Heat4All

Application of Optimisation Model in Heating Decarbonisation

Xinyao Liu

Dr Lirong Liu

Prof Matthew Leach

Dr Michael Short

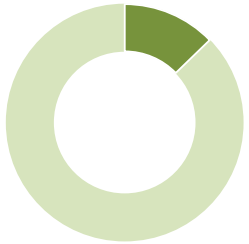
Dr Mona Chitnis

Floris Bierkens, Ishanki De Mel

Net-Zero heating

2019

Emission of building sector:
91 $MtCO_2e$



13%

of the UK's total GHG emissions comes from *direct CO_2 of residential buildings*[1], accounting for 50% building sector emission.

5%

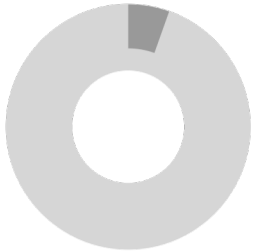
of the UK's total heat demand in buildings is currently met by low carbon sources[2].

2050

Projected emission of building sector:
1 $MtCO_2e$

55%

of emission reduction in building sector will come from *residential building-scale low carbon heating*[3].

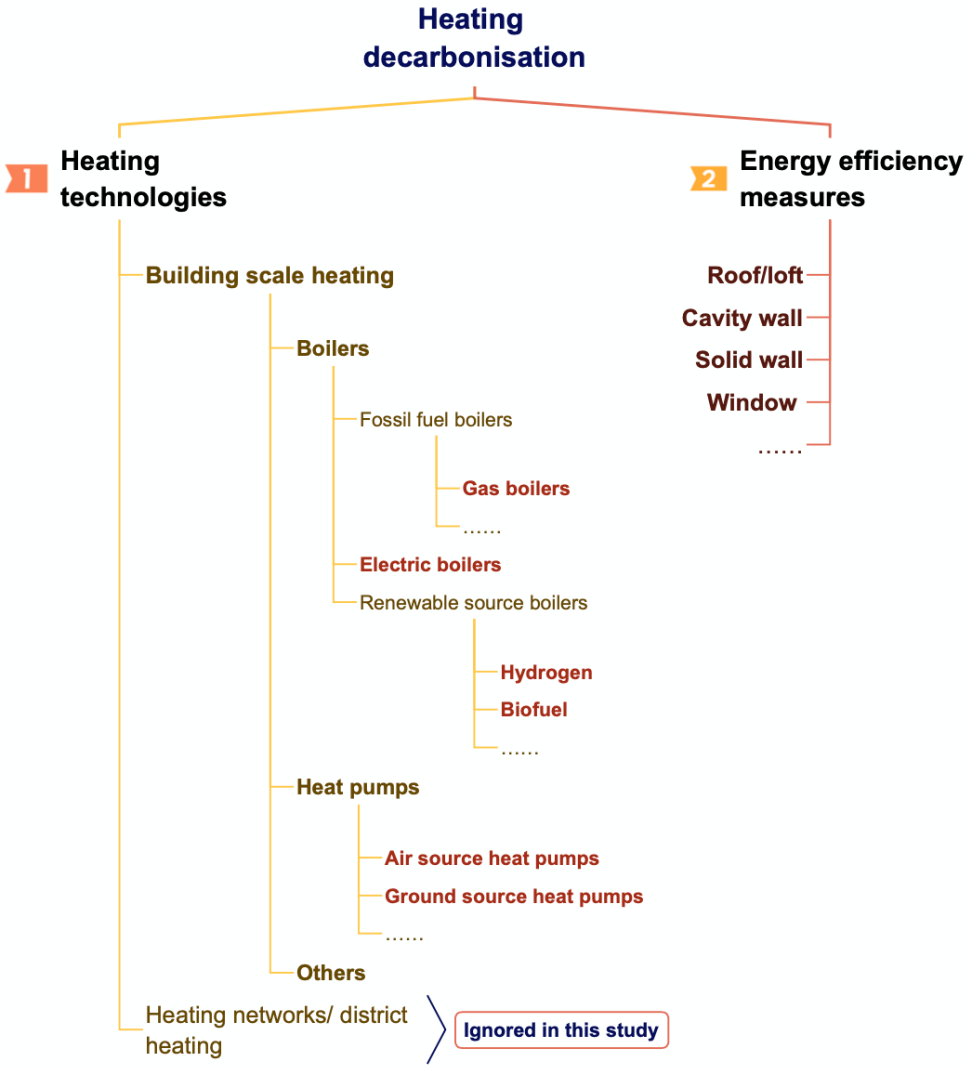


5%

of emission reduction in building sector will come from *residential energy efficiency improvement*[3].

1 Committee on Climate Change, 2019. *Net Zero. Technical Report.*
2 Committee on Climate Change, 2019. *UK housing: Fit for the future?*
3 Committee on Climate Change, 2020. *The Sixth Carbon Budget - The UK's path to Net Zero*.

Fuel poverty



13.4% of households of the UK (3.18 millions households) are classified as fuel poor[1].

Costs of heating system optimisation and current fluctuation of energy price remind policymakers to propose careful decarbonisation strategy to avoid exacerbating fuel poverty.

1 Annual fuel poverty statistics report, 2021

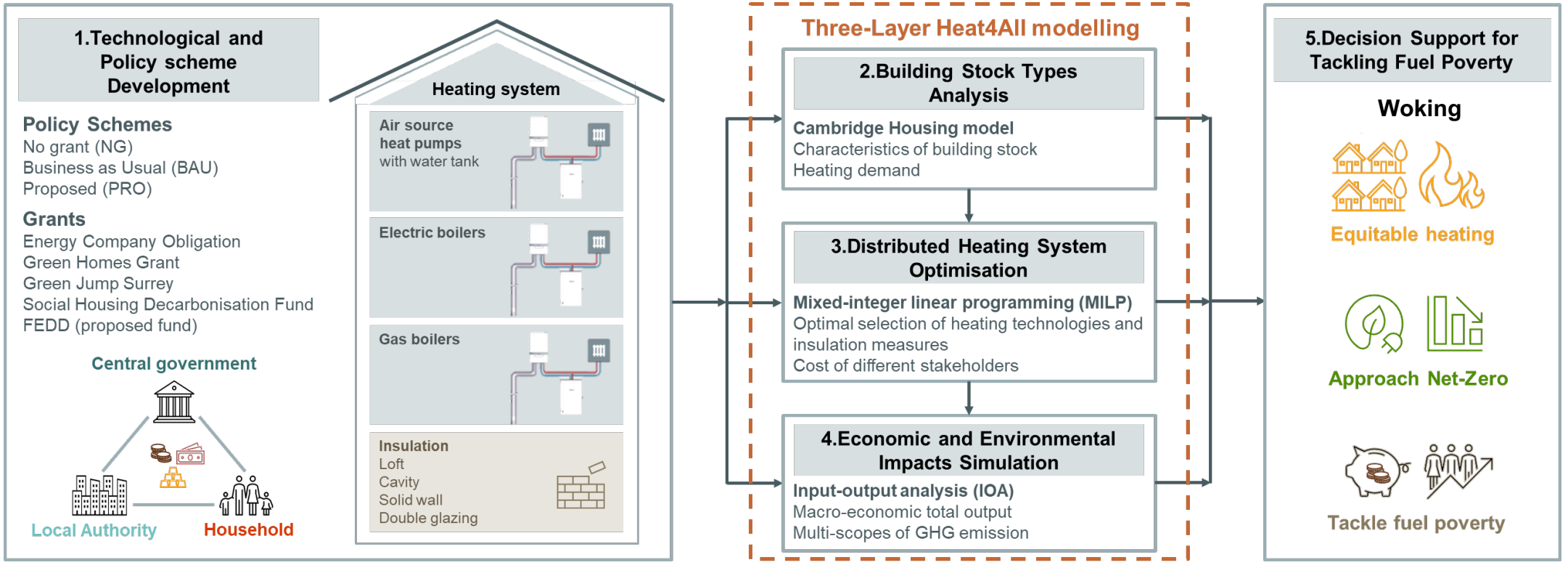
Project overall

Aim 1

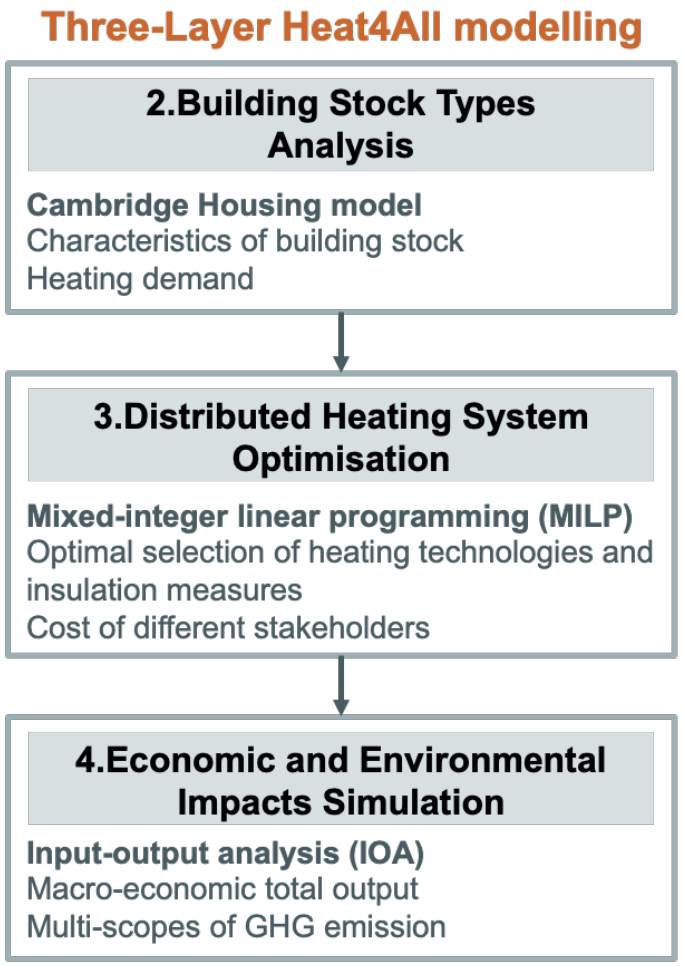
Establish a systematic analysis framework of heating decarbonisation to minimise fuel poverty

Aim 2

Perform a case study and propose technological and policy solutions



Three-Layer Heat4All modelling



Cambridge housing model

- ❑ provide characteristics of building stock collected in UK housing survey
- ❑ simulate the heating demand before and after retrofitting heating decarbonisation measures for each building

Objective function of MILP model: Minimise household cost

- ❑ Social housing: energy bills
- ❑ Other Building stock: Energy bills + Capital investment – Grant support

Constraints: Emission reduction targets, Grant budget, etc

Input-output analysis

- ❑ 4 sectors, **electric equipment, construction, gas and electricity** are directly related with heating system decarbonisation
- ❑ Changes in their **final demand** brings about whole system impacts

Distributed heating system optimisation

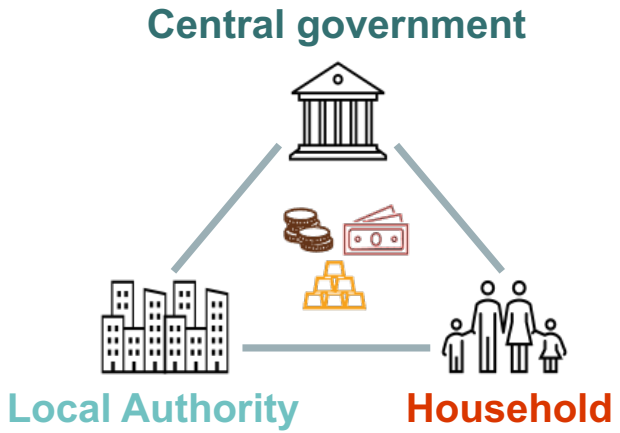
Objective Function: Minimise household cost

- **Social housing**

  Energy bills

- **Other building stock**

  Energy bills + Capital investment – Grant support



Distributed heating system optimisation

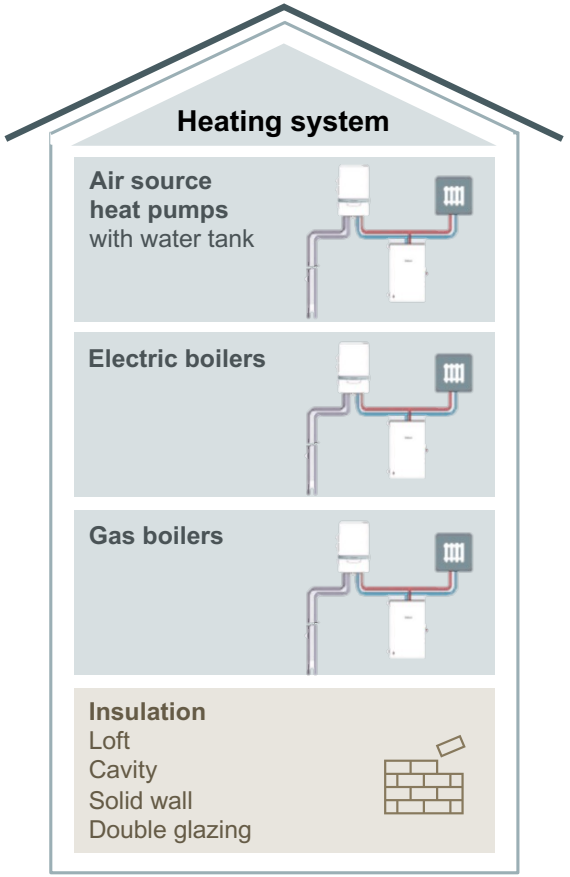
Decision variables: retrofit options

Heating technologies

3 options of gas boilers, electric boilers and heat pumps

Energy efficiency measures

Multiple options of retrofits for loft, cavity, solid wall and double glazing



Distributed heating system optimisation

Heating technologies

ASHP	Listed capacity (kW)	CoP at $T_t^{amb} = 2°C$	CC_p^{pump} (£)	T_p^{ws} (°C)
HP50	5.0	1.98	2333	55
HP60	6.0	2.45	3053	55
HP85	8.5	2.30	3577	55

Hot water tank	V_k (L)	CC_k^{Tank} (£)	H_k^{loss} (kW)
150L	150	1510	0.048
170L	170	1565	0.051

Boiler	cap_b^{boiler} (kW)	CC_b^{boiler} (£)	η_b	Type
7E	7	1030	1.000	Electric
11E	11	1110	1.000	Electric
12E	12	1439	1.000	Electric
24G	24	811	0.911	Gas
25G	25	744	0.891	Gas
30G	30	852	0.891	Gas

Energy efficiency measures

Insulation form	Detached $C_{i,j}^{ins}$ (£)	Semidetached $C_{i,j}^{ins}$ (£)	End-terrace $C_{i,j}^{ins}$ (£)	Mid-Terrace $C_{i,j}^{ins}$ (£)	Flat $C_{i,j}^{ins}$ (£)
Loft	525	438	438	350	N/A
Cavity	534	416	416	341	N/A
Solid wall	4189	3281	3281	2188	N/A
Double glazing	7100	5950	5950	4450	3000

Distributed heating system optimisation

Constraints

Emission reduction target

Direct emission reduction of heating system
(gas + electricity)

Grant eligibility and budget

Energy Company Obligation
Green Homes Grant
Green Jump Surrey
Social Housing Decarbonisation Fund
FEDD (proposed fund)

Policy schemes and grant eligibility

Grants	GHG-GJS	ECO	SHDFd	SHDFe	FEDD
Applicable policy schemes					
NG	-	-	-	-	-
BAU	+	+	+	+	-
PRO	+	+	+	+	+
Grant details					
Eligible EPC	E,F,G	E,F,G	D	E	D,E,F,G
Household Limit	£15,000	£10,000	£10,000	£12,000	N/A
Case Study Limit	£300,734	N/A	£402,073	£482,488	N/A
Heating technologies					
Gas Boilers	-	-	-	-	
Electric Boilers	-	-	-	-	S
ASHPs	P	-	S	S	S
Hot water tanks	-	-	-	-	S
Energy efficiency measures					
Loft	P	P	P	P	P
Cavity	P	P	P	P	P
Solid wall	P	P	P	P	P
Double glazing	-	P	P	P	P

Note:
1: 'P' indicates Primary and 'S' indicates Secondary measures.
2: Green Jump Surrey is a county addition to the Green Homes Grant, the two are combined into one grant for modelling purposes. Budget limitations for the Social Housing Decarbonisation Fund differ based on the dwelling's EPC rating. Hence, the fund is divided into two individual grants.

Three-layer Heat4All modelling

456000 Scenario

Future policy scheme **3**

Minimum emission reduction target (ERT) **25 (0-100%)**

Projected carbon intensity of grid (GCI) **16 (0-15 gCO2e/kWh)**

Projected future natural gas prices **19 (0.01-0.1 £/kWh)**

Projected future electricity prices **20 (0.1-1.5 £kWh)**

Output of each scenario

Optimised retrofitting plan

Costs of different stakeholders

Impacts on industry sectors and total outputs

Impacts on multi-scopes of GHG emissions

Case study in Woking

1658 social housing dwellings

BAU policy scheme

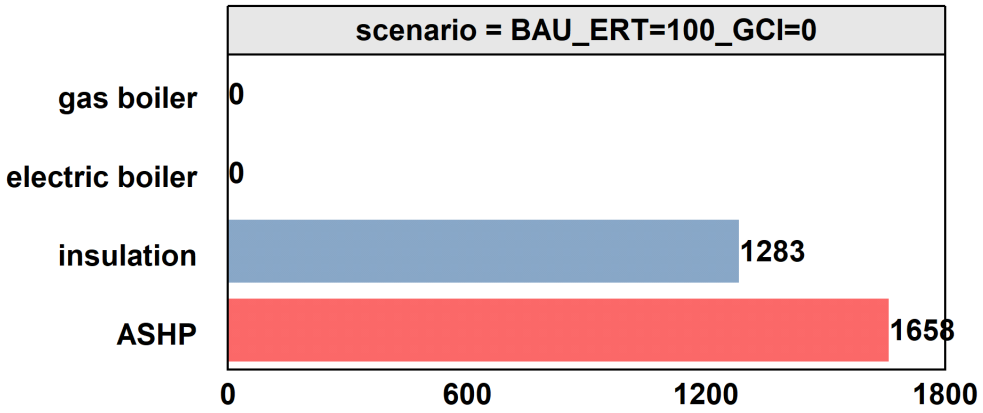
100 % GHG emission reduction

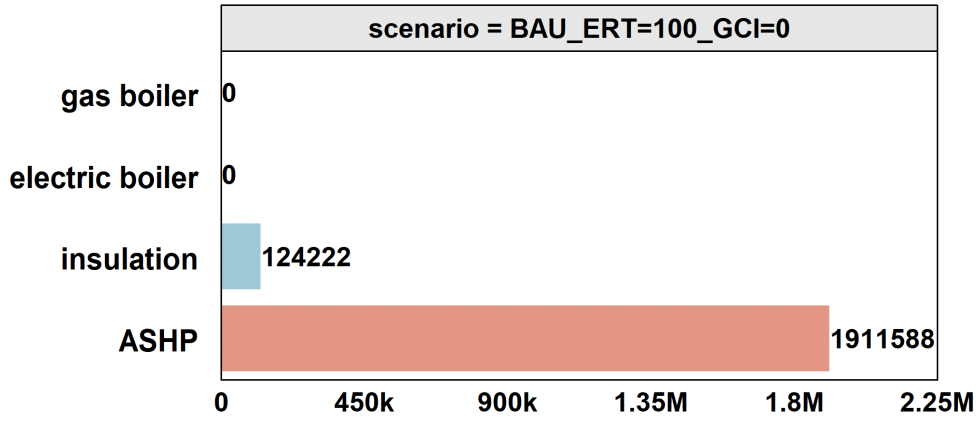
0 gCO_2e/kWh

0.231 £/kWh future electricity price

0.055 £/kWh future gas price

Selection of retrofits





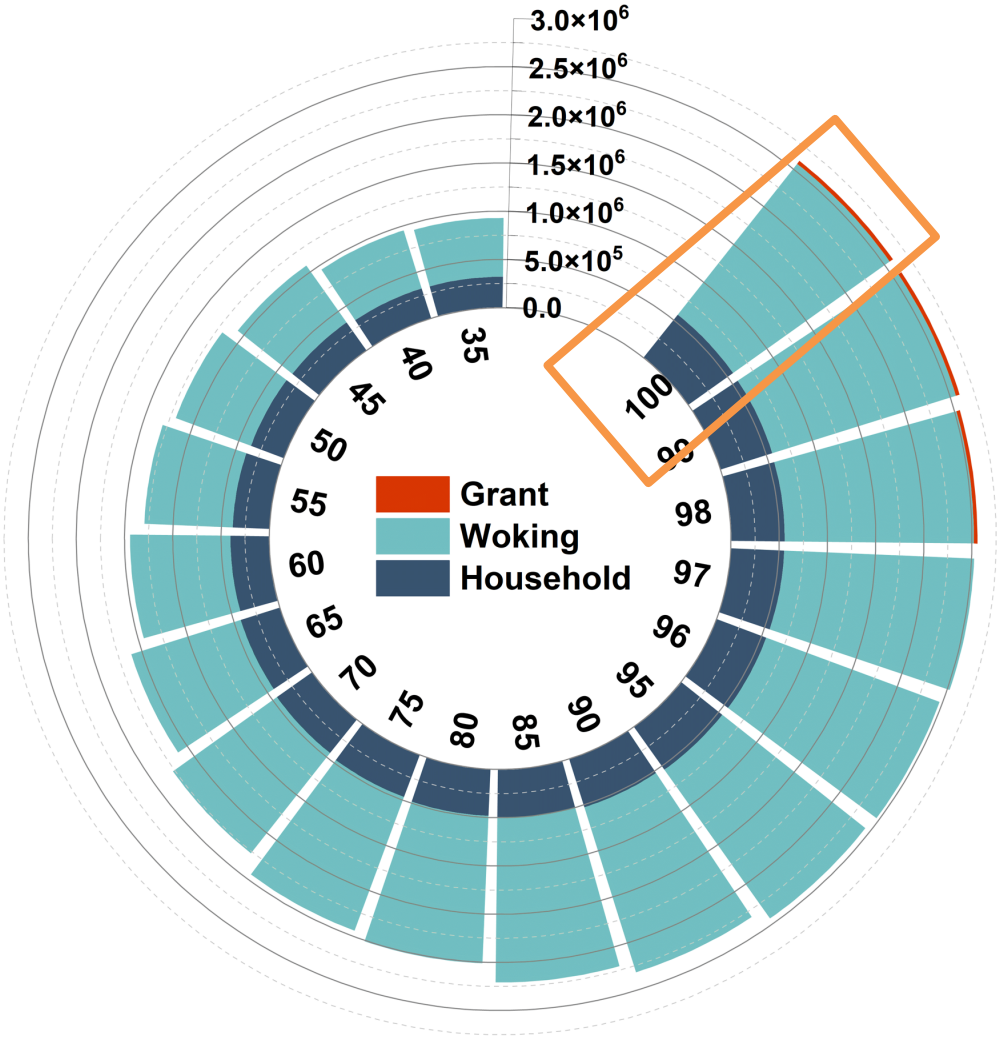
Installation numbers in total

- Only heat pumps are selected

Annualised retrofitting costs

- heat pumps: **£ 1.91 million**

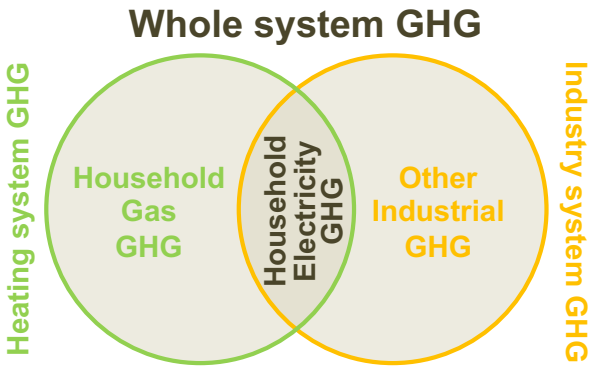
Cost of stakeholders

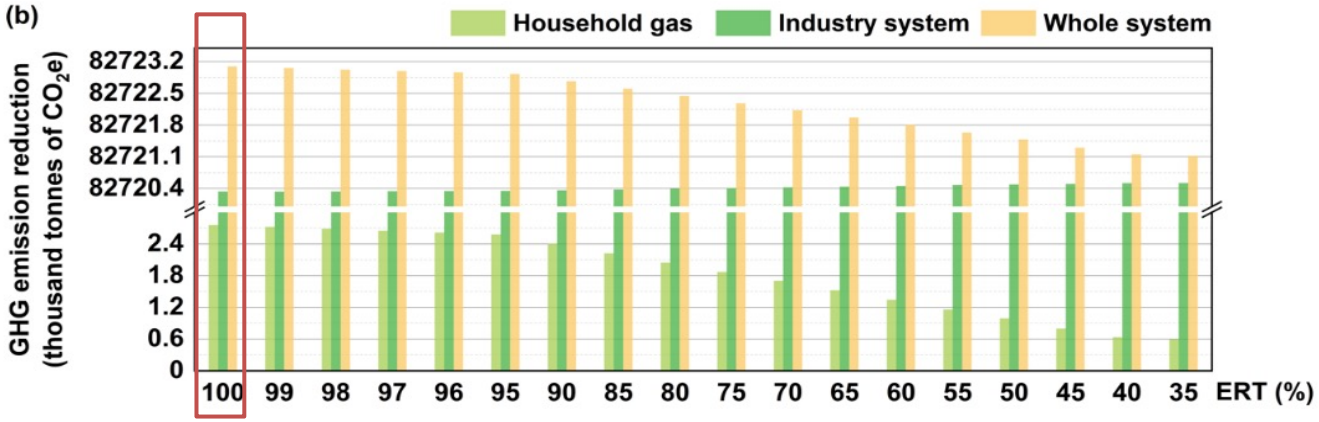


Annualised cost of stakeholders (£)

Current grants contribute to very limited part of capital investments (mainly in air source heat pumps)

Whole system GHG emissions



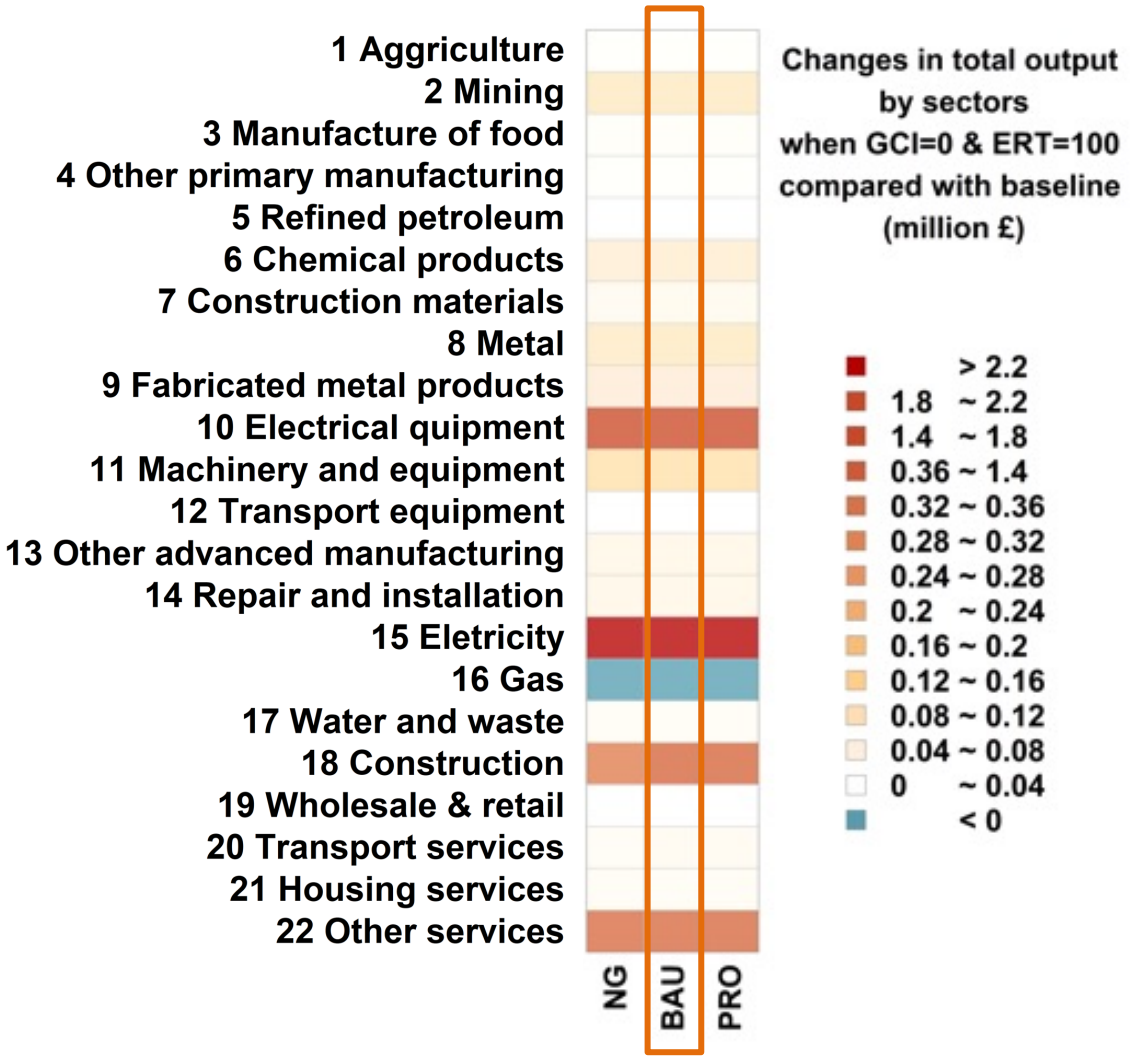


Multiple scopes of GHG emissions (thousand tonnes of CO_2e)

Whole system emission reduction: 82723

- *Household gas* : 2.760
- *Household electricity* : 0.805
- *Industry system* : 82720, dominating emission reduction of whole system

Impacts on industry sectors



Total output by sectors

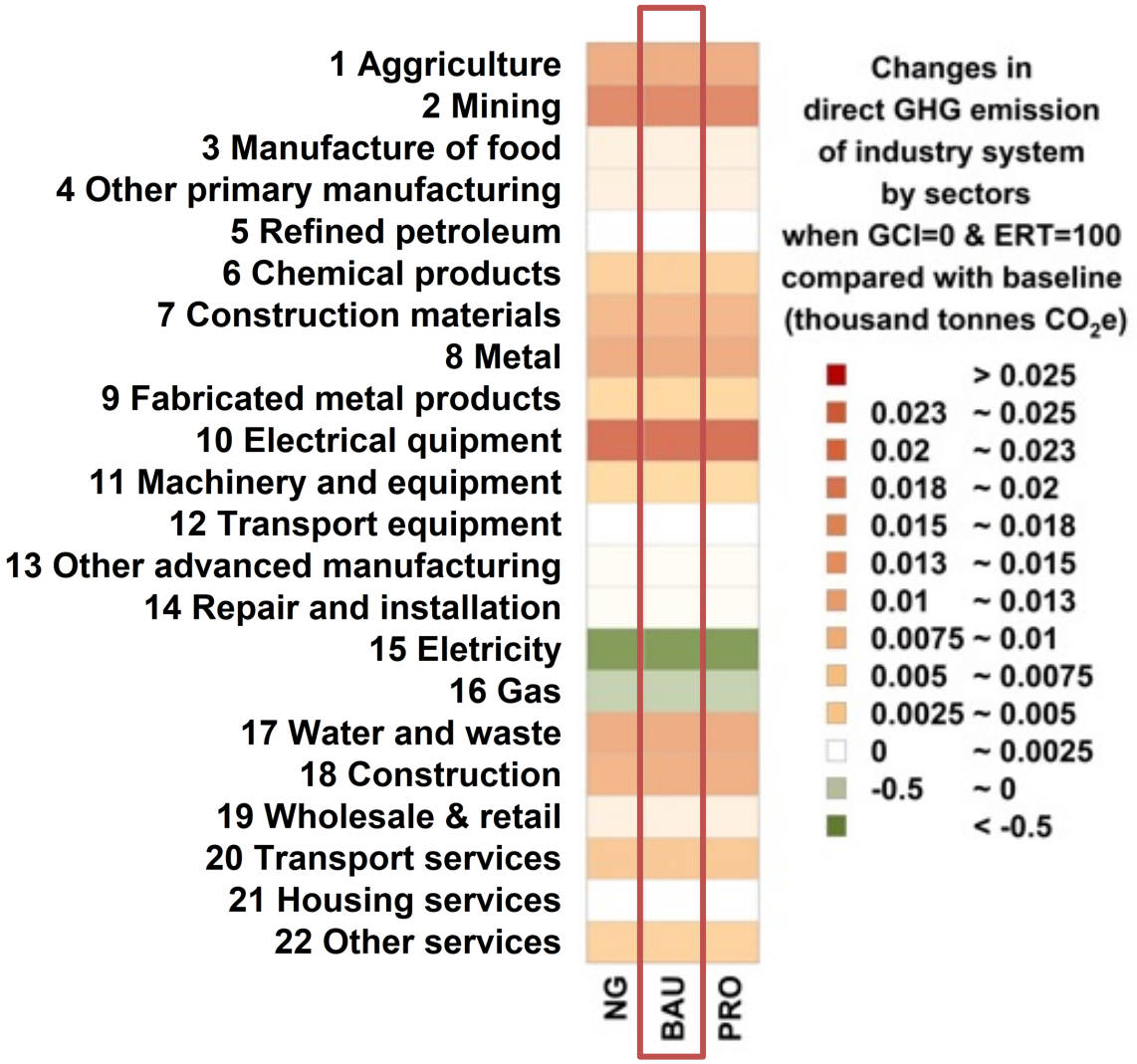
- Only Sec16(Gas) decreases
- Stronger increases in Sec10(Electrical equipment), Sec15(Electricity), and Sec18(Construction)

Impacts on industry sectors

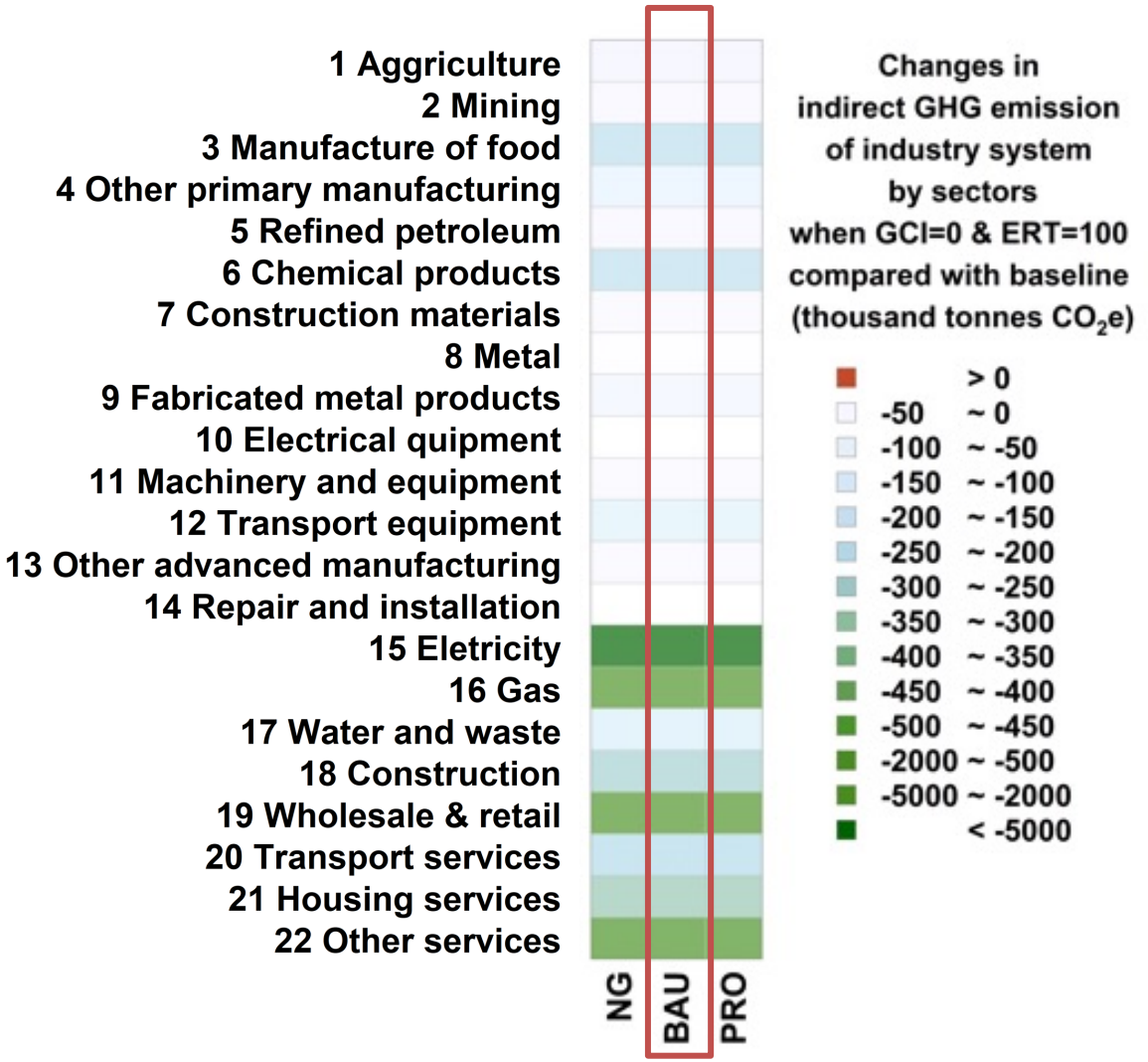
Direct GHG emission by sectors

Trends are similar to changes in total output, but sectors have various emission factors.

- Sec15(Electricity): huge changes in GCI (187 to 0 gCO_2e/kWh).
- Sec16(Gas): decreased gas consumption.



Impacts on industry sectors



Indirect GHG emission by sectors

- Trends are different from changes in direct GHG
- Decreases in all sectors because of huge changes in GCI (187 to 0 gCO_2e/kWh)

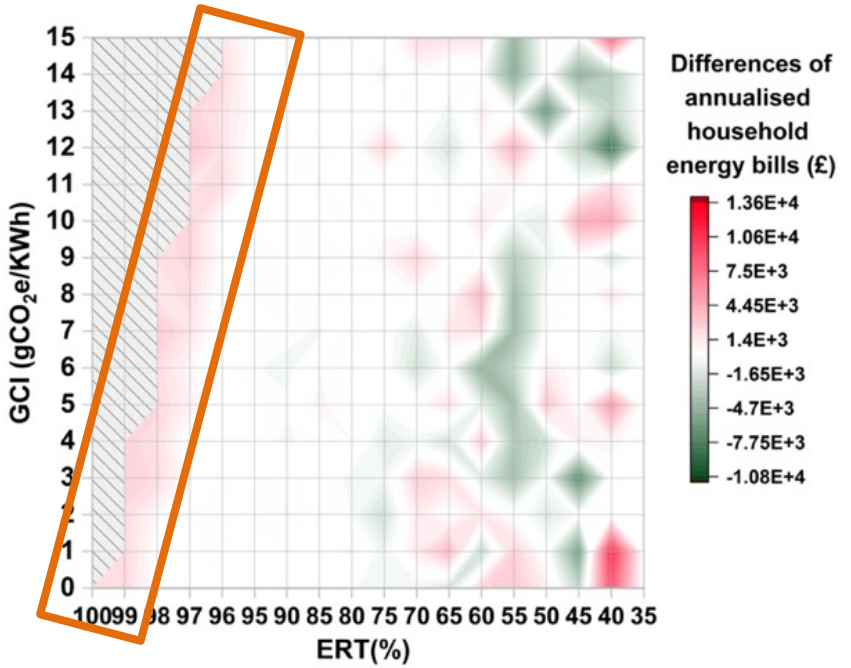
Discussion

Policy schemes

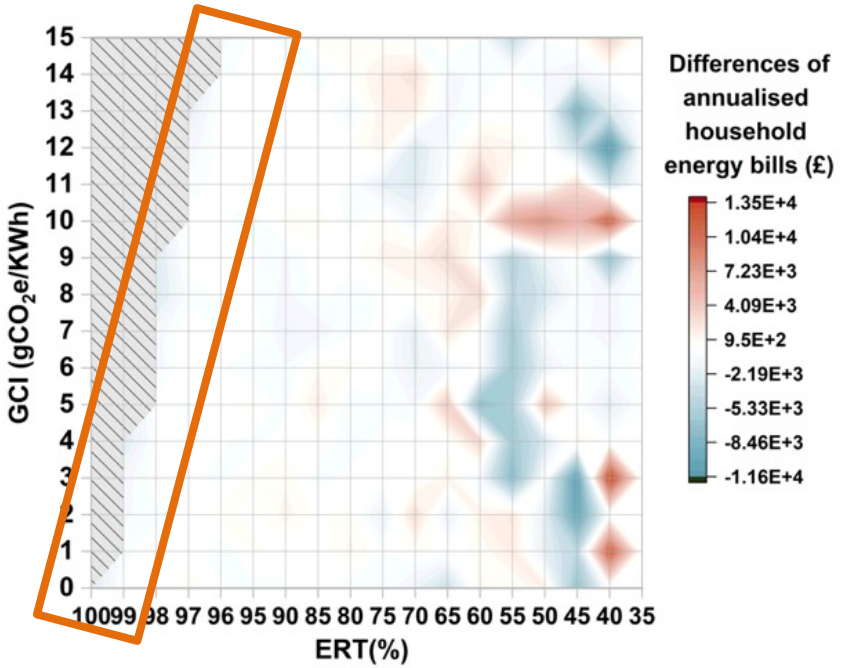
Energy Prices

Policy schemes

When comparing different policy schemes



NG-BAU

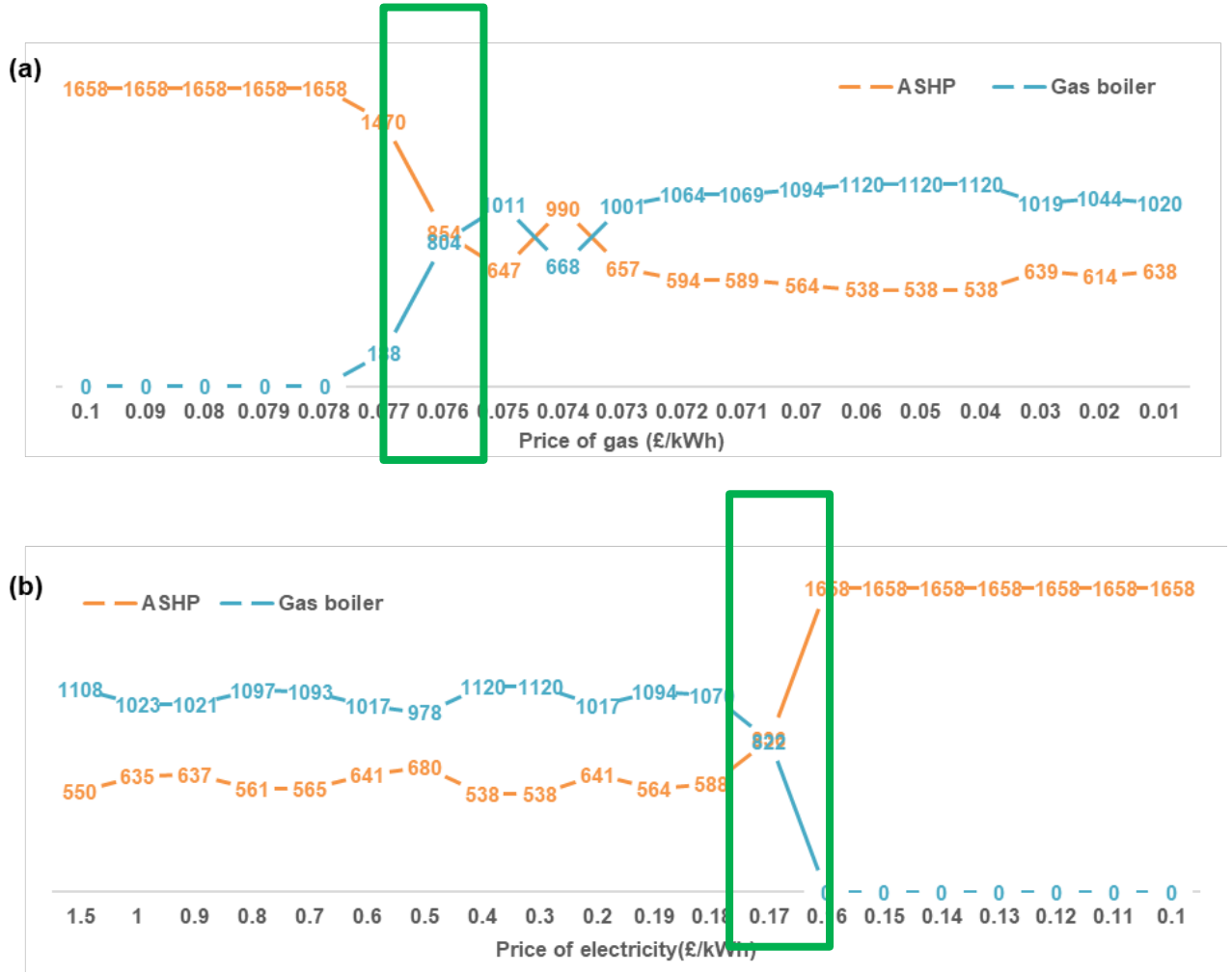


PRO-BAU

When ERT is close to the upper limit, PRO provides the cheapest plan for households, followed by BAU and NG.

Energy Prices

When electricity price is 3 times of gas price…



Sensitivity of

(a) gas price when GCI is 15 gCO_2e/kWh, ERT is 60%, and price of electricity is 0.231 £/kWh under PRO;

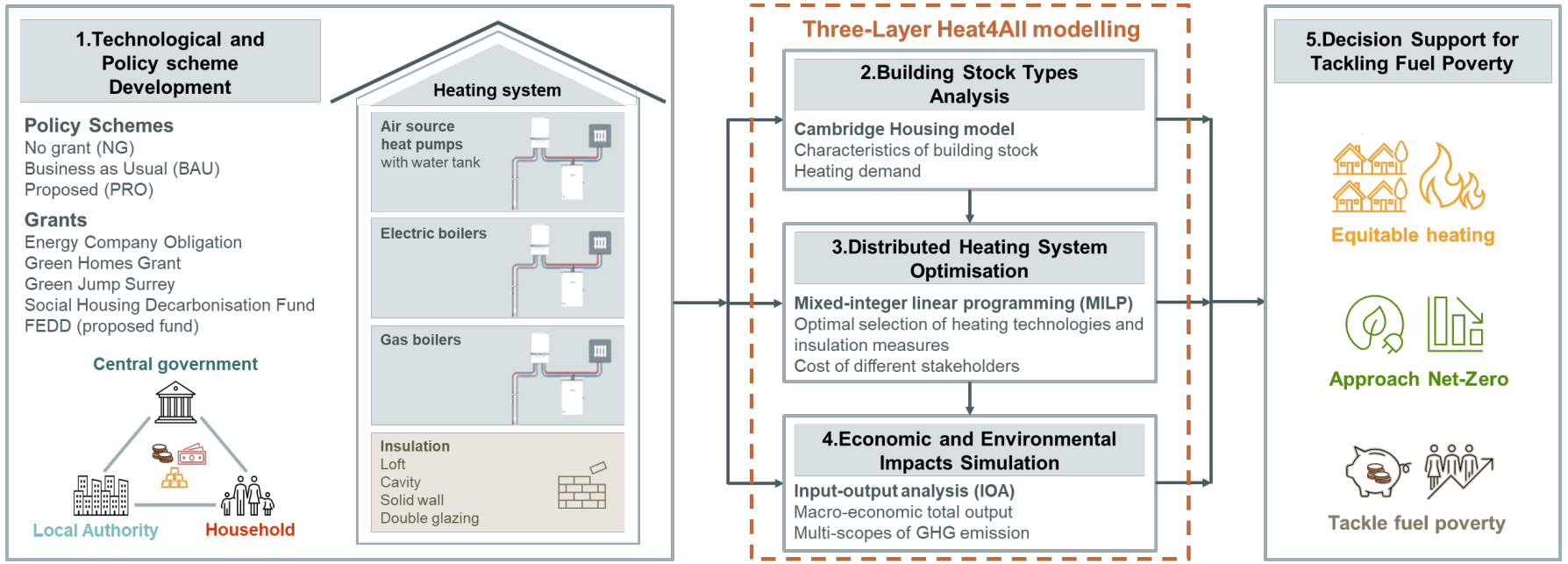
(b) electricity price when GCI is 15 gCO_2e/kWh, ERT is 60%, and price of gas is 0.055 £/kWh under PRO

Summary

MILP helps tackle heating decarbonisation and fuel poverty at community level

Three-layer Heat4All integrates MILP optimisation and explored wider system impacts of heating decarbonisation

Future works could integrate decarbonised electricity system, and polish grants design, etc.



Future
Equitable
Decarbonised
Distributed
Heating system

THANKS