Carbon Savings in the Buildings Sector_24i **Gordon Taylor** **2008-02-18**

Summary

The on-site generation of electricity and heat from renewables – often called microgeneration - has been proposed in the U.K. for saving carbon – reducing carbon emissions – in the buildings sector. This has been taken up by local and national government. For example, the Merton Rule is said to require that 10% of the building energy demand be met from on-site renewable measures. However, there is no evidence that these are the most cost-effective at saving carbon.

The Government has proposed that new homes reach a 'Zero-Carbon' target from 2016, apparently with the help of on site renewables. However, there is no evidence that this is the most cost-effective way of reducing the carbon emissions of buildings.

Microgeneration includes several ways of generating electricity and heat. However, the performance, efficiency and cost of all energy supply units are affected by scale, where the scale ranges are from 1000 to 100,000 to 1. The capacity factor or efficiency falls as the unit size – kW rating – is reduced. These effects are particularly strong for the generation of electricity by small wind turbines and of heat by micro-chp units. However, they also apply to the generation of electricity by photovoltaic (PV) arrays, and of heat by solar collectors, heat pumps and biomass heaters and boilers. Moreover, for all types, the specific cost is increased as the unit size – kW rating – is reduced.

Due to these scale effects, the cost of carbon saving for most microgeneration measures is high or even infinite when the carbon saving is zero. They are compared with those for fossil fuelled Combined Heat and Power (CHP) in the chart on page 25. Although the data is drawn from various sources, with different values for the carbon intensities, this is sufficient to compare the costs of carbon savings in order of magnitude. Of the on-site renewable measures, only biomass heating gives costs of carbon saving comparable with that of off-site fossil CHP. Moreover, the other on site renewable measures would place wholly disproportionate demands on the U.K. building industry. Yet they would be largely limited to new buildings. Furthermore, since all energy technologies require 'embedded' energy to be invested, 'Zero Carbon' requires that this be repaid within the plant lifetime. Thus the Energy Return on Energy Invested (EROI) must be greater than one – indeed the higher the better. This means recognizing the beneficial effects of large scale, which can only be realised by off site measures.

The evidence in this paper confirms what has been proven in over 'a thousand' cities on the Continent: district heating from off-site large-scale CHP and renewables is far more effective, cost- and energy-effective at saving fossil fuel and carbon. A major IEA study on CHP/DH found: 'The City-wide CHP/DH system benefits from a high efficiency, low capital cost, CCGT power plant, which more than offsets the additional costs of city-wide heat distribution'. 'A further advantage of the larger-scale DH systems is the ability to obtain heat from other sources including waste to energy plants and industry'. Moreover, it can be deployed 'city-wide' in many cities at once, thus serving the majority of existing and new buildings, and in about seven years. Existing buildings account for the vast majority of carbon emissions – especially when weighted for heat loads. For new buildings, Continental countries are also increasingly adopting the Passive House standard, that reduces space heating demands by about 90%. For electricity demands, they are adopting high efficiency appliances and lighting, with supply from the large CHP stations and large wind turbines. Hence the fuel and carbon emissions savings can be fastest and greatest. Furthermore, many energy savings measures have negative lifecycle costs. A major study by Vattenfall with McKinsey considered the costs of Greenhouse Gas abatement measures for all sectors. Those for the buildings sector 2030 are not on-site renewables (microgeneration), but energy savings and increased energy efficiency - all with negative lifecycle costs.

Within a framework of Carbon Emission Obligations, energy saving measures and off site fossil CHP and renewables could be implemented profitably by Energy Service Companies, which – unlike most consumers – have the necessary skills and access to low-cost, long-term capital, and could deliver the vital carbon savings.

Introduction

The on-site generation of electricity and heat from renewables – often called microgeneration - has been proposed in the U.K. for saving carbon – reducing carbon emissions – in the buildings sector. This has been taken up by local and national government. For example, the Merton Rule is said to require that 10% of the building energy demand be met from on-site renewable measures. However, there is no evidence that these are the most cost-effective at saving carbon.

The Government has proposed that new homes reach a 'Zero-Carbon' target from 2016, apparently with the help of on site renewables. However, there is no evidence that this is the most cost-effective way of reducing the carbon emissions of buildings.

Microgeneration includes several ways of generating electricity and heat. However, scale effects are common in engineering, so that what is attractive at large-scale, may be far less attractive at small-scale. The performance, efficiency and cost of all energy supply units are affected by scale - e.g. the output capacity rating in kW. Moreover, the scale ranges are from 1000 to 100,000 to 1. Thus the capacity factor or efficiency falls as the unit size – kW rating – is reduced. These effects are particularly strong for the microgeneration of electricity by small wind turbines and of heat by micro-chp units. (See http://www.energypolicy.co.uk/sustainpres.htm Slides 19 and 26). However, they also apply to the generation of electricity by photovoltaic (PV) arrays, and of heat by solar collectors, heat pumps and biomass heaters and boilers. In addition, for all types of plant, the specific cost rises as the unit size – kW rating – is reduced. (See http://www.energypolicy.co.uk/epolicy.htm Fig. 3).

Initial References

When considering on site renewable (microgeneration) measures in the UK, yields of electricity and heat have often been taken from these references.

- 'Integrating Renewable Energy into New Developments: Toolkit for Planners, Developers and Consultants', Faber-Maunsell, September 2004. (http://www.london.gov.uk/mayor/environment/energy/docs/renewables_toolkit.pdf).

- 'Microgeneration strategy and low carbon buildings programme: consultation', June 2005, DTI, Annex A. (http://www.berr.gov.uk/files/file13989.pdf). (The double-quoted and italicised text below is taken from this reference).

- 'Potential for Microgeneration – Study and Analysis', Energy Saving Trust, December 2005. (http://www.berr.gov.uk/files/file27558.pdf).

- 'Powering London into the 21st Century', by PB Power for the Mayor of London and Greenpeace, March 2006. (http://www.london.gov.uk/mayor/environment/energy/docs/powering-london-21st-century.pdf).

ELECTRICITY

Micro Wind Turbines

"A typical small scale system costs between £2,500 - £5,000 per kWe installed[37]. A small wind turbine of 6kW capacity (sufficient for all of the electricity requirements of two or three typical UK households), costing about £20,000 to install, will generate about 10,000 kWh per year[38]. This might amount to financial savings of around £700 per year[39] and would equate to carbon saving of 4.3 tCO2/year[40]. The pay back time on an average 6kWp system would therefore be around 29 years (based on current electricity prices).

[37] Summary of renewable energy technologies characteristics, from the London Renewable: Toolkit for planners, developers and consultants', section 3; www.london.gov.uk/mayor/environment/energy/london_renew.jsp
[38] BRE. Based on case study from Clear Skies programme.
[39] The price assumes a net metering arrangement where the community receives similar rate for export as for import of electricity of around 6 – 7p/kWh
[40] Carbon saving calculated using the DEFRA electricity displacement coefficient of 0.43kg CO2./kWh used since 2000".

● Results for small wind turbines of 15 and 6 kWe have been published Thames Valley Energy. (http://www.tvenergy.org/case-studies.htm).
These show that the capacity factors vary not just with unit size, but also significantly between locations.

● The initial results for an Ampair 600 wind turbine were 14 kWh in 694 hours. (See 'The Warwick Urban Wind Trial Project', Interim Report, March 2007.
http://www.warwickwindtrials.org.uk/resources/Warwick+Wind+Trials+Interim+Report+Final+2.pdf Page 11).
With a rated capacity of 600 Watts, this implies an annual output of 179 kWh and a capacity factor of 3.4 %.

● Further results for Ampair 600 wind turbines have come from the Warwick trials. However, they are only for month-long periods, and thus merely indicative. (http://www.my-energy.org.uk/MY/NetworkWorkshop-9thMay-sig.nsf/ab283684d03f231d80256b520047d321/94dd0f7e28559c3c802572f9003cdb66?OpenDocument Slide 10).
The Lillington Road site gave 10 kWh per month. Thus the capacity factor was 10 x 12/(0.6 x 8760) = 2.3%.
The Hill Close Gardens site gave 25 kWh per month. Thus the capacity factor was 25 x 12/(0.6 x 8760) = 5.7%.
While the latter is slightly above the range suggested by the Loughborough CFD study (below), this is probably because the turbine is not building- but pole-mounted.
(http://www.warwickwindtrials.org.uk/resources/Warwick+Wind+Trials+Interim+Report+Final+2.pdf Page 25 of 29).

● The capacity factor for an Urban Wind Turbine of about 1 kWe would be between 1% and 5%. (See 'Predicting the yield of small wind turbines in the roof-top urban environment', Simon Watson et al., Loughborough University, presented at EWEC 2007. http://www.ewec2007proceedings.info/allfiles/52_Ewec2007presentation.ppt Slide 13).
Thus, due to scale and environmental effects, the yields and capacity factors for micro wind turbines of about 1 kWe are much lower than those for small wind turbines of 6 and 15 kWe. This comprehensive study is confirmed by the initial findings of the Warwick field trial (above). These results are fundamental and cannot be bettered by any other design of wind turbine. Although they are strictly site-specific, the results for other urban areas would be very similar.

● A study on micro-wind turbines has been published by the BRE, dated November 2007.
http://www.guardian.co.uk/environment/2007/nov/30/windpower.carbonemissions
http://www.bre.co.uk/newsdetails.jsp?id=456 In summary, due to the embedded (or 'grey') energy invested in the hardware, micro-wind turbines would often be not an energy source but an energy sink and increase CO2 emissions.

Micro-WT	Yield – kWh/kW.y	Capacity Factor - %	
	2400	27.4	The Renewable Toolkit for GLA - 2004
	1666	19	Microgeneration Strategy for DTI - 2005
Domestic Commercial		17 25	Potential of Microgeneration for EST - 2005
	2000	22.8	Powering London for MoL – 2006
Measured			
Proven 15 kW Proven 6 kW		19.3, 22.1 7.4 to 22.8	Thames Valley up to 2007
Ampair 600		3.4	Warwick Wind Trial, Lillington Rd, 2007
Ampair 600		2.3 5.7	Warwick Wind Trial, Lillington Rd, 2007 Warwick Wind Trial, Hill Close Gardens, 2007
Urban WT		1 to 5	Loughborough CFD paper, 2007

The quoted text and data above is for a small wind turbine of 6 kWe. Assuming a lifetime of 20 years, and no maintenance, the cost of electricity would be about 20000 x 100/(20 x 10000) = 10p/kWh. This assumes that it is all used on site, or that any exported is sold at the cost price. The carbon saving is 4.3 tCO2/y – i.e. 1.17 tC/y - and the cost of carbon saving is £ 20000/(20 x 1.17) = £ 855/tC/y. However, building mounted micro-wind turbines are much smaller, at around 1 kWe.

According to the Energy Saving Trust, the initial cost of a building mounted micro-wind turbine is from £ 1500. (http://www.energysavingtrust.org.uk/generate_your_own_energy/types_of_renewables/microwind). However, this is for the Windsave 1 kWe turbine, which has yet to be delivered. For the Ampair 600W (600-230), the price is £ 3500. (See ‘The Warwick Urban Wind Trial Project’, Interim Report, March 2007. http://www.warwickwindtrials.org.uk/resources/Warwick+Wind+Trials+Interim+Report+Final+2.pdf P 10 of 29).

Assuming an initial cost of £ 3500, an annual output of 179 kWh, and an electricity price of 9.46 p/kWh, the payback time would be (3500 x 100)/(9.46 x 179) = 207 years. Assuming no maintenance costs over a 20-year lifetime, the cost of electricity would be (3500 x 100)/(179 x 20) = 98 p/kWh – over ten times the present domestic price of 9.46 p/kWh.

Taking the carbon intensity of electricity delivered at low voltage as 0.548 kgCO2/kWh – i.e. 0.149 kgC/kWh, and the annual output as 179 kWh, the carbon saving would be 0.149 x 179 = 26.7 kgC/y. (See Appendix A). The cost of carbon saving would be (3500 x 1000)/(20 x 26.7) = £ 6540/tC/y.

Micro wind turbines in urban areas have extremely low yields, such that the payback time is about 207 years, the cost of electricity is about ten times as high, and the cost of carbon saving is about £ 6540/tC/y. Moreover, when account is taken of the energy invested in the hardware, they are very often not an energy source but an energy sink, and would increase carbon emissions.

Solar PV Systems

"A typical household system of 2kWp could provide an average of between 40-50% of total annual electricity needs. The cost of installing a PV system varies depending on whether it is a standard bolt on system or a more integrated system, but the average cost is around £6,300 per kWp[32].
A 2 kWp system would generate around 1500kWh/yr[33]. This might amount to financial saving (in the form of reduced electricity costs) of around £100[34] per year and would equate to a carbon saving of about 0.65 tCO2/ year[35]. The pay back time on an average 2kWp household system would therefore be around 120 years (based on current electricity prices).

[32] Cost is based on data from the Major PV Demonstration Programme Stream 1
[33] Energy generation is based on following assumption (derived from experiences of the Major PV Demonstration Programme) an average of 750kWh/kWp per year
[34] The price assumes a net metering arrangement where household receive similar rate for export as for import of electricity of around 6 – 7p/kWh
[35] Carbon saving calculated using the DEFRA electricity displacement coefficient of 0.43kg CO2./kWh used since 2000".

- In the BRE Field Trial, many PV systems gave yields of over 800 kWh/kWp and the best over 900 kWh/kWp. The corresponding capacity factors are 9.1% and 10.3%. (See http://www.bre.co.uk/filelibrary/rpts/pvdt/PVDFT_Final_Techn_Report.pdf). Page 6 notes that 'based on a system lifetime of 25 years' and when *'known underperforming systems are removed, the average and maximum costs (of PV generated electricity) are 39.1 p/kWh and 77.8 p/kWh'*. This was nearly 5 and 10 times the then current (domestic) electricity prices of about 8 p/kWh.

- The Thames Valley Energy results for PV systems show that the yields may be significantly lower in practice, with capacity factors from about 5 to 9.2%. (http://www.tvenergy.org/case-studies.htm).

PV	Yield – kWh/kWp.y	Capacity Factor - %	
	854	9.7	The Renewables Toolkit - 2004
	750		Microgeneration Strategy, for DTI - 2005
	846	9.7	Potential for Microgeneration, for EST - 2005
	1000	11.4	Powering London, for MoL - 2006
Measured			
	Many > 800	9.1	Domestic PV Field Trials, by BRE - 2006
Range		~5 to 9.2	Thames Valley results to 2007

The quoted text and data above gives a carbon saving for a PV system of 0.65 tCO2/y – i.e. 0.177 tC/y. Assuming a lifetime of 20 years, the cost of carbon saving is (2 x 6300)/(20 x 0.177) = £ 3559/tC/y.

For PV systems, the Energy Saving Trust web site gives installed costs of £ 5000 to 8000 per kW peak. (http://www.energysavingtrust.org.uk/generate_your_own_energy/types_of_renewables/solar_electricity). At a capacity factor of 9%, a 1 kWp system might generate about 800 kWh/y. The payback time would be 5000 x 100/(800 x 9.46) = 66 to 8000 x 100/(800 x 9.46) = 106 years – over three to five times the lifetime. Also, for a lifetime of 20 years, the cost of electricity would be 5000 x 100/(800 x 20) = 31 to 8000 x 100/(800 x 20) = 50 p/kWh – about three to about five times the present domestic price of 9.46 p/kWh.

Taking the carbon intensity of electricity delivered at low voltage as 0.548 kgCO2/kWh – i.e. 0.149 kgC/kWh, and the annual output as 800 kWh, the carbon saving would be 120 kgC/y. (See Appendix A). The cost of carbon saving would be (5000 x 1000)/(20 x 120) = £ 2091 to (8000 x 1000)/(20 x 120) = £ 3345/tC/y.

HEAT

Micro-chp Units

"Combined Heat and Power (CHP) is a highly fuel-efficient energy technology, which puts to use waste heat produced as a by-product of the electricity generation process. CHP can increase the overall efficiency of fuel utilisation to more than 75% Gross Calorific Value - compared with around 40% achieved by fossil fuel electricity generation plants in operation today, and up to 50% from modern Combined Cycle Gas Turbines - and has the potential to save substantially on energy bills. Most new CHP schemes use natural gas, but a significant proportion burn alternative, including renewable, fuels.

The UK has a target to install 10GW CHP by 2010. Current installed capacity is estimated at around 5GW".

The above shows that in the UK the merit of CHP is seen only in terms of the 'First Law' or energy efficiency, where this refers to the First Law of Thermodynamics. In fact, its real merit is in increasing the 'Second Law' or 'exergy' efficiency. This means making better use of the energy quality of the fuel. Hence the purpose of all CHP systems is to realise the thermodynamic advantage of co-generated heat. In return for a small loss of electricity, there is a substantial gain of useful heat. This implies that it should be considered as a heat pump and thus the correct indices are the Coefficient of Performance (COP) and the Thermodynamic Heating Efficiency (THE). For the derivation of the THE, Effective THE, and Resultant THE, see Appendix B – Analysis of Combined Heat and Power.

In the 'Powering London' report, the electricity efficiency of micro-chp units was assumed to be 30% HHV. However, units of 5.5 kWe based on Internal Combustion Engines (ICEs) give about 22 to 23% HHV. (See below). Moreover, for all micro-chp units, the Resultant THE depends strongly on the electricity efficiency. Hence the RTHE is not 1.29, but only about 1.0. In practice, intermittent operation would reduce the performance, so compared to a good condensing gas boiler, there would be no fuel and carbon saving.

● Data on the energy balance of the Senertec 5.5 kWe ICE micro-chp unit was given in the Swedish Gas Centre Report 106. (http://www.sgc.se/rapporter/resources/sgc106.pdf). Another set was given in an article from the University of Leuven. (http://www.mech.kuleuven.be/docs/energy/papers/pdf/2001P22.pdf). The corresponding steady-state Resultant THEs would be 0.995 and 0.969.

● Data on the energy balance of the Ecopower 5.5 kWe ICE micro-chp unit – quoting the maker - was given in an M.Sc. thesis from the University of Louvain. (http://www.cogen.org/Downloadables/Projects/MSc_Daoud_and_Pierreux.pdf). A second set was given in an M.Sc. thesis from the University of Dundee. (http://www.cogen.org/Downloadables/Projects/MSc_Pantelis_Tsakiris.pdf). The corresponding steady-state Resultant THEs would be 1.060 and 1.032.

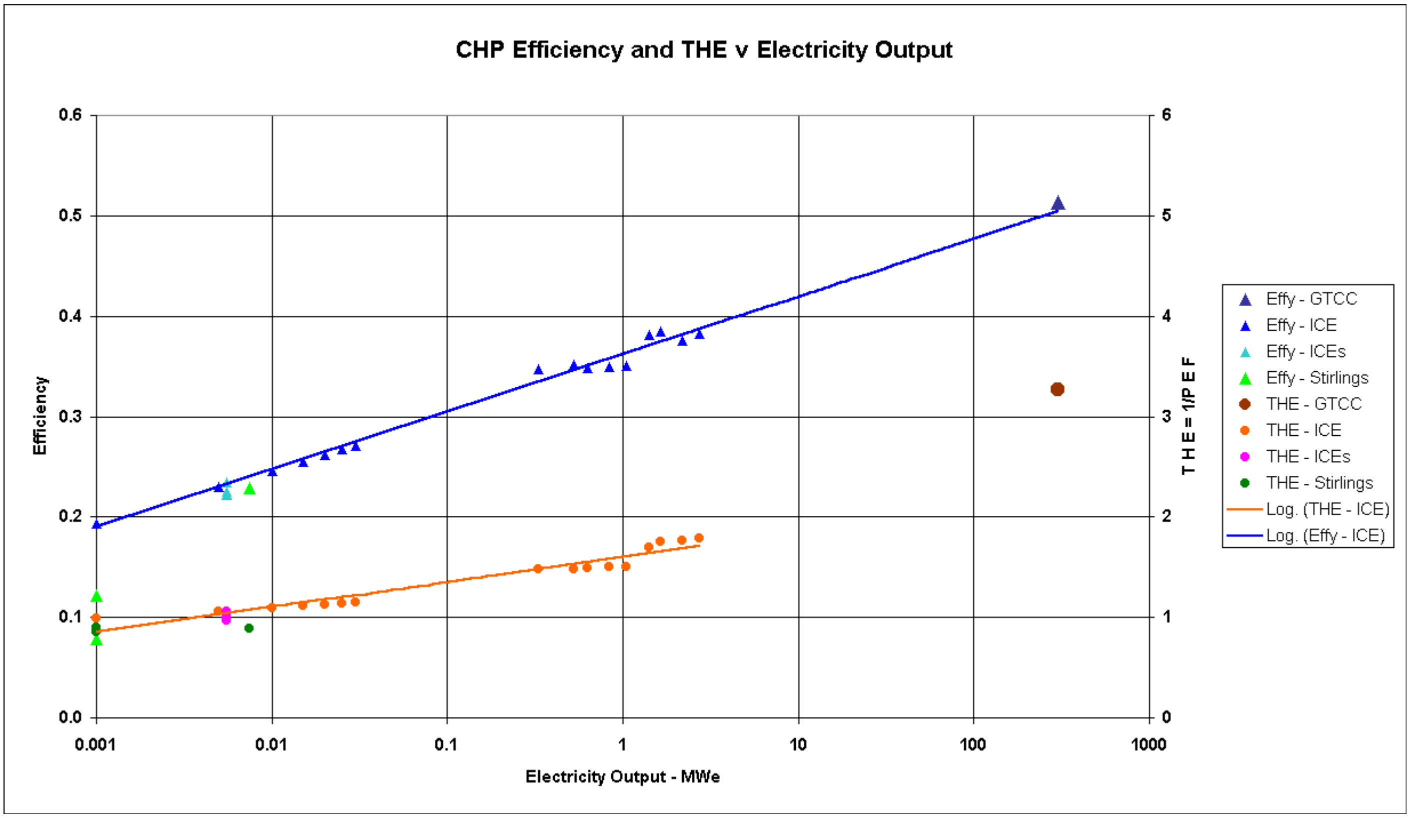
● For the Enatec Stirling micro-chp unit the electricity efficiency was reported in April 2006 as 13.5% (LHV) - i.e. 12.2% HHV. (See http://www.dgs.de/uploads/media/06_Ger_Beckers_ENATEC.pdf Slide 12). Assuming that the total efficiency was 80% HHV, the heat efficiency would be about 67.8%. The steady-state Resultant THE would be about 0.896.

● For eight WhisperGen Stirling micro-chp units the average electricity efficiency was measured as 7.8% (HHV) and the heat efficiency as 71.8%. (See http://www.micropower.co.uk/publications/eonfieldtrial260606.pdf Page 11). The steady-state Resultant THE would be about 0.851.

● The Carbon Trust has published the 'Micro-CHP Accelerator: Interim Report, November 2007. (See http://www.carbontrust.co.uk/technology/technologyaccelerator/small_scale_chp.htm). Even on their analysis, the case is very weak, particularly for domestic units of about 1 kWe output. Moreover, it would become worse over the decades needed to deploy any significant number. They acknowledge that any carbon saving is reduced as the carbon intensity of the grid is lowered. Yet this must be done since it accounts for such a high proportion of the total carbon emissions. Whereupon the carbon savings would become not just zero but negative. Also, the fuel is fossil gas, which is not sustainable. Hence by the time any significant number were deployed, the fuel would be too costly and carbon-intensive.

micro-chp	El. Effy - %	Ht. Effy - %	RTHE	
micro-chp	30 HHV	52 HHV	1.29	Powering London, for MoL - 2006
Measured				
Senertec 5.5 kWe	24.8 LHV 22.3 HHV	60.9 LHV 54.8 HHV	0.995	Swedish Gas Centre Report 106 sgc106.pdf – February 2000
Senertec 5.5 kWe	26.0 LHV 23.4 HHV	56.5 LHV 50.9 HHV	0.969	Uni. Leuven article 2001P22.pdf - 2001
Ecopower 5.5 kWe	24.7 LHV 22.2 HHV	65.8 LHV 59.2 HHV	1.060	Uni. Louvain thesis quoting maker MSc_Daoud_and_Pierreux.pdf - 2001
Ecopower 5.5 kWe	25.0 LHV 22.5 HHV	63.0 LHV 56.7 HHV	1.032	University of Dundee, M.Sc. Thesis MSc_Pantelis_Tsakiris.pdf - 2001
Solo 7.5 kWe	25.4 LHV 22.9 HHV	52.4 LHV 47.2 HHV	0.890	Swedish Gas Centre SGC144.pdf – March 2004
Enatec ~ 1 kWe	13.5 LHV 12.2 HHV	~ 76.5 LHV ~ 68.9 HHV	0.896	06_Ger_Beckers_ENATEC.pdf, p 12 - April 2006
Whispergen ~1 kWe av. - range	7.8 HHV 7.1 to 8.5 HHV	71.8 HHV 69.1 to 73.1	0.851	Eon Carbon Trust Field Trial eonfieldtrial260606.pdf – May 2006

The chart below is based on that in my presentation of July 2007, 'Energy Criteria for Sustainable Energy Solutions', Slide 26. (http://www.energypolicy.co.uk/sustainpres.htm).



It shows - in blue - the Electricity Efficiency for Internal Combustion Engines (ICEs) ranging from 1 kWe to around 1 MWe, plus that for a Gas Turbine Combined Cycle plant of 300 MWe.

From the above table, the chart also shows - in light blue - the Electricity Efficiency for the Senertec and EcoPower ICE micro-chp units of 5.5 kWe, and - in green - those for the Solo Stirling micro-chp unit of 7.5 kWe, and for the Enatec and Whispergen Stirling micro-chp units of 1 kWe. The values for the Senertec and EcoPower ICE units are close to the original ICE trend line. Of the Stirling units, only that of the Solo is close to the line while those for the Enatec - and especially the Whispergen - are markedly lower. This reflects the fact that the top temperature of the thermodynamic cycle of Stirling (and other external combustion) engines is lower than that of internal combustion engines. This is due to the limitations of the metal wall between the heat source and the working fluid.

The above chart also shows - in brown - the Thermodynamic Heating Efficiency (THE) for co-generated heat supplied via District Heating from a 300 MWe Gas Turbine Combined Cycle CHP plant as 3.3 or 330%. It also shows - in orange - the Effective THE for Internal Combustion Engine (ICE) CHP units ranging from 1 kWe to around 1 MWe.

From the above table, the chart also shows – in mauve – the RTHE for the Senertec and EcoPower ICE micro-chp units of 5.5 kWe, and – in dark green – those for the Solo Stirling micro-chp unit of 7.5 kWe, and for the Enatec and Whispergen Stirling micro-chp units of 1 kWe. The values for the Senertec and EcoPower ICE units are close to the original ICE trend line. Of the Stirling units, that of the Solo is below the ICE trend line while those for the Enatec and the Whispergen are below the point for a 1 kWe ICE unit.

While the Effective THE for ICE units of around 1 MWe is about 1.5 or 150%, implying a significant fuel and carbon saving for co-generated heat relative to boiler plant, that for units of around 1 to 10 kWe is only about 1, implying no such saving. Moreover, there is no prospect of small ICE units achieving higher values, since they must run for say 5000 hours a year with minimal servicing. This is roughly ten times as long as in light duty automotive applications. Furthermore, since the Electricity Efficiencies of the small Stirling units are below those of the ICE units, the Resultant THEs for the largely co-generated heat produced are also lower at 0.90 to 0.85. Thus such units offer no fuel savings relative to boiler plant, but rather penalties. Attempting to reduce the fuel and carbon penalties of small Stirling engine units by increasing the Electricity Efficiency and thus the Resultant THE, while running for about 5000 hours a year, would require even more costly alloys for the heater head.

The data shown in the above table and chart are for steady-state operation. However, micro-chp units usually run intermittently, which lowers the electrical output and efficiency, and hence the THE and the Resultant THE. Moreover, the full thermodynamic advantage is realised only if all the heat and the electricity are utilized. Hence the micro-chp unit must be 'heat lead', so that the heat is used immediately or delayed via storage, and the electricity must be either used locally or exported. (See the Eon Carbon Trust field trial report, http://www.carbontrust.co.uk/Publicsites/cScape.CT.PublicationsOrdering/PublicationAudit.aspx?id=CTC513&RedirectDone=1 , p 8).

In the above table and chart, the RTHE values of the Solo, Enatec and Whispergen Stirling engine micro-chp units are less than the annual average efficiency of a good condensing boiler (0.95). Even for the Senertec and Ecopower ICE micro-chp units of 5.5 kWe, the annual average RTHE is unlikely to be higher than that of the boiler, mainly due to the effects of intermittent operation. Hence compared to heat from a good condensing boiler, the carbon savings would be zero and the cost of carbon savings infinite. Furthermore, as well as a far higher initial cost, a micro-chp unit would require expensive new parts every year. In addition, micro-chp units still depend on natural gas, and so are not sustainable.

It is noteworthy that the British Gas Microgen Stirling micro-chp unit of about 1 kWe has been abandoned. (http://inpicenum.com/2007/02/27/end-of-domestic-scale-chp/).

Solar Water Heating

"Systems comprise of solar collectors (evacuated tubes or flat plates), a heat transfer system (a fluid in pipes) and a hot water store (e.g. domestic hot water cylinder). A 4m2 collection area will provide between 50 – 70% of a typical home's annual hot water requirement[45]. The cost of a professionally installed solar system for heating hot water can vary significantly, but a household system (4m2) could cost between £2,500 - £4,000[46].

System savings range from around 454 kWh/ year/m2 of flat plate collector – 582 kWh/year/m2 for an evacuated tube system[47]. This might amount to a saving of around £120 - £150 per year[48] for electrically heated property or be as low as £36 - £46 [49] for a gas-heated property, and would equate to a carbon saving of about 0.79 - 1 tCO2/ year[50] for electrically heated property and about 0.35 – 0.44 tCO2/year for gas-heated property[51]. The pay back time on an average 4 m2 household system would therefore be around 24 years for an electrically heated property and 80 years for a gas-heated property (based on current energy prices).

[45] Summary of renewable energy technologies characteristics, from the London Renewable: Toolkit for planners, developers and consultants', section 3; www.london.gov.uk/mayor/environment/energy/london_renew.jsp
[46] As for footnote 44.
[47] As for footnote 44.
[48] The price assumes the import cost of electricity of around 6 – 7p/kWh
[49] The price assumes the cost of natural gas around 2 p/kWh
[50] Carbon saving calculated using the DEFRA electricity displacement coefficient of 0.43kg CO2./kWh used since 2000.
[51] Carbon savings calculated using gas displacement coefficient of 0.19 kgCO2/kWh and assumes boiler efficiency of 70%".

According to a report on microgeneration for the EST in 2005, solar water heating is by far the most widespread, with 78,470 systems installed in the UK. (http://www.berr.gov.uk/files/file27558.pdf Page 23). Hence the scarcity of measured performance data on such systems is remarkable.

- 'Analysis of Performance Data from Four Active Solar Water Heating Installations', Interim Report, ETSU S/P3/00275/REP, DTI/Pub URN 01/781, The Energy Monitoring Company Ltd. , 2001. (http://www.berr.gov.uk/files/file16522.pdf). This was for four systems in the UK.

System	1	2	3	4
Collector Area – m2	5	3	4	4
Useful solar energy – Year 1 – kWh/y	1101	NA	NA	1129
Useful solar energy – Year 2 – kWh/y	1177	NA	801	882
Solar fraction – Year 1 - %	61	NA	NA	68
Solar fraction – Year 2 - %	62	NA	76	67

The collector areas are relatively large, hence the useful solar energy and Solar Fractions were also large. The average useful solar energy was 1018 kWh/y and that per unit area was relatively low at 231 kWh/m2.y.

The peak power of a typical solar domestic hot water (DHW) system may be estimated. With a maximum insolation in the U.K. of about 800 W/m2, a collector efficiency of 50% and a collector area of 4 m2, it would be 1600 W. In practice, the performance is often expressed as the solar fraction - i.e. the fractional saving of the DHW demand (gross, including the DHW cylinder losses). A typical solar DHW system might save 50%, with a range of roughly 30 to 60%. However, this is usually only a minor share of the total space and water heat. Moreover, the effectiveness and hence cost-effectiveness at saving carbon are directly dependent on the amount of conventional heat displaced. This may be reduced by the losses from any additional or larger storage tank installed as part of the solar system, depending on its location.

The Energy Saving Trust gives the cost of a solar hot water system as from £ 3200 to £ 4500. (http://www.energysavingtrust.org.uk/generate_your_own_energy/types_of_renewables/solar_water_heating).
For the quoted text and data above, the carbon saving for a gas heated property is 0.35 to 0.44 tCO2/y – i.e. 0.095 to 0.120 tC/y. Assume that the lower applies to flat-plate collector system costing £ 3200 and the higher to an evacuated tubular collector system costing £ 4500, both with lifetimes of 20 years. Then the cost of carbon saving is £ 2500/(20 x 0.095) = £ 1316 to £ 4500/(20 x 0.120) = £ 1667/tC/y.

● Data on solar water heating system performance including operating electricity is given in 'Energy Payback Time - A Key Number for the Assessment of Thermal Solar Systems', E. Streicher et al., Eurosun 2004. (http://www.itw.uni-stuttgart.de/ITWHomepage/TZS/Literatur/Eurosun04_es.pdf).
Electricity input to solar DHW system: 43 W x 1500 h + 2 W x 8760 h = 64.5 + 17.52 kWh = 82.02 kWh/y.
DHW demand + store loss 3589 kWh/y and Solar Fraction 55%. Hence the solar output = 3589 x 0.55 = 1974 kWh/y.

My condensing gas boiler has an annual average gas efficiency of about 96% and an annual electricity use of about 519 kWh. At the current (November 2007) prices for gas of 2.451 p/kWh and electricity of 9.01 p/kWh, and a VAT rate of 5%, the value of heat from my system, including both electricity and gas inputs:
((519 x 9.01 x 1.05) + (19036 x 2.451 x 1.05))/(519 + 19036 x 0.96) = (4910 + 48990)/18794 = 2.87 p/kWh.

Assuming a cost of heat from a gas boiler of 2.87 p/kWh, the value of the solar heat output less the operating electricity = (1974 x 2.87) – (82.02 x 9.01 x 1.05) = 5665.38 – 703.81 = 4962 p/y = £ 49.62/y.
Assuming initial costs from £ 3200 to £ 4500, the money payback time would be 64 to 91 years.
The cost of solar heat would be about (3200 x 100)/(1974 x 20) + (82.02 x 9.46)/1974 = 8.1 + 0.393 = 8.5 p/kWh to (4500 x 100)/(1974 x 20) + (82.02 x 9.46)/1974 = 11.39 + 0.393 = 11.8 p/kWh.

● Viridian has measured the performance of a solar DHW system with a V30 solar collector with an area of 3 m2. (http://www.viridiansolar.co.uk/Assets/Files/Viridian_Automated_Test_House_Full_Year_Results.pdf). With a hot water draw-off of 100 l/d at 60C, the total energy for water heating was about 2600 kWh and that from solar was 1462 kWh for the year. With a collector area of 3 m2, the useful solar heat per unit area was 1462/3 = 487 kWh/m2.y.
They give the carbon saving compared to gas heat as 281 kgCO2/y = 77 kgC/y. Assuming a cost of £ 2500 and a lifetime of 20 years, the cost of carbon saving would be (2500 x 1000)/(20 x 77) = £ 1623/tC/y.

SDHW	Yield – kWh/m2.y	Capacity Factor - %	
Flat Plate Evacuated Tube	454 582		Renewables Toolkit - 2004
Flat Plate Evacuated Tube	454 582		Microgeneration Strategy - 2005
Not stated	130	13 % of 1000 kWh/m2.y	Potential for Microgeneration - 2005
Measured			
UK data – av. - range	231 200 - 282		4 UK Systems - 2001
Viridian V30	487		Viridian Full Year Results - 2007

My heating system is instrumented sufficiently to determine how much heat is required for the DHW. For a system with a storage cylinder, this depends only weakly on the hot water usage, since the cylinder losses dominate. However, with the DHW cylinder located inside, the heat leaks to the house, and is useful almost all of the year. In my case, the average over three years of the 'DHW Coil Heat' (which includes the losses from the primary pipework and cylinder) is 1456 kWh/y. Compared with the 'Total Heat', (i.e. the gas-fired heat plus the boiler electricity) of 19555 kWh/y, this is 0.074 or 7.4%. So with a solar fraction of say 50%, the saving could not exceed about 3.6% or 728 kWh/y.

Taking the cost of heat from a gas boiler as 2.87 p/kWh, the value of 728 kWh/y would be only about £ 21/y. Even without considering the operating electricity and any maintenance, the payback time would be from 3200/21 = 152 to 4500/21 = 214 years. Assuming a lifetime of 20 years, but no operating electricity or maintenance, the cost of solar heat would be (3200 x 100)/(728 x 20) = 22 to 31 p/kWh. This is over 7 to 11 times that of heat from the gas boiler.

Taking the carbon intensity of delivered gas as 0.053 kgC/kWh fuel and the boiler efficiency as 0.90, the carbon intensity of gas heat would be 0.059 kgC/kWh. (See Appendix A). With the heat saved being 728 kWh/y, the carbon saving is 0.059 x 728/1000 = 42.8 kgC/y. Assuming that the initial cost is £ 2500, and the lifetime 20 years, the cost of carbon saving is (2500 x 1000)/(20 x 42.8) = £ 2920/tC/y.

Since in most cases in the UK solar water heaters would be displacing gas heat, the carbon saving per unit would be very small, and the cost of carbon saving very high. However, large-scale solar heating is very different. (See below).

Ground Source Heat Pumps

"The cost of a typical household system is £4 - 6,000[54]*. A typical system will provide 95 - 100% of a households heating requirements.*
For a domestic system with a total annual heat load of 30,000 kWh heated by natural gas[55] *the annual carbon emissions would be in the region of 6.3tCO2/ year*[56]*.*
Employing a 9kW (peak heat output) ground source heat pump with a coefficient of performance (CoP) of 3.5 and costing around £9,000 would require 8,570 kWh of electricity to operate the pump. Assuming a normal electricity tariff, the carbon dioxide emissions would equate to 3.7tCO2/ year equivalent to a net saving of 2.6tCO2/ year[57]*. If a 'Green' electricity tariff supplied the electricity for the pump, the carbon dioxide emissions could be reduced to zero.*
Ground Source Heat pumps are most likely to be an option where there is no access to natural gas and so the alternative may be oil or direct electric heating (storage heaters). In the case of the latter, financial savings could amount to around £640[58] *per annum (assuming off-peak electricity). In the case of oil fired heating, the likely running and installation costs would be comparable.*

[54] *Clear Skies website. www.clear- skies.org/households/GrantsAndTechnologies.aspx?intTechnologyID=4*
[55] *This assumes with a new gas condensing boiler with SEDBUK efficiency of around 90%*
[56] *Calculated on basis of 30,000 kWh/ 0.9(boiler efficiency) x 0.19 kgCO2/kWh.*
[57] *Calculated on basis of total gas equivalent CO2 emissions (6.3tCO2/ year) – electricity equivalent CO2 emissions to operate pump (8,570 kWh x 0.43 kg CO2/kWh*
[58] *Calculated on basis that direct electric heating would cost (assuming 3p/kWh might-time rate) 30,000kWh x 3p = £900 per annum and GSHP would cost 8,570kWh x 3p - £257 per annum".*

When quoting the Coefficient of Performance (COP) of heat pumps, it is essential to be clear what electricity inputs are included - compressor, fans, pumps, and auxiliary heating (usually straight electricity).

● In a case study report on a ground source heat pump by BRE, the 'headline' figure for the annual COP is 3.16. (http://www.heatpumpnet.org.uk/files/gir72.pdf). However, the heat pump is undersized to the load (partly to avoid the need for a three-phase supply), so significant direct electric heat is used for space heating, as well as for DHW. On the total figures in Table 1, Page 6, the annual COP is 18680/7825 = 2.38. Page 8 notes that there is scope for improvement - replacing the indoor thermostat with an outdoor sensor part way through the year seems to have helped, and the ground coil pump ran continuously, rather than only with the heat pump. However, this report shows that good performance depends upon good design, workmanship, and control set-up.

Measured performance data on heat pumps has been published in the IEA Heat Pump Centre newsletters. (http://www.heatpumpcentre.org/Home/hem.asp).

● HPC Newsletter, Issue 2/2004, p 15, Swiss field trial. Figs 1 & 2 give the latest averages of annual average COP for brine (ground source) to water as 3.3.

● The Geo-Heat Center Bulletin, September 2004, 'Geothermal (Ground Source) Heat Pumps: A World Overview'. (http://geoheat.oit.edu/bulletin/bull25-3/art1.pdf). P 5 reports that for Swiss borehole systems, seasonal performance factors (annual average COPs) of over 3.5 are achieved.

● HPC Newsletter, Issue 4/2005, p 26-29, German field trial of 14 ground source heat pumps. (Nr 4_2005_klar.pdf). Table 1 gives the annual average COPs, including auxiliaries and supplementary heating, of 3.05 to 4.27, with an average of 3.57. With electricity from the German grid, the average Primary Energy Factor was 0.77, whereas that for new low-temperature or condensing boilers from oil or natural gas is 1.2 to 1.4.

GSHP	COP (SPF)	
	3.5	Microgeneration Strategy for DTI - 2005
	3.16 (from GIR72)	Potential for Microgeneration for EST - 2005
Measured		
UK Monitoring Study, IVT Greenline 4	2.38	BRE Report GIR72 – March 2000
Swiss Field Trial - average for 2002	3.3	HPC Newsletter, No 2/2004
Swiss borehole systems	3.5	GHC Bulletin, September 2004
German Field Trial - average 2001- 2003 - range 2001 - 2003	3.57 3.05 to 4.27	HPC Newsletter, No 4/2005

For the Ground Source Heat Pump reported by the BRE above, the quoted data is sufficient to give the carbon saving. Compared with a condensing gas boiler with an efficiency of 0.9, a GSHP with a COP of 3.5 would save 2.6 tCO2/y – i.e. 0.709 tC/y. Assuming an initial cost of £ 9000 and that of a gas boiler as £ 1000, and a lifetime of 20 years, the incremental cost of carbon saving is (9000 – 1000)/(20 x 0.709) = £ 564/tC/y.

The cost of carbon saving may also be determined with other values for the carbon intensities. (See Appendix A). Taking the carbon intensity for delivered gas as 0.194 kgCO2/kWh, and the boiler efficiency as 0.9, the CO2 emissions for a gas boiler = (30000 x 0.194)/(0.9 x 1000) = 6.47 t/CO2/y. Taking the carbon intensity for low voltage electricity as 0.548 kgCO2/kWh, and the annual average COP as 3.5, the CO2 emissions for a GSHP = (30000 x 0.548)/(3.5 x 1000) = 4.70 tCO2/y. Thus the carbon saving = 6.47 – 4.70 = 1.77 tCO2/y – i.e. 0.483 tC/y. Assuming an initial cost of £ 9000 and that of a gas boiler as £ 1000, and a lifetime of 20 years, the cost of carbon saving is (9000 – 1000)/(20 x 0.483) = £ 829/tC/y. Clearly the value of any carbon saving depends on the relative carbon intensities of gas and electricity, and on the relative efficiency of the boiler and COP of the heat pump. This last is strongly dependent on the use of the backup resistance heater. Hence this value of the cost of carbon saving is only indicative.

Air Source Heat Pumps

● HPC Newsletter, Issue 2/2004, p 15, Figs 1 & 2 give the latest averages of annual average COP for air (source) to water heat pump units in a Swiss field trial as 2.75.

ASHP	COP (SPF)	
Measured		
Swiss Field Trial Average for 2002	2.75	HPC Newsletter, No 2/2004

Air source heat pumps are less expensive than ground source and need no ground area. However, they usually require considerable fan power for the evaporator coil, and energy for defrosting it in winter. Also in winter the source temperature is lower than for a ground source. The effect of all these is to lower the annual average COP to below 3, so reducing any carbon saving.

Taking the carbon intensity for low voltage electricity as 0.548 kgCO2/kWh, the carbon emissions for an ASHP = (30000 x 0.548)/(2.75 x 1000) = 5.98 t/CO2/y. (See Appendix A). Compared with the carbon emissions for a gas boiler of 6.47 tCO2/y, the CO2 savings would be 0.492 tCO2/y – i.e. 0.133 tC/y. Assuming a capital cost of £ 5000 and a lifetime of 20 years, the cost of carbon saving is (5000 – 1000)/(20 x 0.133) = £1501/tC/y. Clearly the value of any carbon saving depends on the relative carbon intensities of gas and electricity, and on the relative efficiency of the boiler and COP of the heat pump. This last is strongly dependent on the use of the backup resistance heater. Hence this value of the cost of carbon saving is only indicative.

Biomass Heating

"The cost of a typical household system is between £2,400 - £2,600 for a single room heater or £200 - £600 per kWth installed for a boiler system[62], with fuel costs of around £15 – 30/MWh for wood pellets[63].
For a typical domestic system with a total annual heat load of 30,000 kWh, a 9kW biomass system could deliver the heat required. In addition to the initial capital outlay, there would be an annual cost for fuel and maintenance[64]. Overall the running costs would be comparable to gas or oil heated properties. But there would be net carbon savings of around 1.74tCO2/ year[65] for a gas heated property and 2.16tCO2/year for an oil heated property.

[62] Clear Skies website: www.clear-skies.org/households/GrantsAndTechnologies.aspx?intTechnologyID=5
[63] See footnote 57.
[64] Assumes a fuel cost of £15 - 30 per MWh
[65] Carbon saving calculated on basis that 95% of the carbon from fossil fuels will be displaced. This means a C saving of 0.058kgC/MWh where gas derived heat is substituted and 0.071kgC/MWh where oil is replaced".

From the above quoted data, the carbon saving for a biomass boiler compared with gas heat is 30 x 0.058 = 1.74 tC/y. (1.74tCO2/y and 2.16 tCO2/y above are wrong). Assuming a biomass boiler lifetime of 20 years and that the fuel has zero net carbon emissions, the corresponding cost of carbon saving is from (9 x 200)/(20 x 1.74) = £ 52 to (9 x 600)/(20 x 1.74) = £ 155/tC/y.

Measured data on the thermal efficiency and emissions of biomass room heaters and boilers at full and part load are available at the BLT web site. (http://blt.josephinum.at/index.php?id=331). This independent testing has been carried out since 1980 on over 200 units, mainly Austrian. Through research and constructive feedback, the efficiencies have risen and emissions fallen greatly, and Austria now has a substantial industry making biomass heaters and boilers. (http://www.tekes.fi/opet/pdf/ssb_austria.pdf).

As with other measures, the specific cost (e.g. euro/kW) of biomass boilers shows a strong scale effect. (http://www.ieeprojects.net/downloads/ELVA/Gussing_Programme_and_Presentations/23_Technologies and benchmarks for using wood.pdf).

Although often considered as microgeneration, biomass heaters and boilers are in a different class entirely. Even against gas, they are cost-effective in saving carbon, so the cost of saving carbon is very low. They are also cost-effective against oil and off-peak electricity and so make sense in rural situations, off the heat and gas networks. Moreover, since they use a renewable fuel, they are already sustainable.

Critiques of certain key documents

Recent documents referring to microgeneration and ‘zero carbon’ include:

● Planning Policy Guidance No. 22, ‘Renewable Energy’, 1993.
This is referred to in the Merton Unitary Development Plan (see below), Page 62 of 343, Para. 2.42.

● ‘MicroCHP - delivering a low carbon future: Report on the market for microCHP’, prepared by the Domestic CHP Section of the SBGI, 8th September 2003. (http://www.sbgi.org.uk/index.php?fuseaction=sbgi.viewFile&id=8010979).

Page 27 mentions that: *‘as no current Stirling Engine-based design is capable of meeting the electrical efficiency requirements of 20% (HHV), they cannot receive Good Quality CHP accreditation under the current rules’.*

The chart on page 7 above shows that for micro-chp units with an electricity efficiency of 20%, the Resultant THE would be only about 0.9. Therefore compared to condensing boilers, units with this or lower electricity efficiencies would save no fuel or carbon.

● ‘Merton Unitary Development Plan’, October 2003. (http://www.merton.gov.uk/udp.pdf).

Page 35 of 343, Table 1.1 includes:

‘4. Energy	*• Energy is used efficiently.*
	• Energy use is minimised.
	• Renewal energy is used where possible’.

Page 62 of 343, Para 2.42 includes: ‘Specifically, government guidance in PPG22 ‘Renewable Energy’, encourages the development of renewable energy schemes where possible. The efficient use of energy and the development of renewable energy is supported by the Objectives outlined in Topic 4, ‘Energy’, of Merton’s Sustainability Criteria described in Chapter 1 of the Plan’.

Hence PPG 22 of 1993 (and later annexes) encouraged the development of renewable energy schemes where possible. Yet this was without any quantitative evidence of performance, cost, and effectiveness and cost-effectiveness at carbon saving being available for such schemes – at least for the UK – and before the potentials had been assessed.

Page 114 of 343, Para 3.132 includes: *‘The Council will expect at least 10% of the predicted energy requirements of businesses occupying large new industrial and commercial developments to be capable of being met by means of onsite renewable energy generation. For the purpose of this policy the means of generating renewable energy include photovoltaic energy, solar-powered and geo-thermal water heating, energy crops and biomass, but not energy from domestic or industrial waste. Where incorporating renewable energy production equipment is shown (by the appplicant) to make the development unviable, it would not be expected’.*

This mentions ‘10%’ and ‘on-site’ but applies only to ‘businesses occupying large new industrial and commercial developments’. Moreover, ‘where incorporating renewable energy production equipment is shown (by the applicant) to make the development unviable, it would not be expected’. Presumably this would include showing that such equipment was either not effective or not the most cost-effective.

Page 181 of 343, Para 4.162 includes: *‘The Government has set a target of generating 10% of electricity from renewable resources by 2010’.*

Para 4.163 includes: *‘The Council will therefore encourage the development of renewable and local energy facilities, subject to their impact on local amenities. These facilities either generate energy themselves, or contribute to savings in energy consumption, or perform both functions. Examples of such facilities would be waste-energy plants, combined* *heat and power plants, facilities which make use of landfill gas, sewage sludge, hydroelectric power and wind energy. Active and passive solar designs are another widely used form of energy generation/conservation'.*

Para 4.165 includes: *'The process of the transmission of energy may be inefficient in that it uses up some of that energy produced and entails costs in the provision of the necessary equipment'.*

The mention in Para 4.162 of '10%' is only in the context of a Government target for generating electricity from renewable resources without any implication that this be generated on-site. Para 4.165 might be construed as favouring on-site generation. Yet 10% on-site would still require 90% to be transmitted from off-site. Moreover, for both electricity and district heating, the transmission losses are small, and are far outweighed by the greater efficiency of generating electricity and heat from large (hence off-site) power and CHP plants. These are included in Para 4.163.

All told, it is hard to see how this document has been interpreted as requiring 10% of the energy for all residential, commercial, and industrial developments to be generated on-site – the so-called 'Merton Rule'.

● 'Planning Policy Statement 22: Renewable Energy', ODPM, 2004.
(http://www.communities.gov.uk/documents/planningandbuilding/pdf/147444).

P10, Para. 3. *'Targets should be set as the minimum amount of installed capacity for renewable energy in the region, expressed in megawatts, and may also be expressed in terms of the percentage of electricity consumed or supplied'.*

P12. Para. 8. *'Local planning authorities may include policies in local development documents that require a percentage of the energy to be used in new residential, commercial or industrial developments to come from on-site renewable energy developments. Such policies:*
(i) should ensure that requirement to generate on-site renewable energy is only applied to developments where the installation of renewable energy generation equipment is viable given the type of development proposed, its location, and design;
(ii) should not be framed in such a way as to place an undue burden on developers, for example, by specifying that all energy to be used in a development should come from on-site renewable generation.
Further guidance on the framing of such policies, together with good practice examples of the development of on-site renewable energy generation, are included in the companion guide to PPS22'.

P 14, Para.18. *'Local planning authorities and developers should consider the opportunity for incorporating renewable energy projects in all new developments. Small scale renewable energy schemes utilising technologies such as solar panels, Biomass heating, small scale wind turbines, photovoltaic cells and combined heat and power schemes can be incorporated both into new developments and some existing buildings. Local planning authorities should specifically encourage such schemes through positively expressed policies in local development documents'.*

It is very strange that this was issued before any theoretical analysis or field test data was available - at least in the UK - on the effectiveness of the various measures per unit, never mind their cost-effectiveness at carbon saving.

● 'Planning for Renewable Energy: A Companion Guide to PPS 22', Arup for OPDM and DTI, 2004.
(http://www.communities.gov.uk/documents/planningandbuilding/pdf/147447).
This is generally qualitative, with numbers mostly for power capacity. It makes no attempt to examine the technical performance – either effectiveness or cost-effectiveness at saving carbon – or provide any such references.

● 'Integrating Renewable Energy into New Developments: Toolkit for Planners, Developers and Consultants', Faber-Maunsell, September 2004. (http://www.london.gov.uk/mayor/environment/energy/docs/renewables_toolkit.pdf).

P 16 includes: *'2.3 WHAT IS A PROPORTION?*

The London Plan asks for a proportion of the site's heat or electricity demands to be met by renewable energy demands, where feasible. No definition of proportion is given - however, the London Plan (paragraph 4.18) does refer to the carbon dioxide emission reduction targets in the Energy Strategy - '20 per cent [reduction] relative to the 1990 level by 2010 as the crucial first step on a long-term path to a 60 per cent reduction from the 2000 level by 2050. It should be possible to reduce emissions to 23 per cent below 1990 levels by 2016.'
In order to reach these targets, in the Energy Strategy the Mayor is expecting the proportion to be at least 10 percent for developments referable to him where feasible (proposal 13).
The Mayor also recommends that boroughs adopt the same policy for major developments'.

P 26 includes: *'Background: The Mayor's Energy Hierarchy*
In the Energy Strategy the Mayor has defined an 'Energy Hierarchy' to help guide decisions on which energy measures are appropriate in particular circumstances. When each stage of the hierarchy is applied in turn to an activity, it will help ensure that London's energy needs are met in the most efficient way:
i. Use less energy (Be lean)
ii. Use renewable energy (Be green)
iii. Supply energy efficiently (Be clean)
London Plan Policy 4A.7 and policy 4A.8 (see section 1.6.3) include requirements regarding energy efficiency.
It is therefore important for energy efficiency as well as renewable energy to be considered in each new development in London. This means that the buildings will use less energy and therefore need to use a smaller amount of renewable energy to supply the same proportion of the site's needs'.

This document responds to the Mayor's Energy Strategy, but does not consider whether additional energy saving measures or increased efficiency measures such as district heating from large-scale fossil-fuelled CHP, could meet the carbon savings objective at lower cost. Yet on the evidence presented here, for on-site renewables (save biomass heating), the costs of carbon saving are high to very high, while they are much lower for biomass heating and large-scale fossil-fuelled CHP, as widely used on the Continent. Also, many energy saving measures have negative lifecycle costs.

This document sets out a quantitative methodology for the performance and cost of renewable energy schemes. For heat from solar thermal collectors, ground source heat pumps and biomass boilers, and electricity from PV and wind turbines, sufficient data is provided to determine the cost of carbon saving. However, the performance of wind turbines is related only to wind speed – presumably because no evidence for urban wind turbines was available from analysis (e.g. Computational Fluid Dynamics) or field test.

P 27 includes: *'Combined Heat and Power (CHP)*
When electricity is generated in central power stations around 60-65% of the primary energy is rejected as waste heat into the atmosphere often via the familiar cooling towers we see dotted around the landscape.
Combined heat and power units generate electricity locally so that waste heat can be used for beneficial purposes. Where all the waste heat generated can be used, CHP units will have overall efficiencies of up to 80-85% compared to 35-40% for conventional power stations'.

The above shows that in the UK the merit of CHP is seen only in terms of the 'First Law' or energy efficiency, where this refers to the First Law of Thermodynamics. In fact, its real merit is in increasing the 'Second Law' or 'exergy' efficiency. Compared to heat from existing gas boilers, the gas and carbon saving offered by co-generated heat from large-scale GTCC CHP with units of about 300 MWe is about 80%. (See below, under Large DH-CHP).

P 156 contains the data (but no source references) enabling the determination of the cost of carbon saving. This is: the Capital Cost Rate (extra)/Annual Carbon Savings. A lifetime of 20 years has been assumed for all measures.

	Annual Carbon Savings	Capital Cost Rate (extra)	Cost of Carbon - £/tC/y
Wind turbine	289.8 kgC/kW	£ 2000/kW	6901/20 = 345

PV	11.30 kgC/m2 panel	£ 850/m2 panel	75200/20 = 3760
SDHW	1.08 kgC/m2 GIFA	£ 14.02/m2 GIFA	12980/20 = 649
GSHP	1.32 kgC/m2 GIFA	£ 32.81/m2 GIFA	24860/20 = 1243
Biomass heating	4.49 kgC/m2 GIFA	£ 32.8/m2 GIFA	6448/20 = 322

● 'A comparison of distributed CHP/DH with large-scale CHP/DH', 2005, Parsons Brinkerhoff Ltd. UK et al for the IEA. (http://www.svenskfjarrvarme.se/download/3477/8dhc-05-01_distributed_vs_large-scale_chp-dh.pdf).

P vi. 'The City-wide CHP/DH system benefits from a high efficiency, low capital cost, CCGT power plant, which more than offsets the additional costs of city-wide heat distribution'. 'A further advantage of the larger-scale DH systems is the ability to obtain heat from other sources including waste to energy plants and industry'.

These are most important findings which should be more widely known in the UK, since they are vital arguments against on site microgeneration and in favour of off site city-wide district heating, as used so widely on the Continent.

P 1. It mentions the UK Government target of a further 5000 MWe CHP capacity by 2010. However, the present 'CHPQA' rules give full exemption from the Climate Change Levy (a type of carbon tax) even for very poor CHP plant, so reducing the economic incentive to save carbon. (http://www.energypolicy.co.uk/epolicy.htm Section 3.11).

P 3. It mentions large-scale CHP/DH schemes in northern and eastern Europe, with examples of Copenhagen, Helsinki and Berlin. However, this massively understates the case, since these are only three of 'a thousand' cities. (http://www.euroheat.org/workgroup4/KN1531 DHCAN Policy Guide.pdf).

P 4. It says that 'future planning policies and regulations on new building design will encourage the use of CHP and renewable energy'. However, this will not be so if the regulations prescribe on-site measures. (See above and below).

P 14. The 'alternative' case assumes individual gas-fired boilers with an average seasonal efficiency of 86%. However, this study considers an existing city, for which an average seasonal gas efficiency of 65% was estimated by the BRE for the PIU Energy Review of 2002. Thus the fuel, economic and CO2 savings are understated for all four cases.

P 23. Table 5.1 shows that the 'Building CHP' case comprises 1149 SIGE units of 122 to 2188 kWe and 102,757 Stirling units of only 0.9 kWe. However, this obscures the fact that the latter offer no fuel saving relative to gas boilers with an average efficiency of 86%, never mind good condensing boilers with even more. (See 'micro-chp' above).

P 40, Fig 9A compares the CO2 emissions for the four cases (scenarios) and the alternative. That for whole-city CHP/DH gives a saving of 27%. However, this is much 'diluted' by considering electricity as well as heat. If only heat is considered, the saving would be about 80%. (http://www.energypolicy.co.uk/epolicy.htm Section 3.9).

P 48. '... a 7-year build-up period was modelled. It is assumed that construction commences at the start of this period, and 100% heat supply market penetration is achieved at the end ...'

● 'Microgeneration strategy and low carbon buildings programme: consultation', June 2005, DTI, Annex A. (http://www.berr.gov.uk/files/file13989.pdf).

P 25 of 60. Para 4.1. *'A range of economic instruments already exists to support microgeneration technologies. These include a VAT rate of 5% for most microgeneration technologies (micro-wind, solar thermal, solar PV, ground source heat pumps, micro-hydro). In the 2005 Budget, the Chancellor extended this reduced rate to cover air source heat pumps and micro-CHP'.*

This is strange, since very little measured data was available - at least in the UK - on the effectiveness of microgeneration technologies at carbon saving – the supposed policy objective. The summary table on p 23 and the chart on p 27 shows that the cost of carbon saving for air source heat pumps is high and for micro-CHP is infinite.

Para. 4.2. *'Micro-CHP also benefits under the Energy Efficiency Commitment (EEC)'.*
This is strange, since thermodynamic analysis (under 'micro-chp' above) shows that it gives no carbon saving. Hence the cost of carbon saving must be infinite.

P 50 of 60. *'Planning policy statement 22, published last year (i.e. 2004), established that local authorities may set targets for on-site renewable energy in residential, commercial or industrial projects'.*
This expressed the requirement for a certain percentage of energy to come from on-site renewables. Yet there was very little measured data available - at least in the UK - on the effectiveness and hence the cost-effectiveness at carbon saving, for these and other measures. Also, experience on the Continent is that energy-saving measures are far more cost-effective at carbon saving – many having negative costs. (See below).

● 'Potential for Microgeneration – Study and Analysis', Energy Saving Trust, December 2005.
(http://www.berr.gov.uk/files/file27558.pdf).

P 40. The cost projections are derived from 'learning curves'. However, these only reflect the past, and should not be extrapolated for cost projections. Technological or scientific barriers, such as the 'physical laws', may arise at any point. Also the demands of increased efficiency and durability – and the increasing scarcity of materials - would cause costs to rise.

P 45. The 'Baseline Fuel Costs for Residential Consumers' (provided by the DTI) are basically level to 2050. It seems that the DTI has not heard of 'Peak Oil' and 'Peak Gas', despite being responsible for collecting the data on UK oil and gas production. This is already decreasing at several per cent a year and increasing scarcity usually leads to rising prices. Certainly this has proved to be the case, with the current (November 2007) world price of oil having increased to $ 90 per barrel.

P 148. PV load factor taken as 9.7%, based on PV-COMPARE data for UK, 1999.
The BRE PV Field Trial report of 2006 gave an average load factor of 9.1%.

P 154. Small wind load (capacity) factors taken for 1.5 kWe as 17% and for 15 kWe as 25%. But for 1.5 kWe, the Loughborough CFD study gives 1 to 5%, for 0.6 kWe, the Warwick field trial gives 3.5%, and for 15 kWe, Thames Valley data gives 19.2% and 22.1%. Hence the measured domestic urban wind turbine yield is only about one-fifth, and the measured commercial wind turbine yield about 0.83, as much as those assumed.

P 167. For solar water heating, the load factor is given as 13%. Assuming a peak insolation on the solar collector of 800 W/m2, and a thermal efficiency of 0.5, the annual yield would be 0.13 x 800 x 0.5 x 8760/1000 = 456 kWh/m2. The field test data for three UK systems gives an average of 231 kWh/m2.y. However, with an average area of 4.3 m2, these systems are probably oversized to the load. Since such systems obey the 'Law of Diminishing Returns', increasing the collector area may increase the total yield, but reduce the yield per unit area. The Viridian test data for a collector of 3 m2 gives 487 kWh/m2.y, which is consistent with 456 kWh/m2.y and hence the load factor of 13%.

P 171. The efficiency of a biomass boiler was taken as 90%. But they seem not to realise that on the Continent such data is given on the Lower Heat Value (LHV) basis. That on the HHV basis may be considerably less, depending on the moisture content of the biomass. This is only about 10% for wood pellets, but can be 30% for wood chips.

P 176. The COP of a Ground Source Heat Pump COP was taken as 3.16, based on a single case study (GIR72). In fact, including the auxiliary electrical heating, the COP was 2.38.

P 184. The electricity efficiency of the Stirling unit of 1.2 kWe and 8 kWth was not stated, but must be about 1.2 x 0.8/ (1.2 + 8) = 10.4%. This is about right.

P 187. The electricity efficiency of the ICE unit of 5.5 kWe was not stated. However, the above chart shows that the electricity efficiency for ICE units of 5.5 kWe would be only about 23% at best, and the corresponding Effective THE and Resultant THE would be only about 1. This is not significantly better than that of a good condensing boiler.

P 188. The electricity efficiency of the ICE unit of 33.3 kWe was not stated.

● 'Powering London into the 21st Century', by PB Power for the MoL and Greenpeace, March 2006. (http://www.london.gov.uk/mayor/environment/energy/docs/powering-london-21st-century.pdf).
P 24 (26 of 56) Figure A, Reductions of CO2 from 2005 to 2025.
For existing buildings, Gas engine CHP was 76.45% and Biomass CHP was 10.09%, making 86.54%, with everything else in single figures.
For new buildings, CCGT CHP Barking was 12.08%, CCGT CHP Tilfen Land was 6.04%, Gas engine CHP was 27.34%, Biomass boilers was 15.34%, making 60.8%. Building chp was only 1.22%. BIWT was 19.05% and PV 15.02%, but because of their low effectiveness per unit and very low cost-effectiveness, these are not credible.

P 38 (40 of 56). Mention of demand in non-domestic buildings as heat of 128 kWh/m2.y and electricity of 154 kWh/m2.y. These are appallingly high, especially as the electricity contributes to the heating. For the Passive House standard, space heat is less than 15 kWh/m2.y and total primary energy is less than 120 kWh/m2.y. If the heat efficiency is 0.9 and the electricity efficiency is 0.33, the electricity demand should be less than (120 – 15/0.9)*0.33) = 34.1 kWh/m2.y. Schools and offices have also been built to this standard.

P 46 (48 of 56). 6 Building-integrated low- and zero-emission technologies.
It seems that market shares were simply assumed, with no concern for effectiveness or cost-effectiveness at saving carbon. They made no reference to any U.K. field trial data, or to experience on the Continent.

P 51 (53 of 56). For micro-chp, they assumed an electricity efficiency of 30%, and a heat efficiency of 52%.
This electricity efficiency is too high for such micro-chp. The chart on page 7 above shows the electricity efficiency for an ICE unit of 5 kWe as 22.5% and of 1 kWe as 18%, while that for Stirling units of ~1 kWe is only 8 to 12%. They evidently fail to realise that the THE for co-generated heat from such micro-chp is only about 1 and 0.86 respectively. Since this is only similar to or lower than the efficiency of a good condensing gas boiler, the carbon savings are about zero and negative respectively. Even for the former, the cost of carbon saving is about infinite.
For building-integrated micro-wind, they assumed an annual yield of 2000 kWh/kWe – i.e. a capacity factor of 22.8%. This latter is far too high. The Loughborough CFD study gave values of 1 to 5%.
For PV, they assumed an annual yield of 1000 kWh/kWp – i.e. a capacity factor of 11.4%. This is higher than any UK field test data. They also fail to mention that the payback time is very long and the cost of carbon saving very high.

● 'Building A Greener Future: Towards Zero Carbon Development', Dept of Communities and Local Government, December 2006. (http://www.communities.gov.uk/documents/planningandbuilding/pdf/153125).

P 10, Footnote 9. *'For projections of cost reductions across a range of microgeneration technologies, see 'Potential for Microgeneration – Study and Analysis', for EST, December 2005'*. However, the use of 'learning curves' and unsupported assertions as the bases of future cost reductions is quite unsound. (See above).

● London's Climate Change Action Plan, February 2007.
(http://www.london.gov.uk/mayor/environment/climate-change/docs/ccap_execsummary.pdf)
P 16 (18 of 32). Fig ix shows that of supply sectors, contributions to CO2 savings by 2025 are:
- microgeneration 7%
- local heat-power networks 31%

- energy from biomass and waste 15%.

Almost all microgeneration saves little carbon per unit and hence is less cost-effective, so it is only a distraction.

● ‘Evidence Base: Climate Change in the Further Alterations to the London Plan’, Arup for GLA, April 2007. (http://www.london.gov.uk/mayor/strategies/sds/further-alts/docs/cc-evidence-base.pdf).

Section 6.5.5 Forecast Cost Changes.
These depend on ‘learning curves’. However, these only reflect the past, and should not be extrapolated for cost projections. Technological or scientific barriers, such as the ‘physical laws’, may arise at any point. Also the demands of increased efficiency and durability – and the increasing scarcity of materials - would cause costs to rise.

Section 8.1 includes:

> *The FALP policies in Chapter 4A revolve around the generation and supply of electricity and heat. In essence, the focus of the Mayor’s policy is on promoting sources of energy which are carbon-friendly and on the generation of electricity locally. The FALP policies say that:*
>
> - *The Mayor’s Energy Strategy is to be supported;*
> - *An energy demand & CO_2 emissions assessment will be required as part of the sustainable design and construction statement;*
> - *The energy hierarchy is to be followed as the primary concern: First, the minimisation of energy use, then efficient supply, followed by renewable energy;*
> - *Decentralised energy is to be included where possible, first through connection to existing CCHP/CHP networks, second by renewable-powered site-wide CCHP/CHP, third by gas-fired CCHP/CHP or hydrogen with renewables, fourth by renewable-powered communal heating/cooling, and last by gas-fired communal heating/cooling;*
> - *Renewable energy is required through a 20% reduction in CO_2 emissions, to be achieved by onsite renewable energy generation;*
> - *In addition to the 20% renewables requirement, sites for zero carbon development and locations for wind turbines should be identified, one large wind power scheme should be encouraged, and new street appliances should be powered by renewables;*
> - *Hydrogen heat and power should be supported and encouraged;*

This starts well with the energy hierarchy, but then becomes prescriptive. In particular, a 20% reduction of CO2 emissions – presumably below the existing regulations – may be achieved at much lower cost by further energy saving measures, as well as by off-site renewables and district heating from large-scale CHP. (See below).

Moreover, hydrogen heat and power makes no sense. Hydrogen is only an energy carrier, and has to be made from natural gas or electricity. This incurs substantial losses, whereas the gas and electricity could be used far better directly. (http://www.energypolicy.co.uk/hydrogen.htm).

Section 10.3. Table 10.1. From an analysis of recent planning applications in London by LSBU, energy efficiency measures accounted for CO2 savings of 25%, whereas renewable energy measures – presumably on-site - saved 9.3%. (See 'Review of the impact of the energy policies in the London Plan on applications referred to the Mayor (Phase 2)', Final Report, by London South Bank University, July 2007.
http://www.london.gov.uk/mayor/planning/docs/lsbu-research.rtf).
However, there is no discussion of which measures are the most cost-effective at saving carbon.

● ‘Guidance to help industry respond to the zero carbon challenge’. 1 October 2007. (http://www.communities.gov.uk/news/corporate/494556).

‘Notes to editors
1. The technical guidance can be found here:
www.planningportal.gov.uk/uploads/code_for_sustainable_homes_techguide.pdf (external link).
2. The Code for Sustainable Homes was introduced in April this year. It provides a comprehensive assessment of the overall sustainability and includes minimum standards for energy and water at all levels.
3. The Budget 2007 stated: "that from 1 October 2007 all new homes meeting the zero carbon standard costing up to £500,000 will pay no stamp duty, and zero-carbon homes costing in excess of £500,000 will receive a reduction in their stamp duty bill of £15,000. The exemption will be time limited for 5 years until 30 September 2012, but before the end of the time limit the Government will review the effectiveness of the relief and consider the case for an extension".
4. The key changes are:
The way energy efficiencies for flats with and without renewables are calculated;
The way water efficiencies are calculated; and
The use of off-site renewable energy sources. In future, these will not be eligible unless directly connected to the development concerned. The Code continues to allow connection to gas and electricity grids as long as the home produces net zero carbon emissions over the year.
5. The Code Technical Guidance, including definition of zero carbon, will be kept under review as new evidence emerges about costs and practicalities, and as technologies develop’.

● ‘Code for Sustainable Homes, Technical Guide’, DCLG, October 2007. (http://www.planningportal.gov.uk/uploads/code_for_sustainable_homes_techguide.pdf).

P 29 of 225. *‘Additionally to meet Level 6 (zero carbon) until SAP is updated, to include the appliances element, each home must also provide an amount of renewable electricity equal to a specified amount per m2 of floor space in addition to that required to meet zero carbon in SAP 2005, to approximate the average appliance energy consumption’.*

P 57 of 225. *‘The following Zero emission technologies may be considered (from the Energy Act 2004) :*
- *Solar:*
- *Solar Hot Water*
- *Photovoltaics*
- *Water:*
- *Small scale hydro power*
- *Wind:*
- *Wind turbines*
- *Other:*
- *Fuel cells using hydrogen generated from any of the above ‘renewable’ sources.*

The Department for Business Enterprise and Regulatory Reform (BERR) have recently launched The Microgeneration Certification Scheme (MCS).This scheme will approve microgeneration equipment and installers. It is a UKAS (United Kingdom Accreditation Service) accredited certification scheme covering products, installers and manufacturers. It provides consumers with an independent indication of reliability of products, assurance that the installation will be carried out to an appropriate standard, and a route for complaints should something go wrong.
This scheme is being managed by the Building Research Establishment (BRE) on behalf of Government.
All micro-generation equipment will need to comply with this scheme in order to satisfy the requirement for credits.
The following Low emission technologies may be considered:
- *Biomass*
- *Biomass single room heaters/stoves*
- *Biomass boilers*
- *Biomass community heating schemes*
- *Combined Heat and Power (CHP)*

- *CHP*
- *Biomass CHP*
- *Community heating, including heating from waste.*
- *Heat Pumps:*
- *Air source heat pumps (ASHP)*
- *Ground source heat pumps (GSHP)*
- *Water source heat pumps (WSHP)*

The Low or Zero Carbon (LZC) Energy Technologies can be situated either on site or off site, with the electricity from the off-site LZC technologies being delivered via an Energy Services Company (ESCo) or from an "accredited external renewable" ..'.

Even though the 'Guidance' above carries a link to the 'Technical Guide', there appears to be a direct contradiction between them. The former says that off-site renewable energy sources *'will not be eligible'* while the latter says that they *'can be situated either on site or off site, with the electricity from the off-site LZC technologies being delivered via an Energy Services Company (ESCo) or from an "accredited external renewable" ..'.*

One possible interpretation is that the renewable energy sources can be either on-site or off-site to satisfy the Code, but only on-site to be eligible for exemption from, or reduction of, the stamp duty land tax. Also on-site measures are to be exempted from increased business rates – at least for five years. (http://www.infomaticsonline.co.uk/business-green/news/2200859/darling-dishes-renewables-tax).

All the so-called 'zero emission technologies' and many of the 'low emission technologies' listed above are either ineffective or far from cost-effective at saving carbon. Also, when the energy invested in the hardware is included, they are worse, even counter-productive. The criterion is not just 'zero carbon' but over the lifetime of the plant, a high value of the Energy Return for the Energy Invested (EROI). (See below). Small scale reduces the EROI. Hence such technologies should not be encouraged by credits, and no certification scheme is required. Only biomass and larger CHP measures are effective and cost-effective at saving carbon. However, small biomass units are mostly Austrian and have long been certified by BLT, Austria. (http://blt.josephinum.at/index.php?id=331). Larger DH systems with CHP using fossil fuels, waste and biomass etc. would be individually designed by competent consulting engineers. The suppliers of plant for such systems would usually provide performance guarantees.

This document seems to have been written without a thought to the feasibility or relative cost-effectiveness. Indeed, it smacks of an 'autonomous house' approach, which is not necessary in urban locations and far from the most cost-effective. Also, it attempts – as so often in the UK – to 'micro-manage', which results in prescription and over-constraint. This almost always prevents the delivery of the most cost-effective solution – here for carbon saving.

It is noteworthy that the Continental Passive House standard specifies limits for space heating energy (less than 15 kWh/m2), space heating power (less than 10 W/m2) and total primary energy (less than 120 kWh/m2), but does not specify any requirement for on-site renewables. Indeed, experience on the Continent is that many energy saving measures are far more cost-effective at saving carbon – having negative lifecycle cost. (See below).

● 'The Role of Onsite Energy Generation in Delivering Zero Carbon Homes', by Element Energy with the Energy Saving Trust for the Renewables Advisory Board, 21 November 2007. (http://www.renewables-advisory-board.org.uk/vBulletin/showthread.php?p=123#post123).

Page 1, paragraph 2. *'The Department of Communities and Local Government (CLG) has been clear that it wants the zero carbon homes policy to stimulate new technology and reduce the cost of low carbon technology for existing homes'.*

This assumes that there are any 'new' technologies to be found. However, all the microgeneration measures have already been explored abroad, and leading positions established. It is fanciful to imagine that anything worthwhile remains for a latecomer like the UK. It also assumes that the cost of carbon saving can be reduced by lowering the cost, while failing to recognise their inherently low and sometimes zero or negative effectiveness.

Page 1, paragraph 2. *'The report suggests that this can be achieved if Ministers are prepared to accept the trade off between cheaper remote generation, and the technology forcing benefits of more expensive onsite generation'*.

This amounts to saying that the cost of carbon saving would be higher - so putting at risk the achievement of the UK national and international objectives. Every engineer knows that there is a price to be paid for meeting more than one objective at once. Instead, the UK should cast any legislation only in performance terms - here absolute carbon emissions - and leave it to the responsible professionals to identify and deliver the optimum solutions. (See http://www.energypolicy.co.uk/epolicy.htm Part II - the case for ESCOs).

● 'Metering and Monitoring of Domestic Embedded Generation', BEAMA, 28 November 2007.
http://83.217.99.100/cfide/beamaprj/downloads.cfm
http://83.217.99.100/cfide/beamaprj/Downloads/MDG_Doc_101_0_1 Final Report Part II.pdf
http://83.217.99.100/cfide/beamaprj/Downloads/MDG Final Presentation parliamentary.pdf

These documents include some performance data expressed as average annual capacity factors.
For the small wind turbines – 4 of 20kWe and 9 of 5 and 2.5kWe – it was 7.8%. The range was from 1% to 15%.
For such a mixture of sizes, this is consistent with other UK field trial data.
For the PV arrays of about 2 kWe, it was 9.8%.
This is consistent with other UK field trial data.
For the Stirling micro-chp units of about 1 kWe, 35 with buffer heat stores and 8 without, it was 8.96%. Most of the time generating electricity was at only 70% of the rated output.
This is particularly revealing, since plant that has such a low capacity factor for the higher value product (electricity) cannot be effective at saving money or carbon. However, this result is wholly understandable. The unit is ‘heat lead’, so running is limited to periods of heat demand. Moreover, such small Stirling units have very low electricity efficiencies, and hence electricity to heat ratios. Furthermore, the engine takes a significant period to reach working temperature, so that in normal intermittent operation, the electricity output is even lower. Hence the 70% figure.

Another finding was that *‘For all of the sites it has been found that the proportion of export relative to power generated is relatively high, ranging from 47% for wind to 31% for PV and microCHP. This will have significant impact on customers who do not have export deals and will adversely affect any payback on their systems’*. Moreover, *‘The major issue for Suppliers is that the cost for them of metering the exports and then processing payments is of a similar value to the value of the exports. Thus, there is little value left to offer to the customer’*.

Summary of Microgeneration Measures

The quantitative data above may be summarised as follows:

	Payback Time - years	Cost of Energy – p/kWh	Cost of Carbon - £/tC/y
Electricity			
Mains electricity, for comp.		9.46	
Wind turbine, Toolkit data			345
Small-WT, 6 kWe Strategy data	29	10	855
Micro-WT, Ampair 600 trial	207	98	6540
PV, Toolkit data			3760
PV, Strategy data	120		3559
PV, BRE field trial		39.1 – 77.8	
PV, derived data	66 - 106	31 – 50	2091 - 3345

Heat			
Gas heat, for comparison		2.87	
Micro-chp, Taylor analysis			Infinite
SDHW, Toolkit data			649
SDHW, Strategy data	80		1316 - 1667
SDHW, Taylor data	152 - 214	22 - 31	2920
SDHW, Streicher data	64 - 91	8.5 - 11.8	
SDHW, Viridian data			1623
GS Heat Pump, Toolkit data			1243
GS Heat Pump, Strategy data			564
GS Heat pump, adjusted data			829
Air Source Heat Pump, trial data			1501
Biomass heating, Toolkit data			322
Biomass heating, Strategy data			52 - 155

The on-site renewable - sometimes called ‘microgeneration’ - measures, should be considered at two scales – for housing (often detached or semi-detached in the UK) and offices. Their attributes may be summarised as follows:

.

Microgeneration Measure	**Housing**	**Offices**
Electricity		
Small wind turbines	Wind speeds are low and gusty. Suffers from scale effect. Extremely small carbon saving. Very long payback time. Noise and vibration. Danger from falling debris.	Wind speeds are low and gusty. Suffers from scale effect. Small carbon saving. Long payback time. Noise and vibration. Danger from falling debris.
Photovoltaic arrays	Very small carbon saving. Very long payback time. Often poor orientation, slope and shading.	Very small carbon saving. Very long payback time. Often poor orientation, slope and shading.
Heat		
Micro-chp	No carbon saving. Suffers from scale effect. High maintenance costs.	Very small carbon saving. Suffers from scale effect. High maintenance costs.
Solar water heating	Very small carbon saving. Long payback time. Often poor orientation, slope and shading.	Very small carbon saving. Long payback time. Often poor orientation, slope and shading.
Ground Source Heat Pump	Small carbon saving versus gas. Very high initial cost.	Small carbon saving versus gas Very high initial cost (except with A/C).
Air Source Heat Pump	Very small carbon saving versus gas. High initial cost.	Small carbon saving versus gas. High initial cost (except with A/C).
Biomass boiler	High carbon saving even against gas. High initial cost.	High carbon saving even against gas. High initial cost. Delivery, storage of wood chips or pellets.

The ‘Continental’ Measures

Some people are advocating – and even seeking to mandate – microgeneration measures, with little or no evidence of their effectiveness, never mind their cost-effectiveness at carbon saving. Yet there is ample evidence of the effectiveness of investing money and embedded energy in – for example – high efficiency appliances and large wind turbines located at windy sites and district heating with large-scale CHP. I have shown by quantitative analysis that these and other measures currently deployed widely on the Continent could enable a 60% carbon reduction in the UK. (See http://www.energypolicy.co.uk/epolicy.htm).

In the White Paper, 'Planning for a Sustainable Future', 2007, p 8, para 1.1, the emphasis is on 'clean and affordable energy'. (http://www.communities.gov.uk/documents/planningandbuilding/pdf/320546). However, it should be on 'sustainable energy services'. This means mostly energy savings with some renewable energy supply. As a guide, the Swiss '2000 Watt' (per capita) documents give the current value for Switzerland as about 6000 Watts per capita. They outline how for sustainable energy services, some 4000 Watts per capita would come from energy savings (in all sectors), while - of the remaining 2000 Watts per capita – 1500 Watts per capita would come from renewable supply and only about 500 Watts per capita be of fossil carbon or equivalent in greenhouse gas emissions. (See Jochem E. (ed), 2004, 'Steps towards a sustainable development'.
http://www.cepe.ethz.ch/publications/Jochem_WhiteBook_on_RD_energyefficient_technologies.pdf).

Large Wind Turbines

The capacity factor of large MWe-class wind turbines in windy locations onshore would be about 30% or more, and in windy locations offshore would be about 40% or more. (http://www.vestas.com/Admin/Public/DWSDownload.aspx?File=%2FFiles%2FFiler%2FEN%2FSustainability%2FLCA%2FLCA_V80_2004_uk.pdf pages 14 and 10 respectively. (2817 full-load hours/y is a capacity factor of 2817/8760 = 32% and 4044 full-load hours/y is of 4044/8760 = 46%). From measurements made at Horns Rev, 3 MWe wind turbines would have a capacity factor of 54%. (http://www.vestas.com/Admin/Public/DWSDownload.aspx?File=files%2ffiler%2fen%2fsustainability%2flca%2flcav90_juni_2006.pdf page 11). These capacity factors are hugely greater than those for small and micro wind turbines and are due to scale effects. As a result, the Energy Return on Investment (EROI) for wind turbines increases with unit size and for those of 3 MWe is about 35. (See http://www.energypolicy.co.uk/sustainpres.htm Slide 19). In other words, wind turbines of multi-MegaWatt size have energy payback times of only about half a year. (http://www.vestas.com/Admin/Public/DWSDownload.aspx?File=files%2ffiler%2fen%2fsustainability%2flca%2flcav90_juni_2006.pdf).

Large DH-CHP

District heating has the huge advantage of being applicable to existing as well as new buildings. This is especially relevant to European countries like the UK, which have many cities with large stocks of heritage buildings. Hence they do not have to be demolished and replaced with new, which would take far too much time, money and energy. Thus district heating can deliver heat from CHP and other low carbon sources. Moreover, it can be deployed 'city-wide' in many cities at once, thus serving the majority of existing and new buildings, and in about seven years. (http://www.svenskfjarrvarme.se/download/3477/8dhc-05-01_distributed_vs_large-scale_chp-dh.pdf page 48). Compared with individual boilers, this can reduce the gas and carbon emissions by 80% rising to 87% and beyond. Hence district heating can give savings of fuel and carbon emissions for heat that are fastest and greatest.

The electricity efficiency of large (300 MWe) Gas Turbine Combined Cycle (GTCC) Combined Heat and Power plants is about 50%. With say 10% of the heat coming from Heat Only Boilers at an efficiency of say 80%, and network heat losses of say 10%, the Resultant 'Thermodynamic Heating Efficiency' of the largely co-generated heat supplied via district heating is about 330%. (See the chart above). Compared with typical existing gas boilers with a gas efficiency of 65%, the fuel saving for heat is about (1/0.65 – 1/3.3)/(1/0.65) = (1 – 0.65/3.3) = 0.80 i.e. 80%. (See http://www.energypolicy.co.uk/epolicy.htm Section 3.9).

- For a typical extraction steam turbine, the fuel consumption for heat production is 0.28 GJ fuel/GJ heat with supply/return temperatures of 100/50 C and 0.23 with 90/40. (See 'Low Temperature Heat Sources', by Flemming Ulbjerg, 'News from DBDH', No. 2, 2003. http://dbdh.dk/images/uploads/pdf-production/low-temp-heat-source.pdf). Hence the THEs in GJ heat/GJ fuel are 1/0.28 = 3.6 and 1/0.23 = 4.3. With say 10% of the heat from Heat Only Boilers at an efficiency of 80% and network heat losses of say 10%, the Resultant THEs would be 2.4 and 2.7. Even for such smaller CHP plants, the fuel saving for heat would still be about (1 – 0.65/2.4) = 73% and (1 – 0.65/2.7) = 76%.

Large DH-CHP using Waste and Biomass

All cities generate municipal solid waste. For Copenhagen, about a quarter of all such waste is incinerated in three large CHP plants, which accounted for 30% of the district heat in 2005. (See 'News from DBDH', 2/2006, page 9). Adding biomass (straw and wood pellets) burnt in another large CHP plant helps to increase the fossil fuel savings for district heating. Expressed as a 'Primary Resource Factor' of 0.13, this saving is already 87% for the western part of Copenhagen. (See the DBDH journal, 1/2007, http://www.e-pages.dk/dbdh/2/ Page 2).

Large-scale Solar Heating

The improvement in price/performance ratio in going from an installation of 5 m2 to one of 20,000 m2 was factor six. (http://dbdh.dk/images/uploads/pdf-ren-energy/side22-23.pdf). This shows the favourable effects of large-scale on the specific cost and performance of solar heating. An article 'EU Aim at Great Expansion of large-scale Solar Thermal Plants' appears in the DBDH Journal No 4/2007. (See http://www.e-pages.dk/dbdh/2/). The article starts at pages 12-13 and the chart of interest is shown on pages 14-15 (actually 15). This shows the major scale effect of the size of plant on the production price per MWh (heat) output from solar collector arrays. Of course, this can only be realised in conjunction with District Heating.

As noted in the above article, Denmark is rapidly expanding the number of large-scale solar heating systems, of e.g. 3000 to 40,000 m2. (See also http://www.solarge.org/uploads/media/9_DENMARK_Runager.pdf especially Slide 14). Indeed, Denmark plans to meet 50% of heat consumption (for space and water heating) by solar heating in the long term. In the light of the scale effect on cost, this will be predominantly via large and very large solar collector systems, supplying District Heating networks. (See http://www.solarge.org/uploads/media/CSTS_Market_Development_Denmark_RAMBOLL_Steffensen.pdf especially Slide 5)'.

Passive Houses and Buildings

After years of research in building physics, Professor Bo Adamson, Dr (now Professsor) Wolfgang Feist and others defined the Passive House standard. This is an 'optimal' design, in which the levels of insulation and air-tightness is such that no conventional heating system is required. (http://malmo.se/download/18.1f60430104c0456fc68000698/Feist.ppt Slides 22 and 23). Most of the heat comes from incidental gains - passive solar, occupants, and appliances. The building also has mechanical ventilation with heat recovery, and a small 'post-heater' to meet the remaining heat load. The space heating energy must not exceed 15 kWh/m2.y, the space heating power 10 W/m2, and the total primary energy 120 kWh/m2.y. The space heating energy

criterion represents a saving of about 90%. (http://malmo.se/download/18.1f60430104c0456fc68000698/Feist.ppt).
The Passive House standard has been achieved in thousands of new buildings, mainly in Germany, but also in Switzerland, Sweden, and France. (http://www.passivehouse.com/07_eng/news/CEPHEUS_final_long.pdf).
It has also been achieved in new schools and offices, and in many refurbished dwellings. (http://www.dena-energieausweis.de/page/fileadmin/waermewert/dokumente/niedrigenergiehaus.pdf).

Summary of 'Continental' Measures

Better measures are in widespread and increasing use – particularly on the Continent. These include:

'Continental' measure	**Housing and Offices**
Electricity	
High efficiency appliances and lighting.	Very effective at carbon saving, with negative lifecycle cost. Lower energy bills means reduced fuel poverty - especially as fuel prices continue to rise.
Large CHP, fossil-fired.	Co-generated heat is valuable and can be sold, producing another income stream.
Large CHP, using waste and biomass etc.	Carbon saving approaches 100%, so very low cost of carbon saving. Off-site location facilitates delivery and storage of bulk waste, wood chips and pellets.
Large wind turbines	Off-site location, including offshore, gives maximum yield. Highly cost-effective and energy-effective at carbon saving.
Heat	
Large DH-CHP, fossil-fired.	Co-generated heat gives carbon saving of about 80%, so very low cost of carbon saving. Reduces urban emissions, so increasing air quality. Off-site location reduces plant room size, so increasing usable floor area.
Large DH-CHP, using waste and biomass etc.	Carbon saving approaches 100%, so very low cost of carbon saving. Off-site location facilitates delivery and storage of bulk waste, wood chips and pellets. Off-site location reduces plant room size, so increasing usable floor area.
Large-scale solar heat	Specific cost e.g. one-third that of small systems, so much lower cost of carbon saving.
Highly insulated, airtight buildings, up to the Passive House standard.	Very effective at carbon saving, with negative lifecycle cost. Eliminates most heating and A/C plant, saving cost and increasing usable floor area. Lower energy bills means reduced fuel poverty - especially as fuel prices continue to rise.

Summary of Costs of Carbon Savings

- ‘Renewable Heat and Heat from Combined Heat and Power Plants - Study and Analysis’, Future Energy Solutions for DTI and DEFRA, September 2005. (http://www.defra.gov.uk/farm/crops/industrial/energy/pdf/fes-renewable-chp.pdf).

P iii Cost of carbon savings:

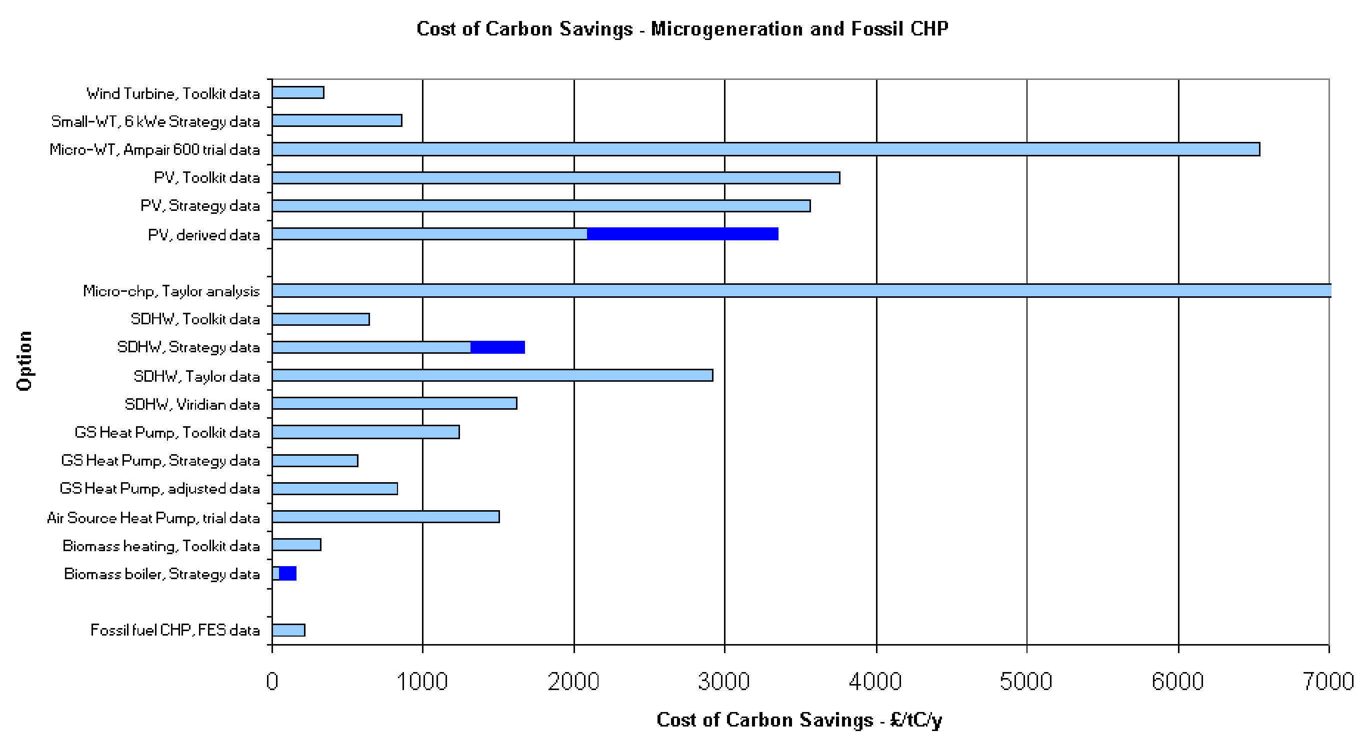
Residential	£ 1085 to £ 4200/teC.
Industrial and Commercial	£ 35 to £ 364/teC (for biomass, Energy from Waste, and Anerobic Digestion).

P iv The Renewable Obligation (electricity only) costs approximately £ 153 per year for each tonne of carbon saved. Most of the potential carbon savings are in the Industrial and Commercial sector, for biomass, Energy from Waste, and Anerobic Digestion, should cost £ 250 to 330/teC, and for CHP, around £ 170/teC.

P v For the community heating, commercial and industrial sectors, fossil fuel CHP costs around £ 210/teC. *‘We do not recommend broadening the scope of such a scheme [for industrial, commercial and community heating above] to include renewable energy [heat] in the domestic sector, as the costs of carbon saved are too high’.*

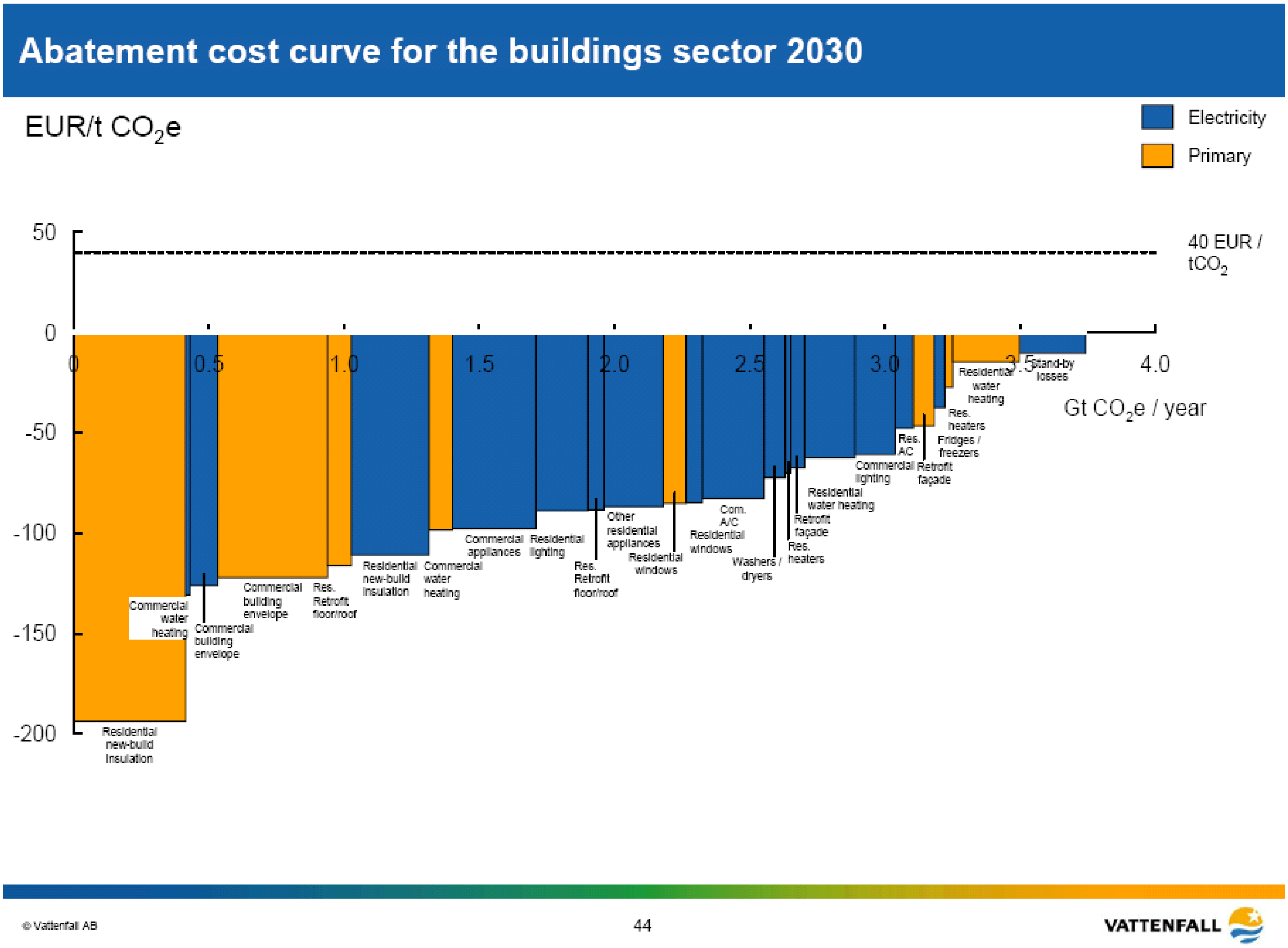
P 79 Residential renewables, taken as biomass first, then heat pumps, and only a tiny amount of Solar DHW, would cost £ 775/teC.

The cost of carbon saving for microgeneration and larger fossil CHP are compared in the chart below.



This shows that the lowest cost carbon savings are with biomass heating and fossil CHP. Due to scale effects on performance and specific cost, these measures are best implemented at large scale, and thus off-site. Hence they are applicable to the urban domestic residential sector, as well as the commercial and industrial sectors.

- ‘Global Mapping of Greenhouse Gas Abatement Opportunities’, Vattenfall, January 2007. (http://www.vattenfall.com/www/ccc/ccc/Gemeinsame_Inhalte/DOCUMENT/567263vattenfall/P0271632.pdf). Slide 44 shows the abatement cost curve for the buildings sector 2030.



Abatement cost curve for the buildings sector 2030

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None of the measures are on-site renewables (microgeneration), but all those shown have negative lifecycle costs. For example, the first measure is Residential new-build insulation, at a cost of -190 euros/tCO2e. At 1 euro = £ 0.67, this is £ -127/tCO2e – i.e. about £ -467/tC.

The background to the above study is given in ‘A Cost Curve for Greenhouse Gas Reduction’, McKinsey, May 2007. (http://www.epa.gov/air/caaac/coaltech/2007_05_mckinsey.pdf).
P 6 includes *‘Looking at specific measures, nearly one-quarter of the abatement potential at a cost of up to 40 euros a ton involves efficiency-enhancing measures (mainly in the buildings and transportation sectors) that would reduce demand for energy and carry no net cost. The measures we include in this category do not require changes in lifestyle or reduced levels of comfort but would force policy makers to address existing market imperfections by aligning the incentives of companies and consumers’.*

This could be done by encouraging fuel and energy suppliers to become Energy Service Companies (ESCOs). With their skills and access to low-cost, long-term capital, they could make a profitable business by implementing the measures shown in the abatement cost curve for the buildings sector. This would also meet the consumer needs and national objectives. (See http://www.energypolicy.co.uk/epolicy.htm Part II).

Discussion

Greenhouse gas emissions are far above the sustainable level. For the UK, targets of 60% reduction in greenhouse gas emissions by 2050 and 80% by 2100 were recommended in ‘Energy: The Changing Climate’, Royal Commission on Environmental Pollution, Report 22, 2000. (See http://www.rcep.org.uk/newenergy.htm). Moreover, faster and greater reductions may well be required. (See the ‘Climate Code Red’ report of February 2008. http://www.carbonequity.info/download.php?id=6). Yet Peak Oil, Gas, and Coal are all imminent. (See e.g. http://www.energywatchgroup.org/Reports.24+M5d637b1e38d.0.html). Therefore the carbon saving measures chosen must be those giving the greatest returns on the invested and operating energy – i.e. the highest EROIs. Moreover, they should be capable of the fastest and greatest carbon reductions. (See http://www.energypolicy.co.uk/epolicy.htm). Indeed, the principle objective of UK planning policy must be to effect a smooth transition to a sustainable future - of which the most critical aspects are climate and energy. (http://www.energypolicy.co.uk/sustainpres.htm).

The Critiqued Documents

The first requirements for renewable energy measures (PPG22, 1993, Merton, 2003) were made without any evidence – analytical or empirical – on their performance, cost, and effectiveness and cost-effectiveness of carbon saving. The initial references (Toolkit, 2004, Strategy, 2005, Potential, 2005, and Powering, 2006) were based on very little traceable measured data. Some documents (PPS22, 2004 and Powering, 2006) gave values for capacity factor for micro-wind, and electricity efficiency for micro-chp that were based on larger units. There is a remarkable failure to understand the purpose of CHP and that the thermodynamics show strong scale effects. These have significant effects on both performance and specific cost of almost all energy technologies. This lead to erroneous – generally inflated - findings for the potentials for carbon saving by on-site renewables. These in turn lead to the continuing requirements for renewable energy measures (Greener, 2006, Action, 2007, FALP, 2007, and Technical Guide, 2007). Yet the necessary evidence is still lacking, as is admitted in Guidance, 2007 with *‘The Code Technical Guidance, including the definition of zero-carbon, will be kept under review as new evidence emerges about costs and practicalities..’*. It seems that Government is not taking full account of the available analyses and field test data and particularly of the far more effective and cost-effective measures adopted on the Continent.

The Merton Rule

The Merton Rule is commonly understood to mean 10% from on-site renewables. Yet the limited evidence available shows most types of on-site microgeneration to be ineffective or to have very high costs of carbon saving. Hence prescribing such microgeneration is actually counter-productive to the declared intent. Moreover, investing in such measures is not sustainable and would reduce competitiveness and security of supply. Instead carbon reductions for new buildings should be effected with energy saving measures such as Passive House standards and for existing buildings off-site measures such as district heating from large-scale CHP and renewables with large-scale wind turbines. These have been proven on the Continent to be highly cost-effective at saving carbon – many at negative lifecycle cost.

The ‘Zero-Carbon’ Idea

A ‘zero carbon home’ - Level 6 in the ‘Code for Sustainable Homes’ – is defined as having *‘zero net emissions of carbon dioxide (CO2) from all energy use in the home’*. (http://www.planningportal.gov.uk/uploads/code_for_sust_homes.pdf). Level 5 is defined as having *‘zero emissions from heating, hot water, ventilation and lighting’*. However, no homes to these standards have yet been built in the UK, occupied and their energy performance confirmed by measurements. Conversely, as noted above, many thousands of homes have been built to the ‘Passive House’ standard in Germany, Austria, Switzerland and elsewhere in Europe and occupied. Moreover, the energy performance of hundreds such has been confirmed by measurements. (http://malmo.se/download/18.1f60430104c0456fc68000698/Feist.ppt Slide 15). The Passive House standard requires space heat of less than 15 kWh/m2.y, and total primary energy of less than 120 kWh/m2.y. If the heat efficiency of the ‘post-heater’ is 0.9 and the electricity efficiency of the grid is 0.33, the electricity demand should be less than (120 – 15/0.9)*0.33) = 34.1 kWh/m2.y. Assuming a dwelling floor area of 100 m2, this implies a space heat demand of less than 1500 kWh/y, and an electricity demand of less than 3410 kWh/y. These validated demands are used below when considering the incremental requirements of a ‘zero carbon home’.

Even a space heat demand of only 1500 kWh/y could not be met by a solar thermal system without a very large and expensive inter-seasonal store. Moreover, a heat pump cannot supply heat with zero carbon when driven by electricity from the GB grid, since this is far from zero carbon. However, according to the ‘zero-carbon’ idea, electricity may be exported to and imported from the grid, and balanced ‘over the year’. A heat pump ‘post-heater’ with an annual average COP of say 3 would require electricity of 1500/3 = 500 kWh/y. To provide this from a PV array would require – at a yield of 800 kWh/kWp.y – an array of about 0.625 kWp. At a specific cost of £ 6300 per kWp, this would cost about £ 3937.

The DHW heat demand might be about 2600 kWh/y, of which a solar thermal system could meet only about 60%. Micro-chp cannot supply zero-carbon heat, since it would usually be fuelled by fossil gas. Only the chance of biogas might make it near-zero carbon. Therefore the most usual measure for near-zero carbon heat would be a biomass boiler. A 9 kW unit – sized to meet the DHW load - might cost 9 x 200 = £ 1800 to 9 x 600 = £5400.

Electricity of 3410 kWh/y might also be produced by PV. However, with a yield of 800 kWh/kWp.y it would require an array of 3410/800 = 4.263 kWp. At a specific cost of £ 6300 per kWp, this would cost about £ 26,857.
Electricity of 3410 kWh/y could also be produced by a small wind turbine. However, at a capacity factor of say 3.5% - i.e. an energy yield 307 kWh/kW.y – this would require a turbine of 3410/307 = 11 kWe. At a specific cost of £ 2500 per kWe, this would cost about £ 27,500. More realistically, this demand might be met with a pole-mounted wind turbine of only 6 kWe, costing £ 20,000, due to a higher capacity factor of perhaps 10 %.
Micro-chp could not supply even near-zero carbon electricity because it would usually be fuelled by fossil gas.

So for urban dwellings the only generally available solutions for near-zero carbon heat would be a heat pump ‘post-heater’ plus PV array at more than £ 3937, or a biomass boiler for £ 1800 to 5400. For near-zero carbon electricity, a PV array would cost about £ 26,857 and a small wind turbine around £ 20,000. Hence the total cost would be at least £ 1800 + £ 20,000 = £ 21,800. Not only is this almost prohibitive, but the invested energy would be quite excessive. Also it is over three times the average cost of £ 6000 per dwelling (range £ 1000 to £ 13,000) foreseen by the Renewables Advisory Board. (http://www.renewables-advisory-board.org.uk/vBulletin/showthread.php?p=123#post123).
Although the Passive House standard is very effective and cost-effective at saving carbon emissions, seeking ‘Zero Carbon’ by on site measures is futile. As so often in engineering, the ‘Law of Diminishing Returns’ applies. Moreover, on-site plant is smaller in scale, and hence has a higher specific cost (per unit output). Also it cannot benefit from the ‘diversity factor’, which enables the plant to be sized for only a fraction of the aggregate demands. This may be 0.6 for large networks. Furthermore, it is less reliable – being built down to a price, worse commissioned, worse operated and maintained, and having no backup.

It would be challenging enough for the UK building industry to meet the Passive House standards, with very high air tightness and moisture barrier integrity, and minimum thermal bridges, without getting side-tracked with on-site renewables. As well as being ineffective or far from the most cost-effective, these would increase the demands on builders, installers, and building inspectors out of all proportion. Done badly – which is all too possible – even those that should be marginally effective would instead waste energy. Indeed, the above evidence shows that on-site generation of electricity or heat is far from the best use of money and energy – both invested and operating.

Since all energy technologies require ‘embedded’ energy to be invested, ‘Zero Carbon’ requires that this be repaid within the plant lifetime. Thus the Energy Return on Energy Invested (EROI) must be greater than one – indeed the higher the better. This means recognizing the beneficial effects of large scale, which can only be realised off site. Moreover, high EROIs are crucial, since a share of the fast-depleting fossil energy must be invested most carefully to obtain the best return in sustainable energy services for the future. (See my presentation ‘Energy Criteria for Sustainable Energy Solutions’, July 2007 http://www.energypolicy.co.uk/sustainpres.htm).

The Continental Measures

Major savings of money and energy in the provision of water, waste-water, piped heat, gas and mains electricity have been achieved by the favourable scale effects of large off-site units. These include the 'diversity factor' which enables the plant to be sized for only a fraction - typically 0.6 - of the aggregate demands. Also, the specific cost (per unit output) is lower yet they are far more reliable, being better built and commissioned, better operated and maintained, and with backup available. Now that carbon reduction is the principle policy objective, building owners could sign long-term contracts with Energy Service Companies (ESCOs). The latter should operate under Carbon Emission Obligations and be free to choose the mix of measures – whether large, off-site plant or additional energy saving measures. Many of the latter are shown in the above chart from the Vattenfall-McKinsey study as having negative lifecycle costs. The professionals who implement such measures would have a direct interest in their effectiveness and cost-effectiveness at carbon saving. Moreover, as corporates rather than voters and far fewer in number, the carbon emissions of ESCOs would be far easier to monitor. This would greatly increase the chances of the U.K meeting its national and international targets for reduced carbon emissions. (http://www.energypolicy.co.uk/epolicy.htm Part II).

Conclusions

Any policy maker seeking to influence planners, architects and engineers should know that requirements - such as carbon targets - should be specified not by prescription of measures but as the performance of the system. Prescription constrains the solution, while the optimum may be quite different. The prescribed measure may be ineffective, or less effective, cost-effective and energy-effective than other measures. If so, the client, the nation and the planet would receive less – or even no - benefit for the investment of money and embedded energy. By thus precluding better investments, such measures would actually prevent meeting the UK’s targets for carbon reduction.

For all the on-site renewables (microgeneration) measures save biomass heating, the costs of carbon savings are high. Moreover, these are for fundamental engineering reasons such as scale effects and thermodynamics. Biomass heaters and boilers are the most cost-effective in saving carbon, because the fuel is almost carbon-neutral. However, micro-chp units are quite ineffective at saving carbon, so the cost of carbon saving is infinite. Although PV, micro-wind, solar water heaters, and ground and air source heat pumps might save small amounts of carbon, their costs of carbon saving are high or very high. Moreover, they would place wholly disproportionate demands on the U.K. building industry. Yet they would be largely limited to new buildings. Furthermore, since all energy technologies require ‘embedded’ energy to be invested, ‘Zero Carbon’ requires that this be repaid within the plant lifetime. Thus the Energy Return on Energy Invested (EROI) must be greater than one – indeed the higher the better. This means recognizing the beneficial effects of large scale, which can only be realised by off site measures.

The evidence in this paper confirms what has been proven in over ‘a thousand’ cities on the Continent: district heating from off-site large-scale CHP and renewables is far more effective, cost- and energy-effective at saving fossil fuel and carbon. A major IEA study on CHP/DH found: ‘The City-wide CHP/DH system benefits from a high efficiency, low capital cost, CCGT power plant, which more than offsets the additional costs of city-wide heat distribution’. ‘A further advantage of the larger-scale DH systems is the ability to obtain heat from other sources including waste to energy plants and industry’. Moreover, it can be deployed ‘city-wide’ in many cities at once, thus serving the majority of existing and new buildings, and in about seven years. Existing buildings account for the vast majority of carbon emissions – especially when weighted for heat loads. For new buildings, Continental countries are also increasingly adopting the Passive House standard, that reduces space heating demands by about 90%. For electricity demands, they are adopting high efficiency appliances and lighting, with supply from the large CHP stations and large wind turbines. Hence the fuel and carbon emissions savings can be fastest and greatest. Furthermore, many energy savings measures have negative lifecycle costs. A major study by Vattenfall with McKinsey considered the costs of Greenhouse Gas abatement measures for all sectors. Those for the buildings sector 2030 are not on-site renewables (microgeneration), but energy savings and increased energy efficiency - all with negative lifecycle costs.

Within a framework of Carbon Emission Obligations, both these could be implemented profitably by Energy Service Companies, which – unlike most consumers – have the necessary skills and access to low-cost, long-term capital, and could deliver the vital carbon savings.

Appendices

A - Carbon Intensities

The carbon intensity of natural gas is 0.185 kgCO2/kWh (HHV basis). (See http://www.defra.gov.uk/environment/business/envrp/pdf/conversion-factors.pdf Annexe 2).
With a transmission and distribution loss of 5%, largely to power compressors, the carbon intensity of delivered gas is 0.194 kgCO2/kWh – i.e. 0.0529 kgC/kWh.

The carbon intensity of GB electricity is often taken as 0.43 kgCO2/kWh. (See http://www.defra.gov.uk/environment/business/envrp/pdf/conversion-factors.pdf Annexe 3). This is described as the 'Long Term Marginal Factor', taken as that for gas-fired generation. However, this is far from correct for the average, and would distort carbon emissions and savings, and their costs.

This reference gives the rolling average for the years 2001 to 2005 as 0.52300 and the average for 2005 as 0.52657 kgCO2/kWh – i.e. 0.144 kgC/kWh. These values are averages for all the electricity consumed. However, in 2003 the average transmission and distribution loss was 8.7%, but that for low voltage customers was 12.2 %. (http://www.chpa.org.uk/news/reports_pubs/Time to Take a Fresh Look at CHP October 2005.pdf). Hence the average carbon intensity of GB electricity delivered at low voltage should be multiplied by (100 - 8.7)/(100 – 12.2) = 1.040. So that in 2005 was 0.52657 x 1.040 = 0.548 kgCO2/kWh – i.e. 0.149 kgC/kWh.

B – Analysis of Combined Heat and Power

Consider a CHP plant which in co-generation mode, has a Heat Efficiency of ηh, an Electricity Efficiency of ηe, and a Total Efficiency of (ηh + ηe), and in power-only mode has a Heat Efficiency of 0, an Electricity Efficiency of ηc, and a Total Efficiency of ηc.

A CHP plant has a 'Virtual Heat Pump' with a heat output proportional to ηh and a work input proportional to the difference in Electricity Efficiency of the central plant in the power-only and co-generation modes (ηc - ηe). Therefore the ratio of the heat output to the work input, the Coefficient of Performance (COP) = ηh/(ηc - ηe). Hence the Thermodynamic Heating Efficiency (THE) = Electricity Efficiency x COP = ηc x ηh/(ηc - ηe). Although the value can exceed 1, it is otherwise directly comparable with the thermal efficiency of boilers etc. which cannot. The THE for co-generated heat is the reciprocal of the Primary Energy Factor used on the Continent. However, due to peak loads, a fraction – say 5% - of the heat would be supplied by heat-only boilers (HOB), often with an efficiency of about 0.8. Also, there would be network heat losses of say 7%. Hence the Resultant THE = 1/(1.07*(0.95/THE + 0.05/0.8)).

In the case of micro-chp, the heat and electricity are generated on-site. Although the average electric grid loss is about 8.7%, that for low voltage loads is about 12.2%. (http://www.chpa.org.uk/news/reports_pubs/Time to Take a Fresh Look at CHP October 2005.pdf Page 6). Hence for low voltage sites the transmission and distribution efficiency ηt is about (1 – 0.122) = 0.878. Therefore the Effective Electricity Efficiency of the central power-only plant = ηc x ηt. In this case, the heat output is proportional to the heat efficiency of the micro-chp plant ηh and the work input is proportional to the difference in Electricity Efficiency of the central power-only and the micro-chp plants = (ηc x ηt - ηe). Therefore the ratio of the heat output to the work input, the Coefficient of Performance (COP) = ηh/(ηc x ηt - ηe). Hence the Effective Thermodynamic Heating Efficiency (ETHE) = Effective Electricity Efficiency x COP = ηc x ηt x ηh/(ηc x ηt - ηe). However, due to peak loads and water heating, a fraction – say 10% - of the heat would be supplied by a heat-only boiler (HOB), often with an efficiency of about 0.8. Hence the Resultant THE = 1/(0.9/ETHE + 0.1/0.8).

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