Routes to energy efficiency: complementary energy service products in the UK residential sector

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Abstract

Energy service companies represent a potential vehicle for transformation of the way the UK residential energy market operates and a windfall gain in supply-side energy efficiency. We consider two potential energy services company products that can provide economic and/or environmental benefits; grid-connected micro-Combined Heat and Power (CHP) and a time-of-use electricity tariff. We analyse each product independently, and then consider the synergies that exist between them. We draw upon a residential electricity demand model based on behavioural patterns which allows "shiftable" load to be identified, and assume that a consumer will shift load from high-priced periods to lower-priced ones. The economics of a time-of-use tariff as an independent product are thus evaluated. A cost minimisation model that chooses the best operating strategy and optimum micro-CHP electrical generation capacity to meet energy demand for the consumer is then applied to energy demand cases with and without load shifting under the time-of-use tariff. It is found that time-of-use charging and micro-CHP are weak complementary measures in an economic and environmental sense because load shifting results in only a slightly higher portion of the electricity load being met by the more efficient micro-CHP unit, resulting in a small decrease in equivalent annual cost and a small greenhouse gas emission reduction over and above that of each product independently. Both the time-of-use tariff and micro-CHP products are independently effective, offering a positive economic outcome to the investor. The synergy between the two products is small, but comes at no additional capital cost, and is therefore welcome.

Introduction

ESCOs serving the residential market offer an elegant means of addressing a number of efficiency, environmental, and social issues through offering energy as a service rather than through the traditional unit-based sales model [Biermann 2001]. Efficiency may be improved by more rapid introduction of new technology or increased penetration of existing technology, with associated reduction in carbon emissions and pollution, and possible alleviation of fuel poverty when achieved economically. Stakeholders principally tackle these issues in the centralised large-scale electricity supply industry by lowering costs and reducing environmental damage, but a shift in focus to the point of consumption using ESCOs as the vehicle could reap significant gains.

In UK residential properties, electricity is almost always supplied via the grid, and heat is delivered through a variety of means including boilers burning natural gas, electric heating (storage or direct), and occasionally district heating or other means such as heating oil or solid fuels such as coal [DTI 2004]. The efficiency of these modes of energy provision can be improved by new technology such as micro-CHP that can meet electricity and heat demand simultaneously. In addition to this supply-side efficiency gain, the cost of meeting a residential customer's electricity demand may be further reduced through incentives such as suppliers passing through time-of-use information via a time-of-use (ToU) tariff, allowing them to respond to price signals by shifting load from high-priced periods to low-priced ones. ESCOs offer a potential vehicle for delivery of products such as these to the large residential market.

This paper considers economic and environmental impacts of a hypothetical ESCO product offering customers a time-of-use electricity consumption tariff and/or micro-CHP onsite generation to residential customers. Each element of this ESCO product (i.e. the time-of-use tariff and micro-CHP unit) is considered individually, and then the extent of synergies between them are considered. The reason this particular combination of products was chosen is that they are perceived to have a symbiotic relationship in that shifting of load (in response to the ToU tariff) onto the morning heating period will result in more electrical load being met by the more efficient micro-CHP unit, reducing costs and greenhouse gas emissions.

We first present a brief background on residential Energy Service Company (ESCO) activity in the UK and elsewhere, followed by a review of micro-CHP technology and the principles of time-of-use charging. A model of a hypothetical ESCO product is then presented, where the micro-CHP unit is installed in an average UK residence, and that residence is also subject to a time-of-use tariff for grid electricity. We draw upon a model of residential electricity demand that allows "shiftable" load to be identified [Lampaditou and Leach 2005], and consider the economic and environmental outcomes of a case where the resident does not respond to the ESCO product (i.e. no load shifting) and a case where they shift load according to a few simple rules. Note that load reduction is not considered in this study; only load shifting where the customer chooses an appropriate time to consume electricity based on a time-of-use tariff and/or the heating cycle of a micro-CHP unit.

Background on Energy Service Companies

ESCO MARKET AND THE DISCOUNT RATE BARRIER

The restructuring of the electricity industry has curtailed traditional opportunities for integrated resource planning [Biermann 2001] and created new incentives for each market player. In most of Western Europe, overcapacity and competition among electricity producers have brought low electricity prices for residential customers. Since in industrialized countries electricity is a commodity, some end-customers choose their electricity supplier on the basis of least charged cost, but many do not even apply this judgment. However, some electricity vendors started to offer additional energy services, in an effort to differentiate from one another, segment and target their customer base, improve customer retention and increase profitability. This has been instrumental to the emergence of the Energy Service Companies (ESCOs) industry.

The services that ESCOs could offer to energy industry stakeholders including final energy users comprise:

- Supply and installation of energy-efficient equipment
- Maintenance and operation of local energy systems
- Building refurbishment
- Facility maintenance
- Supply of energy – including heat
- Energy use optimisation and monitoring
- Account management, tariff optimisation, consolidated billing
- Arranging finance for the operation of energy systems
- Guarantee of energy savings

Investment attractiveness of these energy services is usually determined by a trade-off between high transaction costs (i.e. capital or other initial up-front costs) and lower operating costs. Therefore, the discount rate applied to these investments and access to capital markets is important. A disparity exists between discount rates applied by energy supply companies and residential consumers for energy efficiency investments (i.e. supply and demand side respectively). Energy supply companies can often accept low rates of return on investment, such as those for large power stations or other infrastructure, while the implied rates for residential consumer purchases are invariably much higher [Commission of the European Communities 2003]. This discount-rate gap was noted in a number of empirical studies dating from the 1970s and its basis has been argued since in a broad body of research which suggests a number of possibilities to explain the discrepancy. These generally are: 1) consumer's preferences are well-formed and they are exposed to large intangible risks and costs associated with purchasing equipment, or 2) if consumer preferences are imperfectly formed, there exists a "no-regrets" potential for energy efficiency, or 3) there are a large number of social and psychological factors outside the realm of economics that influence consumer investment in this type of equipment [Nyober and Bataille 2004]. Regardless of its basis, it is apparent that this disparity creates potential to increase penetration of the energy efficiency technology through, for example, an ESCO-Supplier partnership that may provide a low enough required rate of return to justify investment supplementary to that which would occur if a residential consumer were making the energy efficiency investment decision. An ESCO-Supplier partnership should also have better access to capital markets than a residential consumer. A remaining barrier relating to the high discount rates applied by premises owners occurs where a property is leased in that responsibility for provision of energy often does not lie with the potential energy efficiency investor (i.e. the tenant is responsible for the energy bills whilst the landlord is responsible for the energy efficiency investment). This "split incentives" dilemma is a barrier because the benefit obtained from lower operating costs is not obtained by the investor, making payback impossible.

ESCO-RELATED ACTIVITY IN THE EUROPEAN UNION

At the European level, the European Commission has been promoting the ESCO industry and Third Party Financing since 1988. In 1993 a standard ESCO-type contract was drawn up for 12 countries; while in 2002 the European GreenLight programme identified ESCOs operating in the lighting field [Bertoldi *et al.* 2003]. Member states are bound to fully liberalize domestic electricity markets by July 2007; however, as the process of deregulation of the electricity industry has had distinct national characteristics for each member state, it would be premature to think that a EU-wide ESCO industry has developed. In 2003 [Vine 2003] the number of ESCOs varied from 4 in Belgium to 500-1 000 in Germany, but a large number of barriers to industry development were evident. In Vine's study, the most important barriers to the development of an ESCO industry included lack of information, public procurement rules and low energy prices. In late 2003, the European Commission put forward a proposal for a Directive on Energy End-Use Efficiency and Energy Services that is currently legislation in progress. The justification for this is a number of perceived barriers to realising potential greenhouse gas emissions reduction of energy efficiency measures including [Commission of the European Communities 2003].

- Lack of harmonised credible framework of instruments, mechanisms, definitions, and information regarding energy efficiency services and measures
- Institutional and legal barriers
- Fragmentation of the efficiency market
- Lack of visibility of savings potential
- Limited access to capital markets
- Lack of knowledge of cost effectiveness, returns and risks of investment

The UK government has placed great emphasis on the role of ESCOs in enhancing the competitiveness and sustainability of the UK energy system [Jones *et al.* 2001], and their contribution to greenhouse gas emissions reduction targets. Local authorities have been involved in several schemes, led by electricity vendors or other private sector partners, aimed at providing full energy services to residential customers. The primary policy instrument behind these actions is the Energy Efficiency Commitment (EEC). The EEC requires suppliers to deliver energy savings through energy efficiency measure in UK households, and had delivered more than three quarters of the 62 TWh energy efficiency target by its second year [OFGEM 2004]. A proposal to extend the EEC for a further six years (2005-2011) includes incentives for energy services and innovative products such as micro-CHP [Lord, Whitty 2004]. The energy efficiency target for the extension period appears likely to be 130 TWh. Also in the UK, the Energy Saving Trust (EST), established in 1992/3 to stimulate the market for energy efficiency amongst domestic customers, has had a key role in facilitating progress; however, as Biermann reports [Biermann 2001], the low price of energy is perceived as a strong barrier to the development of an ESCO industry.

Many suppliers in the UK cited the "28-day rule" as a barrier to the development of energy services. The 28-day rule stipulates that a customer is entitled to switch suppliers with 28 days notice. Suppliers claimed that this prevented them investing in energy efficiency measures with substantial transaction costs as the payback period was greater than 28 days. OFGEM argued that the 28-day rule was not a substantial barrier as suppliers could still recover their costs of the energy efficiency measure after the customer has switched suppliers. However, in May 2004 OFGEM, the regulator, suspended this rule in a pilot project [OFGEM 2004].

ESCOS AND COMPLEMENTARY ENERGY PRODUCTS

Complementary energy services are defined as a combination of products or services that when supplied together produce a complementary effect in that the economic result is better than the addition of the result obtained when each product is supplied separately.

The literature regarding complementary energy services, as investigated in this study, is relatively sparse. However, almost all ESCOs offer very basic complementary energy services through the combination of energy efficiency advice and energy efficiency measures (e.g. the combination of energy efficient lighting and advice regarding where in the premises it should be installed). Lawrence Berkeley National Laboratory [Mills 2002] has suggested a complementary energy services approach but focuses on the role of insurance and risk management industry and lists examples of complementary loss-prevention and energy service products well received by customers. Overall, recent developments in policy and industry actions noted in this paper suggest that the products offered by ESCOs will continue to become innovative as stakeholders become more familiar with the industry and with the potential for added value obtainable from energy product synergies.

Micro Combined Heat and Power: Technology and Prospects

Micro-CHP is a technology in design and development phase, with several companies investigating new technology for the market, and some moving forward to demonstration and early manufacturing-line style production. The primary technologies for the residential market are Stirling engines, fuel cells, and gas engines in a range of 1 kWe to 5 kWe.

In the UK Stirling Engines appear to be the first to market. For example, Whispergen technology is to be marketed by Powergen in the UK, with 400 units installed in winter 2004/2005, and a commitment to the purchase of 80 000 units over the next five years if this trial is successful [E.ON|UK 2004; Whispergen 2004]. Stirling engines are characterised by low electrical efficiency in the 10-20% range, and good heat recovery characteristics providing overall efficiencies around 90-95%.

Solid Oxide Fuel Cell (SOFC) technology is also a promising prospect for micro-CHP. This technology is embryonic, primarily in the research and development phase, but shows great potential for the micro-CHP market. Electrical efficiencies are of the order of 45%, and overall efficiencies around 80-90% depending upon final balance of plant loads. SOFCs benefit from the ability to be fuelled directly by natural gas, with fuel reformation occurring directly on the anode. SOFC technology is the focus of this study.

Proton Exchange Membrane (PEM) fuel cell technology is also a contender for micro-CHP. Stakeholders considering this technology include Avista Labs, Ballard, H Power, and others. Expected electrical efficiencies are around 30%, with an additional 38% of energy recoverable as heat. High capital costs and the need for a direct hydrogen fuel supply (or additional fuel reformation processes) hamper the introduction of PEMFCs.

Gas engines are presently the most widely used micro-CHP technology in Germany, with the German manufacturer Senertec and Swiss company Ecopower as market leaders in the 3 to 5 kWe range. Further units will be available soon. Some gas engine examples are the Marathon Engine Systems Ecopower Micro-CHP (3.7 kWe), and the Baxi DACHS gas reciprocating engine (5.5 kWe).

Time-Of-Use Charging for Electricity: Principles and Practice

The marginal cost of consuming electricity is dependent on the time of use. A simplistic explanation for this is that the more efficient and/or cheaper generating plant is likely to be running in the baseload, and thus at times of high demand, less efficient and/or more expensive generation is dispatched, resulting in higher prices per unit. Electricity prices on the UKPX (UK Power Exchange) reflect this trend, and exhibit significant volatility at times of high demand, further contributing to electricity cost at these times as stakeholders incur additional expense in managing the risk of their positions. This fact is well understood by generators and suppliers, and results in suppliers offering time-of-use tariffs to customers that consume larger amounts of power. These time-of-use tariffs form part of contracts between suppliers and customers and are specific to each customer's electricity consumption profile. However, residential customers are typically offered a tiered tariff (i.e. tariff 1 for the first x kWh of electricity consumed per quarter, tariff 2 thereafter). This situation is not ideal because the resulting lack of price signals in this sector leads to larger electricity demand peaks that are linked to economic inefficiency, additional greenhouse gas emissions, and avoidable investment in generation assets. This is particularly notable as the residential sector used approximately 30% of electrical energy but accounted for 46.8% of system peak electrical demand in the UK in 2001 [Efflocom.Project 2003]. Approximately 6% of residential demand at peak times is accounted for by wet appliances, which are the focus of load shifting in this study [Lampaditou and Leach 2005].

With recent breakthroughs in communications technology (e.g. PLC Broadband, Wireless, etc), and price reductions in metering equipment, it is conceivable that a cost-reflective time-of-use tariff could be offered to residential customers. In the UK a very basic time-of-use tariff is available through most suppliers. Commonly referred to as "Economy 7", these tariffs offer lower prices in the early hours of the morning (and higher prices than the standard tariff during the day) primarily to encourage households with electric storage heaters to use them at these times. This relatively coarse time-of-use tariff could be much improved to include within-day components that reflect the actual time-dependant cost of electricity from the grid, causing residents to shift load from higher price to lower price periods or avoid consumption in high priced periods.

Recent studies [Lebot et al. 1997; Grønli and Livik 2001; Sidler 2003] indicate that ToU tariffs reflecting the time-dependent nature of electricity prices are effective in influencing customer behaviour, so as to reduce peak power by factors ranging from 2.8% to above 12%.

This study considers the economic impact of a time-of-use tariff where the resident can choose to shift load of wet appliances from high-priced periods to lower-priced periods. Load reduction is not considered.

An Example Energy Service Company Product

There are many potential ESCO products, ranging from simple energy saving advice to complete analysis of a premises and installation of energy efficiency and energy generation technology. In this analysis we use a specific example of a combination of potential ESCO products that offer the possibility of a symbiotic effect where economic and environmental outcomes are improved by the products' interaction over and above the individual contribution of each product combined. The combination of products we have chosen as an example are a time-of-use tariff and Solid Oxide Fuel Cell (SOFC) micro-CHP.

The hypothesis is that a time-of-use tariff (resulting in load shifting) and micro-CHP have complementary effect for the following reasons: in the absence of efficient/affordable energy storage, CHP generation is more efficient at times when electricity and heat demands are both high. Therefore, if we install CHP in a residential property, and shift electricity loads to improve the coincidence of electricity and heat demands, we should obtain an economic benefit because the CHP unit will meet a larger portion of electricity and heat loads simultaneously. The primary target is to move electricity loads to the morning heating period, when residential electricity load is typically low. This effect is coupled with a positive environmental outcome in that more grid electricity import will be avoided. As grid electricity typically has a higher emissions rate than efficient onsite cogeneration, and grid electricity import is avoided, less carbon dioxide will be produced as a result of the overall energy consumption.

For modelling purposes we have employed London Energy's Competitive Half-Hourly tariff for our time-of-use tariff, and have based the micro-CHP on optimally dispatched SOFC technology simulated by the cost minimisation model presented in the next section. The electricity buy-back rate is assumed to be half of the London Energy Competitive HH tariff from 11 am to midnight, and zero at all other times.

Equivalent Annual Cost Minimisation Model

An existing model developed by the authors is applied to analyse the example ESCO product outlined above.

The purpose of the model is to identify the minimum "equivalent annual cost" (EAC – in UK pounds), and corresponding "optimum" micro-CHP electrical generation capacity (kWe) and supplementary boiler thermal output capacity (kWth), to meet a given energy demand profile. The system is optimally dispatched (i.e. dispatched to provide minimum energy cost) and is grid-connected. Equivalent annual cost (EAC) of meeting energy demand is defined as the equivalent cost per year of owning the micro-CHP/boiler system over their entire lives at a given discount

Table 1. Selected Input Parameters.

Variable Name	Value	Notes
SOFC Stack and BOP Cost	£250/kW$_e$ + £250	£250 for any SOFC, plus £250 for each SOFC kWe installed
Supplementary Boiler Cost	£50/kW$_{th}$ + £1 000	£1 000 for any Boiler, plus £50 per kWth installed
SOFC Annual Maintenance Cost	£20/year	
Boiler Annual Maintenance Cost	£45/year	
SOFC Lifetime	10 years	Medium-term technology
Boiler Lifetime	10 years	Present technology
SOFC Efficiency Curve	$0.049r^3 + 0.008r^2 - 0.285r + 0.59$	Where *r* is the instant load factor (power output divided by capacity)
Boiler Efficiency Curve	0.9	
Dwelling Annual Electricity Demand	4,356 kW$_e$h	Near UK Average
Dwelling Annual Heat Demand	17 950 kW$_{th}$h	Near UK Average
Peak Electricity Demand	5 kW$_e$	
Peak Heat Demand	16.2 kW$_{th}$	
Discount Rate for Equipment Purchase	12%	A reasonable commercial rate

rate, plus the cost per year of providing whatever fuel and supplementary electricity is necessary to meet energy demands in the dwelling. It is necessary to use equivalent annual cost in this study rather than net present value as the CHP unit and supplementary boiler can have different lifetimes. The optimisation performed can choose optimum capacities of the CHP unit and of the additional boiler, along with the operating regime for each time period, or can choose the optimum operating regime for each time period for specified fixed capacities of the micro-CHP and additional boiler.

EAC can be broken down into 9 components. These are:

1. Equivalent annual capital cost of the micro-CHP unit.
2. Equivalent annual capital cost of the supplementary boiler unit.
3. Annual maintenance cost of the micro-CHP unit.
4. Annual maintenance cost of the supplementary boiler unit.
5. Variable maintenance cost of the micro-CHP unit, per kWh electrical output.
6. Variable maintenance cost of the supplementary boiler unit, per kWh thermal output.
7. Annual cost of natural gas to fuel the micro-CHP unit and the supplementary boiler unit.
8. Annual cost of electricity import to the premises.
9. Annual revenue from electricity export from the premises.

Therefore, the model simulates a complex trade-off between the capital cost of the micro-CHP against the capital cost of the supplementary boiler unit, in terms of the total cost of meeting the given energy demand profile. Increased micro-CHP capacity provides a high capital cost option to displace electricity import from the grid or export energy to the grid whilst simultaneously meeting heat demand. The supplementary boiler provides the option to meet heat demand efficiently at low capital cost, but provides no electricity import displacement/export benefits. Thus the two technology options, one high value high cost, the other low value low cost, compete in terms of total energy-provision cost for a "market share" of the energy demand.

The model uses 6 "typical" days energy demand data – 2 days for each season (Summer, Shoulder and Winter). Both electricity and heat demand data exhibit fine temporal precision (5-minutes per time-step) in order to adequately capture demand peaks and fluctuations [Hawkes and Leach 2005a].

Further details of the modelling approach are available in [Hawkes and Leach 2005a] and [Hawkes and Leach 2005b]. Other similar modelling approaches in this area have been undertaken by Lawrence Berkeley National Laboratory [Siddiqui et al. 2003] and National Renewable Energy Laboratory [NREL 2004].

Model Input Data

A selection of input data that were used are now presented.

The energy demand profiles employed here are designed to represent an average UK dwelling with approximately three bedrooms and occupied by approximately four people. Sample load profiles and ToU energy tariffs are provided in the appendix.

Results and Discussion

The equivalent annual cost minimisation model is now applied to our specific case of residential electricity and heat demand. We first identify the baseline case – where a boiler-only system is purchased by the investor and a time-of-use tariff is applied to electricity purchase, but no load shifting is undertaken. We then consider the economics of a case where load shifting is undertaken and the time-of-use tariff

Table 2. Equivalent Annual Cost (£/year) of meeting an average UK residential energy demand, and associated carbon dioxide emissions (kg CO2/year), and installed micro-CHP capacity (kWe).

Case	Equivalent Annual Cost - £/year (Euro/year)[1]	Carbon Dioxide Emissions - kg/year	Installed Micro-CHP Capacity - kW_e
Baseline	1 021 (1 429)	4 802	0
Load Shifting	990 (1 386)	4 802	0
Micro-CHP, No Load Shifting	1 009 (1 413)	3 748	1.5
Micro-CHP, with Load Shifting	973 (1 362)	3 728	1.5

is applied as an independent product. Optimum micro-CHP capacity is then identified for the energy demand profile without load shifting, and its cost advantage over the baseline boiler-only system is presented. Then the combination of the micro-CHP product and the time-of-use tariff (with load shifting) product is investigated. In addition to economic performance, the carbon efficiency outcomes for the cases are presented.

BASELINE RESULT

The baseline scenario for this study is that where the consumer chooses to invest in a boiler-only system, and to meet all electricity requirements by importing from the grid, and does not shift any load. The baseline result is presented in the first row of Table 2.

LOAD SHIFTING RESULT

This result is for the case where the customer shifts wet appliance load in response to the time-of-use tariffs, but no CHP unit is installed at the premises. Load shifting resulted in a saving of £31/year (43 Euro/year) on the cost of energy for this dwelling. As we are using grid-average emissions rate for electricity import, carbon dioxide emissions are unchanged by load shifting alone (note that a marginal emissions rate based on time of day and season is required to obtain the actual emissions reduction resulting from load shifting, but this is beyond the scope of this study).

MICRO-CHP UNIT RESULT

We now consider the possibility of using a micro-CHP unit to meet a portion of the onsite electricity and heat demands. We apply the equivalent annual cost minimisation (EAC) model to determine the minimum EAC, optimum micro-CHP capacity, and associated carbon dioxide emissions. This result assumes that the consumer does not undertake load shifting. As displayed in Table 2, the benefit to the investor from using a 1.5 kWe micro-CHP unit is £12/year (17 Euro/year). Carbon dioxide emissions reduction over the baseline (boiler-only) system is 1 054 kg/year assuming grid-average emissions rates for imported electricity.

LOAD SHIFTING COMBINED WITH MICRO-CHP UNIT RESULT

The EAC minimisation model is employed again to determine the energy provision cost and optimum micro-CHP capacity in a scenario where wet appliance load shifting has been undertaken by the consumer. The load shifting undertaken in this case is identical to that investigated above where load shifting was considered independently. The result for this case is presented in Table 2, with a cost benefit to the investor of £17/year (24 Euro/year) over the case with load shifting as an independent product. The optimum micro-CHP capacity remains at 1.5 kWe. Carbon dioxide emissions reduction over the baseline (boiler-only) system is 1 074 kg/year assuming grid-average emissions rates.

DISCUSSION

Under the tariff and load conditions investigated, load shifting, as an independent measure, provides the most significant financial benefit to the investor. Also, the micro-CHP unit alone is an attractive investment with improved EAC over that baseline at a discount rate of 12%, and has significant environmental benefits with over a tonne of CO_2 abatement. But perhaps the most interesting result is the cost-free complementary interaction between the time-of-use tariff and the micro-CHP unit. Based on the result for micro-CHP as an independent product, we would expect a £12/year reduction in cost with the addition of a micro-CHP unit (i.e. the EAC difference between the baseline and micro-CHP only cases is £12/year). However, the actual reduction in cost observed is £17/year, implying that £5/year (7 Euro/year) is a direct result of the complementary interaction within our example ESCO product. While this gain is modest, it does prove that these symbiotic relationships exist between energy services even at the residential level. Additionally, when compared with the £12/year difference between the baseline (boiler-only) system and independent micro-CHP system result, this modest gain does not seem so small.

Figure 1 plots the equivalent annual cost (EAC) of meeting the energy demand, against the installed micro-CHP capacity in kWe for cases with and without load shifting.

In Figure 1, as noted in the results above, the minimum EAC is reached when 1.5 kWe of micro-CHP capacity is installed for both cases (with and without load shifting). A slight divergence between the two lines is apparent. This divergence is the result of the complementary nature of the considered energy products.

The reason for the modest nature of the economic gain from the complementary effect is now considered. Avoided electricity import is the primary cost driver behind the synergy, because load shifting onto the heating periods allows electricity to be generated onsite, thus avoiding high cost electricity import. Figure 2 plots the electricity import cost versus installed micro-CHP capacity, and demonstrates the extent of the economic gain when combining load shifting and CHP. The divergence between the lines representing cases with and without load shifting is the extent of the symbiotic effect. However, Figure 2 does demonstrate that elec-

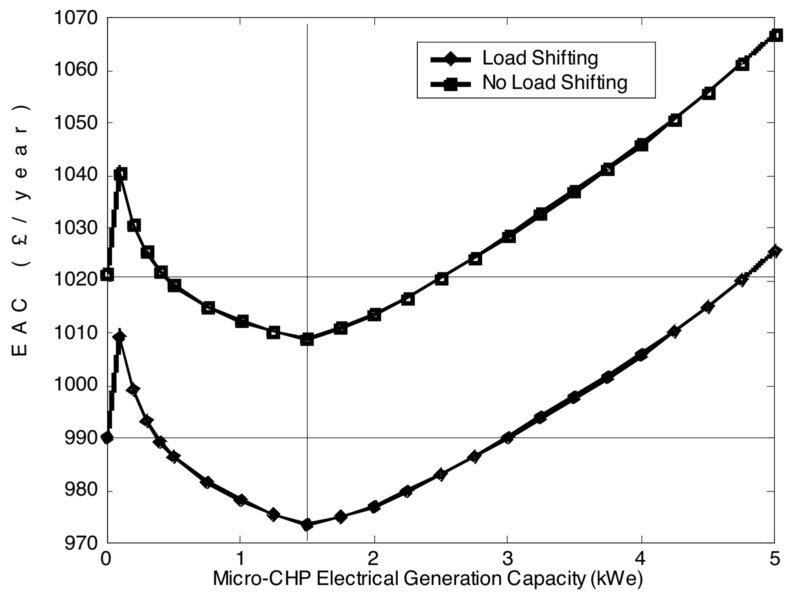

Figure 1. *Equivalent Annual Cost (EAC) of meeting an average residential energy demand versus installed micro-CHP capacity (kWe) for cases with and without load shifting.*

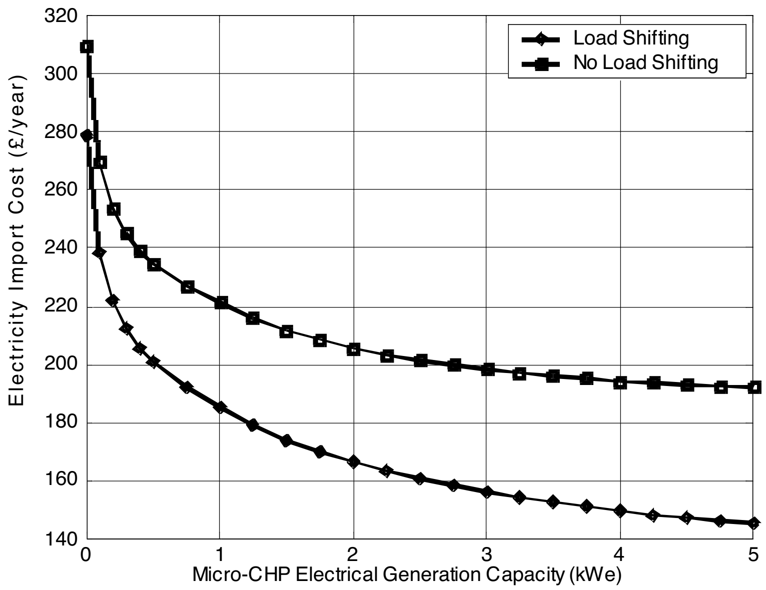

Figure 2. *Electricity Import Cost per year (£/year) versus installed micro-CHP electrical generation capacity (kWe) for cases with and without load shifting.*

tricity import is the most important factor regarding the synergy, as it accounts for the full £5/year "symbiotic" benefit noted above.

Now that we have identified electricity import cost as the source of the symbiosis, we consider the reasons why its influence is so modest. The following list provides an explanation:

1. When load is shifted, it is added to load pre-existing in the heating period. Therefore the shifted load may be out of the capacity range of the CHP unit, and some electricity import will still be necessary.
2. The cost of importing power in low-priced periods is approximately equal to the cost of generating heat, and displacing the cheap electricity import (because the morning period is cheaper than later in the day). Therefore shifting electricity import from low-priced periods to the heating period will result in little financial benefit.
3. The amount of wet appliance "shiftable" load is small, so any complementary effects of combining load shifting and CHP are also small. Only 200 kWh (approx) electricity import is avoided through combining load shifting and micro-CHP (for a 5.0 kWe unit). As the cost parity

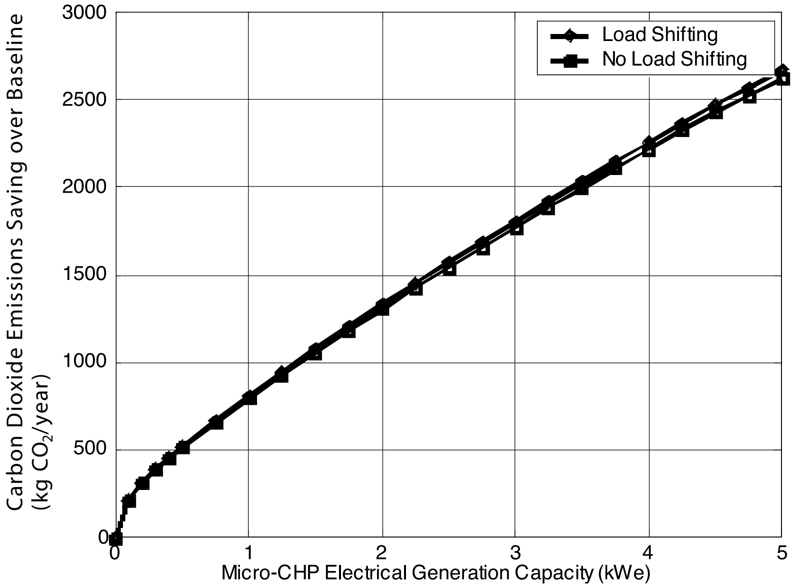

Figure 3. *Carbon Dioxide Emissions Saving relative to Baseline (boiler-only) versus installed micro-CHP capacity for cases with and without load shifting.*

between importing electricity (in the case without load shifting) and generating electricity/heat (in the case with load shifting) is small, 200 kWh is insufficient to have any significant impact on economic outcomes.

The carbon savings relative to the baseline are now investigated. Grid-average emissions rate (0.43 kg CO_2/kWh) is used as an approximation, and carbon emissions from burning natural gas are assumed to be 0.189 kg CO_2/kWh. Figure 3 shows that while the carbon dioxide emissions saving relative to the baseline is substantial, with a saving of more than one tonne per year for the optimum 1.5 kWe micro-CHP system, the difference in carbon dioxide emissions saving with and without load shifting scenarios is small at only 20 kg CO_2/year (i.e. the two lines are very close to one another). The reasons for this outcome are identical to the three economics points noted above. The reader should note that emissions calculations have been performed here using grid-average emissions rates. Marginal emissions rates should be used for more precise estimation.

Conclusion

The concept of complementary combinations of energy-related products has been introduced in the context of energy service companies in the UK residential sector. The background for energy service companies is considered, and we find there is substantial activity relating to this area, and products, services and policies presented by stakeholders are becoming more extensive and more innovative.

We then considered the case of a specific combination of complementary energy service products as an example. We apply a model to minimise the equivalent annual cost of meeting a residential electricity and heat demand profile using a micro-CHP unit and a supplementary boiler, under conditions of a time-of-use tariff for electricity. We consider the outcomes from this model under one case where load is shifted to the morning heating period, and one case where it is not shifted.

We find that the time-of-use tariff is effective as an independent product, providing for £31/year energy cost saving if the consumer shifts wet appliance load to the early-morning time periods. The micro-CHP unit is also effective as an independent product, providing £12/year cost reduction (under a discount rate of 12%), and more than one tonne of CO_2 abatement per year. The combination of these products yielded a modest £5/year additional cost saving over and above the sum of the independent product outcomes. The greenhouse gas emissions reduction resulting directly from the interaction between time-of-use tariff and micro-CHP amounted to only 20 kg CO_2/year, which is dwarfed by the reduction achieved by the micro-CHP unit alone. The modest nature of this result is due to the difficulty of avoiding electricity import with a low capacity micro-CHP generator when load is shifted because of load superposition, small cost parity between low-price import and CHP-generation, and the relative scarcity of "shiftable" load.

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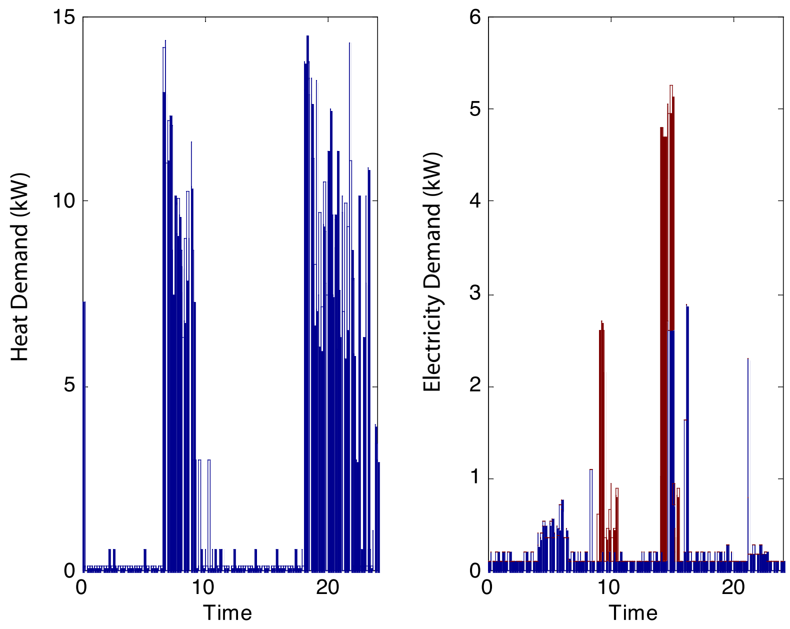
Appendix

SAMPLE INPUT LOAD PROFILES – ONE DAY IN WINTER:



SAMPLE TIME-OF-USE TARIFFS FOR DECEMBER/JANUARY: