# MUSE: A new global energy model – Overview and Application to the Residential Building Sector of the UK

Julia Sachs

Imperial College, London

17th of May, Seminar FEEM, Milan

Imperial College London | SUSTAINABLE GAS INSTITUTE

# **M**od**U**lar energy system **S**imulation **E**nvironment

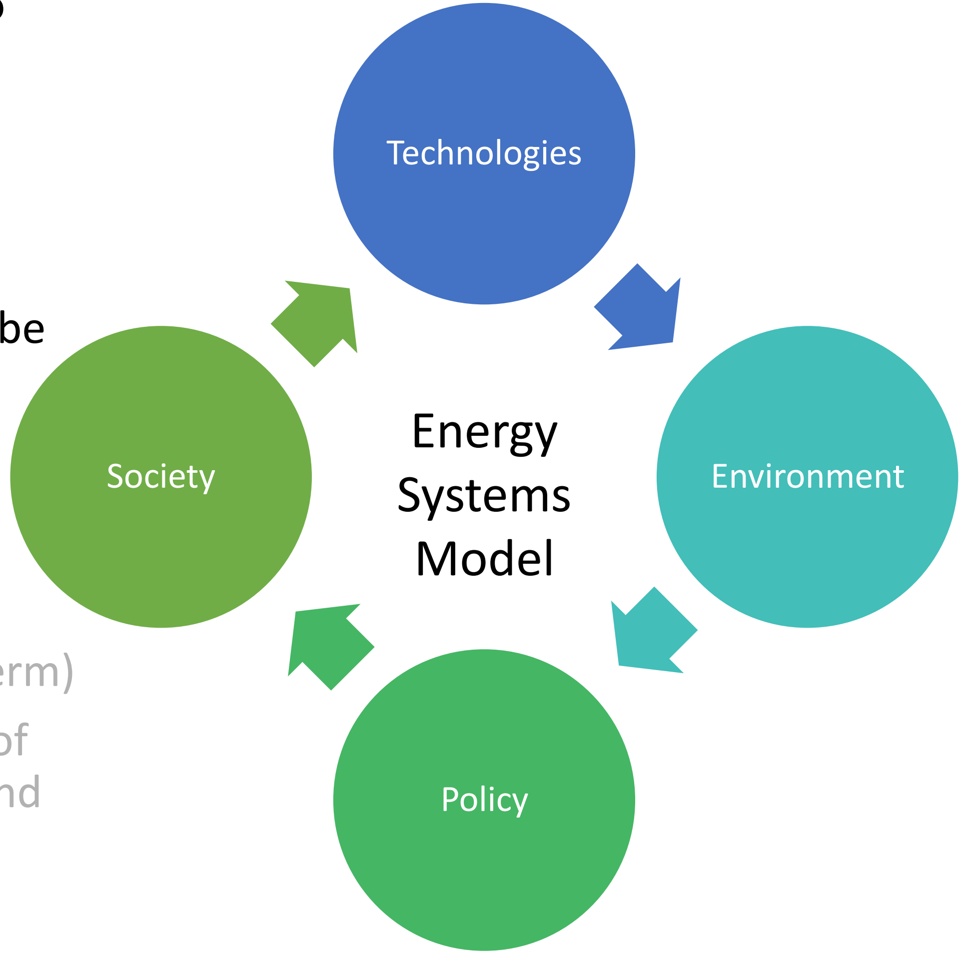
Developing a unique energy systems simulation tool to analyse the energy system, and the role of technologies within it.

MUSE → Building Sector → Agent-Based Method → Case Study

# Background

Imperial College London | SUSTAINABLE GAS INSTITUTE

- **What is an Integrated assessment model (IAM) ?**
  - Type of scientific modelling often used by the environmental science and environmental policy analysis.
  - Integrate knowledge from several domains – e.g. techno-economic model and climate model
  - IAMs are methods to analyse all the ways that resources can be transformed (supply) and used to meet the future energy demand.




- **Why do we build an IAM?**
  - Climate change mitigation pathways assessment (i.e. long-term)
  - Strategy and business model development against a variety of scenarios (e.g. governments could assess long-term energy and environmental policies)
  - R&D prioritisation of value and role of technologies

# “Decision making” in models



## Most common analysis techniques

- ❑ Top-down models
- ❑ Bottom-up (or engineering) models
- ❑ Decomposition of energy trends
- ❑ Econometric trends
- ❑ Sector-specific micro-analyses

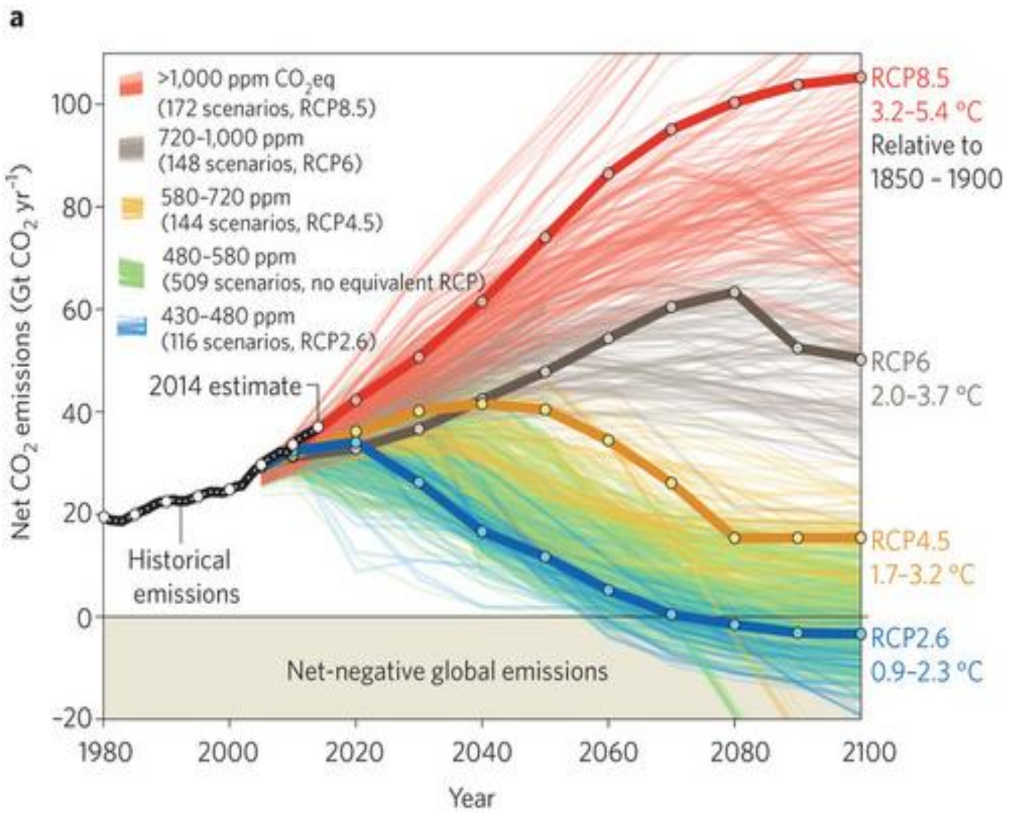
## Geographical scope

- Single countries/regions (e.g. UKTM, NEMS)
- Global models (e.g. IEA ETP Times)

## Methodology

- Optimisation
- Simulation
- Hybrid

**IPCC (Intergovernmental Panel of Climate Change) 5th Assessment Report**




Source: Fuss et al (2014) Betting on negative emissions. Nature Climate Change 4, 850–853

# muse "Decision making" in models

Imperial College London | SUSTAINABLE GAS INSTITUTE

MUSE

- **Typical Energy System Model**
  - Optimized, rational
    - e.g. minimizing system cost, intertemporal optimization
  - Perfect foresight
  - Perfect liberalized market
  - Single investor for each sector
  - No difference between short term (5-10 years) and long term (10+ years) investments

- **Real World**
  - Imperfect information
  - Bounded rationality
  - Uncertainty and hedging
  - Limited access to capital
  - Financing challenges
  - Transaction costs
  - Regulation

**Most models provide a too optimistic view of the future energy transition, lack clarity on the input assumptions and flexibility.**

# MUSE: Why and how?



## Why a new model?

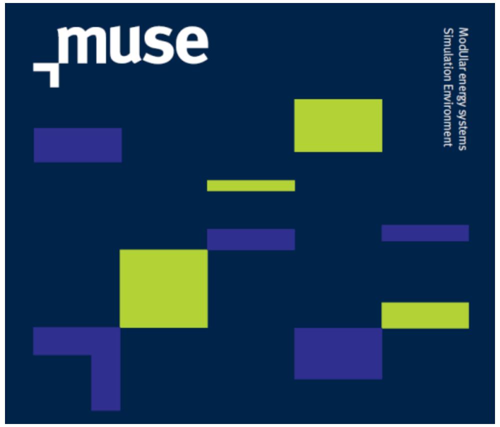
- An ***investor view*** of energy system transitions
- ***Imperfect foresight*** – simulate real decision making
- The need for ***transparency*** in methods, assumptions and results
- Bringing ***engineering reality*** to systems-level modelling

## How?

- ***Simulation*** not optimisation
- ***Agent-based*** modelling
- ***Flexible sector modules*** – entirely new approach
- ***Open-access***, clear communication, ***credibility***

## Which framework?

- All sectors are modelled in Python
- GitHub - Collaborative, agile software development
- API -
- Tools and methodology for any team to build their own MUSE

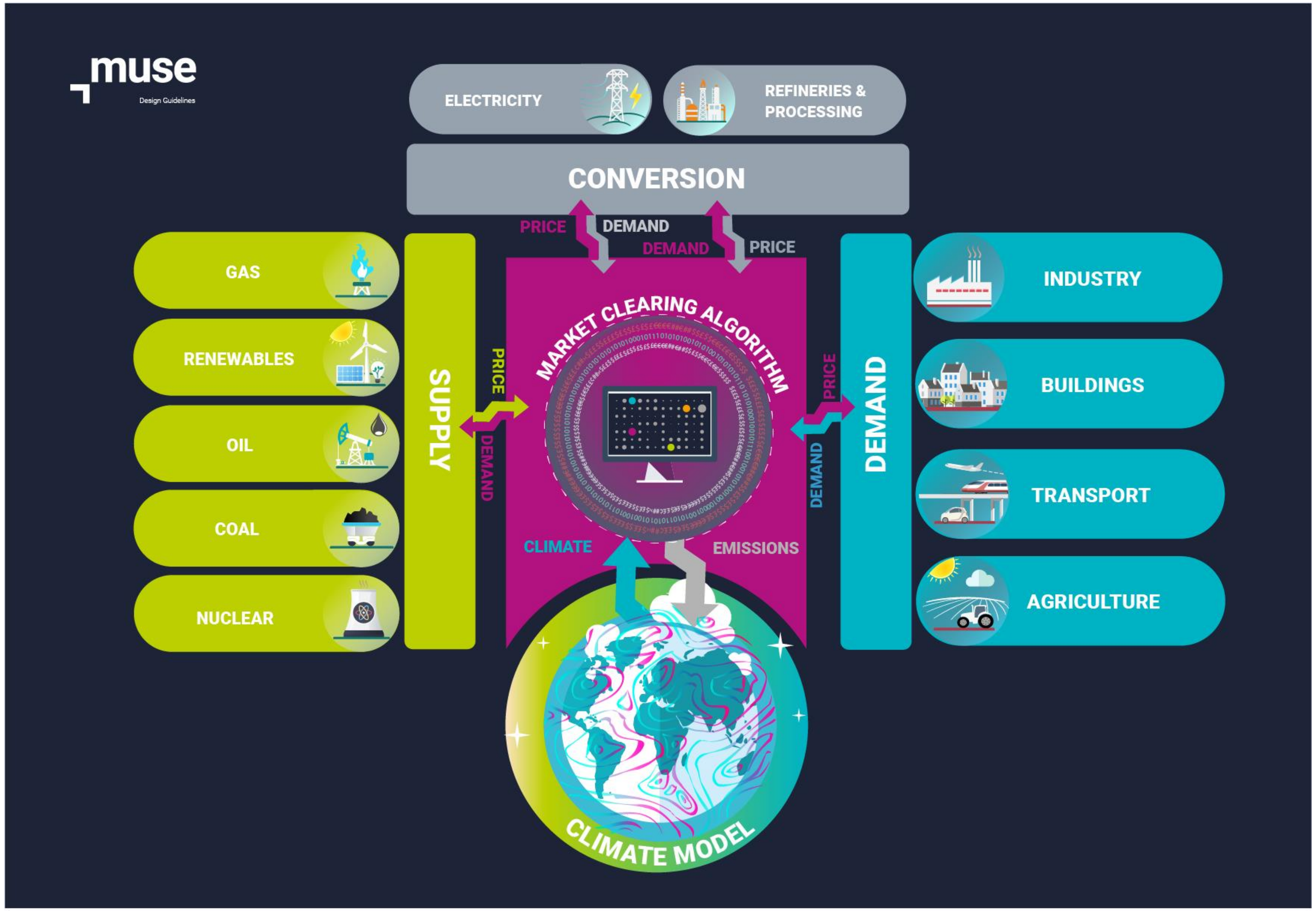



python™

GitHub

# MUSE overall structure

MUSE



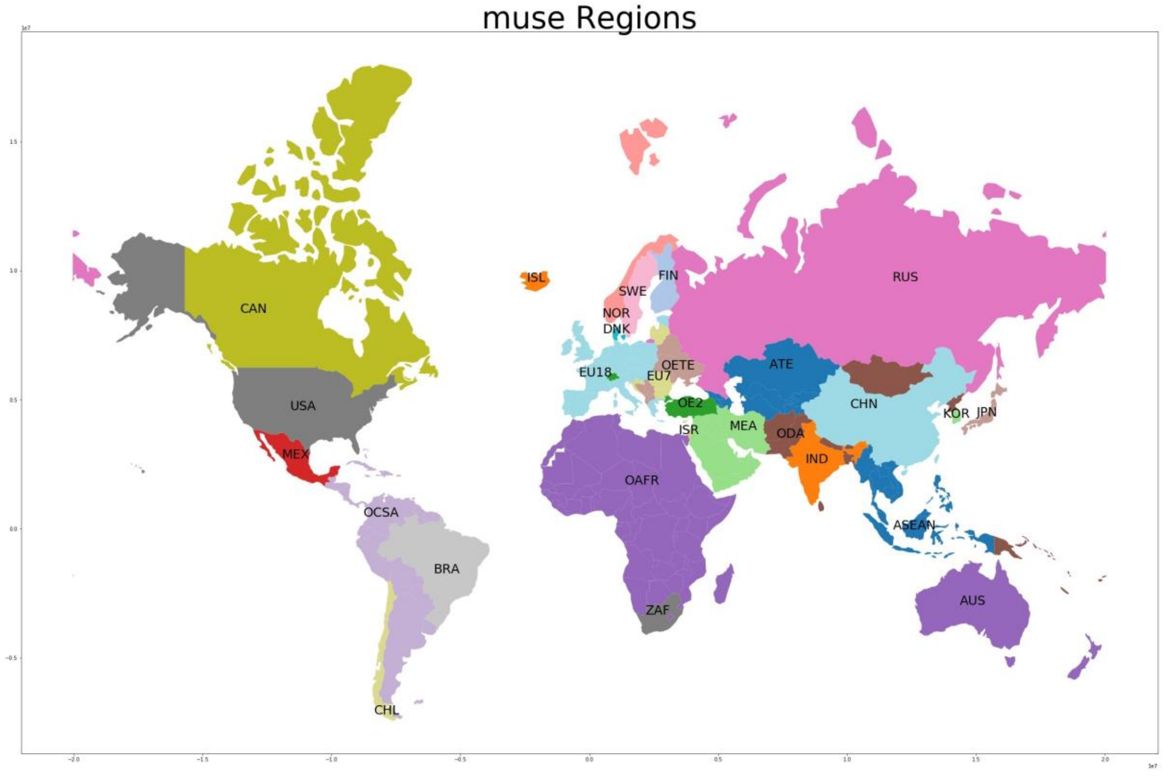

- Covers all the sectors in the energy system
- Modular: Each sector is modelled in a way that is appropriate for that sector
- Engineering-led and technology-rich with a bottom-up technoeconomic characterization
- Microeconomic foundations: all sectors agree on price and quantity for each energy commodity
- Partial equilibrium on the energy system (models supply and demand)
- Policy instruments modelled (e.g. carbon price, subsidies)

# MUSE characterisation

MUSE

- Time horizon from 2010 to 2100 years aggregated into periods
- Each period is disaggregated into time slices (30 maximum)
    - summer, winter, spring/fall
    - weekday, weekend
    - morning, afternoon, evening, night, early peak (weekday), late peak (weekday)

- Global scale with regional disaggregation
    - Countries are clustered in 28 regions
    - Some regions are 1-country regions (i.e. Brazil, Mexico, USA), while others are a collection of many countries

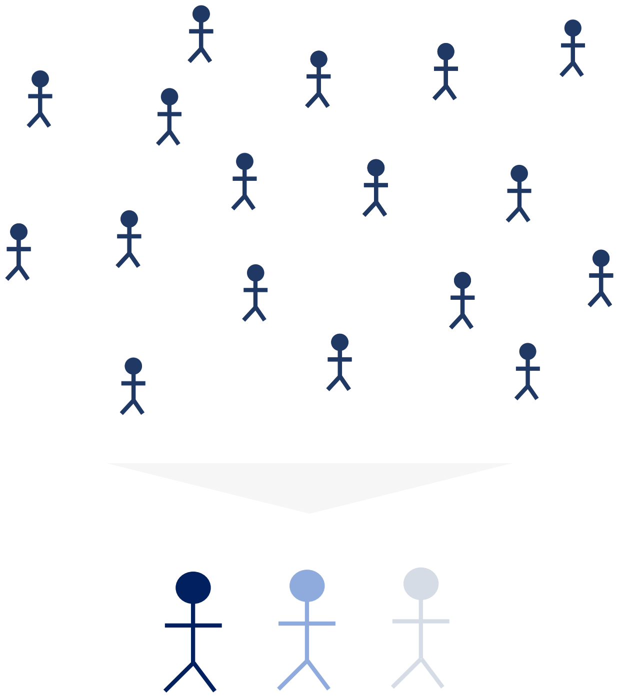


**Challenge:**

- The outcome of the investment decision for each person is likely to vary dependent on one's budget, values, and perception of a technology even if an identical decision task is faced.
- A cost optimising framework assumes economically rational, homogeneous actors, is sensitive to cost assumptions of technologies and can suddenly switch fully to alternative technologies

**Idea:**

- Definition of multiple individual agents to represent population
- Mimic decision making process of people
    - Information gathering
    - Validation of information
    - Decision making
- Macro system characteristics results from simulation of all agents and individual behaviour



# Building Model overview

MUSE | Building Sector

**Exogenous Inputs:**

- Macroeconomic drivers
- Assumptions on policies
- Operational constraints /cost/efficiency/existing stock/retirement profile by asset type
- Emissions
- Resources

**RCBSM**

**Investment decisions**

**Determination of fuel consumption**

**Demand projections for end-uses**

**Specific Outputs:**

- Aggregate economic metric (CAPEX, OPEX, NPV,..)
- Production by asset type
- Emissions by asset type
- Capacity by asset type
- Consumption by asset type

**MCA**

To RCBSM:

- Supply curve primary fuels
- Carbon price

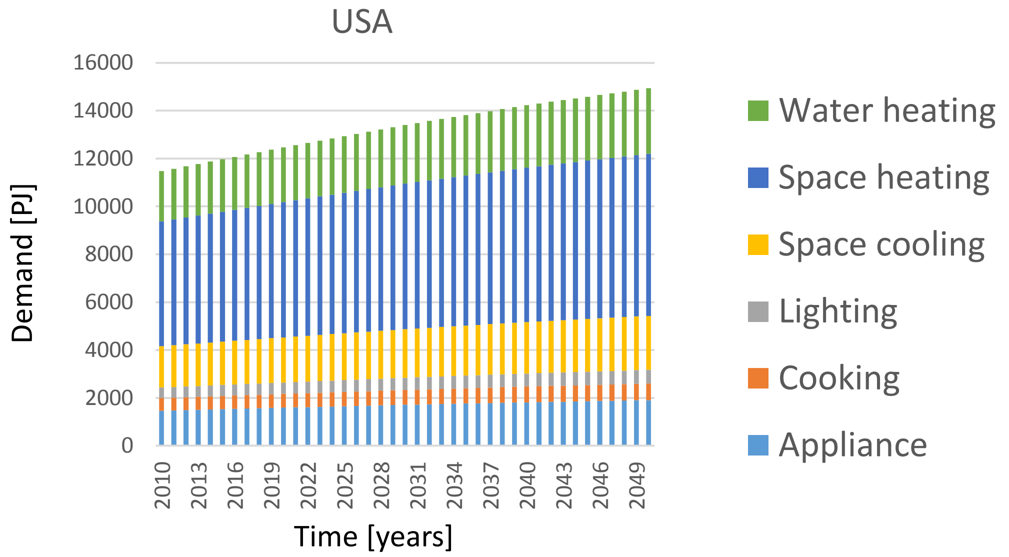
From RCBSM:

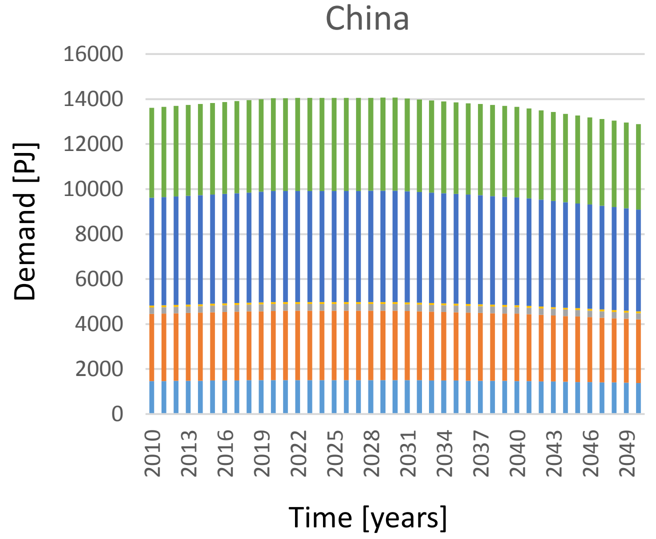
- Demand for fuels
- Emissions

# Regression of end-use demand

MUSE | Building Sector

- IEA balances for residential and commercial sector
- Definition of energy share of different end uses by fuel type
- Calculation of correlation between past demand and macrodrivers (GDP per capita ($GDP\_cap$), GDP pre household)
- Determine parameters a, b, and c for logistic function $Demand = \frac{a}{1 + be^{c * GDP\_cap}}$
- Demand projections over time horizon for different end-uses
- Not dependent on efficiency of technologies
- Different trends for regions can be observed



# Building Model challenge

MUSE | Building Sector

48 Technologies with different characteristics

- Cooking facility
- Boiler
- District Heating + source of heat
- Combined heat power (CHP)
- Micro CHP
- Water heater/Stand-alone heaters
- Heat Pumps (Air source, Ground source)

- Coal
- Gas
- Biomass
- Kerosene
- Electricity
- Solar

- Air conditioner
- Appliances
- Light bulbs

- Conventional
- Advanced
- Energy saving

Different objectives and decision processes for investments in energy technologies

- Economic criteria
- Capital cost
- Equivalent annual cost (EAC)
- Net present value (NPV)
- Operation cost
- Payback time

- Environmental criteria
- Energy consumption
- Emissions

- Emotional criteria
- Comfort

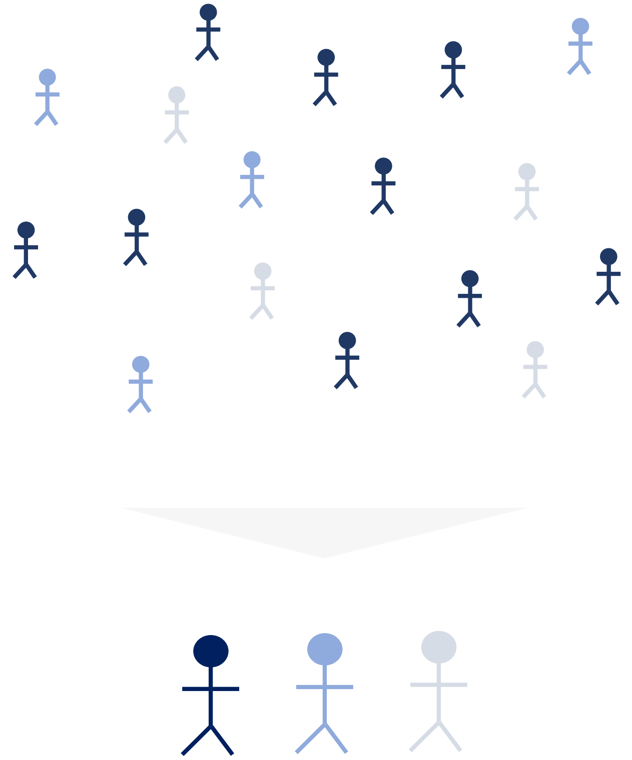
# Agent-based approach

- Split of population into subcategories represented by single agents
- Characterization of individual agents
- Each agent has different attributes (budget, search strategy, decision method, location, retrofit, new...)

$$A = \{Obj, SP, DS, TP, PP\}$$

  - $Obj$ objective
  - $SP$ search space
  - $DS$ decision strategy
  - $TP$ type
  - $PP$ percentage of population

- Change of agents to endogenous factors (cost change, policies,..)
- Determination of investment decision based on characteristics



# Agent attributes



**Attributes of Agents** $A = \{Obj, SP, DS, TP, PP\}$

**Search Space**
$SP$

**Objective(s)**
$Obj$

**Decision Strategy**
$DS$

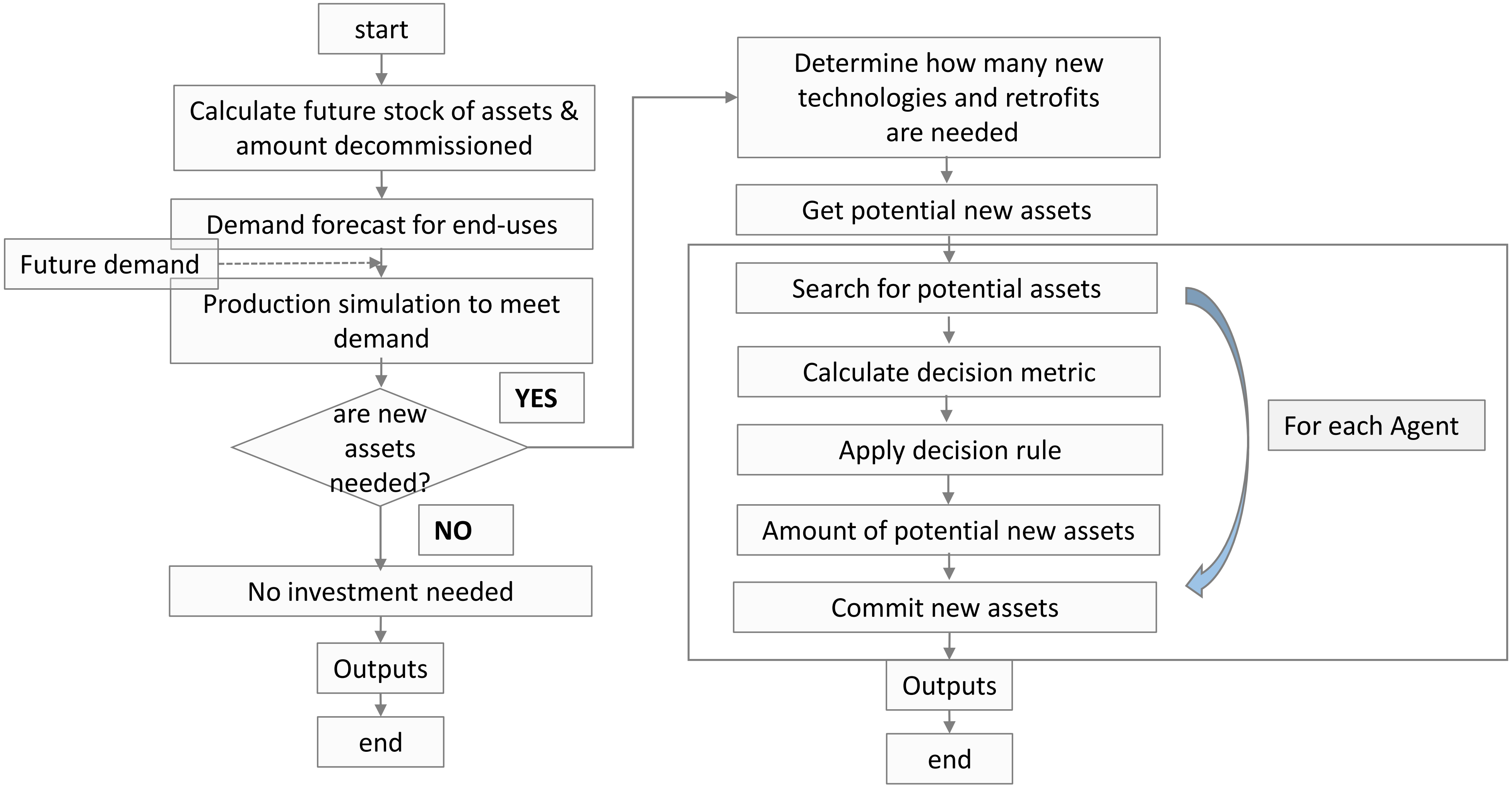
- Find all available alternatives
- Find same type or fuel
- Find popular alternatives (society, past decisions, peer group, etc.)
- Find mature alternatives

- Economic (capital, payback, NPV, etc.)
- Environmental impact (energy consumption, CO2, etc.)
- Comfort

- One objective
- Multiple objectives
  - Weighted sum
  - Epsilon-constraint
  - Lexicographic strategy

# Determination of investment

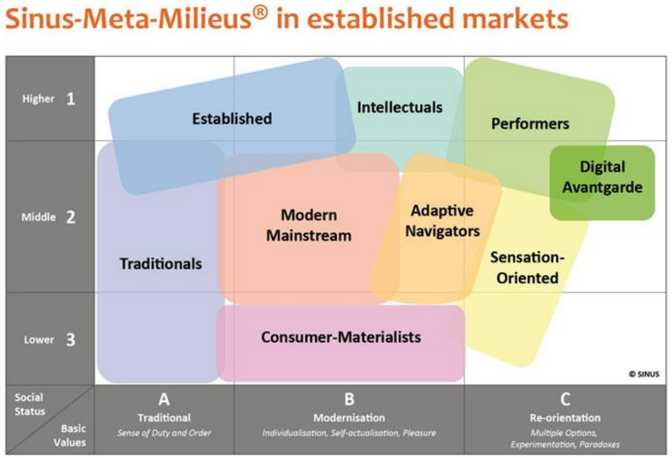
**Agent-based method (ABM)**



# Agent definition



Social Status




Basic Values

| Agent Group | Quantity, % | Type | Budget, MUS$ |
|---|---|---|---|
| modern performers1 | 0.008 | New | 3600 |
| modern performers2 | 0.081 | Retrofit | 3600 |
| Post-materialists1 | 0.026 | New | 2600 |
| Post-materialists2 | 0.084 | Retrofit | 2600 |
| ground breaker1 | 0.011 | New | 2300 |
| ground breaker2 | 0.057 | Retrofit | 2300 |
| pleasure seeker1 | 0.016 | New | 4200 |
| pleasure seeker2 | 0.125 | Retrofit | 4200 |
| quite peaceful Britain1 | 0.018 | New | 4200 |
| quite peaceful Britain2 | 0.168 | Retrofit | 4200 |
| Precarious | 0.113 | Retrofit | 1600 |
| Established | 0.102 | Retrofit | 2100 |
| Traditional | 0.191 | Retrofit | 2400 |

**Sinus-Milieus**

- Groups population according to their social status and basic values
- Based on market research

**Further classification - Link with demographic data and household survey data**

- Income distribution based on profession
- Age distribution data within each agent group
- Amount of households live in new constructed building
- Household expenditure data (presented by household representative person)

**Definition of 13 agents**

# Case Study

**Aims**

- Illustrate functionality of ABM
- Highlight benefits and suitability of ABM for RCBSM
- Comparison of agent-based method to single-objective -> Partially modern agent: EAC
- Determine diffusion of technologies between 2010 – 2050 in the USA

**Assumptions**

- Changes in cost over time are not considered
- Macrodrivers SSP2 by IIASA
- Capacity addition limits for single-objective case:
  - 5% growth
- Limited foresight of 5 years

# Conclusion and Challenges



**Conclusion:**

- Counterfactual to purely cost driven approach
- Increased flexibility in modelling the investment decisions by including homogeneous actors and enables a broader representation of the population
- Limited uptake of technologies by the inclusion of multiple individual decision-makers with distinct objectives, budget, understanding of the technology and decision methods
- Representation of transition phase where different technologies compete over the market share
- Captures several aspects of the human behaviour: information gathering, analysis strategies, decision making
- With increasing market share technologies are assumed to be more mature and more agents consider these options since it appears in their search space

# Conclusion and Challenges



### Agent Specification

The definition of the agents still requires a lot of investigation and study of empirical data to be able to accurately define representative decision-makers

### Agent Interaction

Interactions between agents are difficult to be modelled for the simulation. Possible change in agent attributes and decision strategy.

### Current Stock of Technologies

Data is needed to give an accurate representation of the technologies currently available in households on a global scale.

### Cultural and Geographic Influence

The cultural difference between countries need to be considered.

The suitability of a technology for a certain country need to be identified.

# MUSE Team

Dr Adam Hawkes
*Senior Lecturer*

Dr Sara Giarola
*Research Fellow*

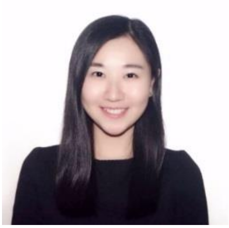
Dr Daniel Crow
*Research Associate*

Dr Sara Budinis
*Research Associate*

Dr Ivan Garcia-Kerdan
*Research Associate*

Dr Julia Sachs
*Research Associate*

Mr Cheng-Ta Chu
*PhD Student*



Ms Yingjian Guo
*PhD Student*

Mr Jonny Bosch
*PhD Student*

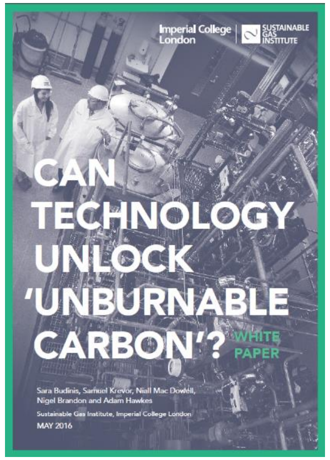
# Sustainable Gas Institute

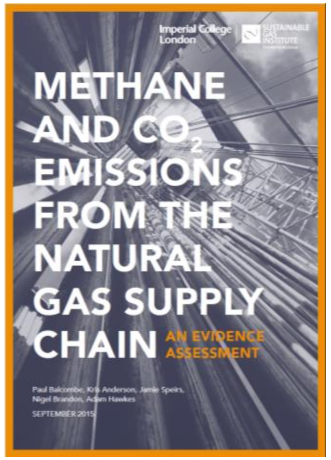
**The Institute:**

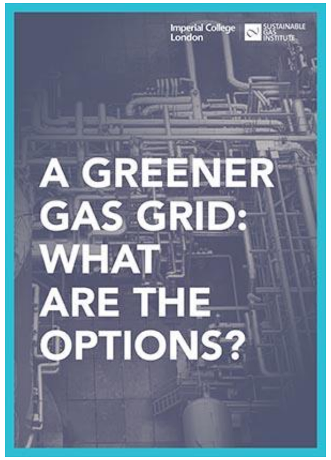
- Founded in 2014 by ICL and BG Group (now Royal Dutch Shell)
- Collaboration between industry and academia, UK and Brazil (University of Sao Paulo)

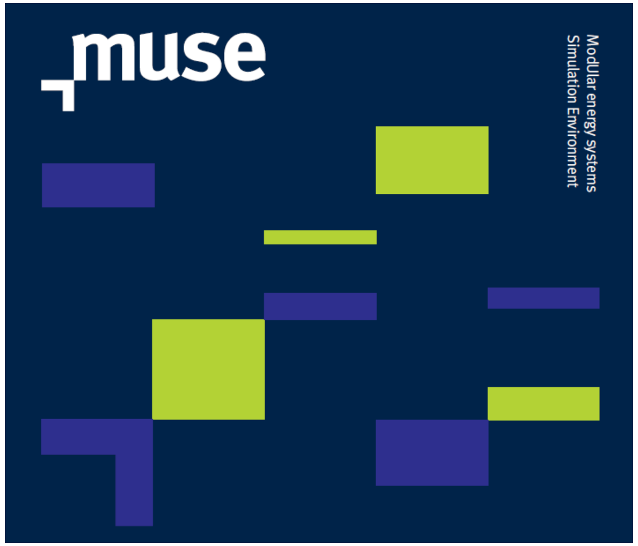
**Research activities:**

- White paper series
- MUSE: ModUlar energy system Simulation Environment



muse

An energy systems module

Julia Sachs
j.sachs@imperial.ac.uk