Using Time Use Data to Model Residential Electricity Load Profiles

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WORKSHOP ON ELECTRICITY DEMAND:
NEW MODELLING PERSPECTIVES

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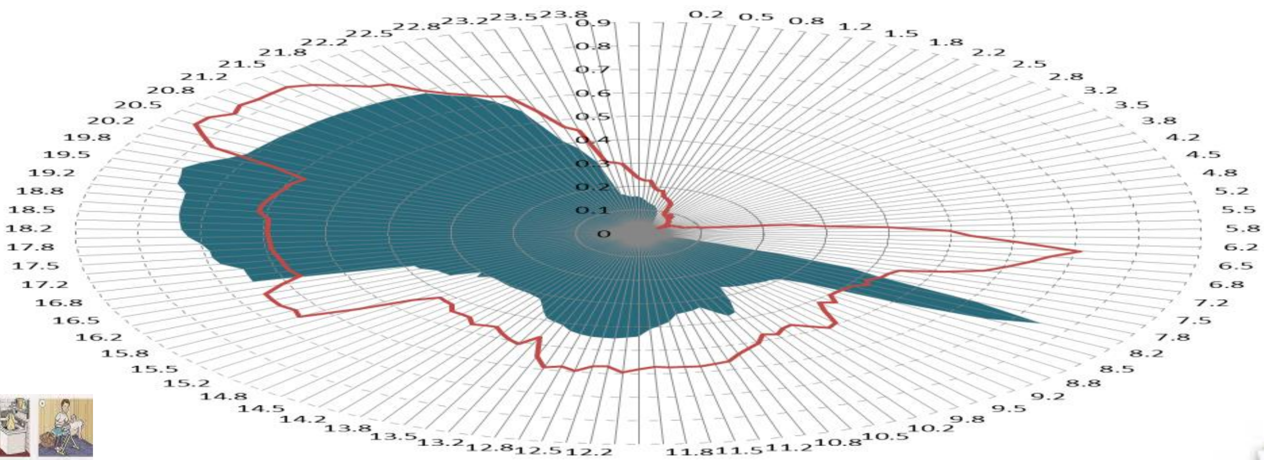
Starting point / problem definition

- Peaks in electricity demand bring about significantly negative environmental and economic impacts
- In the UK, the residential sector is responsible for about one third of overall electricity demand and up to 40% of peak demand
- In the future the peak problem will worsen due to the integration of intermittent renewables in the supply mix as well as electric vehicles and electric heat pumps
- Little is known about residential peak demand and what levels of flexibility might be available

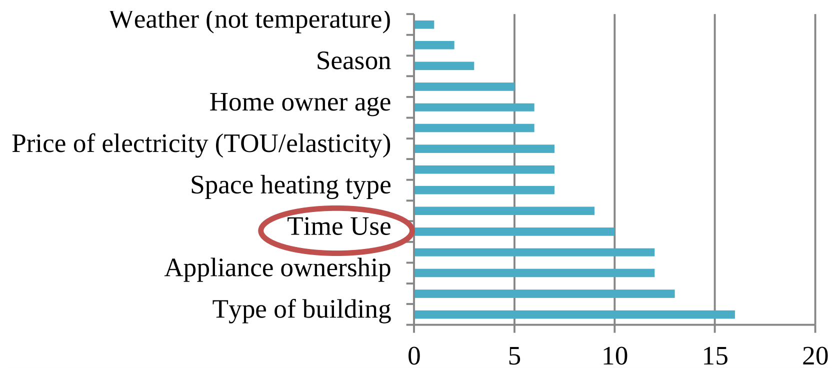
- Weekday
- Weekend



Outline

- Deriving load profiles from time use data
- Deriving occupancy for 15 European countries
- Applications in Spain and UK
- Implications for price elasticity

State-of-the-art in residential electricity demand studies



-Building, occupants' income, appliance ownership and bill-related price of electricity are some of the most used data in models for residential electricity demand

-These variables so far been able to explain less than 40% of variation (DECC, 2013)

-They are not able to explain in-day load profiles

The timing of people's activities plays a vital role in explaining residential load profiles

	Number of dwellings (simulation)	Sample size (from time use surveys)	Country	Duration	Period	Approach	Time resolution (in minutes)
Capasso et al (1994)	95 (4 buildings)	40000	Italy	1 year	1/6/1988 - 31/5/1989	Montecarlo analysis	15
Duffy et al (2010)	5	-	Ireland	6 months	1/7/2009 - 31/12/2009	Markov chain compared with measured data	30
Richardson et al (2008)	50	9991	UK	1 year	2000	Markov chain compared with measured data	10
López-Rodríguez et al (2013)	-	9541	Spain	1 year	2009-2010	Estimating occupancy variances	10
Richardson et al (2010)	22	9991	UK	1 year	2000	Markov chain compared with measured data	10
Stokes et al (2004)	100	-	UK	1 year	1/3/1996 - 30/4/1997	Stochastic approach to model residential light demand	1
Torriti (2012a)	-	73215	EU15	1 year	1991-1006	Estimating occupancy variances	10
Widén et al (2009a)	217	3980	Sweden	1 year	1996 and 2007	Markov chain to model residential hot water demand	5
Widén et al (2009b)	14	3980	Sweden	1 year	1996 and 2007	Markov chain to model residential light demand	10
Widén and Wäckelgård (2010)	169	3980	Sweden	1 year	1996 and 2007	Markov chain compared with measured data	1
Wilke et al (2013)	20	15441	France	1 year	1998-1999	Markov chain to calculate probabilities of different activities	10

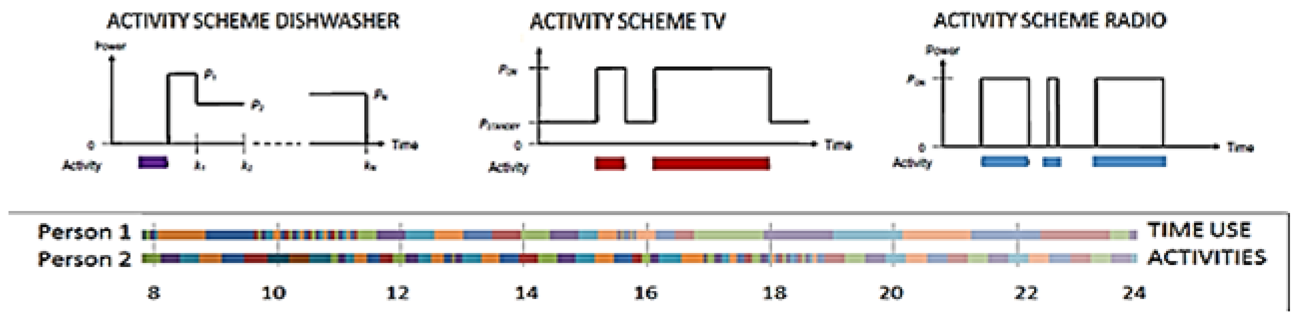
Time use data

- Self-recorded diary
- 10 minute granularity

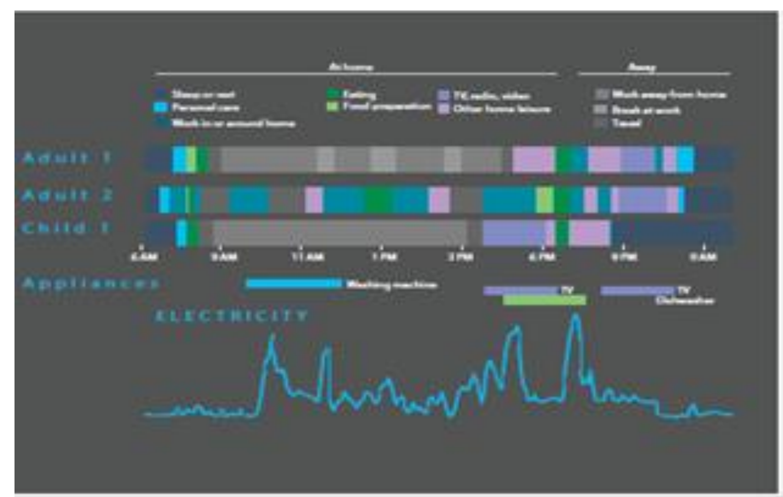
Diary/ person id	Starting Time	Ending Time	Main activity	Parallel activity	Who with:				Where/mode of tranport
					Alone	Spouse	Small child	Other pers.	
AA23	04:00	07:20	Sleep						At home
AA23	07:20	07:50	Shower						At home
AA23	7:50	08:30	Had breakfast	Read newspaper			Ch		At home
AA23	08:30	08:40	Walked to bus		A				By foot
AA23	08:40	09:00	Bus to job					OP	By bus

Country	StartTime	Work and study	Travel to/from work/study	Household work	Sleep and other personal care	Eating	Freetime	TV and video	Unspecified time
Belgium	04:00	1.04	0.07	0.16	97.16	0.15	1.01	0.17	0.24
Belgium	04:10	1.09	0.09	0.28	97.14	0.18	0.85	0.14	0.23
Belgium	04:20	1.09	0.15	0.18	96.94	0.4	0.81	0.17	0.25
Belgium	04:30	1.13	0.35	0.23	96.51	0.27	1.09	0.17	0.27
Belgium	04:40	1.23	0.34	0.36	96.46	0.2	0.97	0.15	0.29
Belgium	04:50	1.26	0.35	0.44	95.81	0.49	1.16	0.18	0.31
Belgium	05:00	1.53	0.34	0.61	94.76	0.49	1.78	0.21	0.27
Belgium	05:10	1.6	0.47	0.68	94.82	0.61	1.34	0.21	0.27
Belgium	05:20	1.71	0.64	0.61	94.54	0.65	1.25	0.24	0.36
Belgium	05:30	1.83	0.95	0.7	93.31	0.77	1.84	0.22	0.37
Belgium	05:40	1.94	1.26	0.99	92.77	0.74	1.74	0.24	0.3
Belgium	05:50	2.31	1.22	1.08	91.76	0.98	2.09	0.21	0.36
Belgium	06:00	3.08	1.06	1.39	88.08	1	4.81	0.23	0.34

Time use data and load profiles



Activity schemes can enable to link time use activities with appliance and electricity use

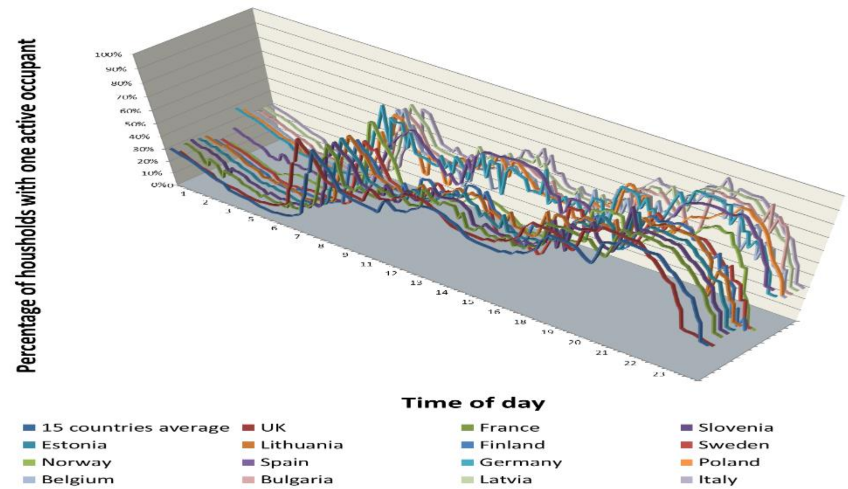


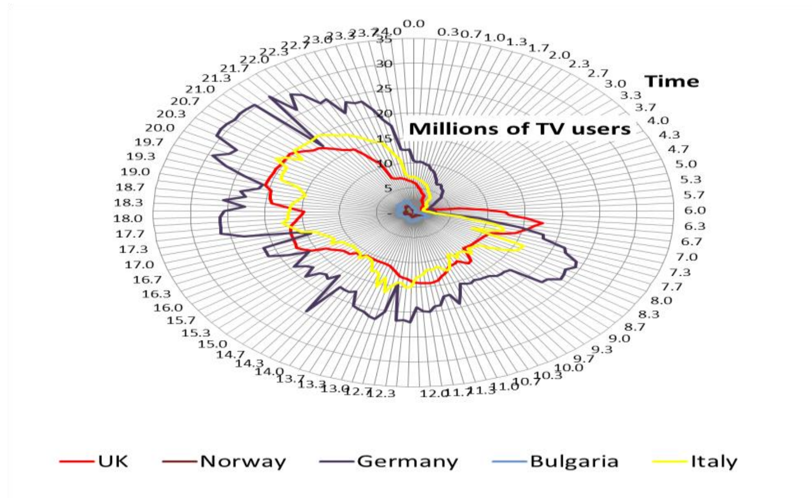
Deriving occupancy for 15 European countries

Deriving active occupancy ← **Multinational Time Use Dataset**

-Harmonised European Time Use Survey (HETUS) database consists of 220,464 residential users across 15 countries

-Active occupancy: how much occupancy varies within peak periods





Activities at home of single households between 20h10 and 20h20

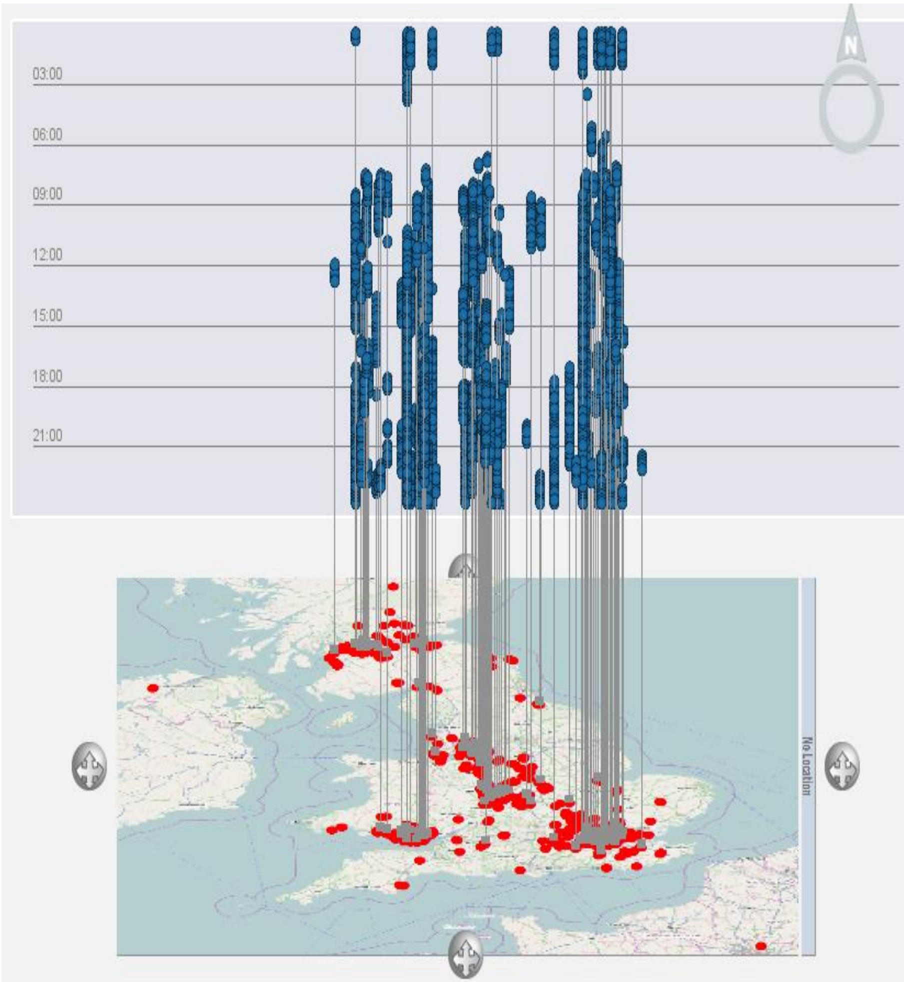
Country	Start Time	End Time	Work and study (%)	Travel to/from (%)	Household work (%)	Sleep and other (%)	Eating (%)	Free time (%)	TV and video (%)	Unspecified time (%)
Belgium	20:10	20:20	4.5	0.63	15.37	4.58	13.72	22.1	36.76	2.35
Bulgaria	20:10	20:20	3.66	0.75	16.08	3.75	26.53	10.11	38.84	0.28
Finland	20:10	20:20	6.86	0.62	16.87	7.4	6.95	26.76	32.52	2.02
France	20:10	20:20	4.49	1.05	15.88	4.29	36.71	10.34	24.58	2.65
Estonia	20:10	20:20	7.08	1.55	19.86	5.56	9.29	20.08	35.86	0.73
Germany	20:10	20:20	4.49	0.79	12.32	3.22	9.83	29.63	38.58	1.14
Italy	20:10	20:20	4.1	1.44	18.45	4.18	38.97	16.46	15.06	1.34
Latvia	20:10	20:20	8.18	2.25	15.12	4.94	13.16	16.22	39.63	0.51
Lithuania	20:10	20:20	7.76	1.13	17.2	6.91	11.45	13.96	40.9	0.68
Norway	20:10	20:20	6.89	0.61	18.86	2.61	7.86	39.08	23.69	0.38
Spain	20:10	20:20	11.37	2.66	25.03	4.92	8.68	34.16	12.72	0.46
Poland	20:10	20:20	6.22	0.81	15.48	7.99	10.54	17.38	40.74	0.86
Sweden	20:10	20:20	6.88	0.65	16.69	3.29	8.8	29.22	33.58	0.89
Slovenia	20:10	20:20	6.34	0.75	15.08	8.48	8.85	21.07	39.08	0.35
UK	20:10	20:20	5.68	0.9	15.18	4.2	9.16	26.44	37.29	1.15

- High peak variance→*smart appliances*
- Low peak variance→*manual and incentive-based DSM programmes*
- Low non-peak variance→ *DDSC*
- High baseline variance→ *ToU*

Country	β	μ_{MP} μ_{EP}	$(\beta - \mu_{MP})$ $(\beta - \mu_{EP})$
Belgium	0.193 (0.027)	0.051 0.034	0.142 0.159
Bulgaria	0.194 (0.071)	0.048 0.011	0.146 0.183
Finland	0.130 (0.056)	0.024 0.010	0.106 0.120
Estonia	0.127 (0.028)	0.008 0.021	0.119 0.106
Germany	0.113 (0.015)	0.043 0.022	0.070 0.091
Italy	0.124 (0.023)	0.049 0.024	0.075 0.100
Latvia	0.128 (0.027)	0.011 0.024	0.117 0.104
Lithuania	0.131 (0.025)	0.009 0.018	0.122 0.113
Norway	0.130 (0.026)	0.057 0.012	0.073 0.118
Spain	0.192 (0.031)	0.064 0.057	0.128 0.135
Poland	0.101 (0.019)	0.051 0.012	0.060 0.089
Sweden	0.126 (0.025)	0.054 0.014	0.072 0.112
Slovenia	0.144 (0.023)	0.041 0.025	0.103 0.119
United Kingdom	0.165 (0.023)	0.091 0.020	0.074 0.145

Applications in UK and Spain: Knowing where and when

Computer use-UK



TV use-Spain

Average TV electricity consumption in Spain (MWh)

		Morning Peak	Evening Peak
Weekdays	Minimum	7,93	82,35
	Maximum	17,45	181,18
Weekends	Minimum	17,30	104,13
	Maximum	38,06	229,08

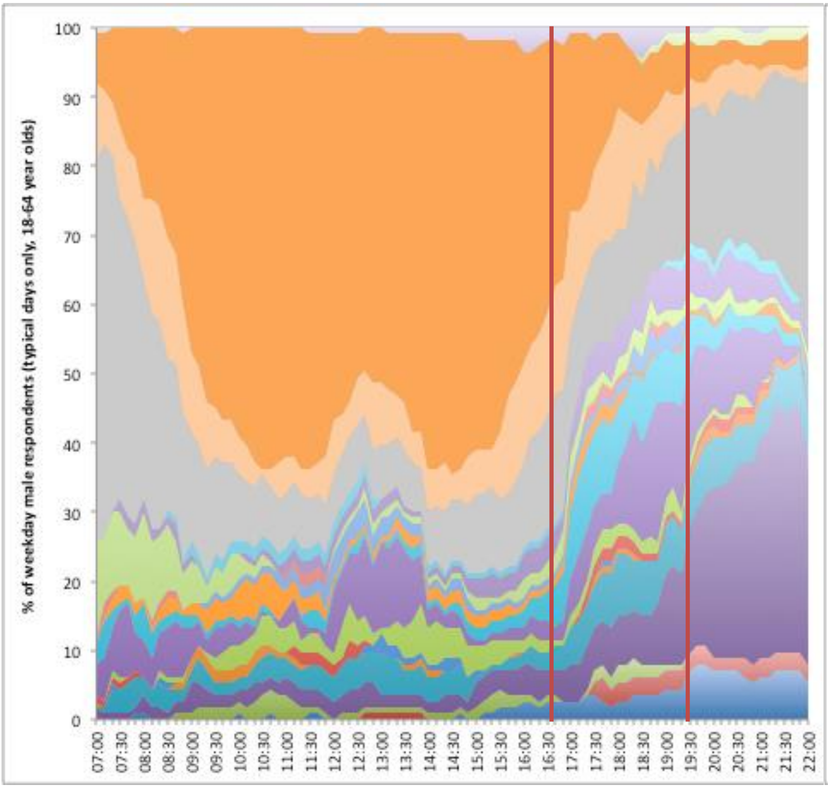
UK Trajectory time use dataset

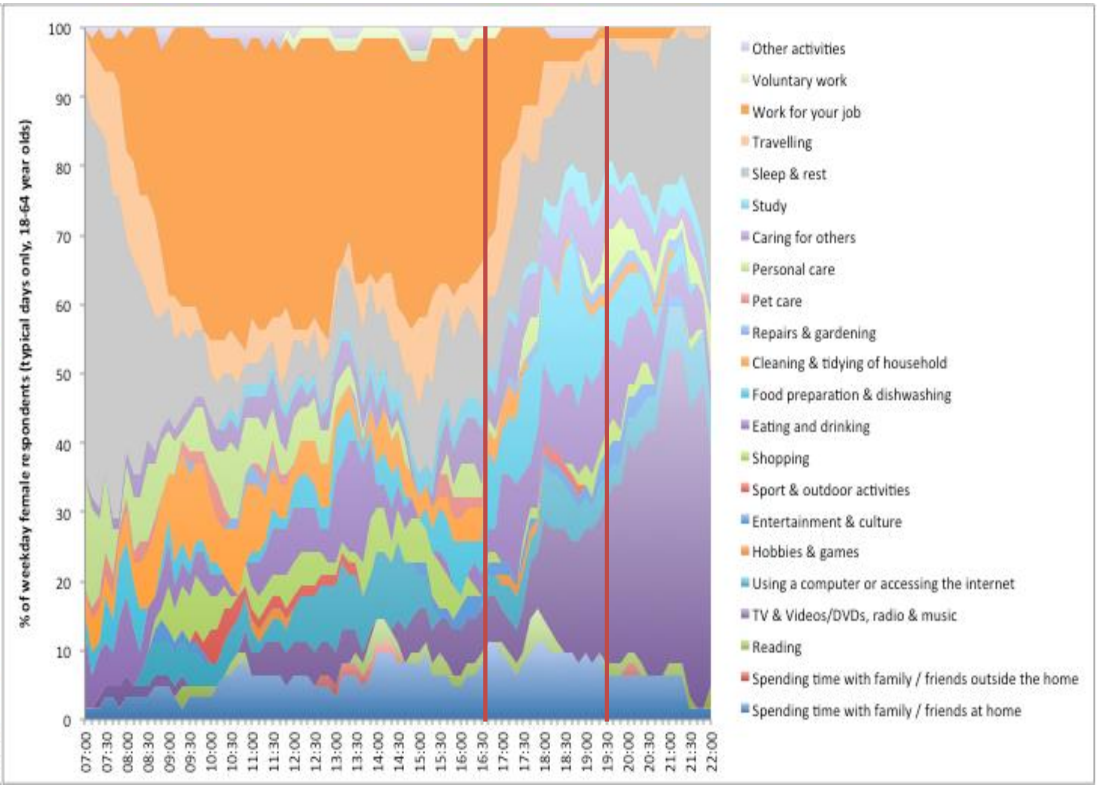
- 500 respondents
- with GPS devices for 3 days
- collecting 10 minute interval data (May-November 2011)
- + diary and questionnaire information on what people were doing at any given time of the day
- The Trajectory dataset allows temporal analysis to be combined with spatial analysis of the data

UK data - gender

Men

Women

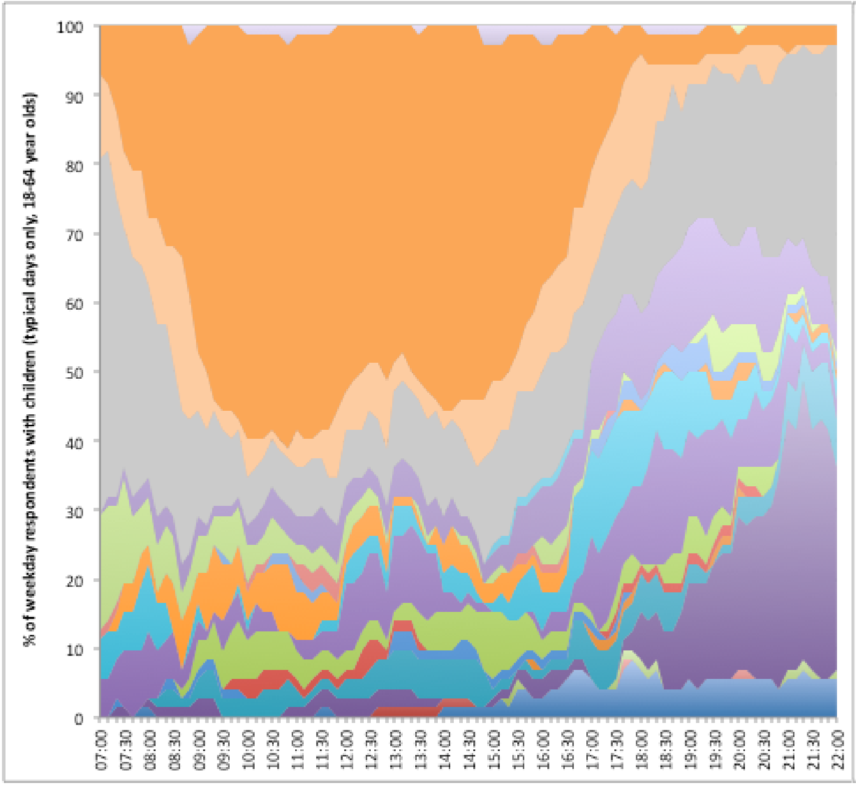


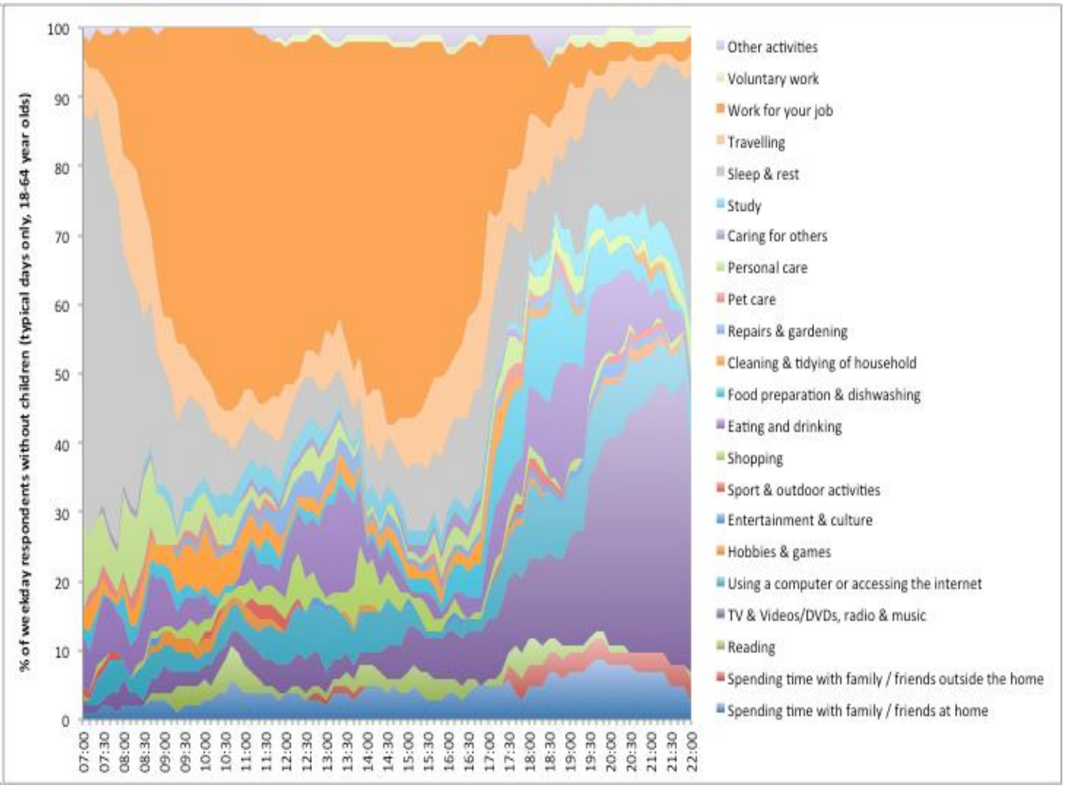


UK data: with or without children

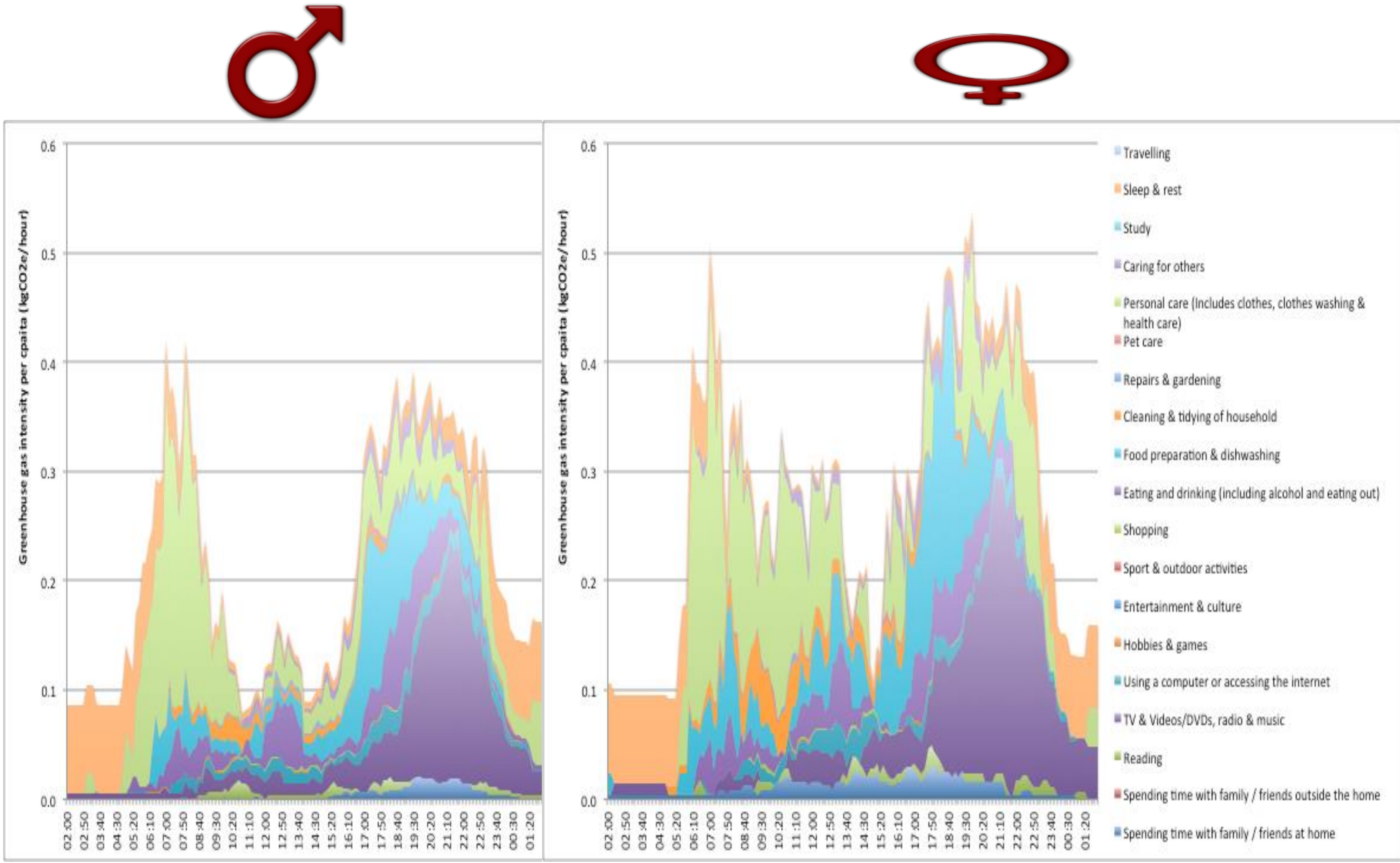
With Children 

Without children 





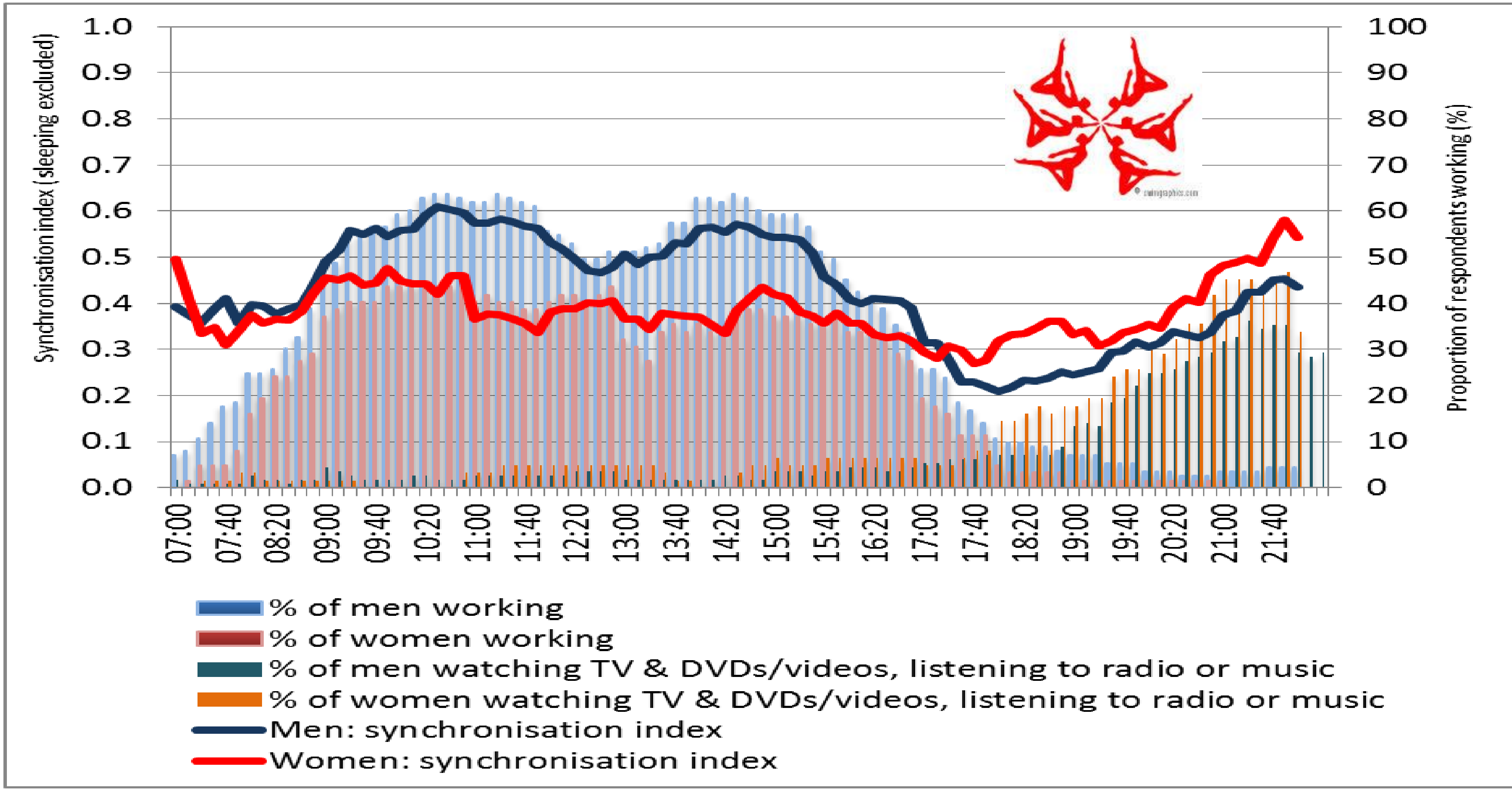
UK data: Greenhouse gas emissions



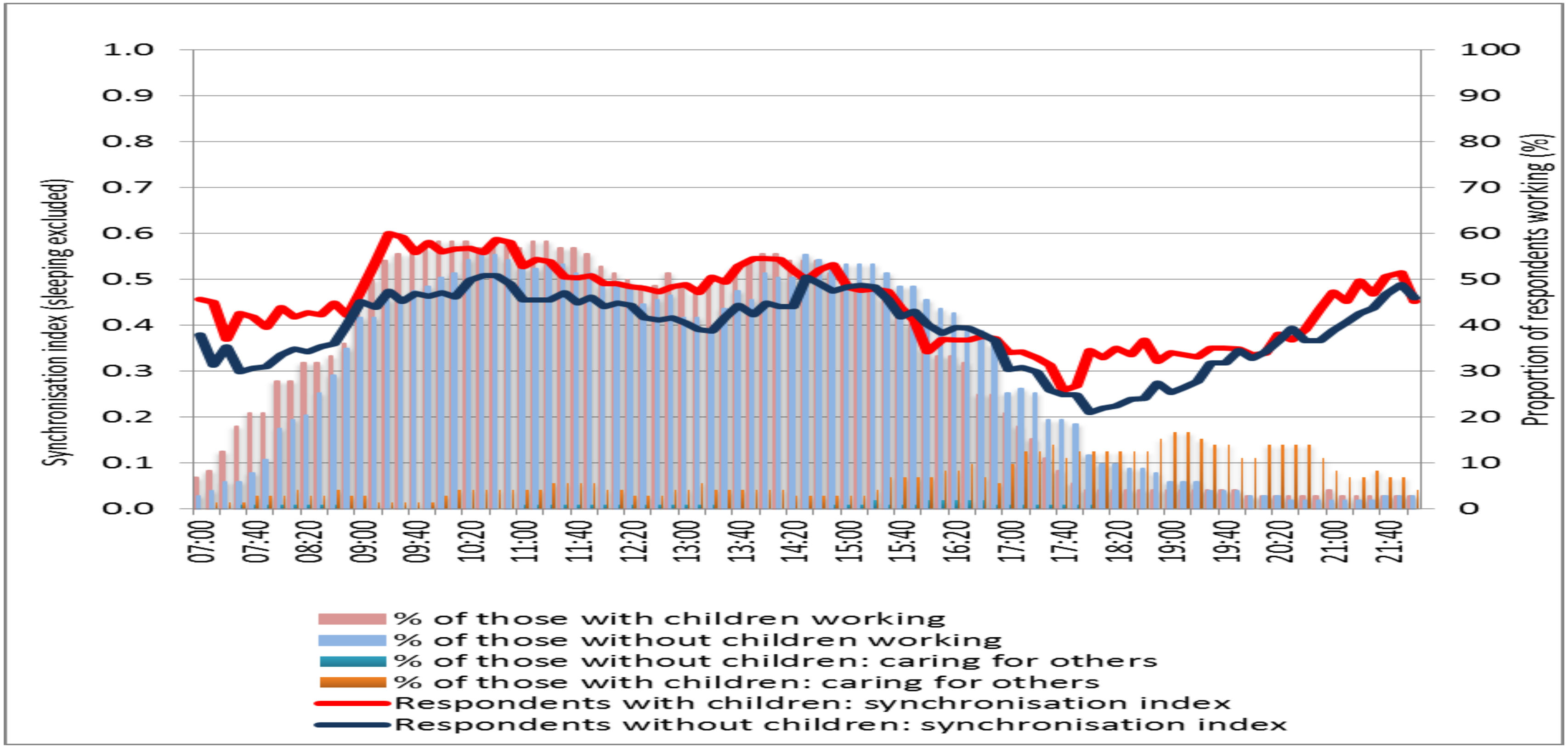
Flexibility index

- (i) higher synchronicity index implies higher societal constraints (i.e. lower flexibility)
- (ii) A higher number of activities distributed through the day makes it more difficult to move activities to different times of the day (i.e. lower flexibility).
- (iii) a higher number of shared activities with others implies that there is higher simultaneity of loads and within-the-household synchronisation, making it more difficult to move shared activities in time (i.e. lower flexibility)
- (iv) higher spatial mobility at a given time leads and lower active occupancy for an extended period of time imply that there is more time to do things (i.e. higher flexibility)

1: Synchronisation: men and women



1: Synchronisation: respondents with children compared to those without children



2: Variation and activities over time

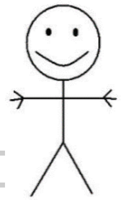
- **Variation index** = number of activities performed over a given time period (from a total of 38 activity codes) and changes in location

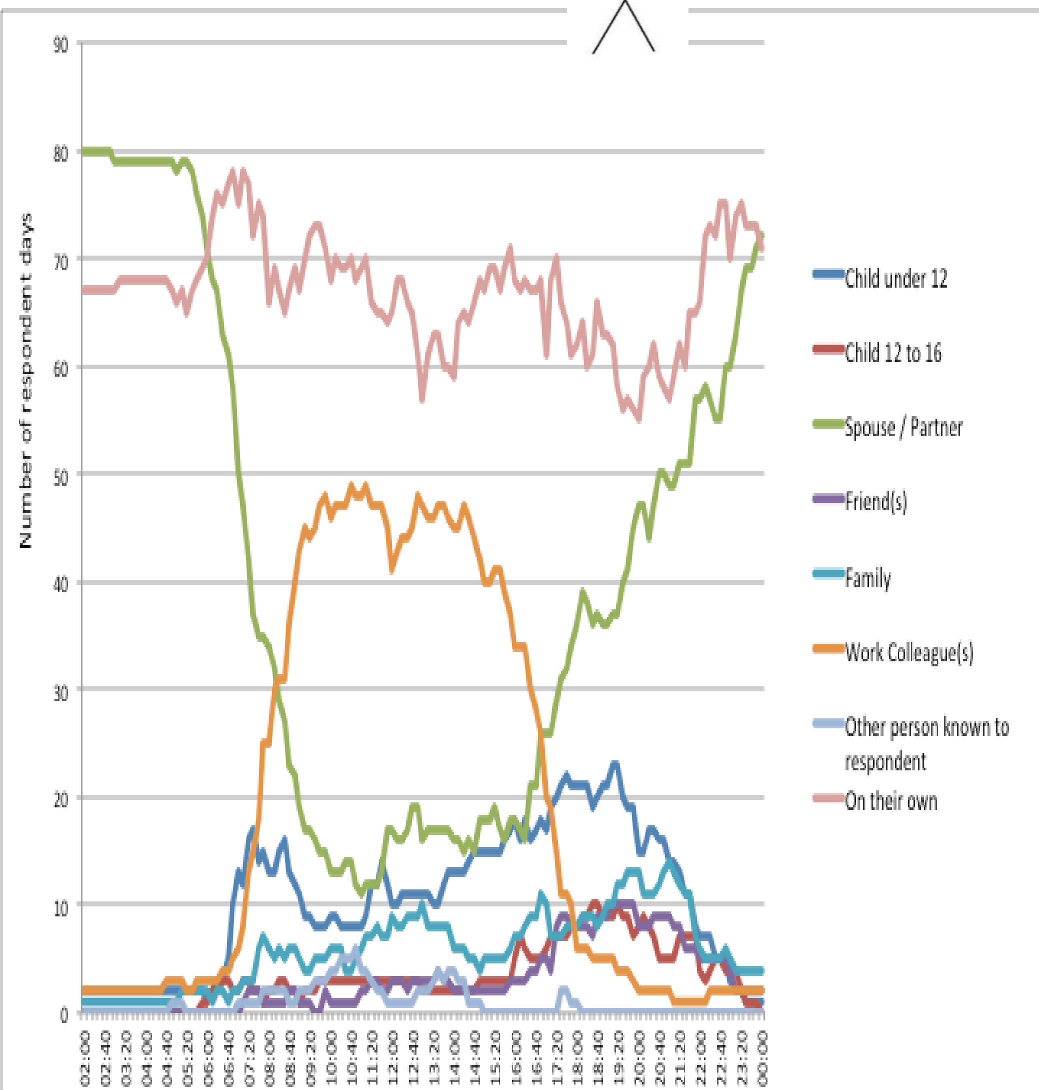
Demographic group	2am - 2am	Morning peak: 7am - 10am	Evening peak: 4pm - 10pm	Average % of time, 2am – 2am: working	Average % of time, 4pm – 10pm: food preparation, cooking & washing up
All males	8.1	3.6	4.8	23.1%	5.6%
All females	9.6	4.0	5.3	14.5%	8.1%
Males who worked	8.4	3.9	5.2	31.9%	4.2%
Females who worked	9.4	4.3	5.8	29.1%	10.3%

N.B. Respondents of working age / typical days only

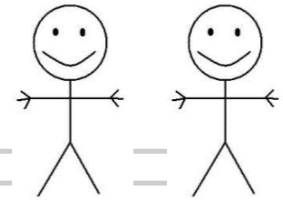
3: Who respondents were with (weekdays)

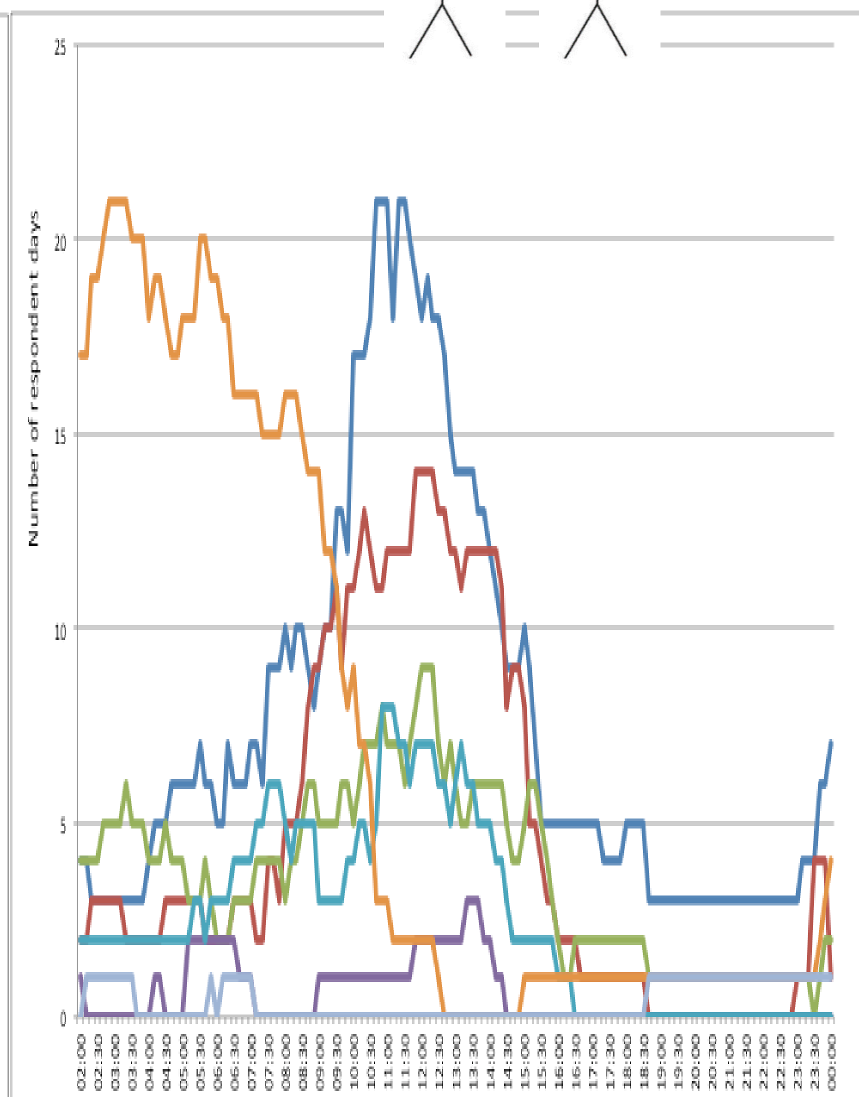
1st person





2nd Person



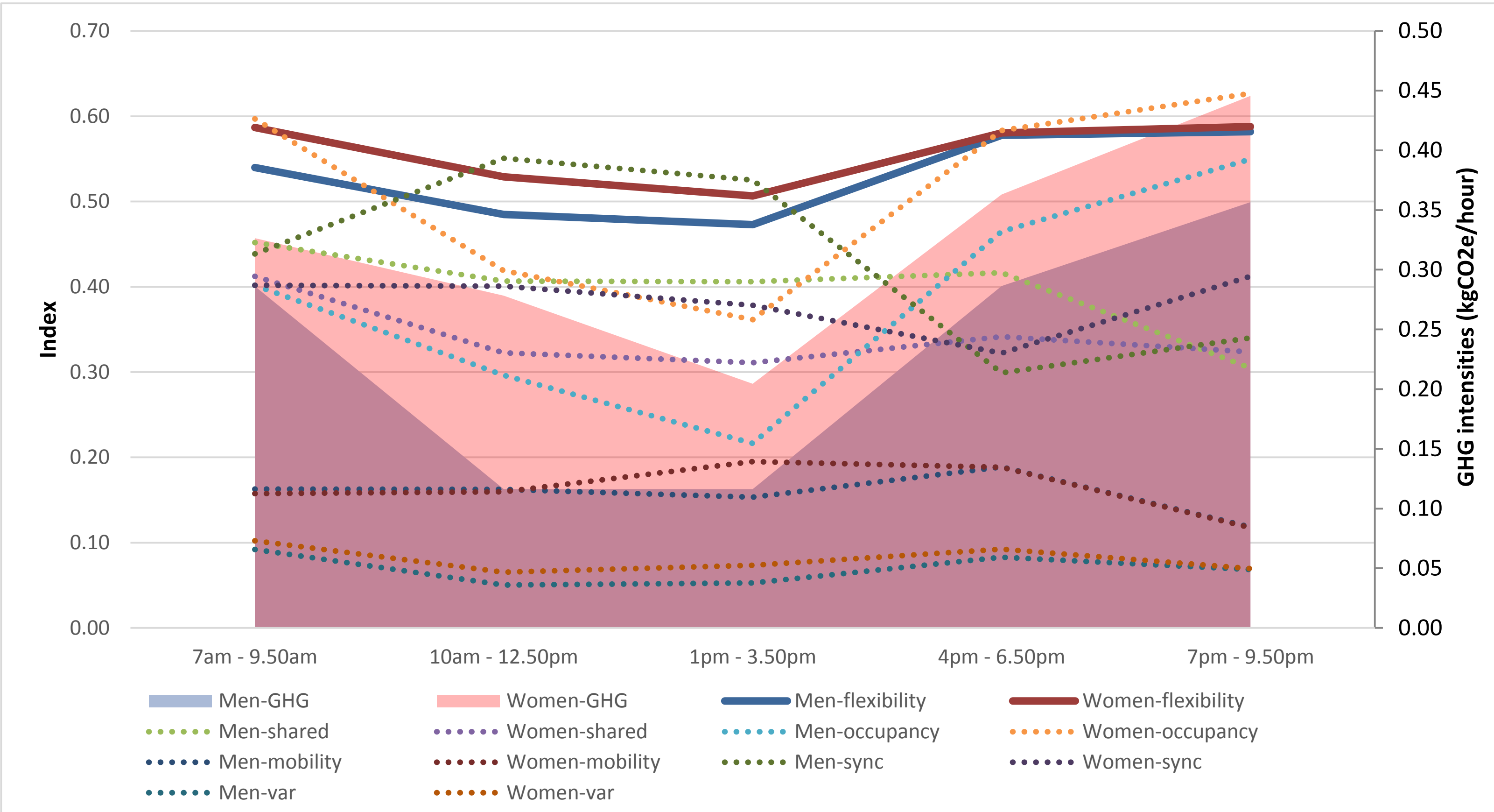


4: Space and occupancy

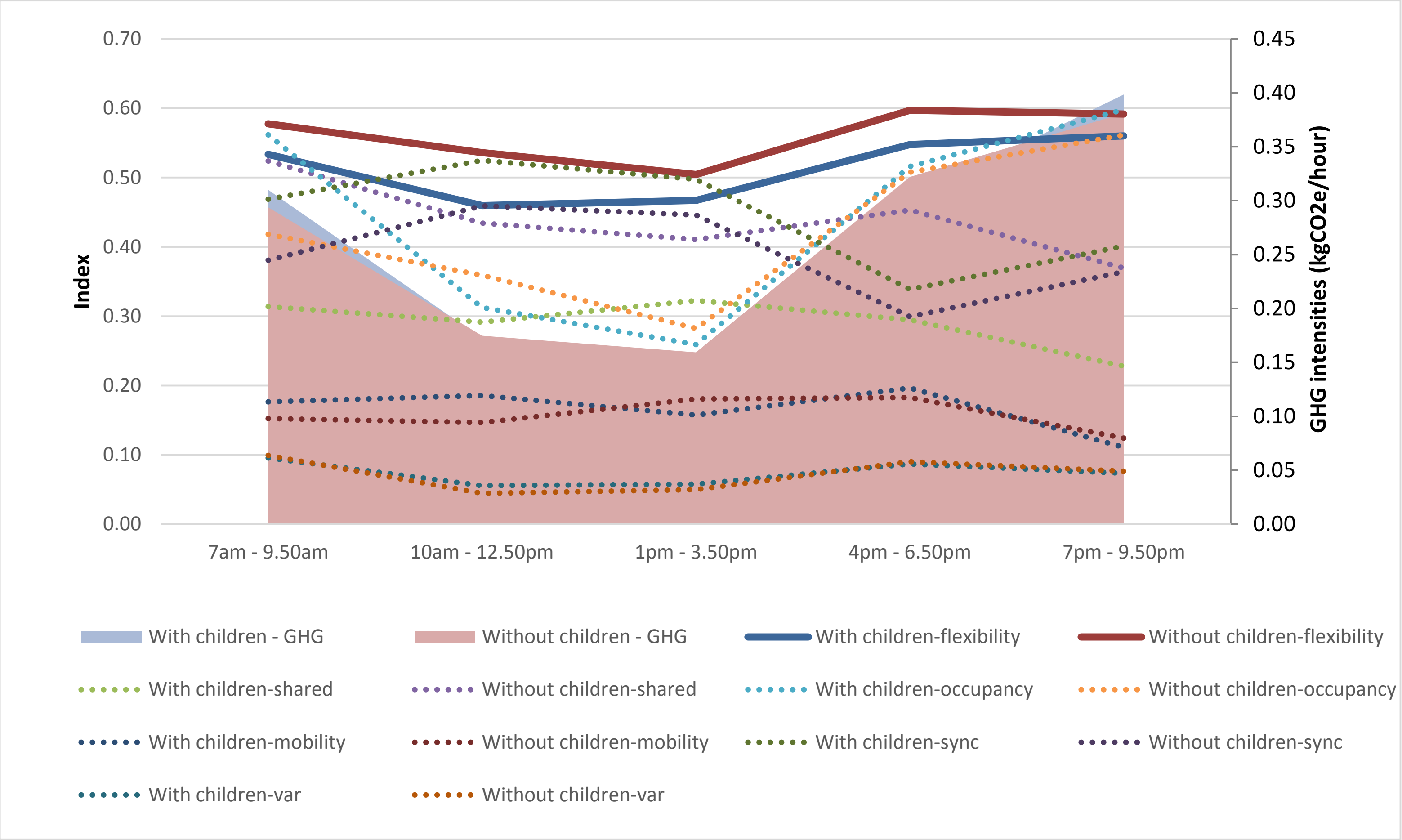
Spatial mobility and active occupancy

1. Spatial mobility	7.00am – 9.50am	10am – 12.50am	1pm – 3.50pm	4pm – 6.50pm	7pm – 9.50pm
All males	0.16	0.16	0.15	0.19	0.12
All females	0.16	0.16	0.20	0.19	0.12
All respondents with children	0.18	0.19	0.16	0.20	0.11
All respondents without children	0.15	0.15	0.18	0.18	0.12
2. Active home occupancy	**7.00am – 9.50am**	**10am – 12.50am**	**1pm – 3.50pm**	**4pm – 6.50pm**	**7pm – 9.50pm**
All males	0.40	0.30	0.22	0.46	0.55
All females	0.60	0.42	0.36	0.58	0.63
All respondents with children	0.56	0.31	0.26	0.52	0.60
All respondents without children	0.42	0.36	0.28	0.51	0.56

Flexibility index: men and women



Flexibility index: with and without children



Implications for price elasticity

- Study on effect of Time-of-Use tariffs (without flexibility):

usage by household

Fixed-effect

Day of week

TOU band

$$\ln E_{it} = \alpha_i + \mathbf{W}_{it}\boldsymbol{\gamma} + Peak_t \cdot \beta_1 + Day1_t \cdot \beta_2 + Day2_t \cdot \beta_3 +$$

$$+(Peak_t \times Treat_{it} \times POST_t) \cdot \delta_1 + (Day1_t \times Treat_{it} \times POST_t) \cdot \delta_2 + (Day2_t \times Treat_{it} \times POST_t) \cdot \delta_3 +$$

$$+(Night_t \times Treat_{it} \times POST_t) \cdot \delta_4 + \varepsilon_{it}$$

Hh receiving TOU

Trial in progress

- Study on effect of Time-of-Use tariffs (with flexibility):

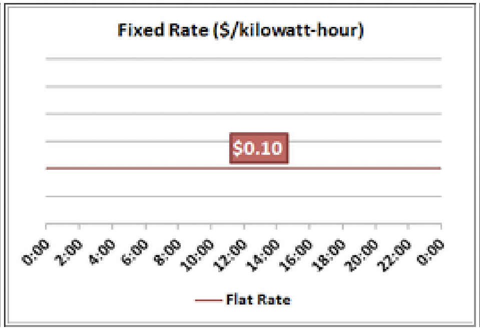
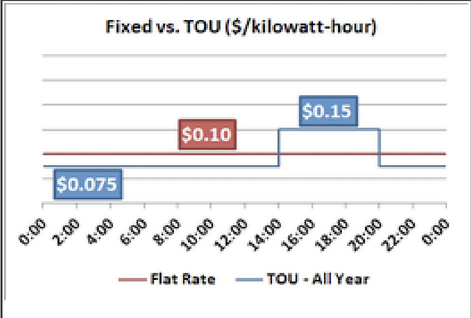
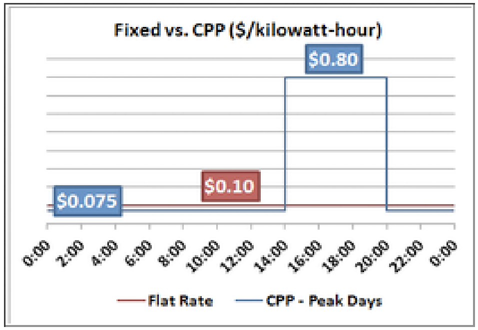
$$\ln E_{it} = \alpha_i + \mathbf{W}_{it}\boldsymbol{\gamma} + Peak_t \cdot \beta_1 + Day1_t \cdot \beta_2 + Day2_t \cdot \beta_3 +$$

$$+(Peak_t \times Treat_{it} \times POST_t \times Flex_t) \cdot \delta_1 + (Day1_t \times Treat_{it} \times POST_t \times Flex_t) \cdot \delta_2 + (Day2_t \times Treat_{it} \times POST_t \times Flex_t) \cdot \delta_3 +$$

$$+(Night_t \times Treat_{it} \times POST_t \times Flex_t) \cdot \delta_4 + \varepsilon_{it}$$

Choice Experiment

- Simple web-based choice experiment to elicit preferences for fixed tariffs and two dynamic tariffs (TOU and CPP)
- The price attribute was framed as an electricity bill discount (i.e. a WTA format) to switch to the dynamic tariff
- Respondents were presented with four labelled choice cards
- Respondents were randomly divided into two sub-samples, with environmental and system benefits information presented to only one

Tariff Type	Fixed	Time of Use (TOU)	Critical Peak Pricing (CPP)
Description	*Price stays the same throughout the day.	***Cost:** Rate is 50% higher than your current fixed rate 6 hours of the day, every weekday, from 2pm until 8pm, during daily high demand. ***Benefit:** Rate is 25% lower than your current fixed rate all other times.	***Cost:** On 10 weekdays selected by the electric company prices will raise 8x from your current fixed rate for 6 hours, from 2pm to 8pm, during emergency conditions. Your electric company notifies you one day in advance. ***Benefit:** Rate is 25% lower than your current fixed rate all other times that day and all other days in the year.
Environmental and Grid Benefits	*None	*Less water and air pollution. *Aid the expansion of renewable energy. *Increased electricity reliability. *Slow the rate of electricity price increases.	*Less water and air pollution. *Aid the expansion of renewable energy. *Increased electricity reliability. *Slow the rate of electricity price increases.
Graphic			
Required Behavior Change to get Savings	*None - it's your current plan.	**Sustained, moderate changes during daily high priced times:** ***All regions:** Shift all listed appliances. ***U.S.:** Adjust thermostat up by 2F (1C) from 75F (25C) during the summer. ***Europe:** If you use electric heating, adjust your thermostat down by 2F (1C) from 68F (20C) during the winter. Use stand-alone electric room heaters at their lowest setting.	**Oneoff, significant changes during 10 days' high priced times:** ***All regions:** Shift all listed appliances. ***U.S.:** Adjust thermostat up by 5F (2.5C) from 75F (25C) during the summer. Turn off window and room air conditioning units, and all but essential lighting. ***Europe:** If you use electric heating, adjust your thermostat down by 5F (2.5C) from 68F (20C) during the winter. Turn off stand-alone electric room heaters. Turn off all but essential lighting. Restrict use of electric cooking appliances by 50%.
Potential Bill Increase with No Behavior Change	0%	0% to 5% $0 to $5.00 per month	0% to 5% $0 to $5.00 per month
Potential Bill Savings with Behavior Change **Note: the last 2 columns in this row change with each selection.**	0%	10% Approximately $10.00 per month	5% Approximately $5.00 per month
Please Select One	Choice 1	Choice 2	Choice 3

Information collected

- socioeconomic information
- electricity usage
- use of appliances
- heating, and cooling
- attitudes toward personal energy consumption and policy goals
- tariff choice motivations
- attitudes towards technologies and services

Model

- Conditional and mixed logit model
- A likelihood ratio shows that the mixed logit model provides a better fit for the data at the highest levels of significance

Model Results with Customer Attribute Interactions

	Coefficient	Std. Error	MWTA[a]	Std. Error[b]
DISCOUNT	0.163***	0.020		
TOU[c]	-1.993**	0.830	12.22%	4.91%
E&SxTOU	1.599***	0.622	-9.81%	3.87%
MALExTOU	-1.779***	0.627	10.91%	3.91%
HIBILLxTOU	1.255**	0.619	-7.70%	3.82%
STUDENTxTOU	-0.056	0.629	0.34%	3.86%
EASYxTOU	2.848***	0.657	-17.47%	4.19%
CPP[c]	-3.009***	1.039	18.45%	6.20%
E&SxCPP	2.086***	0.788	-12.80%	4.87%
MALExCPP	-1.437*	0.790	8.81%	4.88%
HIBILLxCPP	-0.390	0.793	2.39%	4.86%
STUDENTxCPP	-1.728**	0.804	10.60%	4.97%
EASYxCPP	1.981**	0.802	-12.15%	5.01%
	Standard Deviations of Random Coeffs.			
TOU	2.776***	0.381		
CPP	3.365***	0.535		
Df			13	
Replications			1000	
Observations			1920	
Log likelihood			-438.380	
LR χ^2		SDs (2)	205.56***	

REDPeAk (Residential Electricity Demand: Peaks, Sequences of Activities and Markov chains)

DEePRED (Distributional Effects of Dynamic Pricing for Responsive Electricity Demand)

The Association for Decentralised Energy

ade

Bringing Energy Together

ofgem

e.on

University of Surrey

Department for Business, Energy & Industrial Strategy

KiWiPOWER demand management

NEA

Bloomberg New Energy Finance

SecondLaw

DEMAND Dynamics of Energy, Mobility and Demand

Research Councils UK Energy For a Low Carbon Future

REDPeAk: recruiting now

Post-Doc Research Assistant:

https://jobs.reading.ac.uk/displayjob.aspx?jobid=469

PhD Studentship:

https://www.findaphd.com/search/ProjectDetails.aspx?PJID=83869&LID=3959

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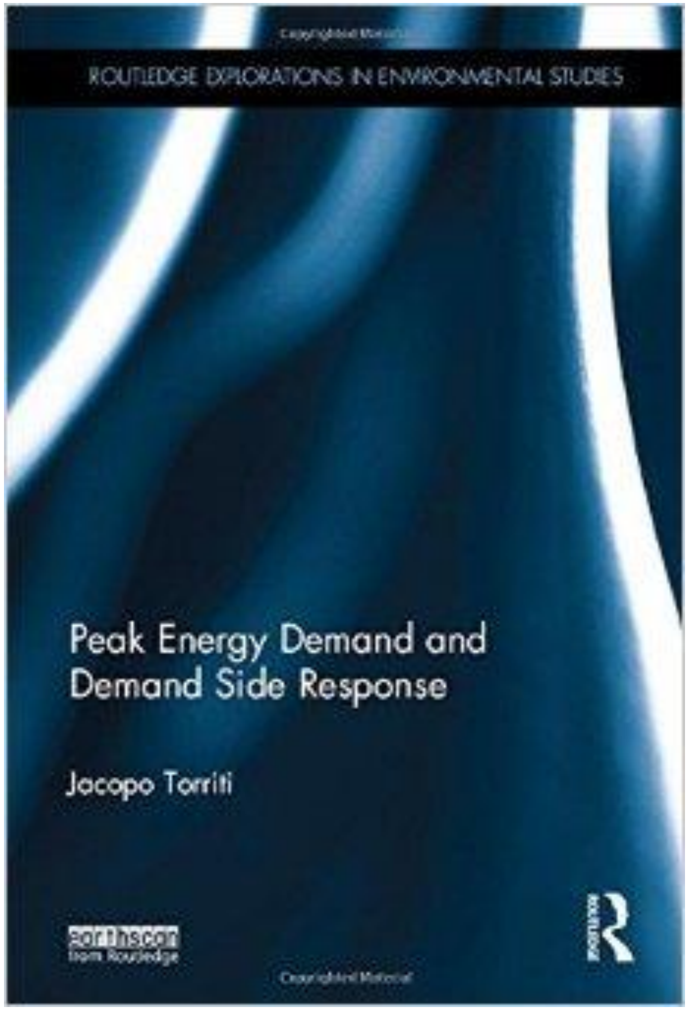

Peak Energy Demand and Demand Side Response (Routledge), pp. 172

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