The development of a carbon roadmap investment strategy for carbon intensive food retail industries

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Context

• Mitigate risks from energy security, affordability, and CO$_2$
• Inform the business strategy on sound policies
• Multi-disciplinary approach assessing complex problems

• Started in 2010 and now in its 9$^{th}$ year
Problem

- COP21 Climate Accord
- Corporate Sustainability
- Science Based Targets
- 98% carbon reduction by 2050
- How can we get there?
- Case study: 60 properties

Sainsbury's total carbon footprint in 2015
Total emissions: 1,130 ktCO2

- 47.1% Scope 1 emissions
- 52.9% Scope 2 emissions

Data from: J Sainsbury GHG Report Numbers 2016/17
Method

- MAC curve concepts
- Project specific
- Techno-economic and environmental analysis
- Need for strategic decision-making tools

Optimal technology size for each store
- Carbon, energy and cost savings

Store savings averaged over representative set of stores

Financial equation:

\[
MAC \left( \frac{\text{£}}{tCO2} \right) = \frac{Total \, investment(\text{£}) - NPV(\text{£})}{CO2 \, saved \, per \, year \times tCO2 \times Years}
\]
Method

0. Data sourcing and management

1. PV and CHP optimization models in Python

2. MARS model finds coefficients

3. Simulate properties and develop scenarios

4. GAMS solves MILP problem

5. Results and analysis
Technology Library

- Large DER database

<table>
<thead>
<tr>
<th>Unit</th>
<th>CAPEX (£)</th>
<th>Annualised Maintenance Costs (£/yr)</th>
<th>Electrical Efficiency (%)</th>
<th>Thermal Efficiency (%)</th>
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</thead>
<tbody>
<tr>
<td>CHP 35</td>
<td>£143,626</td>
<td>£6,988</td>
<td>30.90%</td>
<td>54.90%</td>
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<td>CHP 50</td>
<td>£171,317</td>
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<td>CHP 100</td>
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<td>CHP 110</td>
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<td>£14,526</td>
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<td>CHP 150</td>
<td>£312,352</td>
<td>£17,710</td>
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<td>CHP 165</td>
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<td>£18,822</td>
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<td>CHP 185</td>
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<td>CHP 210</td>
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<td>CHP 230</td>
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<td>CHP 310</td>
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<td>CHP 1950</td>
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<td>£93,529</td>
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<td>CHP 2020</td>
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<td>£107,855</td>
<td>42.70%</td>
<td>41.00%</td>
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</table>
Simulation

1. **Objective** simulate store operation under different technologies
   - Historical half-hourly data of electricity and gas loads

2. **Technology models**

   **PV model**
   - $\text{Electricity production (kWh)} = \text{Irradiance} \left( \frac{\text{kJ}}{\text{m}^2} \right) \times \text{efficiency} \times N_{\text{panels}} \times \frac{\text{Area}_{\text{panel}}(\text{m}^2)}{3,600}$

   **CHP model**
   - $\text{Electricity production (kWh)} = a_{\text{fuel}} \times \text{part load} + b_{\text{fuel}}$
   - $\text{Heat production (kWh)} = a_{\text{th}} \times \text{part load} + b_{\text{th}}$
Regression Model

- Carbon reduction for mix of CHP and PV installed capacity (example)
- OPEX savings for mix of CHP and PV installed capacity (example)
Regression Model

- The regression models were built using Multivariate Adaptive Regression Splines (MARS) analysis
  
  ▶ OPEX reduction regression:
  Linearization of OPEX savings for each combination of technology.

  \[ OPEX \text{ savings} = a + b \times CHP + c \times PV \]

  ▶ Average R\(^2\) = 0.95
Simulated Scenarios

- **Steady State (SS)**
  - Business as usual
- **Two degrees (2ºC)**
  - High Level prosperity
  - High level of Investment in Technologies
- **Slow Progression (SP)**
  - Low Economic Growth
  - Desire to decrease Carbon Emissions
- **Consumer Power (CP)**
  - High Economic growth
  - Low inclination to become environmentally friendly
  - Behaviour Driven by Technological advancements

http://fes.nationalgrid.com/fes-document/
## Simulated Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Electricity price</th>
<th>Natural Gas price</th>
<th>Biomethane price</th>
<th>CHP unit price</th>
<th>PV panel price</th>
<th>Carbon factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>p/kWh</td>
<td>p/kWh</td>
<td>p/kWh</td>
<td>£/Wp</td>
<td>£/unit</td>
<td>kgCO2/kWh</td>
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<tr>
<td>Current values</td>
<td>11.9</td>
<td>2.35</td>
<td>2.89</td>
<td>0.437</td>
<td>95k-556k</td>
<td>0.371</td>
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<tr>
<td>Steady State</td>
<td>+4.5%</td>
<td>+2.5%</td>
<td>+2.5%</td>
<td>-0.25%</td>
<td>-0.75%</td>
<td>-3%</td>
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<tr>
<td>Two Degrees</td>
<td>+7%</td>
<td>+3.5%</td>
<td>+3.5%</td>
<td>-0.25%</td>
<td>-1.5%</td>
<td>-6%</td>
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<tr>
<td>Slow Progression</td>
<td>+6%</td>
<td>+3%</td>
<td>+3%</td>
<td>-0.25%</td>
<td>-1%</td>
<td>-4%</td>
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<tr>
<td>Consumer power</td>
<td>+3.5%</td>
<td>+3.5%</td>
<td>+3.5%</td>
<td>-0.5%</td>
<td>-1.25%</td>
<td>-3%</td>
</tr>
</tbody>
</table>
MILP Optimization

Carbon reduction, OPEX and CAPEX are calculated using input regression coefficients.

- **Objective function**
  \[ \min f = \sum_t Yearly\ investment(t) - \sum_t \sum_s OPEX\ savings(t, s) \]

- **Constraints**
  \[ g_8: x(tech, t, s) > x(tech, t - 1, s) \]
  \[ g_9: \sum_s savings_{CO2}(t, s) > CO2\_saving\_targets(t) \]

- **Yearly investment flexibility constraints**
  \[ g_7: \sum_s capex(t, s) < Yearly\ investments(t) \]
  \[ g_{10}: (1 - \alpha) \times Yearly\ investments(t - 1) < Yearly\ investments(t) \]
  \[ g_{11}: (1 + \alpha) \times Yearly\ investments(t - 1) > Yearly\ investments(t) \]
Capex Results

Each Year

Measure Names
- ConsumerPower (£)
- SlowProgression (£)
- Steady State (£)
- TwoDegrees (£)

Value
- 0K
- 500K
- 1000K
- 1500K
- 2000K
- 2500K

1,91M
2,45M
2,31M
2,69M
CHP Results

![CHP Results Graph]

Measure Names:
- CHP Steady State
- CHP - SlowProgression
- CHP - TwoDegrees
- CHP - ConsumerPower

Years:
- 2020
- 2022
- 2024
- 2026
- 2028
- 2030
- 2032
- 2034
- 2036
- 2038
- 2040
- 2042
- 2044
- 2046
- 2048
- 2050

KWh:
- 0K
- 2K
- 4K
- 6K
- 8K
- 10K
- 12K
- 14K
- 16K
- 18K
PV Results

Measure Names
- PV - ConsumerPower
- PV - SlowProgression
- PV - SteadyState
- PV - TwoDegrees

Years
- 2020
- 2025
- 2030
- 2035
- 2040
- 2045
- 2050

kW
- 0K
- 5K
- 10K
- 15K
- 20K
Carbon Results
Conclusion

• Property portfolio optimization to meet Science Based Targets has been presented
• CHP and PV technologies are financially beneficial
• Carbon targets are feasible if biomethane is available
• There are model limitations but uncertainties can be reduced through periodical reviews
• Framework adaptable to other technologies
Contact

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