Emission Intensity	Low	High in regions with fossil fuels	Medium
Fossil Constraints	Preferences shift away from fossil fuels	No limitations; utilization of unconventional resources for local use	No specific trend
International Trade and Cooperation	Strong	Weak	Moderate
Environmental Policy	Enhanced management of local and global affairs with stricter control of pollutants	Minimal emphasis on environmental concerns	Focus on local pollutants, effectiveness varies
Institutions	Effective at national and international levels	Weak global institutions; dominance of national governments in societal decisions	Uneven distribution
Alternative Energy Sources	Shift away from fossil fuels, focus on efficiency and renewables	Gradual technological change aimed at domestic energy sources	Partial investment in renewables, continued dependence on fossil fuels

Methodology

- Model parameters are adjusted according to the scenario:

Parameter	**Harmony Horizon**	**Turbulent Times**	**Base Scenario**
Emission Target γ	-80%	-10%	-40%
Renewable Target μ	70%	15%	40%
Discount Rate DR	10%	15%	6%
Capacity Factor Gas	1.0	0.4	0.8
Demand Scaling η	-40%	+10%	+0%
Maximum Capacity κ	Wind: INF PV: INF Hydro: 12 GW Gas: 32 GW Coal: 38 GW Biomass: INF Other: INF	Wind: 200 GW PV: 200 GW Hydro: 4.9 GW Gas: INF Coal: INF Biomass: INF Other: INF	Wind: 400 GW PV: 400 GW Hydro: 9 GW Gas: INF Coal: 38 GW Biomass: INF Other: INF

Methodology

- A mathematical optimization problem is introduced:

Objective Function:

$$Z = \min \sum_{t} C_{ann}(t) + \sum_{t} \sum_{h} C_{var}(t,h) \tag{2}$$

Decision Variables:

$V_G(t,h)$: Variable generation from a given technology for a given hour

$I_C(t)$: Total installed capacity for a given technology

Parameters:

μ : Target value for renewables

γ : Target value for reducing emissions

η : Demand scaling factor

κ : Maximum Installed Capacity

Methodology

- With respective constraints:

Constraints:

$V_G(t,h)$: Variable generation

$\eta D(h)$: Scenario-specific demand

$I_C(t)$: Installed capacity

$Cf(t,h)$: Capacity factor

$V_E(t,h)$: Total emissions

$Ei(t)$: Emission intensity

$V_G^{REN}(t,h)$: Variable generation renewables

$$V_G(t,h) \geq \eta D(h) \tag{3}$$

$$V_G(t,h) \leq I_C(t) Cf(t,h) \tag{4}$$

$$I_C(t) \leq \kappa \tag{5}$$

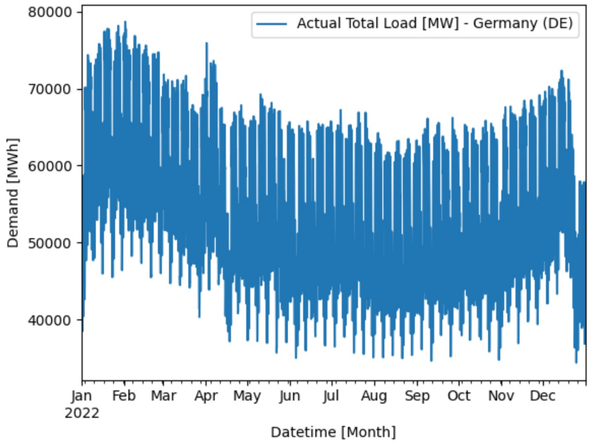
$$V_E(t,h) \leq V_G(t,h) Ei(t)(1-\gamma) \tag{6}$$

$$V_G^{REN}(t,h) \geq \mu V_G(t,h) \tag{7}$$

Methodology

- Data implemented in the model:

  - Demand Dataset
  - Capacity Factor
  - Variable Costs
  - Emission Intensity Data
  - Annuitised Costs




```
h1.wind 0.4487
h2.wind 0.4918
h3.wind 0.5389
h4.wind 0.5713
h5.wind 0.6156
h6.wind 0.6572
h7.wind 0.6884
h8.wind 0.7076
```

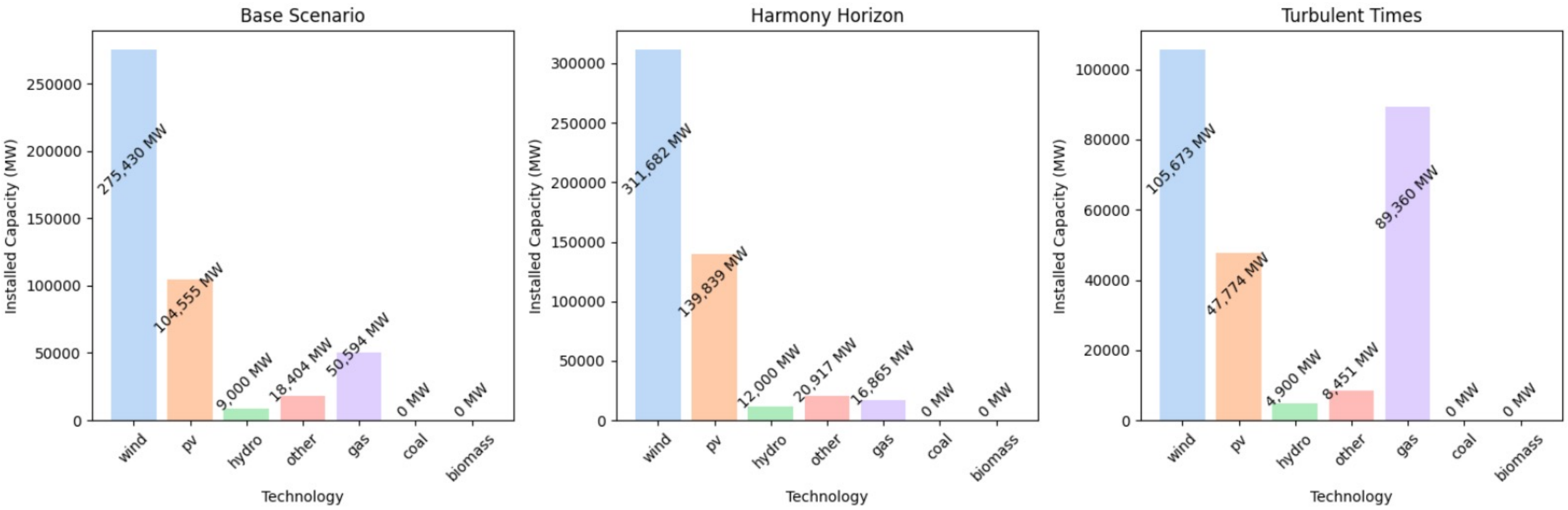
Tech.	Variable Costs [EUR/MWh]	Emission Intensity [tCO2/MWh]	Lifetime [Years]
Wind	0.5	0.013	20
PV	0.035	0.035	30
Hydro	0.3	0.011	25
Gas	3.5	0.593	30
Coal	13	1.152	40
Biomass	5.0	0.230	30
Other	10000	0	-

Tech.	Harmony Horizon (10% DR)	Turbulent Times (15% DR)	Base Scenario (6% DR)
Wind	315 700 [EUR/MW]	416 600 [EUR/MW]	240 770 [EUR/MW]
PV	95 970 [EUR/MW]	132 270 [EUR/MW]	67 750 [EUR/MW]
Gas	115 160 [EUR/MW]	158 730 [EUR/MW]	81 300 [EUR/MW]
Coal	371 400 [EUR/MW]	523 500 [EUR/MW]	249 300 [EUR/MW]
Biomass	383 870 [EUR/MW]	529 100 [EUR/MW]	271 000 [EUR/MW]
Hydro	297 900 [EUR/MW]	402 140 [EUR/MW]	217 700 [EUR/MW]
Other	10 000 000 [EUR/MW]	10 000 000 [EUR/MW]	10 000 000 [EUR/MW]

Results

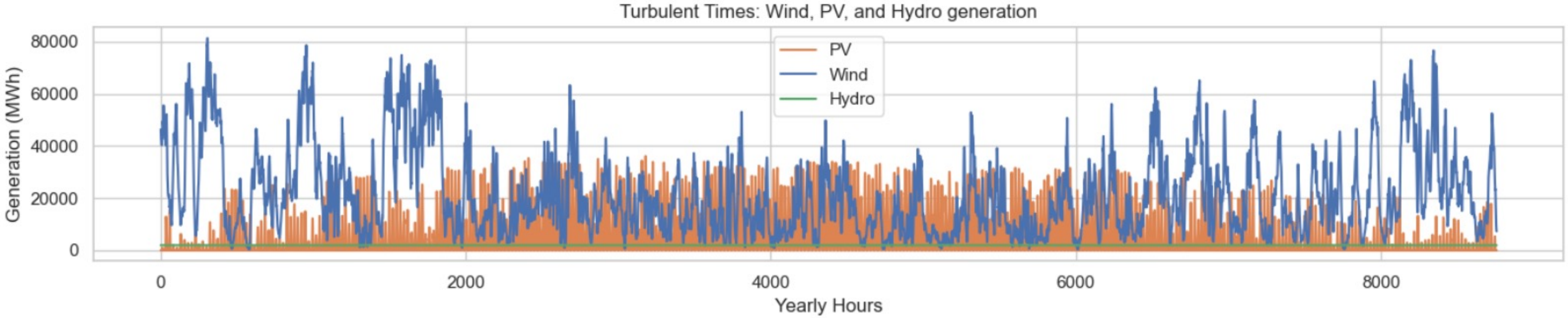
Results

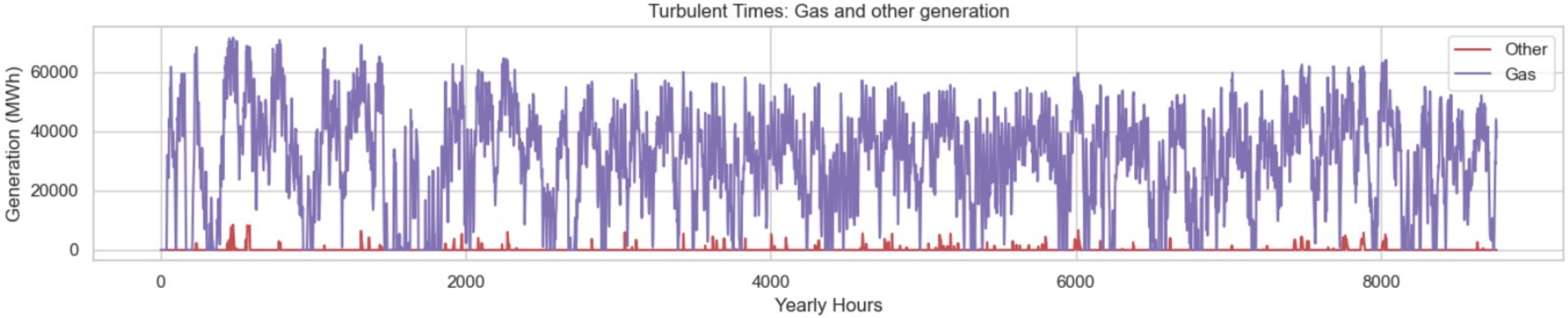
- Cost-optimal energy system configuration(s):



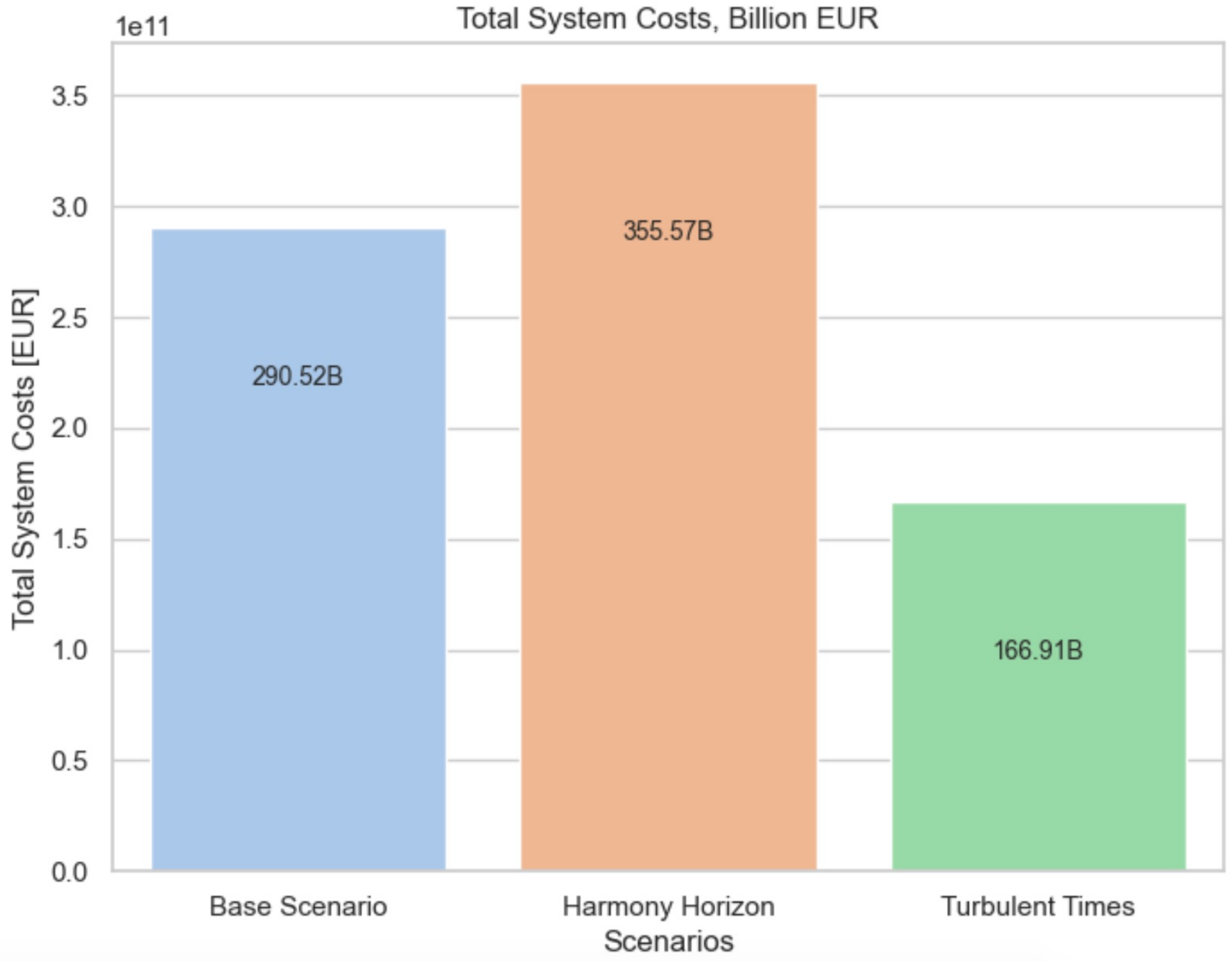
Results

- Cost-optimal variable energy generation:





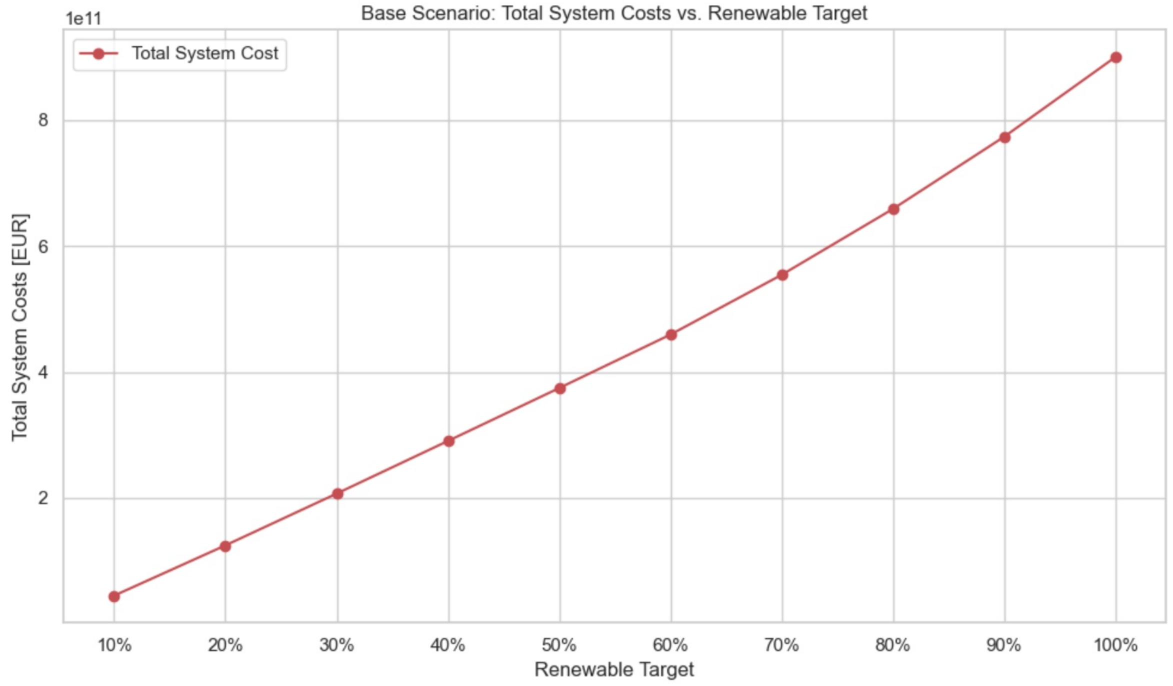
Results

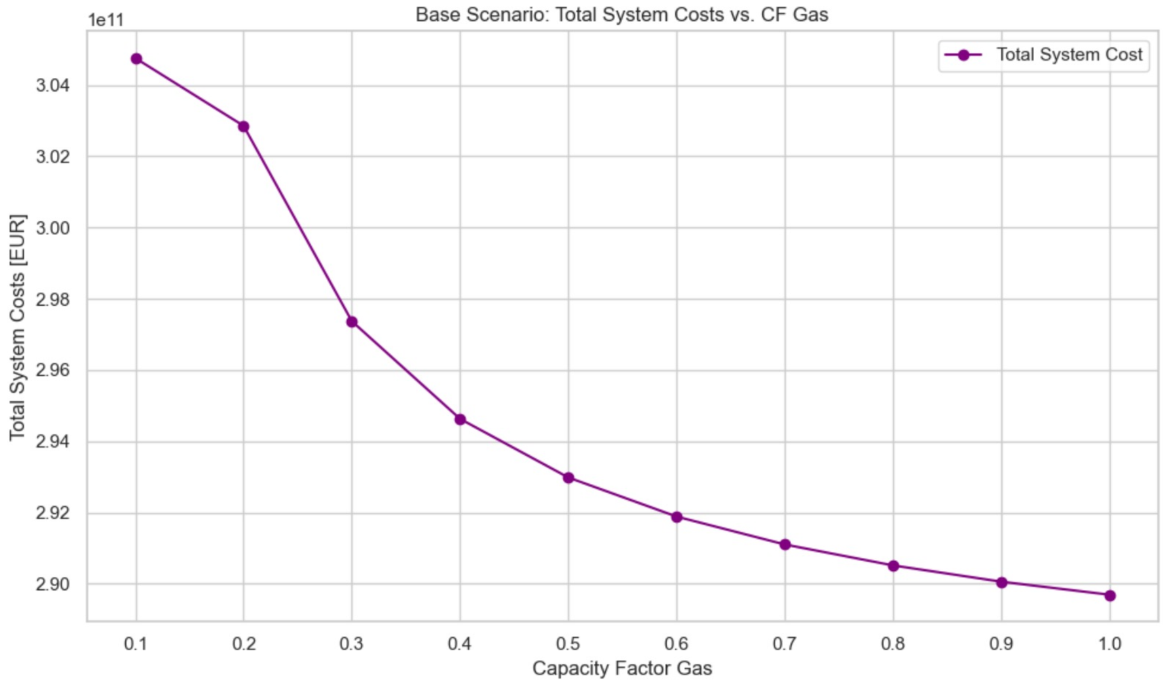


Total System Costs, Billion EUR
1e11
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Total System Costs [EUR]
290.52B
355.57B
166.91B
Base Scenario
Harmony Horizon
Turbulent Times
Scenarios

Sensitivity Analysis

- Total system costs against renewable target value and CF gas:





Discussion

Discussion

I. Substantial variations in cost-optimal system configurations driven by constraints and geopolitical considerations

II. Expansion of wind and PV needed to meet future demand efficiently

III. Importance of accurate parameter estimates emphasized through the sensitivity analysis

IV. This study serves more as a guide, indicating how societal trends may impact the German energy transition, due to model assumptions/simplifications!

References

- Full reference-list provided upon request

Bellakhal, R., Kheder, S. B., and Haffoudhi, H. (2019). Governance and renewable energy investment in mena countries: How does trade matter? *Energy Economics*, 84:104541.

Cadoret, I. and Padovano, F. (2016). The political drivers of renewable energies policies. *Energy Economics*, 56:261–269.

Caetano, R. V., Marques, A. C., Afonso, T. L., and Vieira, I. (2022). A sectoral analysis of the role of foreign direct investment in pollution and energy transition in oecd countries. *Journal of Environmental Management*, 302:114018.

Cheikh, N. B. and Zaied, Y. B. (2023). Renewable energy deployment and geopolitical conflicts. *Journal of Environmental Management*, 344:118561.

Chen, C.;Xue, B. G. H. S. (2019). Comparing the energy transitions in germany and china: Synergies and recommendations. *Energy Reports*, 5:1249–1260.

UNIVERSITETET
I OSLO

DEPARTMENT OF TECHNOLOGY SYSTEMS
TEK5410 ENERGY MARKETS AND REGULATION:
MODELLING AND ANALYSIS

Thank you for the attention!

Hans Kristian Haraldseth

University of Oslo

December 2023