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Characterising and integrating demand response within a long-term energy system analysis

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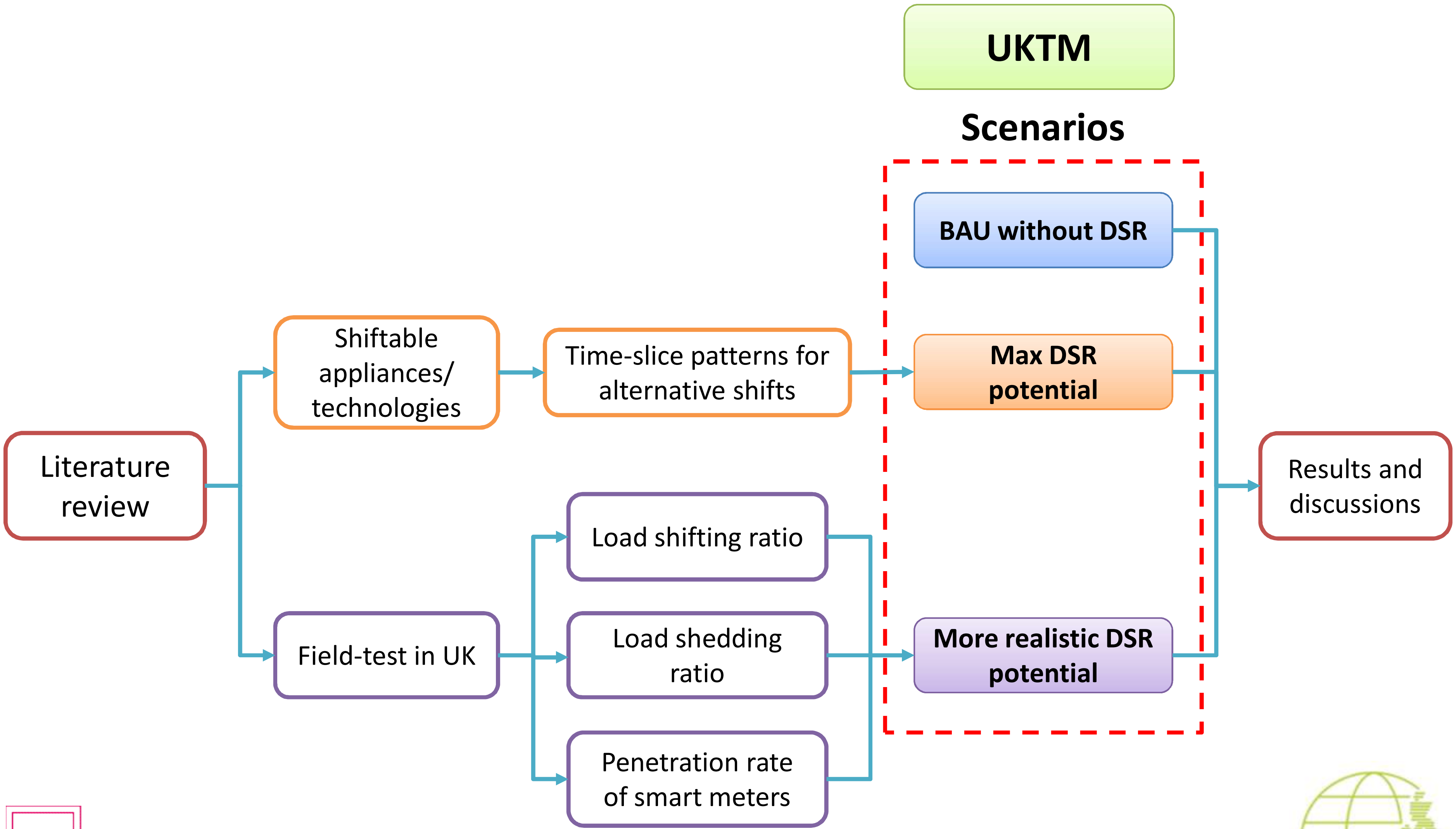
Outline

- Introduction
- Demand Response in the UK
- UK TIMES
- Incorporate Demand Response in the UKTM
- Scenarios
- Preliminary results
- Conclusions and Future works

Introduction

- 2050 GHG target: 80% reduction on 1990 level
- 5th Carbon Budget: 57% by 2030
- **Low carbon electricity**
  - decommission coal power plants by 2025
  - high penetration rate of intermittent RE
- **Potentially higher peak load**
  - decarbonize heating sector
  - decarbonize transport sector
- **More flexible electricity system** is essential
  - Reduce requirements for capacity during peak periods
  - Manage intermittent RE
  - Reduce overall cost

Research Procedure



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Demand Response in UK

- **Previous studies:** Fixed projections of technologies
  Focus more on electricity system

Study	Sector/Tech	Scenario	Benefits
Teng and et al. (2016)	EV (reduce peak load by 80%) HP (reduce peak load by 35%)	fixed demand-side and supply-side capacities based on DECC Carbon Plan (2011) and LCL report	reduce 5~13 gCO2/kWh; 1.5~7 pounds/MWh (for EV/HP)
Kreuder and Spataru (2015)	Heat pump in residential sector	Base: 2.5 millions HPs Ideal: 5.7 millions HPs Reduce peak load by optimization (turn off for 3hrs)	Peak load reduction: **6.3~5.7GW**
Element Energy (2014)	Washing appliances (100% shiftable); Water heating; Cold appliances	Aggregate household potential to national scale	Peak shift potential: **2GW**
Pudjianto et al. (2013)	Smart plug-in vehicle Smart heat pump Network voltage regulators	Full penetration of EVs and HPs Optimal operations Three demand scenarios from Transition Pathways project (Foxon, 2012)	Reduce peak load increase from 117GW to 78GW Save 10bn pounds over 40 yrs
Barton et al. (2013)	Water heating (7hr in night) Space heating (deferred 1 hr) EV and PHEV charging (deferrable Cev/7) Pumped hydro	Three demand scenarios from Transition Pathways project (Foxon, 2012) Optimal operations	Reduce peak load by **10GW** Reduce capacity operating less than 10% Reduce maximum surplus power
REDPOINT(2012)	Heat pumps with storage, EV, smart appliances, non-smart cold & wet appliances	SToU, Load Control, CPP EV update projection DECC heat pump uptake projections to 2030	Peak demand reduction: **0.5~2.5GW** by 2030 Save 500m pounds by 2030 System balancing and DNO saving: 350m pounds Avoid 3.2GW of OCGTs Reduce GHG by 0.4~1.2mt in 2030
Hamidi et al. (2009)	Residential sector: heating, wet and cold appliances	Bath and North East Somerset Area; Aggregated load profile	Potential responsive level: **~35%**

Demand Response in UK

- Field tests show varied peak load reductions

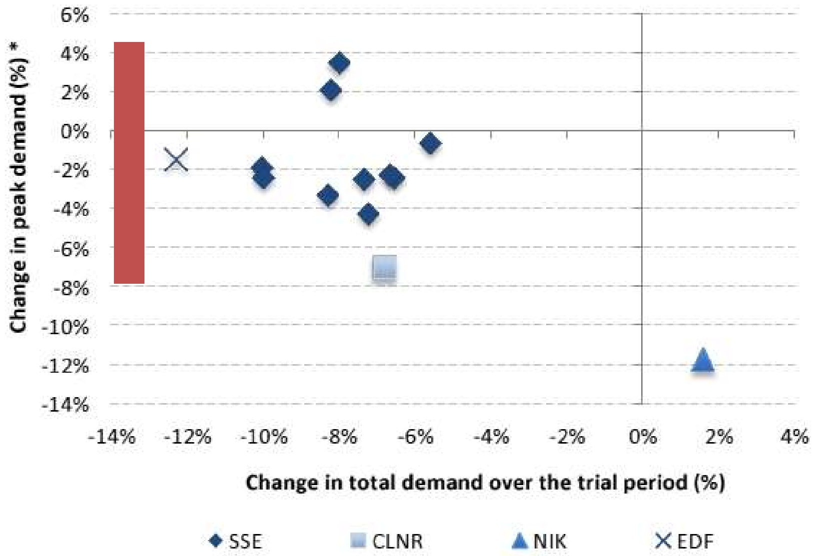
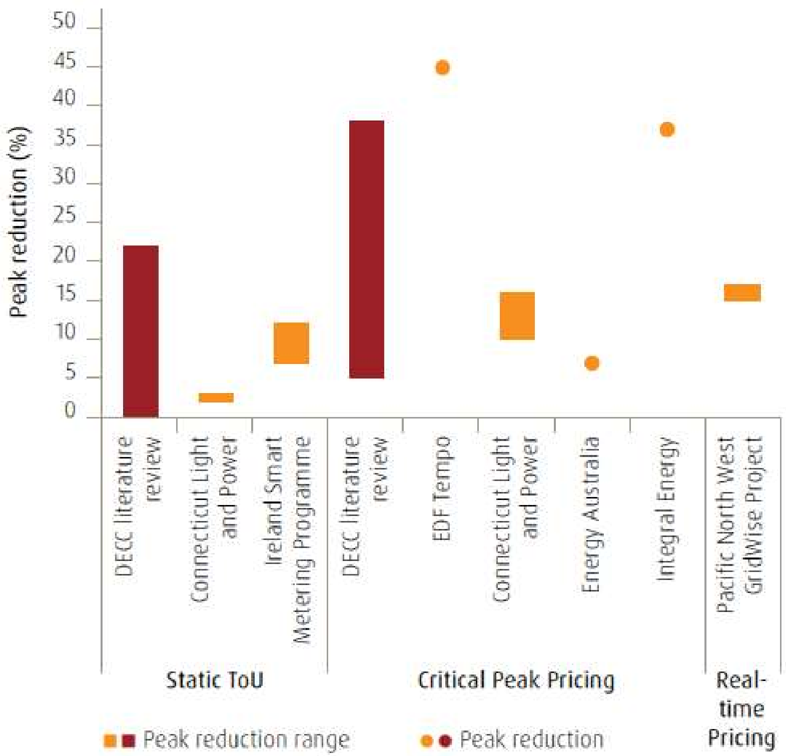


Figure 5: The change in electricity demand during the peak period versu the change in total electricity demand over the whole trial period.[9]



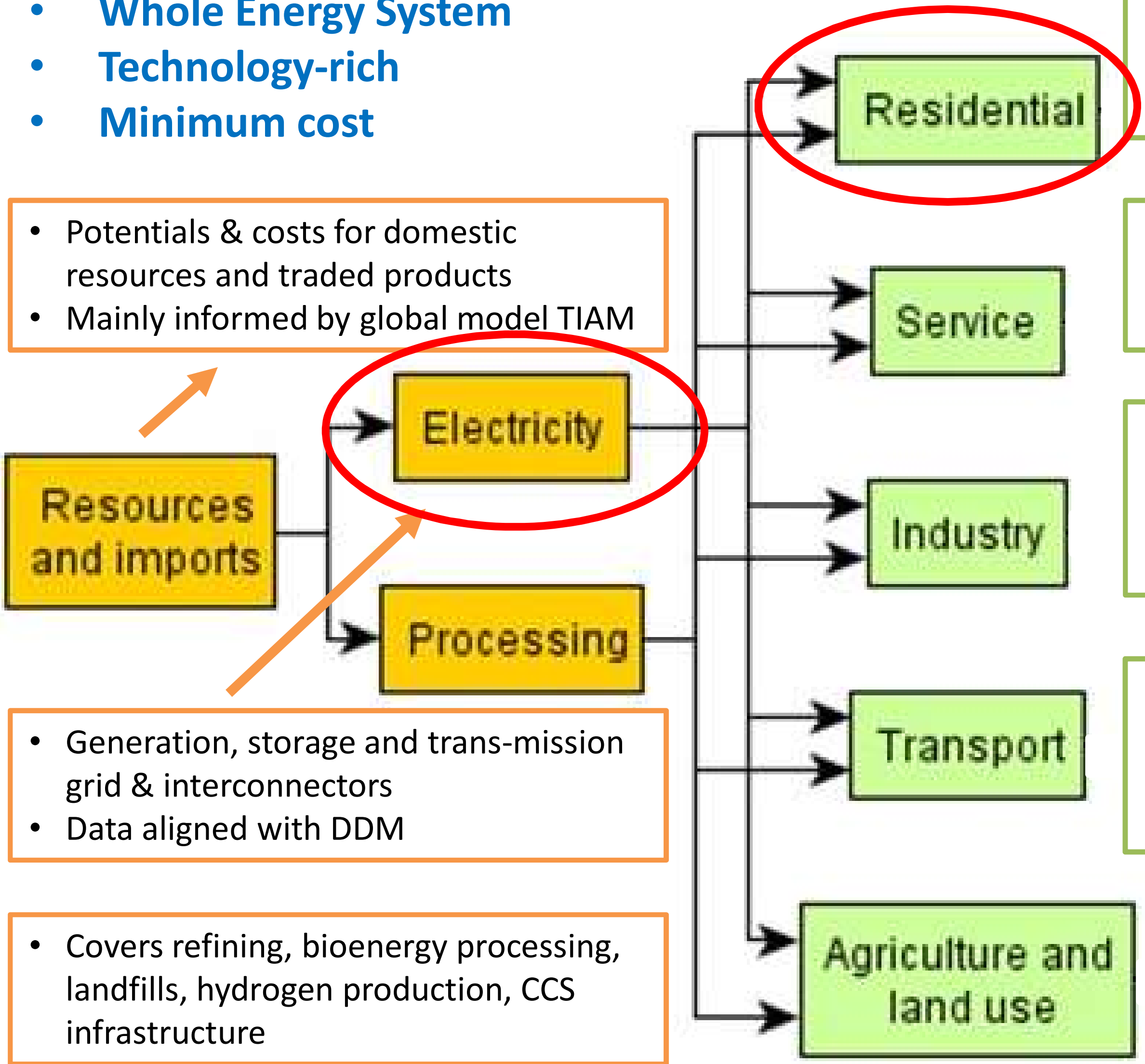
Time-of-use **CPP** **RTP**

Source: element energy, 2014, Electricity price signals and demand response, report for DECC.

Source: J. Schofield, R. Carmichael, S. Tindemans, M. Woolf, M. Bilton, G. Strbac, "Residential consumer responsiveness to time-varying pricing", Report A3 for the "Low Carbon London" LCNF project: Imperial College London, 2014.

UKTM-The UK TIMES Model

- **Whole Energy System**
- **Technology-rich**
- **Minimum cost**



- Potentials & costs for domestic resources and traded products
- Mainly informed by global model TIAM

- Generation, storage and trans-mission grid & interconnectors
- Data aligned with DDM

- Covers refining, bioenergy processing, landfills, hydrogen production, CCS infrastructure

- Divided in existing & new houses
- Space heat, hot water, other ser.
- Technology data based on various UK-focused studies

- Divided in low- and high consumption buildings
- Structure similar to residential

- 8 subsectors, 4 modelled in a process-oriented manner
- Demand projections aligned with DECC Energy model

- Differentiated in 9 modes
- Demands calibrated to NTM
- Technology data sourced from Dodds and McDowall (2014).

- Differentiated in demand for transport, heat and electricity
- Land use and agricultural emission taken into account

Time slicing in UKTM

- Capture **temporal characteristics** of technologies

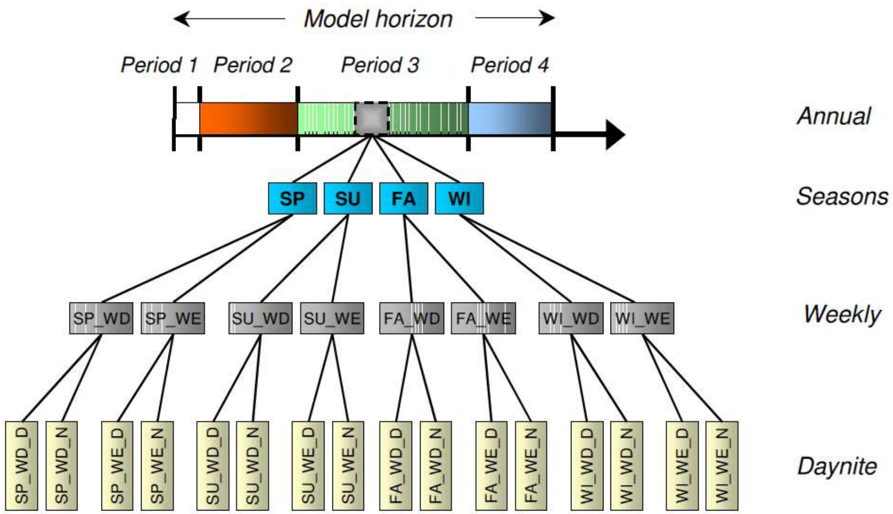


Figure 2.1: Example of a timeslice tree

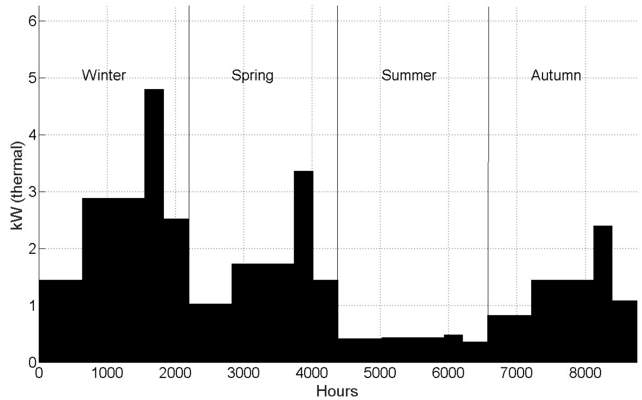
Time-slice tree in UKTM

Definition of time-slices

Table 1: Time-slices in UKTM

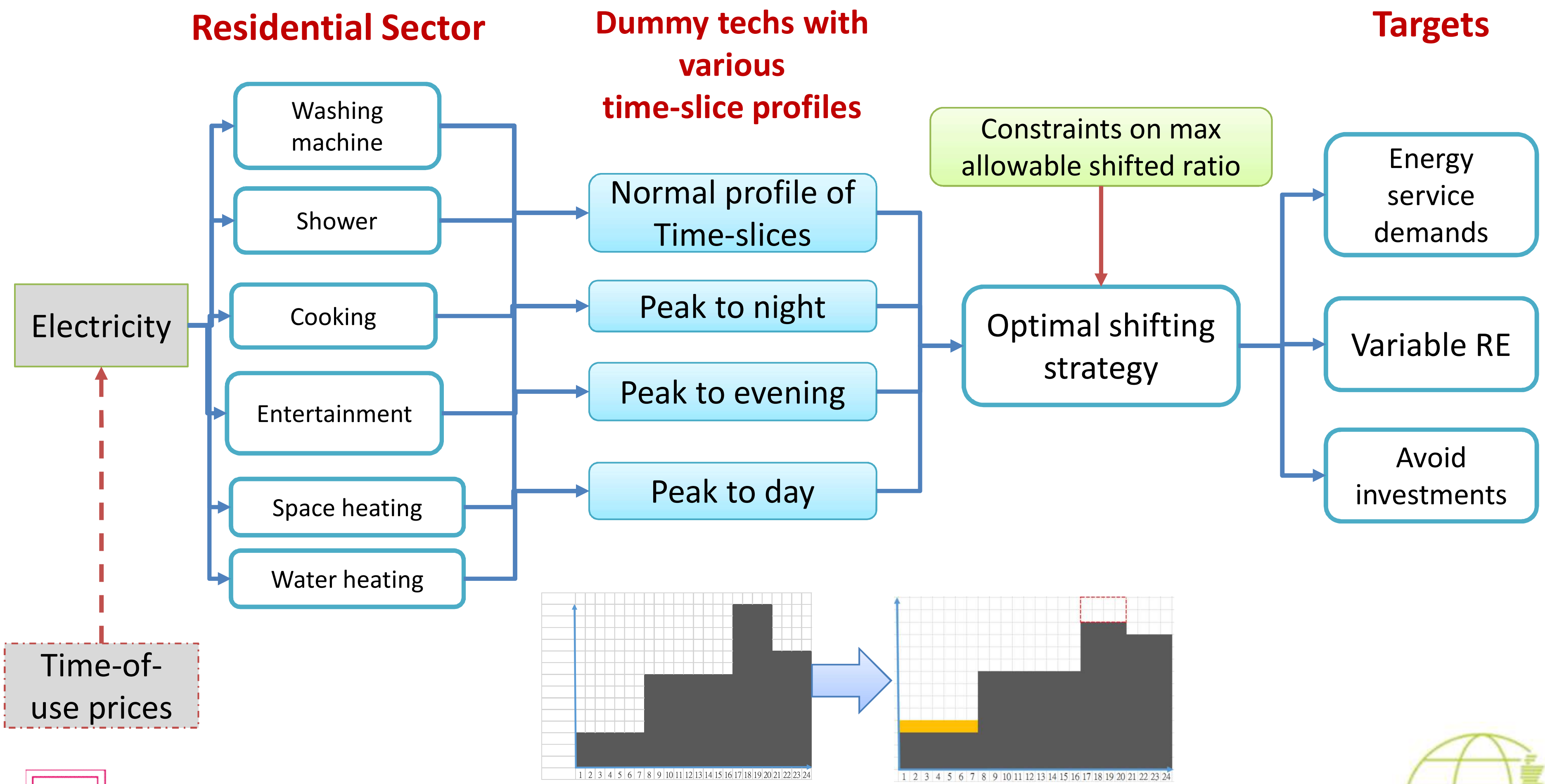
Season	Intra-day period	Time represented	Notes
Winter (W)	Night (N)	00:00–07:00	Lowest demand
Spring (P)	Day (D)	07:00–17:00	Includes morning peak
Summer (S)	Evening peak (P)	17:00–20:00	Peak demand
Autumn (A)	Late evening (E)	20:00–00:00	Intermediate

Time-slices for heating technology



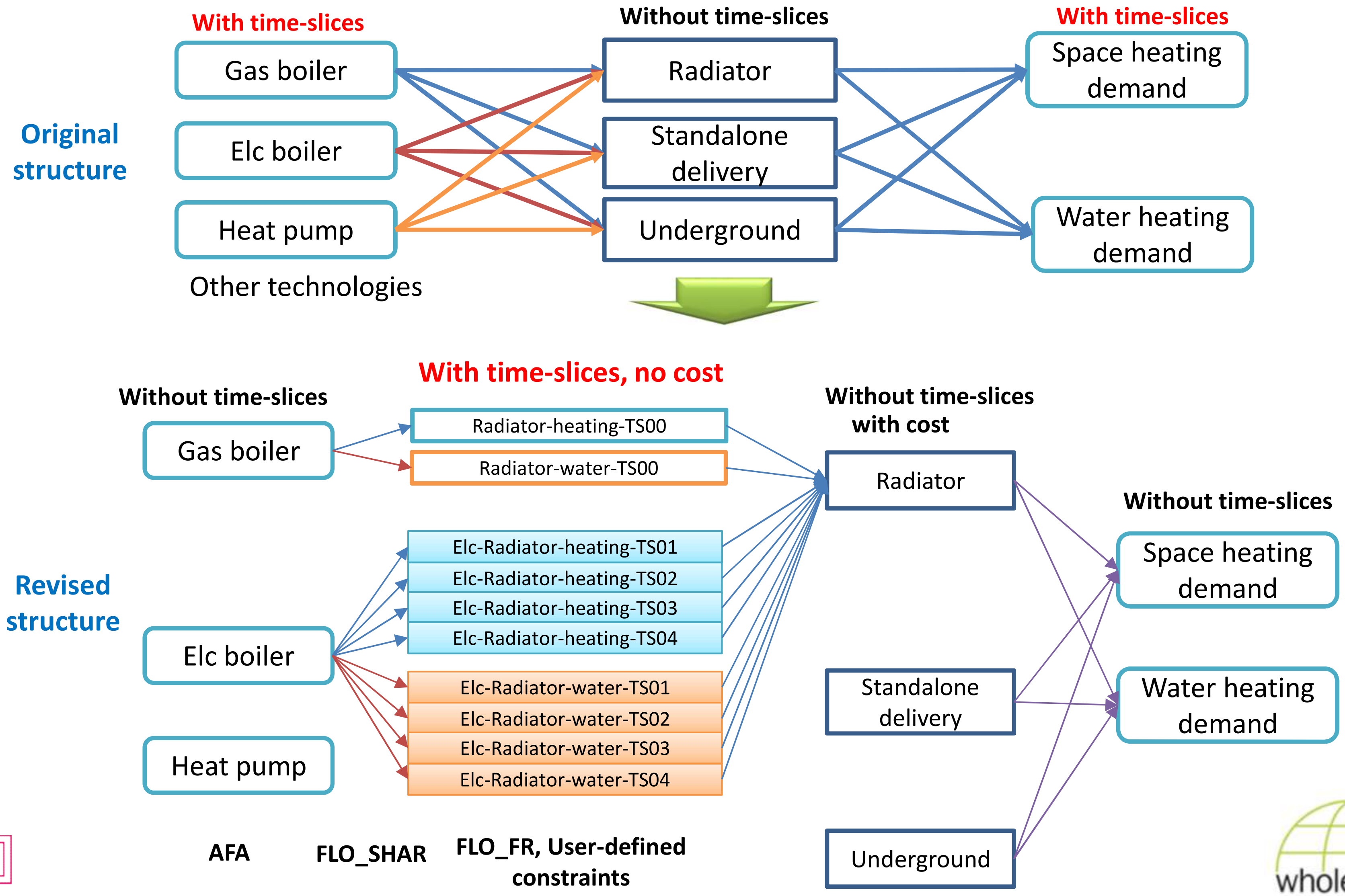
Incorporate Demand Response in the UKTM

- **Load shifting: for each shiftable appliances in residential sector**



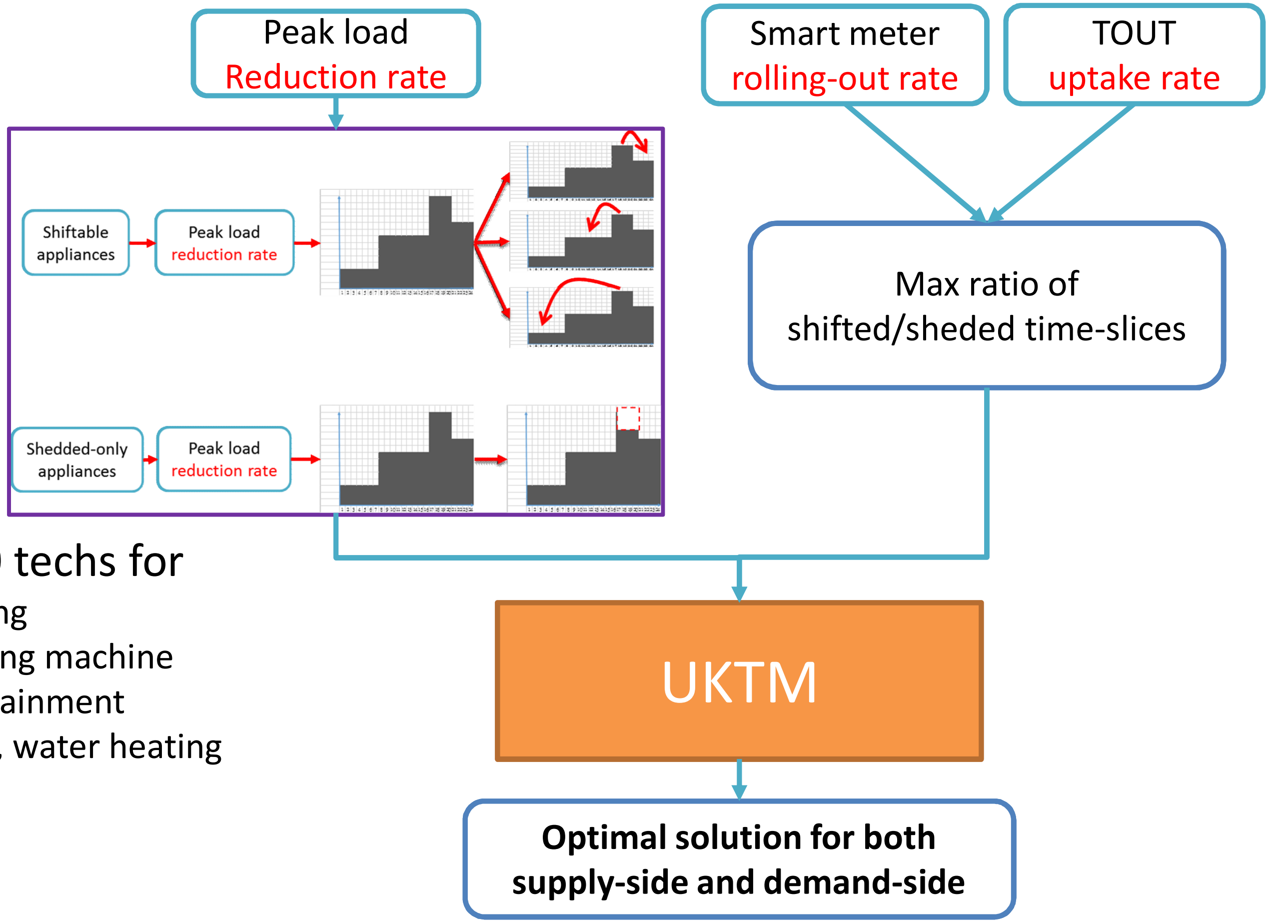
Incorporate Demand Response in the UKTM

- **Residential heating: only shift electric techs**



Incorporate Demand Response in the UKTM

- **DSR-UKTM framework**
  - **Time-of-use tariff: consumer behaviour**
  - **Load control: automated**



~200 techs for
Cooking
Washing machine
Entertainment
Space, water heating

Scenarios

- For each scenarios
  - Smart meter deployed in households
  - Take up smart appliances (by 2020)
  - Take up some form of DSR

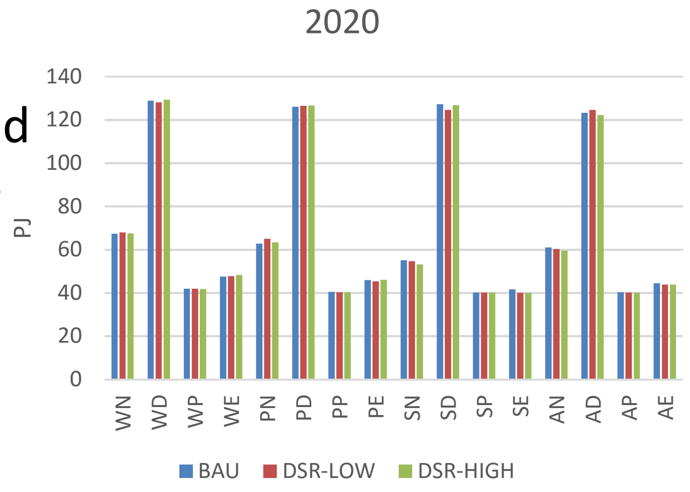
Scenario	Description			2020	2030
Business-as-usual	No DSR	**TOU LC**	% take-up	0	0
			% peak demand shifted	0	0
Low potential DSR	Without strong policy supports and tech deployment	**TOU**	% take-up	8	30
			% peak demand shifted	5	20
		LC	% take-up	0	4
			% peak demand shifted	100	100
High potential DSR	With strong policy supports and tech deployment	**TOU**	% take-up	8	60
			% peak demand shifted	10	40
		LC	% take-up	0	12
			% peak demand shifted	100	100

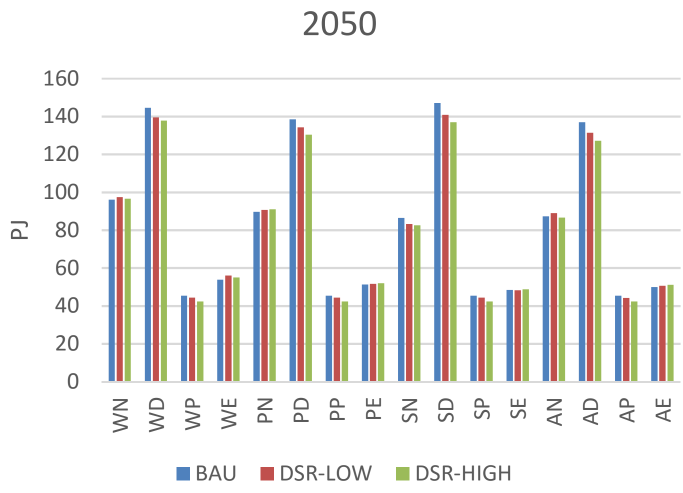
Note: These are percentages of households with shiftable appliances.
Base on **Element energy (2012)**'s scenarios.

Results (1/4)

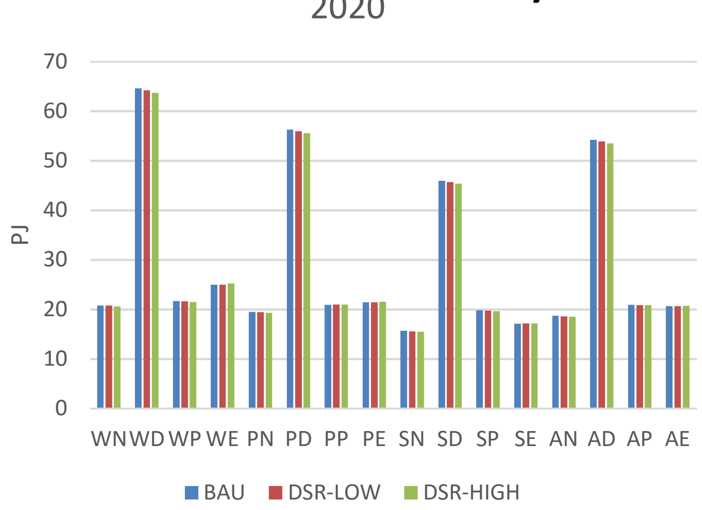
Electricity consumption for each time-slice

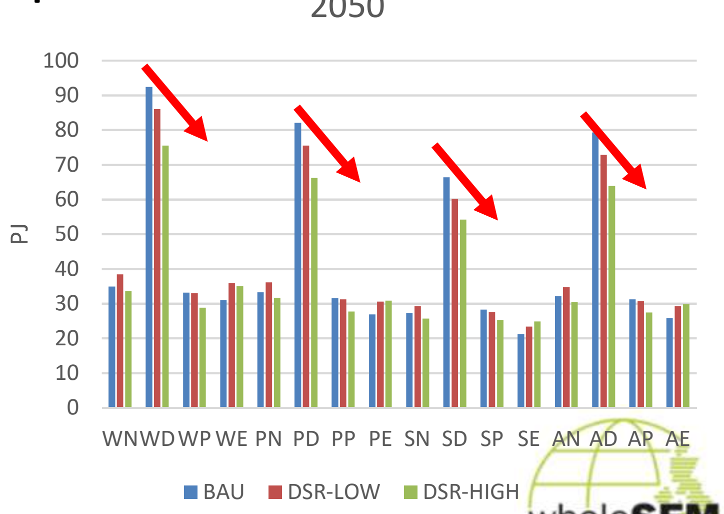
- Peak load reduced
- Profiles are more smooth





Residential electricity consumption for each time-slice

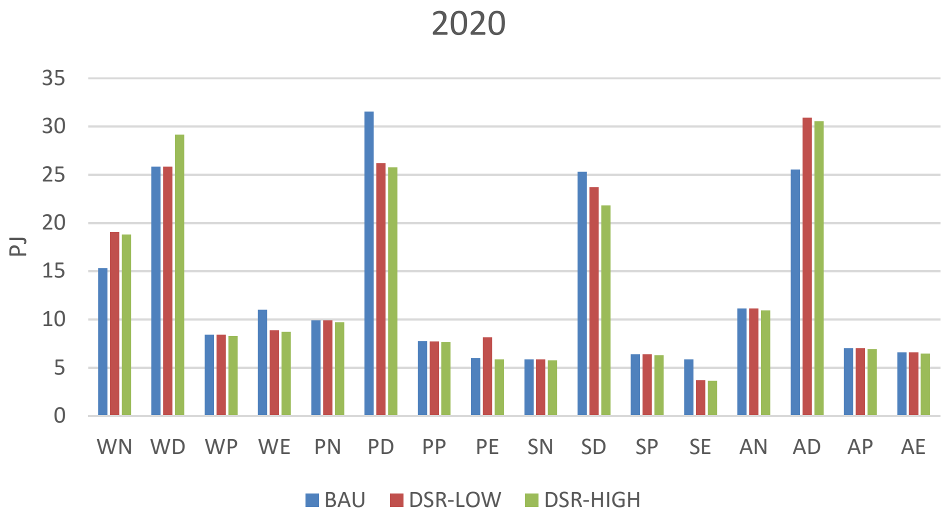


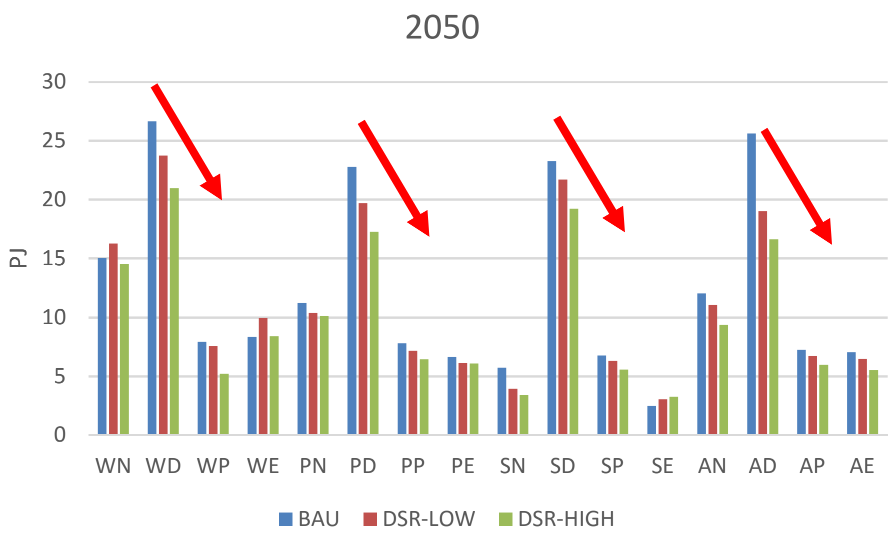


Results (2/4)

- Renewable energy supply pattern changes accordingly

Electricity supply by renewable energy





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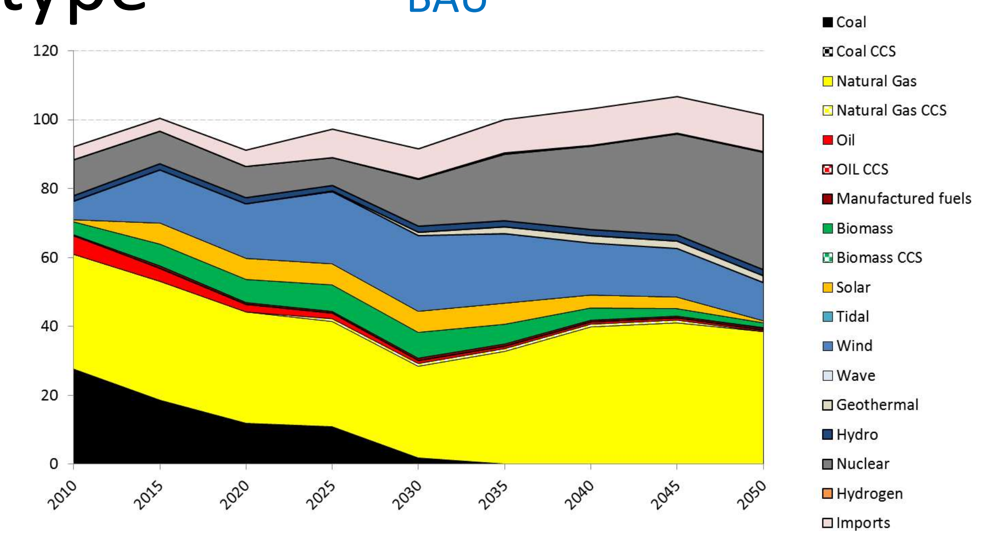
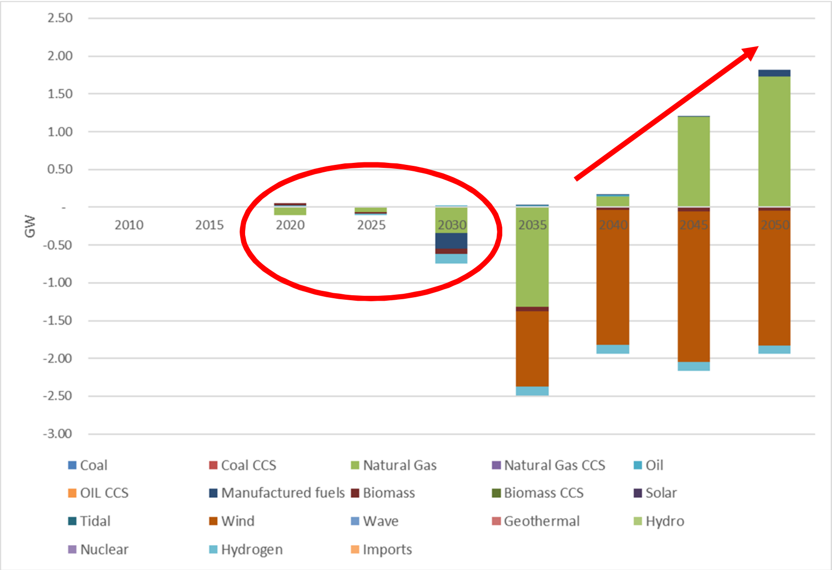
Results (3/4)

- Electricity capacity by type
  - Both scenarios avoid a lot of investments in new capacities
  - DSR-LOW
    - Peak load is not shifted enough in longer term
  - DSR-HIGH
    - Peak load is shifted significantly

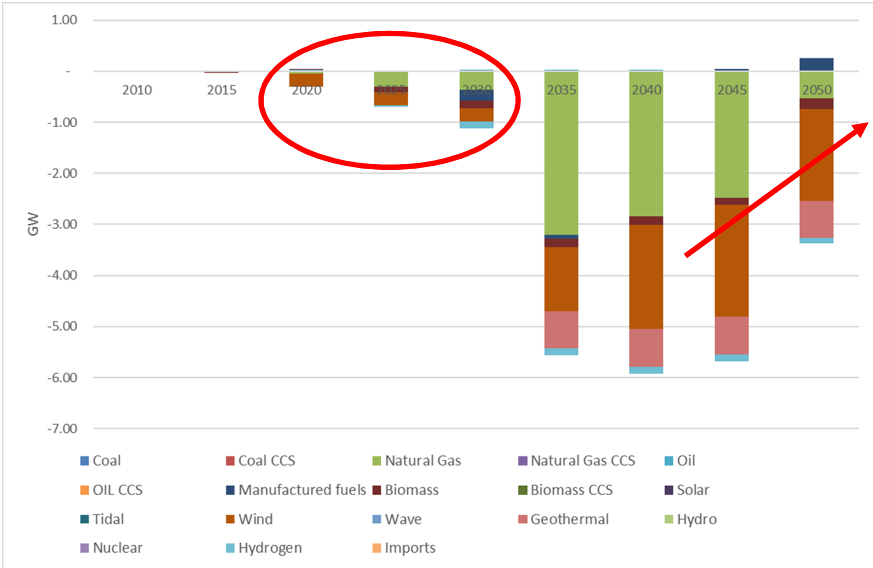
BAU



DSR-LOW



DSR-HIGH



Results (4/4)

- Cost saving over time is significant

Annual undiscounted energy system cost (M£) (to be further justified)

Diff btw DSR_LOW, DSR_BAU

(for reference only)

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Activity costs	0	-1	-4	-15	-29	-144	-54	-41	-31
Flow costs	0	-3	-37	-83	-576	-670	-533	-319	-303
Fixed O&M costs	0	-5	-55	-310	-745	-1139	-1286	-1516	-1889
Investment costs	0	51	-71	-438	-1132	-1517	-1697	-1748	-2375
Elasticity costs	0	-53	51	-156	-146	-39	2	-747	-62
Sum	0	-11	-117	-1003	-2628	-3508	-3568	-4370	-4659

Diff btw DSR_HIGH, DSR_BAU

(for reference only)

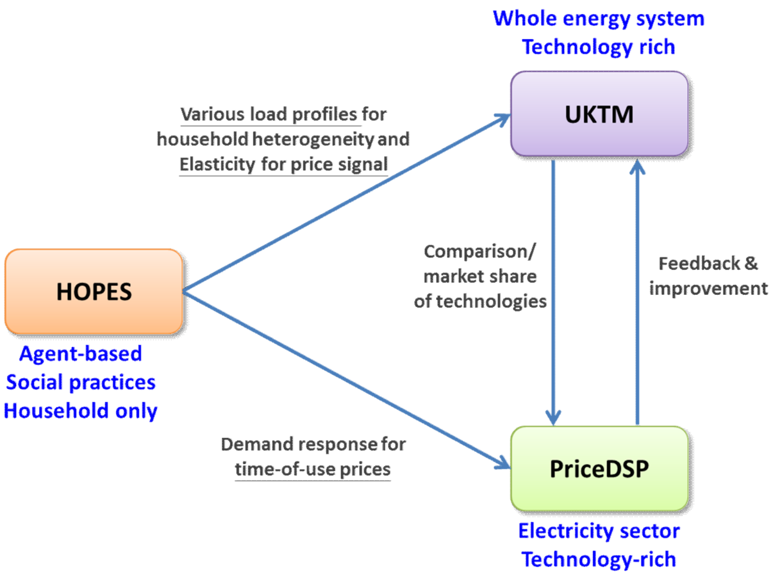
	2010	2015	2020	2025	2030	2035	2040	2045	2050
Activity costs	0	-1	-23	-47	-64	-221	-149	-115	-93
Flow costs	0	-15	-107	-202	-999	-821	-728	-603	-551
Fixed O&M costs	0	-25	-162	-771	-1203	-1725	-1974	-1906	-1716
Investment costs	0	71	-204	-1152	-1745	-2648	-3086	-3015	-3500
Elasticity costs	0	-58	276	-235	101	63	9	-651	-1093
Sum	0	-28	-221	-2407	-3909	-5351	-5928	-6290	-6952

Conclusions

- Developed **DSR-UKTM** can incorporate DSR as a key measure for long-term energy planning
- Incorporation of DSR in whole energy system impact the planning significantly
- **With DSR**
  - Reduce peak load
  - Profiles of time-slices become more smooth
- **Profiles of RE**
  - Influence the installed capacity
- **Avoid considerable investments** in new power generation capacity
- Further uncertainty analysis is essential!

Future works

- **Incorporate social practices: discrete choice models (DCMs) based on real survey data (probability of shifting)**
  - **Laundry:** gender, age, original use-of-time, dwelling type, income, ownership of appliances
  - **Heating:** age, original use-of-time, dwelling type, income, ownership of appliances
  - **Shower:** age, original use-of-time, dwelling type, education level, resident number
  - **Dish-washing:** original use-of-time, dwelling type, income, resident number
  - **Cooking:** age, original use-of-time, dwelling type, education level, income, ownership of appliances
  - **Entertainment:** original use-of-time, education level, dwelling type, ownership of appliances
- **Include other sectors: service, transport (EV) and industry.**
- **Link with other models (HOPES, PriceDSP)**



Thanks for your attention!

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