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Combined Heat and Power (CHP) Control Strategies under Uncertainty

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BACKGROUND

Sainsbury's, as one of the largest supermarket chains, has a commanding market share of around 16.0% [1] and they are trying to reduce the GHG carbon emission 30 per cent by 2020 [2]. Combined Heat and Power (CHP), as a distributed energy system technology, could not only generate electricity but also recycle the waste heat to supply the heating loads of buildings. With the target to grow the business sustainably, Sainsbury's considers installing a CHP system in the stores. An efficient control strategy could help the CHP units to be appropriate for different situations and achieve the maximum profits.

AIMS & OBJECTIVES

This project is aimed to investigate the optimal control strategies for the operation procedure of the CHP system in the supermarket, by modelling the energy system with the control system and then evaluating different operational strategies from analysis of the simulation results.

- Evaluating current operational schedule and control strategies of CHP system
- Maximise the energy savings and minimise the carbon emissions

METHODOLOGY

There are two basic optimal control strategies. The first one is to minimise the operational cost and the second one is to minimise the green house emission. The objective functions are shown below. The cost and emission values are determined by part load values of CHP system. Use black box method to simulate the CHP system.

Equation 1 Min. Operational Cost

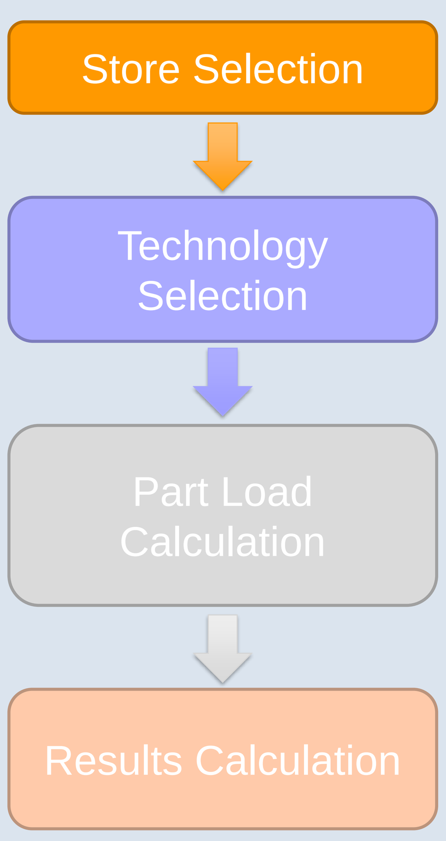
$$\min_{PL_i, y_i^{el}, y_i^{th}} Cost^{Op} = \sum_i \left(Cost_{Fuel\_gas} + Cost_{Heat\_imp} + Cost_{Ele\_imp} - Benefit_{Ele\_exp}\right)$$

Equation 2 Min. Greenhouse emission

$$\min_{PL_i, y_i^{el}, y_i^{th}} Emission^{CO_2} = \sum_i \left(Ems_{Fuel\_gas} + Ems_{Heat\_imp} + Ems_{Ele\_imp} - Ems_{Ele\_exp}\right)$$

The improved optimal strategy is used a weight factor to combine two control strategies, which is aimed to make a balance between two objectives.

A model is built in the software, Python. The whole model consists of main code script and classes. The structure of main code is shown below.



- **Filter void stores** (Demand/Price/Emissions)
- **Select** suitable **techniques** from 20 different CHP systems
- Criteria:
  - Minimise payback time
  - Or/and
  - Minimise GHG emission
- **Simulating the operational processing** of different control strategies
- Optimal control strategies (Max. saving/Min. emission)
- Load follow strategies (FEL/FTL)
- ON/OFF
- Heuristic
- Trade-off between two optimal strategies
- Optimal strategy combined with opening hours
- **Calculate results**
- yearly saving/emission/payback time/…

RESULTS & DISCUSSION

There are 1399 stores in the database but only 63 stores have enough information and 30 stores are selected from these 63 stores, with different size and HTPR. The technology selection is to choose the one which has the minimum payback time. From the model, the average values of annual cost savings and emission reductions for 30 selected stores are shown in the table 1. The results are comparing with Business-as-usual scenario, which is imported all of electricity and heat from outside.

Table 1 Comparison between BAU and CHP system with two optimal control strategies

	Avg. Cost Savings (£)	%Variation	Avg. Emission Reduction (tCO_2eq)	%Variation
Min. Cost	60176.15	-22.08%	267.23	-14.84%
Min. Emission	18454.54	-6.75%	610.08	-33.02%

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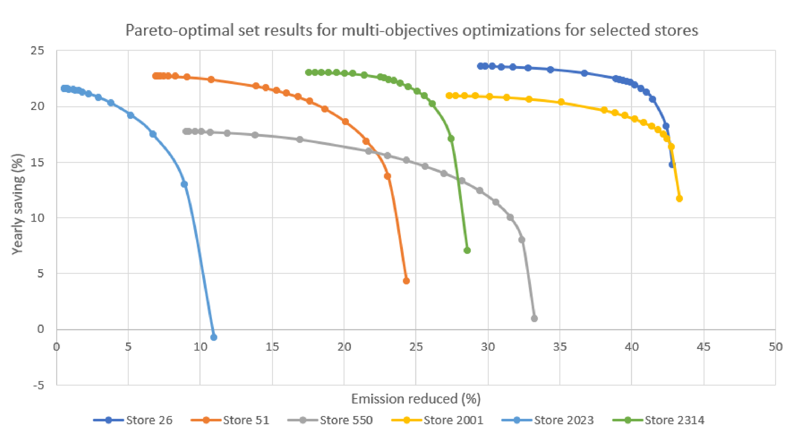
RESULTS & DISCUSSION CONTINUED

Comparing with the results of common control strategies, the basic optimal control strategies take two objectives into account and sometimes one of the results is lower than that of common method. To trade-off these two control strategies and try to meet different requests, the optimal control strategies are combined together with the weight factor to be a new strategy. Pareto-Optimal set results are involved to present the relationships between the results from different strategies.

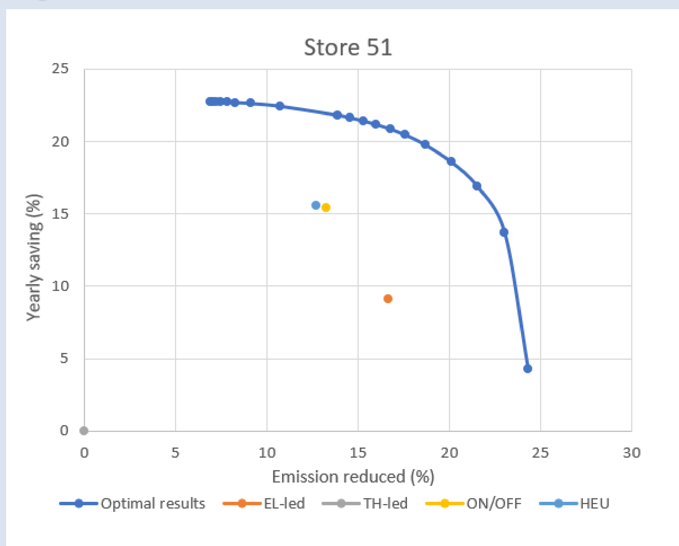
Figure 1



Select 6 stores as samples. The results of different stores are related to the level of HTPR, which means that the store with higher HTPR will perform better under the optimal strategy and the impact on emission reduction is obviously. The size will also impact on the cost and emission values. Store 51 with medium size and HTPR is presented as a case study here.

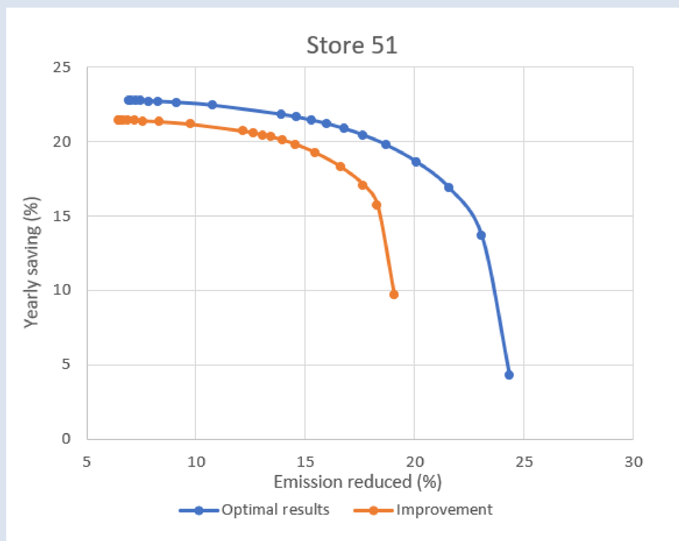
CASE STUDY FOR STORE #51

Figure 2



Use the multiple objectives method with the weight factor. The results obtained from common strategies are inside the area under the optimal set results. Based on the theory of Pareto optimality, the multi-objective optimal strategy has better performance than the common methods. If set the optimal curves as the frontier, these figures could prove that the points of results are not **Pareto-efficient**. It could help to achieve less cost with the same emissions or vice versa.

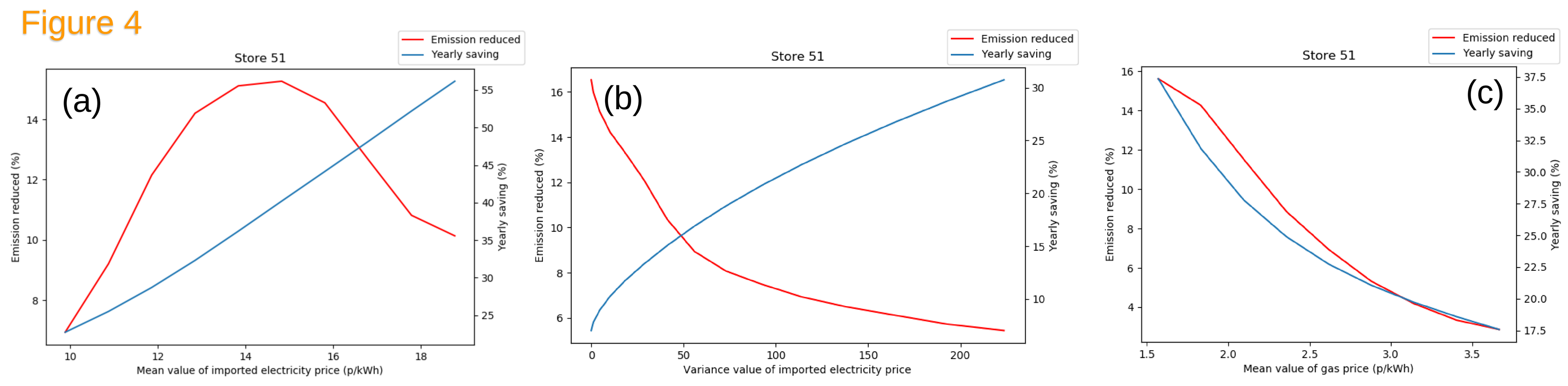
Figure 3



The values of the two endpoints of improved strategies are decreased. There exists the difference in emission reduction results obtained from the same optimal strategy of different opening time schedule. The distance between two opening time schedule is **related to the HTPR**, which means that for the stores with high HTPR, the difference is more obvious. When the HTPR is high, it means that the values of electricity and thermal demands are similar.

SENSITIVITY ANALYSIS

Figure 4



Use store 51 as the sample for sensitivity analysis. Figure 4 (a) shows the value of cost savings and emission reductions changing with the mean value of imported and exported electricity price. (b) presents the changing with the variance of electricity price and (c) is the results changing with the mean factor of gas.

CONCLUSION

As a result of the project, the optimal control strategies for minimising the operational cost and minimising the GHG emissions has been designed. The simulation performance of the optimal control strategies is better than that of BAU scenario and common control strategies. The increasing of electricity imported prices, variance and thermal demands will encourage the use of the CHP system. In contrast, the increasing of gas price will cause the less usage of CHP units.

REFERENCES

[1] Tassou, S. A. et al. (2011) 'Energy consumption and conservation in food retailing', Applied Thermal Engineering, 31(2–3), pp. 147–156.

[2] J Sainsbury plc (2017) 'Live Well For Less：Annual Report and Financial Statements 2018', pp. 1–191.