SOONER OR LATER
Shifting the timing of electricity demand

Professor Jacopo Torriti

15th May 2019
Outline

• Peaks
  • What they are
  • The peak problem
  • Understanding peaks

• Flexibility
  • Individuals
  • Activities
  • Winners and losers
When I tell people I do research on peak electricity demand...
…but it is about this:
THE PEAK PROBLEM
The peak problem

The peak problem

- Peaks in electricity demand bring about significantly negative environmental and economic impacts

- In the future:
  - intermittent renewables in the supply mix
  - electric vehicles and electric heat pumps
UNDERSTANDING PEAKS
Peaks every day

Comparison of the National demand across seasons
Peaks: price and carbon intensity

Source for Carbon intensity:
• Weekday

• Weekend
### Data on what people do

<table>
<thead>
<tr>
<th>Diary/person id</th>
<th>Starting Time</th>
<th>Ending Time</th>
<th>Main activity</th>
<th>Parallel activity</th>
<th>Who with:</th>
<th>Where/mode of transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA23</td>
<td>04:00</td>
<td>07:20</td>
<td>Sleep</td>
<td></td>
<td></td>
<td>At home</td>
</tr>
<tr>
<td>AA23</td>
<td>07:20</td>
<td>07:50</td>
<td>Shower</td>
<td></td>
<td></td>
<td>At home</td>
</tr>
<tr>
<td>AA23</td>
<td>08:30</td>
<td>08:40</td>
<td>Had breakfast</td>
<td>Read newspaper</td>
<td>Ch</td>
<td>At home</td>
</tr>
<tr>
<td>AA23</td>
<td>08:40</td>
<td>09:00</td>
<td>Bus to job</td>
<td></td>
<td></td>
<td>OP By foot</td>
</tr>
</tbody>
</table>

### Belgium

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

Men

Women

Women trigger evening peaks in residential electricity demand
Peaks and children

With Children children

Without

At 5pm, a fifth of those with children is still working

They do everything earlier

At 5pm, a quarter of those without children is still working
Knowing WHEN and WHERE

### Computer use - UK

- **Morning Peak**
  - Minimum: 7.93
  - Maximum: 17.45
- **Evening Peak**
  - Minimum: 82.35
  - Maximum: 181.18

### TV use - Spain

- **Average TV electricity consumption in Spain (MWh)**

<table>
<thead>
<tr>
<th></th>
<th>Morning Peak</th>
<th>Evening Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weekdays</td>
<td>Minimum</td>
<td>7.93</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>17.45</td>
</tr>
<tr>
<td>Weekends</td>
<td>Minimum</td>
<td>17.30</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>38.06</td>
</tr>
</tbody>
</table>
Peaks and greenhouse gas emissions

Higher home occupancy reflects higher greenhouse gas emissions
Peaks and occupancy in different countries
Peaks in Germany and the UK

- Probability of >=1 active person undertaking one of these six activities

- Stronger midday peak in DE, morning peak more pronounced in UK
- Higher evening peak in DE, compared to flatter/broader one in UK
- Strong similarities in evening TV watching habits
Peaks across decades

- Relative decrease in mid-day demand
- Evening peak is later
- This is especially visible in July

Source: National Grid half-hourly demand data (England & Wales) 2006-2016
Peak demand period shown shaded
Activities across decades

- Shift to later eating for all (especially working age)
- Reduced or shifted evening media use (squeezed between later eating and sleep)
- Reduction in morning weekday and Saturday ‘personal/home care’
- Household care tasks have been shifted from weekdays to the evening peak period
...AND THINK
• What is energy demand for?
• Which concepts help explain the dynamics of energy demand?
• Why is there societal synchronisations?
• How can peaks be mitigated with non-energy arrangements?
Individual behaviour

KWh € CO2
Social practices

FLEXIBILITY
Flexibility: a win-win?

- Improving balancing with renewables
- Reducing costs of electricity generation
- Making the most of smart systems and battery storage

£17-£40 bn

£265 m
Time of Use (ToU) tariffs

<table>
<thead>
<tr>
<th></th>
<th>Current Trends</th>
<th>High Renewables</th>
<th>Electrification</th>
<th>Electrification w/Automation [1]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Static TOU</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opt-in</td>
<td>5%</td>
<td>5%</td>
<td>7%</td>
<td>8%</td>
</tr>
<tr>
<td>Opt-out</td>
<td>3%</td>
<td>3%</td>
<td>4%</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>OTOU</strong></td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opt-in</td>
<td>N/A</td>
<td>10% [2]</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

APPROACH 1: Individual behaviour => price elasticity of demand

- Simple web-based choice experiment to elicit preferences for fixed tariffs and two dynamic tariffs (Time of Use and Critical Peak Pricing)
- 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
<table>
<thead>
<tr>
<th>Tariff Type</th>
<th>Fixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>*Price stays the same throughout the day.</td>
</tr>
<tr>
<td>Time of Use (TOU)</td>
<td>*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.</td>
</tr>
<tr>
<td>Critical Peak Pricing (CPP)</td>
<td>*Cost: On 10 weekdays selected by the electric company prices will rise 8% 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 days that day and all other days in the year.</td>
</tr>
<tr>
<td>Environmental and Grid Benefits</td>
<td>*None</td>
</tr>
<tr>
<td>*Less water and air pollution. *Aid the expansion of renewable energy. *Increased electricity reliability. *Slow the rate of electricity price increases.</td>
<td></td>
</tr>
<tr>
<td>Graphic</td>
<td>Fixed Rate ($/kilo-watt-hour) Fixed vs. TOU ($/kilo-watt-hour) Fixed vs. CPP ($/kilo-watt-hour)</td>
</tr>
<tr>
<td>Required Behavior Change to get Savings</td>
<td>*None - it's your current plan.</td>
</tr>
<tr>
<td>Sustained, moderate changes during daily high priced times: *All regions: Shift all listed appliances. *US: 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.</td>
<td></td>
</tr>
<tr>
<td>One-off, significant changes during 10 days' high priced times: *All regions: Shift all listed appliances. *US: 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 3F (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%.</td>
<td></td>
</tr>
<tr>
<td>Potential Bill Increase with No Behavior Change</td>
<td>0%</td>
</tr>
<tr>
<td>0% to 5%</td>
<td>$0 to $5.00 per month</td>
</tr>
<tr>
<td>0% to 5%</td>
<td>$0 to $5.00 per month</td>
</tr>
<tr>
<td>Potential Bill Savings with Behavior Change</td>
<td>0%</td>
</tr>
<tr>
<td>10%</td>
<td>Approximately $10.00 per month</td>
</tr>
<tr>
<td>5%</td>
<td>Approximately $5.00 per month</td>
</tr>
<tr>
<td>Please Select One</td>
<td>Choice 1</td>
</tr>
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</table>
Discount needed for shifting electricity demand

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>MWTA(^a)</th>
<th>Std. Error(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DISCOUNT</td>
<td>0.163***</td>
<td>0.020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOU(^c)</td>
<td>-1.993**</td>
<td>0.830</td>
<td>12.22%</td>
<td>4.91%</td>
</tr>
<tr>
<td>E&amp;SxTOU</td>
<td>1.599***</td>
<td>0.622</td>
<td>-9.81%</td>
<td>3.87%</td>
</tr>
<tr>
<td>MALEXTOU</td>
<td>-1.779***</td>
<td>0.627</td>
<td>10.91%</td>
<td>3.91%</td>
</tr>
<tr>
<td>HIBILLxTOU</td>
<td>1.255**</td>
<td>0.619</td>
<td>-7.70%</td>
<td>3.82%</td>
</tr>
<tr>
<td>STUDENTxTOU</td>
<td>-0.056</td>
<td>0.629</td>
<td>0.34%</td>
<td>3.86%</td>
</tr>
<tr>
<td>EASYxTOU</td>
<td>2.848***</td>
<td>0.657</td>
<td>-17.47%</td>
<td>4.19%</td>
</tr>
<tr>
<td>CPP(^c)</td>
<td>-3.009***</td>
<td>1.039</td>
<td>18.45%</td>
<td>6.20%</td>
</tr>
<tr>
<td>E&amp;SxCPP</td>
<td>2.086***</td>
<td>0.788</td>
<td>-12.80%</td>
<td>4.87%</td>
</tr>
<tr>
<td>MALEXCPP</td>
<td>-1.437*</td>
<td>0.790</td>
<td>8.81%</td>
<td>4.88%</td>
</tr>
<tr>
<td>HIBILLxCPP</td>
<td>-0.390</td>
<td>0.793</td>
<td>2.39%</td>
<td>4.86%</td>
</tr>
<tr>
<td>STUDENTxCPP</td>
<td>-1.728**</td>
<td>0.804</td>
<td>10.60%</td>
<td>4.97%</td>
</tr>
<tr>
<td>EASYxCPP</td>
<td>1.981**</td>
<td>0.802</td>
<td>-12.15%</td>
<td>5.01%</td>
</tr>
</tbody>
</table>

Standard Deviations of Random Coeffs.

<table>
<thead>
<tr>
<th></th>
<th>Std. Error</th>
<th>Df</th>
<th>Replications</th>
<th>Observations</th>
<th>Log likelihood</th>
<th>LR $\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOU</td>
<td>2.776***</td>
<td>0.381</td>
<td>13</td>
<td>1000</td>
<td>1920</td>
<td>438.380</td>
</tr>
<tr>
<td>CPP</td>
<td>3.365***</td>
<td>0.535</td>
<td>13</td>
<td>1000</td>
<td>1920</td>
<td>SDs (2) 205.56***</td>
</tr>
</tbody>
</table>
APPROACH 2: Activities as the unit of analysis

- Clustering based on what people do at peak time

- Imposing Time of Use tariffs on different:
  - Socio-demographic groups
  - Clusters

- Automation and everyday life
Comparison peak and off-peak activities: income

Comparison peak and off-peak activities: household composition
Peak to off-peak ratio: Income

**Cooking on a weekday**

- Low and high categories are plotted over time from 02:00 to 00:00.

**Active occupancy on a weekday**

- The graph shows the percentage of active occupancy from 04:00 to 22:00.

**Watching TV on weekday**

- The chart displays the percentage of time spent watching TV from 02:00 to 00:00.
Clustering households by activity

Mean and median for cluster 0 with size: 4166

Family Type (%)

- Single
- M/C w/children
- M/C w/o children
- Sp. w/children
- Sp. w/o children
- M/C in complex
- SP in complex
- Other

Employment (%)

- Empl.
- Self-Emp.
- Retired
- Study
- Unempl.

Monthly Income (£k)

- Residents
- Children
- Rooms
- Age
- Home

<table>
<thead>
<tr>
<th>Home Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>House</td>
<td>84%</td>
</tr>
<tr>
<td>Flat</td>
<td>16%</td>
</tr>
<tr>
<td>Flat</td>
<td>&lt;1%</td>
</tr>
</tbody>
</table>
Peak to off-peak ratio

Comparison of peak-time and non-peak time activities for parameter: cluster

Product of probabilities: cooling, laundry and ironing

Ratio of peak-time to non-peak time
<table>
<thead>
<tr>
<th>Income £k</th>
<th>Age Median</th>
<th>Residents</th>
<th>Rooms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Comparison of peak-time and non-peak time activities for parameter: Close

- **Close:**
  - Residents: 10, 12, 14, 16, 18
  - Rooms: 0, 2, 4, 6, 8

### Comparison of peak-time and non-peak time activities for parameter: Single

- **Single:**
  - Residents: 0, 1, 2, 3, 4
  - Rooms: 6, 8, 10, 12, 14

### Comparison of peak-time and non-peak time activities for parameter: MC w/ children

- **MC w/ children:**
  - Residents: 5, 7, 9, 11, 13
  - Rooms: 15, 17, 19, 21, 23

### Comparison of peak-time and non-peak time activities for parameter: SP w/ children

- **SP w/ children:**
  - Residents: 15, 17, 19, 21, 23
  - Rooms: 25, 27, 29, 31, 33

### Comparison of peak-time and non-peak time activities for parameter: MC in computer lab

- **MC in computer lab:**
  - Residents: 21, 23, 25, 27, 29
  - Rooms: 31, 33, 35, 37, 39

### Comparison of peak-time and non-peak time activities for parameter: SP in computer lab

- **SP in computer lab:**
  - Residents: 27, 29, 31, 33, 35
  - Rooms: 37, 39, 41, 43, 45

### Comparison of peak-time and non-peak time activities for parameter: Other

- **Other:**
  - Residents: 33, 35, 37, 39, 41
  - Rooms: 43, 45, 47, 49, 51

### Project of probabilities costs laundry & food

- Costs: 3, 5, 7, 9, 11
  - Laundry: 13, 15, 17, 19, 21
  - Food: 23, 25, 27, 29, 31
From time use data to load profiles

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

Cluster: 01
Cluster: 02
Cluster: 03
Cluster: 04
Cluster: 05
Cluster: 06
Cluster: 07
Cluster: 08
Cluster: 09
Cluster: 10
Cluster: 11
Cluster: 12
Cluster: 13
Cluster: 14
Cluster: 15
Cluster: 16
Cluster: 17
Cluster: 18
Cluster: 19
Cluster: 20
Applying Time of Use tariffs

CSE - Centre for Sustainable Energy. 2014. “Investigating the Potential Impacts of Time of Use (ToU) Tariffs on Domestic Electricity Customers: Smarter Markets Programme.”

Impact of Time of Use tariffs

Residual mean of the bill reductions

%
Impact of Time of Use tariffs

Residual mean of the bill reduction

Cluster

%

CSE-ToU-3
CSE-ToU-2
CSE-ToU-1
Brattle-sToU

Winners
Losers
Power to the (flexible) people? What happens to those who do not have the time and means for demand-side flexibility?

Time and non-energy arrangements

The single mother nurse
- Protecting her from flexibility costs?
- Excluding her from flexibility opportunities?
References


• Torriti, J. (2017), Understanding the timing of energy demand through time use data: Time of the day dependence of social practices. Energy Research & Social Science, 25, 37-47.

THANKS