operations research
QUANTITATIVE INFRASTRUCTURE SYSTEM MODELING

Long-term Development of European Natural Gas Markets

Scenario Analysis using the Global Gas Model (GGM)

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Agenda

Motivation

Putins invasion of Ukraine

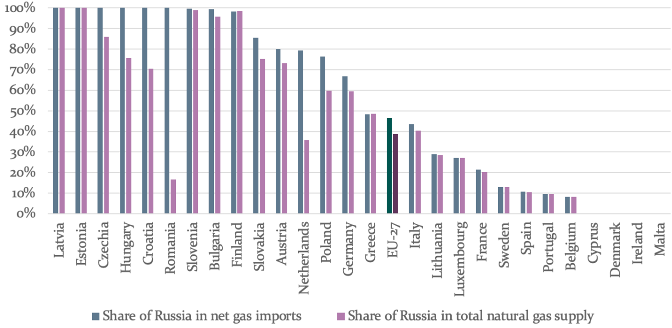
- Unexpected for decades, war within Europe has once again become a reality
  - Invasion of Ukraine started on Feb 24th 2022
  - Afterwards, Russian natural gas supplies to Europe (and especially Germany) have become a topic of discussion

Disruption of Supply vs Demand

- Despite a discussion in the German public about an interruption of demand via economic sanctions, supply was disrupted by the Russian side
- Since early September 2022, there have been no more pipeline imports from Russia to Europe via Germany or Poland
- Explosions of the Nord Stream pipelines on September 26th, 2022 have further cemented this state of a new normal in European gas markets

Motivation

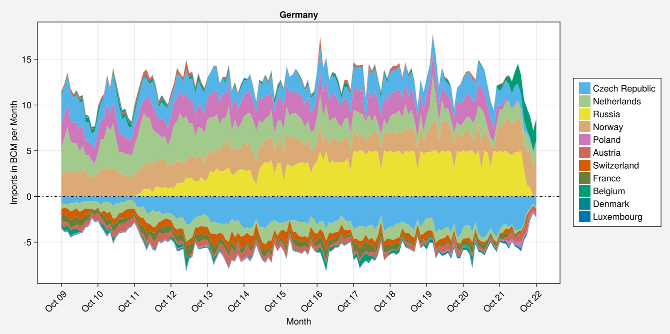
Russias role in European natural gas supplies



Source: Based on Eurostat, cf. Holz et al. (2022)

Russias role in European natural gas supplies.

Historical Overview of German Natural Gas Trade Flows



Source: Own depiction, based on IEA (2023)

Historical Natural Gas Trade Flows.

Medium and Longer Term Outlooks

- Short term:
  - Winter 2022/23 went by with relatively high storage levels towards the end
  - No serious shortage/outage in gas supplies occured
  - What about the longer term effects of Putins invasion?
- Medium term:
  - Massive extensions of LNG import infrastructure in Germany
    - ~40BCM of FSRU capacity in the short term
    - ~40BCM of onshore terminals planned
- Longer Term:
  - Onshore terminals do not provide relief in the short term
  - And are likely to turn stranded if Germany adheres to the Paris Agreements
  - More on this in the scenario section

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Literature

Previous Literature on Russian Supply Disruptions

- Russian supply disruptions have been a possibility discussed and modeled in previous literature
  - With the European Gas Model:
    - Egging et al. (2008)
  - With the World Gas Model:
    - Huppmann et al. (2011)
  - With the Global Gas Model:
    - Richter and Holz (2015)
    - Egging and Holz (2016)
    - Holz et al. (2017)
    - Egging-Bratseth, Holz, and Czempinski (2021)
  - And with other models:
    - Abrell and Weigt (2011)
    - Lochner (2011)
    - Bouwmeester and Oosterhaven (2017)

Agenda

1. Motivation

2. Literature

3. The Global Gas Model

4. Scenario Overview

5. Results

6. Conclusions and Outlook

7. Discussion

8. References

Overview

- Originally a Mixed Complementarity Model
  - Exertion of market power in accordance with Nash-Cournot
- Now a convex QP (Egging-Bratseth, Baltensperger, and Tomasgard 2020)
  - With KKTs equivalent to the MCP
  - Structurally similar to a social welfare optimization
    - Linear inverse demand functions
  - With a market power adjustment term
- Old Data documentation
  - New data
  - New calibration
  - etc.

Objective

$$\max_{\substack{q^S_{tndy},q^P_{tnrdy},\\ f^Z_{tzdy},\Delta^Z_{z,y}}} \quad \sum_y r_y \left[\sum_d d_d \left[\sum_{t,n} \left(INT_{ndy} - SLP_{ndy} \sum_{t'} q^S_{t'ndy} \right) q^S_{tndy} + \frac{1}{2} \sum_n SLP_{ndy} \left(\sum_t q^S_{tndy} \right)^2 \right. \right.$$
$$- \frac{1}{2} \sum_n SLP_{ndy} \sum_t cv_{tny} \left(q^S_{tndy} \right)^2 - \sum_{t,n,r} c^{Pl}_{tnry} q^P_{tnrdy} - 0.5 \sum_{t,n,r} c^{Pq}_{tnry} \left(q^P_{tnrdy} \right)^2$$
$$\left. - \sum_{t,a} c^A_{ay} f^A_{tady} - \sum_{t,n,w} c^X_{nwy} f^X_{tnwdy} \right]$$
$$\left. - \sum_a c^{\Delta^A_{ay}}_{ay} \Delta^A_{ay} - \sum_x c^{\Delta^X_{xy}}_{xy} \Delta^X_{xy} - \sum_w c^{\Delta^W_{wy}}_{wy} \Delta^W_{wy} \right] \tag{1}$$

Constraints

$$s.t. \quad \forall t,n,r,d,y \qquad q^P_{tnrdy} \leq CAP^P_{tnry} \tag{2a}$$

$$\forall t,n,d,y \qquad \sum_r q^P_{tnrdy} + \sum_{a \in A_n^+} \left(1 - l^A_a\right) f^A_{tady} + \sum_w f^X_{tnwdy} = q^S_{tndy} + \sum_{a \in A_n^-} f^A_{tady} + \sum_w f^I_{tnwdy} \tag{2b}$$

$$\forall a,y \qquad \Delta^A_{ay} \leq \bar{\Delta}^A_{ay} \tag{2c}$$

$$\forall a,y \qquad \sum_t f^A_{tady} \leq CAP^A_{ay} + \sum_{y'<y} \Delta^A_{ay} \tag{2d}$$

(2e)

Constraints cont'd

$$\forall t, w, d, y \qquad \left(1 - l_w^l\right) \sum_d f_{twdy}^l = \sum_d f_{twdy}^X \tag{3a}$$

$$\forall n, w, y \qquad \Delta_{nwy}^X \leq \bar{\Delta}_{nwy}^X \tag{3b}$$

$$\forall n, w, y \qquad \Delta_{nwy}^W \leq \bar{\Delta}_{nwy}^W \tag{3c}$$

$$\forall n, w, y \qquad \sum_t f_{tnwdy}^X \leq CAP_{nwy}^X + \sum_{y' < y} \Delta_{nwy}^X \tag{3d}$$

$$\forall n, w, y \qquad \sum_{t,d} d_d f_{tnwdy}^X \leq CAP_{nwy}^W + \sum_{y' < y} \Delta_{nwy}^W \tag{3e}$$

Agenda

Scenario Overview

STEPS 2021 New Normal

	Reference Demand	Supply Disruption
2020	3,900 BCM	Active
2030	4,500 BCM	Active
2050	5,000 BCM	Active

STEPS 2021 Status Quo Ante Bellum

	Reference Demand	Supply Disruption
2020	3,900 BCM	Inactive
2030	4,500 BCM	Inactive
2050	5,000 BCM	Inactive

APS 2021 New Normal

	Reference Demand	Supply Disruption
2020	3,900 BCM	Active
2030	3,800 BCM	Active
2050	2,600 BCM	Active

APS 2021 Status Quo Ante Bellum

	Reference Demand	Supply Disruption
2020	3,900 BCM	Inactive
2030	3,800 BCM	Inactive
2050	2,600 BCM	Inactive

Scenaro Overview

STEPS 2021

- Scenario approximately following the World Energy Outlook 2021 "Stated Policies Scenario" (IEA 2021)
  - Where the energy system might go without additional policy implementation
  - Not designed to achieve an outcome, in particular not compatible to the Paris Agreements

APS 2022

- Scenario approximately following the World Energy Outlook 2022 "Announced Pledges Scenario" (IEA 2022)
  - Takes account of all the climate commitments made (including Nationally Determined Contributions)
  - Hence still fails to achieve the Paris Agreements

What about scenarios that are actually compatible to the Paris Agreements???

- Candidates are the World Energy Outlook 2022 "Sustainable Development Scenario" and the "Net Zero Emissions by 2050 Scenario" (IEA 2022)
  - Calibration is underway, but higher demand scenarios tend to show more pronounced effects of disruptions

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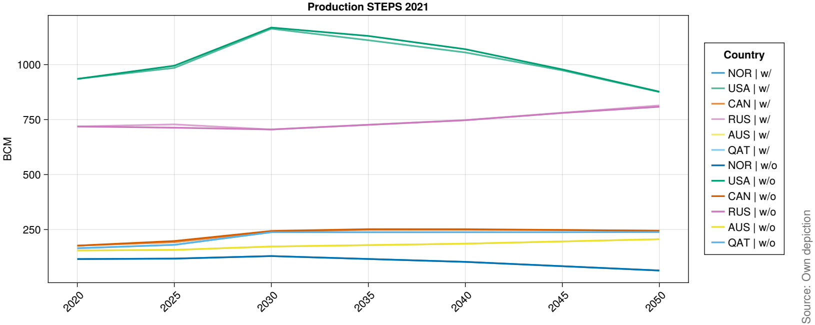
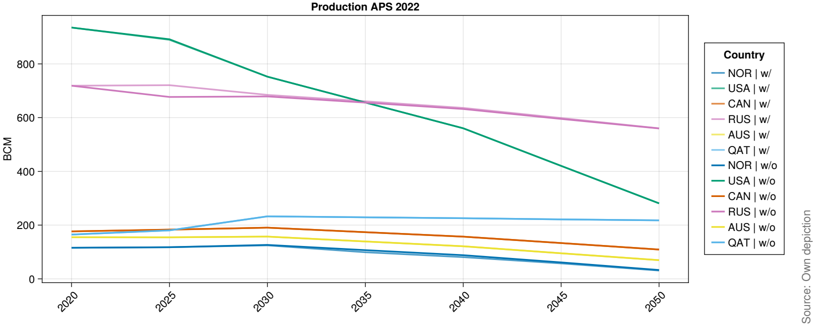
Production in STEPS 2021



Future natural gas production for selected producers.

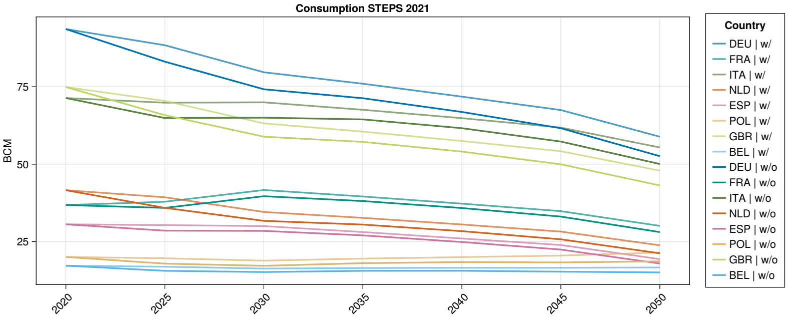
Production in APS 2022



Future natural gas production for selected producers.

Results

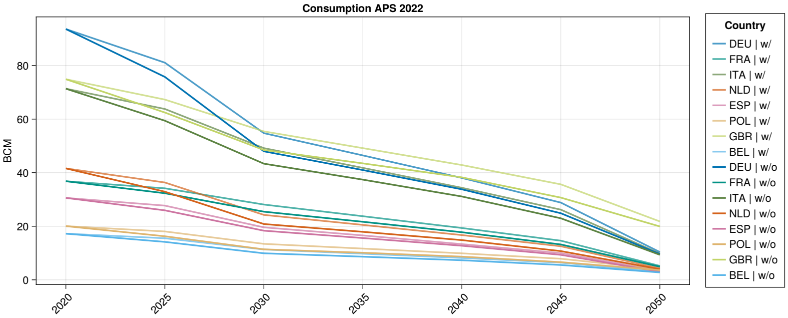
Consumption in STEPS 2021



Source: Own depiction

Future natural gas consumption for selected countries.

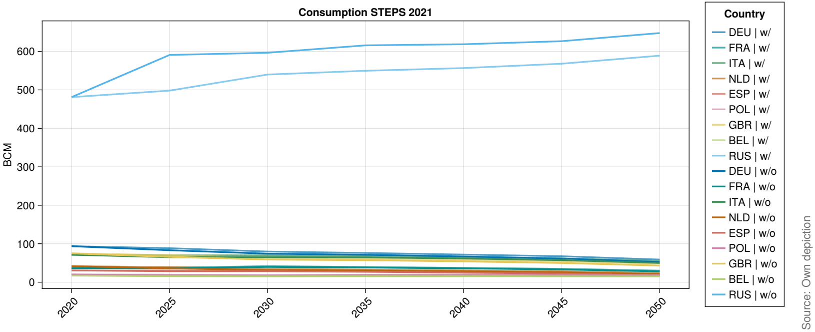
Consumption in APS 2022



Source: Own depiction

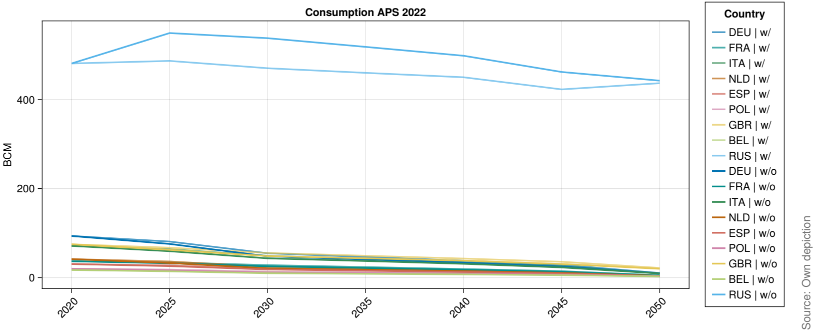
Future natural gas production for selected countries.

Consumption in STEPS 2021



Future natural gas consumption for selected countries.

Consumption in APS 2022



Future natural gas production for selected countries.

Where does Germany get its natural gas from?

German Supply STEPS 2022 New Normal 2030

- ~25 BCM from NOR
- ~20 BCM from USA
- Rest diverse: North Africa, NLD and others
- Total Demand of ~74 BCM

German Supply APS 2022 New Normal 2030

- ~22 BCM from NOR
- ~12 BCM from North Africa
- Rest diverse: LNG, NLD and others
- Total Demand of ~48 BCM

German Supply STEPS 2022 New Normal 2050

- ~14 BCM from NOR
- ~8 BCM each from USA and North Africa, rest diverse
- Total Demand of ~53 BCM

German Supply APS 2022 New Normal 2050

- ~3.5 BCM from NOR
- Rest diverse, mostly from the Caspian Region and Middle East
- Total Demand of ~9-10 BCM

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Conclusions and Outlook

Conclusions

- The model does not see an incentive to build LNG terminals beyond current FSRU plans
  - Exogenous total capacity of ~24 BCM by 2025 and 32 BCM by 2030 suffices
- Limited effects of Russian supply disruption on European natural gas markets
- Russia mostly compensates for disruption by increasing domestic demand
  - Several aspects remain unclear:
    - Model assumes marginal pricing in domestic markets of large suppliers,
    - Unclear if politial will exists to see prices go down while export revenues drastically decrease
    - Model also does not consider feasibility in domestic grids etc.

Outlook

- Calibration of a "Net Zero by 2050" scenario is underway, interesting to see what happens if global demand for natural gas further decreases
- Current results are preliminary, additional fine tuning in some regions of the world (especially African LNG developments) is still required

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Discussion

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