Modeling long term interactions between energy vectors: a case study for gas and electricity systems in France

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Topology of gas/electricity systems interactions

1st biomethane injection: 2015

Power-to-Gas

Natural gas

Synthetic gas

H2

Electricity production

Competition between technologies

Gas for electricity production

MIX

Gas demand

Electricity demand
~ 450 TWh/year
Similar to final electricity demand

1st biomethane injection: 2015

Pilot project - 1 MW / 2018

- Natural gas
- Electricity production
- Competition between technologies

~ 9% of total installed capacity in the power sector

Gas for electricity production

Gas demand

Similar to final electricity demand

~ 9% of total installed capacity in the power sector
Prospective approach in order to assess…

- **Technological choices**
  - Gas system (hydrogen, gas from methanation, biomethane)
  - Electricity system (gas-to-power…)

- **System operation**
  - Hourly gas and electricity mix variation
Understanding systems topology and operation: focus on the Power-to-Gas chain
Modeling challenges

- Embed system complexity:
  - Various technological pathways, from primary resources to final demand

- Determine the best configuration given various hypothesis:
  - Demand assumption,
  - Energy prices,
  - Emissions constraints,
  - …

Optimal paradigm
Our choice: TIMES model generator

Demand

Constraints

Primary Energy
- Oil
- Gas
- Biomass
- Coal
- Etc.

Available Process
- Process 1
- Process 2
- Process 3
- Process X...

Output
- Electricity
- Production of materials
- Production of services
- Heat

Technological choices

Minimization of the total discounted cost over horizon
TIMES_FR_GazElec: french gas/electricity system joint optimisation model

Joint work between two PhD students:
- Jérôme Gutierrez (CMA)
- Rémy Doudard (CMA/GRTgaz)

Electricity system modeling (electricity final demand)

Gas system modeling (gas final demand)

Power-to-gas chain modeling

Detailed representation of power plants

TIMES_FR_GazElec
12 months, 2 representative days (Sem/We), 24h (576 timeslices)
## Definition of long-term constraints

<table>
<thead>
<tr>
<th>Case study</th>
<th>Final energy demand scenario</th>
<th>Constraints</th>
<th>Associated scenario</th>
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</table>
| BASE       | « Basis » scenarios of French electricity & gas TSOs | No CO2 increase from the electricity system  
Share of nuclear power limited to 50% from 2025 to 2050 | BASE |
| CO2 constraint | Factor 4 /2012 | F4 |
A first decarbonization pathway

CO2 constraint - factor 4

kt CO2

2010 2015 2020 2025 2030 2035 2040 2045 2050 2055
Results – « factor 4 » scenario
Use of methanation from 2025 to 2050...

- Use of hydrogen and synthetic gas $\rightarrow$ « stress » on electricity and CO2 supply
...but the CO2 trajectory makes the system « overconstrained »

- Hydrogen and synthetic gas are « imported » by the model with a very high cost

- Marginal cost of CO2: cost change in the objective function if we decrease CO2 emissions by one unit
What happens when we modify the decarbonization pathway?

+50% emissions

Initial pathway
Comparison of CO2 marginal costs

Comparison with basis scenario for following slides

System not overconstrained anymore
Electricity & gas mix cross-analysis

Higher electricity production in order to supply electrolyzers

Hydrogen & synthetic gas injection
Analysis for all timeslices (1 weekday and 1 weekend per month)

The activity of the electrolyser is lower at annual peak demand (January) and also at low availability of intermittent renewable energy.
Energy flow for gas system in 2050

Global efficiency of the methanation chain: 60%
Conclusion

- Prospective approach in order to investigate interactions between gas and electricity systems in France

- A bottom-up approach is necessary in order to understand and quantify these long-term interactions

- Two combined effects influence the level of interactions:
  - «Timing» of CO2 constraint
  - Availability of technologies
Further work: flexibility of multi-energy systems, prospective approach

- Gas
- Hydrogen
- Electricity
- Heat

- Storage
- Grid
- Import/Export
- Petrol
- Other sources
- Residential / Tertiary Industry
- Mobility
- Centralised production
- Import/Export
- Storage
- Grid
Further work: flexibility of multi-energy systems, prospective approach

Gas

- Storage
- Grid
- Import/Export
- Biomethane

Hydrogen

- Petrol
- Other sources
- Storage
- Local solar

Electricity

- Mobility
- Residential / Tertiary Industry
- Storage
- Local solar
- PV local

Heat

- Centralised production
- Import/Export
- Storage
- Grid
Further work: flexibility of multi-energy systems, prospective approach
Thank you for your attention!

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Appendices
Up to +23% of cumulated emissions in 2050
Electricity mix
Demand assumptions

One load profile and consumption annual mean growth rate for each sector

RTE BP 2014, scénario C

Perspectives gaz naturel et renouvelables, scénario A
Energy prices assumptions

Source petrol/coal/natural gas: WEO 2013 new policies

Source panorama du gaz renouvelable en 2016
CO2 capture - industry

Capture cost assumption: 75€/t

Source: Reiter et al., Evaluating CO2 sources for power-to-gas applications – A case study for Austria, 2015
Methanation process

- Assumption: stoechiometric conditions

\[ \text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \]
Electricity Import/Export

Source: Vincent Krakowski, 2016, « Renewable energy integration and power grid extension : reconciling spatial and temporal scales in long term planning exercises »