INNOVATIVE STRATEGIES TO INCREASE ENERGY EFFICIENCY AND ECONOMIC PERFORMANCE IN SUPERMARKETS

Salvador ACHA
Imperial College London – UK
salvador.acha@imperial.ac.uk

Pierluigi MANCARELLA
Imperial College London – UK
p.mancarella@imperial.ac.uk

Nilay SHAH
Imperial College London – UK
n.shah@imperial.ac.uk

Goran STRBAC
Imperial College London – UK
g.strbac@imperial.ac.uk

John ASHFORD
Sainsbury's – UK
john.ashford@sainsburys.ac.uk

David PENFOLD
Sainsbury's – UK
david.penfold@sainsburys.ac.uk

ABSTRACT

Electricity consumption in the UK commercial sector accounts for 19% of the total annual electricity demand. Exploiting this fact, supermarkets offer a huge potential for controlling demand to provide services to the power system. In particular, contribution from demand response programs is envisaged to play an ever increasing role in the UK power system. Hence, on-site energy generation on the one hand and power system services on the other can lead into developing new business models which are worth exploring. Within the above context, this paper presents innovative approaches that are being pursued by the Imperial College London and Sainsbury's partnership to develop new business energy models while also meeting the environmental targets of the company. Specifically, two research concepts are presented in this work; namely defined as the ***smart-grid*** *and* ***off-grid*** *stores.*
The analysis framework for each store concept is presented and conceptual results are given. The smart-grid store results illustrate the ideal periods in which an on-site low-carbon generator should run. Meanwhile, the off-grid store results depict how different on-site generation options compare to each other regarding their economic, energy and emission performance when installed within the premises of a supermarket. The studies carried out will represent a benchmark for making commercial stores an important player within the power industry, therefore establishing the contributions supermarkets can bring to smart-grid applications.

INTRODUCTION

The partnership between Imperial and Sainsbury's aims delivering practical solutions to reduce the carbon footprint from daily operation of supermarkets. Overall, this means reducing Sainsbury's impact on climate change on a global level, as well as supporting the UK in pursuing its challenging environmental targets. In fact, supermarkets are among the largest consumers of energy, with their consumptions summing up to approximately 5% of the UK's annual energy consumption [1]. The combined energy consumption of these chains in 2004 was estimated to be 9,891 GWh. Therefore, within a climate change context, supermarkets today have the intriguing challenge of continuing to return value to shareholders while reducing energy consumption and carbon intensity.

Energy demand in a supermarket comes from various essential end uses; they are composed by the following (percentages are given relative to annual consumption) [2]:

- Refrigeration – 45%;
- Lighting – 25%;
- Ventilation (HVAC) – 15%;
- Bakery – 11%;
- Others (e.g. hot water services, staff area) – 4%;

In order to achieve savings, the above sub-systems present within a supermarket facility have the potential to be integrated while delivering the same services. Furthermore, if the power capacities from different Sainsbury's sites are aggregated and demand response strategies [3] applied to shift/schedule loads, high-value ancillary and back-up generation services could be offered to the grid.

As Figure 1 shows, profiles for 9 typical days during the year were developed for a 2500 m^2 store (e.g. Dartmouth), showcasing the load range with which the store varies in its base (70 kW), peak (163 kW), and average (114 kW) demand throughout the year.

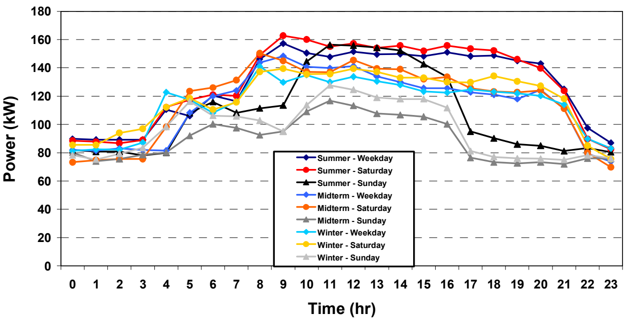

Figure 1 – Depiction of load profiles for 9 typical seasonal days.

SMART-GRID STORE

Objective & Background

The *smart-grid store* concept focuses on managing the different processes occurring within a supermarket (including on-site generation) with the objective of enhancing its dispatchable loads for mutual cost benefits of both Sainsbury's and the electric utility. Once the potential capacity of individual stores is known, optimisation of demand across multiple stores can be performed. This will be a major component of the research aimed at maximising both commercial opportunities and CO_2 savings in electricity consumption that Sainsbury's can deliver. Hence, following up on the current activities that Sainsbury's already provides in the area of frequency regulation services, this project will develop a store-to-grid (S2G) service concept and identify appropriate technologies that will complement conventional energy efficiency measures. Naturally, the project will intend to identify and exploit the opportunities for the development of intelligent stores that can actively participate in demand response programs (i.e. load control management). *Load flexibility* is thus the key concept in this project, allowing through demand dispatch to support the grid whenever necessary at the right 'price'. Similarly, low cost electricity purchase could be targeted by shifting the demand of refrigeration, HVAC, bakery, and other services when convenient.

Table 1 summarises the challenges the smart-grid project represents, while there is also some risks and assumptions that need to be taken into consideration.

Table 1 – Where are we now and where do we want to be?

As it is	To be
- Store systems are controlled independently of each other; - Flexibility in HVAC, bakery, refrigeration, etc. is not being exploited; - Opportunities for revenue sharing with operators exist but not explored.	- Apply store level intelligent controls; - Link and aggregate the capacity of multiple stores using intelligent controls; - Identify and exploit opportunities with distribution and transmission operators.

Actions: Assessing a biodiesel generator at Hythe

Thus far Imperial College London researchers have focused their efforts by collaborating in implementing adequate on-site generation and monitoring systems in the soon to open store at Hythe and which will be used as the test bed for smart-grid trials and practical proof of concepts.

Based on load data taken from existing stores of similar floor area it was possible to estimate a 1000 MWh annual electricity demand at Hythe. This fact allowed the Imperial team to determine the optimal capacity of an on-site generator to be installed for peak looping purposes; yielding a 180 kW combustion engine running on biodiesel.

The engine capacity was determined since the peak demand in the summer period is 160 kW with an 80 kW base load. Hence, the engine is sufficient to function as a back-up generator while it can also work at partial load to reduce peak demand when prices of electricity are relatively high.

Furthermore, by assuming a flexible tariff scheme for the price of energy – correlated to the spot market price [4] – the optimal manner in which the unit should be operated was determined. This allows the stakeholders to identify for how many hours during the day, based on the seasonal period; the unit should run in order to achieve economic profitability. The economic benefit of running on-site generation can be obtained using the following formula:

$$\text{Profit from generation} = \text{Average spot peak price} - \text{Cost of operation} \quad (1)$$

Where: Profit from generation in £/MWh
Average spot peak price in £/MWh
Cost of operation = Capex + Opex in £/MWh

This formulation was assessed for different operational patterns and varying seasonal spot market prices. Figure 2 illustrates the length of 'sweet spot' operation for different seasons. As it can be seen in the example, due to the high cost of electricity, during wintertime it is advantageous to run the unit 75% of the time, while in midseason it is closer to 60% of the day, and in the summer there is no benefit in using the generator at all. These operational variations occur because the operating cost of running the unit is not profitable unless the wholesale price of electricity is above a certain range (e.g. $65/MWh); this clearly illustrates why it is counter-effective to run the unit 24 hours a day.

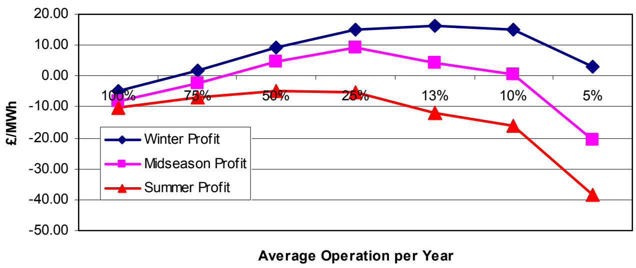

Figure 2 – Showcases the profitability of operating an on-site generator, positive values are the duration the generator should be run.

The calculations above are considering double renewable obligation certificates (ROCs), the results show the economic attractiveness of the project is strongly dependent on obtaining double ROCs by utilising the low-grade heat produced in the combustion process [5]. In other words, the ROCs benefits must be fully exploited to make the unit more financially viable if operated according to spot market prices. The double ROCs can be achieved by employing the low-grade heat produced when the engine is working, thus additionally providing both hot water and space heating services (besides electricity).

If double ROCs are not achieved, due to the high cost of the vegetable oil fuel, the operation of the unit becomes unattractive. At a cost of £550 per Mt and an average maintenance of £0.02/kWh, Figure 3 illustrates the profitability of running an on-site generator is null if the low-grade heat is not employed and dumped.

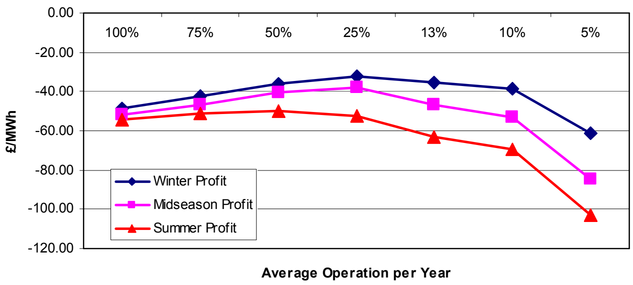

Figure 3 – Illustrates that high costs of biodiesel and without making the most of incentives, the low-carbon generator does not become economically viable during any seasonal period.

OFF-GRID STORE

Objective & Background

The *off-grid store* concept focuses on exploring innovative energy solutions whereby future Sainsbury's stores could profitable operate with on-site generation and as a consequence become partially independent from the grid. Furthermore, this project is oriented towards developing integrated energy solutions through a cost-benefit analysis that illustrates the trade-offs in adopting different technologies within a site. The off-grid store programme will be a more extreme design case than the smart-grid store concept, since its facilities on average will tend to operate independently from the UK power grid, while occasionally even becoming net power producers. Issues to be considered include: optimising demand management and energy storage to enable appropriate selection and smooth operation of generation equipment. Furthermore, assessment of co- and tri-generation schemes with community integration potential (e.g. district heating) must be explored.

Alternative designs will be developed and compared against a series of metrics including: whole life cost and sensitivity of the results to future changes (e.g. energy prices), and lifecycle green house gas emissions. Although, within the present energy context, the relative benefits of this store design concept is not clear – an important outcome will be a cost–benefit analysis defining the set of technologies best positioned to offer low carbon energy solutions.

Initial work has begun by building a comprehensive database that showcases the existing range of alternatives currently existing for distributed energy resources (DERs); this database considers both heat and power provision through low-carbon technologies such as PVs and CHPs.

Table 2 summarises the challenges the off-grid project represents, while there are also risks and assumptions that need to be taken into consideration as well.

Table 2 – Where are we now and where do we want to be?

As it is	To be
- Each innovative store design is done as a one-off exercise; - Technology vendors offer a variety of useful technologies, however not clear how they work together as a system; - Energy resource efficiency has to be traded off against investment costs.	- A re-usable methodology for resource-efficient store design will be developed; - An informed approach to technology selection and integration will be used; - Robust low cost win-win energy solutions will be identified.

Actions: Levelised Cost Analysis of DER Solutions

Levelised cost represents the present value of the total cost of building and operating a power plant over its financial life, converted to equal annual payments and amortised over expected annual energy generation from an assumed duty cycle [6]. Hence, once the DER database is populated for different sets of technologies, it has been possible to begin levelised cost analysis of distributed energy resources. This has lead to identify which technologies are currently better positioned to be adopted in low carbon off-grid stores.

Initial calculations have focused on assessing how four different technologies compare their capital costs against the carbon emissions they generate. The analysed technologies are a combined heat and power (CHP) internal combustion engine (ICE), CHP fuel cell, non-CHP ICE, and biomass generator (the only zero carbon unit, the rest of the options have a similar range of emissions). Taking a store similar to Dartmouth, a levelised energy cost analysis was conducted for a 25 year time period for the four technologies. These studies consider both flat and spot price tariff structures, resulting in Figures 4 and 5, respectively. The graphs depict, that if on-site generation (of various installed capacities) is present within a supermarket there is a great potential of energy cost reduction when compared to the current 'flat' tariff structure Sainsbury's has in place; this fact is more evident in Figure 5. All DER options, but specially the biomass generators provide carbon emission reductions, while ICE options are the most economical.

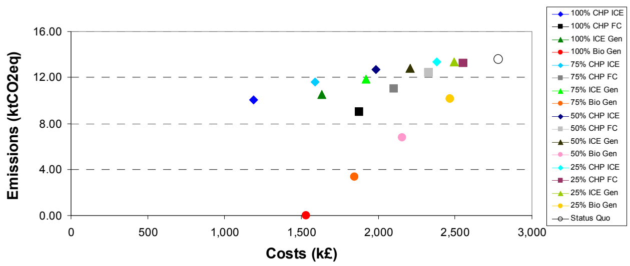

Figure 4 – Emission/cost performance of DER solutions for off-grid supermarket with a flat tariff of electricity imports.

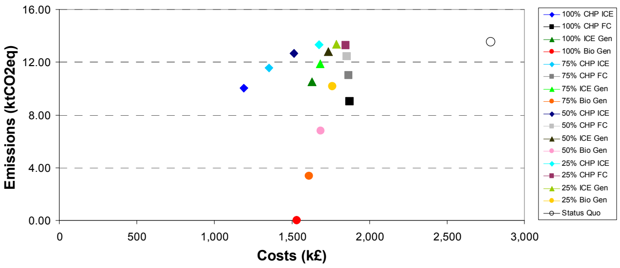

Figure 5 – Emission/cost performance of DER solutions for off-grid supermarket with a spot price tariff of electricity imports.

CONCLUSIONS AND FURTHER WORK

The partnership between Imperial College London and Sainsbury's aims to research and deliver innovative practical solutions to cope with climate change challenges and support Sainsbury's to reduce the carbon footprint of its store portfolio and as a consequence the amount of energy it consumes in its day to day operations.

From the different projects Imperial College and Sainsbury's have in the works, this paper has presented the *smart-grid* and *off-grid* studies currently being conducted.

As mentioned previously, the idea behind the smart-grid project is to detail *energy shifting* and *power modulation* characteristics that demand can provide depending on the level of flexibility of specific devices/systems. Deliverables of the smart-grid research will be to develop an integrated approach that defines the anticipated store resources demands and then design the integrated supply and conversion systems that satisfy the end-use services while supporting grid operation. This methodology will benefit from researching cost-effective energy solutions and closely assessing the performance of the Hythe store. An important feature of the technology solution selection for all stores is the robustness and future proofing they must show; thus ensuring that the energy provision models will remain relevant, useful, and economically sound for the life of the supermarket.

The assessment conducted on the biodiesel generator showed how on-site generators are economically viable to run according to spot prices of electricity; these values and time intervals vary depending on seasonal periods as well.

Meanwhile, the off-grid concept presented here is oriented around developing integrated energy solutions for stores through a cost-benefit analysis which shows the potential of sties to self-supply most of its energy needs independently from the grid. The deliverables of this research project will consist in conducting long term cost and environmental analysis of different energy solutions while also defining comparable benchmarks and hopefully becoming viable for Sainsbury's in the near future; hence proposing off-grid store prototypes that guarantee a low-carbon solution.

Initial results from the off-grid studies depict that although the ICE CHP is the most attractive economical option to generate electricity on-site, the biomass generator offers very attractive carbon emission reductions for supermarkets.

Further work will consist in continuing each work stream of the smart-grid and off-grid projects. Activities will include a thorough monitoring and control of the different services at the Hythe store, which will serve as a test bed to obtain early results on the load flexibility capacity in the store. Furthermore, the results from Hythe will serve to construct an in-store model that portrays all the interactions between the supermarket services. Features of such model will include characterisation of the flexibility of HVAC systems while maintaining certain comfort levels, possibility of shifting refrigeration and bakery schedules, and operation of local generation to relief distribution network constraints at peak times will be considered as well. Likewise, a smart-grid model focusing on assessing the aggregated flexible capacity the supermarkets can offer will be explored as well.

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