

What makes you peak? Cluster analysis of household activities and electricity demand

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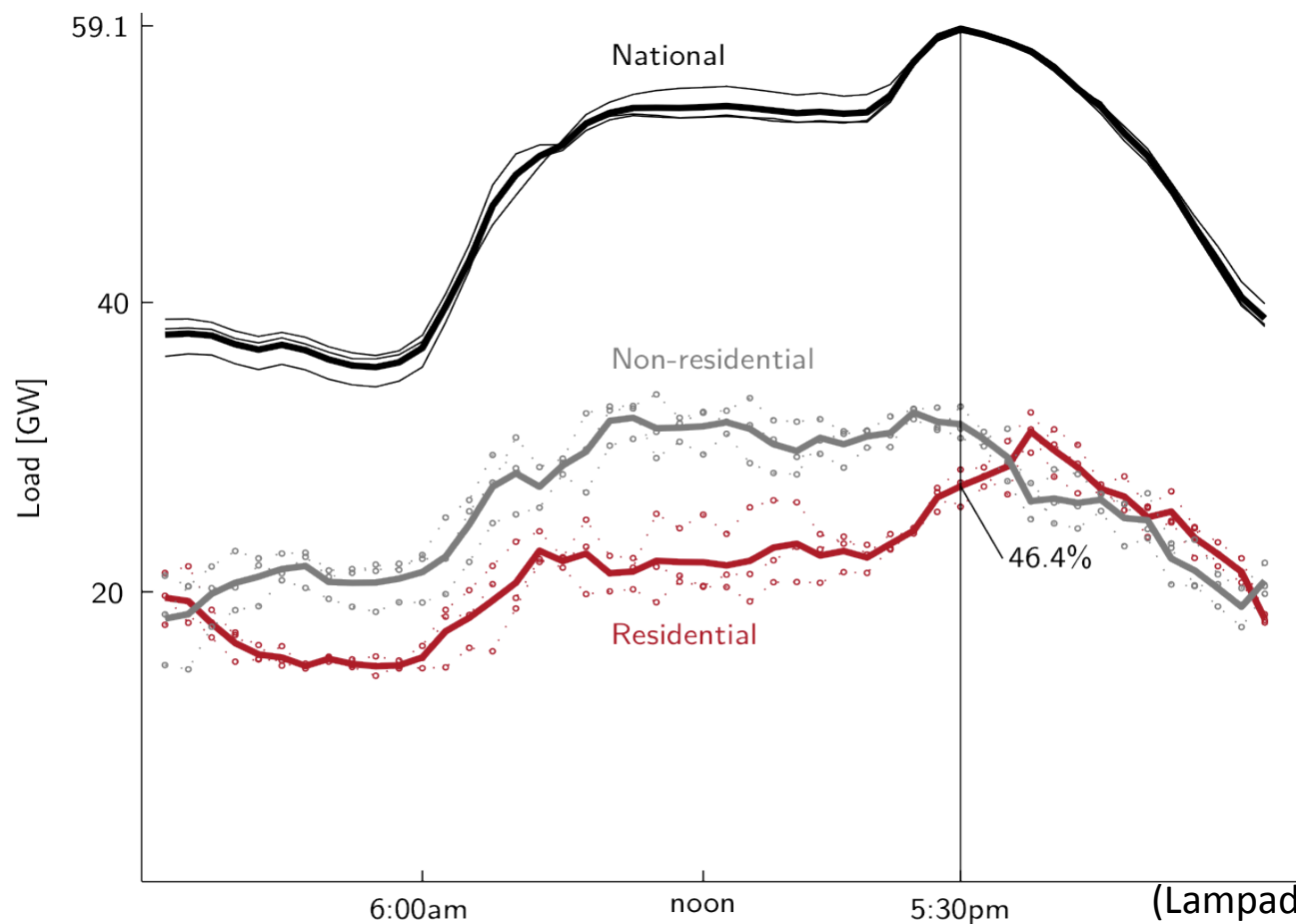
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Environmental Change Institute



ECEEE 2019 Summer Study on Energy Efficiency in Buildings
Presqu'île de Giens, France
June 5, 2019

UK residential contribution to peak demand



Customer	% peak demand
Interruptible I&C	3.8%
Firm I&C	16%
SME	30.2%
Domestic	50%
Total	100%

(Ofgem, 2010) – Table A2.1

Measuring and Evaluating Time- and Energy-use Relationships



METER

Measuring and Evaluating Time- and Energy-use relationships (METER)

Day 1 Time: 7am – 10am Morning				Day 1 Time: 7am – 10am				Were you alone or with somebody you know? Mark all relevant boxes								How much did you enjoy this time? 1 = not at all 7 = very much
Time: 7am-10am Morning (am)	What were you doing? Please write down one main activity.	If you did something else at the same time, what else did you do?	Did you use a smartphone, tablet, or computer?	Where were you? Location, or mode of transport	Alone	Spouse / partner	Mother	Father	Child aged 0-7	Other person	Others you know					
7am-7.10	Woke up the children		<input type="checkbox"/>	At home	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	5				
7.10-7.20	Had breakfast	checked emails	<input checked="" type="checkbox"/>	↓	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	6				
7.20-7.30	"	Talked with my family	<input type="checkbox"/>		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	5				
7.30-7.40	Cleared the table	Listened to the radio	<input type="checkbox"/>		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	4				
7.40-7.50	↓	↓	<input type="checkbox"/>		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	↓				
7.50-8am	Helped the children dressing	Talked with my children	<input type="checkbox"/>	↓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	↓				
8am-8.10	"	↓	<input type="checkbox"/>	on foot	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	↓				
8.10-8.20	Went to the day care centre	↓	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	1				



Engineering and Physical Sciences
Research Council



Location	Activity				Other people	Enjoyment
Home	Personal	Next...	Cold meal	Next...	No one	Very much
Outdoors	Joint	Prepare	Hot meal	Oven	1	Somewhat
Work	Work	Lay of clear	Baking	Hob	2	So so
Public Place	Food	Eat	Lay table	Microwave	3	Not much
Travel	Appliances	Snack	Next...	Kettle	4	Not at all
Elsewhere	Customise	Hot drink		Toaster	More	Skip

3 selections → discriminate 216 options

f) Edit

Survey

?

Hot drink at 2:20pm

I did more

Repeat

Rename

Change time

End

Delete

Back

Home

a) Home

Home

You

Help

Survey

?

What I did

Now 9:36

Recently

Monday

9:35 pm

Computer

5:05 pm

Prepare hot meal

2:20 pm

Hot drink

1:00 pm

Resting

Sunday

11:45 pm

Exercise

Back

Home

METER Energy-use.org

b) Location

Survey

?

Where are you at 9:36?

Home

Garden / Outdoors

Work

Public place

Travel

Elsewhere

Back

Home

c) Activity

Survey

?

Your activity

Personal

Joint activity

Work / Housework

Food / Drink

Appliances

Customise

Back

Home

d) Other people

Survey

?

How many people are you doing this with?

No one

1

2

3

4

More

Back

Done

[...]

e) Enjoyment

Survey

?

How much do you enjoy this?

Very much

Somewhat

So so

Not much

Not at all

Skip

Back

Done

Environmental Change Institute

eci

OXFORD

Cluster analysis of household activities and electricity demand



Cluster analysis: what is it and how does it work?

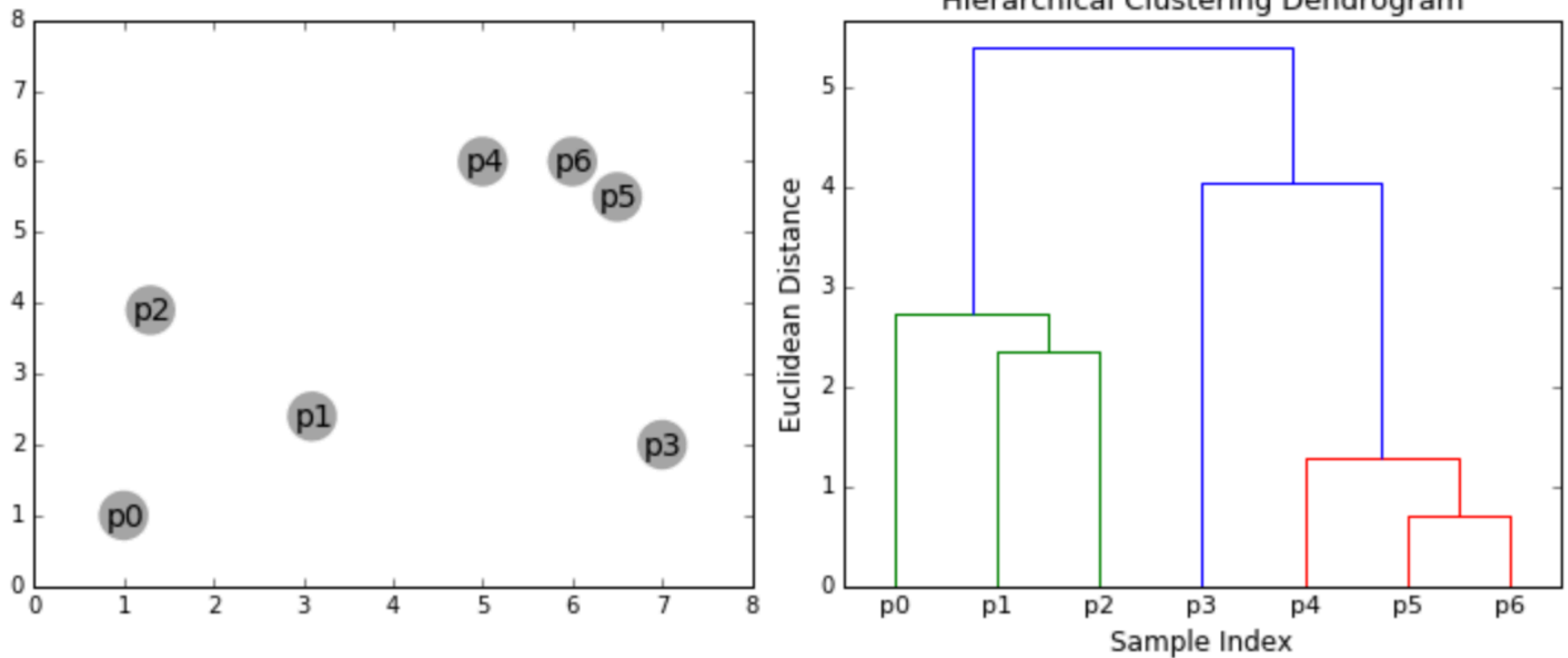
What is it?

- An algorithmic approach to identify homogenous groupings of data where no a priori grouping exists
- Aims to group objects such that those in one cluster are **more similar** to each other than those in other clusters

How does it work?

- What does “more similar” mean?
- Conventional clustering methods use **geometric distances** to determine “similarity” (e.g. Euclidean distances)

Cluster analysis: what is it and how does it work?



Source: <https://towardsdatascience.com/the-5-clustering-algorithms-data-scientists-need-to-know-a36d136ef68>

Paper methods: process map

Pre-process data

- Remove poor quality data
- Select sampling method

Normalise data

- Determine what to cluster on (i.e. total usage, discretionary usage, etc)

Exploratory cluster analysis

- Compare different distance methods and clustering algorithms

Evaluate clusters

- Validation index to determine cluster "distinctness" and "compactness" scores
- Determine optimal number of clusters

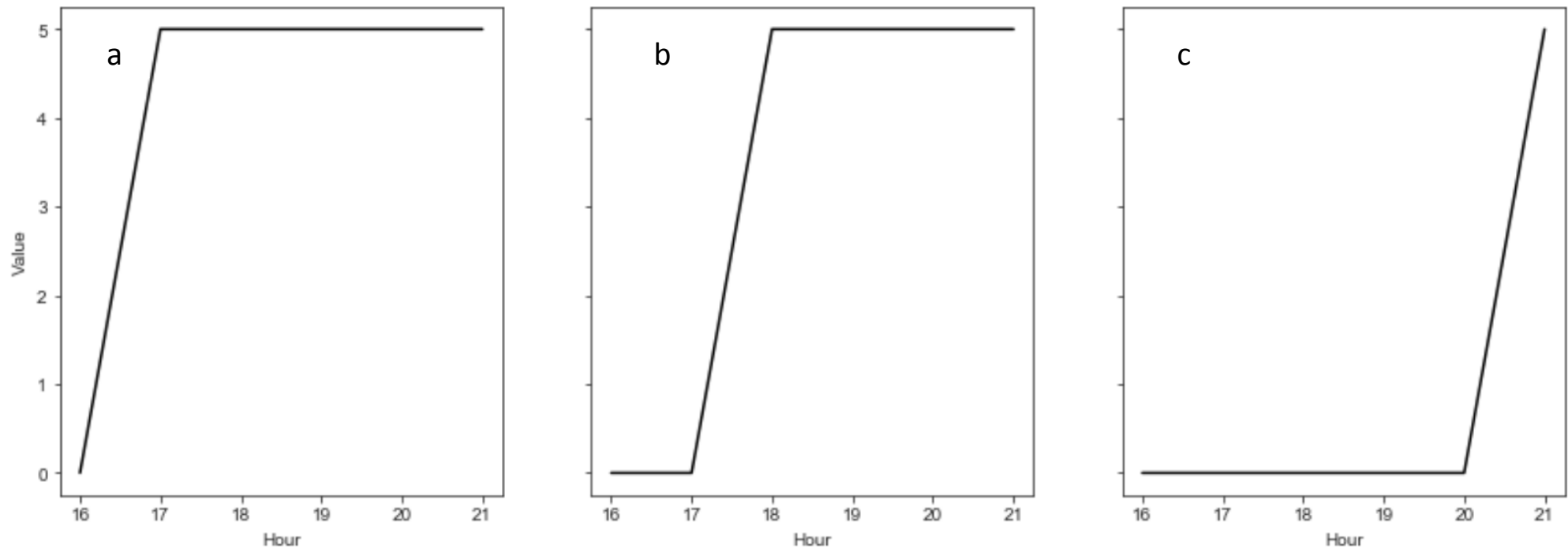
Cluster analysis of peak period electricity load profiles

Clustering approach	Data pre-processing	Data normalization	Clustering distance measure	Clustering algorithm	Cluster validation index
Raw data-based [11, 4, 12, 13]	Missing data imputation [7, 14]	Daily maximum demand normalization [11, 4, 10, 14]	Euclidean (e.g. Manhattan, Chebyshev) [11, 4, 12]	Partitioning methods (e.g. K-means, Fuzzy c-means) [11, 4, 10, 14, 12]	Cluster Dispersion Indicator (CDI) [4, 14, 12]
Feature-based (e.g. load factor, timing of peak load, etc) [15, 14, 16]	Data stratification (e.g. week-day versus weekend) [11, 10, 14, 16]	Min-max normalization [12]	Correlation (e.g. Pearson's correlation coefficient) [11]	Hierarchical methods (e.g. agglomerative, divisive) [15, 11, 4, 12]	Davies-Bouldin Index (DBI) [4, 12]
Combined raw data- and feature-based [7]	Data reduction (e.g. Principal Components Analysis) [11, 4]	Mean normalization [16]	Time-series specific (e.g. Dynamic Time Warping, Earth Mover's Distance)	Density-based methods (e.g. DBSCAN)	Mean Index Adequacy (MIA) [10, 14, 12, 13]
	Representative Load Profile (RLP) [4, 14, 12]	De-minned normalization [17, 18]	Angular cosine [11]	Model-based methods (e.g. mixture model, Self-organizing Map (SOM) [15, 11, 14, 12, 13, 16]	Silhouette Index (SI) [18, 19, 20]
	Hourly averages, 4-9PM				Gap Statistic [7]

Cluster cumulative load profiles!

Table 1: Summary of methodological approaches and key considerations for electric load profile clustering.

Why cluster cumulative load profiles?



Now a) and b) are 'closer' using Euclidean distance

Paper methods: process map

Pre-process data

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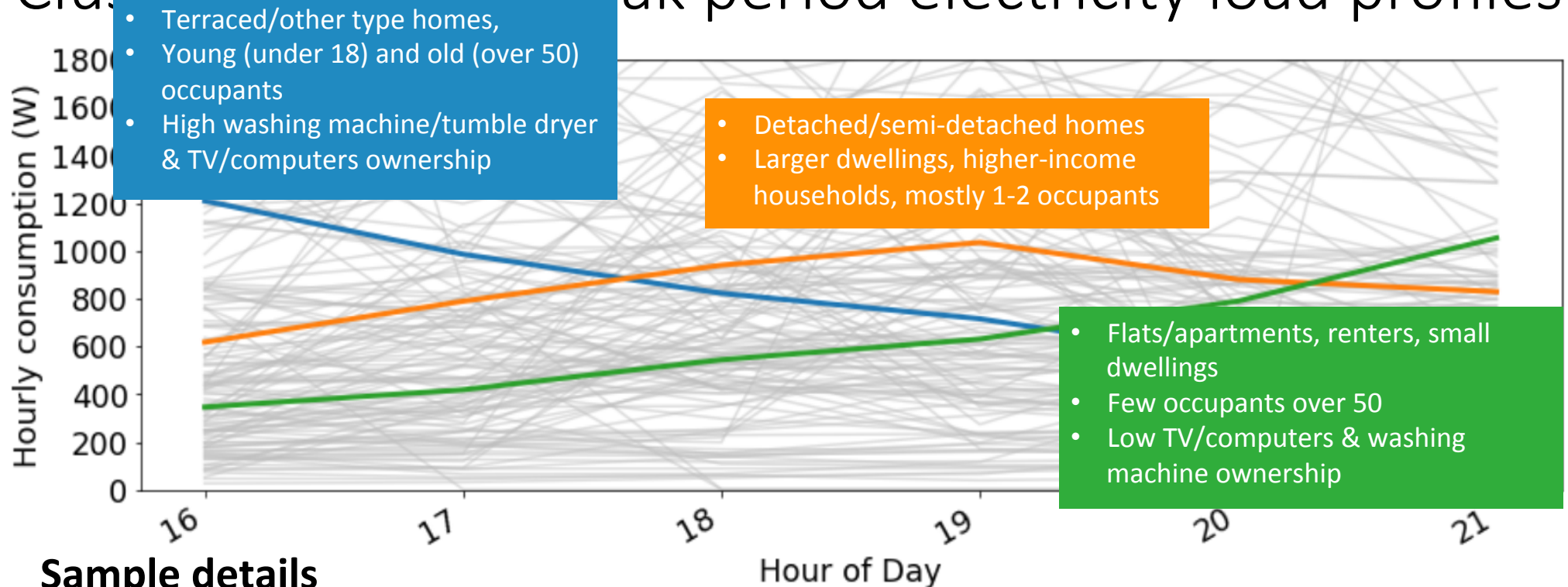
Exploratory analysis of household characteristics and activity patterns

- Link survey and activity data to load profile clusters

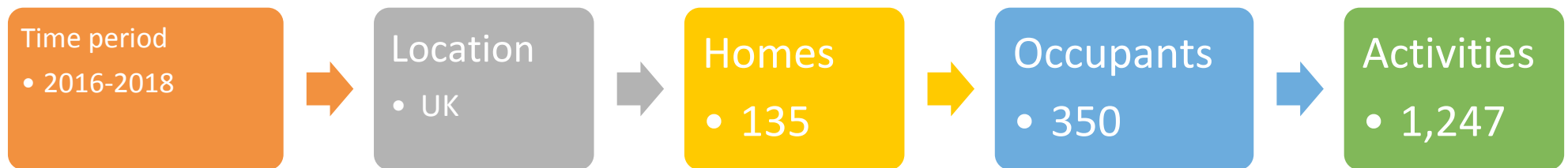


Results

Cluster analysis of peak period electricity load profiles



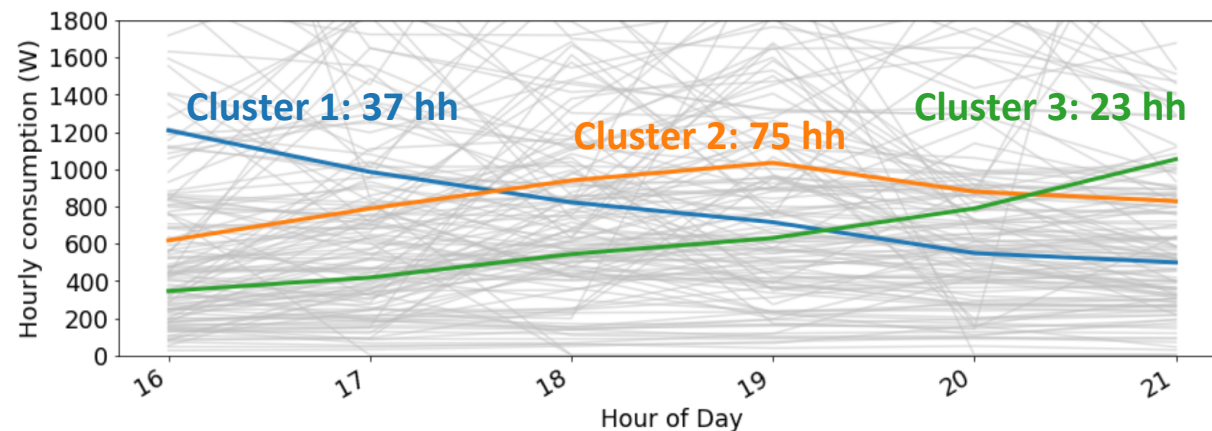
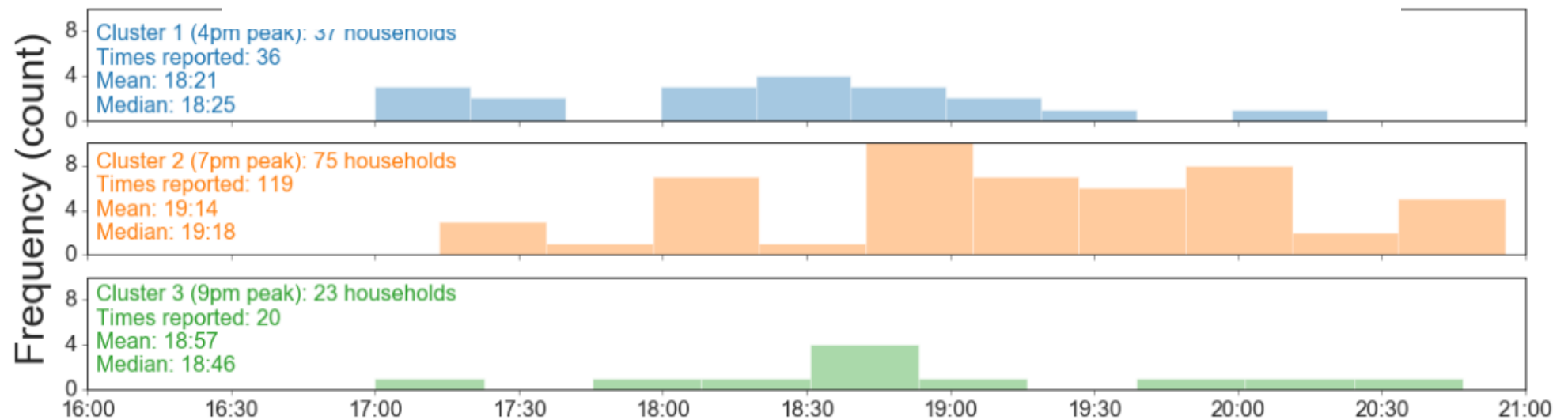
Sample details



Exploring activity patterns for household clusters



Activity: eating & eating hot meal



Takeaways – 3 important messages

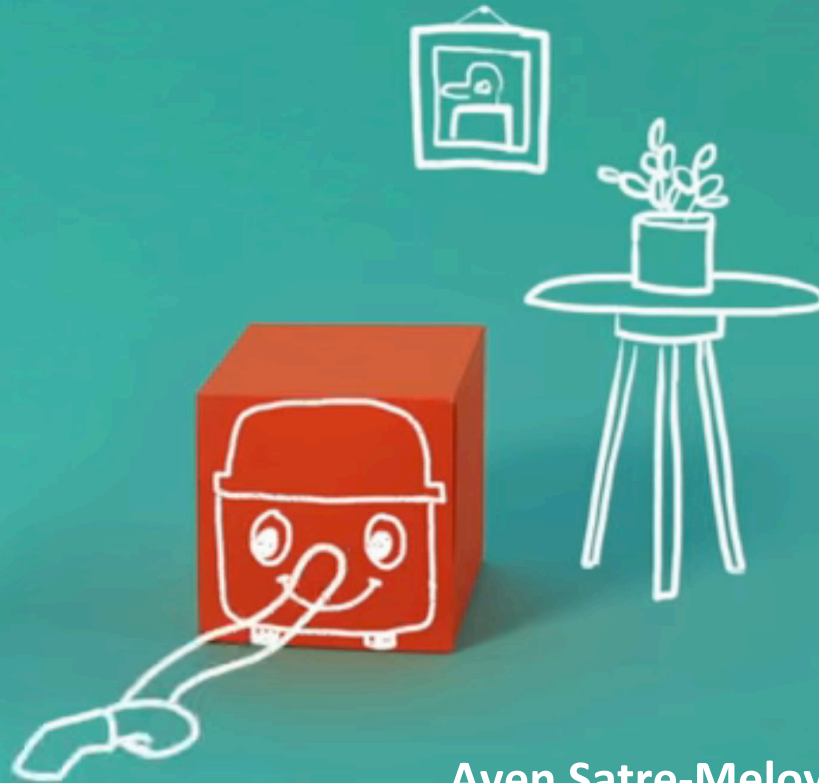
1. Pre-processing steps are essential for fully capturing temporal shape of time series load profiles through cluster analysis
 - Cumulative profiles enable appropriate use of Euclidean distance metrics
2. Demographic differences between clusters can be used to identify/prioritise groups for targeted interventions to reduce peak demand (i.e. which intervention is most appropriate?)
 - Households with children that peak earlier require different interventions than renters/apartments that peak later
3. Meal times and preparation are key for differentiating households based on timing of peak demand
 - Can inform ‘activity-led’ demand response (Grunewald & Diakonova, 2018)

METER aims to be a laboratory for exploring these questions (across different countries & household demographics/activity patterns)

Thank you!



www.github.com/PhilGrunewald



Aven Satre-Meloy
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01:00

02:00

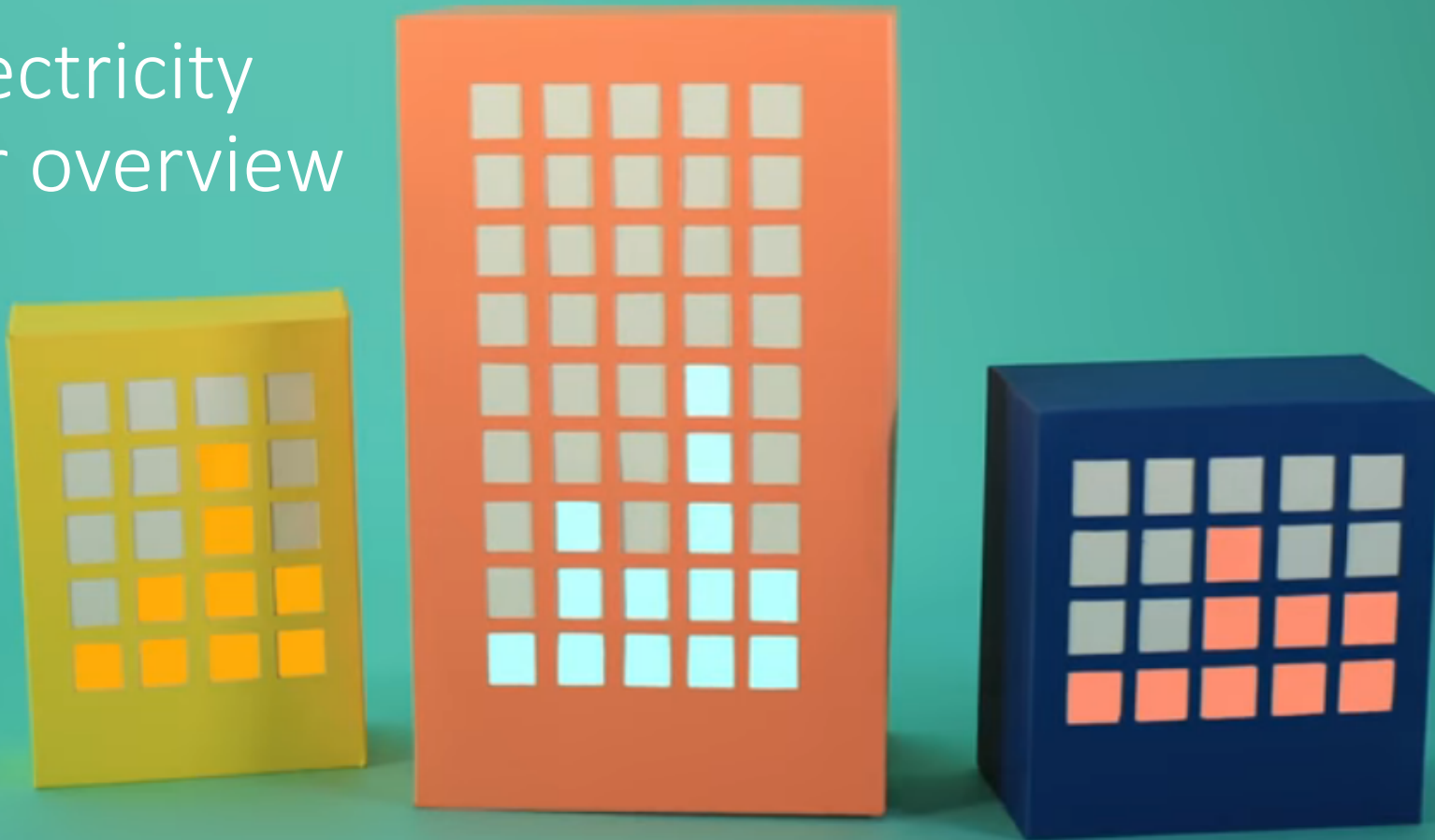
03:00

References

- BEIS, 2018a. 2017 UK Greenhouse gas emissions, provisional figures. Department for Business, Energy and Industrial Strategy, London, United Kingdom.
- BEIS, 2018b. DUKES chapter 5: statistics on electricity from generation through to sales, in: Digest of UK Energy Statistics (DUKES): Electricity. Department for Business, Energy & Industrial Strategy, London, United Kingdom.
- DECC, 2014. Household Electricity Survey. Department of Energy and Climate Change, London, United Kingdom.
- Grunewald, P., Diakonova, M., 2018. Flexibility, dynamism and diversity in energy supply and demand: A critical review. *Energy Research & Social Science* 38, 58–66. <https://doi.org/10.1016/j.erss.2018.01.014>
- Lader, D., Short, S., Gershuny, J., 2006. The Time Use Survey, 2005: How we spend our time. Office for National Statistics, London, United Kingdom.
- Lampaditou, E., Leach, M., 2005. Evaluating participation of residential customers in demand response programs in the UK 12.
- Ofgem. (2010). Demand Side Reponse. A Discussion Paper (p. 87). London: Office of Gas and Electricity Markets. <https://www.ofgem.gov.uk/ofgem-publications/57026/dsr-150710.pdf>
- Palmer, J., Terry, N., Kane, T., 2013. Further Analysis of the Household Electricity Survey. Early Findings: Demand side management (No. 475/09/2012). Cambridge Architectural Research Limited, elementenergy, and Loughborough University.
- Priestley, S., 2018. UK Fifth Carbon Budget 24.
- Torriti, J., Hanna, R., Anderson, B., Yeboah, G., Druckman, A., 2015. Peak residential electricity demand and social practices: Deriving flexibility and greenhouse gas intensities from time use and locational data. *Indoor and Built Environment* 24, 891–912. <https://doi.org/10.1177/1420326X15600776>

Additional Slides

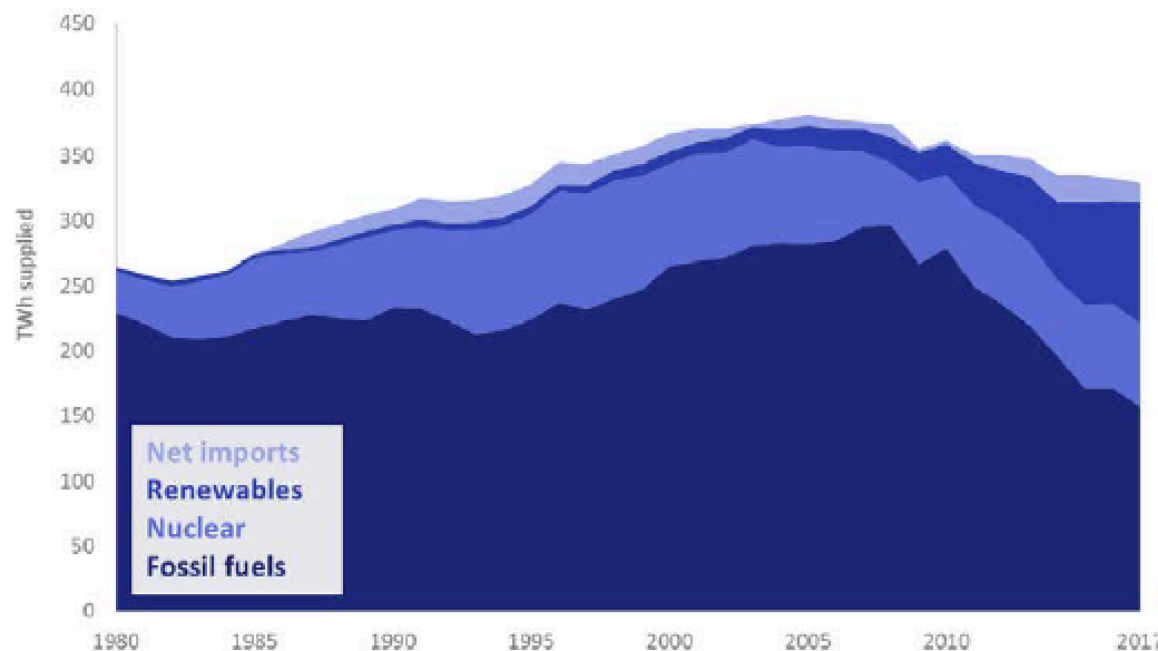
UK electricity sector overview



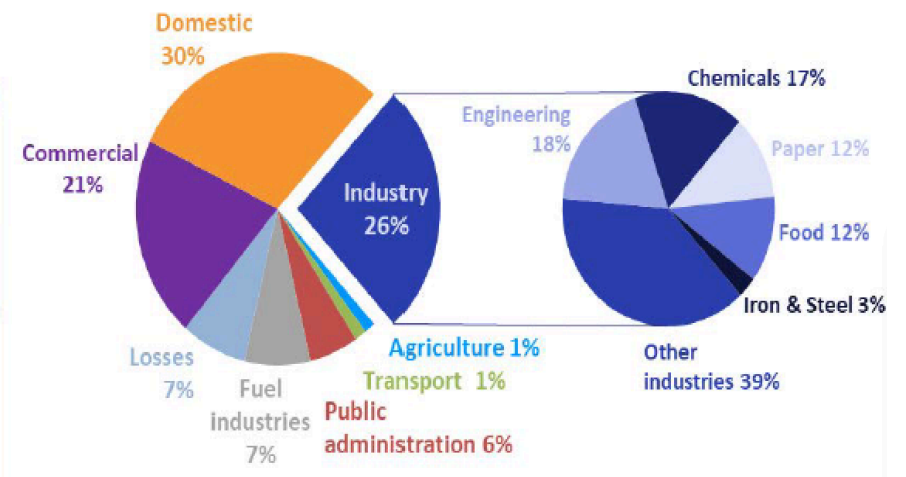
UK electricity sector overview

UK electricity supply, 1980-2017

Electricity demand by sector 2017

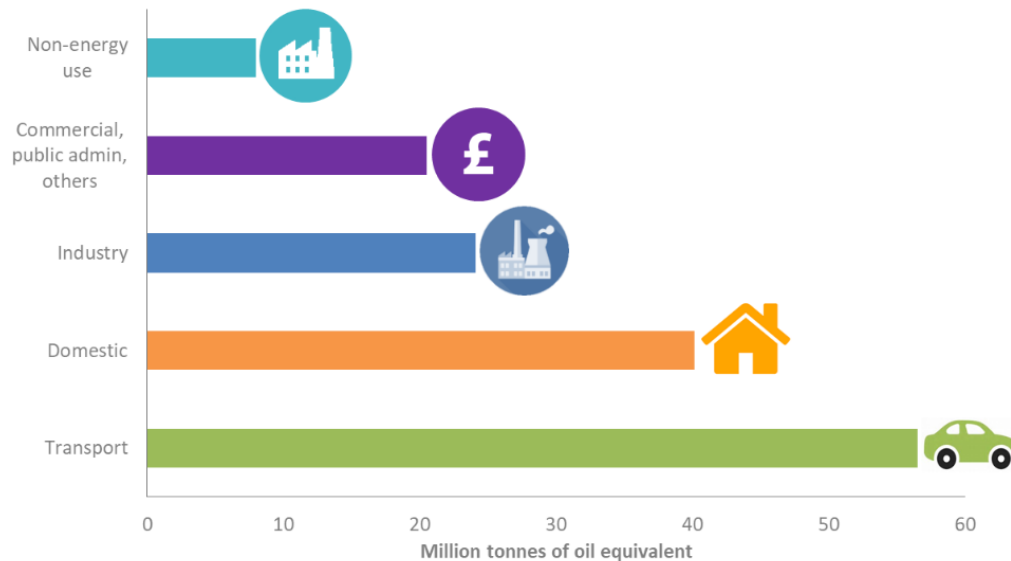


(BEIS, 2018)



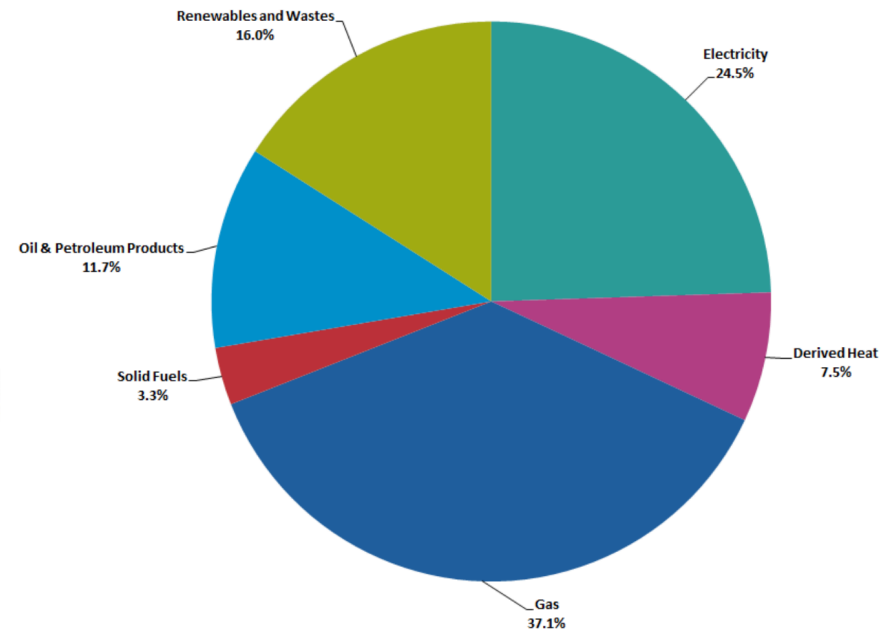
UK energy sector overview

Consumption by sector

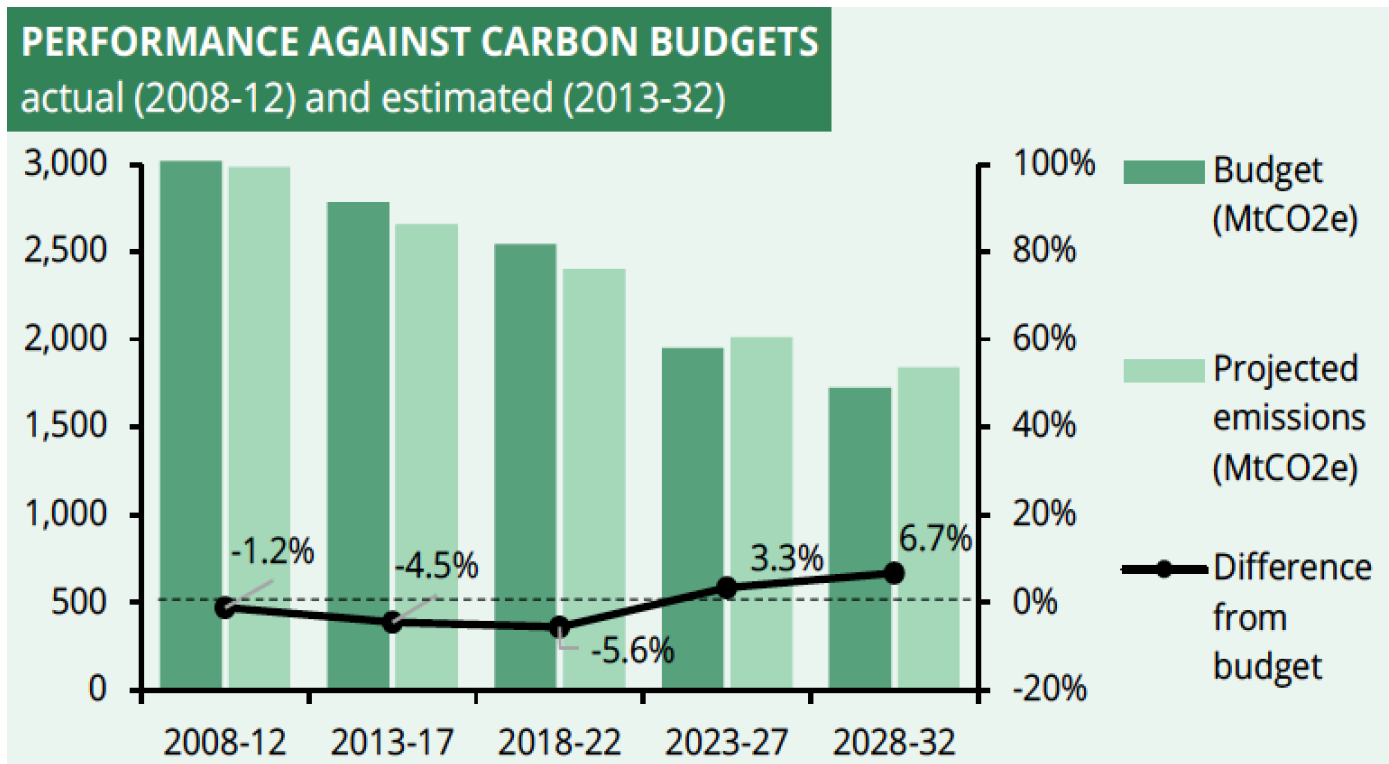


(BEIS, 2018)

Domestic consumption by fuel



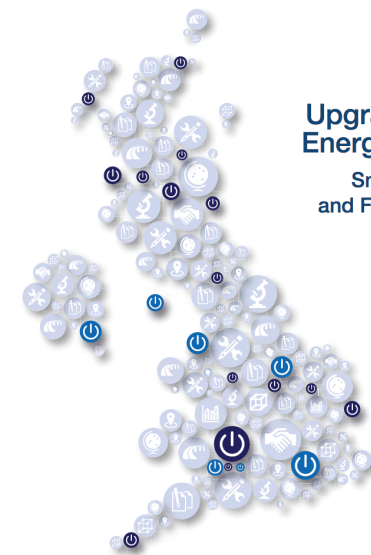
UK carbon budgets & clean growth strategy



(Priestley, 2018)

HM Government

ofgem
Making a positive difference
for energy consumers



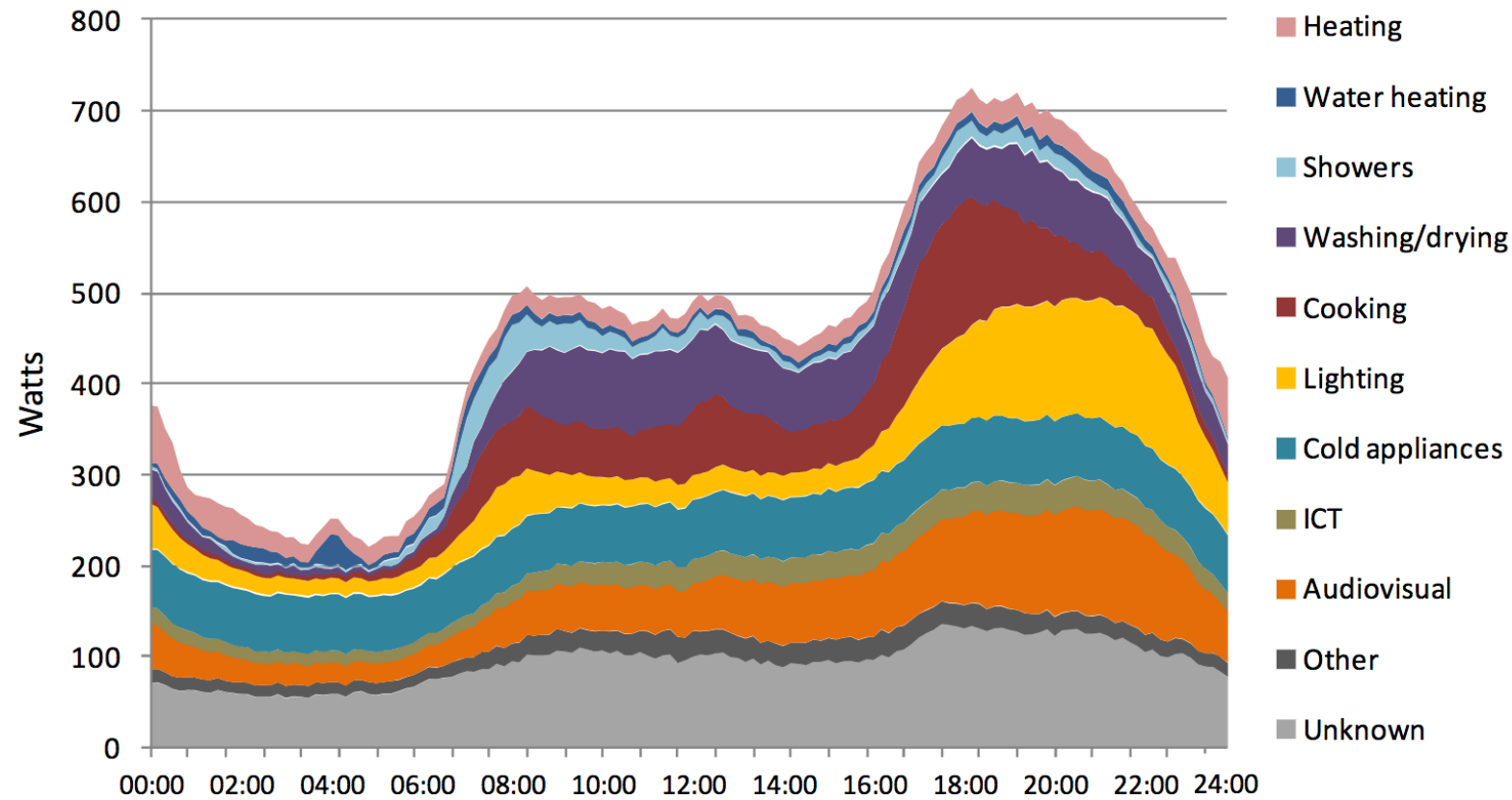
**Upgrading Our
Energy System**
Smart Systems
and Flexibility Plan
July 2017

Building our
Industrial Strategy

Environmental Change Institute

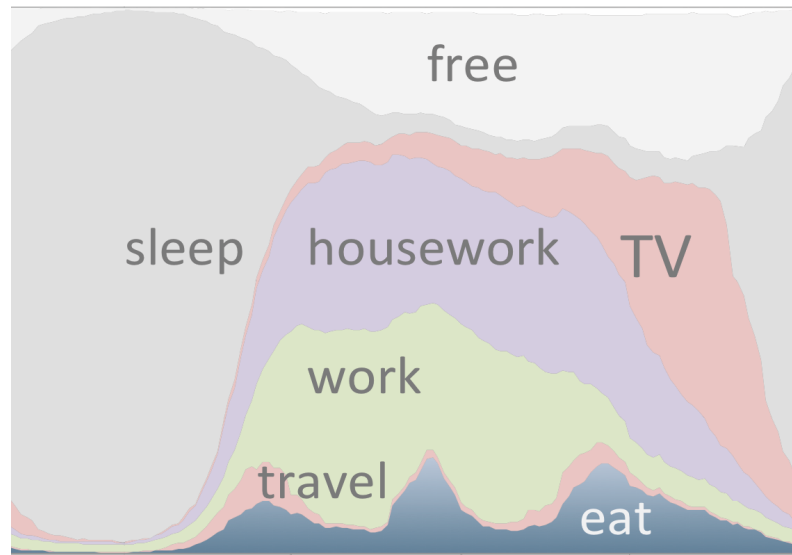


Daily load profiles: UK Household Electricity Survey

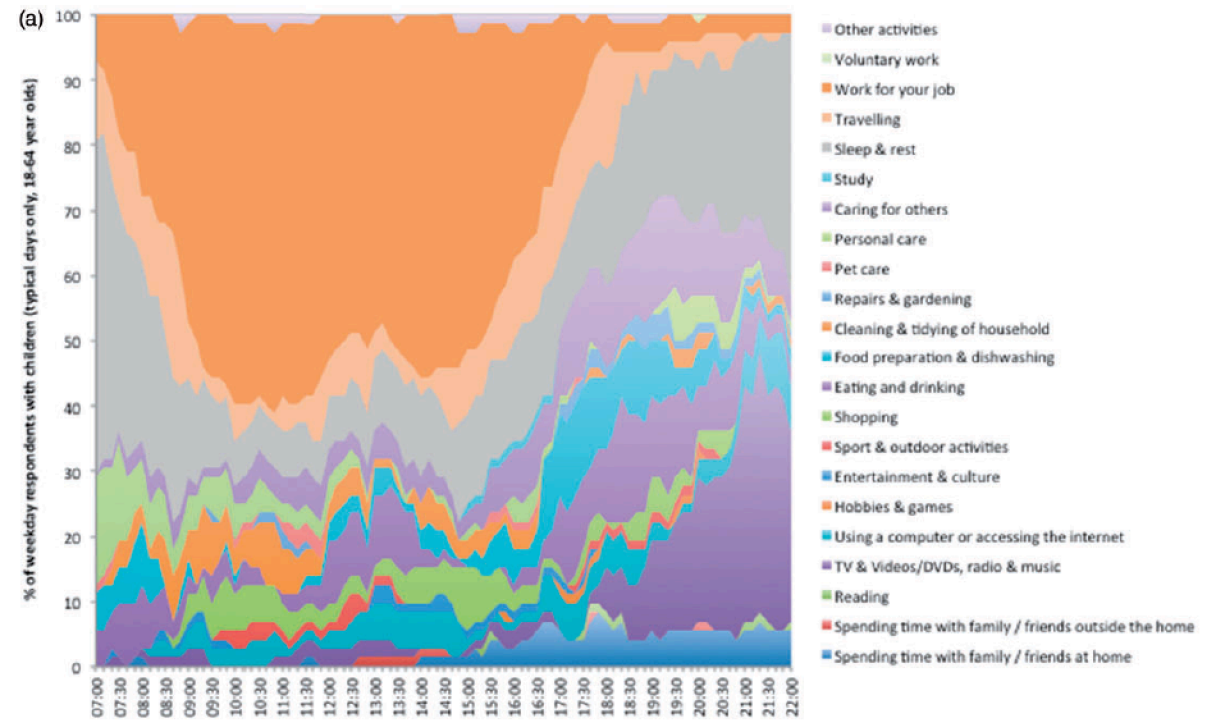


(DECC, 2014, Palmer et al. 2013)

Time-use data in residential electricity models

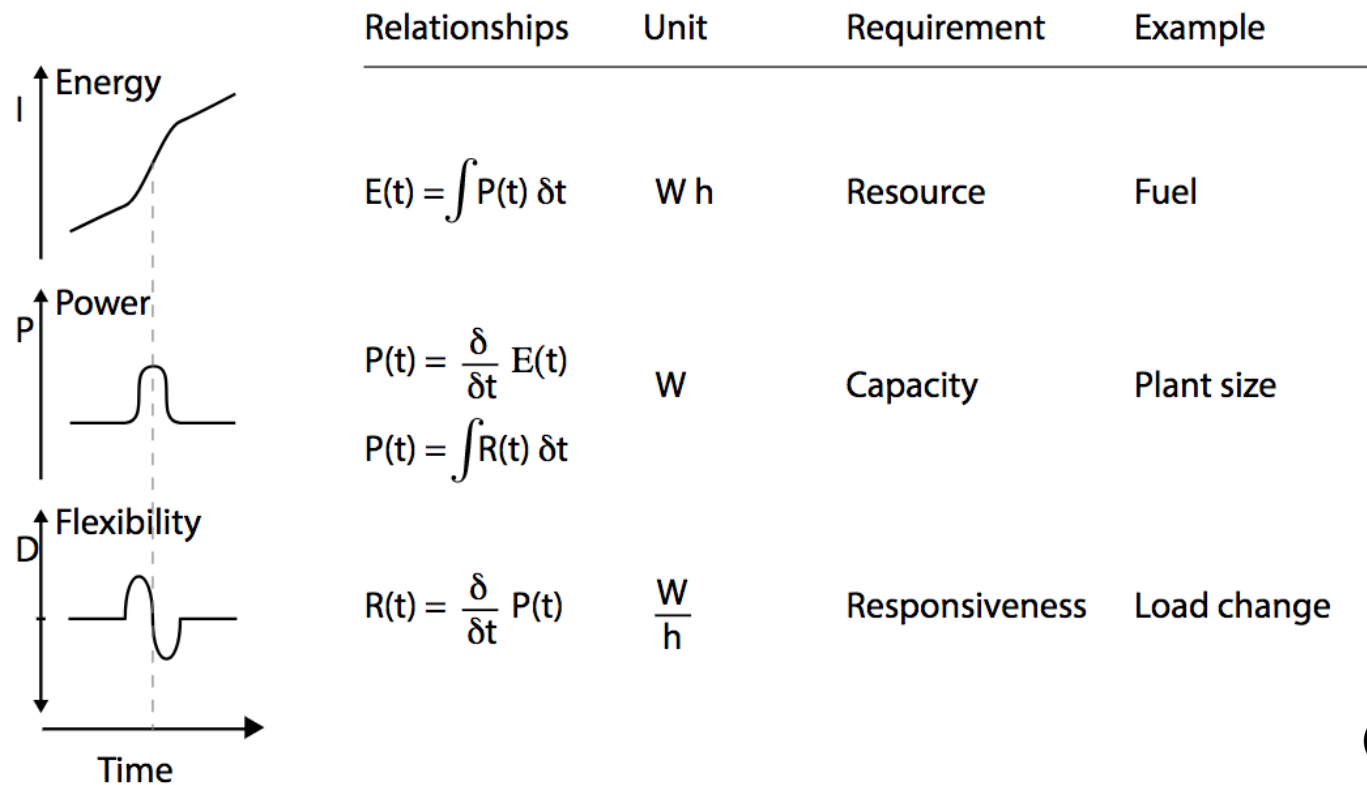


(Lader, Short, and Gershuny, 2006)



(Torriti et al., 2015)

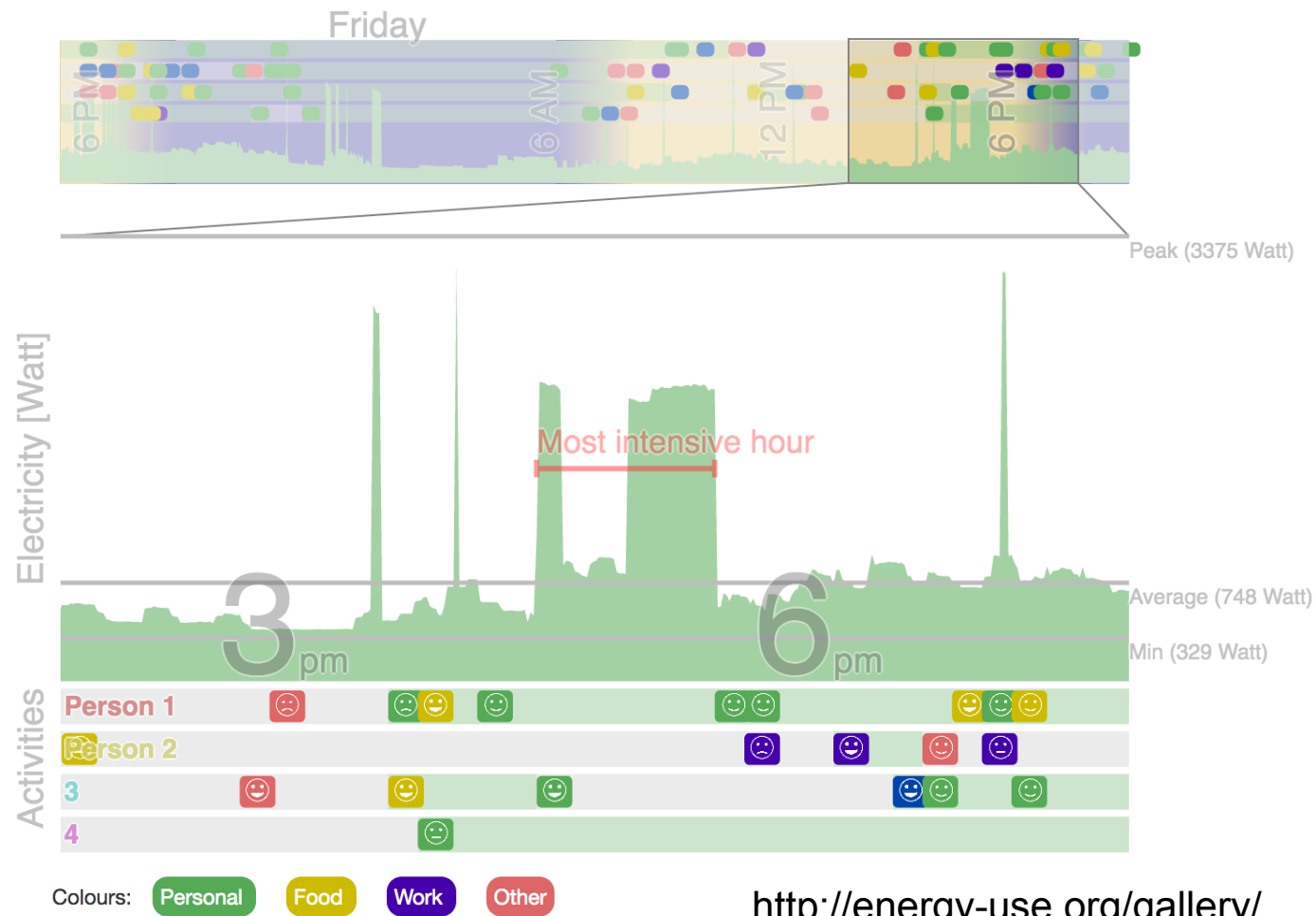
Energy, power, and flexibility



(Grünewald, 2016)

Figure 1: Energy, Power, Flexibility - a relationship of derivatives



Sample household electricity profile



Household survey variables

Table 1. Select socio-demographic, physical dwelling, and appliance characteristics of sample.

Description	Response
Home type	Flat/apartment Detached Semi-detached Terraced and other
Tenure	Rent Own
No. of rooms	2 or fewer 3-5 6 or more
Household income	<£15,000 <£25,000 <£35,000 <£50,000 >£50,000
No. of occupants	1-2 3-4 >4
Age	Under 18 19-50 Over 50
Monthly electric bill	<£400 <£700 >£700
Large appliances	Washing machine Tumble dryer Washer dryer Underfloor heating Gas boiler Heat pump Electric stovetop Electric vehicle Electricity display PV panels Solar thermal
Other appliances (count)	TV/computer screens Dehumidifiers Air conditioners Portable heaters Night storage heaters Power showers

Your home

What type of house do you live in?

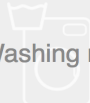

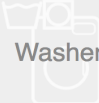
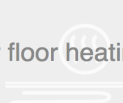
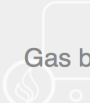
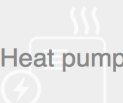
Flat apartment	Detached house
Semi-detached house	Terraced house
Bungalow house	Other <input type="text" value="Please specify"/>

◀ Back
Next ▶

24%

Your appliances

Which of these do you have?
Click anything you have in the house.

 Washing machine	 Tumble dryer
 Washer dryer	 Under floor heating
 Gas boiler	 Heat pump

◀ Back
Next ▶

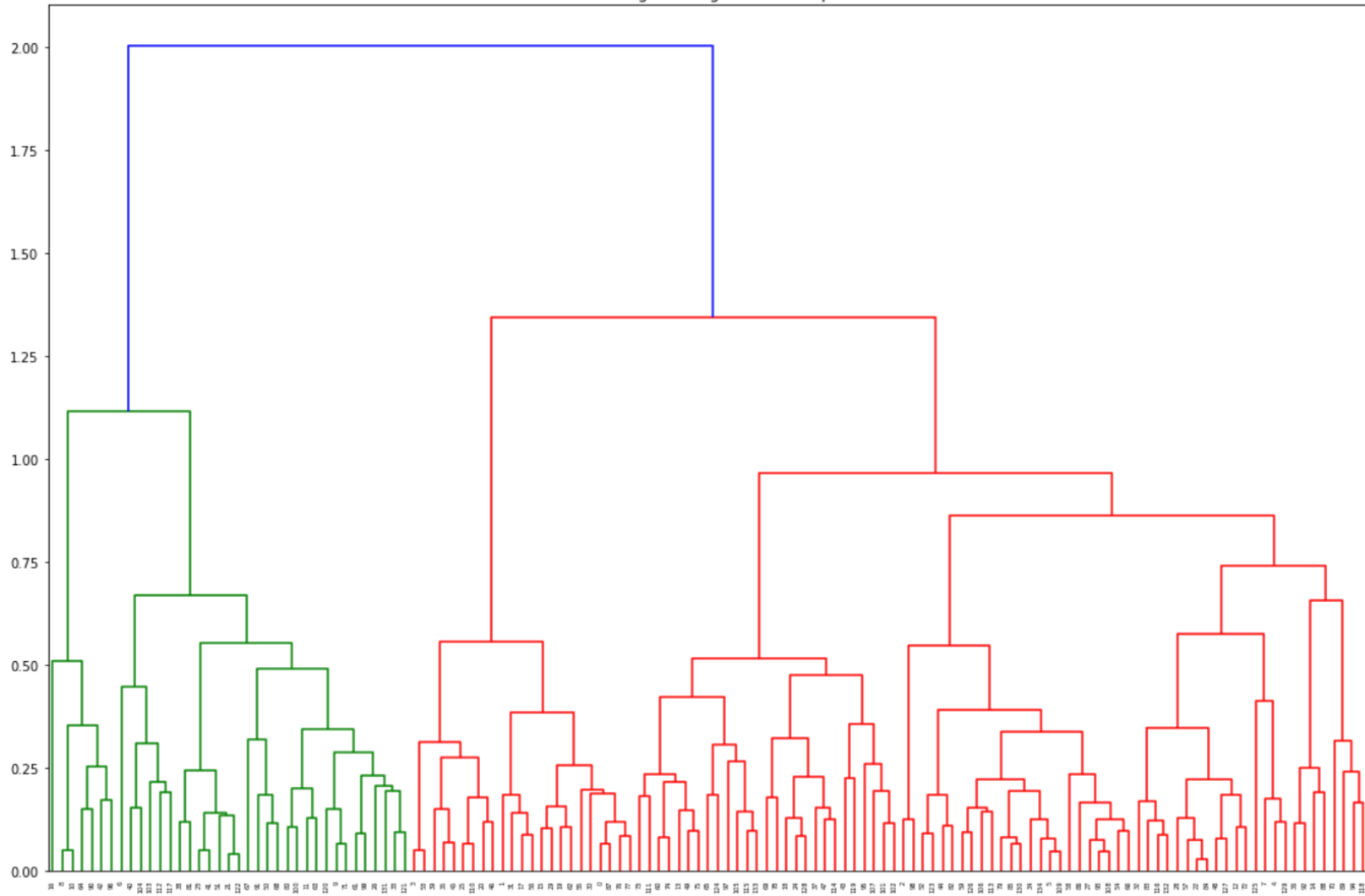
47% Complete

National figures are based on estimates from Office for National Statistics. *Source:* [ONS \(2016, 2017, 2018a, 2018b\)](#); [DECC \(2013\)](#).

Cluster analysis of peak period electricity load profiles

Clustering approach	Data pre-processing	Data normalisation	Clustering distance measure	Clustering algorithm	Cluster validation index
Whole time series	Select peak hours (i.e. 4-9pm) and downsample to hourly average	1) De-min (subtract baseload) 2) Normalize by maximum value after de-minning 3) Take integral	Exploratory analysis of Euclidean variants and others; final analysis uses Euclidean distance	Hierarchical agglomerative clustering (HAC) with complete linkage criterion	Silhouette index (measures both intra-cluster compactness and between-cluster distinctness)

Hierarchical Clustering Dendrogram for 'Complete Euclidean'



Exploratory analysis of household survey data

Cluster 1: 'Early peak' (4pm)

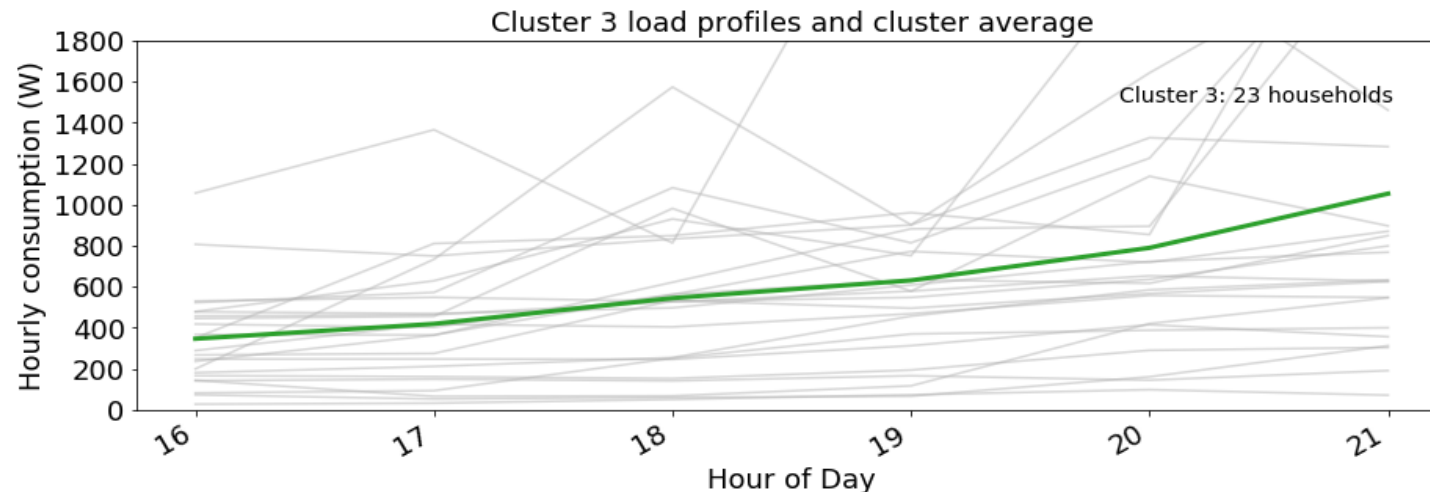
- 37 households
- 4pm peak (1200W) and highest 5pm demand
- Primarily terraced/other house type, with highest number of young (under 18) and old (over 50) occupants
- Highest washing machine/tumble dryer ownership & TV/computers

Cluster 2: 'Mid peak' (7pm)

- 75 households
- 7pm peak (1000W) but moderately high 5pm demand
- Primarily detached/semi-detached house type, larger dwellings, higher-income homes, mostly 1-2 occupants
- Highest ownership of portable heaters/electric hobs

Cluster 3: 'Late peak' (9pm)

- 23 households
- 9pm peak (1200W) and lowest 5pm demand
- Highest frequency of flats/apartments, renters, small dwellings; lowest frequency of occupants over 50
- Lowest frequency of TV/computers & washing machines



Current research: predicting cluster membership using activity data

Pre-process data

- Remove poor quality data
- Select sampling method

Normalise data

- Determine what to cluster on (i.e. total usage, discretionary usage, etc)

Exploratory cluster analysis

- Compare different distance methods and clustering algorithms

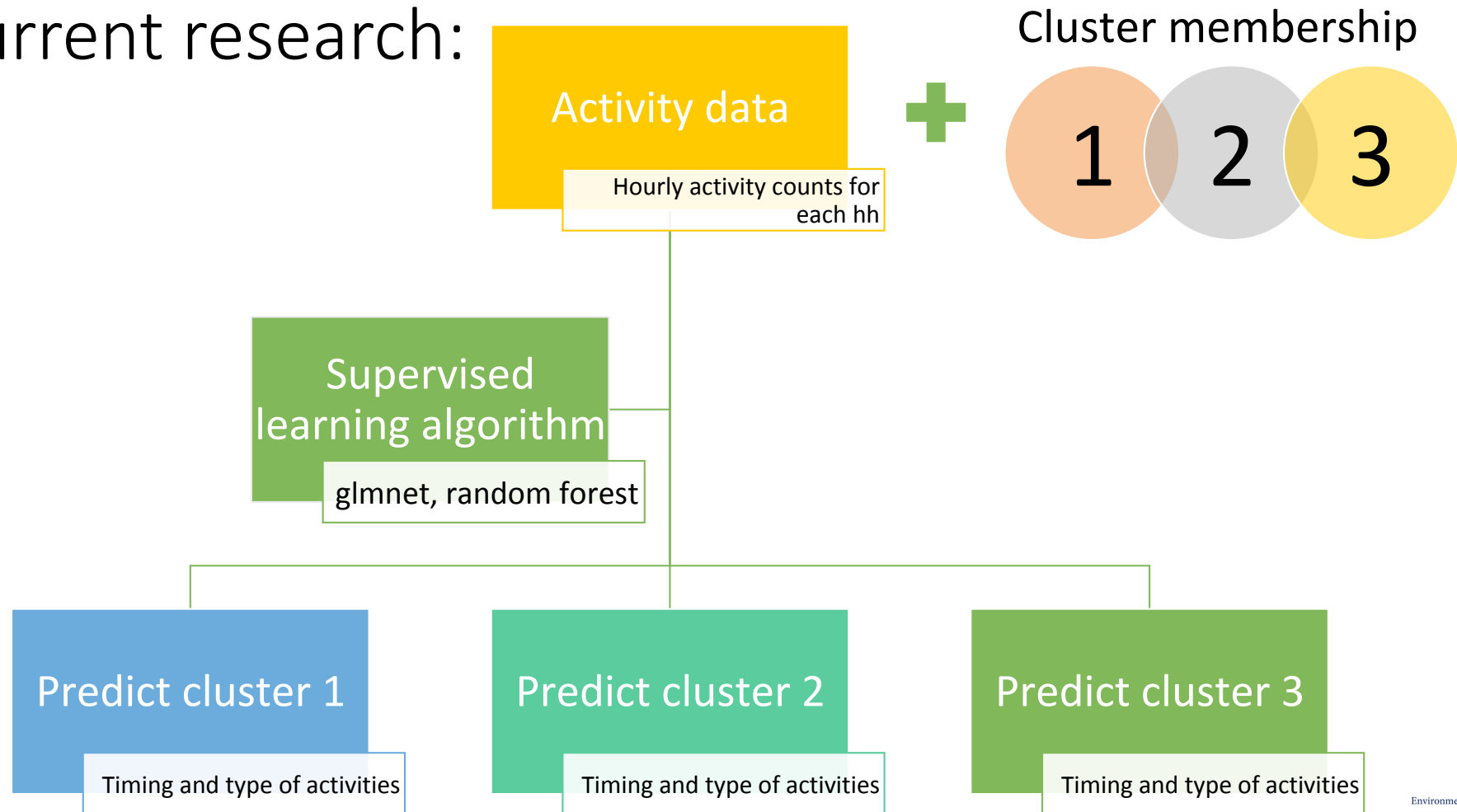
Evaluate clusters

- Validation index to determine cluster "distinctness" and "compactness" scores
- Determine optimal number of clusters

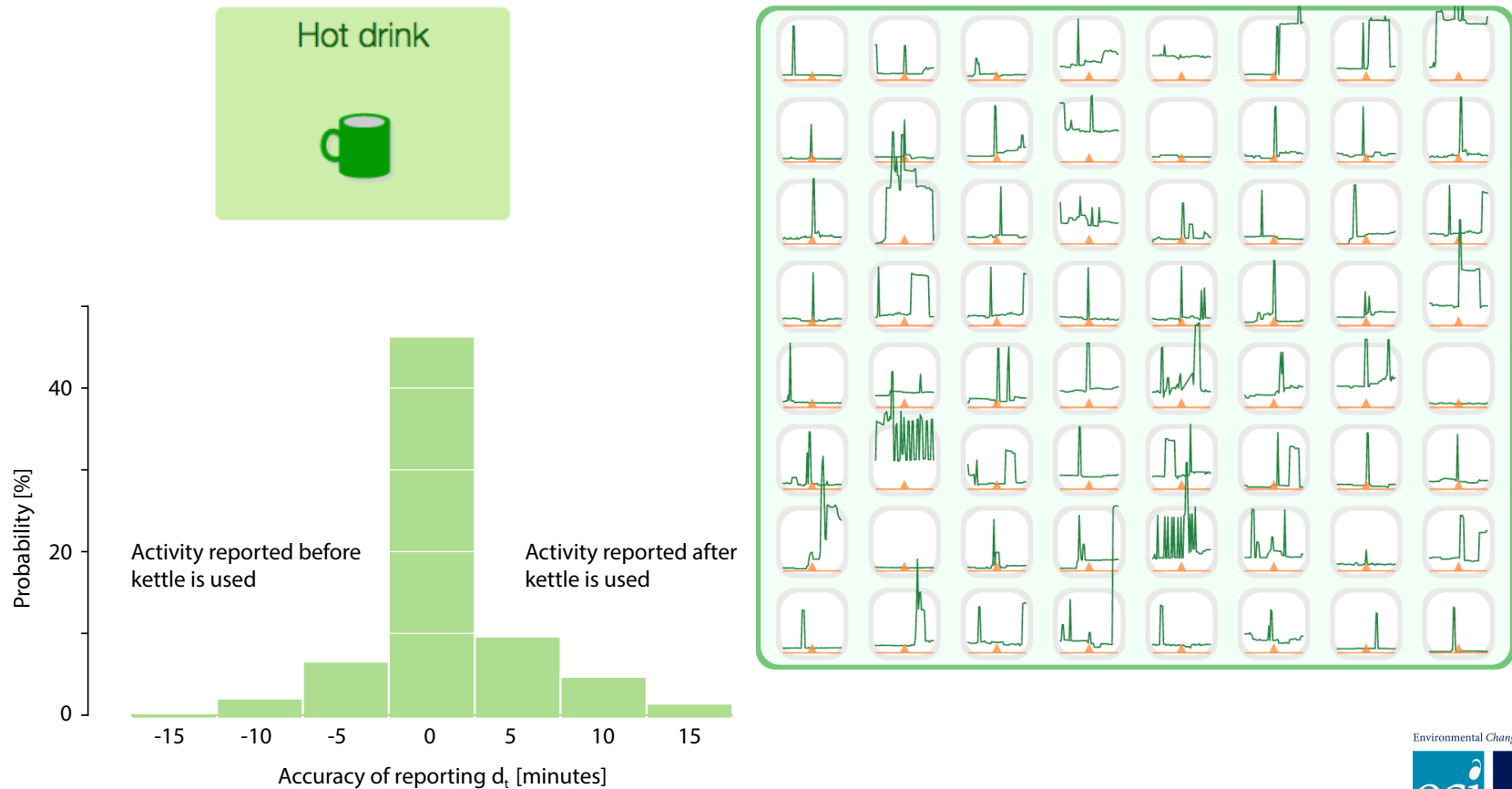
Predictive modelling using supervised learning

- Model likelihood of being in certain cluster using activity patterns

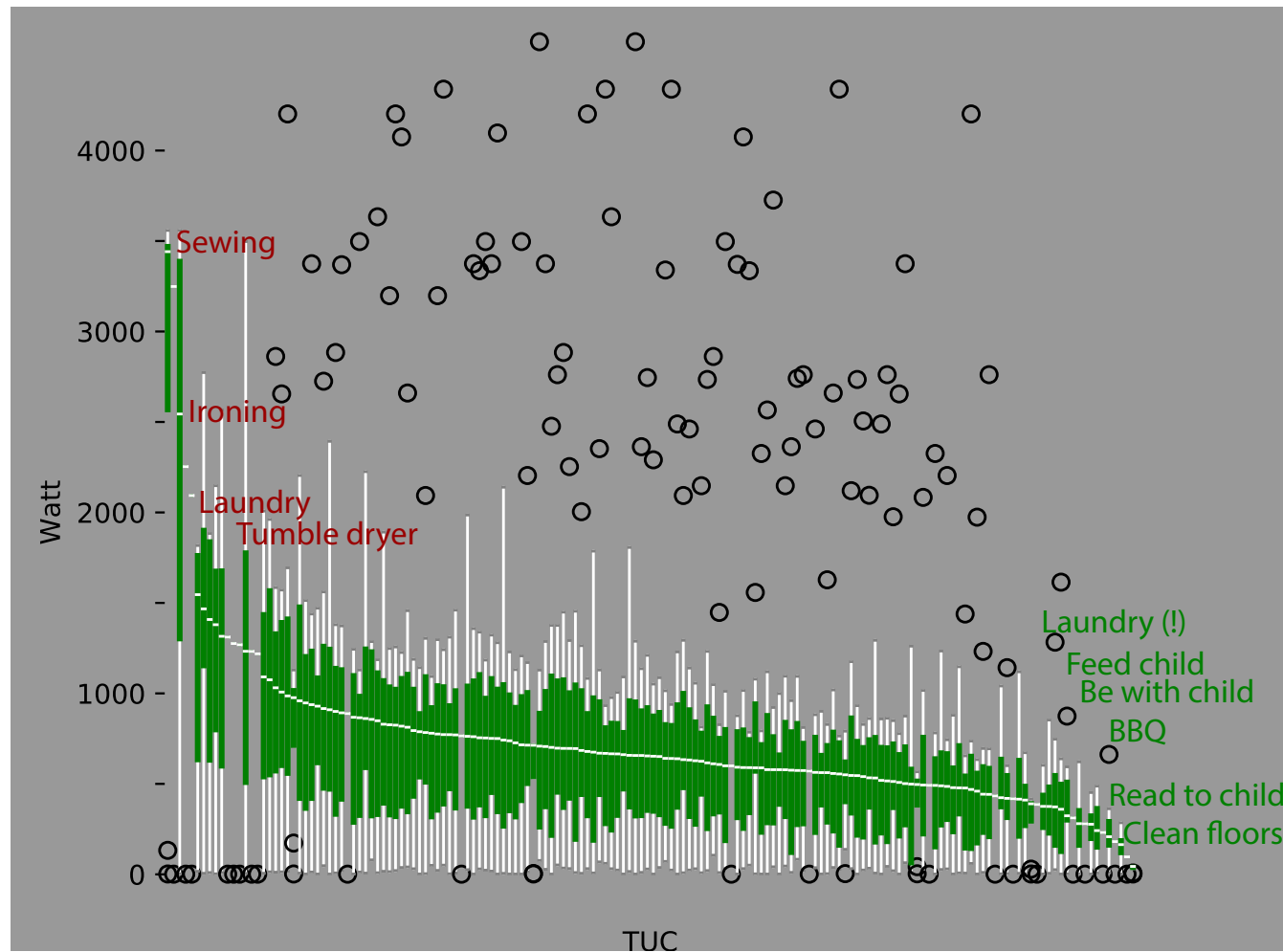
Current research:



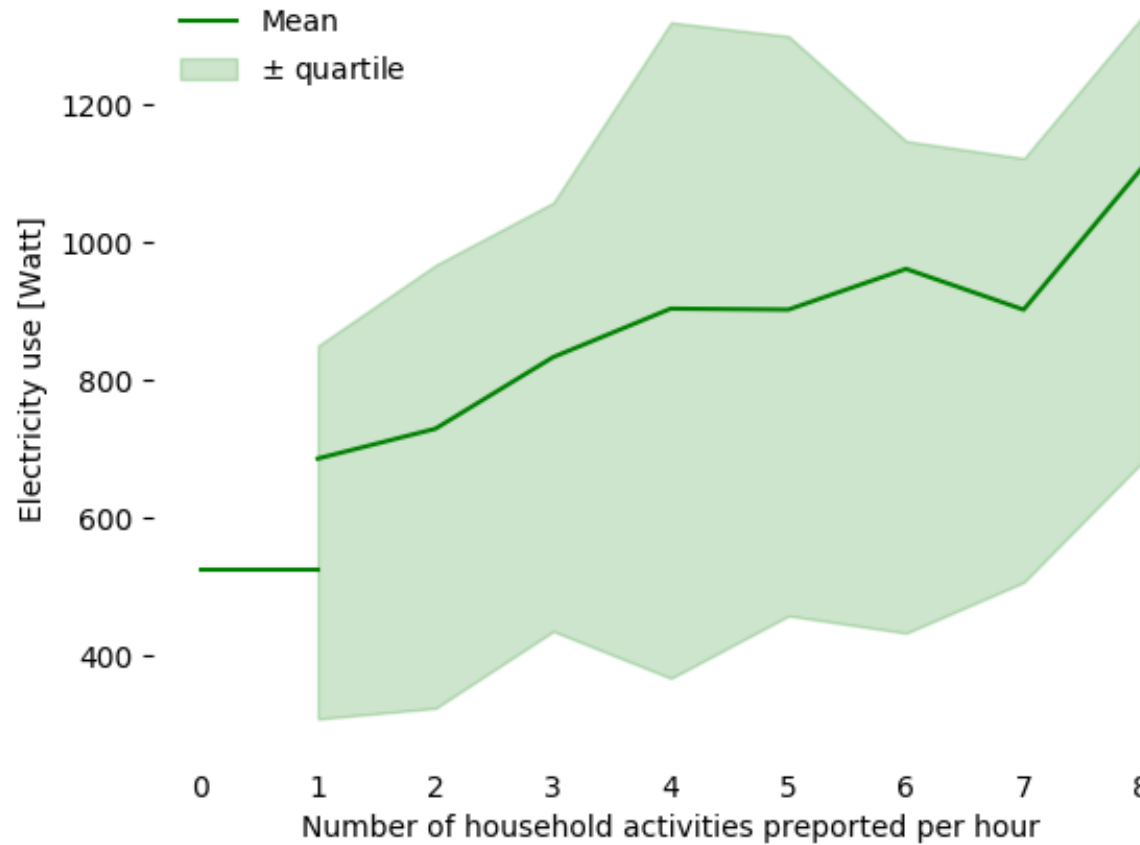
Validating activity-electricity signatures



Power footprint of activities

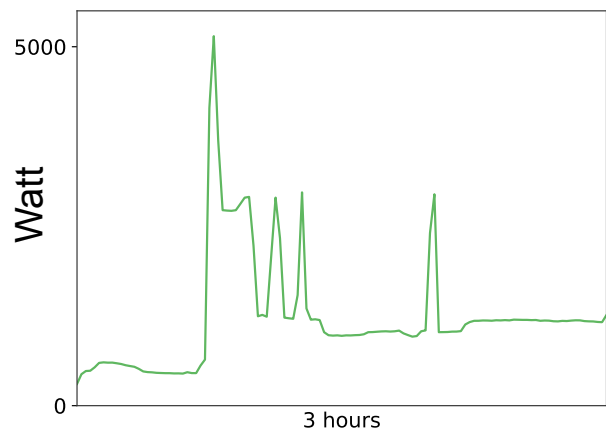
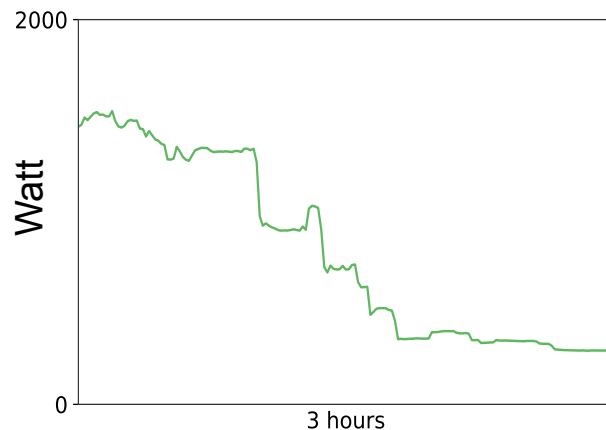


Link between activity reporting and electricity consumption

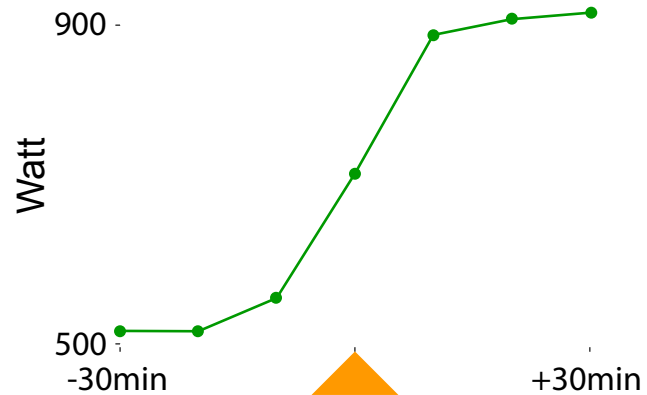
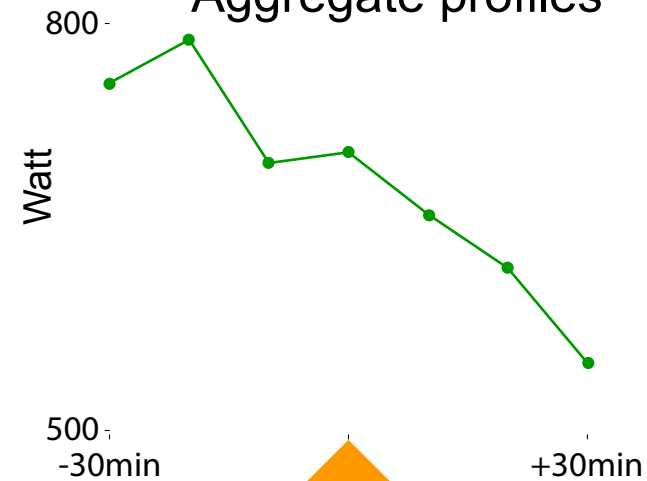


Aggregating electricity profiles for various activities

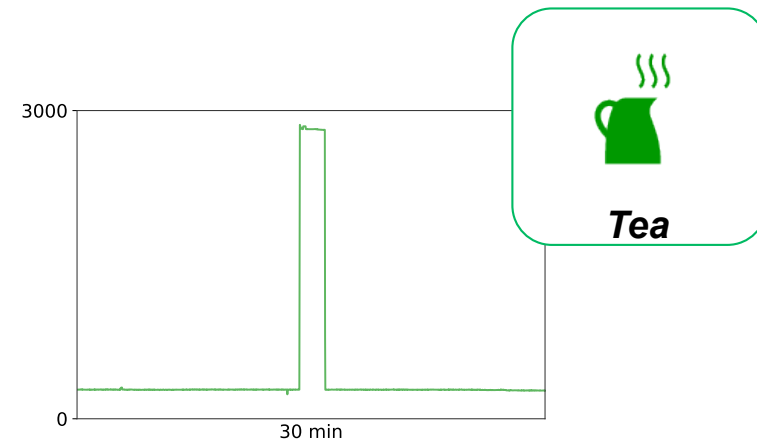
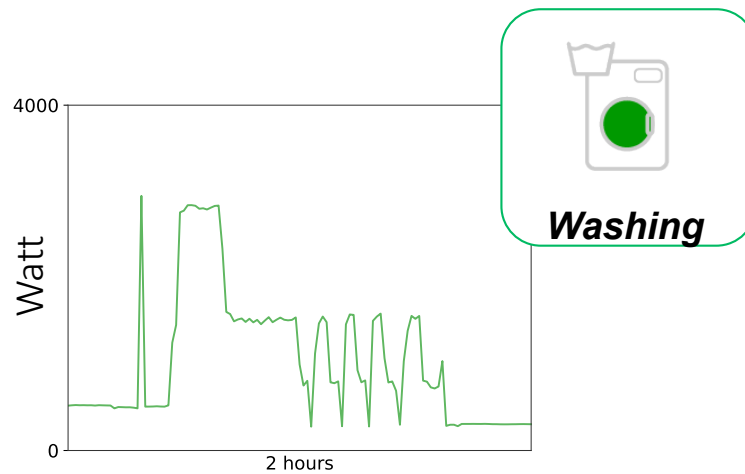
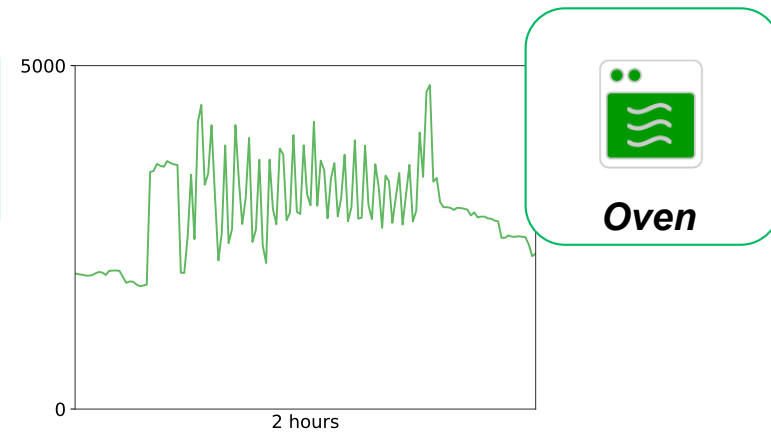
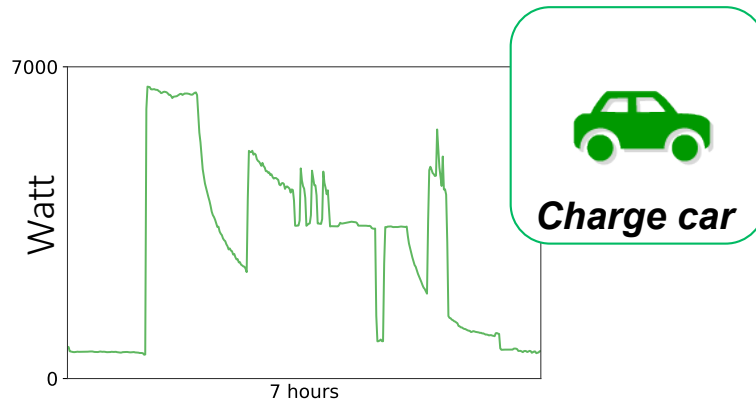
Individual profiles



Aggregate profiles



Let's test your load profile knowledge



OFF THE GRID Fears of huge power surge during England's World Cup game as millions watch crunch match

England are aiming to reach a first quarter final since 2006 but such a huge TV audience poses a potential power crisis for the National Grid

By Thomas Burrows

3rd July 2018, 9:35 am | Updated: 3rd July 2018, 12:16 pm



COMMENT
NOW

THE demand of electricity is expected to soar across the country tonight when England fans flick the switches on their kettles or open their fridge doors to fetch a beer at half-time.