A DECENTRALISED ENERGY SYSTEM CONTRIBUTION TOWARDS A LOW CARBON ECONOMY – UK

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Abstract
In order to meet the energy demands of London's homes, business and infrastructure through the provision of an efficient, affordable and secure supply of low and zero carbon energy, the Mayor of London plans to deliver 25% of London's energy needs through decentralised systems by 2025. Decentralised energy (DE) is the local supply of heat and power from an energy generation source to end users. This plant is often located in an energy plant containing a combined heat and power (CHP) installation as the lead heat source, and a back-up boiler for providing additional heat. A network of insulated pipes transports the heat from the energy centre to where the heat is used. DE also includes the generation of power into the local distribution network. DE is usually produced close to where it is used and cuts the energy wastage by improving the efficiency of supply, thus reducing carbon emissions and costs. Moreover, as well as reducing CO_2 emissions by moving the electricity supply from inefficient power stations, generating electricity onsite can reduce energy costs for the consumer. A whole range of power plants, including gas, oil, biomass, waste, etc., can be used in CHP mode. This paper discusses the drivers for a low carbon economy in the UK and illustrates the difficulties associated with the operation of a CHP engine using a case study. Hence, many buildings in London do include a CHP engine, but do not operate it because it is not regarded to be financially beneficial. To undertake a cost analysis, a hotel made up of 785 rooms located in central London is used as a case study. Finally, the CO_2 emission saving with the use of the CHP engine is also quantified.

Keywords
Combined heat and power, decentralised energy, renewable obligation

1 INTRODUCTION

District heating (DH) is defined as the local supply of heat from an energy plant to end users. This plant often includes a CHP unit operating as the lead heat source and an accumulator for storing the heat produced by the CHP unit and boilers to meet the heating load demand. A network of insulated pipes transports the heat from the energy source to where the heat is used. Decentralised energy (DE) differs from the concept of DH as it also covers the generation of power into the local distribution network. In DE, the energy is produced close to where it is used. As shown in Figure 1, it also provides a fuel-flexible infrastructure that can allow fossil fuels to be replaced by renewable fuels in the future and as new technologies are developed. A DH system includes 3 elements: Production, Distribution and Delivery.

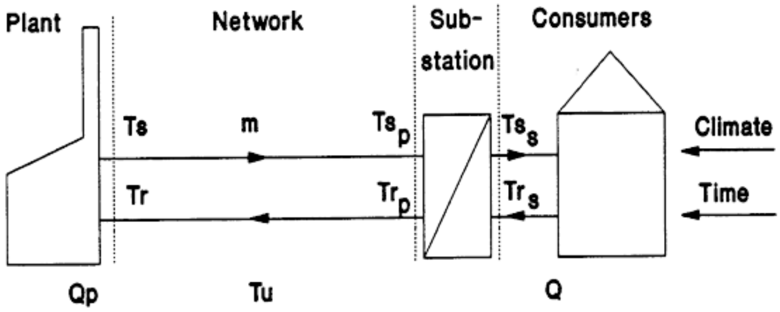

Figure 1: A schematic diagram of a DH system (Bøhm et al. 2002).

As the plant is separated from the consumers, DH enables whole communities to benefit from new and emerging technologies and any system changes will not cause any disruption to residents. DH is best installed in an area with a high concentration of heat demand. Moreover, DH can offer ways of supplying low-carbon or renewable heat to to buildings with spatial constraints. Furthermore, the use of CHP fired by renewable fuels is expected to grow in the medium term through technologies such as:

- Gasification of wood chip to produce synthetic gas;
- Combustion of biomass (rankine cycle);
- Engine with liquid biofuels.

A CHP unit is optimally sized to meet the base load and a proportion of the seasonal space heating demand. In operation, the CHP can either modulate with the heating load or a thermal storage can be used to supply the produced heat to the DH network when the CHP plant is producing electric power alone or to optimally redistribute the produced heat over a period of time (Palsson, Ravn 1994).

2 DRIVERS TOWARDS A LOW CARBON ECONOMY

In 2011, the UK was the world's 7^{th} greatest producer of man-made carbon emissions; producing around 1.8% of the total emissions generated from fossil fuels, see Figure 2. However, the UK is now responding to the drive for a Low Carbon Economy (LCE). A LCE seeks to minimise the output of greenhouse gas (GHG) emissions into the environment. Scientific evidence suggests that GHG emissions due to human activity are causing global warming and scientists are concerned about the negative impacts of climate change on humanity in the foreseeable future. Thus, the UK government is seeking to deliver a LCE to limit climate change. Accordingly it has set targets for reducing carbon dioxide emissions using the 1990 emissions as a baseline where the UK emitted an estimated 778 $MtCO_2$. There are currently 3 binding targets for UK emissions:

- In 1997, the Kyoto Protocol set a target for the UK to cut its CO_2 emission by 12.5% by 2012.
- The Climate Change Act 2008 introduced a legal obligation for the UK to cut CO_2 emissions by (DECC 2009a):
    - 33% by 2020;
    - 80% by 2050.

In March 2006, after the publication of Energy White Paper (DEFRA 2003)); and guided by the 2006 Energy Review (HM Government 2006), the Government Updated the 2000 Climate Change Programme. This updated programme provided a framework and a comprehensive strategy for a more sustainable future by committing the UK to reducing its emissions by 60% by 2050 with a real progress by 2020. These initiatives led to the current energy policy set out in the Energy White Paper of July 2009: “The UK Low Carbon Transition Plan” (HM Government 2009) and The Climate Change Act 2008 that became law on 26 November 2008. In summary, “The UK Low Carbon Transition Plan” outlines the Government international and domestic strategy for responding to the following challenges:

- To cut carbon emissions;
- To ensure secure, clean and affordable energy.

The Climate Change Act 2008 makes it the duty of the Secretary of State to ensure that the net UK carbon that accounts for all six Kyoto green house gases for the year 2050 is at least 80% lower than the 1990 baseline. The Act aims to enable the United Kingdom to become a LCE and gives ministers powers to introduce the necessary measures to achieve a range of GHG reduction targets. An independent Committee on Climate Change has been created under the Act to provide advice to UK Government on these targets and related policies. This new independent body advises the UK Government on setting carbon budgets. Moreover, on 1st December 2008 the committee published its first major report entitled “Building a low-carbon economy – the UK’s contribution to tackling climate change” (Committee on Climate Change 2008). This report recommends that the UK adapts its long-term target to reduce emissions of all greenhouse gases to 80% by 2050. In line with this report, the Government set a target to cut its carbon emission by 33% by 2020.

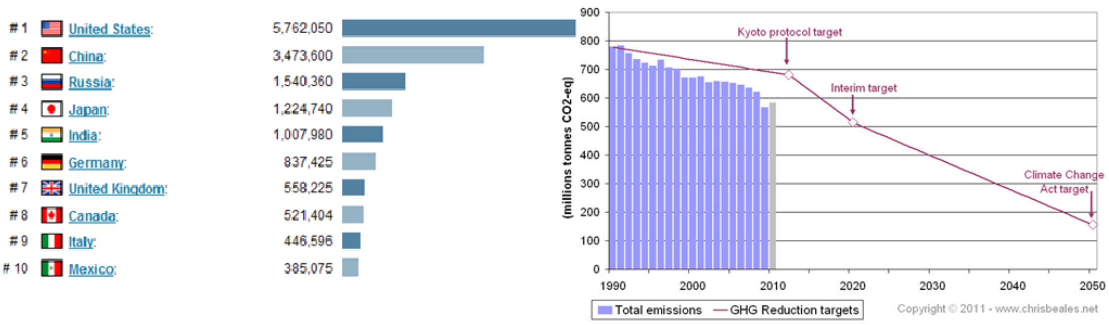

Figure 2: National CO_2 emissions greatest producers in 2011(Nationmaster 2011); UK greenhouse gas emissions compared to targets (DECC 2011e).

3 GENERATING ENERGY FROM RENEWABLE SOURCES

The UK has had two main drivers for the generation of electricity through renewable energy sources (RES):

- The Non Fossil Fuel Order (NFFO) from 1990 to 1998; and
- The Renewable Obligation (RO) from 2002 to today.

However, it has been proved necessary to add further means for generating renewable energy for smaller scale generators and for the production of renewable heat:

- The Feed-In-Tariff (FIT), April 2010 (HM Government 2008);
- The Renewable Heat Incentive (RHI) (DECC 2011d).

In April 2002, the Renewable Obligation (RO) was introduced in England and Wales. The RO sets an obligation on electricity supply companies to source a steadily increasing amount of their electricity from eligible renewable sources. Each supplier is to provide evidence of compliance with the RO on an annual basis, after the end of each compliance period. Compliance is achieved through the presentation of the required Renewable Obligation Certificates (ROCs). Since 1st April 2002, electricity suppliers have been required by the government to ensure that an increasing proportion of the electricity they sell comes from renewable energy sources. This was set at 4.9% in 2004/5 and will rise annually until it reaches 15% in 2015.

To date (2010) the RO has had limited impact and has been criticised for its lack of effectiveness, largely because it was not designed to reduce risk for investors but instead initiated competition between technologies in an attempts to minimise costs to consumers(G. Wood 2010). Indeed, a renewable generator was originally awarded a ROC for each MWh of electricity generated. Therefore, as all technologies received the same level of support, there was a clear incentive for companies to source the cheapest available power to meet their obligation. In other words, the RO was originally designed to be technology neutral and was designed to run until 2027(Woodman, Mitchell 2011). However, in April 2009, following the 2007 White Paper on Energy recommendation (HM Government 2007), banding was introduced: established technologies receive fewer ROCs per MWh than emerging technologies. Hence, banding the RO addresses price risk for less developed technologies by attaching more value to a MWh of their generation and thereby incentivising investment. For example, Landfill gas receives 0.25 ROCs/MWh, whereas tidal steam receives 2 ROCs/MWh; existing projects continue to receive 1 ROC/MWh regardless of what technology is being used. Therefore, banding makes the non-mature renewable energy technologies receive a higher level of subsidy, so helping their development. However, it does not reflect different sizes of project, thus it still lets an impetus to concentrate on economies of scale to maximise income.

The reason behind reforming the RO was that the UK Government indicated that leaving the RO unchanged meant that the 2010 (10%), 2015 (15%) and 2020 (proposed 30-35%) targets would not be achieved. Moreover, the UK has already failed to meet RES targets: as shown in Figure 3 the 2009 RES contributed 6.6% of electricity generated against the yearly target of 9.1%. Thus, the NFFO and the RO have for so far not delivered deployment at the expected level. As RO gives an impetus to concentrate on economies of scale, a Feed-In tariff was introduced in April 2010 for small-scale renewable generation up to 5MW. Indeed, the government acknowledged that smaller scale renewable projects were limited in the extent to which they could benefit from the RO by the high investment risks associated with the mechanism. Under a FIT system, suppliers are under obligation to buy all the output from a project, so removing volume and market risk. In comparison, even under the redesigned RO, generators have no guaranteed market but are instead still required to negotiate a price for their output with electricity suppliers.

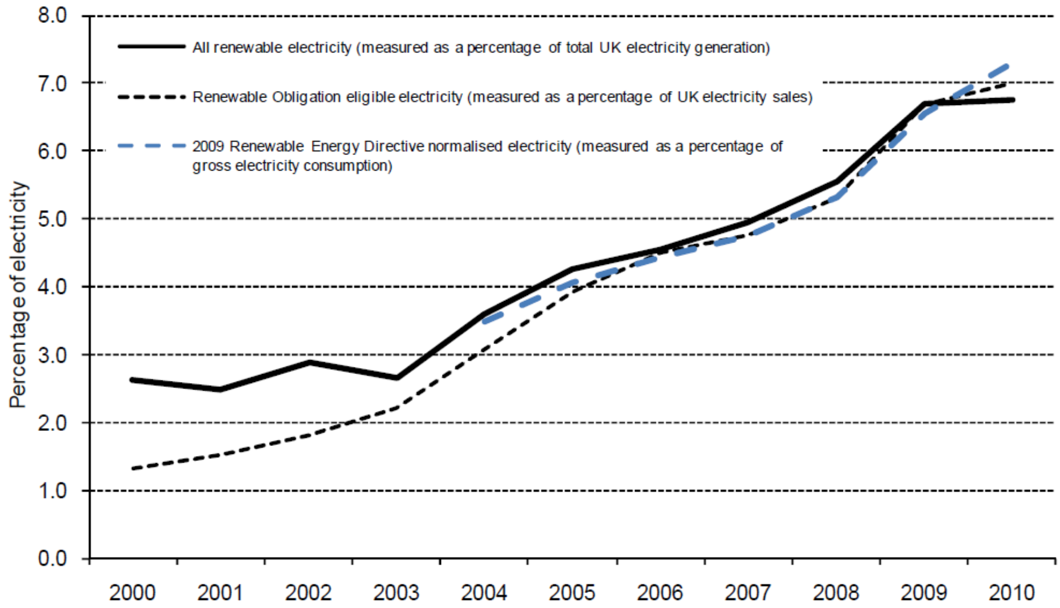

Figure 3: Growth in electricity generation from renewable sources (DECC 2010).

4 DECENTRALISED ENERGY FINANCIAL ANALYSIS

There are different approaches to costing and financing decentralised energy (DE). However, the benefits of any DE technology are only realised through the appropriate operation of the system. The economic benefits of installing a CHP unit on any particular site are achieved when the annual cost savings are sufficient to offer return on the capital invested by the owners of the plant. A large-scale CHP project cannot be evaluated financially in isolation because its capital cost is likely to be sufficiently large to affect the company's overall financial profile. Hence, the company has got to include the CHP's assessment in its overall financial appraisal; the aims of a financial appraisal are (DECC 2011a):

- To determine which investments make best use of the company's funding;
- To guide the optimisation of benefits from each investment opportunity;
- To guide the company's risk management strategies;
- To provide a basis for the subsequent analysis of investment performance.

The capital cost is not a straightforward calculation for a CHP plant. Indeed, a CHP project is not directly process related. Regarding the overall cost savings, the first step is to determine the site's base-load energy demands and the energy costs of meeting this demand over several time bands without the use of CHP. This also indicates the heat to power ratio of the site during each time band. The second step is to calculate the costs of meeting the same energy demands using the CHP plant selected. The energy cost savings associated with the CHP plant can then be determined. The third step is to include in the analysis:

- A cost estimate for maintaining the CHP plant;
- The installation cost.

4.1 Maintaining the CHP plant

The incorporation of a CHP unit will include the costs of maintaining the unit, the electrical generator and other associated equipment. Table 1 provides indicative maintenance costs expressed in p/kWh of generated electricity for different technologies operating for 4,500 and 8,000 hours per year.

Table 1: CHP technology indicative maintenance costs (DECC 2011c)

	4500 Operating hours / year	8000 Operating hours / year
Gas turbines	0.4 p/kWh	0.35 p/kWh
Gas engines	0.7 p/kWh	0.6 p/kWh
Dual-fuel compression ignition engines	0.8 p/kWh	0.7 p/kWh
Steam turbines	Less than 0.05 p/kWh	Less than 0.05 p/kWh

4.2 Installation Cost

Most suppliers offer total CHP packages as part of their business: they will provide quotes for installation costs. However, an alternative method of working out an installation cost for financial analysis purposes is to refer to preceding installations of CHP plant costs and to produce a chart from them, such as in Figure 4.

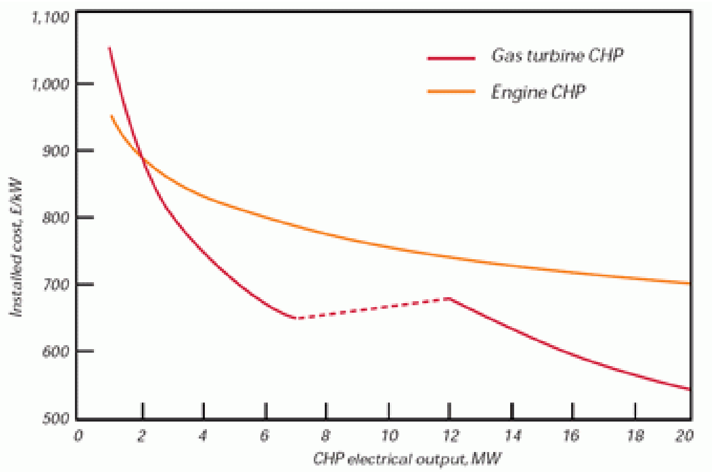

Figure 4: Typical installation costs (DECC 2011b).

4.3 Financing Method

There are two overall approaches to financing CHP units: an “On Balance sheet Approach” and an “Off Balance Sheet Approach”. However, whichever method of financing is chosen, the decision to invest in a large-scale CHP involves a long-term commitment.

On Balance Sheet Approach: A company purchases the CHP unit outright so that it appears as an asset on its balance sheet. Such a capital purchase may deliver maximum benefits, producing the highest NPV, however the initial cash flow will be negative. Finally, a capital purchase is funded using internal funding, external funding or a mixture of both. Another option of On Balance Sheet Approach is to lease a CHP rather than to purchase it.

- **Internal Funding:** With internal funding, the company provides the capital for the CHP unit and for its installation. In doing so, the company retains full ownership of the project and reaps the maximum potential benefits. However, while investing in a CHP plant, the company bears a considerable amount of technical and financial risk.
- **External Funding:** A large capital purchase is often funded by a combination of external and internal funding; External finance generates some dept for the company. As with full internal financing, the residual technical and financing risks remain with the company; at the same time, the company retains the full benefits of the installation.
- **Leasing:** Leasing is a financial arrangement that allows a company to use an asset over a fixed period. For the asset to remain on balance sheet, the lease will be a finance lease (as opposed to an operating lease) whereby the lessee retains full risks of ownership.

Off Balance Sheet Approach: This financing option is particularly attractive for companies that cannot provide the funds for the capital purchase of their CHP unit. Although this approach avoids the up front cash outflow, the NPV tends to be lower than for the capital purchase option. In the United Kingdom, two types of organisation can arrange or supply off balance sheet financing for CHP plant:

- **Equipment Supply Organisations** offer a leasing package to the company. They pay all the costs of design, installation, maintenance and operation and thereby retain most of the technical risk associated with the system. The operating company pays for the fuel and contracts to buy the electricity and the heat generated from the CHP engine at an agreed price. Generally, the operating company's financial savings will be significantly lower under this arrangement than under a capital purchase arrangement, and they will also retain the risks relating to fuel price fluctuations.
- **Energy Services Company (**ESCo**)** arrangements can vary greatly. In all arrangements, the ESCo supplies heat and power to the company at agreed rates. The ESCo may also take responsibility for fuel purchase and for other on-site energy plant. In some cases, it will size the CHP plant to meet the heat requirement of the company and produce surplus electricity that can be exported and sold. In this case, the operating company will only receive part of the overall value of the energy savings, but as these overall savings are greater than the savings that would have been achieved under a smaller capital purchase scheme, the company's share may still have a greater value. Moreover, an ESCo can adapt the proposal depending on the operating company's requirements and its objective. Although an ESCo may not finance the entire energy system / CHP unit (unlike an equipment supplier) it will bring some investment to the project, the scale of this investment being dependent upon the savings and revenues that the energy centre can achieve. Below is a list of the principle variables to be resolved:

    - Who will operate the plant on a day-to-day basis and therefore, bear the performance risk?
    - Who will maintain the plant?
    - Who will own the plant at the end of the initial agreement period (typically 10-15 years)?

4.4 Economic factors

The viability of a CHP plant is not only dependent on its size and its good operation, but also on economic factors including:

- fuel prices,
- electricity prices,
- taxes, and
- prices for other heating alternatives.

Economic profitability improves if (Reidhav, Werner 2008):

- Market conditions allow for a competitive DE heat and electricity price;
- Low marginal heat generation costs;
- Low service and maintenance costs;
- Low demands on rate of return from the owners.

The economics of CHP plants depend greatly on taxation levels with high consumption taxes on oil, natural gas and electricity working to the benefit of CHP as they generate both heat and electricity efficiently.

5 CASE STUDY: A HOTEL IN CENTRAL LONDON

This Hotel is a steel structure building and opened its doors in 1909. With 785 guest rooms, it is a 31,000m^2 building located in central London; it accommodated 317,000 guests in 2010. There is at present no air conditioning in the guest rooms of the hotel, but this is available in the 'public' spaces. The hotel was awarded "Silver" under the Green Tourism for London scheme in 2010 and is aiming to achieve "Gold" for 2011. Indeed, the Chief Engineer is passionate about system performance and has a good relationship with their CHP supplier.

The energy plant is located in the basement of the hotel and includes two CHP engines of 250kWe and three 500kW boilers. The electrical base load of the hotel is 800kWe. The electrical output from the CHP engines replaces some grid electricity and the heat output replaces the use of gas boilers. These CHP engines operate 24/7 during the winter months at approximately full rate; in the summer months, as no thermal tank is included in the plant, the CHP engines are turned off to avoid dumping any heat.

5.1 Commercial terms

The CHP engines are leased from a supplier over a 12 year term and as such are 'off balance sheet' for the hotel. The hotel pays a unit price per kWh of electricity generated, set by the supplier to cover all maintenance costs and to give them an effective return on capital:

- 4p/kWhe day rate
- 1.39p/kWh night rate

It is understood that, as the Chief engineer has a good relationship with the supplier, slightly non-standard terms have been agreed whereby the amount paid by the hotel is effectively fixed each month based on a monthly day rate output of 1,000MWhe regardless of actual output. Thus when the hotel runs the engines 24/7 during winter months any output above 1,000MWhs is effectively ‘free’. This is offset by the summer months when the engines are turned off. On this basis, the actual amount paid to the equipment supplier in 2010 was of the order of £91k. From the hotel’s point of view, this represents their maintenance and financing costs of the plant. All fuel (for the CHP engines and the heat only boilers) is purchased directly by the hotel.

5.2 Financial and environmental analysis

The left hand figure below gives the monthly heating produced by the CHP units and the heat only boilers. The combined total is equivalent to the total hotel heat demand. The right hand figure gives the monthly electricity generated by the CHP units and that imported from the grid (at low rate - night tariff, and normal rate – day tariff). The combined total is the total hotel electricity demand. Table 2 gives the annual heating and electricity generation from every energy unit and the grid electricity imported. This study compares the operation of the hotel’s energy plant with a baseline corresponding to the case when the hotel is assumed to be heated with natural gas boilers and the electricity is taken from the grid. The natural gas boilers have been assumed to operate with a seasonal efficiency of 85% (CIBSE 1998).

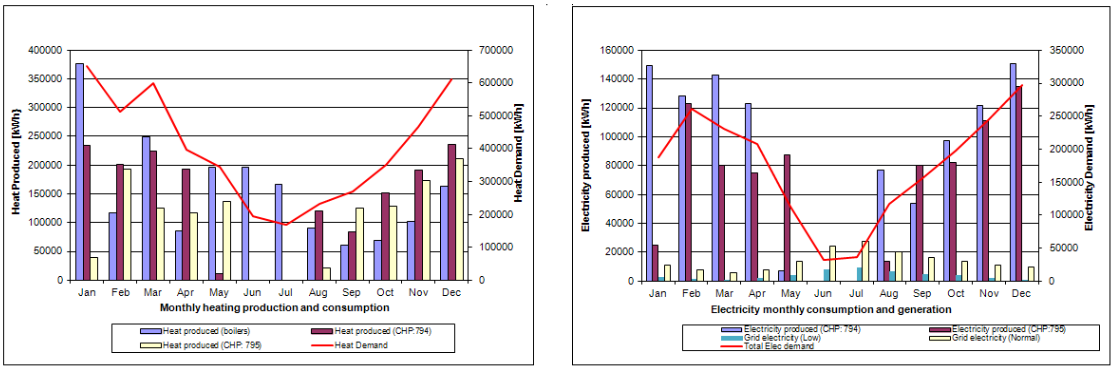

Figure 5: Hotel's heat and electricity monthly consumption

5.3 Carbon analysis

To calculate CO_2 savings, carbon factors used are taken from The Government’s Standard Assessment Procedure for Energy Rating of Dwellings (DECC 2009b):

- Natural gas: 0.198 kg CO_2/kWh;
- Grid electricity: 0.517 kg CO_2/kWh.

Multiplying the carbon factor by the annual heat and electricity consumed from the hotel, see Figure 5, the hotel’s baseline emission would be:

- Heat: 4796546 * (0.198/0.85) = 1,117,313 [kg CO_2/kWh]
- Electricity: 2081485 * 0.517 = 1,076,128 [kg CO_2/kWh]
- Total CO_2 emissions: 2,193,441 [kg CO_2/kWh]

The total CO_2 emission from the actual operation of the hotel, as given in Table 2, is of 1,758 tonnes CO_2/kWh. Hence, the incorporation of the CHP engines in the energy plant contributed to 20% CO_2 reduction in 2010.

Table 2: Heat produced and electricity consumed from the hotel in 2010.

	Heat produce	Electricity produced or imported	CO2 emission - hotel
	kWh/year	kWh/year	kg CO2/year
Boilers	1874087	--	436552.0737
CHP: 794	1647784	1050967	681498.7078
CHP: 795	1274675	812996	527186.6038
Grid electricity (Low)	--	48243	24941.631
Grid electricity (Normal)	--	169279	87517.243
Total	4796546	2081485	1757696.259

5.4 Financial analysis

Figure 6 shows the actual monthly cost of operating the hotel energy plant with its CHP engines during 2010 compared with the baseline equivalent. Actual costs comprise payments to the equipment supplier as described above, fuel costs and the costs of grid electricity imported to meet total demand. Baseline costs have been calculated using the actual electricity and gas unit prices as applied to total gas and electricity demand. As described above, the gas use is calculated using heat demand and an assumed efficiency of a heat only boiler of 85%.

One difference between unit rates for gas between the CHP and baseline scenarios relates to the Climate Change Levy (CCL), an environmental energy tax. The CCL is payable by non-domestic energy consumers per unit of energy purchased. For gas, the rate in 2010 was 0.01791p/kWh. A qualifying CHP plant is exempt from paying this tax on gas purchases. In the case of this hotel, the effect was an approximate 95% reduction in CCL paid. Figure 6 shows clearly that when the CHP is operating fully during the winter months, the total cost of running the plant, including payments to the equipment supplier (red / pink) are less than would be payable under the baseline scenario (blue). However, in summer months, the costs of the CHP unit are greater.

Over the whole year, summing the monthly savings or losses, the cost of running the CHP engines was slightly more (£564) than the cost of running only gas boilers and importing all energy from the grid. Considering energy costs alone however (i.e. excluding payments to the equipment supplier) the costs of running the CHP engines would have been considerably less, therefore yielding greater savings: if an allowance is made for maintenance cost that would have to be paid (approximately £13k based on an indicative value of 0.7p/kWh given in Table 1), the value of these savings would have been ~£77k. These savings are magnified by the differential between gas and electricity prices. Until September 2010 the hotel was purchasing gas and top-up electricity under fixed price contracts. When these contracts ceased, the cost of electricity increased significantly while gas stayed roughly the same. The savings in October-December thus increased due to the value of grid electricity being displaced.

The analysis highlights the importance of the financing structure for realising the efficiency benefits of CHP. In this case study, the supplier is the owner of the CHP engine and receives £91k per year. Based on an installed capital cost of two 250kWe CHP engines of £420,000 and maintenance costs of 0.7p/kWh per year (Table 1), payback for the equipment supplier will be approximately 4 years. This contrasts with the breakeven position of the hotel as the energy user.

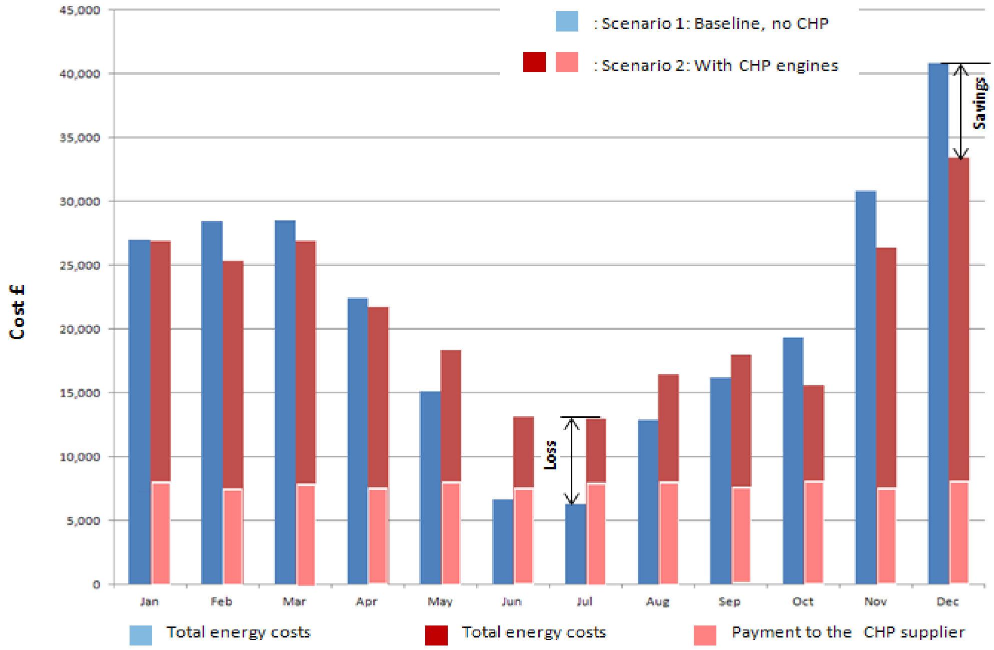

Figure 6: Financial operation of the hotel's energy plant compared to the baseline.

6 CONCLUSION

In response to the threat posed by climate change, the Government intention is to decarbonise the economy. It seeks to achieve this through carbon reduction targets and incentivises for investment in renewable energy (RE). In this context, a natural gas fired CHP engine can help towards decarbonising the economy in the near term by generating heat and electricity more efficiently and at a local level. In the longer term as the grid decarbonises, the carbon impact of a natural gas fired CHP engine will reduce; however there is significant potential to introduce alternative technologies and renewable fuels. Furthermore, if the natural gas engine to be replaced is connected to a DH network, no disruption to the end consumers will be caused.

This study has investigated the environmental and financial implications of using a DE system in the UK in the current conditions. A technology generating both heat and electricity, a CHP engine, has been selected to better identify the economic and technical implications linked to DE. It has been demonstrated that incorporating a CHP engine within a building is not trivial. However, the financial and environmental performance of a natural gas fired CHP engine in the UK has been validated: a natural gas fired CHP engine can reduce the operating cost of an energy plant and as long as grid electricity includes a small percentage of renewable sources or nuclear energy, the CO_2 emissions are also reduced. It has been shown that, in the absence of a heat store or alternative use of surplus heat, the operation of the CHP engine varies greatly between winter when the engine is beneficial and summer when the CHP engine may be oversized. In a further study the incorporation of an absorption chiller will be analysed to assess its viability while guaranteeing the good functioning of the CHP engine in the summer months. Finally, this case study has also shown that the financing structure of a DE system is important in terms of which entity realises the benefits of more efficient generation.

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