Agent based modelling approach applied to the investment decision making of the industrial sector

Sara Budinis*, Sara Giarola, Julia Sachs and Adam Hawkes

*Sustainable Gas Institute - Imperial College London
*s.budinis11@imperial.ac.uk
• Conclusions: «limited access to capital reduces the pace of decarbonisation»

• Why?
  • Carbon Capture and Storage (CCS) is (currently still) expensive
  • New green technologies are (initially) expensive

Not all the enterprises can afford them

Content list:
• Outlook on the industrial sector with a focus on the chemical sub-sector
• MUSE framework (ModUlar energy system Simulation Environment)
• Agent Based Modelling
• Case study
• Results
• Summary and conclusions
Conclusions: «limited access to capital reduces the pace of decarbonisation»

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• MUSE framework (ModUlar energy system Simulation Environment)
• Agent Based Modelling
• Case study and agents definition
• Results
• Conclusions
Outlook on the industrial sector
Global industrial sector*:  
- 36% TFEC (154 EJ)  
- 24% CO2 emissions (8.3 GtCO2)  
- Current growth TFEC: 1.5% annual (expected for 2DS target: 1.2%)  
- **KEY: Decoupling of industrial production from CO2 emissions**  
  - Regional perspective: non-OECD countries (China)  
  - Sectorial perspective: chemicals (third most emitting subsector 13%)  

**Chemicals and petrochemicals***:  
- 28% industrial TFEC (largest energy user)  
- HVC, ammonia and methanol alone: 73% chemical TFEC  
- Current growth: HVC 19%, ammonia 13%, methanol 51%  
- Bio-based routes present promising avenues for decarbonisation however mainly at pilot scale

*IEA: ETP 2017 (data: 2014)
Case study: ammonia production:

- 88% ammonia demand due N-fertiliser demand
- Main producers: China (34% w/w), Russia (8%), USA (7%) and India (7%)
- Main feedstocks: gas (39%), coal (35%) and heavy oil (3%). Currently biomass-based ammonia production at pilot scale

China:

- China: feedstocks: 71% coal, 21% natural gas, 8% heavy oil
- Preferential policies due to strategic role for food security; satisfies internal demand
- Huge variety of production technologies (performance, consumption, emissions)

MUSE framework: ModUlar energy system Simulation Environment
MUSE framework:

- Covers all the sectors in the energy system (highly disaggregated)
- Global scale with regional disaggregation
- Simulation with time horizon 2010 to 2100
- Modular: Each sector is modelled in a way that is appropriate for that sector
- Engineering-led and technology-rich with a bottom-up technoeconomic characterization
- Microeconomic foundations: all sectors agree on price and quantity for each energy commodity
- Partial equilibrium on the energy system (models supply and demand)
- Policy instruments modelled (e.g. carbon price, subsidies)
MUSE Industrial Sector Module (ISM):

- Sector: Industrial
- Subsector: e.g. Chemical
- Commodity: e.g. Ammonia
- Technology: e.g. Coal-based ammonia

Exogenous inputs:
- Macroeconomic drivers
- Assumptions on policies
- By asset type: Cost, Efficiency, Emissions, Operational constraint, Existing stock, Retirement profile

Specific Outputs:
- Aggregated CAPEX
- Aggregated OPEX
- By asset type: Production, Emissions, Capacity

Data exchange with Market Clearing Algorithm (MCA):
- ISM provides demand for fuels and emissions
- MCA provides supply costs of fuels, carbon price

Further options including:
- Choice of feedstock
- CCS availability

28 regions, 15 commodities, 200 technologies
Agent Based Modelling
Investment decision within MUSE:

- Start
- Calculate future stock of assets & amount decommissioned
- Demand forecast for end-uses
- Production simulation to meet demand
- Are new assets needed? (YES/NO)
  - Yes: Future demand
  - No: No investment needed
  - Outputs
  - End
Investment decision within MUSE:

1. **Future demand**
   - Demand forecast for end-uses
   - Production simulation to meet demand
   - Are new assets needed?
      - **YES**
        - Calculate future stock of assets & amount decommissioned
      - **NO**
        - No investment needed
        - Outputs
        - end

2. **Determine how many new technologies and retrofits are needed**
   - Get potential new assets
   - Search for potential assets
   - Calculate decision metric
   - Apply decision rule
   - Amount of potential new assets
   - Commit new assets
   - Outputs
   - end

Options:
- One agent, or
- Multiple agents
Agent Based Modelling (ABM) approach:

- Each type of investors is an agent in the market, with a certain share. All the agents together form a population of agents.
- Each agent has different objectives e.g. economical (e.g. risk prone vs risk adverse), environmental friendliness.
- Each agent has different characteristics, called attributes e.g. decision strategy.
- Depending on objectives and attributes, the agent makes the investment decision in his/her search space.
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\[ A = \{Obj, DS, SP, PP\} \]

- \textit{Obj} objective:
  - Economic (capital, payback, NPV, etc.)
  - Environmental (energy consumption, CO2 emissions, etc.)
- \textit{DS} decision strategy:
  - One objective
  - Multiple objectives (weighted sum, epsilon constraint, lexicographic strategy)
- \textit{SP} search space:
  - All available alternatives
  - Same type of fuel
  - Popular alternatives (e.g. past decisions)
  - Mature alternatives
- \textit{PP} percentage of population e.g. initial market share
Case study
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*SME and LE:
- Seek profit (investors)
- Own their assets
- Can decide if retrofitting existing assets or building new assets to meet demand
- Subjected to carbon price (rather than carbon budget)

Energy use

Feedstocks share

Market size by plant scale

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Feedstocks share

Market size by plant scale
Relevant scenarios:

One agent (average):
- high NPV
- Zero carbon price
- Carbon Price

Two agents:
- LE (18% output): High NPV
- SME (82% output): Low CAPEX*

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Results
Results: scenario 1

- Single agent: Aiming for high NPV
- Zero carbon price

![Capacity graph]

- Electrolysis
- NG + CCS
- NG
- HFO + CCS
- HFO
- Hard coal + CCS
- Hard coal
- Biomethane + CCS
- Biomethane

![CO2 graph]

- emitted
- captured
Results: scenario 2

- Single agent: Aiming for high NPV
- Carbon price
Results: scenario 3

- Two agents:
  - SME (82% output): Aiming for low CAPEX
  - LE (18% output): Aiming for high NPV

- Zero carbon price
Results: scenario 4

- Two agents:
  - SME (82% output): Aiming for low CAPEX
  - LE (18% output): Aiming for high NPV
- Carbon price

[Graphs showing capacity and CO2 emissions over years]
Results change case by case: full industrial sector

- Two agents:
  - SME (67% output): Aiming for low CAPEX
  - LE (33% output): Aiming for high NPV

Zero carbon price

Carbon price
Summary and conclusions
Conclusions: «limited access to capital reduces the pace of decarbonisation»

Why?
- Carbon Capture and Storage (CCS) is (currently still) expensive
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- Limited access to capital for SME slows down the decarbonisation rate of the sector
  - Without carbon price, there is a limited reduction of CO2 emissions
  - A carbon price profile can further decrease CO2 emissions
  - If a carbon price is implemented without supporting access to capital for SME, then the decarbonisation will take longer

Further developments include:
- Multiple agents and objectives with a trade off against computational effort: agents refinement
- Downside: data availability? validation?
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Co-authors

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Dr Julia Sachs
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Dr Adam Hawkes
Co-Director

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