DIW BERLIN

Strommarktgruppe

Market power, fuel subsitution and infrastructure – A large-scale equilibrium model of global energy markets

DIW Discussion Paper 1370, 2014

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Berlin, July 8, 2014

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The conundrum of climate change mitigation, environmental policy and the energy system

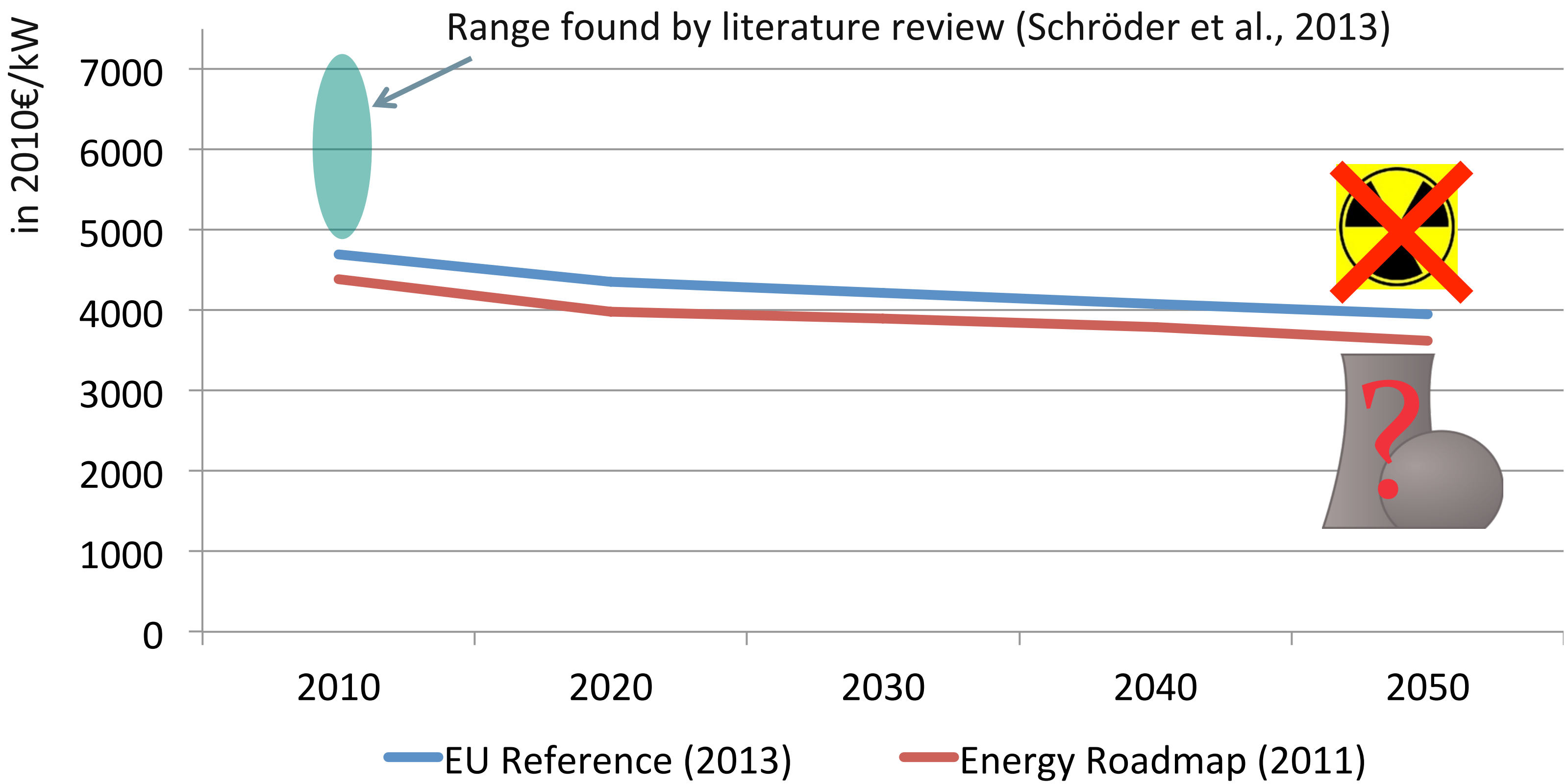
Analysing energy scenarios and the impact of climate change mitigation policies requires large-scale numerical models

Frederic Edwin Church – The Iceberg (1891)

Picture from Wikimedia commons

(downloaded July 2, 2014)

Cost estimates for nuclear power plants vary widely and the assumptions have substantial impact on model results



Assumptions on capital cost development for nuclear generation capacity

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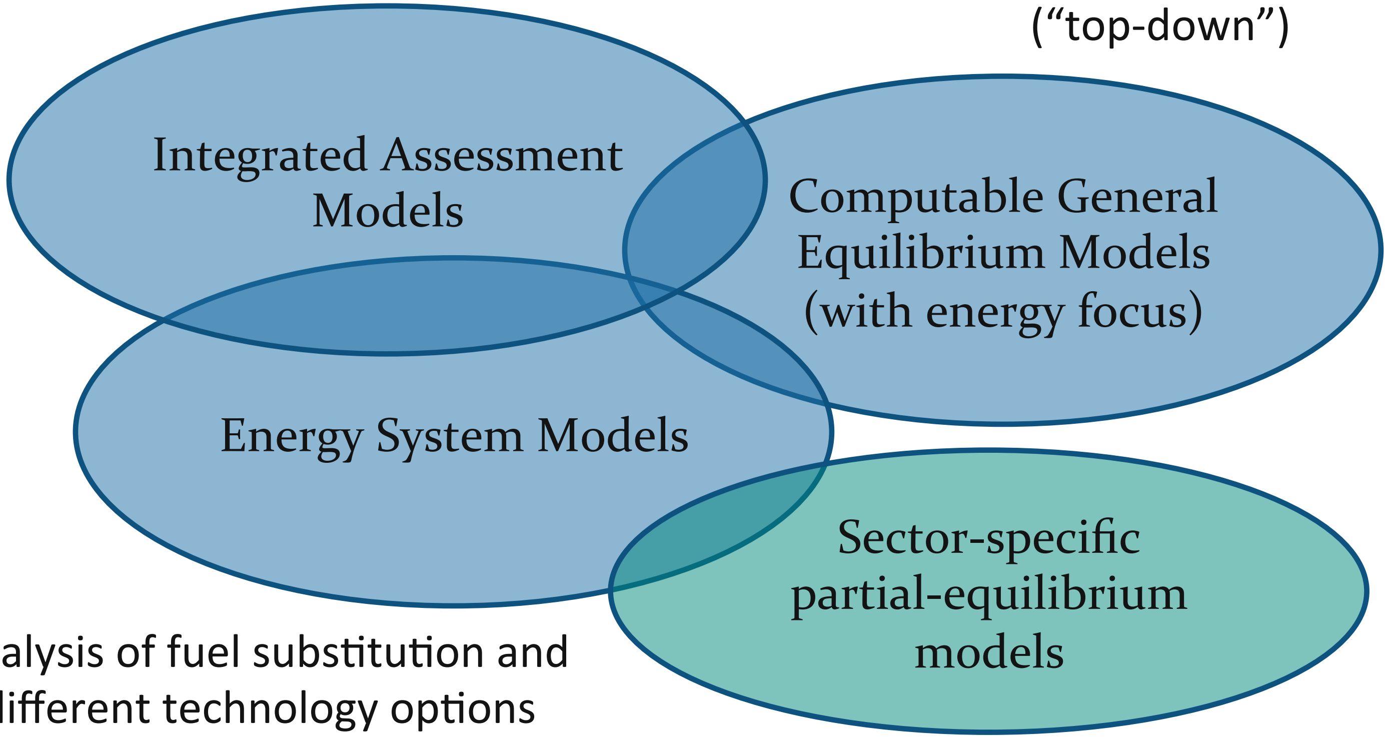
Model types currently applied in the policy arena

A crude attempt at model classification

Effects between the energy system and climate/environmental aspects

Effects between energy markets and the wider economy (“top-down”)



Analysis of fuel substitution and different technology options (“bottom-up”)

Detailed analysis of market power and infrastructure constraints

Examples of our sector-specific modelling work

Natural gas

Holz, F., C. von Hirschhausen and C. Kemfert. A Strategic Model of European Gas Supply (Gasmod). *Energy Economics* 30(3):766-788, 2008.

Egging, R., F. Holz and Steven A. Gabriel. The World Gas Model – A multi-period mixed complementary model for the global natural gas market. *Energy* 35:4016-4029, 2010.

Coal

Haftendorn, C. and F. Holz. Modeling and analysis of the international steam coal trade. *The Energy Journal* 31(4):201-225, 2010.

Crude oil

Huppmann, D. and F. Holz. Crude Oil Market Power – A shift in recent years? *The Energy Journal* 33(4): 1-22, 2012.

Electricity

Leuthold, F. U., H. Weigt and C. von Hirschhausen. A large-scale spatial optimization model of the European electricity market.
Networks and Spatial Economics 12(1):75-107, 2012.

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Developing a large-scale energy system model from scratch

Our own motivation, and what we did so far…

Why build an energy system model from scratch?

- Methodological: to bridge the gap between model classes, and to study market power in energy system models
- Educational: to understand which assumptions are implicit within IEA World Energy Outlook, EU Energy Roadmap 2050, etc.
- Policy evaluation: own scenarios, sensitivity analysis, etc.

Development history to date:

- Joint project by NTNU Trondheim and DIW Berlin, launched in 2011
- First (conference) paper published in spring 2012
- Model description discussion paper published in spring 2014
- Currently participating in Energy Modeling Forum (EMF), Round 31

Understanding the impact of climate change mitigation policies requires large-scale numerical models

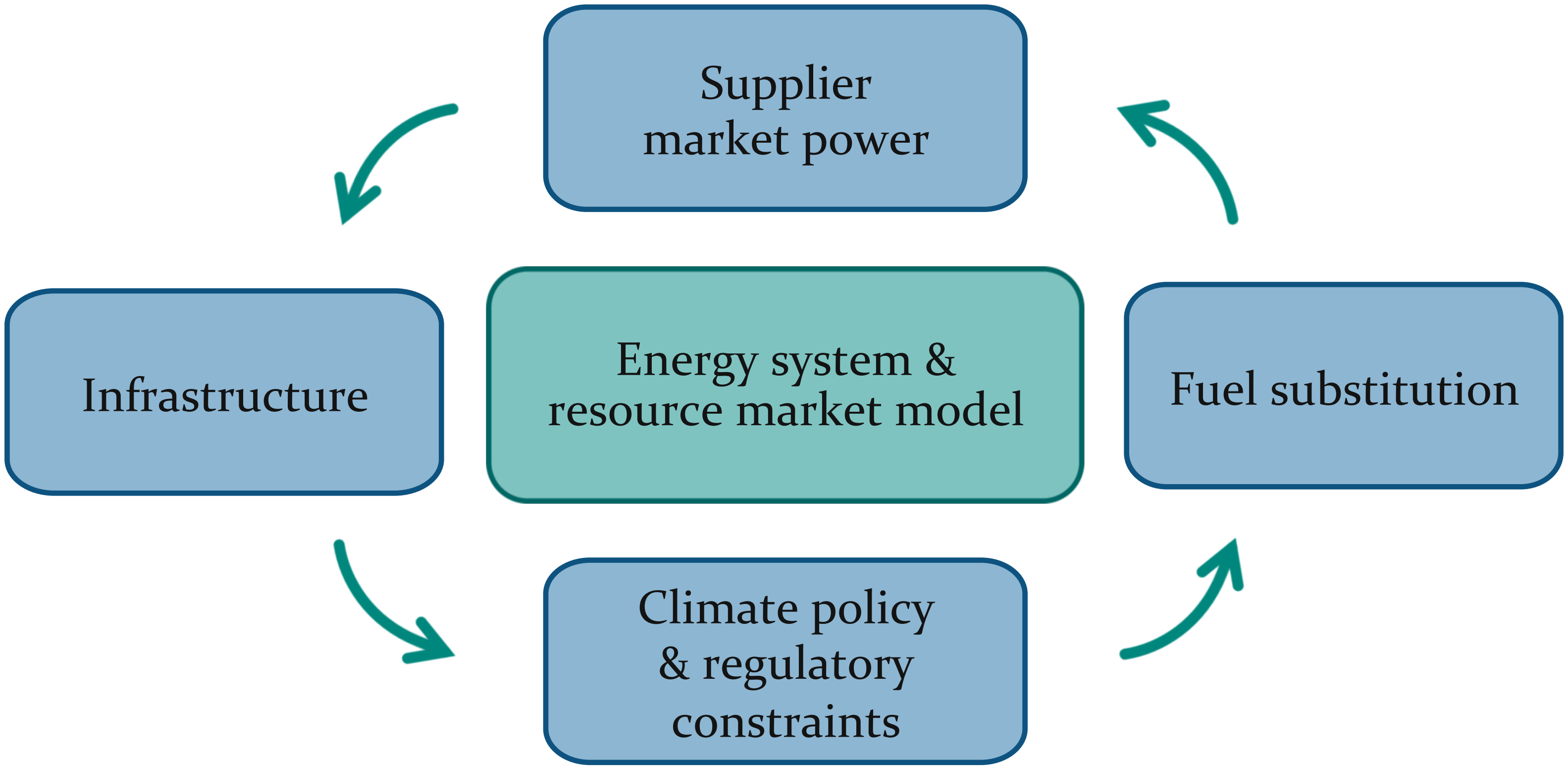
- Large-scale numerical models are widely used for scenarios and pathway simulation, as well as policy impact assessment

- But in currently used approaches, there is a divide between …

… energy system models	… sector-specific models
fuel substitution & technology options	strategic behaviour & infrastructure investment
Times-Markal (Loulou et al., 2005)	World Gas Model (Egging et al., 2010)
PRIMES (EC, 2011)	CoalMod (Haftendorn and Holz, 2010)
NEMS (Gabriel et al., 2001)	ELMOD (Leuthold et al., 2012)

The aspects covered by the multi-fuel energy market model

The multi-fuel model combines the advantages of energy system and sector-specific approaches



Short overview

Players in the model

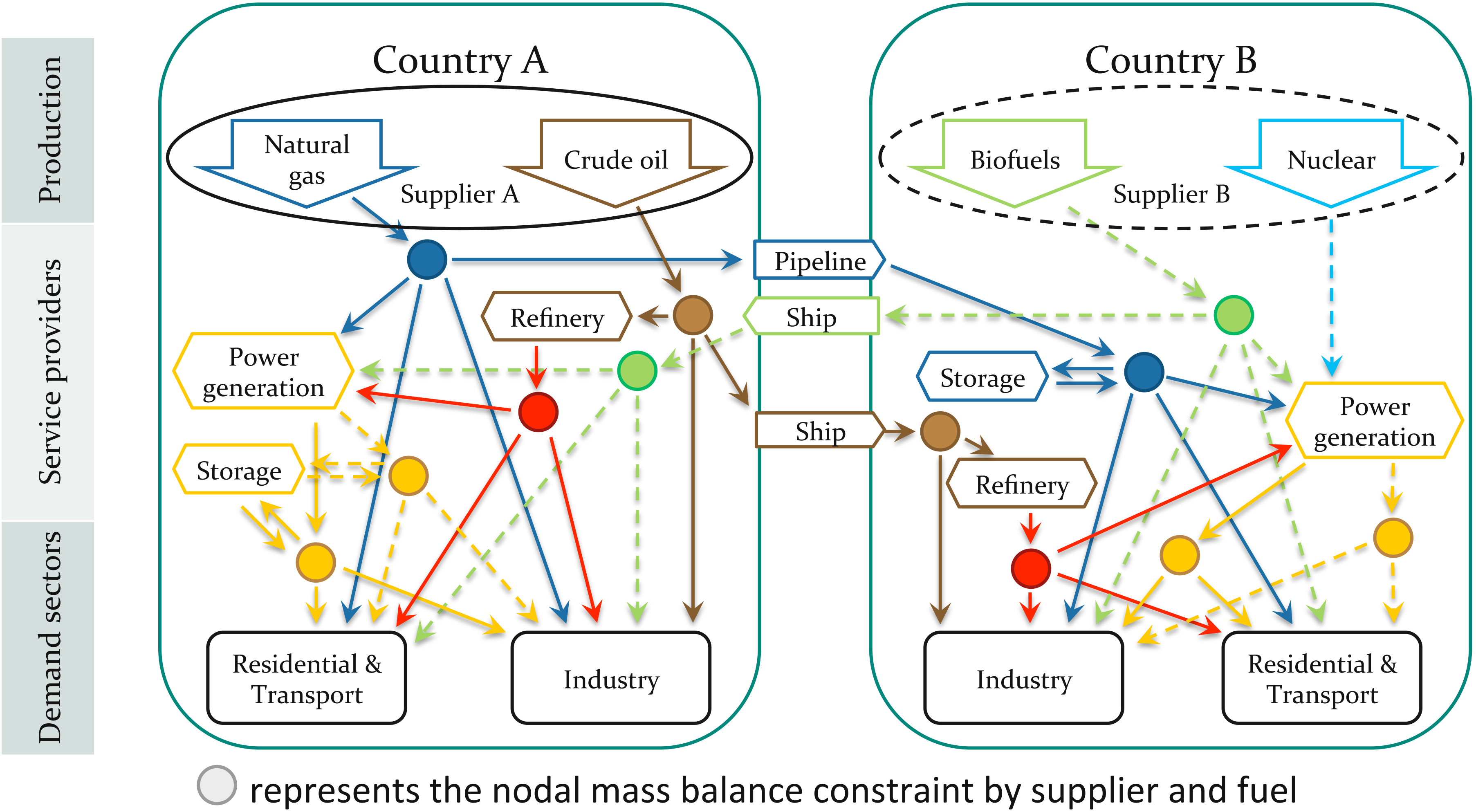
- Suppliers of fuels
- Arc operators (pipeline, ship, rail, LNG, etc.)
- Transformation technology operators (power plant, refinery)
- Storage operators (gas storage, pump-hydro storage)
- Final demand (by sector)
- Emission permit auctioneer

Solution strategy

- Take first-order (KKT) conditions of each player's profit maximization problem, coupled with market clearing constraints
- Use conjectural variations to represent market power by suppliers
- Solve for (Generalized) Nash equilibrium as Mixed Complementarity Problem (MCP) in GAMS

Illustration of the supply chain in an energy system model

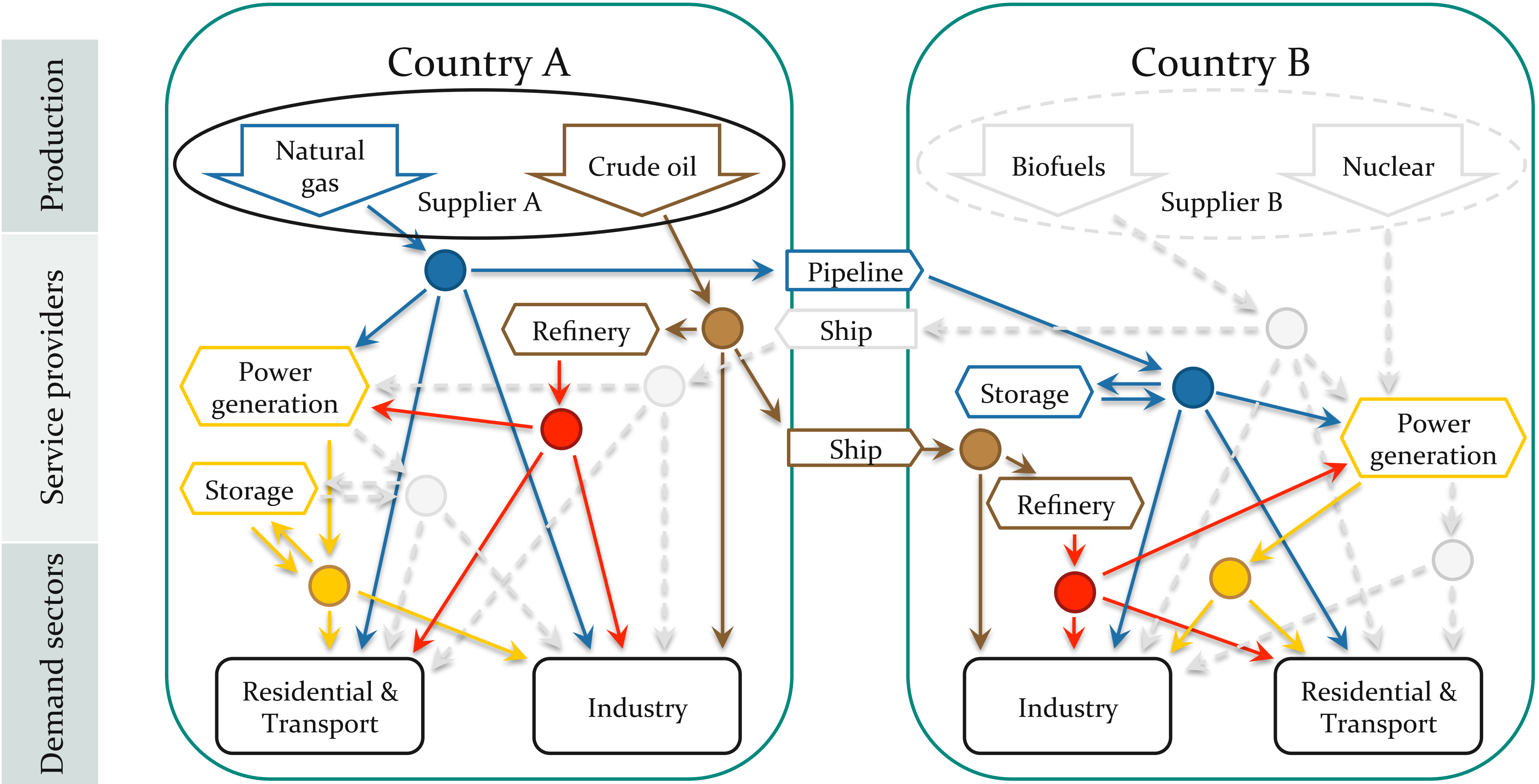
Supply chain illustration in a two-node, four-fuel setup



represents the nodal mass balance constraint by supplier and fuel

3 Illustration of the supply chain in an energy system model

Illustration of cross-fuel market power



Assumption: Suppliers remain owners of the fuel for the entire supply chain

The model implementation is flexible & scalable and the large-scale data set allows for detailed analysis

- Global coverage, represented by 62 nodes
  - 11 nodes: European Union members (or aggregates)
  - 4 nodes: non-EU European countries (or regions)
  - 13 nodes: non-European regions
  - 34 nodes: to represent the LNG chain (liquefaction & regasification)
- 10 fuels (crude oil, natural gas, hard coal, lignite, oil products, electricity, hydro, nuclear, renewables, biofuels & waste)
- 5 steps (2010 – 2020 – 2030 – 2040 – 2050)
- 2 seasons per year (winter – summer)
- 3 demand sectors (industry, transport, residential & commercial)

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The reference data set & base case

Base year data:

- Production and consumption quantities:
  IEA *World Energy Statistics* 2013
- Production and investment costs, capacities, transformation efficiencies, losses, etc. from own sector-models and data collections
- Assumptions on elasticity, seasonal variation from various sources

Projections:

- Quantities: IEA *World Energy Outlook (WEO), new policies scenario*

⇒ But it is impossible to match it exactly, because…
… the WEO doesn‘t provide enough detail
… disaggregations don‘t conform

- Potential: IEA *WEO* (*450 scenario*)*;* BP *Energy Outlook; Green-X* (EEG)

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Some numerical scenario results

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General comments and observations across scenarios

Less optimistic baseline for US fossil fuel potential

- Natural gas production increases until 2030, then starts to decline
- Crude oil production flat until 2030, then starts to increase

No prospect for nuclear or CCS

- Unless very strong policies for GHG emission reduction are enacted, we do not find substantial investment in either new nuclear power plants or carbon-capture-and-sequestration (CCS) technology

North America remains self-sufficient w.r.t. natural gas

- In all scenarios, there are virtually no imports or exports of LNG to or from North America
- But the net trading balance for crude, oil products and coal varies according to global demand shifts or resource availabitily scenarios

The model functionality & policy relevance is illustrated using three scenarios on energy and climate policy

We compare the calibrated model results to three scenarios:

- Scenario *A Shale Disappointment*

⇒ The US shale gas boom cannot be sustained (cf. Richter, 2013)

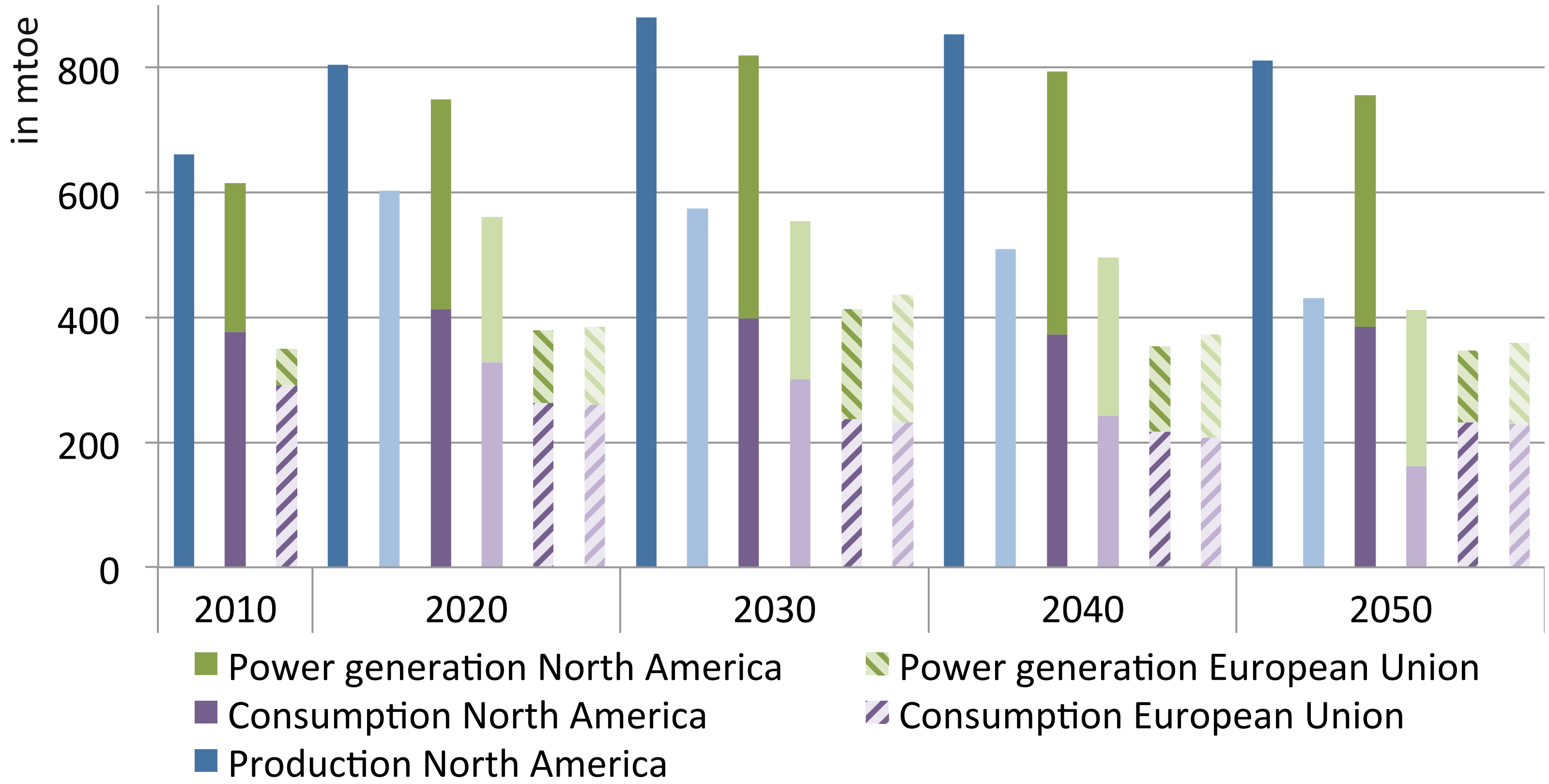
- Scenario *Truly Renewable*

⇒ The European Union enacts a reduction of CO_2 emissions by 80% until 2050 and a stronger biofuel mandate in the transport sector

- Scenario *US Policy Circus*

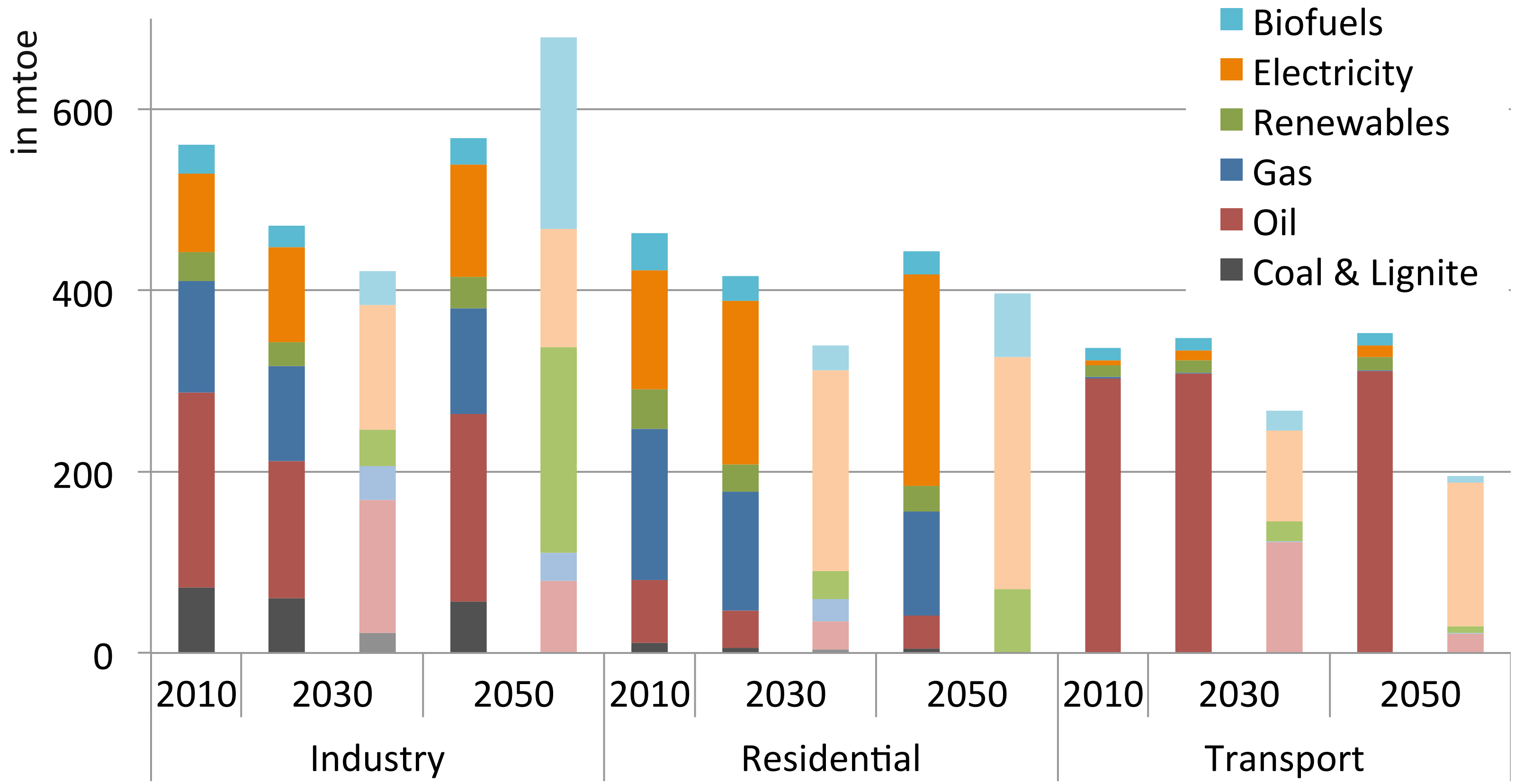
⇒ North America imposes an emission ceiling on the power sector

A reduction of shale gas availability leads to an increase of natural gas consumption in the European Union



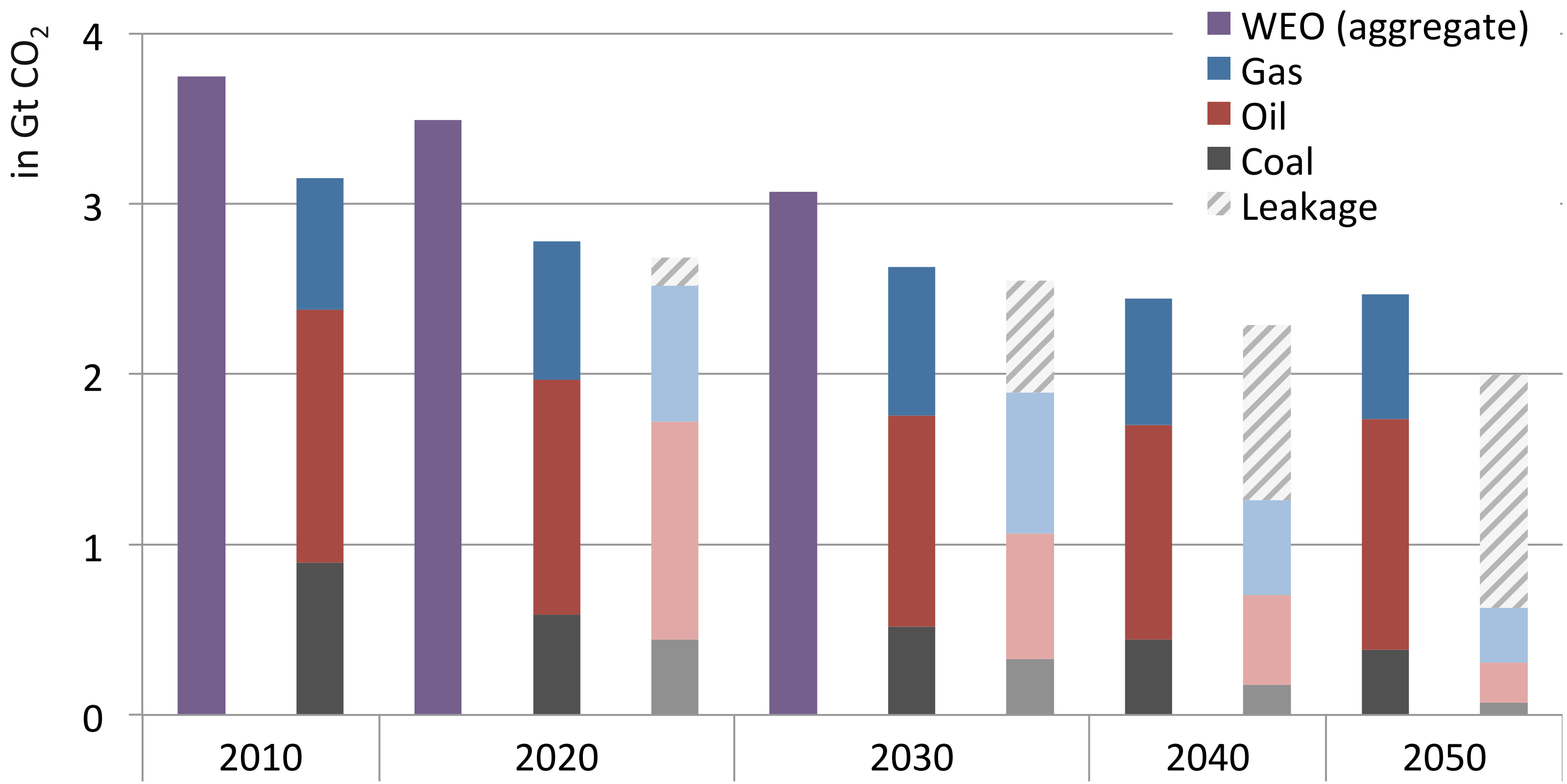
Natural gas production and consumption (Base case: dark, scenario: light)

Strong carbon reduction policies in the European Union lead to an electrification of the transportation sector



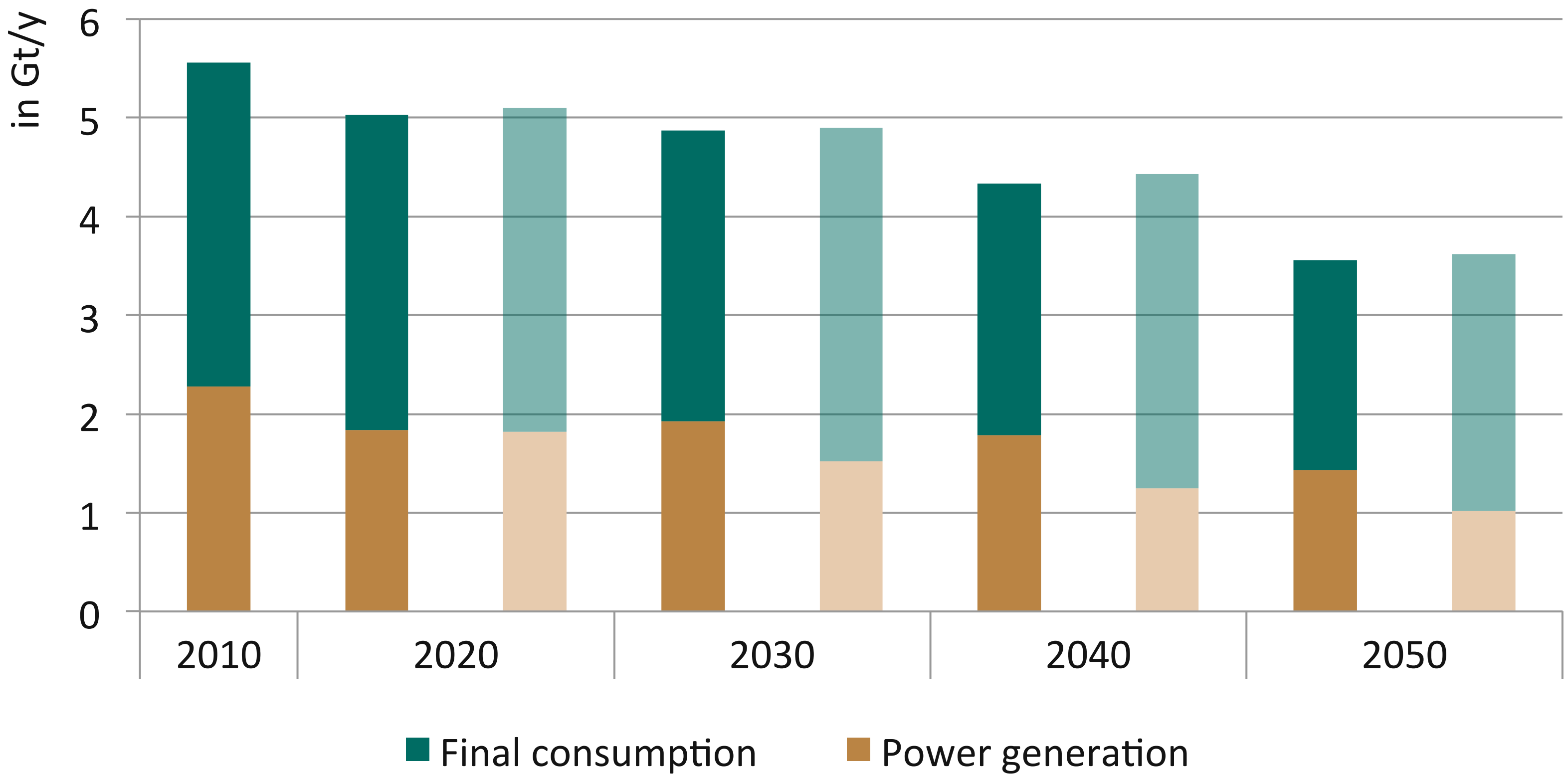
Secondary energy consumption in the European Union (Base case: dark, scenario: light)

Unilateral emission reduction policy by the European Union leads to substantial leakage to other regions



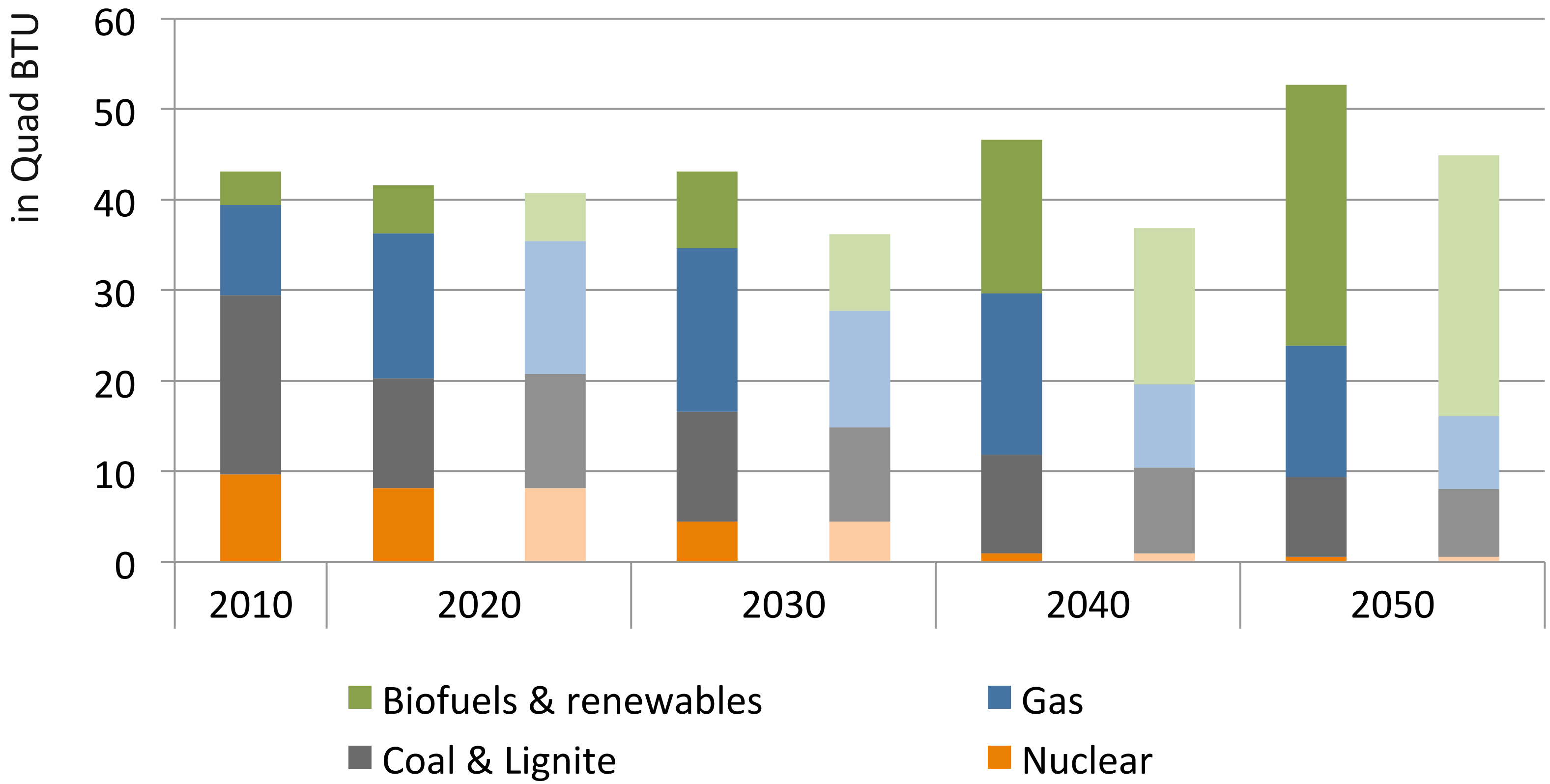
Emissions according to WEO and model results (Base case: dark, scenario: light)

A sector-specific mandate leads to higher total emissions by substituting electricity with direct use of fossil fuels



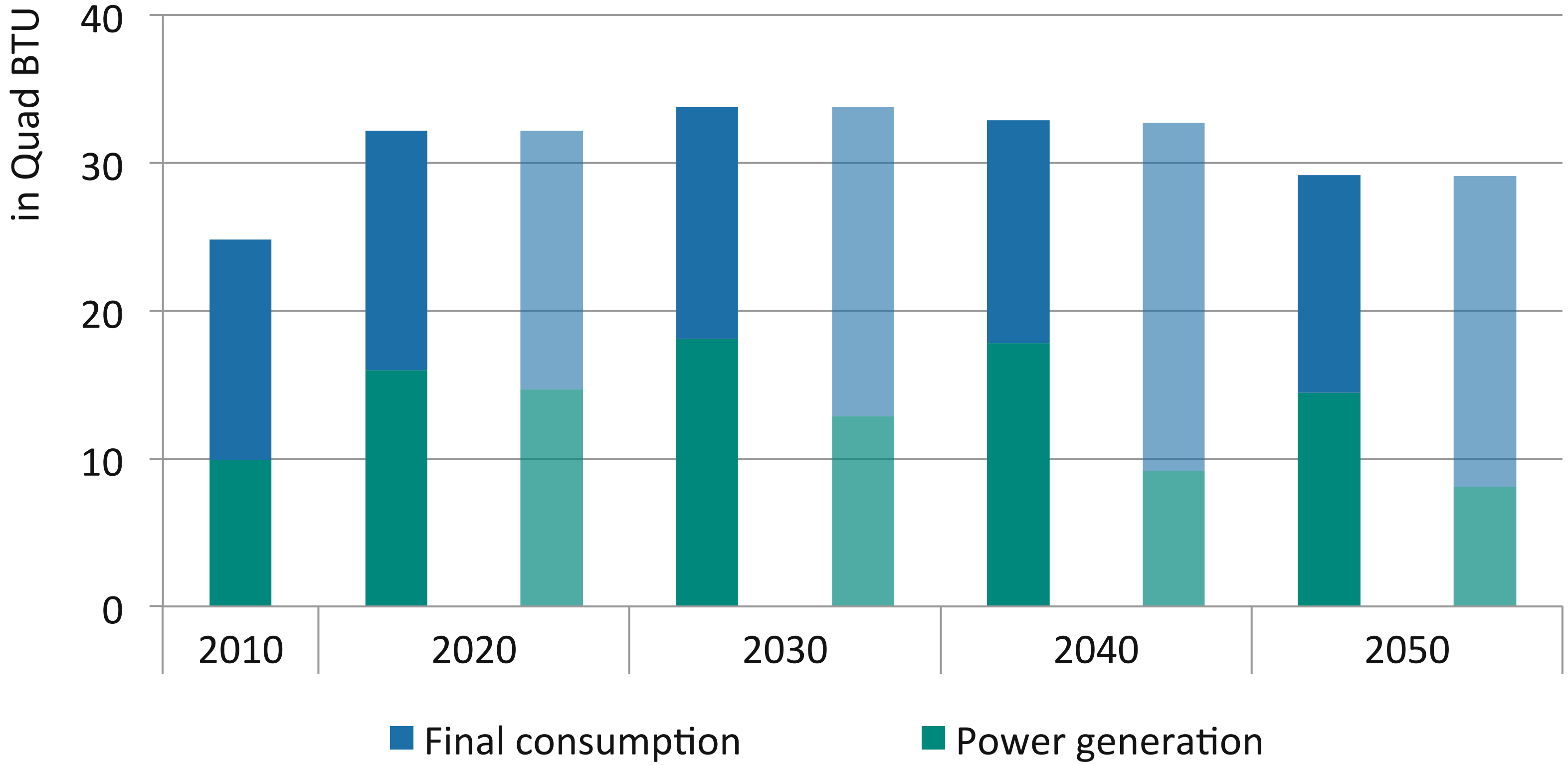
CO_2 emissions by sector (dark: base case; light colors: scenario results)

Natural gas does not see an increase in power generation as it is used directly in industrial processes instead



Fuel mix in power generation (dark: base case; light colors: scenario results)

The emission ceiling in power generation leads to a drastic shift to direct use of natural gas



Natural gas use in North America (dark: base case; light colors: scenario)

The multi-fuel model is a first-of-its-kind "proof of concept" to a more comprehensive approach to energy modelling

- Methodological advances:

⇒ Combining market power, infrastructure considerations and fuel substitution in an integrated large-scale partial-equilibrium model

- Policy relevance:

⇒ The model will be used in the analysis and impact assessment of various energy, climate and emission reduction policies

- Going open-source?

Energy efficiency offers the biggest potential for carbon reduction, but poses methodological and practical hurdles

- The "old approach" to energy system modelling

⇒ Assume some exogenous energy demand, find least-cost supply

- Energy efficiency promises an easy way to decarbonize energy supply

⇒ But we have to capture and quantify the "rebound effect"

⇒ Subjective discounting by final demand and incentive compatibility

- Implementing energy efficiency properly is not straightforward

⇒ How to properly formulate investment in energy efficiency in a sufficiently aggregated model?

⇒ How to find data to parametrize the model?

Thank you very much for your attention!

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