# Unravelling load patterns of residential end-uses from smart meter data

eceee 2015, Presqu'ile de Giens, 3 June 2015

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# Motivation

**Understanding hourly electricity load patterns is essential**

- For power system management and capacity planning

**End-use specific load profiles can shed light on hourly electricity consumption**

- To understand electricity consumer behaviour
- To avoid system load peaks
- To estimate load management potentials

**How to generate appliance specific hourly load profiles?**

- Direct metering of a large number of individual end-uses is costly
- Consumers may oppose to end-use records due to data protection concerns

**But: Smart-meter roll-out will generate massive amount of household load records.**

⇨ **We aim to demonstrate how these records can be transformed into load profiles.**

# Methodology I

**Conditional demand analysis (CDA)**

- To transform household-level metered load data into end-use specific load profiles
- Demand per time interval is regressed on a set of explanatory variables
- Information for the explanatory variables is typically collected via survey
- Parameter estimates represent the actual load profiles of the different end-uses

**State of research**

- Most existing studies focus on the US, rely on a low sample size or observation period
- None of the existing studies generate sub-hourly end-use load profiles

**Data basis for the CDA applied in this study**

- Half-hourly smart meter load data from a representative sample of 4,200 Irish households
- Recorded between July 2009 and December 2010 (17 months) by the Irish regulator CER
- Plus: household survey on socio-economic characteristics, appliance stock and building

# Methodology II

**Set-up of the CDA**

- OLS regression for 48 half hours of nine typical days (432 regressions)
- 40 explanatory variables, considering non-linear effects (e.g. for TVs or nb. of adults)
- Natural logarithm for dependent variable

**Generation of load profiles**

- Parameter estimates of the end-uses are transformed from logarithmic to linear
- Insignificant coefficients are set to zero
- The 48 coefficients equal the load profile

**Application to Irish electricity demand**

- Partial decomposition of Irish system load

**Dependent variable**

✓ Mean half-hourly electric load

**Explanatory variables**

✓ Number of adults and children
✓ Electricity saving efforts
✓ Building type and age
✓ Building insulation
✓ Heating system
✓ Share of energy saving bulbs
✓ Equipment with white appliances
✓ Equipment with consumer electronics

# Results I
# Econometric analysis

**Excerpt of regression results for the typical winter weekday**

| | | 1 (12.00 to 12.30 am) | 9 (4.00 to 4.30 am) | 17(8.00 to 8.30 am) | 25 (12.00 to 12.30 pm) | 33 (4.00 to 4.30 pm) | 41 (8.00 to 8.30 pm) |
|---|---|---|---|---|---|---|---|
| white goods | stove | 0.021* | 0.004 | 0.047*** | 0.095*** | 0.137*** | 0.089*** |
| | washing | 0.005 | 0.001 | 0.044 | 0.067 | 0.026 | -0.025 |
| | dryer | 0.051*** | 0.015*** | 0.106*** | 0.138*** | 0.149*** | 0.131*** |
| | dish_washer | 0.1*** | 0.031*** | 0.117*** | 0.033** | 0.06*** | 0.225*** |
| | freezer | 0.043*** | 0.038*** | 0.03* | 0.058*** | 0.074*** | 0.034** |
| | water_pump | 0.029** | 0.029*** | 0.043** | 0.029* | 0.027 | 0.047** |

Note: *** indicates significance at p<0.01, ** indicates significance at p<0.05 and * indicates significance at p<0.1 in an individual two-tailed t-test based on robust standard errors

**General**

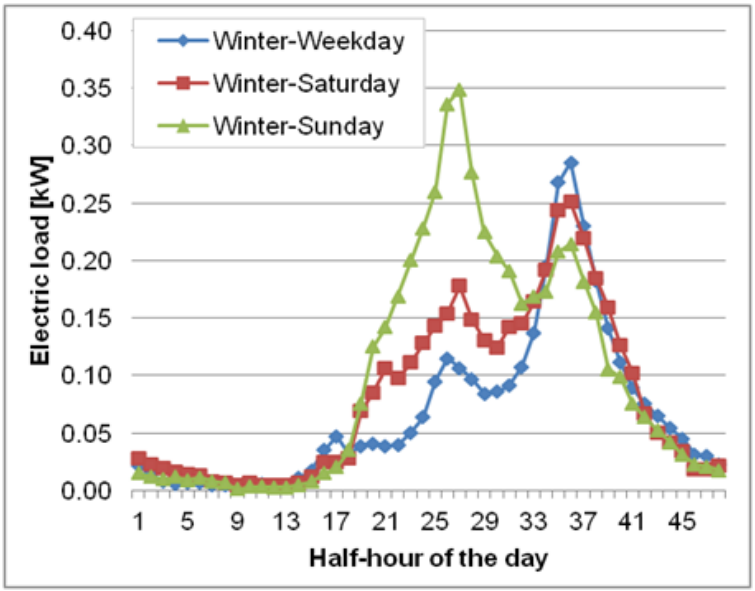
- Coefficient of determination for the 432 regressions varies between 25% and 50%

**Results on electric end-uses**

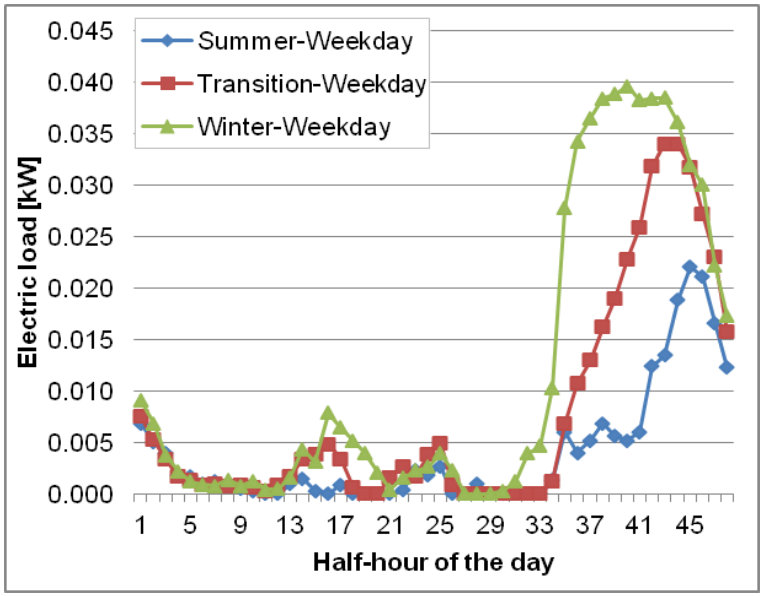
- Dish washers, dryers, freezers and ICT: significant during nearly all half-hours
- Stove, lighting and TVs: coefficients are statistically significant in day/evening/night times
- Washing machines: not statistically significant due to lack in heterogeneity
- Laptops: significantly higher use during evening and night, compared to day time

# Results II
# Generation of load profiles

**Electric stove**




**Lighting**

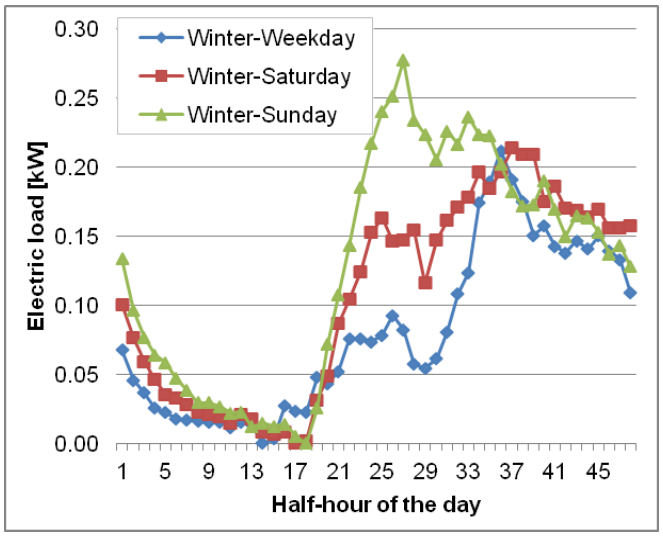



**Load profiles are generated for:**

- Electric stove
- Dishwasher
- Dryer
- Lighting (based on energy saving bulbs)
- TV (for two and more TVs, ≥21“)
- Freezer (stand-alone)
- Heating (night-storage)

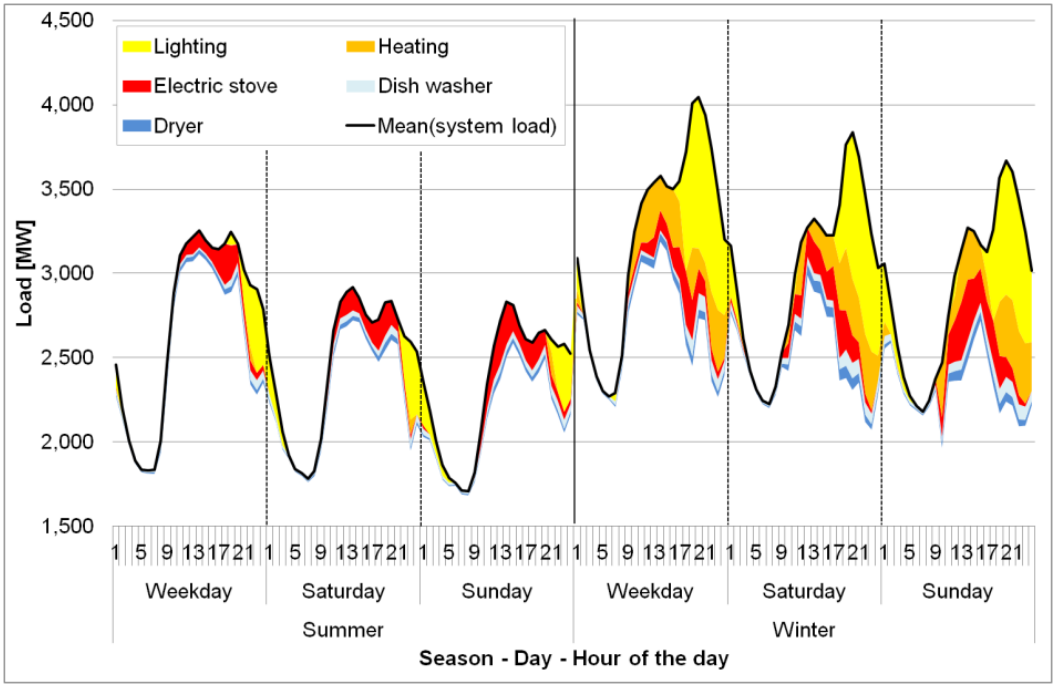
# Results II
# Generation of load profiles

**Load profile for two TVs (≥21")**




**How to explain the peak at 1:30 pm on a Sunday?**

# Results III
# Application of profiles to 2011 Irish demand




**Partial decomposition of 2011 Irish system load**

- On winter Sundays at 10pm, lighting accounts for up to 0.9 GW or 24% of the Irish load
- Electric heating and stoves make up for up to 10% of the overall winter load
- Load of dryers and dishwashers never exceeds 3% of the overall system load

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# Discussion and conclusion

**Content-wise**

- The generated load profiles allow **understanding up to 40%** of the Irish system load
- The winter evening **load peak** is primarily driven by **lighting and electric heating**, the lower midday load peak is related to electric stoves
- **Energy efficiency** should be the first choice: reducing lighting demand by 33% could make the **peak load drop** by 8%, reducing the need for back-up capacity
- **Load shifting** should focus on electric heating (rather than on white goods)

**Methodology-wise**

- CDA works particularly well for **electricity-intensive** end-uses, for lighting and for end-uses with **well-mixed ownership patterns**
- Approach **stands out** from existing studies by generating **load profile for lighting**
- With increasing availability of **smart meter data**, similar analyses could easily be carried out for **other countries** or regions
- **Future studies** could integrate weather and geographic data and more technical data

# Thank you for your attention!