INTEGRATING ELECTRICITY AND NATURAL GAS PLANNING: LINKING MODELS AND ASSESSMENT OF RECIPROCAL EFFECTS

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Outline

1. Background and motivation: gas-electricity links
2. Objectives and Research questions
3. Electricity and Natural Gas planning models
4. Models linkage, interaction and implementation
5. Results and insights
6. Conclusions and future work
Link: Gas to electricity

• Amount of gas used to generate electricity
  • Demand for gas: long-term contracts and short-term nominal (daily) intakes

• Gas supply infrastructure based on geographical location
  • Infrastructure (production fields and pipeline network) to deliver gas at certain nodes
  • Gas power units dependency on gas transmission infrastructure

• Gas market prices influence the investments in the electricity generation mix
  • Gas price hikes could push-up the marginal cost of gas units
Link: Electricity to Gas

• Compressors electricity consumption (power for compressors)
  • E.g. Compressors at Kollnes Gas processing plant consumed 1TWh/y
• Short term demand (wind/solar variable output) for gas may trigger gas network issues and limit gas flexible generation
  • Might constraint the gas transmission network ability to rout gas effectively
• Expansion of the power system & location of new gas power plants
• Electricity prices (gas revenue sales) and gas contracts (long-term)
  • Might influence investment decisions on the gas network design
Literature on Electricity-Gas nexus

• Overall: various papers dealing with modeling the two systems together for short-term operations. Few consider a joint long term perspective

• Most papers focused on the security of electricity supply (gas-electricity dependency under a risk/reliability perspective)

• Integrated gas-electricity models showed reduced costs compared to individual models. But the difference is around 1% better, not much.

• Linkage: mainly on gas supply limits to gas-fired power plants and the location of the plants (effects on gas network design)
Objectives and research questions

• How investments on the gas infrastructure affects the evolution of the electricity sector and vice-versa?
  • Study gas-electricity sector coupling

• Could gas power plants compensate RES fluctuations without creating instability in the gas transmission network?
  • Effects of short-term effects on long-term investment decisions
  • Coping with gas maximal demand vs. level of utilization
Gas planning model: RAMONA

- Mixed integer Optimization – maximizing social surplus
- 2010-2050 time horizon, 5 year granularity
- 40 nodes "countries", 34 European and aggregated regions for the rest of the world (e.g. Russia, Asia, etc)

Maximize social surplus
Market price * volume sold
Less Investment costs
Less Operational costs

Subject to:
- Production & flow limits
- Market demand
- Mass balance
- Investment enables capacity
- Etc…

Model Output:
- Pipeline investments
- LNG investments
- Production
- Gas Flow
Electricity investment model: EMPIRE

European Model for Power system Investment with (high shares of) Renewable Energy
- Central planner viewpoint: minimizing net present value of investment & operational cost
- Investments in generation and cross-border transmission capacity

**EMPIRE model spatial detail**

**Modeling assumptions**
- Perfect competition (system cost minimization formulation)
- Inelastic demand
- Generation capacity aggregated per technology (i.e. do not model individual plants)
- Investments are continuous
- Lines are independent (i.e. transportation network)
- Perfect foresight about fuel prices, carbon price, and load development.
Multi-horizon Stochastic programming framework

- Long term investments vs short term dynamics (operations) under uncertainty
  - formulated as a sequenced two-stage stochastic program
- Perfect foresight in the long-term
  - Fit to analyze the energy system transition for a pathway scenario

- $x_i$: investments in period $i$ (2015, 2020, ..., 2050)
- $y_{i\omega}$: Operational variables (dispatch, flows, etc.) period $i$, stochastic scenario $\omega$
EU case study setup

• Gas infrastructure planning:
  • ENTSOG PCI projects selected for 2020-2035, which ones to prioritize?
  • Follow decarbonisation targets (PRIMES reference case)
  • Follow PRIMES and ENTSOG gas demand & productions outlooks
  • RAMONA outputs: Pipeline and LNG capacity expansion

• Electricity infrastructure planning:
  • Follow decarbonisation targets (PRIMES reference case)
  • Inputs from IEA reports and outlooks (e.g. long-term fuel prices)
  • Assumption: CCS development in 2040-2050 and open to “high” transmission expansion
  • EMPIRE outputs: Investments in electricity generation and transmission; Gas expansion; and capacity factor of Gas units
Gas planning model results

- Russia-Ukraine gas constraints
- Prioritize gas intake from Africa
- LNG expansion: Greece and Croatia
- New 2020-2025 suggested cross-border connections:
  - Bulgaria: GR-BG, BG-RS, and BG-TR
  - Poland corridor and Baltic countries
- Other investments: LNG Ireland and Spain-France connection
- In short, total new investments:
  - New Cross border capacity: 2900 GWh/day
  - New LNG Capacity: 385 GWh/day
  - Total Investments: 6.4 billion euros
EMPIRE results
Gas-Electricity reciprocal effects

- Gas capacity expansion: Switzerland, Poland, Belgium, Germany

- Belgium & Germany - Mainly used for baseload operation (high utilization)

- Switzerland & Poland - low utilization, frequent cycling, steep ramping
Conclusions and Future (ongoing) work

• 2025-2030 critical years for the EU energy transition
  • The decarbonization analysis shows that naturals gas plays an important role as a bridging fuel for possible CCS development and RES integration
• Further sensitivity analysis on the importance of gas PCI projects and include other potential projects not considered by ENTSO-G
• Multi-horizon stochastic programming provides a useful framework for modelling uncertainties at different scales: Strategic & operational

• Future work
  • Develop a common Electricity-Gas optimization framework
  • Implement a finer time resolution for RAMONA. Also implement some capacity mechanism incentives to trigger (realistic) investments
  • Test new decarbonization pathways: Restriction on electricity transmission expansion
Thank you :)  

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More about the SET-Nav project: http://www.set-nav.eu/
Project partners
SET-NAV THREE Pillars

- Combining theory of technology innovation, diffusion & spill-overs with large-scale numerical energy-economy-engineering models.
- Developing the methodological framework & technical infrastructure for effective model integration to adequately capture interdependencies across levels, energy carriers, and sectors.
FROM MACRO TO THE SYSTEM

SET-Nav integrates a wide variety of models across different levels, sectors, and spatial/temporal disaggregation.

- Feedback between the **wider economy** and the energy system
  - NEMESIS: interaction between economy, prices, energy demand
  - REMES: interaction between economy, prices, demand, trade between regions

- Scenarios of **global resource markets** and their impact on the fuel mix
  - MultiMod: global energy system, energy balance by country
  - EMPIRE / RAMONA: electricity and natural gas, investment + dispatch
  - Enertile: power sector dispatch and investment model

- In-depth analysis of **specific sectors** (electricity, gas, buildings, ...)
  - TEPES/Nexus-Security: detailed electricity power flow model
  - GGM: natural gas model for investment + dispatch, import into Europe
  - CCTSMOD: carbon capture, transport and storage, focus on infrastructure
  - INVERT: building sector energy demand model
  - FORECAST: energy demand (multiple sectors)
  - Green-X: RES policy and investment model

The methodological research question:
How to link across **multiple models**, ensuring consistency of model results and numerical convergence...