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Incorporating Homeowners' Preferences for Heat Technologies in the UK TIMES Model

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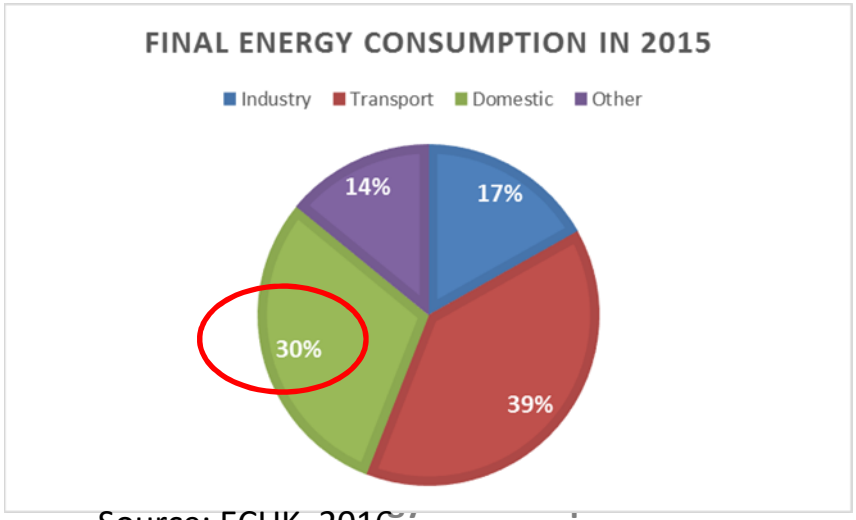
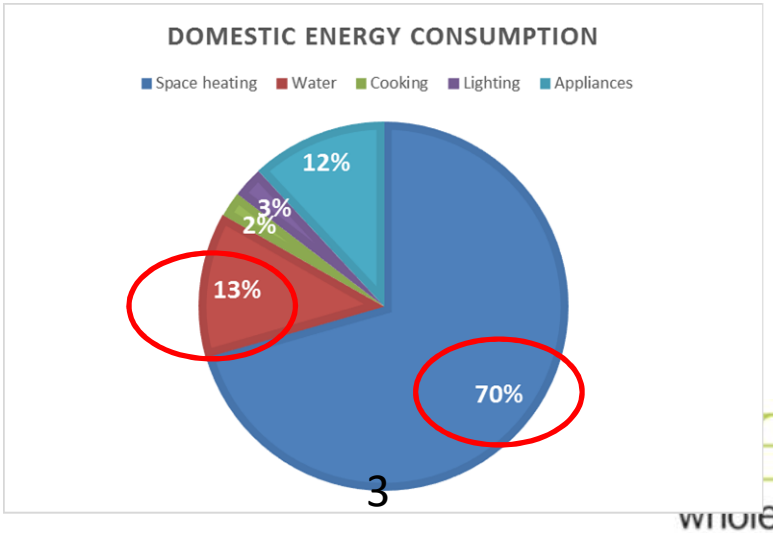
Introduction

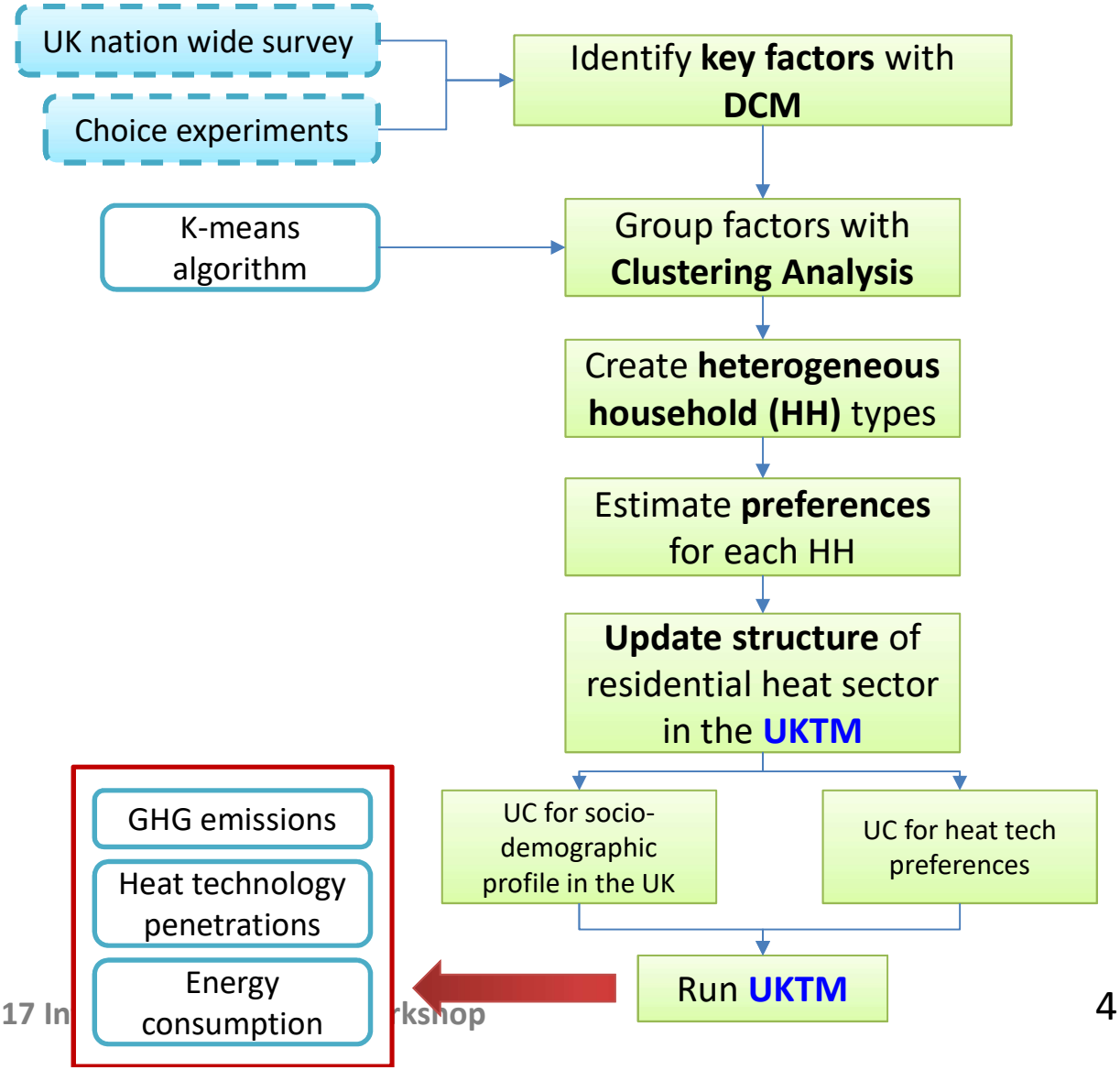
- 2008 UK Climate Change Act: 80% reduction by 2050
- Residential heating should be decarbonised dramatically by adopting low-carbon heat technologies
- CCC (2016): 2.3 million heat pumps by 2030; 31 million by 2050
  - Require radical behavioural adjustment
- Homeowners' preferences of heat technology choice
  - Not yet reflected in energy modelling well!





Source: ECUK, 2016

Research Procedure



Discrete Choice Experiment (1/2)

- Nationwide survey in 2015
  - 1,007 respondents
  - 721 completed choice experiment
  - 442 homeowners
- Multinomial logit model (MNL)
- Considered factors (wider range)

Example choice

Type of heating system	Gas	Electric storage	Heat pump	Solid fuel
Upfront cost	£2,000	£1,500	£12,000	£4,000
Annual cost	£1,000	£2,300	£150	£300
CO_2 emissions, where the typical house in the UK emits about 3 tonnes per year	Average emissions (around 3 tonnes)	Very low emissions (0-1 tonnes)	Very low emissions (0-1 tonnes)	High emissions (more than 4 tonnes)
Lifetime (Years)	15 years	20 years	20 years	20 years
Operation hassle	None	None	Substantial	Some
PLEASE INDICATE THE SYSTEM YOU WOULD CHOOSE	☐	☐	☐	■

Category	Factors
Socio-demography	Gender, age, household income, education level, work status
Economy	Upfront cost*, annual cost* (operation & maintenance cost), responsibility of bill payment
Environment	Carbon emission*
Technology	Lifetime*, operation hassle*, existing heat technology
Dwelling	Type, age, bedroom number, family size, region, length of stay
Eco-knowledge	Awareness of eco-technologies (PV, CFL, electric storage heater, heat pump, wood pellet boiler and etc.)

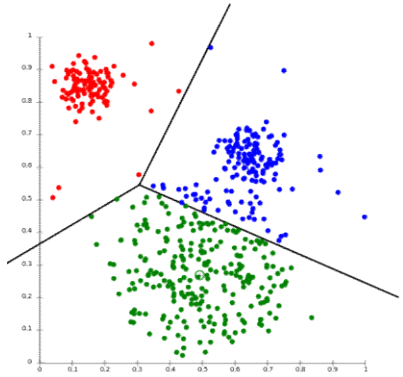
Discrete Choice Experiment (2/2)

- Significant factors
  - Region, Dwelling type, Bedroom number, Age, Income, Existing heat tech, Awareness of eco-tech
  - Consistent with previous findings (DECC, 2013)

	GAS	ELC	HP	SOLID
Existing Tech	Gas heater+ Oil boiler+	Elc Storage + Elc other -	Heat pump+ Oil boiler+	Elc other + Open fireplace+
Cost/Tech Attribute		Upfront Cost(>Gas) - Hassle -	Cost/gas cost -	Upfront cost(>gas)-
Socio-demographic	Age(<60)+	Age+	Income(<15k)-	Age(35-44)+ Income(>80k)+ Income(30k~80k)+
Region	East Mid + North East +	London + Scotland +	East Midland+	Scotland+ York&Humber+
Dwelling		Detached + Semidetached+ Flat -	Bedroom no+	Bedroom no+
Awareness	Insulation+ CFL – Elc Storage -	Smart meter – Heat pump -	Insulation+ Heat pump+ PV+	PV+ Wood pellet boiler+

Clustering Analysis (1/2)

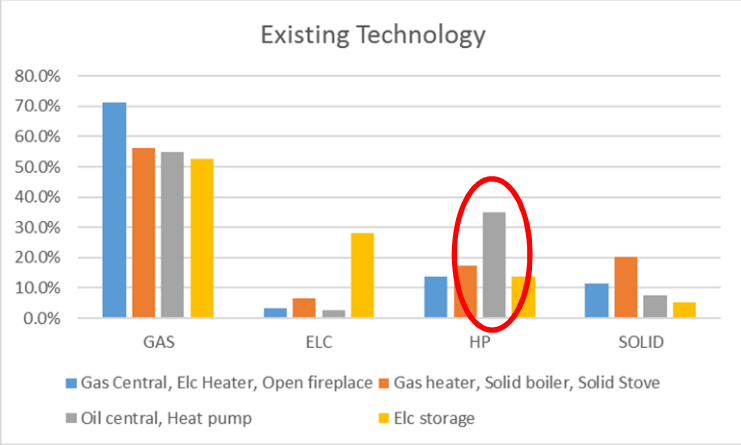
- Reduce total number of households
  - Easily reach thousands types
- Determine how to group attributes of factors
- Clusters for
  - Existing technology, awareness, region, bedroom number
- K-means++ algorithm
  - partition *n* observations into *k* clusters in which each observation belongs to the cluster with the nearest mean
  - Multiple runs to find better results

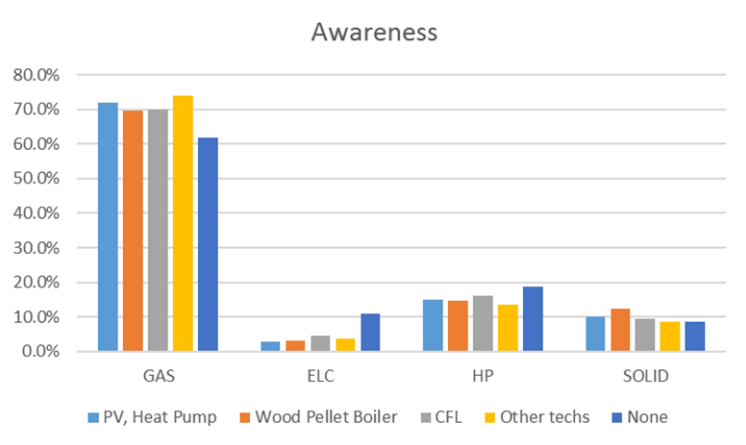


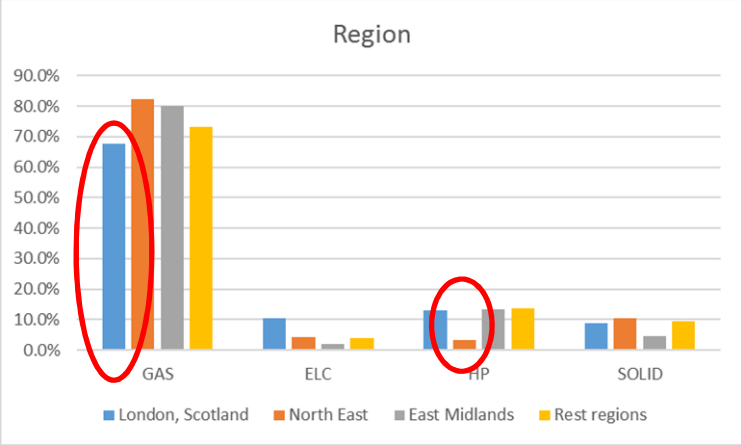
$$\min \sum_{i=1}^{k} \sum_{x \in S_i} \|x - \mu_i\|^2$$

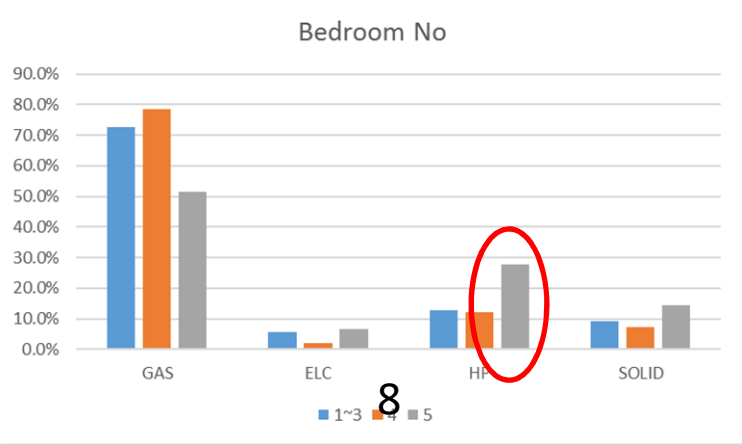
Clustering Analysis (2/2)

Clusters	Existing Technology	Awareness	Region	Bedroom no
	Gas Central, Elc Heater, Open fireplace	PV, Heat Pump	London, Scotland	1~3
	Gas heater, Solid boiler, Solid Stove	Wood Pellet Boiler	North East	4
	Oil central, Heat pump	CFL	East Midlands	5
	Elc storage	Other techs	Rest regions	
		None		



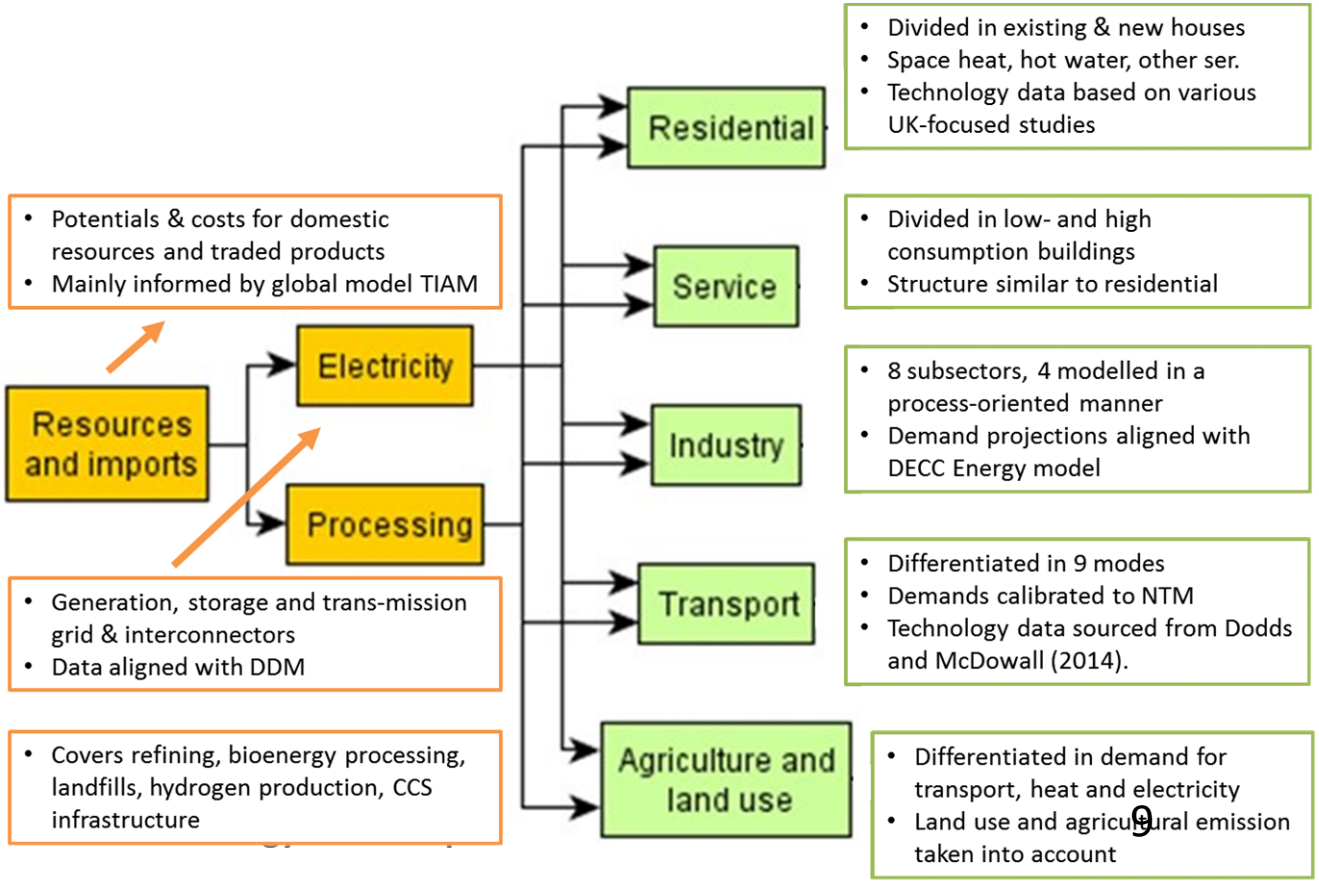






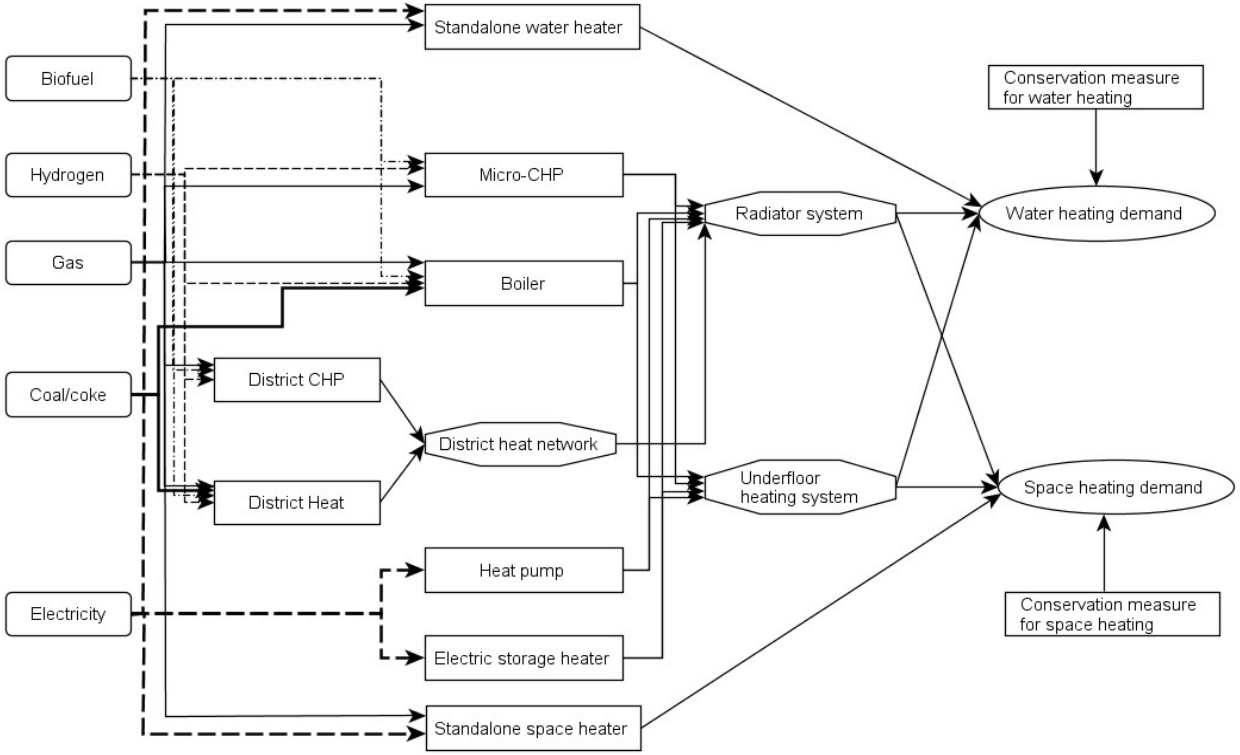
UKTM-The UK TIMES Model

- **Developed by UCL Energy Institute under wholeSEM project**
- **Whole Energy System**
- **Technology-rich**
- **Minimum cost**
- **Adopted by UK government (BEIS, CCC) for policy making**



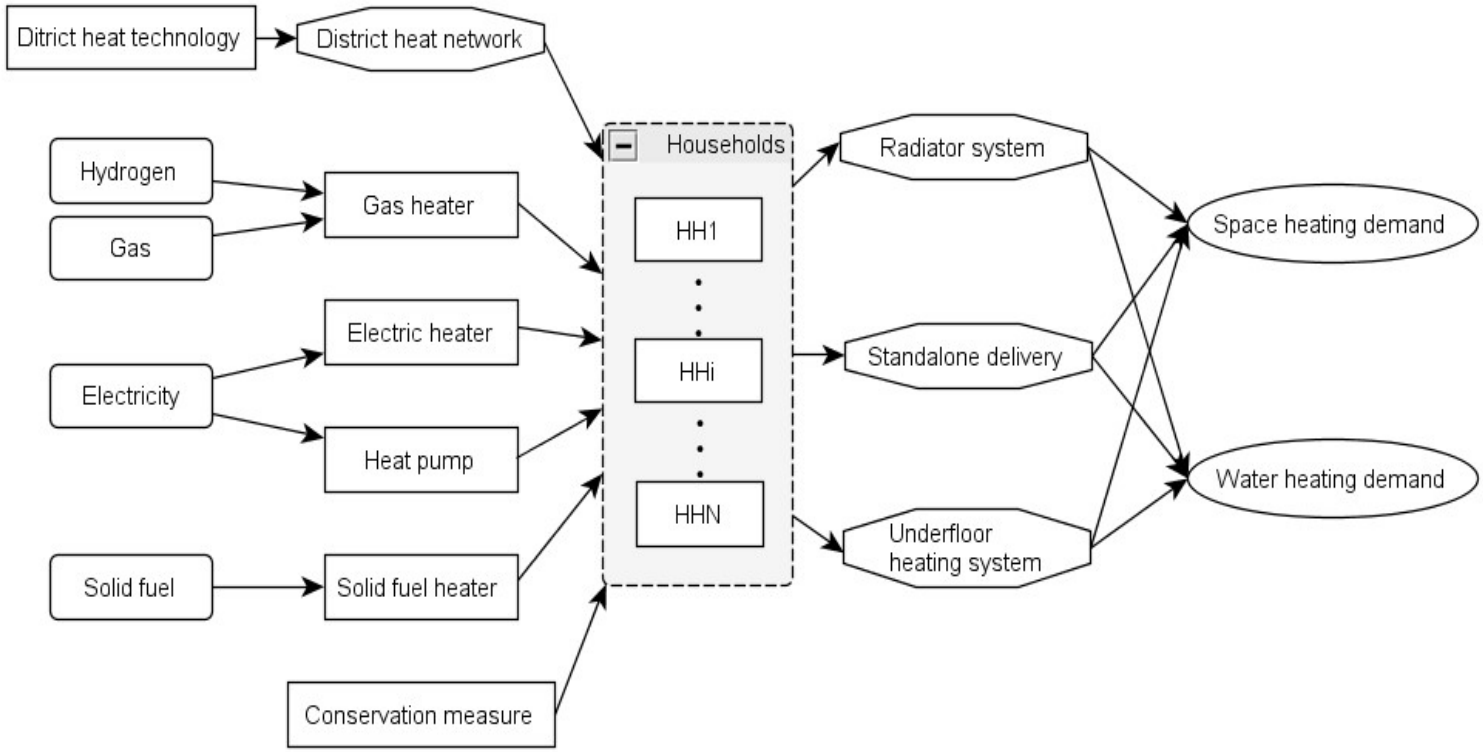
Residential Heating in UKTM

- UKTM includes a wide range of heating technologies to fulfill **water heating and space heating demands**
- **Heat technology (~100):** gas central heater, electric heater, heat pump, solid fuel heater, micro-CHP, hybrid heater, district heat network
- **Delivery technology:** pipe radiator, underfloor, standalone



Heterogeneous Households in UKTM

- Introduce **heterogeneous households into the model** to represent various behaviours of each household type
- **Duplicate heating technology, district heat and conservation measures** for each household type (~1200 heating technologies)



Preference Model on Heating Technology Choice

- ***Regulate households' behaviour in the model***

$$\text{Minimize} \sum_{t=1}^{T}\sum_{i=1}^{N}\sum_{k=1}^{F} c_{i,k,t} \times nc_{i,k,t} + other\ existing\ system\ costs$$

Minimal cost

Demographic constraint: *heat demand spreads among household types*

Growth constraint: *decommissioned heating technologies in a household type should be replaced by newly chosen heating technologies (ensure heterogeneity of households in the model)*

Preference constraint: *reflect households' preferences for heating technologies*

New capacity constraint: *convert heating activity of new technology into capacity for cost estimation*

Constraints on conservation (CSV) and district heating (DH):
Activities of CSV and DH for each household type should be less than the corresponding maximum potential

Preferences of each household type

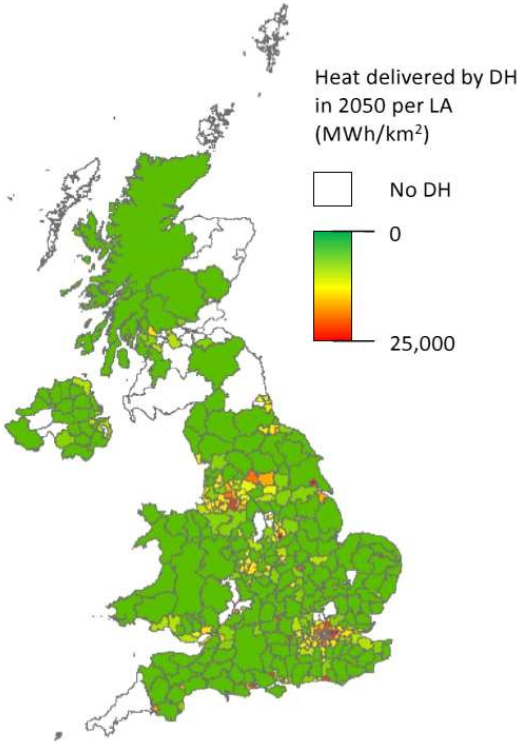
- Most influential factors:
  - **No. of bedrooms, Existing heating technology**
- Preference ratios
  - Samples for 4 and 5 bedrooms with existing heat pumps were missing

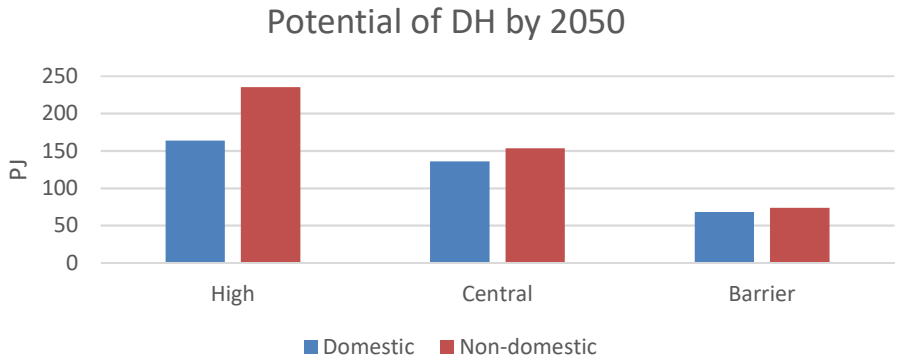
Household type	Existing heater	Chosen heater			
		Gas	Elc	Heat	Solid
1~3 bedrooms	Gas	75.7%	4.7%	11.5%	8.1%
	Elc	62.7%	14.8%	11.9%	10.6%
	Heat	53.1%	3.1%	40.6%	3.1%
	Solid	65.2%	3.7%	14.9%	16.2%
4 bedrooms	Gas	78.9%	2.2%	11.7%	7.3%
	Elc	75.0%	4.2%	12.5%	8.3%
	Heat	53.1%**	3.1%**	40.6%**	3.1%**
	Solid	67.7%	-	24.0%	8.3%
5 bedrooms	Gas	60.2%	6.3%	19.9%	13.6%
	Elc	40.0%	2.5%	45.0%	12.5%
	Heat	53.1%**	3.1%**	40.6%**	3.1%**
	Solid	47.5%	-	37.5%	15.0%

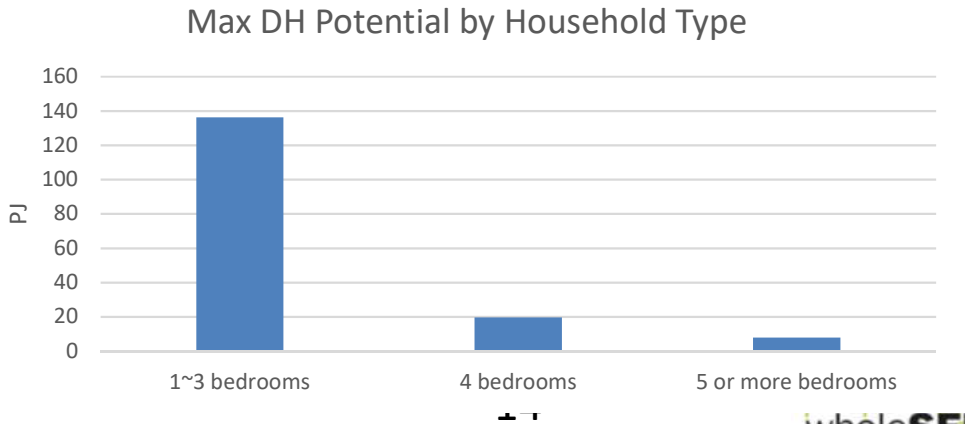
**assume the preferences are the same as those for 1~3 bedrooms

Max Potential of District Heating in the UK

- Based on **detailed spatial analysis**: UK heat map, heat sources (waste heat from industrial sector, river and etc.)
- Introduce **max potential of district heating** for each household type as constraints
  - English Household Survey
  - Shares of households in urban area







Source: Element Energy, 2015, Research on district heating and local approaches to heat decarbonisation

Scenarios

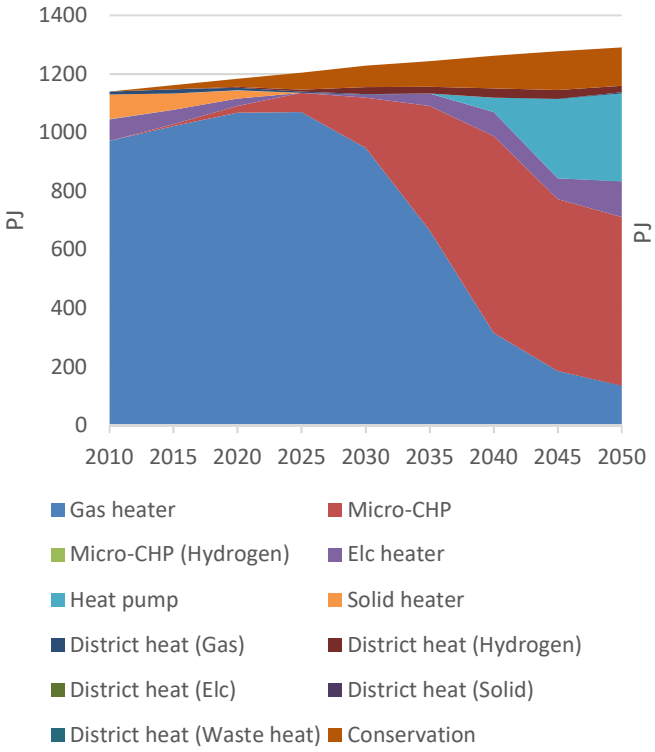
- **To reveal the influences of households' preferences on heating technology choices**
- **GHG targets:**
  - **The Climate Change Act 2008**: 80% reduction on 1990 level by 2050
  - **5th Carbon Budget:** 57% reduction on 1990 level by 2030

Scenario	GHG targets	Preference settings
LowGHG_Cost	80% reduction on 1990 level by 2050 Carbon budgets (1st to 5th)	Without Preference related constraints
LowGHG_Pref	80% reduction on 1990 level by 2050 Carbon budgets (1st to 5th)	With Preference related constraints

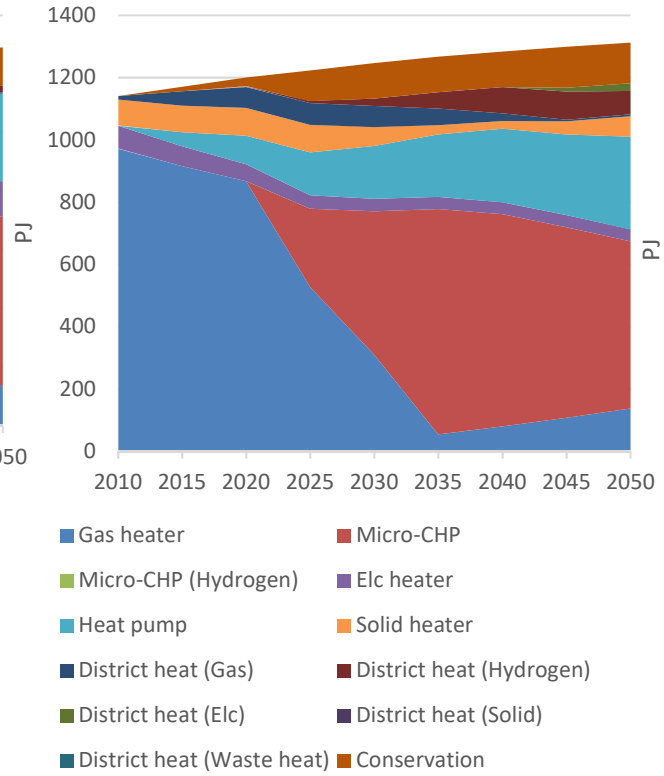
Results(1/3): Heating Technologies

- **Heating technology:**
  - **Minimum cost:** abrupt U-turn to increase heat pumps approaching 2050, more electric heaters
  - **Preference:** heat pumps increase gradually, more solid fuel boilers, more micro-CHP to improve efficiency
- **District heating:** much more; transit from gas, hydrogen to electric heating
- **Conservation measure**: Introduced earlier in preference case

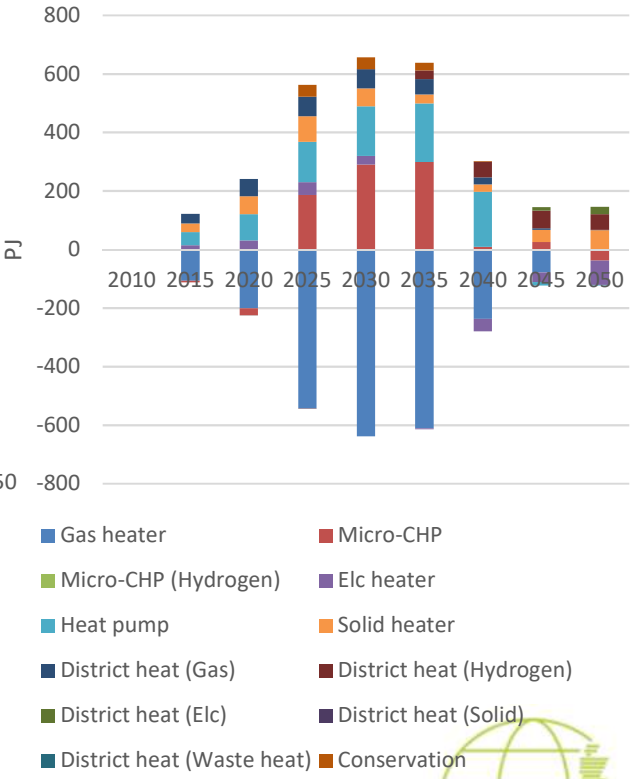
Minimum cost only: LowGHG_Cost



Preferences included: LowGHG_Pref

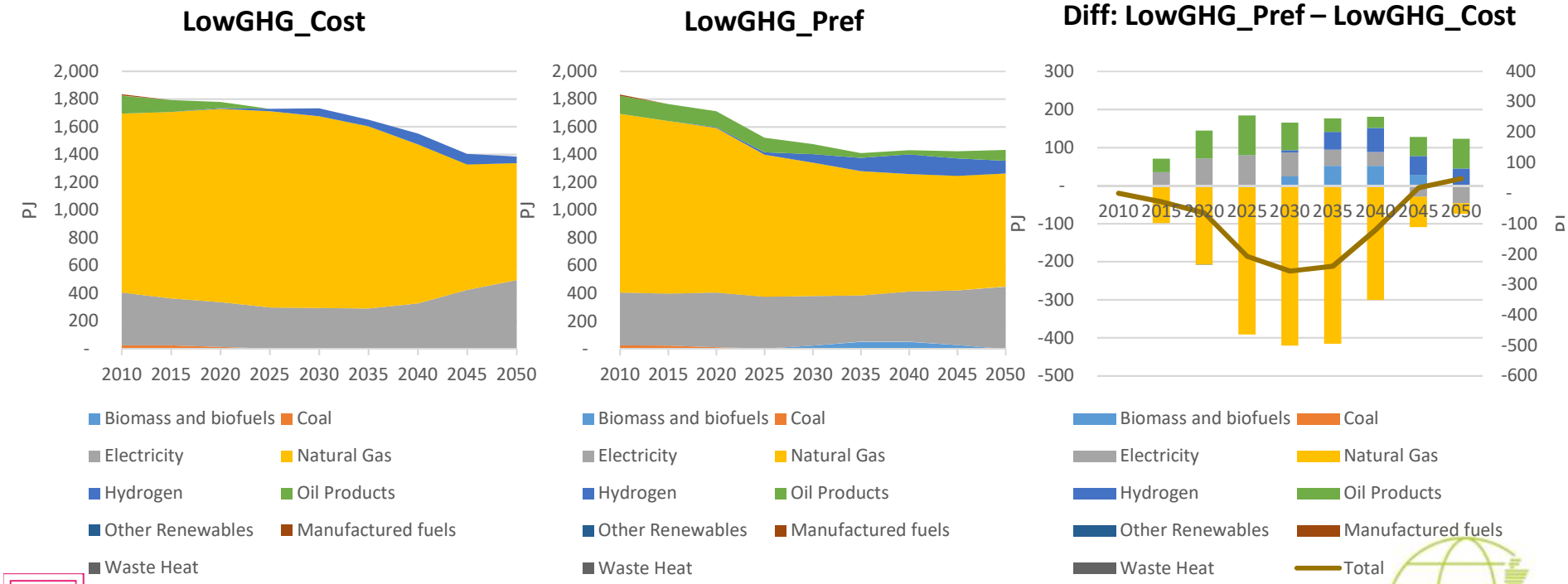


Diff: LowGHG_Pref – LowGHG_Cost



Results (2/3): Fuel consumption in residential sector

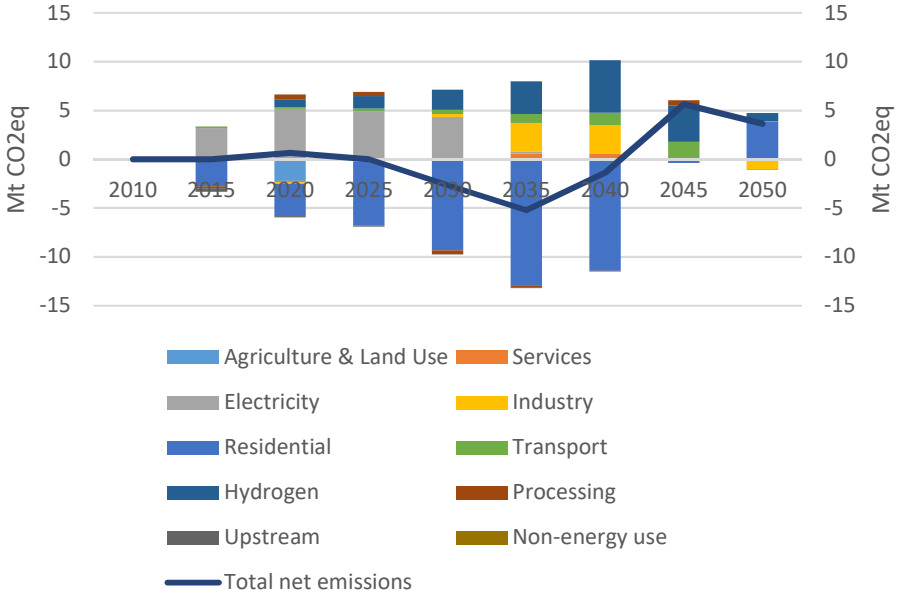
- **LowGHG_Pref:**
  - **Before 2045**
    - Less fuel consumption before 2045: more heat pumps
    - Less gas consumption
    - More oil and electricity consumption
  - **After 2030: More hydrogen consumption:** district heating
  - **By 2050:** Less electricity consumption (more heat pumps in **LowGHG_Cost**)



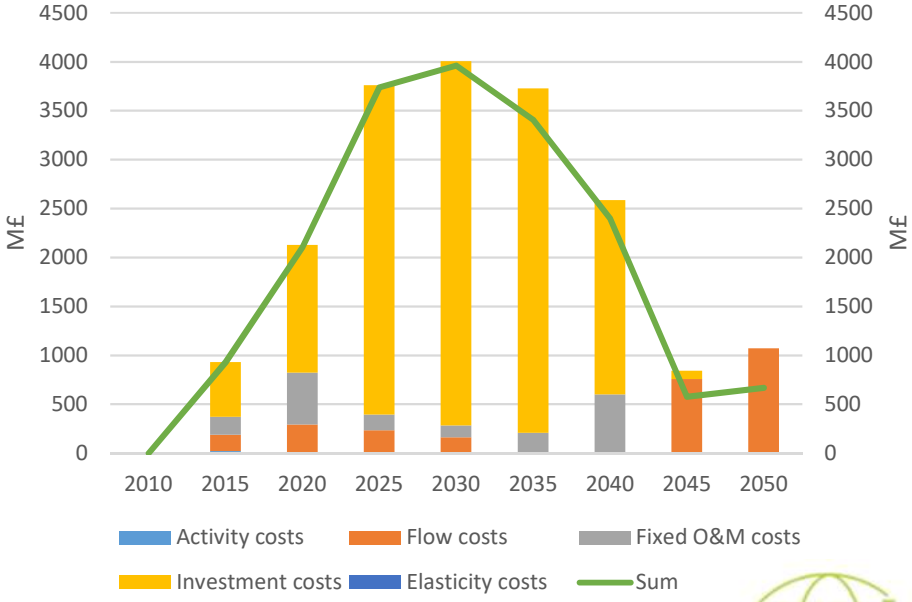
Results (3/3): GHG Emissions and Cost

- **GHG Emissions**
  - Tradeoff between sectors
  - More emissions for hydrogen production
  - LowGHG_Pref: ~4 million tones of CO2eq more (2%)
- **Total System Cost**
  - More investment costs in residential sector, more flow costs approaching 2050
  - LowGHG_Pref: 87.6 billion GBP more

Diff of GHG Emissions by Sector



Diff of Total System Costs



Conclusions and Future Works

- The developed framework can well represent households' preferences in the Energy System Model (TIMES)
- With homeowners' preferences, the future projection is more realistic
- **Micro-CHP and district heating** are crucial to decarbonise residential heating in the UK
- Future works
  - Scenarios
    - Consider other influential factors, such as awareness of technology and subsidy
  - Sensitivity analysis
    - Variations of households' preferences

Thanks for your attention!

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