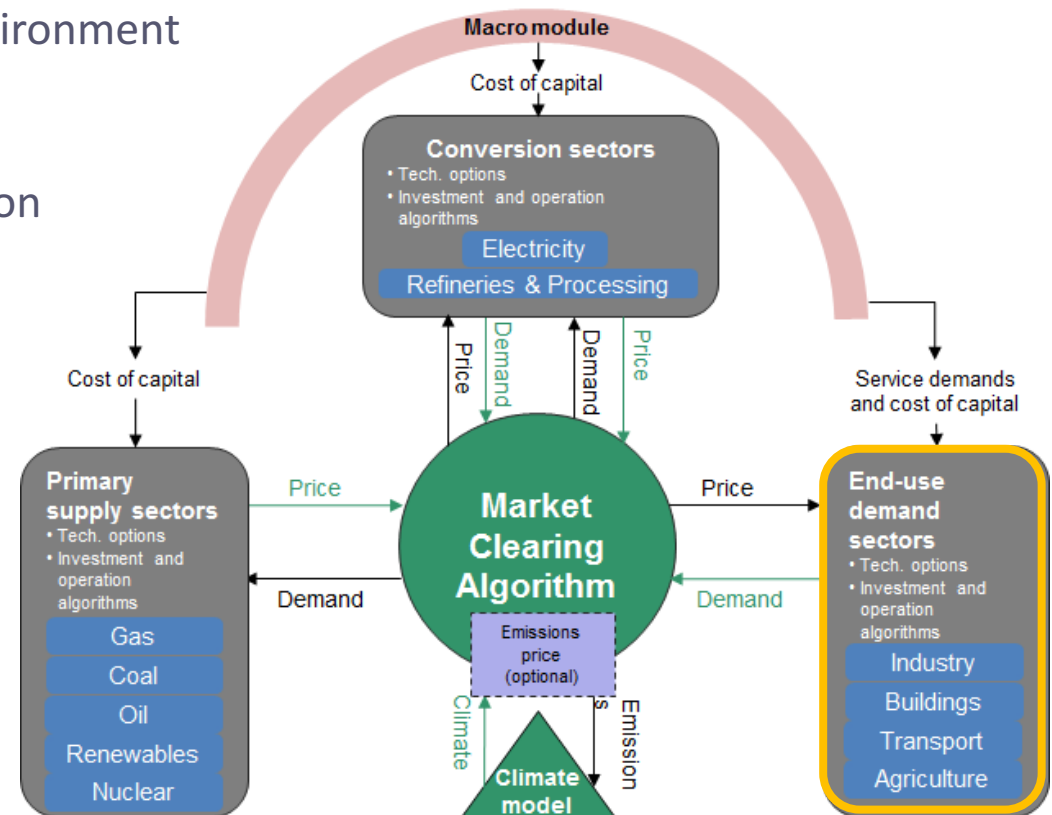


Agent-Based Model for Energy-Related Investment Decisions in the Residential Building Sector

MUSE - ModUlar energy systems Simulation Environment

Julia Sachs, Sara Giarola, Adam Hawkes
Sustainable Gas Institute, Imperial College London

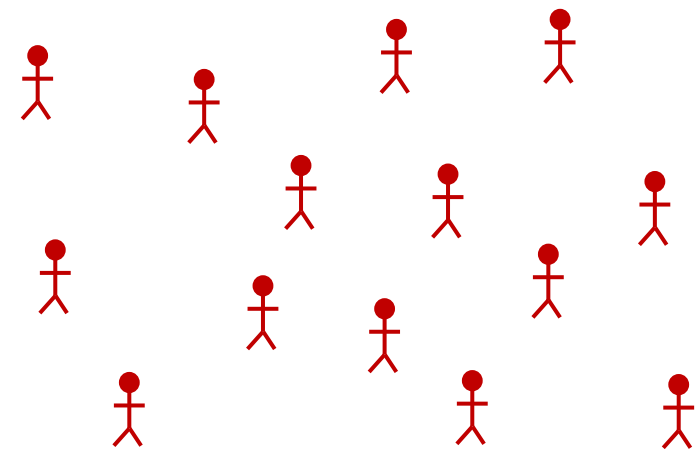
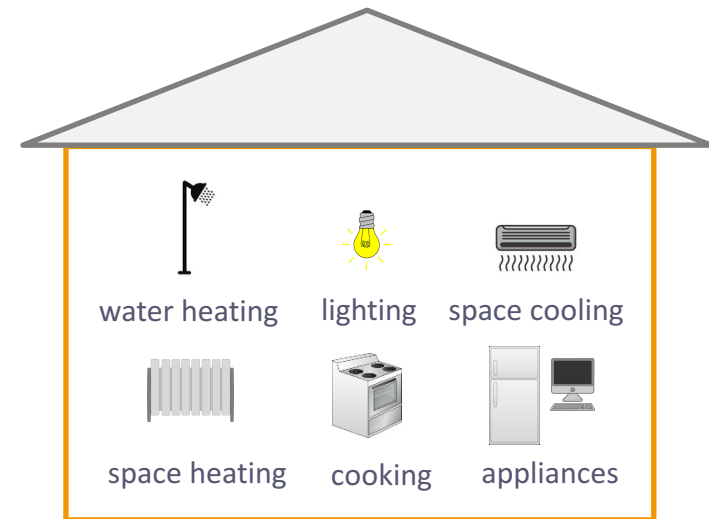
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Building Module overview

Residential and Commercial Building Sector Module (RCBSM)

- Demand sector
- Focus on six different end-uses
 - Water heating, lighting, space cooling, space heating, cooking, appliances (computer, fridge, freezer, washing machine,...)
- Investigation of people's behaviour in making investment decisions -> Agent-based modelling (ABM)
- 48 technologies are considered
- 30 Timeslices
 - Winter/summer/autum+spring
 - Weekend/weekday
 - Morning/afternoon/early peak/late peak/evening/night



Building Module overview

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 Costs (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

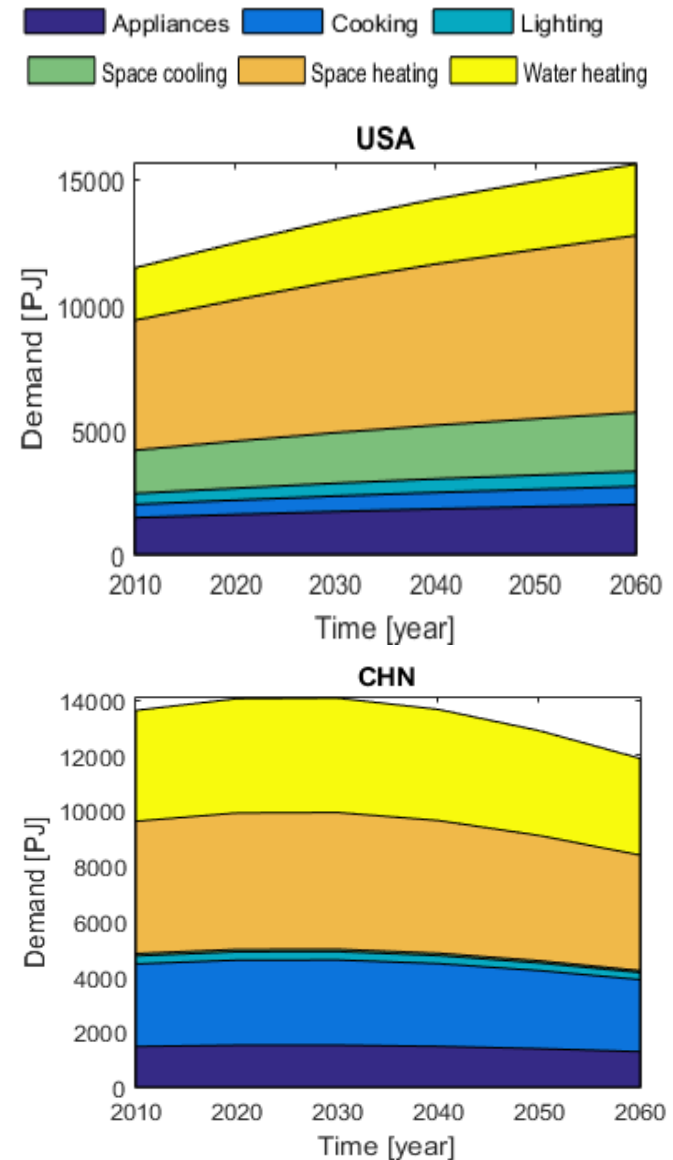
Regression of end-use demand

Demand projections

- 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_cap, GDP_hh)
- Determine parameters a, b, and c for logistic function

$$Demand = \frac{a}{1 + be^{c * GDP}}$$

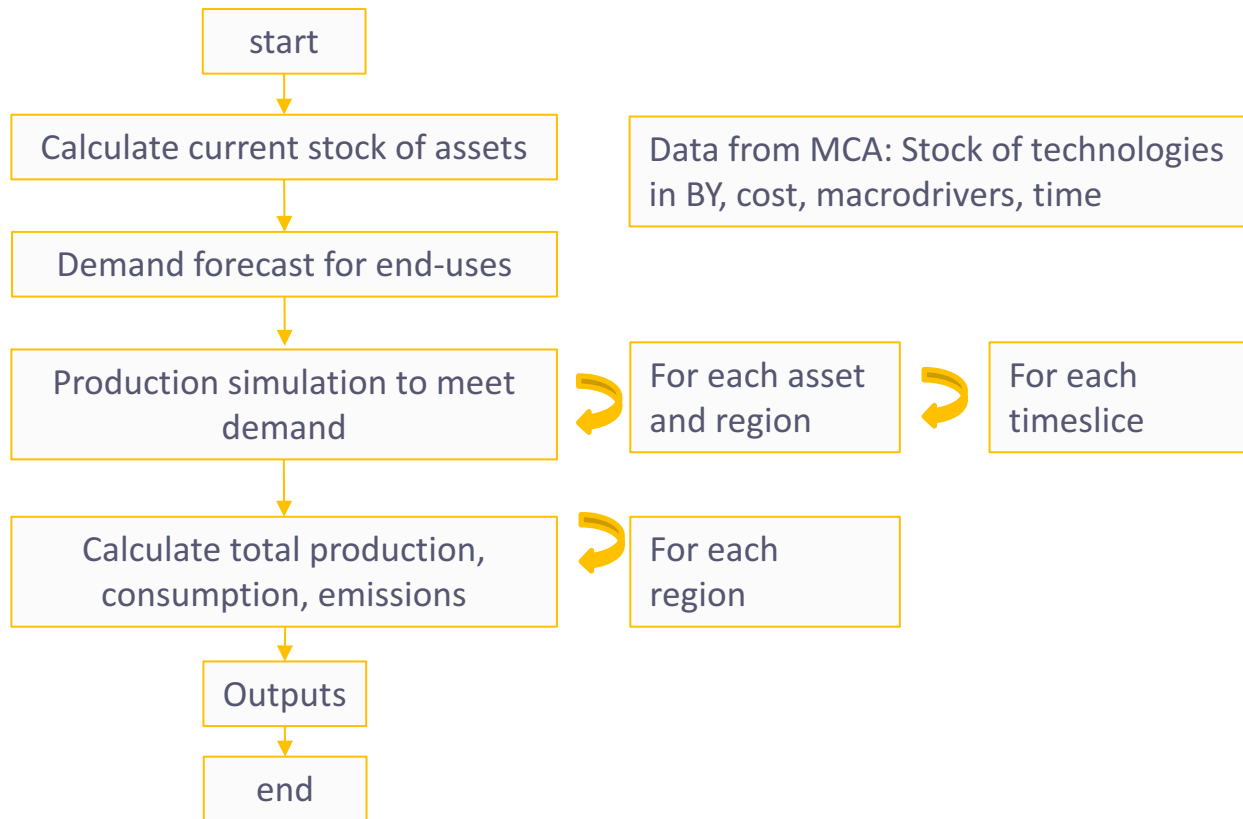
- Demand projections over time horizon for different end-uses
- Not dependent on efficiency of technologies
- Different trends for regions can be observed



Determination of fuel consumption

Demand projections

Fuel Consumption



Data from MCA: Stock of technologies in BY, cost, macrodrivers, time

Stock of Technologies in base year (BY)

- IEA balances (CHP, auto/main heat producer, commercial, residential)
- Platts for CHP, EurObservER heat pumps, Euroheat & Power district heating

Aggregation of data to feed back to MCA

Building Model overview

Demand projections

Fuel Consumption

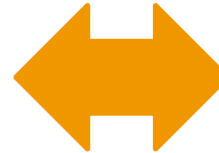
Investment decision

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)
- Air conditioner
- Appliances
- Light bulbs

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

- 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

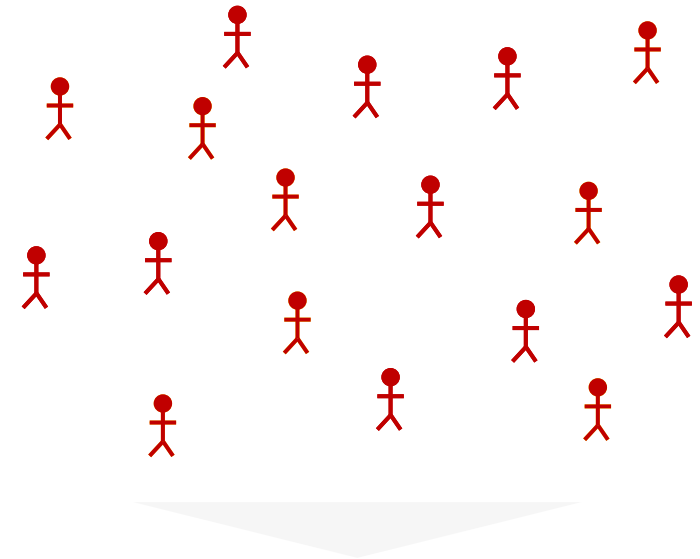
Agent-based approach

Demand projections

Fuel Consumption

Investment decision

- Definition of multiple agents to represent population
- Characterization of individual agents
- Macro system characteristics results from simulation of all agents and individual behaviour
- Each agent has different attributes (budget, search strategy, decision method, location, retrofit, new...)
- Change of agents to endogenous factors (cost change, policies,..)
- Determination of investment decision based on characteristics



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

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

Agent attributes

Demand projections

Fuel Consumption

Investment decision

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

Search Space
 SP

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

Objective(s)
 Obj

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

Decision Strategy
 DS

- One objective
- Multiple objectives
 - Weighted sum

$$\min \sum_{i=1}^3 w_i obj_i$$
 - Epsilon-constraint

$$\min obj_1$$

$$obj_2 \leq \varepsilon_2 \quad obj_3 \leq \varepsilon_3$$
 - Lexicographic strategy
 - 1) $obj_1^* = \min obj_1$
 - 2) $\min obj_2$
 $obj_1 \leq obj_1^* \delta_1$

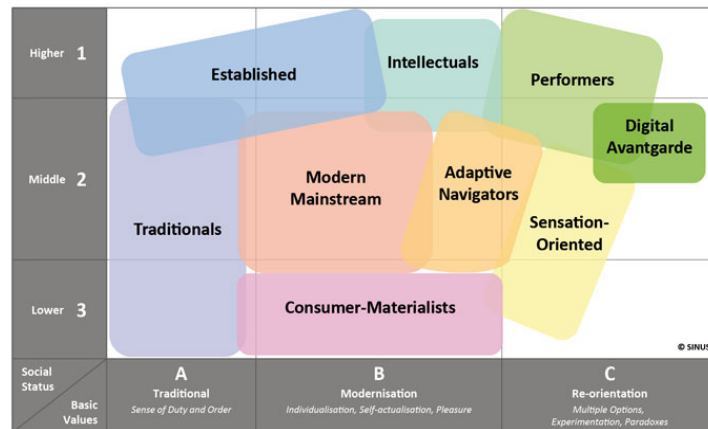
Agent definition

Demand projections

Fuel Consumption

Investment decision

Sinus-Meta-Milieus® in established markets



- Groups population according to their social status and basic values
- USA shows a wide span between different groups
- Definition of 6 agents to guarantee simplicity

				Obj3	SP	DS	TP
Traditional	20%	Capital Cost	-	-	Type & Maturity	Single obj.	Retrofit
Partially Modern	15%	NPV	-	-	Type	Single obj.	Retrofit
Modern Middle America	40%	NPV	Emissions	Capital Cost	Fuel	Weighted sum	Retrofit
Performers	25%	Emission	Payback Time	Efficiency	All	Epsilon-con.	Retrofit
Traditional	40%	Capital Cost	Efficiency	Operation Cost	Maturity	Epsilon-con.	New
Modern	60%	Emissions	Payback Time	Efficiency	All	Weighted sum	New

Challenge: Adequate definition of agents on a global scale

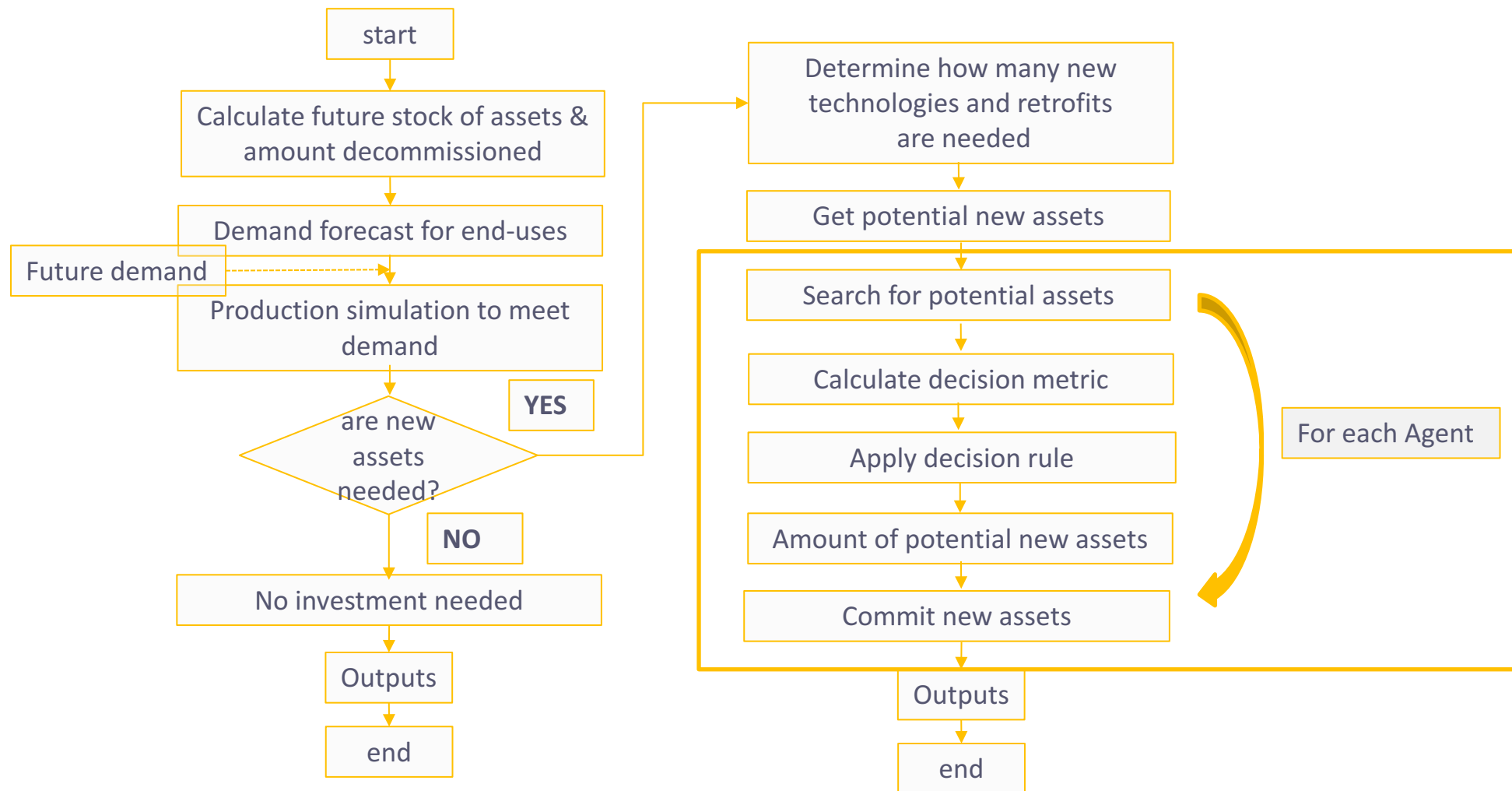
Determination of investment

Demand projections

Fuel Consumption

Investment decision

Agent-based method (ABM)



Aims

- Illustrate functionality of ABM
- Highlight benefits and suitability of ABM for RCBSM
- Comparison of agent-based method to single-objective -> Partially modern agent: NPV
- Determine diffusion of technologies between 2010 – 2100 in the USA

Assumptions

- Changes in cost over time are not considered
- Macrodrivers SSP2 by IIASA
- Capacity addition limits for single-objective case:
 - 10% growth
 - maximum addition of 20% of installed capacity
 - total capacity of 120% of the installed technology for one end-use
- Limited foresight of 5 years

Diffusion of appliances and lighting

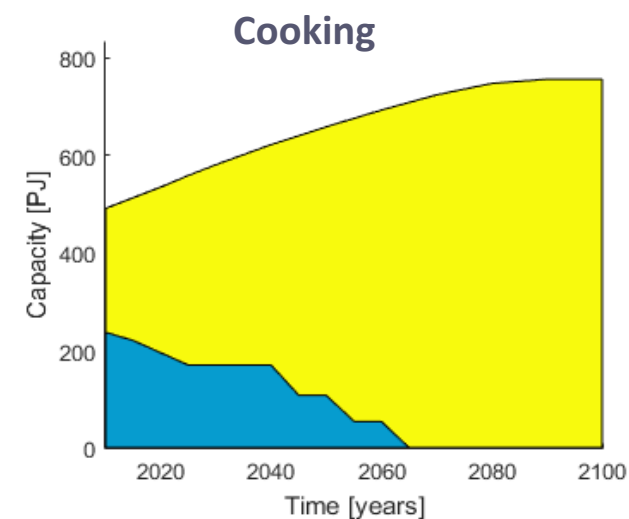
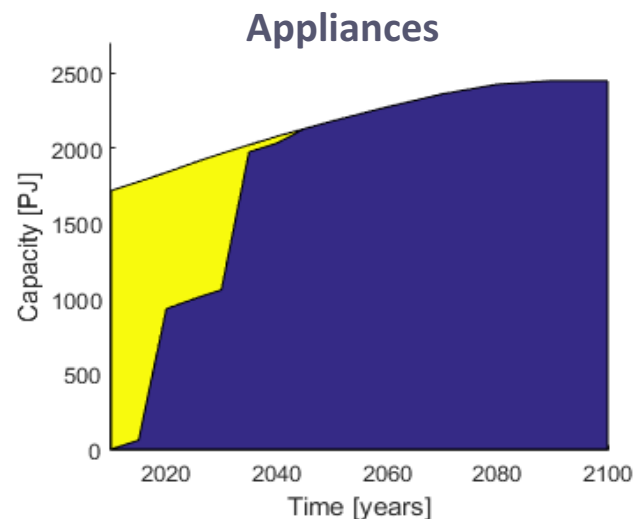
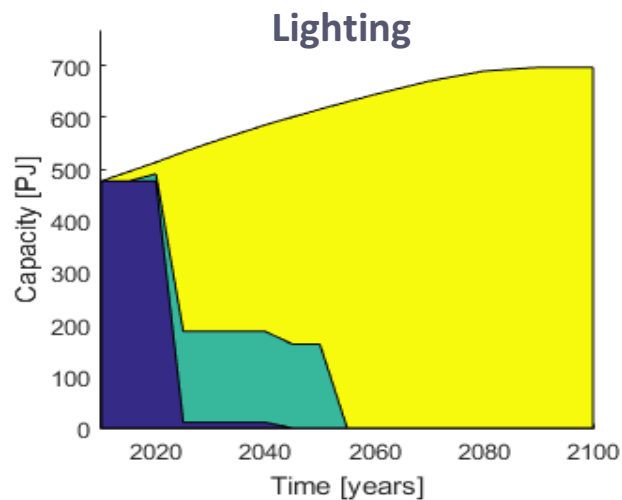
Demand projections

Fuel Consumption

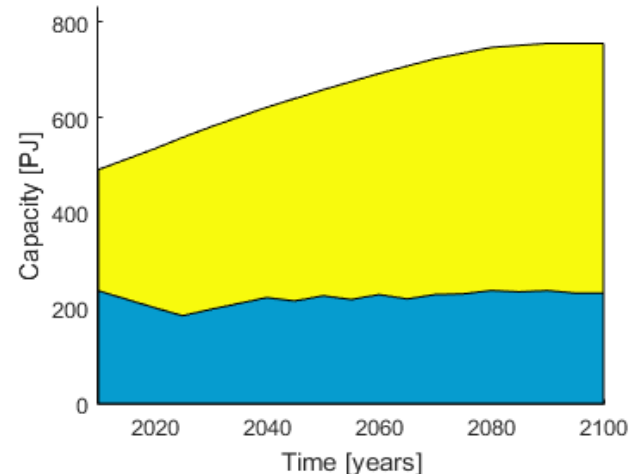
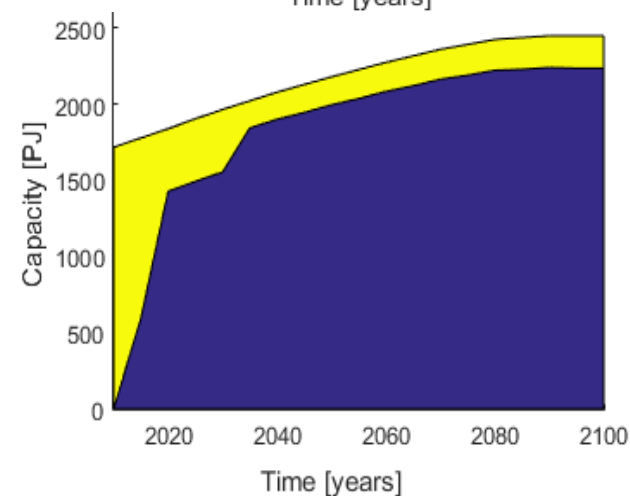
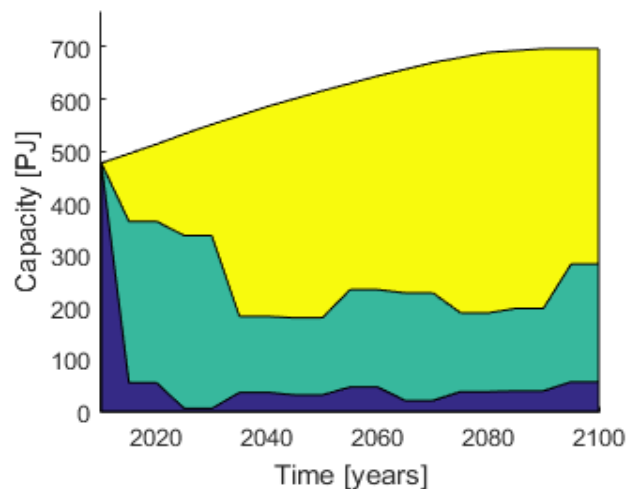
Investment decision

Case Study

Single objective



Agent-based method



Lighting Conventional
 Lighting LED
 Lighting Energy Saving

Appliances Advanced
 Appliances Conventional

Cooking Biomass
 Cooking Elec
 Cooking NG

Diffusion of heating technologies

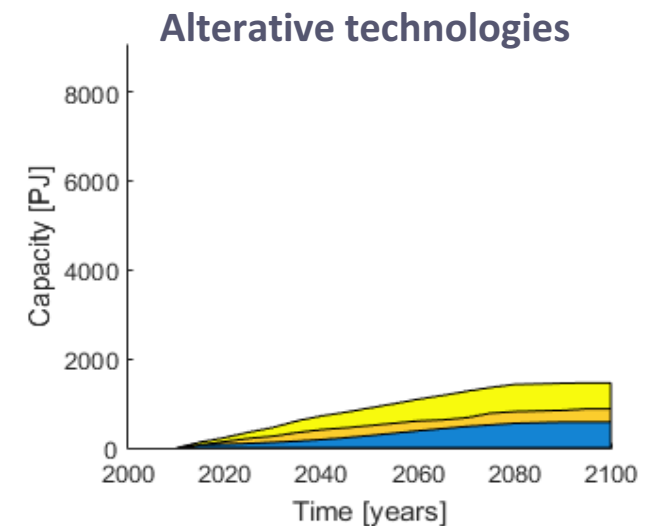
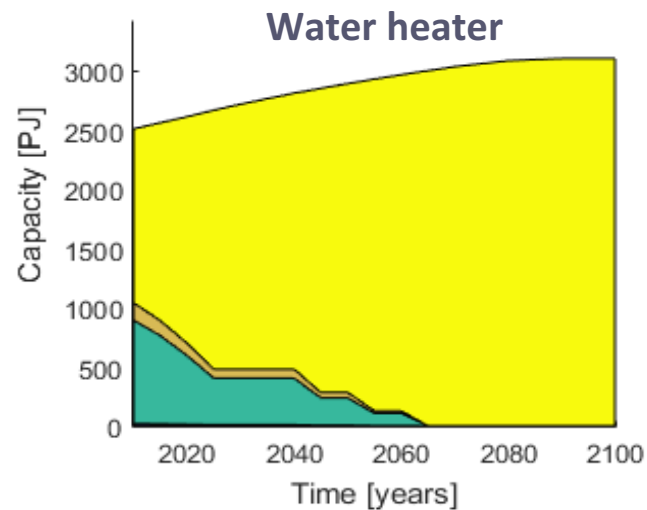
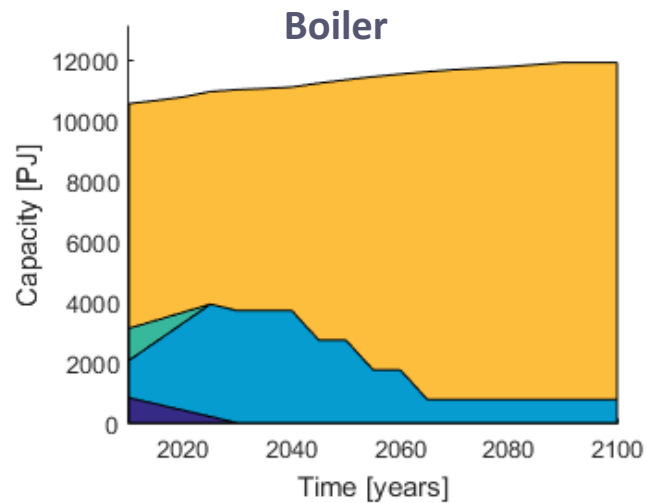
Demand projections

Fuel Consumption

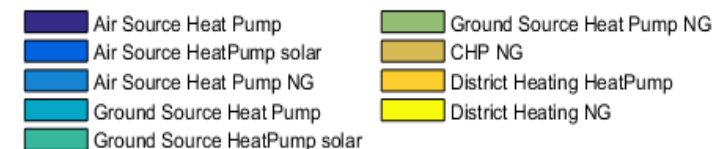
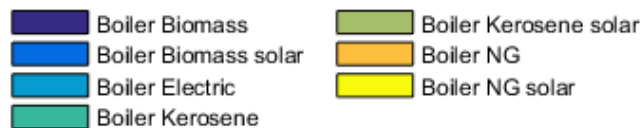
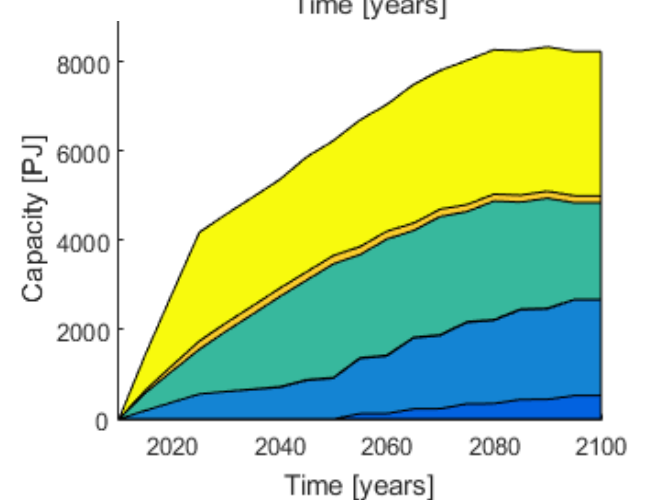
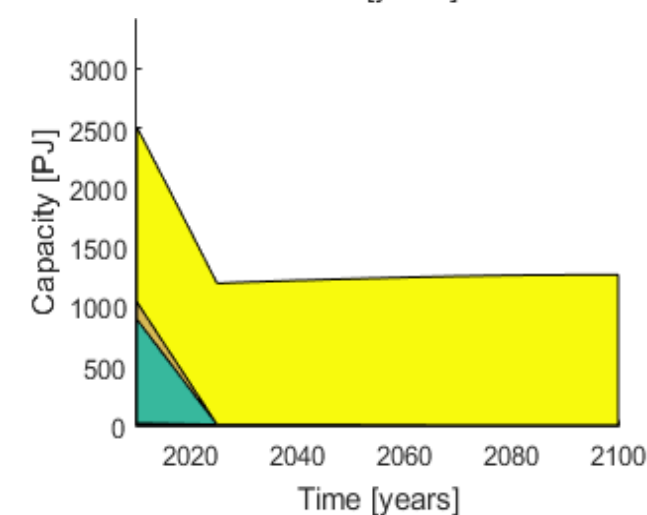
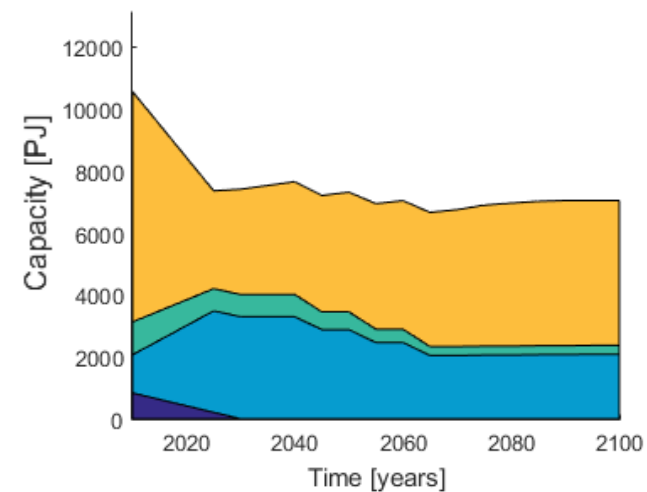
Investment decision

Case Study

Single objective



Agent-based method



Demand projections

Fuel Consumption

Investment decision

Case Study

- ABM presents effective framework for the determination of energy-related investment decisions in the residential building sector
- ABM yields a plausible scenario for the diffusion of technologies
 - Gain in market share of technologies with low lifetime cost
 - Upcoming of new efficient technologies
 - Continuous investment of people in cheap technologies
- Single-objective method highly dependent on capacity constraints whereas ABM reduced sensitivity of results towards changes in parameters
- ABM enables the inclusion of a variety of different objectives and investment methods to capture the diversity in the behaviour of a population
- Captures several aspects of the human behaviour: information gathering, analysis strategies, decision making

Demand projections

Fuel Consumption

Investment decision

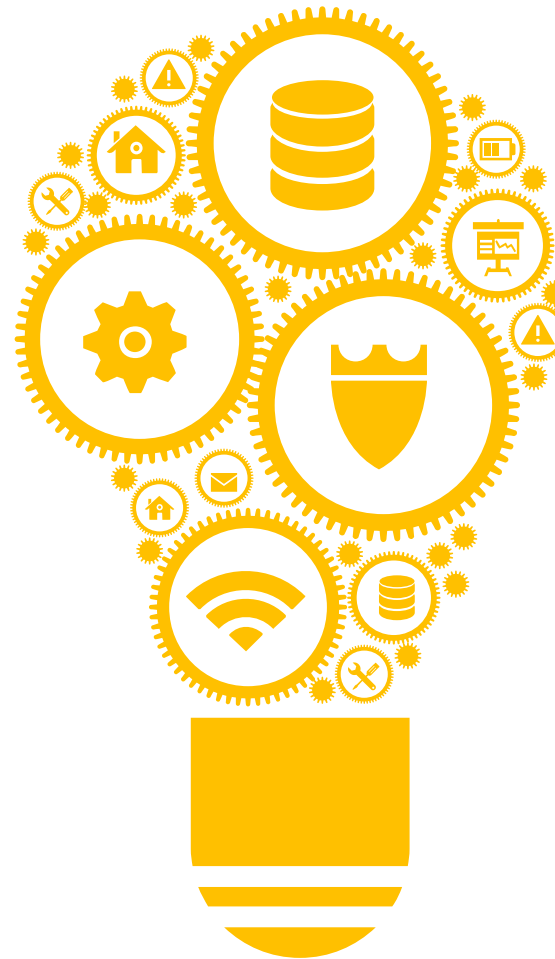
Case Study

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

Current Stock of Technologies

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



Agent Interaction

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

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.

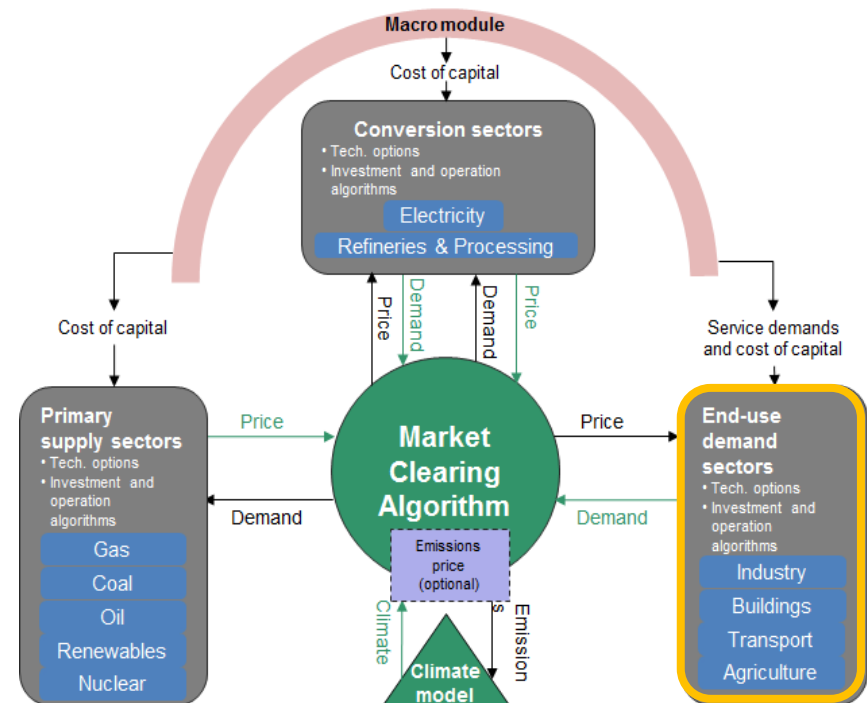
Thank you for your attention

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