Putting the ‘Smarts’ in the Smart Grid

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The energy status quo is challenged by three impending factors

- **Finite resources**
  - Demand outstrips production capacity

- **Energy security**
  - Resources are not evenly distributed

- **Climate change**
  - Increasing atmospheric CO2 concentration
Addressing these issues requires changes in the way we use energy

• Treat it as a scarce and valuable commodity
  – Understand usage options and their implications

• Increase efficiency through electrification
  – Transport
  – Heating

• Use more low carbon sources
  – Wind
  – Solar
The Smart Grid represents a modern vision of a dynamic electricity grid

A fully automated power delivery network that monitors and controls every customer and node, ensuring a two-way flow of electricity and information between the power plant and the appliance, and all points in between. Its distributed intelligence, coupled with broad-band communications and automated control systems, enables real-time market transactions and seamless interfaces among people, buildings, industrial plants, generation facilities, and the electric network.

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Our ongoing work using smart technologies

- Personalised Tariff Recommendations
- Smart Heating Control
- Vehicle to Grid
- Virtual Power Plants
Our ongoing work using smart technologies

Personalised Tariff Recommendations

Smart Heating Control

Electric Vehicles

Virtual Power Plants
Tariff selection is complex and uninteresting

In UK, “there are more than 120 different tariffs. Currently, 7 out of 10 people aren’t on the best tariff for them”

Nick Clegg, April 2012
Comparison Websites

• How much will you consume? Peak or off peak?
• How do I make the best of a tariff?
• Who is using my data?
• How is the electricity supplied?

In year ending March 2013, only 16% of households switched supplier. Despite potential savings of £100-£150 pa.

Ed Davey, Secretary of State for Energy and Climate Change
AgentSwitch

(Fischer et al., 2013)

• Predict consumption
• Find best tariff
• Personalise recommendations
• User understanding
Predicting Energy Consumption
Smart Meter Infrastructure

- Hourly data from ~50 homes in Nottingham & Southampton
  - Use AlertMe monitors
- Develop prediction techniques to estimate annual consumption:
  - Bayesian Quadrature
  - Quasi-Periodic covariance suitable for household power consumption data
Predicting Energy Consumption
Minimal Infrastructure

(Rogers et al., 2012)

• Sense temperature at thermostat
  • Infer heating operation and thermal performance of the home
  • Calculate impact of interventions
    • Savings from reducing thermostat setting

• Low cost easy to use temperature sensor
  • Returned after trial
  • Very low marginal cost (£2 postage)
Predicting Energy Consumption
Minimal Infrastructure

(Rogers et al., 2012)

• 650 users since December 2012
  • Average saving per user 10-20%
    • £100-200 per year
  • Identified two faulty thermostats
    • Setting 20C but getting 23C

• Completed additional data collection for DECC smart heating control trial

• Discussing follow on with energy advice charities
  • Centre for Sustainability Energy & Global Action Plan
Find the Best Tariff

**Your cheapest tariffs** Why?

Based on our calculations we estimate you use 5272kWh during the day per year, and 1375kWh during the night per year. We found these Economy 7 tariffs are available in your area (OX12LN), and ordered them by estimated annual cost for your usage profile.

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Plan</th>
<th>Estimated Annual Cost</th>
<th>Save on this tariff</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFix 201310</td>
<td></td>
<td>Total: £ 753</td>
<td>£ 42 by shifting 20.0% of your day time usage (kWh) to Economy7 times.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>show cost breakdown ↓</td>
</tr>
<tr>
<td>SCOTTISHPOWER</td>
<td>Online Fixed Price Energy March 2014</td>
<td>Total: £ 779</td>
<td>£ 57 by shifting 20.0% of your day time usage (kWh) to Economy7 times.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>show cost breakdown ↓</td>
</tr>
</tbody>
</table>
Personalise Recommendations

What can I do?

Save by shifting loads. Shift the use of your *washing machine*, *dish washer* or *tumble dryer* from day time to night time. We predict that the yearly use of these kinds of appliances (640 kWh) accounts for **10% of your overall electricity consumption**. From your profile, we have detected you typically use those kinds of appliances at least **33 times per month**. How it works

Inspecting the times when you typically use those appliances, we predict their use would cost you at least **£69 per year** on the selected tariff. It appears that **97% of the time** you would use these appliances during the day rate hours of the selected tariff. As a result, you would spend at least **£68 for day time use** and **£1 for night time use** of your washing machine, dish washer, and tumble dryer.

How much could I save by shifting loads?

From your profile, we have calculated how much you could save on the selected tariff.

<table>
<thead>
<tr>
<th>Potential Annual Savings</th>
<th>£8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Save £8 by shifting a quarter of your day time use of washing machine, dish washer or tumble dryer to night times.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Potential Annual Savings</th>
<th>£17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Save £17 by shifting half of your day time use of washing machine, dish washer</td>
<td></td>
</tr>
</tbody>
</table>

15
Personalise Recommendations: Identify appliances that can be shifted

(Parson et al., 2012)

- Non-intrusive load monitoring
  - Identify when appliances are on from smart meter data
- Challenges
  - Low data resolution
  - No training data
- Approach
  - Based on hidden Markov model method
Personalise Recommendations: Identify appliances that can be shifted

• Mixed human and automated system for understanding current energy usage.
• Explore options for savings.

(Costanza et al., 2012)
User Understanding:
Preference Elicitation

• Trade-offs between cost and comfort
• Interfaces to extract preferences
• Use minimax regret to choose the best strategy
User Understanding:

Data Accountability

Total: £ 1223

Save £ 176 by shifting 20.0% of your day time usage (kWh) to Economy7 times.

[Image of a network diagram with labels and connections]
Our ongoing work using smart technologies

- Personalised Tariff Recommendations
- Smart Heating Control
- Electric Vehicles
- Virtual Power Plants
How can we help householders manage their energy use?

• Domestic energy use accounts for 27% of UK CO₂ emissions
  – 60% of this is due to heating

• Heat pumps and time of use tariffs make life hard for consumers

Use software agents to autonomously model the home and provide advice.
Developing intelligent agents to manage and optimise home heating

- Build thermal model of home
  - Thermal leakage rate
  - Heater output

- Predict local weather conditions
  - External air temperature
  - Combine local observation and weather forecast with Gaussian processes

- Optimise energy use to maintain comfort whilst
  - Provide real-time energy feedback
  - Heat the room while energy is cheap
Developed adaptive and bespoke latent force thermal models of homes using real data

1) Accurate day-ahead internal temperature predictions
2) Unknown latent forces that affect the thermal dynamics
3) Gaussian Process used to model the unknown latent forces from data
We are evaluating models in real homes owned by the University of Southampton
Learning the thermal properties of this home.

Operating as a conventional thermostat until this process is complete.
With a predictive model we can control the heating system to minimise cost or carbon.
Our ongoing work using smart technologies

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Widespread introduction of EVs will place significant strains on infrastructure.

1) At Home:

- Local Transformer (limited maximum capacity)
- Household: 10 kWh per day
- EV battery: 24 kWh

2) En-Route:

- Only 3 public charging stations in central Edinburgh.
Key Research Challenge

• How to utilise the charging infrastructure efficiently without exceeding its constraints?
  – **Time of Use Tariff**: may simply shift peak and no guarantee to meet constraints.
  – **Scheduling**: participants can **strategise**.

**Our Approach**: Using *mechanism design*, we define allocation and payment rules that can ensure a range of desirable properties:

<table>
<thead>
<tr>
<th>Incentive Compatibility</th>
<th>Efficiency</th>
<th>Individual Rationality</th>
<th>Budget Balance</th>
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</table>
Mechanism Design for Home Charging

(Gerding et al., 2011)

1. **On each arrival:**
   Driver/agent reports charging requirements.

2. **Ongoing:**
   Mechanism (with model of likely future arrivals) schedules charging.

3. **On each departure:**
   Driver pays mechanism.

Our mechanism is **incentive compatible, individually rational** and (weakly) **budget balanced**.
Evaluation using Real-World Data

- Based on data from a large-scale trial of EVs in the UK.
  - 110 vehicles over 4 years.

- Driving behaviour sampled from real journey data recorded by GPS.

- Constraints derived from typical household electricity consumption.
Evaluation using Real-World Data

Our mechanism achieves around 90% of optimal efficiency.
Mechanism Design for En-Route Charging

- To avoid queues and ensure availability, charging stations increasingly allow drivers to place advance reservations.

- This leads to a two-sided market between stations and drivers.

- Using a greedy allocation rule, we achieve incentive compatibility for drivers, but show it is impossible (in general) for stations.

- Thus, we compare a range of alternative payment rules for stations.

(Gerding et al., 2013)
Evaluation of Pricing Rules

Second Price achieves high efficiency, but runs small deficit.

First Price achieves **high efficiency** and is **budget balanced**.

Critical Value is **incentive compatible** in this particular setting, but achieves **low efficiency** (and runs high deficit).
Our ongoing work using smart technologies

Personalised Tariff Recommendations

Electric Vehicles

Smart Heating Control

Virtual Power Plants
Cooperative Virtual Power Plants

(Robu et al., 2012)

• Renewable sources need to be integrated into the electricity network
  – feed-in tariffs: unsustainable!

• However, such sources are unreliable, unpredictable and very small scale of supply
  – …next to impossible to use for production planning!

• Come together and join forces
  – reliability and efficiency of a large power plant

• Incentivise agents to give truthful estimates
Eliciting truthful predictions

- Payment functions are **super-linear** (more payment for larger productions)
  
  **Encourages coalitions to form**

- Encouraging reliable predictions
  
  - **Scoring rule-based payments**: way of eliciting probabilistic estimates
  
  - Grid interested in average expected production ($\mu$) and variance ($\sigma$)
  
  - Payment function designed in such a way *both* are truthful

**Illustration for an agent predicting it would produce 400 kwh**

High confidence in prediction (reporting $\sigma=0$):

- Max payment share if correct, very large penalty if wrong

Low confidence prediction (reporting $\sigma=400$):

- Lower payments if correct, but also much lower penalty for errors
The Data

- 10 weeks of hourly data from 16 **Ecotricity** sites distributed across the UK
- For each farm, a wind speed prediction is obtained for 1 to 24 hours in advance
- Comparison between 2 payment schemes:
  - Based on a scoring rule (CRPS)
  - Payments using only the average prediction (point estimates)
- Participating alone or in CVPP
Results

- Being in a CVPP always better than selling in market as a single agent
- Scoring rule-based (CRPS) payments better than state of art method that does not allow agents to report how confident they are
- Predicting longer in advance leads to lower payments, as predictions are harder to make
- BUT with scoring rules payments, agents can declare lower confidence and be penalized less
Conclusions

Putting the ‘Smarts’ into the Smart Grid

Communications of ACM - April 2012
Conclusions

• Exciting and important real-world domain
  – Work with real data, easily deployable.

• Smart grid work can benefit from state of the art work in smart technologies
  – Autonomous decision making
  – Incentive engineering
  – Personalisation & adaptation
  – Human-Agent Collectives
The Team

Alex Rogers
Enrico Gerding
Valentin Robu
David Parkes
Gopal Ramchurn

Steve Reece
Siddhartha Ghosh
Enrico Costanza
Sebastian Stein
Oliver Parson
Publications

- Fischer, J. E. et al. (2013) ”Recommending Energy Tariffs and Load Shifting Based on Smart Household Usage Profiling” *Intelligent User Interfaces*.
- Ramchurn, S., Vytelingum, P., Rogers, A. and Jennings, N. R. (2011) ”Agent-Based Homeostatic Control for Green Energy in the Smart Grid.” *ACM Trans on Intelligent Systems and Technology* 2 (4)
- Ramchurn, S., Vytelingum, P., Rogers, A. and Jennings, N. R. (2011) ”Agent-Based Control for Decentralised Demand Side Management in the Smart Grid” *AAMAS*
Spare Slides
Real-time feedback energy monitoring at the level of the building and the individual

• Zigbee network of Plogg energy meters
Real-time feedback energy monitoring at the level of the building and the individual
Real-time feedback energy monitoring at the level of the building and the individual
Real-time feedback energy monitoring at the level of the building and the individual
Real-time feedback of UK grid carbon intensity via mobile devices

- Compile live generation mix data into a grid-wide carbon intensity (gCO₂/kWh)

GridCarbon

2000+ downloads
Online energy quiz to learn perceptions of energy use within businesses