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EXPANDING NATURAL GAS CROSS-BORDER FLOWS IN EUROPE THROUGH THE OPTIMAL USE OF THE PIPELINE GRID: A STYLIZED MODEL COMPARISON

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Agenda

1) Introduction

2) Theory and state of Literature

3) Scenarios with the Global Gas Model (GGM)

4) Scenarios with GENeSYS-MOD

5) Discussion and Conclusion

Introduction: Russian gas dependency, Ukrainian War and acceleration in the diversification of the European Gas supply

2019 | 2020 | 2021 | 2022 | 2023

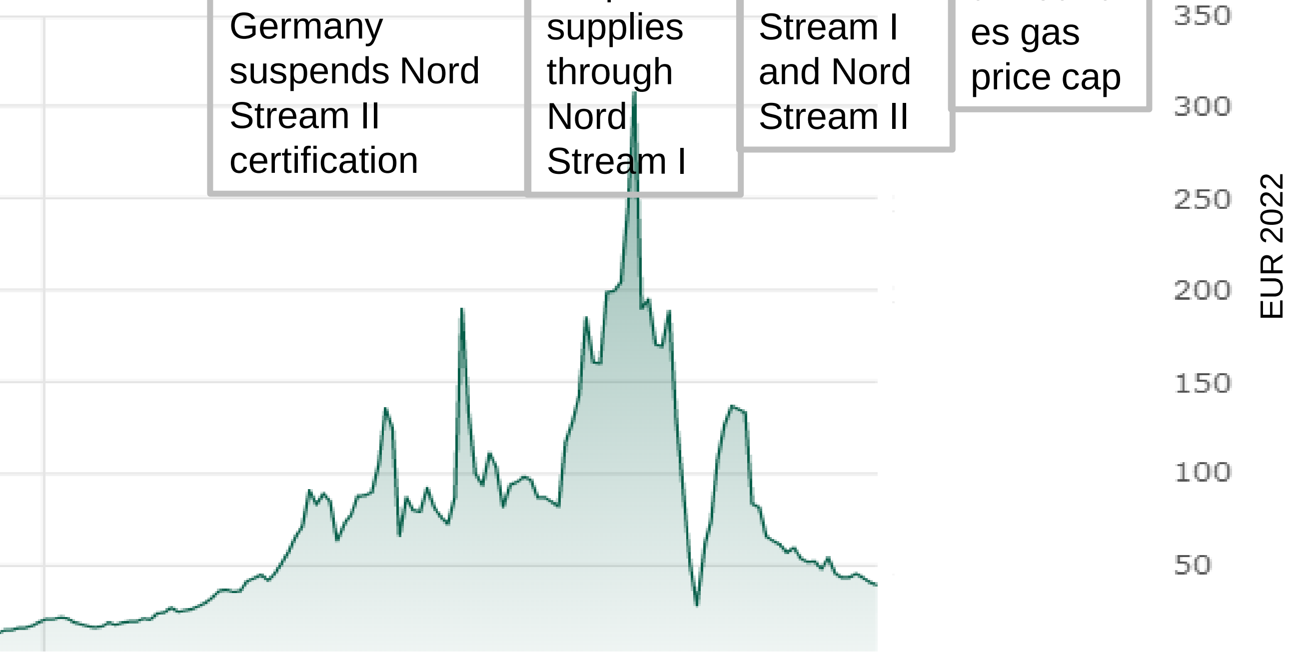
COVID Pandemic

Russia invades Ukraine Germany suspends Nord Stream II certification

Russia suspends supplies through Nord Stream I

Blow up of Nord Stream I and Nord Stream II

EU announces gas price cap

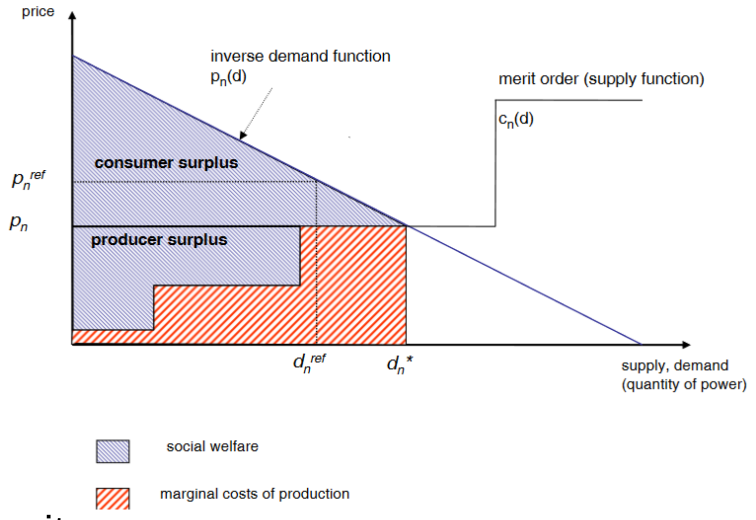


Source: https://www.wallstreet-online.de/rohstoffe/dutch-ttf-daily-natural-gas-forward-daily-futures-preis#t:5y||s:lines||sfill:true||a:abs||v:week||ads:null

Introduction: A long-term consideration

~ Importance of trans-boundary grid infrastructure for flexibility and supply security
~ Long-term issue, with regular peak of attention:

- FERC Order 636 (1992), the "final restructuring rule", was a milestone in moving from "simple" non-discriminatory third-party access (TPA) towards a fundamental vertical unbundling of transportation and sales activities
- EU Directive 98/92: unbundling and efficient use of capacities
- First Russian-Ukrainian gas crisis 2006 …
- … natural gas / energy crisis of 2022



~ Theoretically: "nodal pricing" yields short-term welfare optimization / cost minimization

~ Application gap:

- US applies nodal pricing since the 1990s
- Europe started reforms in the 2000s, but is still stuck with entry-exit

~ Topic gained importance through the energy and natural gas crisis

~ Particular issue with "reverse flows", i.e. differentiated capacity caps on flows from A ➔ B ≠ B ➔ A

➔ In this paper, we compare existing network regulation in Europe with entry-exit and uni-directional caps with a (hypothetical) situation of bidirectional nodal prices

Agenda

Theory and state of literature

~ Nodal pricing has its origins in the electricity sector (Schweppe et al. 1988; Hogan 1992), recent update by Hogan and Harvey (2022)

~ Based on simple welfare maximization

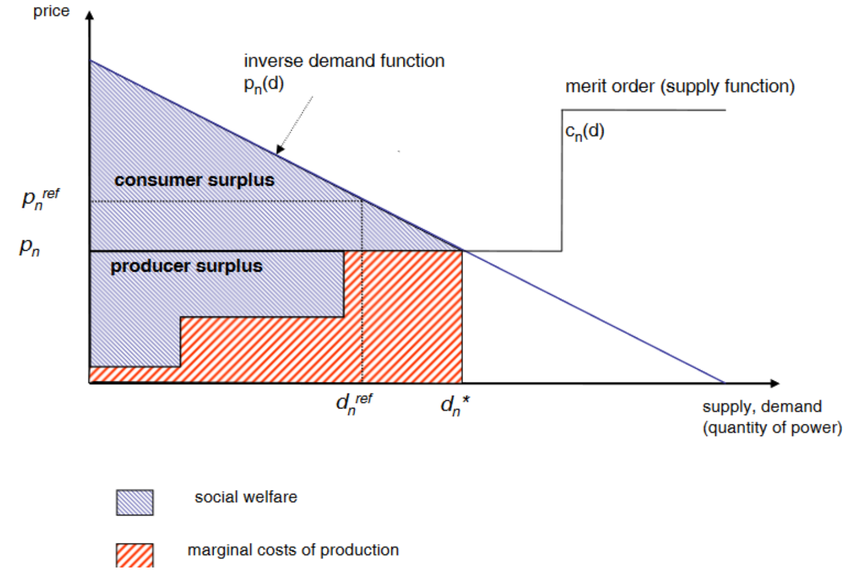
~ First applications in the US:

~ Electricity after US FERC order 888 (“provide open access transmission service on a comparable basis to the transmission service they provide themselves”)

~ Natural gas (Lochner, et al., :

~ Technically less complex than electricity (no loop flows)

~ But complexity through non-linear flows (“Weymouth equation”, etc.)



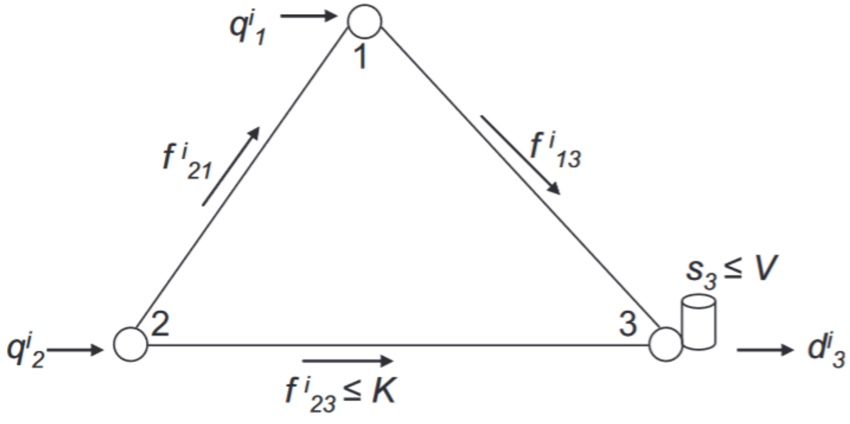
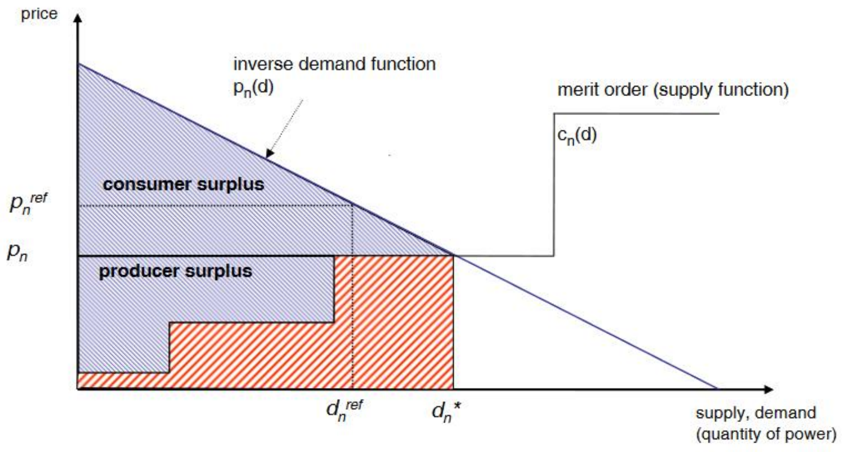


Fig. 1. Simple pipeline network with storage.

The principle of “nodal pricing”

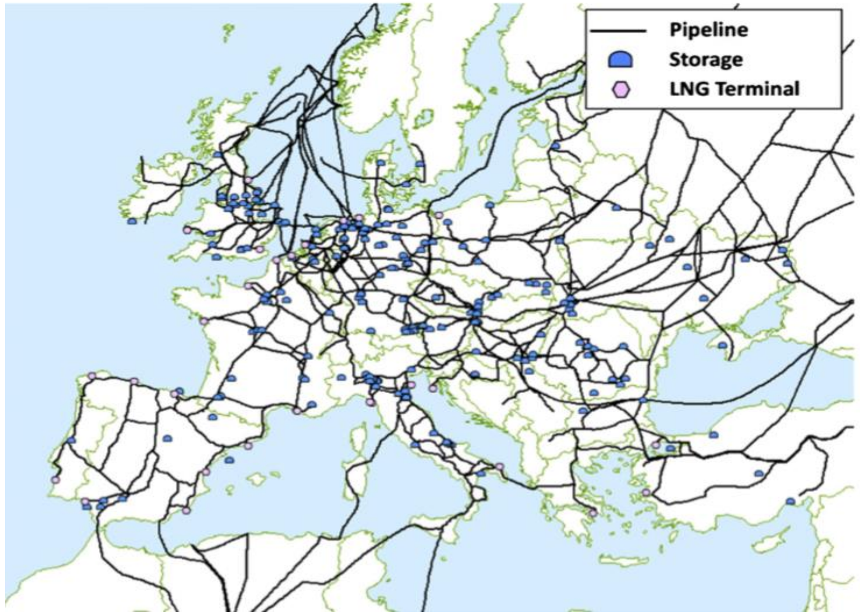
Problem: uniform pricing → congestion not properly determined?



Nodal Pricing

= location value of energy:

Node specific costs from energy generation and transmission (e.g. losses and congestion)



Node: physical location on the transmission grid (incl. generators and loads)

Calculation: market clearing prices for all nodes subjects to physical and security constraintss

-> reflects real conditions and costs in the grid for every node
-> Indicate and price congestions when overstepping transmission limits

Optimization Problem

Objective function: Social welfare

$$\max W(d_n^*) = \left(\int_0^{d_n^*} p^*(d_n^*)d * d_n^* - \int_0^{d_n^*} c(d_n^*)d * d_n^*\right)$$

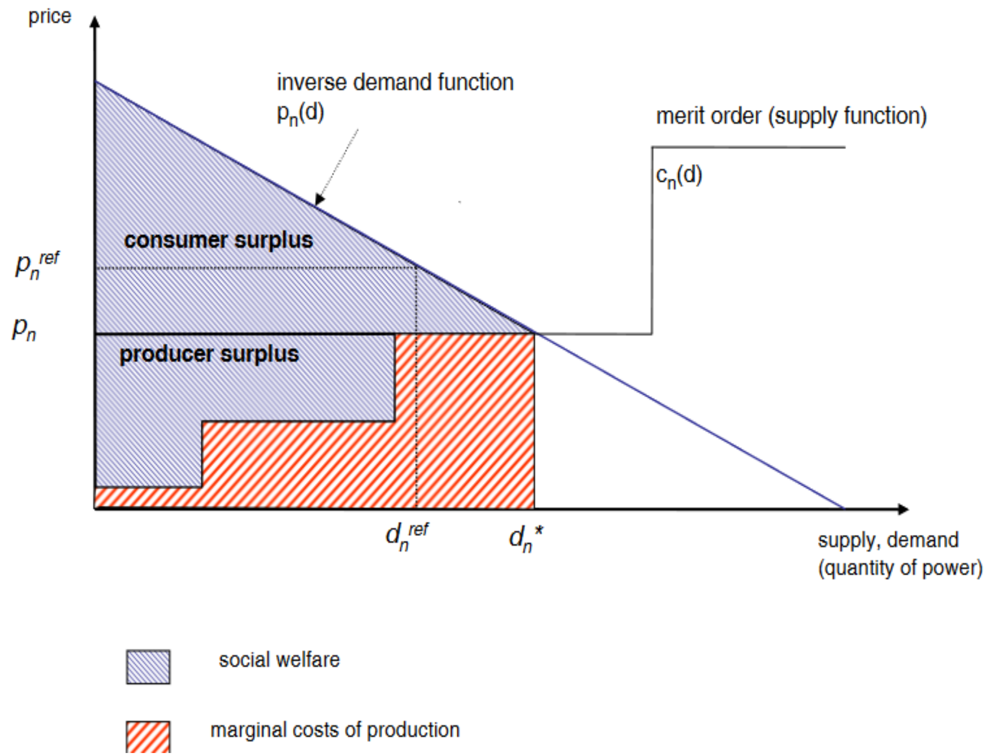
s.t. $|P_i| \leq P_i^{max}$ line flow constraint

$\sum_n g_n = \sum_n d_n + L$ energy balance constraint

$\sum_{n,t} g_n^t \leq \sum_{n,t} g_n^{t,max}$ generation constraint (per type of plant)

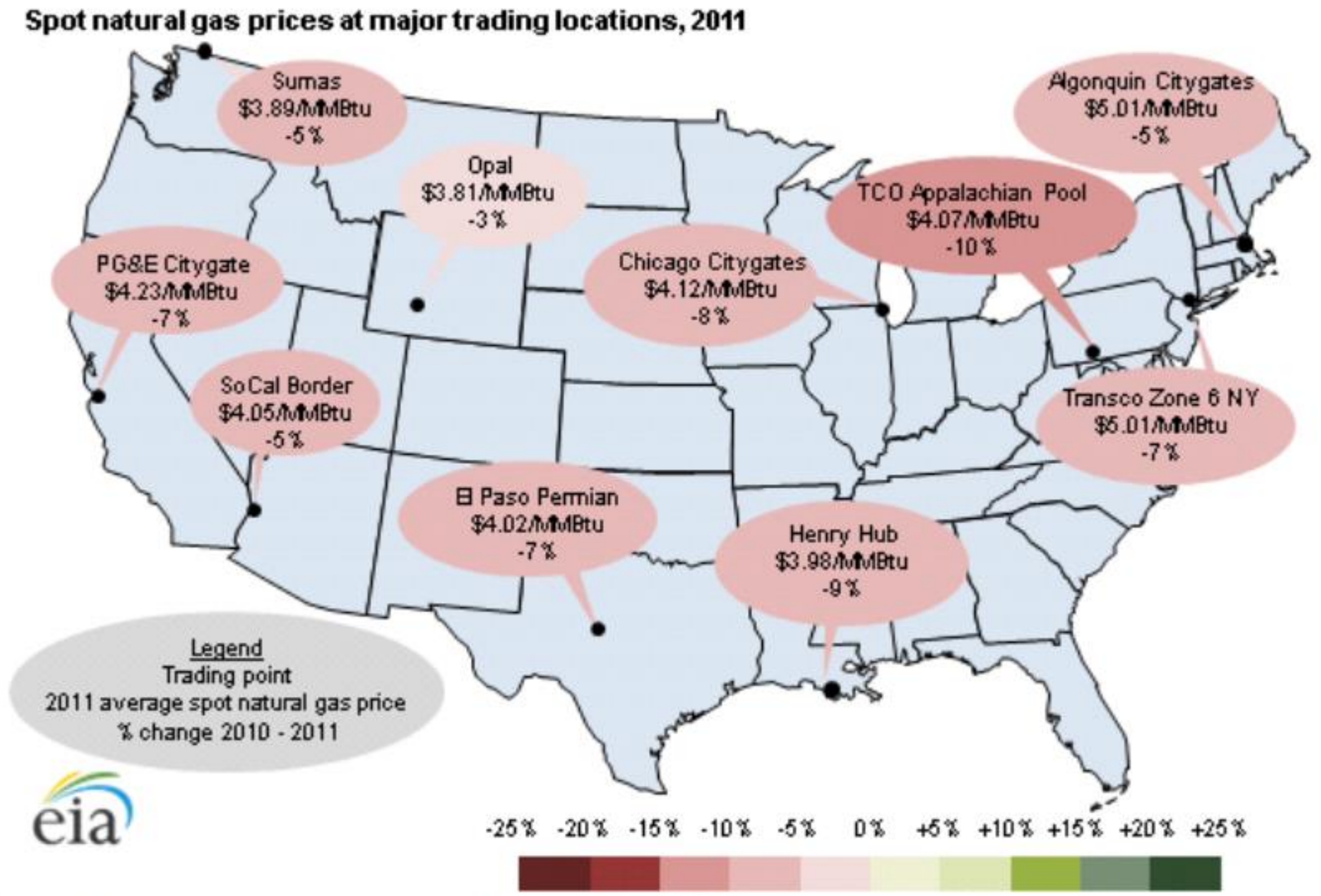
Inverse demand function or each node

$$p_n = p_n^{ref} + \frac{1}{\varepsilon} * p_n^{ref} * \left(\frac{d_n^*}{d_n^{ref}} - 1\right)$$



Assumption: Competition

US Trading Points (2011)



Source: U.S. Energy Information Administration, based on Bloomberg.
Note: Average spot natural gas prices reported in the map for 2011 are based on data from InterContinentalExchange and vary slightly values reported in the current Short-Term Energy Outlook, which are based on Reuters data.

ENTSOG


Skagerrak
Kattegat
Baltic Sea
Gulf of Riga
GOTLAND
DENMARK
COPENHAGEN
LATVIA
RIGA
LITHUANIA
VILNIUS
RUSSIA
RUSSIA
CIS
BELARUS
MINSK
KIEV
UKRAINE
MOLDOVA
CHISINAU
POLAND
WARSAW
GERMANY
BERLIN
THE NETHERLANDS
AMSTERDAM
BELGIUM
BRUSSELS
LUX
PARIS
CZECH REPUBLIC
PRAGUE
SLOVAKIA
BRATISLAVA
AUSTRIA
VIENNA
HUNGARY
BUDAPEST
SWITZERLAND
BERN
BORNHOLM
BALTIC PIPE
NORD STREAM
NORD STREAM 2
VTP-GAZ-SYSTEM
VHP-GASPOOL
VHP NCG
ZTP
TTF
ETF
GTF
CEGH
OTE

Cross-country Capacities

- Capacities based on data from ENTSO-G
- Larger capacity used for scenarios with bidirectional pipeline capacity
- Some already known investments are included in future years, e.g. German FSRUs

➔ Hypothetical simulation where the maximal capacities are used

Region A	Region B	Capacity A → B	Capacity B → A
DE	AT	**20.99**	10.44
DE	BE	**12.16**	9.91
DE	CH	**10.07**	5.31
DE	CZ	**55.37**	37.81
DE	DK	**4.18**	0.13
DE	FR	**18.84**	**18.84**
DE	NL	58.76	**74.56**
DE	NO	0	**67.86**
DE	PL	7.17	**28.60**
AT	IT	**35.30**	5.94
BE	FR	**26.71**	8.29
CH	IT	**19.66**	13.64
FR	ES	5.05	**6.89**

Table 1: Selection of cross-country capacities for gas pipelines in bcm

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The Global Gas Model (Structural Overview)

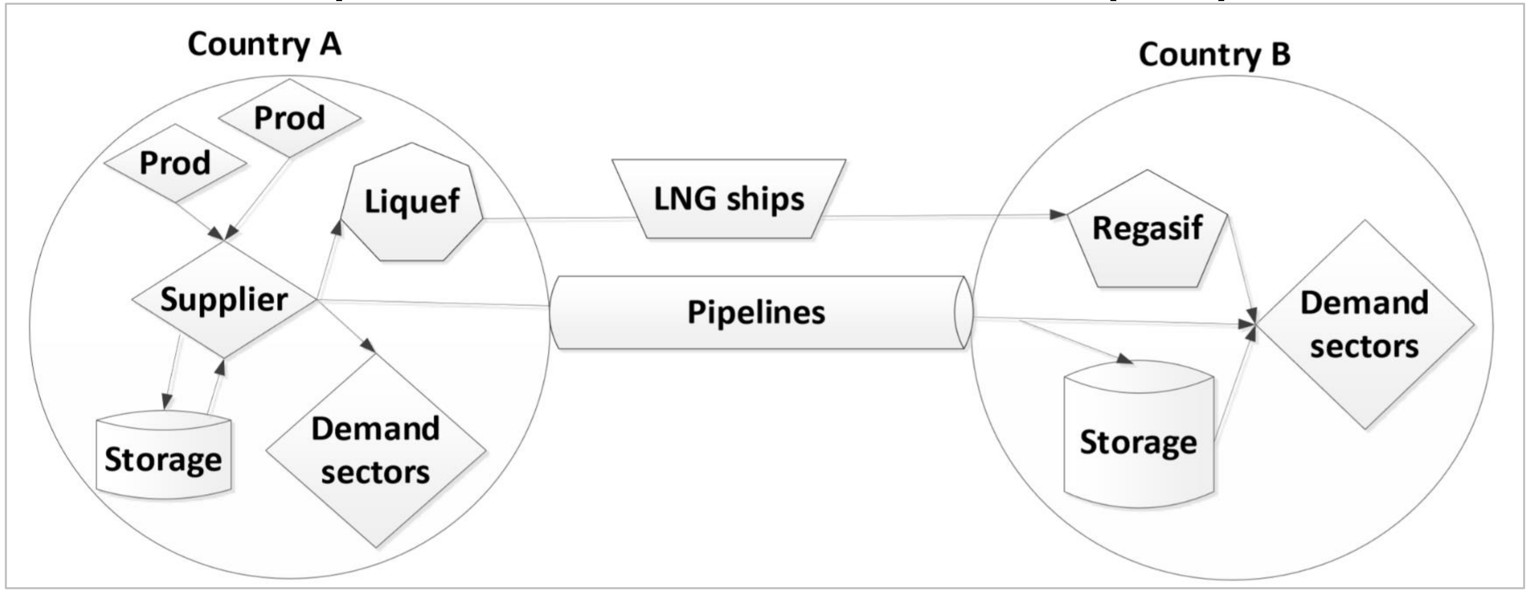
- Multi-Period Model of oligopolistic competition in natural gas markets à la Nash-Cournot

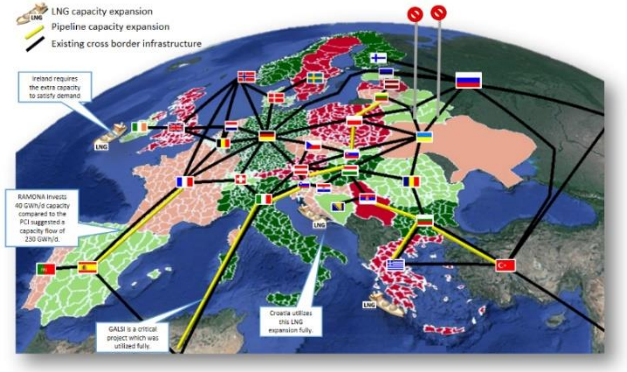
- Single commodity partial equilibrium model

- Covering practically the entire global natural gas production and consumption value chain

- Exertion of market power happens via traders that channel production from multiple model nodes (e.g. different regions in the US, Canada or Russia)

Schematic - Representation of the Global Gas Model (GGM)



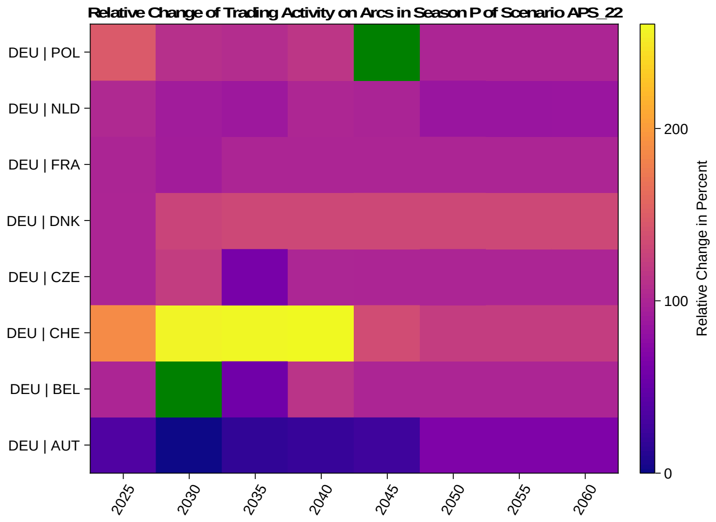


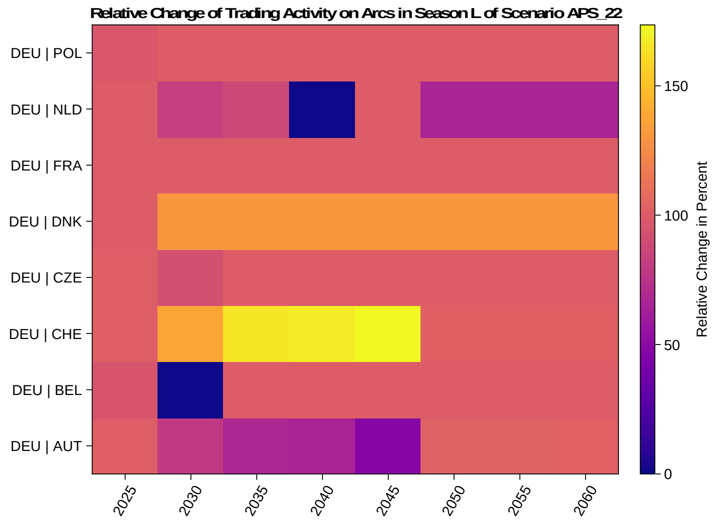
Source: https://www.ntnu.edu/iot/energy/energy-models-hub/ggm

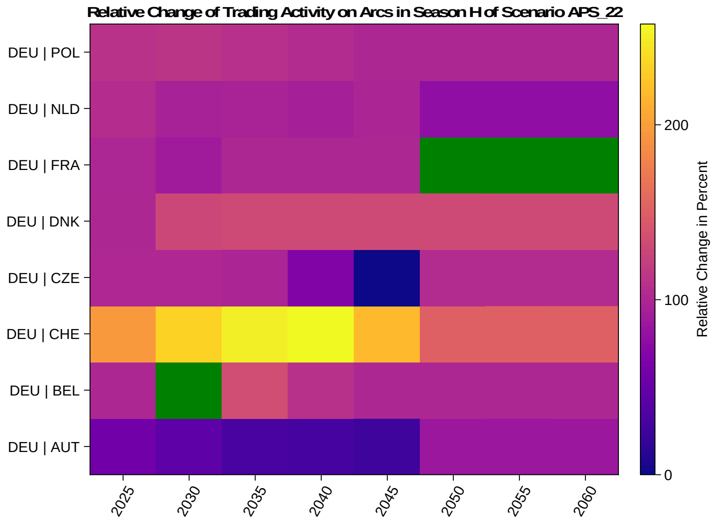
First Results with the Global Gas Model (Relative Changes of Trading Activity)

Heat-Maps with indication on relative changes of total cross border trades

- Total trades are defined as the sum of flows from A -> B and B -> A
- A value of 100% indicates that no change in total flow occurs after introducing bi-directionality
- A value of 200% indicates that total trade flows double after allowing for bi-directionality
- A value of 60% indicates that total trade flows between nodes decrease accordingly
- Trading activity between DEU and CHE rises drastically, while trading activity between DEU and AUT decreases







Result – table of Annual German Consumption (BCMA)

- Annual German Consumption (BCMA) before and after introducing bidirectionality
- While trading activity differs considerably, influences on prices and quantities remain marginal for German markets
- Similar results for the higher demand STEPS_21 scenario
- Howerver, more pronounced results could be expected for introducing the same mechanism in other regions such as Eastern Europe

Year	APS baseline	APS bi-directional
2020	93,62	93,63
2025	75,75	75,78
2030	47,98	48,06
2035	40,98	41,05
2040	33,79	33,83
2045	24,86	24,93
2050	9,62	9,63
2055	9,62	9,63
2060	9,62	9,63

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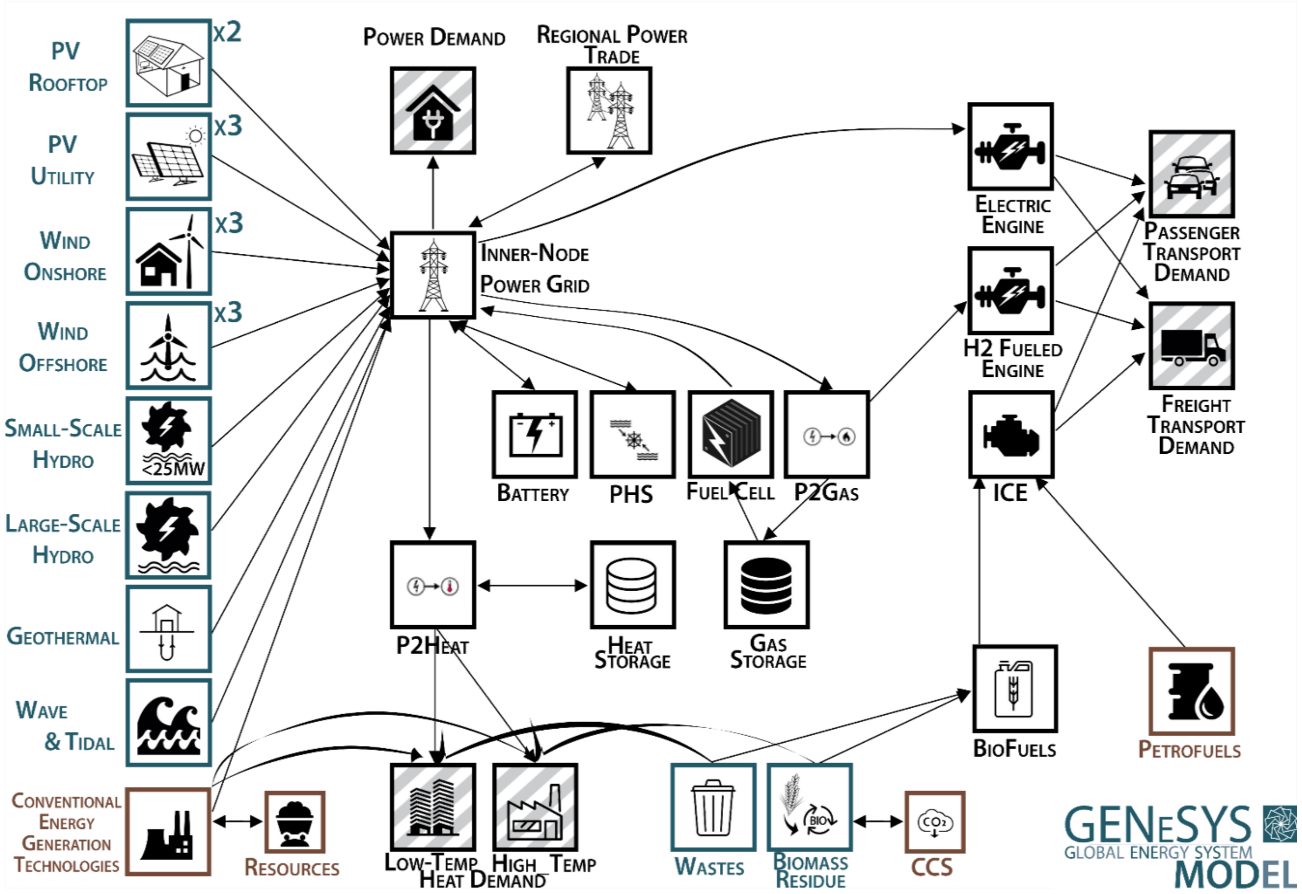
GENeSYS-MOD…

Energy system model resolution

… based on OSeMOSYS and developed since 2016

…publicly available with model, data, and manual[1]

…Results in this presentation (mainly) based on European and German case-studies



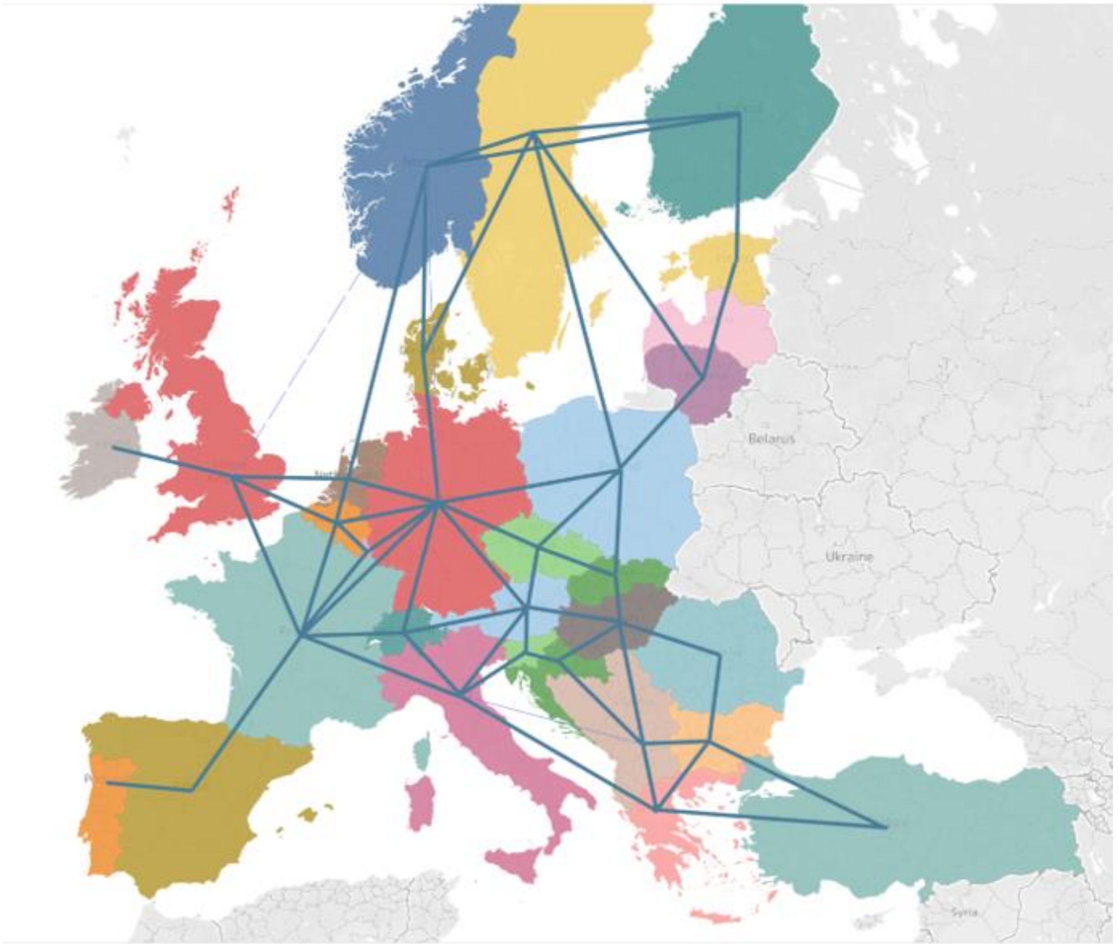
[1] https://git.tu-berlin.de/genesysmod/genesys-mod-public

Scenario specific model settings

Spatial and temporal resolution

- Europe disaggregated into 30 regions
  - Mainland EU-25
  - Norway, Switzerland, Turkey, UK
  - Aggregated non-EU Balkan region

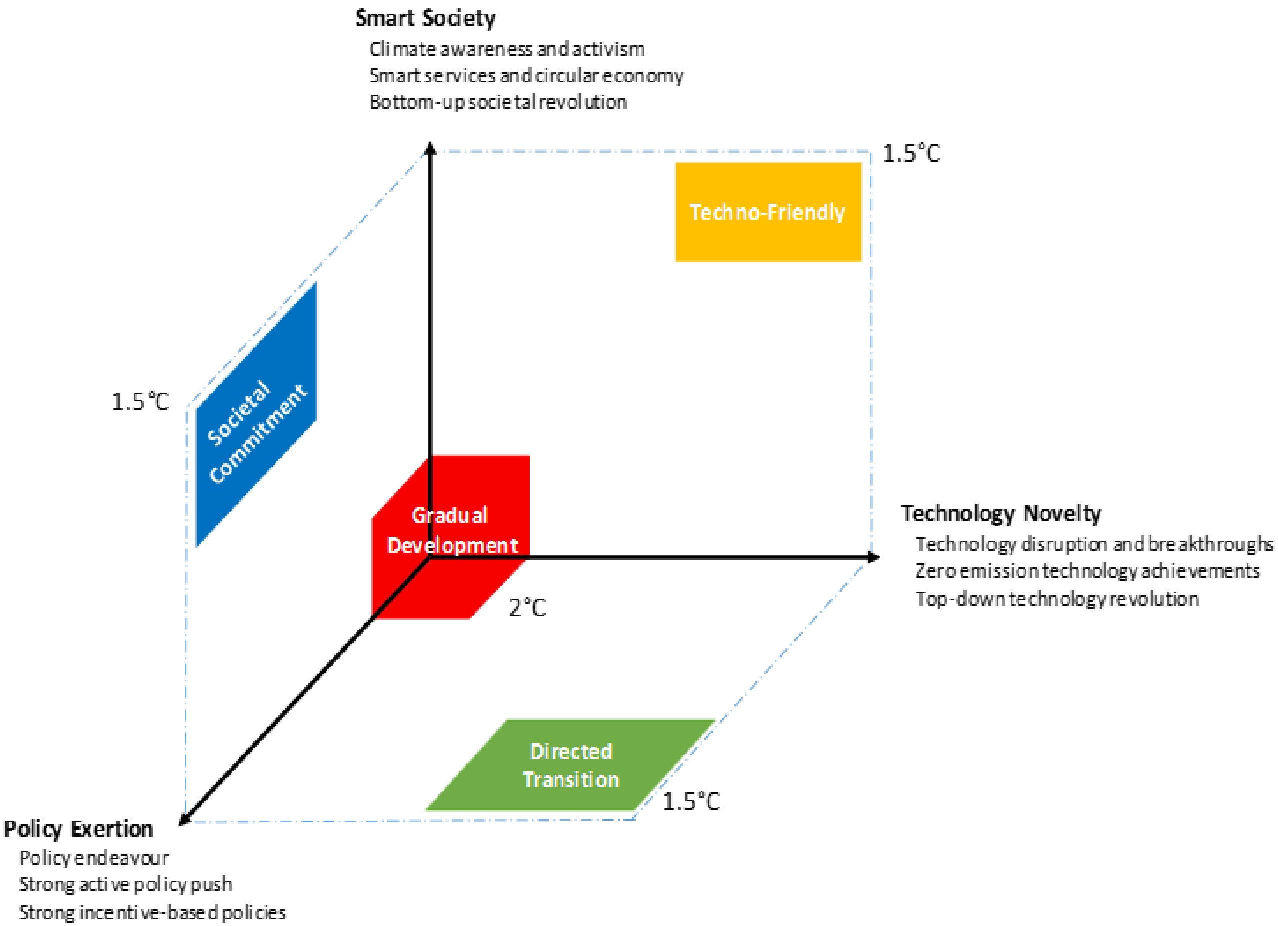
- Hourly time-series for renewable potentials and demands
  - Reduced by time-series clustering algorithm[1]
  - Results in temporal resolution of every 244th hour (35 time slices)



Scenario definition

H2020 Gradual Development Scenario

- Net-zero 2050 following a 2℃ pathway
- Combines societal, technological, and political aspects
- Carbon price drives decarbonization
  - 2030: 76.4 €/tCO_2
  - 2050: 355 €/tCO_2
- Reductions in energy demand until 2050
  - Electricity demand 2018: 10.48 EJ
  - Electricity demand 2050: 10.33 EJ



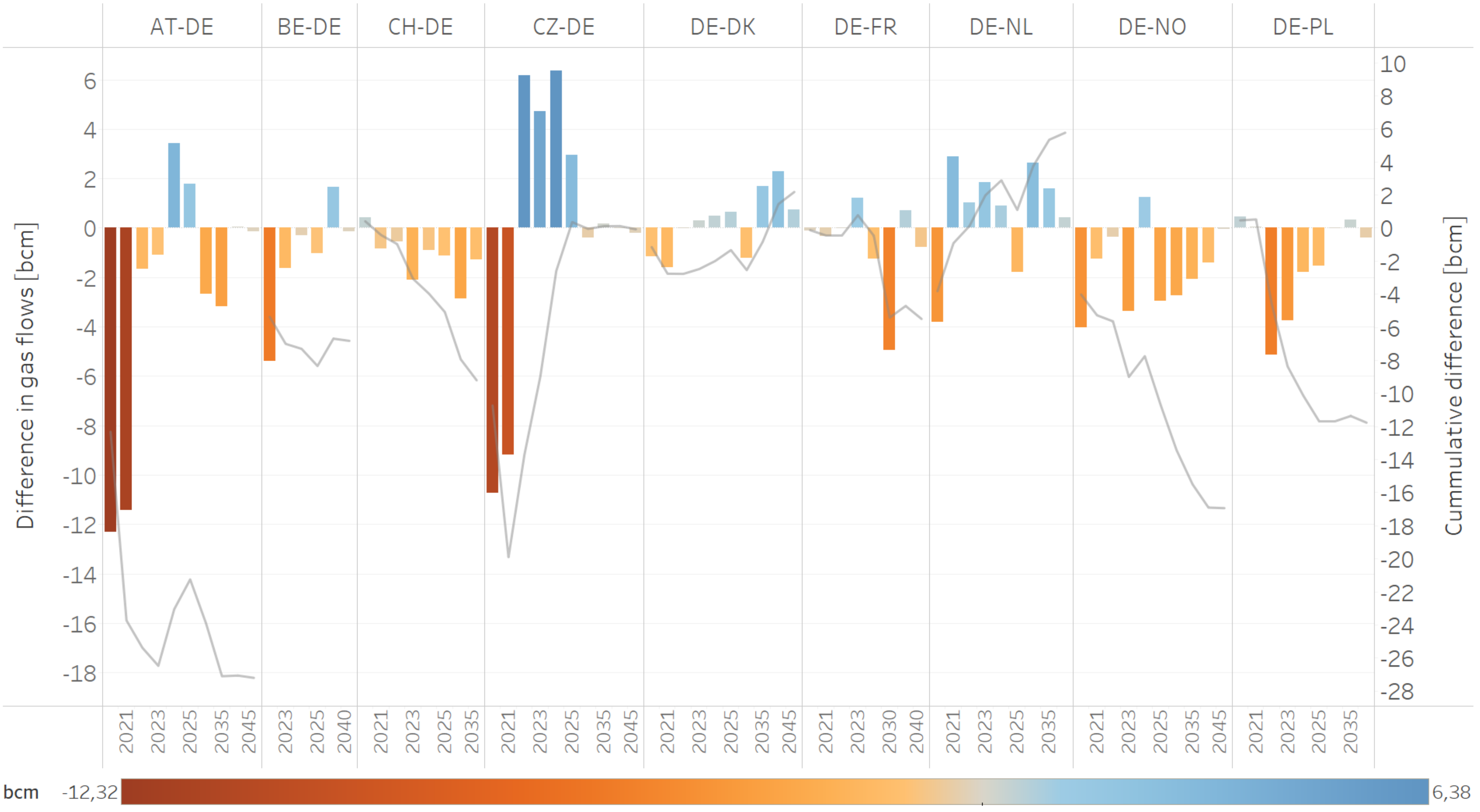
Source: Auer et al 2020

Results

- Difference in gas flows between bidirectional and monodirectional pipeline capacities

- Negative values represent increased gas flows for bidirectional capacities

- The trendline shows the cumulative gas flows



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Discussion and Conclusion

~ Cross-border flows are an important element of supply security

~ However, unidirectional flows seem to modest play a certain role in aggregate analysis

~ While trading activity differs considerably, influences on prices and quantities remain small for German markets

~ Howerver, more pronounced results could be expected for introducing the same mechanism in other regions such as Eastern Europe

~ Some inconsistencies observed, in both models

~ More in-depth analysis of scenarios requires

~ Eventually pipeline-specific analysis for each node / country