UNIVERSITY OF CAMBRIDGE | Energy Policy Research Group

EPRG research on large-scale numerical modelling of energy markets

An application to natural gas and possible extensions

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Gas Market Modelling

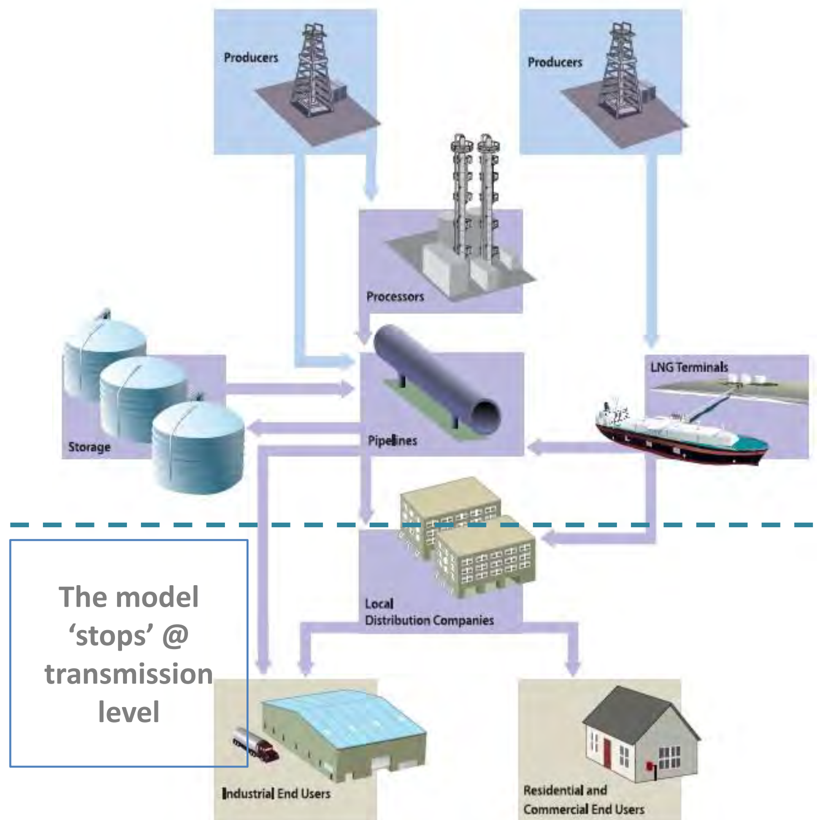
- Model is founded in concepts from:
  - Microeconomics
  - Game Theory
- Objective:
  - Systematic, evidence-based analyses of energy policies
- Features:
  - Each player maximizes profit under constraints
  - Includes gaming in the upstream gas market by large producers
  - Works under perfect competition mode too
  - Flexible and generalizable under various market assumptions and data inputs
  - Takes into account both operational and investment decisions
  - Covers entire gas value-chain from production to transmission level

Gas Market Modelling

- Model outputs at different time resolution and modelling horizon:
  - Cleared gas prices and consumption
  - prices for gas transmission services and LNG services
  - Gas trade quantity between contracted parties
  - Production quantities at each production field (depending on data availability)
  - Storage withdrawal/injection quantities
  - Gas flows for both LNG and pipeline
  - Investment in gas infrastructure facilities (production, pipeline, LNG, storage)

The gas market model: an application to gas storage markets

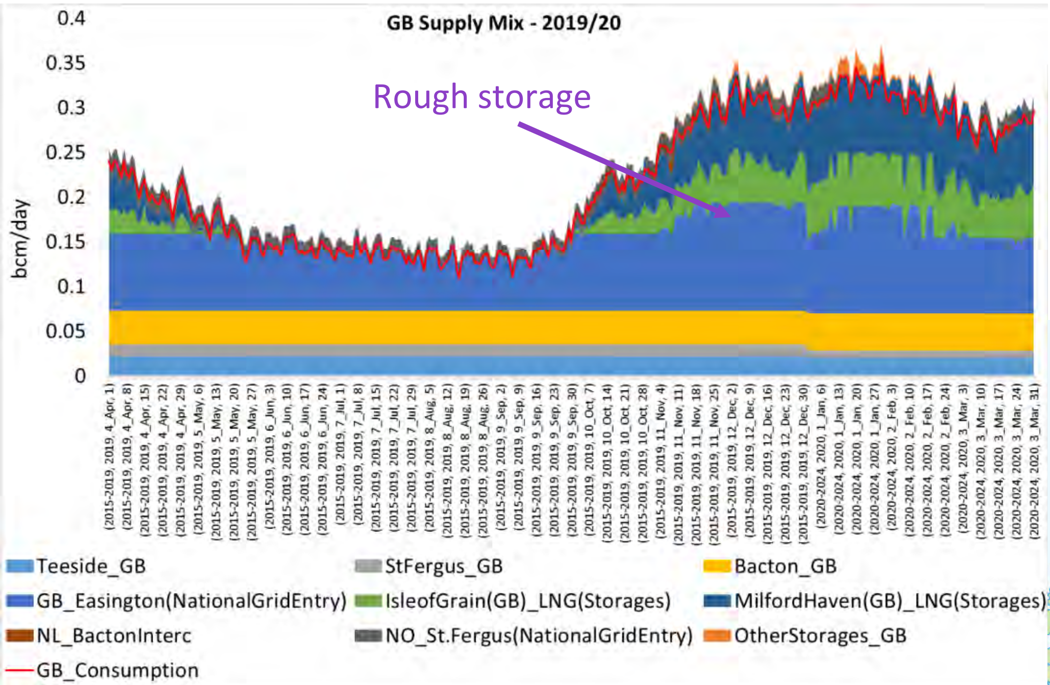
- **Geographic scope - Global**
  - Main producing countries, such as Russia and Qatar are explicitly represented in the model as separate supply 'nodes'
  - Other producers are aggregated into regions, e.g., North America (USA, Canada and Mexico) etc.
  - Europe (EU27+GB) disaggregated into national MS markets (wholesale level)
  - Other demand centers are aggregated to regional level, such as Middle East, or JKT (Japan, S. Korea & Taiwan)
- **Time Resolution - Daily**
  - We run the daily model for 365 time periods (days) for representative years
- **Supply chain**
  - Covers entire supply chain down to the transmission level, i.e., distribution is not taken into account
  - Represents production, transit, demand, LNG and gas storage facilities



Representing the European transmission network

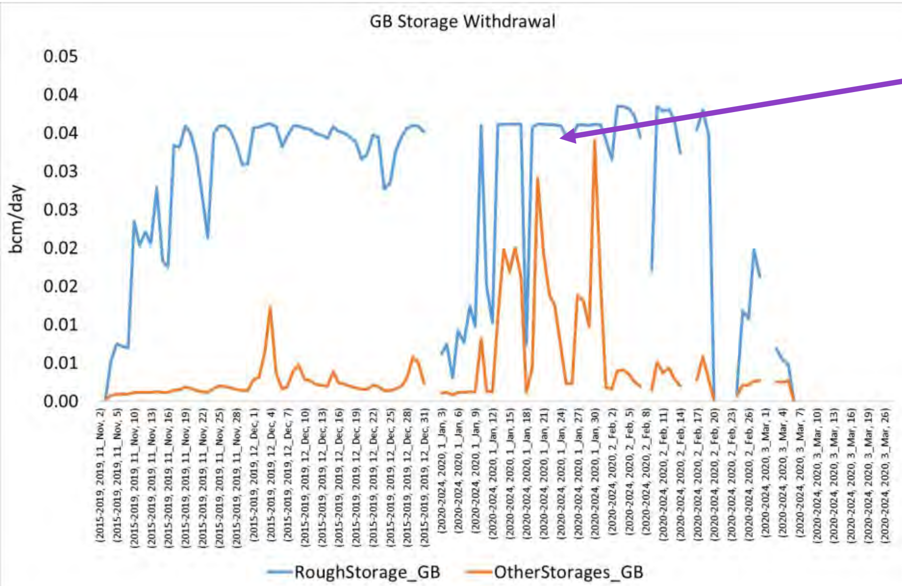
- **EU cross-border transmission capacities & tariffs**
  - The model incorporates <u>ALL existing cross-border interconnector points (IP), as they are reported by ENTSO-G '2015 Capacity Map'</u>
  - New cross-border capacities and LNG regas capacities in EU were added in the model based on their FID status - those projects which took FID as outlined in ENTSOG's 2015 TYNDP report were added in the model with start time & capacities as reported by these projects.
  - For the transmission cost structure we assume existing tariffs as reported in ACER's latest Market Monitoring Report (2015)
- **Storage capacities & costs**
  - All existing storage sites were aggregated to country level (i.e., each country/market area has one storage 'node' and hence no differentiation between types of storage; further disaggregation down to individual storage site is possible, but not necessary, as such, for the purpose of this analysis - -> see next slide)
  - New storage facilities will also be taken into account according to their FID status (as reported in ENTSOG's 2015 TYNDP)
  - Marginal cost of different types of storage is based on public information

Results from the model for 2019/20 storage year - GB

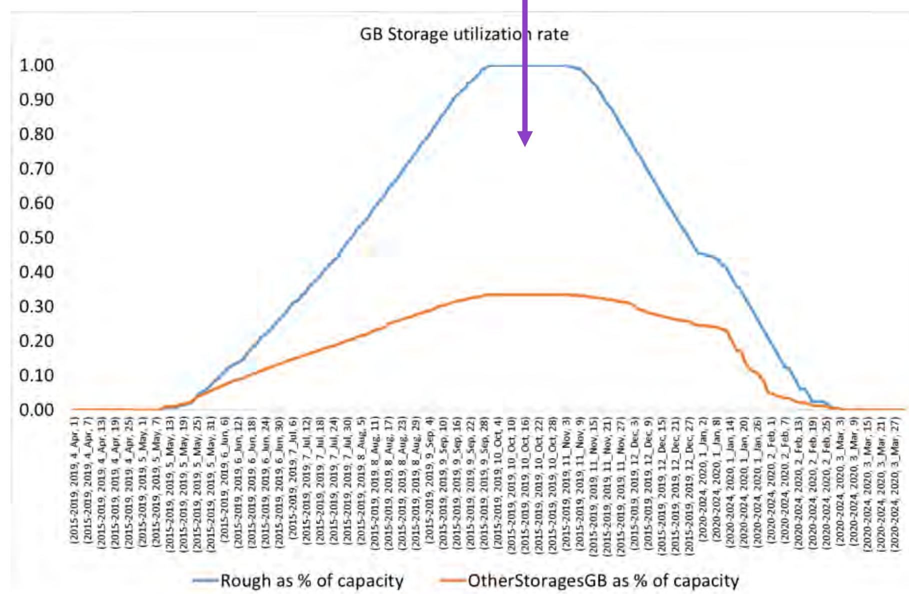


- UKCS & NCS are baseload
- LNG, imports from the continent (Netherlands) and storages as peaking options

Results from the model for 2019/20 storage year - GB



- Entry/exist charges to/from Rough storage is lower than for other storage assets therefore
- Rough is being called first before relying on other storage facilities in GB (mid and fast cycle storage)



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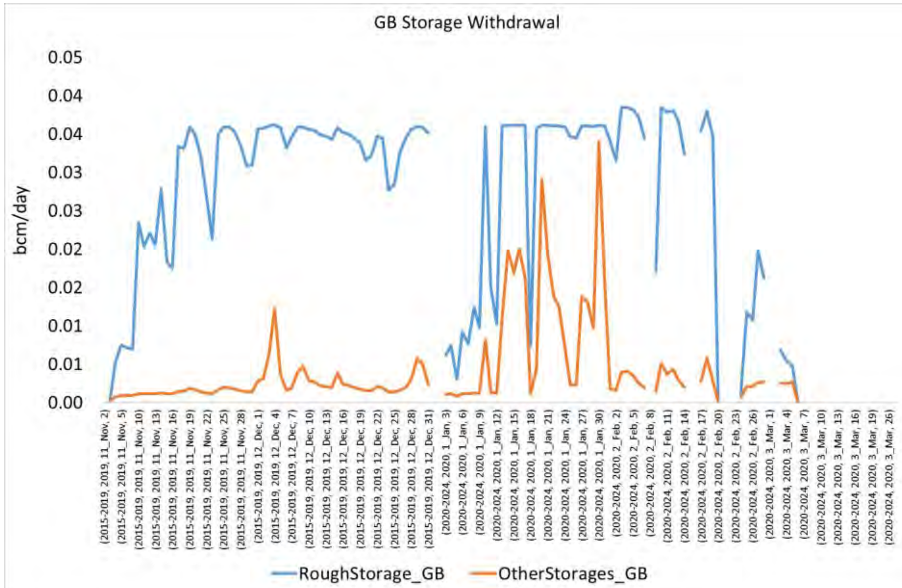
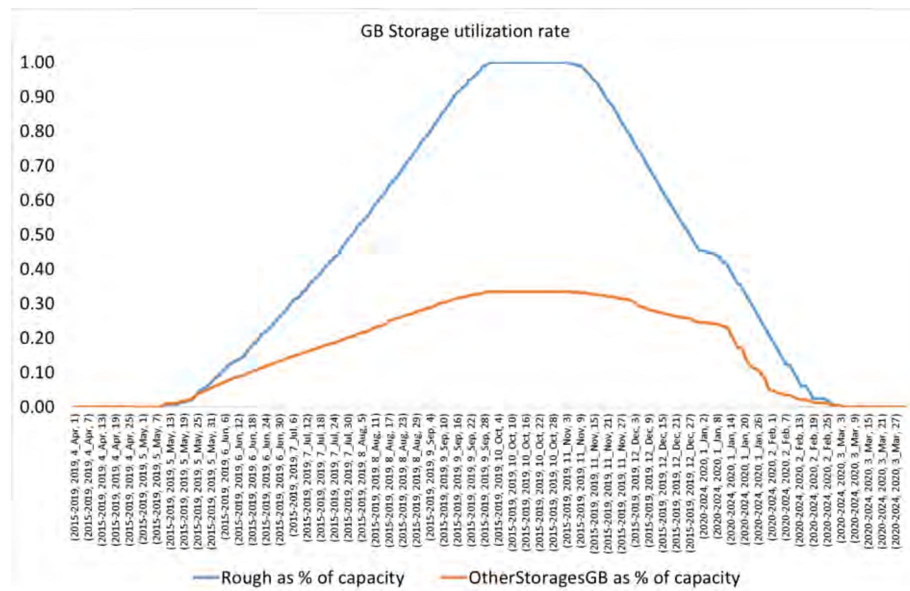
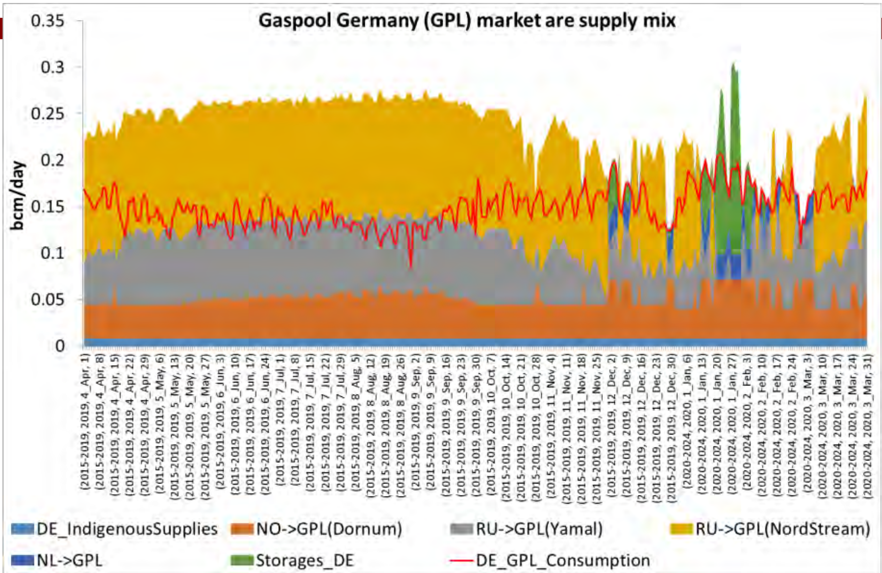
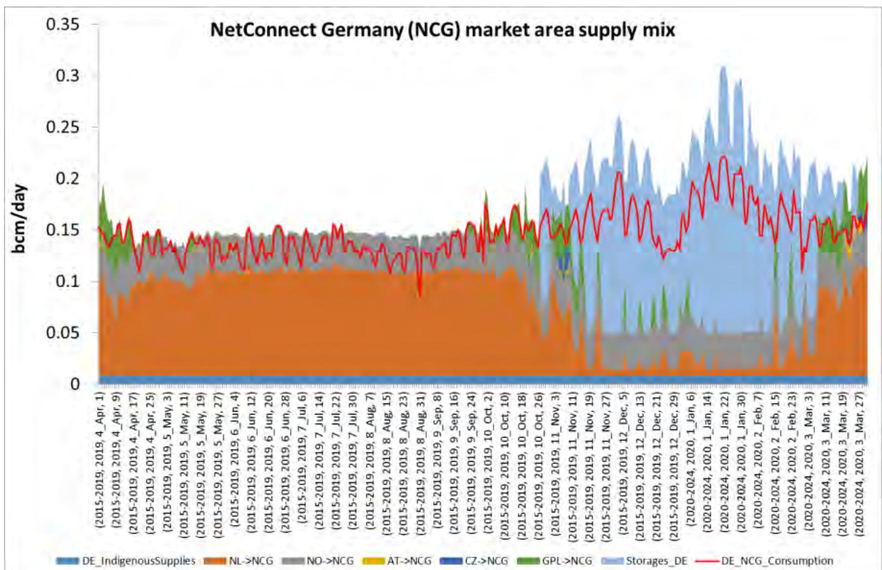


- Not all storage capacity (esp. short/mid range storage) will be fully utilised EVEN when reservation price = *SRMC+ existing entry/exit charges* → not all storage sites are able to recover capacity cost



Results from the model for 2019/20 storage year - DE





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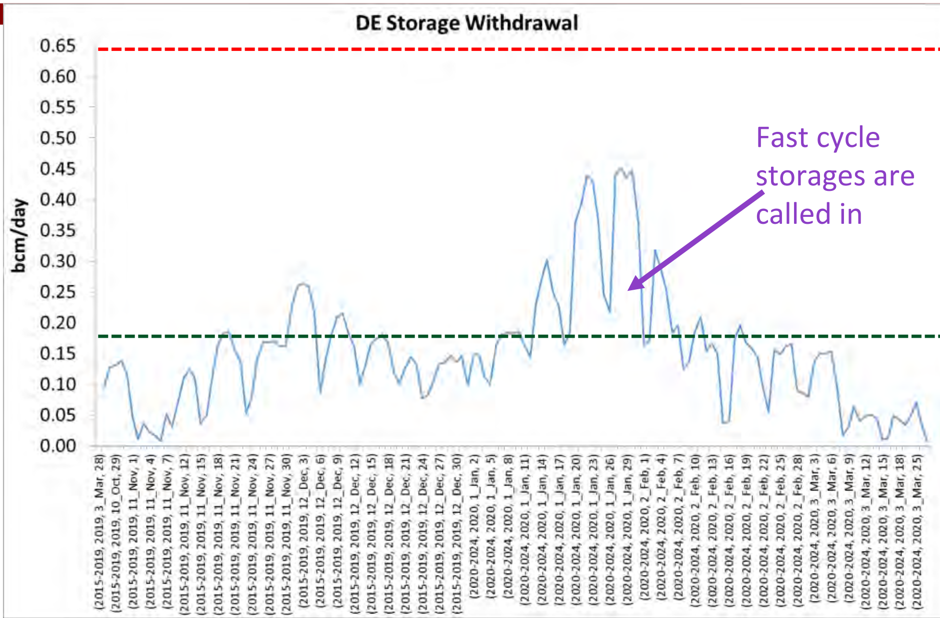
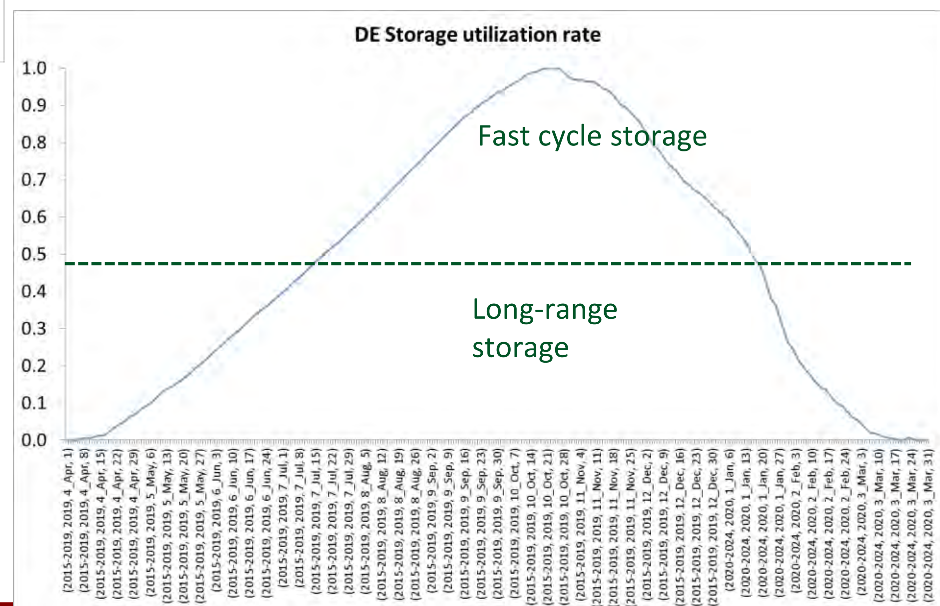


Max withdrawal rate for long-range storage + fast cycle storage

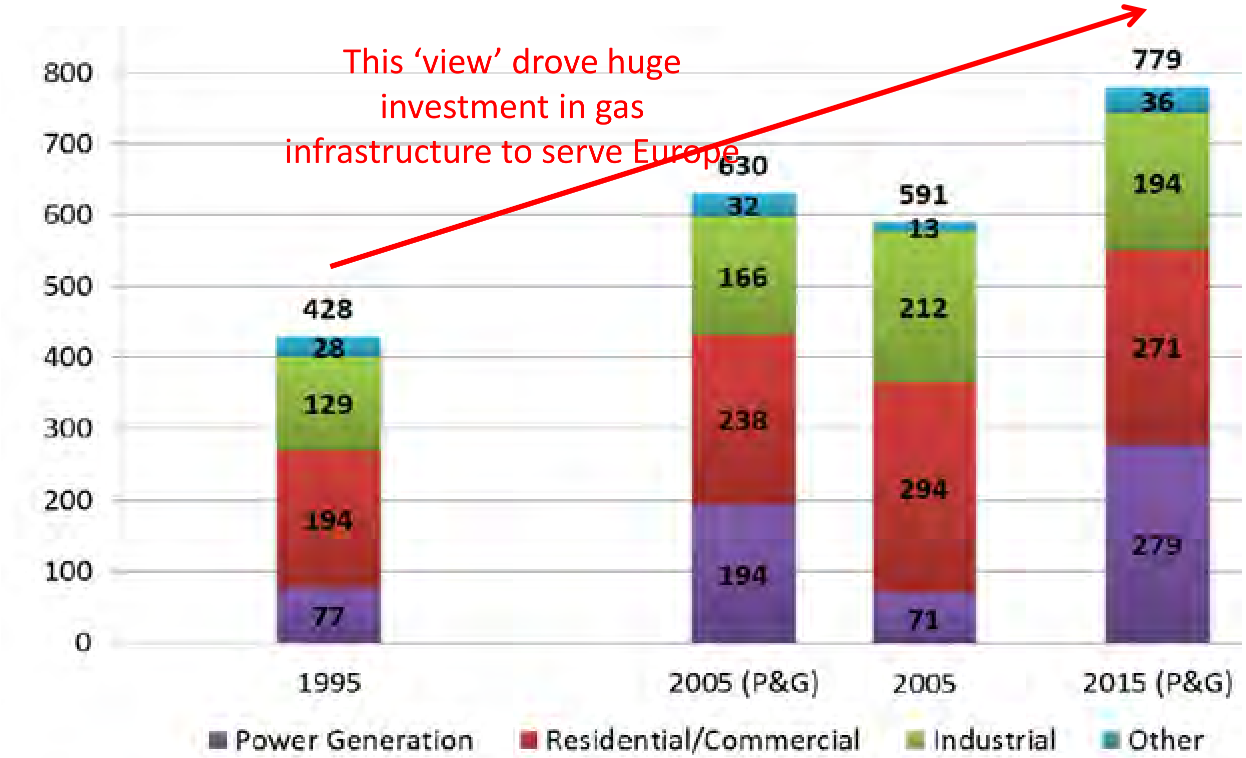
Max withdrawal rate for long-range storage

Summary:

- Setting the reservation price = *SRMC + existing entry/exit charges* encourages full utilization of storages in DE
- But there is only one day in the year when congestion rent is generated, ca. $7/tcm
- This is rather low and the overall picture is that of oversupply and that long-range storage in Germany is in competition with flexible supply from NO, NL & RU



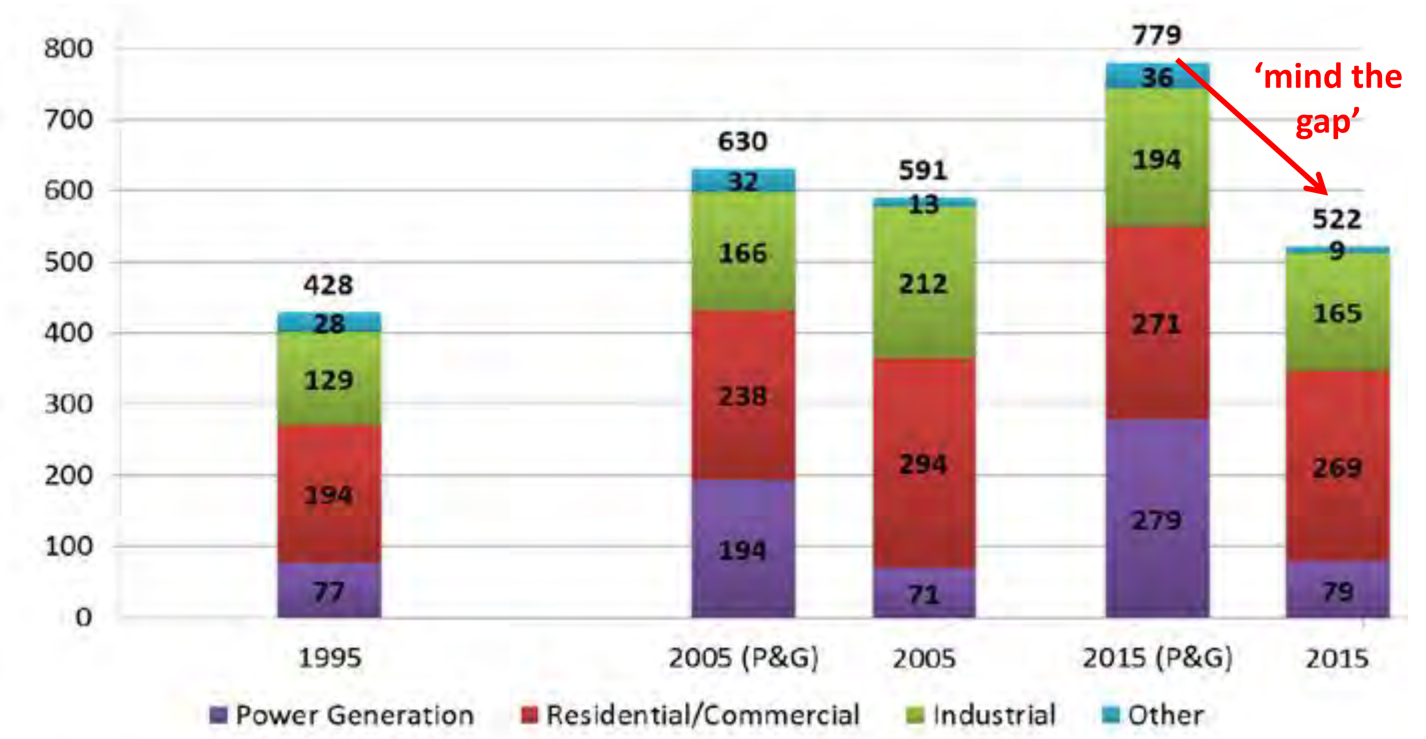
Gas demand in Europe: Expectations vs. reality



Source: Purvin and Gerts 1998 Forecast for 2015, Gazprom Export calculations

Source: Gazprom Export

Gas demand in Europe: Expectations vs. reality



Source: Purvin and Gerts 1998 Forecast for 2015, Gazprom Export calculations

Source: Gazprom Export

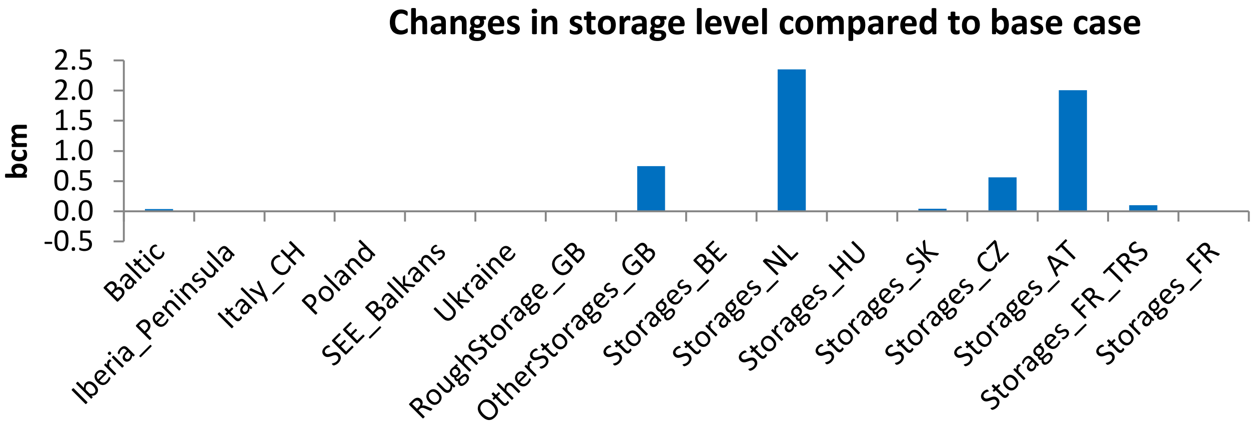
Competing sources of flexibility for DE gas market

- In order to understand sources of competition to seasonal gas storage located in Germany, we simulated 2019/20 gas year with all inputs as before BUT reducing Germany's total storage working volume by 50% of the original total capacity (base case)

- Results from these scenario, such as storage level, LNG send-out rate, Russian gas supplies through various export routes as well as total cleared gas demand, are then compared to the original results (base case)

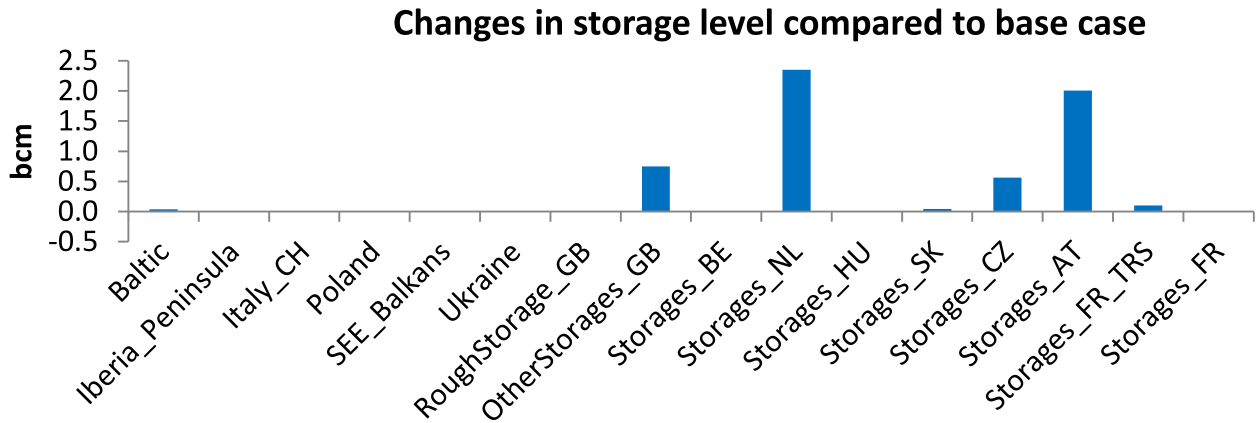
- These changes in supply mix are reported below

Competing sources of flexibility for DE gas market



Storage facilities in GB, NL, CZ & AT are in direct competition with storage in DE: when storage capacity in DE is reduced by 50%, more gas is stored in GB, NL, CZ and AT

Competing sources of flexibility for DE gas market



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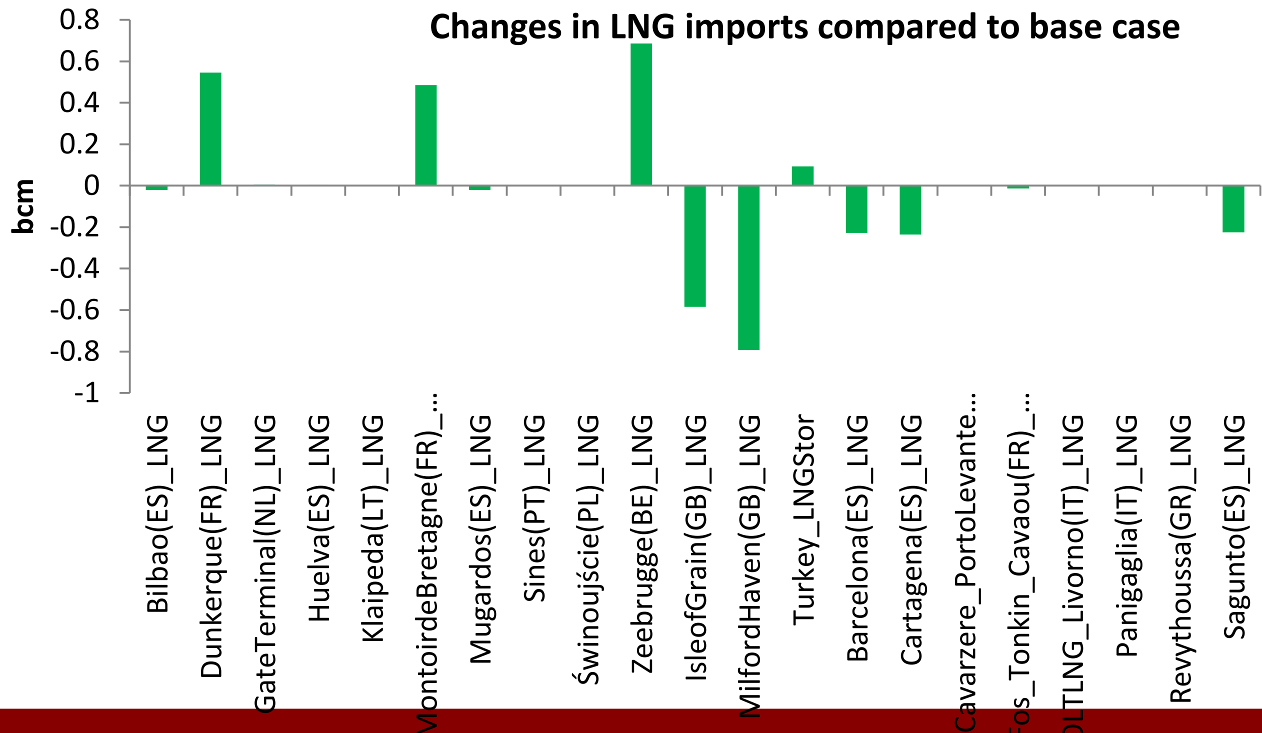
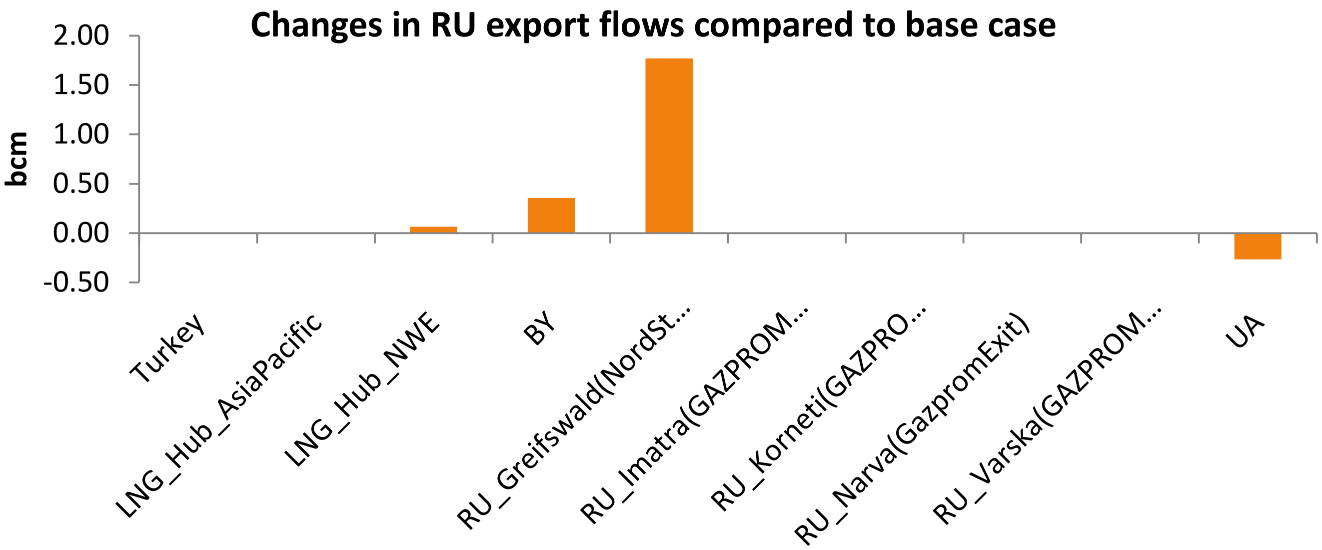


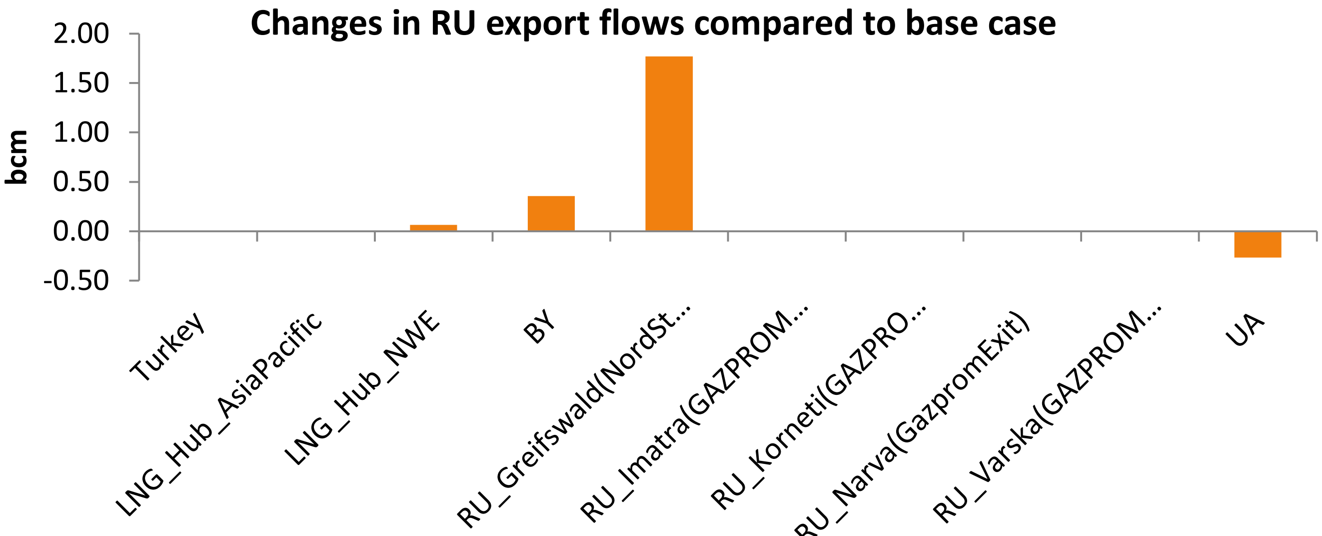
LNG to FR and BE directly competes with DE storage facilities: LNG market 're-dispatches' in response to a reduction in storage capacity in DE – less LNG is imported into GB, ES and more into FR and BE

Competing sources of flexibility for DE gas market



Russian flex gas comes mostly from Yamal & Nord Stream and less so from UA route

Competing sources of flexibility for DE gas market



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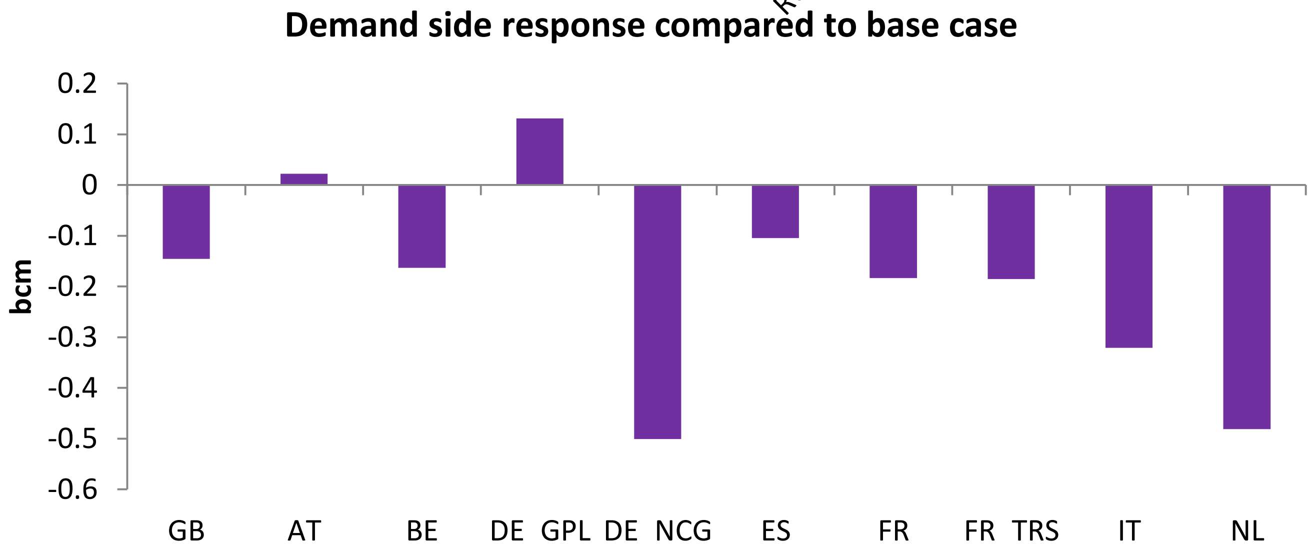


Rather strong demand response ca. 2bcm in total or 20% of entire DE depleted field capacity

Possible extensions using our modelling framework

Hydrogen supply chain

Hydrogen generation technologies	Transport	Storage
Steam methane reformation (with CCS)	Repurposing of gas distribution grid	Salt caverns
Electrolysis	New transmission lines, if needed	Pressurised tanks
Gasification (with CCS)	Possibly CCS network (CO_2 pipes + storage) if SMR and Gasification is used at large scale	Depleted hydrocarbon fields

Possible extensions using our modelling framework

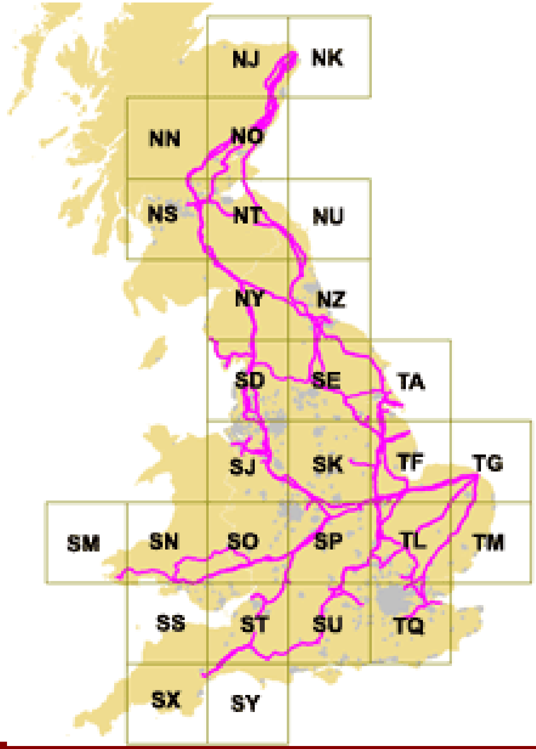
Modelling hydrogen system with electricity sector

- combining electricity modelling with a hydrogen model would systematically give an understanding of the trade-offs between the available policy options to support decarbonisation and the GB 2050 target (80% reduction in CO_2)
- A review of academic literature on hydrogen modelling suggest that using a whole energy system framework, in particular MARKAL and TIMES model families, is not practical in highlighting potential variations in costs of developing hydrogen sector because:
  - spatial dimension is purely represented in MARKAL models (see discussion of Dodds & McDowall (2013)); and
  - time resolution in the model may imply less accurate calculations.

Possible extensions using our modelling framework

Modelling hydrogen system with electricity sector – <u>contribution of our modelling framework</u>

1. *The ability of the model to 'construct' or invest in hydrogen/CO_2 network in a spatially detailed manner.*



Possible extensions using our modelling framework

Modelling hydrogen system with electricity sector – contribution of our modelling framework

2. *Combined modelling of electricity and hydrogen system*

- Why it is important to include electricity in a hydrogen model?
  - the optimal level of offshore wind investment could be higher when we model the two systems simultaneously.
  - allows us to assess the impact of various hydrogen technologies on electricity market prices
  - Another scenario which would impact electricity market, possibly in the opposite direction to the previous example, is a scenario of high wind penetration with and without hydrogen

Possible extensions using our modelling framework

Modelling hydrogen system with electricity sector – expected outputs from the model

- **Hydrogen generation technologies**: sizing, location
- **CCS infrastructure**: sizing and location;
- **Hydrogen storage:** optimal utilization of different type of storage given input assumptions around storage capacity, injection and withdrawal rates and associated operational and investment costs
- **Transporting of hydrogen:** sizing and location
- **End-use demand for hydrogen**: the model will satisfy this demand, disaggregated by sectors of economy as well at different location along a network.

As long as we have data and inputs about possible demand, location of these demands, generation technologies, costs and possible capacities, the model will build up the hydrogen system and operate the electricity market efficiently to meet demand for heat and electricity in the UK, while minimising total system costs.

Possible extensions using our modelling framework

Modelling hydrogen system with electricity sector – <u>example of questions that the model can answer</u>

- cost implications be for different sized hydrogen grids
- cost implications for a centralised hydrogen production model versus a decentralised model
- hydrogen roll-out scenarios, cost implications and effects on other electricity and gas systems
- hydrogen storage requirement
- Hydrogen infrastructure requirement to transport resources through the system
- impacts of different end-uses have on the infrastructure required

Possible extensions using our modelling framework

Modelling hydrogen system with electricity sector – data on costs of hydrogen supply chain in the UK context is a challenge, not modelling

- Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource (Pale Blue Dot, 2016)
- DECC Desk study in the development of a hydrogen-fired appliance supply chain (Kiwa, 2016)
- H21 Leeds City Gate (NGN, 2016)
- The role of hydrogen storage in a clean responsive power system (ETI, 2015)
- A review of low-carbon vehicle and hydrogen end-use data for energy system models (Dodds and McDowall, 2012)
- A review of hydrogen production technologies for energy system models (Dodds and McDowall, 2012)
- A review of hydrogen delivery technologies for energy system models (Dodds and McDowall, 2012)

- **Some data exists, most derived in the context of other countries, e.g., US or regional studies, NO systematic review of the body of evidence for hydrogen supply chain applied to the UK context exists.**