

Ashford's Future

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**Ashford Sustainable  
Energy Feasibility  
Study**

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Cluster Studies

Document ref  
DOC 2 (of 6)

FINAL ISSUE

Ashford's Future

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Energy Feasibility  
Study**

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Cluster Studies

September 2008

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Job number 125575

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## Executive Summary

This report explores the potential for the reduction of CO<sub>2</sub> emissions through the provision of low or zero carbon energy to a series of generic 'clusters' of new developments in the Ashford area.

The clusters examined range in size from 10 dwellings to 18,000 dwellings and incorporate a range of development mixes. They have been selected by Ashford's Future to represent their expectations of development in the growth area.

This exercise provides high level guidance as to the relative costs, benefits and compatibility of CO<sub>2</sub> reduction technologies when applied to the chosen clusters. This in turn illustrates the cost and value implications of the CS10 policy.

The anticipated energy consumption of each cluster has been estimated assuming compliance with current building regulations. Reductions in energy consumption due to fabric improvements as well as the potential for low and zero carbon energy generation have then been considered for each cluster.

For each of the technical options examined, the additional installed costs, compared to installation using conventional sources of heat and electricity, has been estimated.



# 1 Introduction

This report has been prepared as part of the wider 'Ashford Sustainable Energy Feasibility Study' commissioned by Ashford's Future.

The focus of this report is to explore potential for the reduction of CO<sub>2</sub> emissions through the supply of low or zero carbon energy to a series of generic clusters of buildings. The results of the cluster analysis provide high level guidance as to which combinations of CO<sub>2</sub> reduction technologies are most appropriate to the Ashford growth areas.

The Cluster Analysis assesses seven generic clusters of dwellings, with 10, 30, 100, 500, 1000, 6,500 and 18,000 dwellings per cluster, as specified in the client brief, "Sustainable Energy Feasibility Study: Brief for Consultants". The clusters are referred to hereon as Cluster 1, Cluster 2 and so on, as shown in Table 1.

|                     | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|---------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Number of dwellings | 10        | 30        | 100       | 500       | 1,000     | 6,500     | 18,000    |

**Table 1: Number of dwellings in each cluster**

The analysis examines savings possible from the low carbon / renewable energy generation technologies available as well as the savings possible due to the use of improved building technologies.

## 2 Description of Clusters

For the purpose of the analysis it is assumed that the clusters will consist of dwellings and the associated non-residential building types as follows<sup>1</sup>:

- Retail (average 120m<sup>2</sup> per unit)
- Commercial (average 200m<sup>2</sup> per unit/building)
- Primary / preschools (average 440m<sup>2</sup> per unit)
- Secondary schools (average 10,000m<sup>2</sup> per unit)
- Healthcare / doctor's surgeries (average 80m<sup>2</sup> per unit)

The non-residential area in each cluster has been calculated on the basis of the total residential area. It has been assumed that a certain threshold number of dwellings needs to be exceeded before the various types of non-residential building are required. Table 2 below gives details of the threshold of cluster required before each non residential building type will be required. This table also identifies the floor area of each non-residential unit as a percentage of the total residential area of the cluster.

|                  | Minimum number of dwellings<br>per unit | Non residential area as a %<br>of residential floor area |
|------------------|---|--|
| Retail           | 400                                     | 1.5%   |
| Commercial       | 500                                     | 7.0%   |
| Primary School   | 550                                     | 1.0%   |
| Secondary school | 5000                                    | 2.5%   |
| Healthcare       | 400                                     | 0.25%  |

**Table 2: Minimum thresholds for non-residential units**

## 3 CO<sub>2</sub> Savings

### 3.1 Residential CO<sub>2</sub> Savings

Ashford Borough Council policy document CS10 states that dwellings submitted for planning permission in urban areas between 2007 and 2014 must be either Code for Sustainable Homes (CfSH) Level 3 or Level 4 compliant.

The policy also states that developments should deliver a reduction in CO<sub>2</sub> emissions of either 20% or 30% through on-site renewables for new build urban developments depending on the development type.

Compliance with CfSH Level 3 requires regulated<sup>2</sup> CO<sub>2</sub> emissions to be reduced by 25%. The ratio of regulated to unregulated emissions in dwellings varies according to dwelling

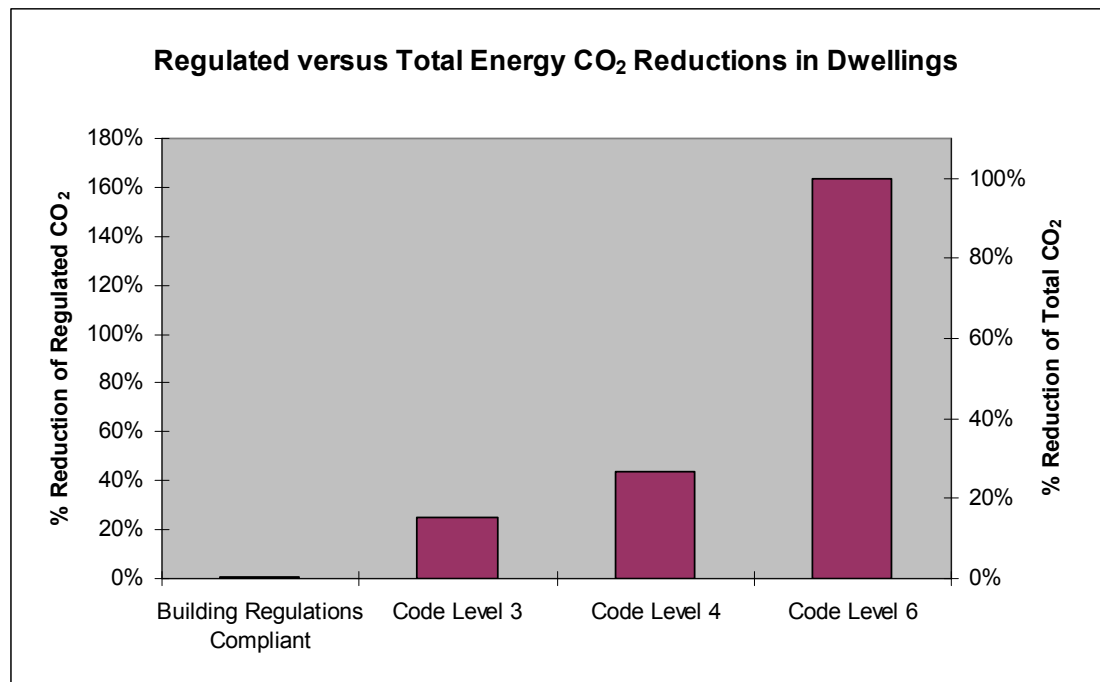
<sup>1</sup> Based on typical UK developments of a similar scale with Ashford specific data where available

<sup>2</sup> Regulated energy describes the portion of energy consumed within dwellings which is subject to the Building Regulations, in particular space heating, hot water and lighting. Unregulated energy encompasses all other energy

size and design. Typically the regulated proportion of the total CO<sub>2</sub> emissions is of the order of 60%. The reduction in CO<sub>2</sub> emissions required, expressed as a percentage of a dwelling's total emissions, is therefore about 15%.

Compliance with CfSH Level 4 requires dwelling regulated CO<sub>2</sub> emissions to be reduced by 44%. The reduction in CO<sub>2</sub> emissions required, expressed as a percentage of a dwelling's total emissions, is therefore about 27%.

The relationship between regulated and total (total equals regulated + unregulated) CO<sub>2</sub> emissions in dwellings is shown in Figure 1 below.



**Figure 1: Regulated versus total energy CO<sub>2</sub> reductions in dwellings**

### 3.2 Non-residential CO<sub>2</sub> Savings

CS10 calls for all non residential buildings to be constructed to BREEAM very good or excellent standards. As the BREEAM rating system does not stipulate minimum CO<sub>2</sub> reduction requirements the CS minimum CO<sub>2</sub> reductions stipulated by CS10 represents the minimum target for any new non-residential development.

### 3.3 Carbon Dioxide Emission Factors

To calculate the quantity of CO<sub>2</sub> saved through the use of good building practise and the use of low or renewable energy generation technologies the CO<sub>2</sub> emission indicators specified in the Part L building regulations have been used. These are as follows:

- Gas 0.194kg/kWh
- Grid electricity 0.422kg/kWh
- Locally generated electricity -0.568kg/kWh
- Biomass 0.025kg/kWh

consumed in a dwelling and is highly subject to occupant behaviour.

## 4 Building Improvements

### 4.1 Residential buildings

It has been assumed that building fabric improvements will be carried out as a first priority means of CO<sub>2</sub> emissions reduction as building fabric improvements are generally a more cost effective means of saving CO<sub>2</sub> than renewable energy generation. It has therefore been assumed that dwellings will be constructed with high levels of insulation which reduces the space heating requirements.

Dwellings will typically be constructed to have a heat loss parameter of no more than 1.0 with windows having a U value  $1.2\text{Wm}^{-2}\text{K}^{-1}$  and walls, roof and ground floor having a U value of  $0.11\text{Wm}^{-2}\text{K}^{-1}$ . The dwellings will be required to have an air tightness of no less than  $3\text{m}^3\text{m}^2\text{h}^{-1}$  @ 50Pa.

It should be noted that for levels 1 to 5 the Code for Sustainable Homes does not specify what proportion of the required level of CO<sub>2</sub> abatement should be met using fabric improvements and what proportion should be met using renewable energy generation.

### 4.2 Non residential buildings

It has been assumed that non residential buildings will be required to reduce CO<sub>2</sub> emissions regulated by the Building Regulations by 20%, compared to 2006 standards, which will be achieved through the use of measures such as improved facades and high efficiency heating and cooling systems.

### 4.3 Combined CO<sub>2</sub> savings due to building improvements

Table 3 below gives the estimated percentage reduction in CO<sub>2</sub> emissions for each cluster due to the fabric and building system improvements described above, compared to an equivalent development compliant with 2006 Building Regulations.

|   | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|---|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| % reduction in CO <sub>2</sub> emissions due to building improvements | 5%        | 5%        | 5%        | 8%        | 8%        | 8%        | 8%        |

**Table 3: Estimated percentage reduction in CO<sub>2</sub> emissions for each cluster due to the fabric and building system improvements**

As Cluster 4-7 include non-residential as well as residential buildings, the balance of CO<sub>2</sub> savings possible is assumed to be higher given the standards of construction assumed in the sections above.

## 5 Renewable / Sustainable Energy Generation Potential

The potential CO<sub>2</sub> savings possible through the use of low carbon and renewable energy generation technologies are examined in this section of the report. The technologies covered include energy generation technologies, which can be located in, or close to individual buildings as well as large, standalone technologies. In many cases, the technologies could be used either integrated with specific buildings, or on a wide-area basis. An overview of the key features of each of the technologies is given in this section. Further details of the technologies covered are available Document DOC6, Background to the Study.

The outline technical and economic feasibility of each of the low carbon and renewable energy technologies has also been considered. The technologies assessed include:

- Photovoltaics
- Small scale roof top wind turbines
- Solar hot water panels
- Ground source heat pumps
- Air source heat pumps
- Biomass boilers
- Large scale wind turbines
- Gas CHP
- Biomass CHP

To facilitate the analysis the following key assumptions have been made:

- For each technology the increase in capital costs has been estimated, compared to a baseline that consists of conventional sources of heat and power. These are assumed to be electricity supplied from the national grid and natural gas for heating using a condensing boiler.
- As all the options considered will require a grid electricity connection, this cost has not been included in the cost estimates, as they are intended to be used for comparison purposes only<sup>3</sup>.
- Where options require a gas boiler and therefore a gas connection, these costs have been included.
- All cost estimates quoted are installed costs. A reduction in unit costs has been included where it is likely that bulk discounts can be negotiated
- Where a solution will require additional space compared to a conventional solution the estimated construction cost of this additional space has been accounted for, but the land cost has not.

It will be noted that for many of the technologies, whether considered individually or in combination with other technologies, the estimated gross % CO<sub>2</sub> savings tend to reduce as the clusters increase in size. This is because the larger clusters contain a greater proportion of energy 'hungry' commercial & employment space, whereas the proportional renewable energy yield stays constant. In order to represent these results in a more intuitive way, we also show the cost of 1% of carbon abatement per m<sup>2</sup> of space, which we believe will be more informative for construction cost management.

<sup>3</sup> Costs for grid connection can vary according to site and plant capacity factors but are of the order of £200,000/MW of installed electrical capacity.

### 5.1 Photovoltaic Panels

Photovoltaic Panels (PV) convert energy from the sun into electricity using semi conductor cells assembled in panels. The maximum capacity of PV able to be installed is limited by the available space for their location.

For the purpose of this analysis it was assumed that PV or solar hot water panels would be located on the roofs of the buildings and not on the building facades. Two key factors which influence the total area of PV panels that can be accommodated on the roofs in the clusters are maintenance access requirements and the minimum spacing needed between rows to ensure that rows do not shade each other.



Figure 2: PV roof © Arup

It has been assumed that on average a maximum of 25% of the available roof area of each building in a cluster can be occupied by PV panels. Table 4 shows the total roof areas of assumed for each cluster.

|                                   | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|-----------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Total roof area (m <sup>2</sup> ) | 660       | 2,000     | 6,600     | 34,000    | 72,000    | 480,000   | 1,300,000 |

Table 4: Assumed total roof areas in each cluster

Table 5 below shows the available CO<sub>2</sub> savings and associated extra capital cost of using PV panels to generate electricity. The costs shown below do not include the additional cost of an electricity export meter. It will be noted that the potential savings due to PV reduce as the clusters increase in size. This is due to the higher energy consumption per unit area of non residential buildings compared to residential buildings. The increase in the cost of PV per percentage CO<sub>2</sub> saved is due to the generally lower heat to electricity consumption ratio of non residential buildings. This means that the (limited) amount of carbon that can be abated through the use of PV progressively makes up a diminishing proportion of the total carbon in each bigger cluster.

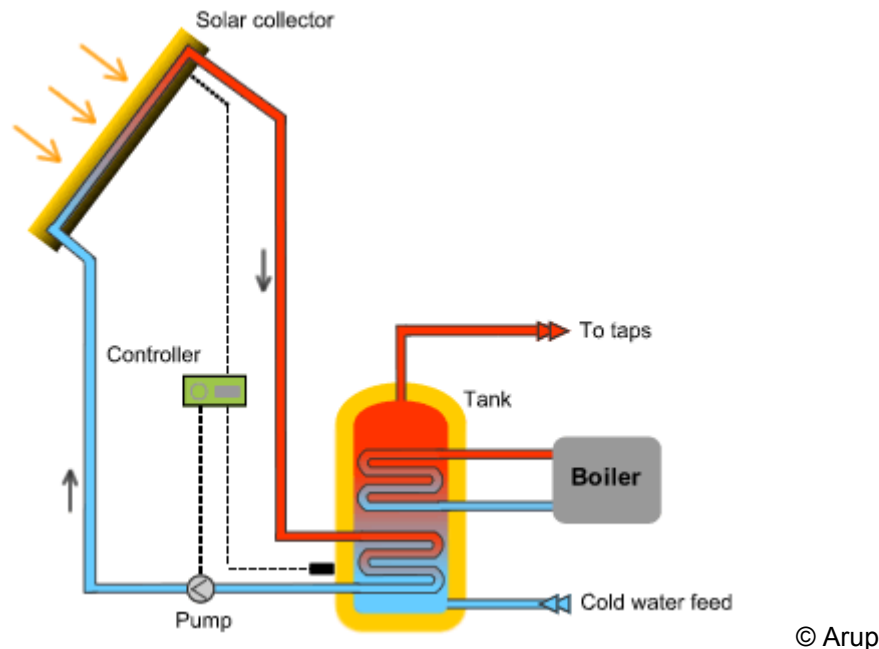
|  | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|--|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Maximum % reduction in CO <sub>2</sub> emissions due to PV                       | 69%       | 69%       | 69%       | 65%       | 60%       | 61%       | 61%       |
| Area of PV panels required (m <sup>2</sup> )                                     | 170       | 500       | 1,600     | 8,400     | 18,000    | 120,000   | 330,000   |
| Estimated additional capital cost  | £230k     | £690k     | £2.3M     | £12M      | £25M      | £170M     | £460M     |
| Estimated additional capital cost per m <sup>2</sup> per % CO <sub>2</sub> saved | £4.1      | £4.1      | £4.1      | £4.4      | £4.7      | £4.7      | £4.7      |

**Table 5: Potential CO<sub>2</sub> savings and associated extra capital costs of using PV**

While high levels of CO<sub>2</sub> mitigation are clearly possible, the costs are also high. PV panel are therefore not an optimum solution.

### 5.2 Solar hot water panels

Solar hot water panels convert the sun's energy into hot water which is best suited to provide domestic hot water purposes rather than space heating. The maximum potential CO<sub>2</sub> savings of solar hot water panels is therefore limited by both the hot water consumption of the development and the space available for the location of the panels.



**Figure 3: Schematic of a Solar Hot Water System**

As with PV, for the purpose of this analysis it was assumed that solar hot water panels would be located on the roofs of the buildings. As for PV panels, space is required to allow maintenance of the panels. Although shading should be avoided it is less of a problem with solar hot water panels. However, for the clusters investigated the limiting factor is the quantity of domestic hot water consumption rather than the available panel capacity. Consequently the available proportion of CO<sub>2</sub> mitigation is limited to 11% to 13% as shown in Table 6.

|  | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|--|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Maximum % reduction in CO <sub>2</sub> emissions due to solar hot water generation | 13%       | 13%       | 13%       | 12%       | 11%       | 11%       | 11%       |
| Area of solar hot water panels required (m <sup>2</sup> )                          | 40        | 120       | 380       | 1,900     | 4,000     | 26,000    | 73,000    |
| Estimated additional capital cost  | £62k      | £190k     | £620k     | £3.1M     | £6.4M     | £42M      | £120M     |
| Estimated additional capital cost per m <sup>2</sup> per % CO <sub>2</sub> saved   | £6.0      | £6.0      | £6.0      | £6.3      | £6.8      | £6.8      | £6.8      |

**Table 6: Potential CO<sub>2</sub> savings and associated extra capital costs of using solar hot water panels**

It can be noted that the possible CO<sub>2</sub> savings decrease as the clusters increase in size. This is due to the increase in the non residential buildings as the clusters grow in size. These buildings consume little domestic hot water so therefore have less potential for CO<sub>2</sub> savings using this technology.

### 5.3 Small scale roof top wind turbines

Several different models of wind turbine which are suitable for roof top mounting are available on the market. Two models were considered for this study, the Swift 1.5kW for installation on houses and the Proven 6kW for installation on or near non-residential buildings. These are well established horizontal axis turbines, of a scale which is appropriate to the cluster sizes. Consideration should also be given to other models if a decision is made to proceed with building integrated turbines.

A simple wind analysis was performed for the study. It was assumed that the turbines would be mounted on the roofs of two storey buildings or higher. Wind speed data for the Ashford area was taken from the BERR NOABL database and adjusted to allow for the local topography. It was assumed that wind speeds would follow a standard Weibull distribution.

The estimated wind speed distribution at the hub height was applied to the power curve for the turbine to give an estimate of the annual energy yield. A further power loss factor of 50% was applied to allow for the effects of the high levels of turbulence to be found in urban areas.

The principal assumptions for the calculations relevant to the small scale wind turbines are:

- One wind turbine will be mounted on every dwelling for the clusters of 10 and 30 dwellings which are assumed to be detached. For the larger cluster sizes, the dwellings are assumed to be mainly semi-detached and terraced houses or flats. It has therefore been assumed that one wind turbine can be accommodated for every two dwellings.
- For the clusters of 100+ dwellings one wind turbine of 5 kW rated power output is added per 1,000 m<sup>2</sup> of non residential area.



It should be noted that due to the complex nature of wind analysis and the restricted availability of wind speed data the predictions of annual electricity generation are highly approximate. In addition the number of wind turbine installations possible is limited by requirement for a distance of at least 5 rotor diameters between adjacent turbines to ensure that one turbine will not be affected by the wake of another.

The estimated CO<sub>2</sub> savings and costs are given in Table 7 below. The cost estimates below do not include the cost of electricity export meters.

|   | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|---|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Maximum % reduction in CO <sub>2</sub> emissions due to small wind turbine generation | 10%       | 10%       | 5%        | 5%        | 4%        | 5%        | 5%        |
| Installed capacity of wind turbines   | 15kW      | 45kW      | 75kW      | 380kW     | 800kW     | 5.3MW     | 15MW      |
| Estimated additional capital cost   | £76k      | £230k     | £380k     | £1.9M     | £3.8M     | £27M      | £74M      |
| Estimated additional capital cost per m <sup>2</sup> per % CO <sub>2</sub> saved      | £9.5      | £9.5      | £9.5      | £10       | £10       | £10       | £10       |

**Table 7: Potential CO<sub>2</sub> savings and associated extra capital costs of using small wind turbines**

#### 5.4 Large scale wind turbines



**Figure 4: Large scale wind turbine**

Possible locations for large wind turbines (100kW+) are limited by a number of factors including proximity to high buildings, available grid connection, shadow flicker and noise. For the purposes of this analysis it is assumed that the primary limiting factor regarding the possible locations is the noise generated by the turbines. The noise produced by large scale wind turbines requires them to be located as much as 500m from residential areas. In non residential areas noise is not considered important so the limiting factor influencing the turbines' location is their proximity to buildings which should not be so close as to affect the air stream.

The environmental impacts and typical dimensions of large wind turbines are described in more detail in Section 6.7.2 in Document DOC6, Background to the Study. Where large scale wind turbines are incorporated into developments these factors should be considered at the planning stage.

After consideration of the above details it was assumed that those clusters with sizable non residential areas would have potential locations for large wind turbines as follows:

- 1000 dwellings cluster – 100kW total wind turbine capacity
- 6500 dwelling clusters – 1,000kW total wind turbine capacity
- 18,000 dwelling clusters – 2,000kW total wind turbine capacity

Where specific sites are not constrained by the factors discussed above, a greater capacity of wind turbines could be installed subject to planning permission.

As with the roof top wind turbines, wind speed data for the Ashford area was taken from the BERR NOABL database and adjusted to allow for the local topography. It was assumed that wind speeds would follow a standard Weibull distribution.

The estimated CO<sub>2</sub> savings and capital costs for each cluster are provided below in Table 8. These figures include an allowance for the cost of connecting the turbines to the National Grid.

|   | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|---|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Maximum % reduction in CO <sub>2</sub> emissions due to large wind turbine generation | 0%        | 0%        | 0%        | 0%        | 2%        | 3%        | 4%        |
| Installed capacity of wind turbines   | x         | x         | x         | x         | 100kW     | 1MW       | 2MW       |
| Estimated additional capital cost   | x         | x         | x         | x         | £390k     | £1.4M     | £2.7M     |
| Estimated additional capital cost m <sup>2</sup> per % CO <sub>2</sub> saved          | x         | x         | x         | x         | £2.2      | £0.7      | £0.4      |

**Table 8: Potential CO<sub>2</sub> savings and associated extra capital costs of using small wind turbines**

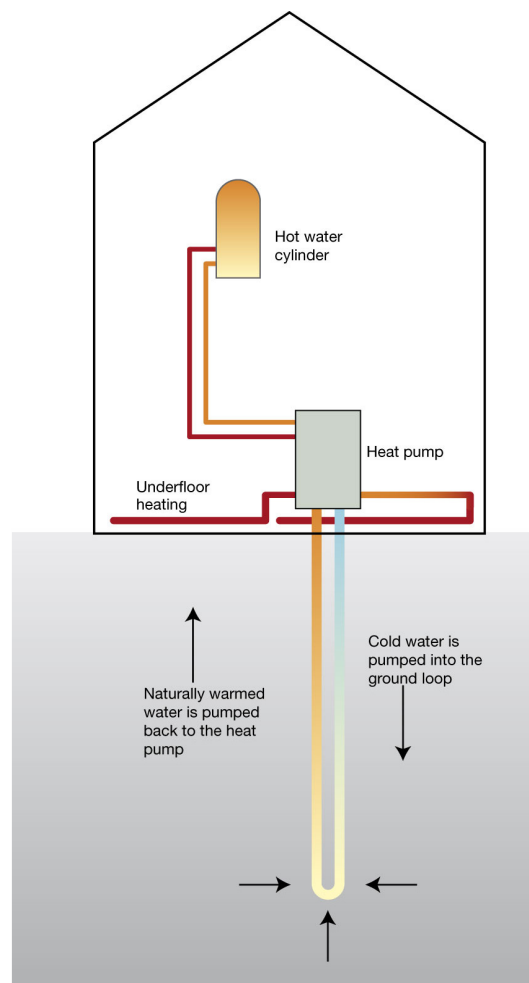
## 5.5 Ground source heat pumps

Ground source heat pumps (GSHP) are low energy systems that use the near constant temperature of the soil and/or ground water together with a heat pump to provide space heating, cooling and domestic hot water.

The potential for the use of ground source heat pumps and thus their CO<sub>2</sub> reduction potential is dependant on the heat to electricity demand of the site, the area of ground available to locate them in, as well as their efficiency. For the purposes of this analysis it was assumed that closed loop boreholes would be used with a depth of 100m and located no closer than 6m from another ground source heating borehole. It was assumed that the dwellings are predominantly detached; semi detached or terraced houses with sufficient garden space to accommodate two boreholes per property. Ground source heat pumps are assumed to fully cover the domestic space heating demand and domestic hot water demand. Gas boilers are therefore not required.

To avoid excessively cooling the ground it is assumed that the non residential buildings receive only a portion of their heating requirements and all of their cooling requirements so that the ground temperature remains balanced. There is assumed to be sufficient ground area available to provide the balanced portion of the heating and cooling demand. As with solar hot water technology, the benefits decrease with increasing cluster size because of the increasing proportion of commercial space, which has low requirements for hot water.

The estimated reduction in CO<sub>2</sub> emissions and capital costs are given in Table 9.



**Figure 5: Schematic of a Ground Source Heat Pump** © Arup

|  | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|--|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Maximum % reduction in CO <sub>2</sub> emissions due to GSHPs                    | 25%       | 25%       | 25%       | 23%       | 20%       | 20%       | 20%       |
| Capacity of GSHPs installed  | 48kW      | 140kW     | 480kW     | 2.4MW     | 4.9MW     | 33MW      | 90MW      |
| Estimated Additional Capital Cost  | £64k      | £190k     | £640k     | £3.2M     | £6.5M     | £44M      | £120M     |
| Estimated additional capital cost per m <sup>2</sup> per % CO <sub>2</sub> saved | £3.2      | £3.2      | £3.2      | £3.4      | £3.7      | £3.8      | £3.8      |

**Table 9: Potential CO<sub>2</sub> savings and associated extra capital costs of using ground source heat pumps**

The capital cost estimates include the estimated additional installed cost of the heat pumps and heat exchangers as well as the construction cost of the space requirements of the heat pumps within the dwellings. The estimated construction cost of the space was included in

the capital cost estimates as heat pumps result in a loss of usable space whereas the wall hung gas boiler option results in little loss of useable space.

## 5.6 Air source heat pumps

Air source heat pumps (ASHP) can be located on the sides of buildings and so have fewer limitations regarding the capacity that can be installed. However the potential CO<sub>2</sub> savings possible with air source heat pumps are limited by two principal factors:

1. Air source heat pumps are used to provide space heating and cooling demand, but not hot water demand. Gas water heaters will still be required.
2. Air source heat pumps are less efficient than ground source heat pumps as they require regular defrosting in winter which uses electricity and so provide lower CO<sub>2</sub> emissions savings per kW installed.

Table 10 below gives the estimated CO<sub>2</sub> reductions and capital costs for each cluster.

|  | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|--|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Maximum % reduction in CO <sub>2</sub> emissions due to ASHPs                    | 6%        | 6%        | 6%        | 5%        | 5%        | 5%        | 5%        |
| Capacity of ASHPs installed  | 24kW      | 70kW      | 240kW     | 1.3MW     | 2.9MW     | 20MW      | 55MW      |
| Estimated Additional Capital Cost  | £31k      | £93k      | £310k     | £1.6M     | £3.8M     | £30M      | £74M      |
| Estimated additional capital cost per m <sup>2</sup> per % CO <sub>2</sub> saved | £6.6      | £6.6      | £6.6      | £7.4      | £8.3      | £9.3      | £8.4      |

**Table 10: Potential CO<sub>2</sub> savings and associated extra capital costs of using air source heat pumps**

The capital cost estimates include the estimated construction cost of the space requirements of the heat pumps within the dwellings. As heat pumps result in a loss of usable space whereas the wall hung gas boiler option results in little loss of useable space, the estimated construction cost of the space was included in the capital cost estimates.

## 5.7 Biomass boilers

Modern biomass boilers are highly efficient heating units with low or zero carbon emissions depending on the fuel used. Generally speaking biomass boilers come in two different types – wood chip boilers and wood pellet boilers. Both wood chips and wood pellets can be made from a variety of different fuel types. These include waste wood from sawmills and industry off-cuts, forestry arisings, and specially grown crops such as coppice willow. Wood chip sizes vary according to the wood chippers used but usually consist of pieces of about 50-100mm in length. In contrast wood pellets are about 6-8mm long and of a uniform size and consistency resulting in a uniform heat output. Wood pellets have a higher energy density than wood chips but are also more expensive and less readily available at this time.

Biomass boilers come in a range of sizes and can be used to heat individual houses or offices or supply many buildings using a district heating network.

For the analysis of the potential CO<sub>2</sub> emissions reduction it has been assumed that individual wood pellet boilers would be used in each residential or non residential unit. Significant economies of scale should be possible by grouping these individual units

together with a shared biomass boiler plant, reducing the capital cost and improving the economic viability of this technology.

The CO<sub>2</sub> emissions savings that result from the use of biomass boilers for the provision of space heating and domestic hot water given in Table 6.8 range from 32% to 36%. Individual biomass boilers alone will therefore provide more than the minimum CO<sub>2</sub> savings required for Code Level 4 dwellings or the minimum on-site requirement of policy CS10.

It should be noted that the use of district heating networks with larger centralised biomass boilers has not been considered in this option. Schemes involving only district heating with heat only generation i.e. not combined heat and power have not been reviewed as they are not generally economically viable.



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**Figure 6: Individual Wood Pellet Boiler**

The capital costs of a wood pellet boiler solution are also given in Table 11 below.

|  | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|--|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Maximum % reduction in CO <sub>2</sub> emissions due to biomass boilers          | 36%       | 36%       | 36%       | 34%       | 32%       | 32%       | 32%       |
| Capacity of wood pellet boilers  | 72kW      | 220kW     | 720kW     | 3.6MW     | 7.3MW     | 48MW      | 130MW     |
| Estimated Additional Capital Cost  | £51k      | £150k     | £510k     | £2.6M     | £5.1M     | £34M      | £93M      |
| Estimated additional capital cost per m <sup>2</sup> per % CO <sub>2</sub> saved | £1.8      | £1.8      | £1.8      | £1.8      | £1.8      | £1.8      | £1.8      |

**Table 11: Potential CO<sub>2</sub> savings and associated extra capital costs of using wood pellet boilers**

The capital cost estimates include the estimated construction cost of the space requirements of the biomass boilers and wood pellet storage within the dwellings. This is

because the space requirement (minimum 2m<sup>2</sup> for domestic wood pellet boilers) is a loss of useable space, when compared to a wall-hung gas boiler.

## 5.8 Combined heat and power (CHP)

In this section of the report the potential for the generation of heat and electricity is assessed for each cluster, using combined heat and power (CHP) technologies at a central location with the heat and electricity then being distributed to each building. Both gas CHP and biomass CHP solutions are assessed.

Heat is distributed from CHP plants to consumers using piped hot water or steam. The heat is usually transmitted from the district heating circuit to the heating circuits of each individual building using heat exchangers. The cost of the district heating network is often the largest cost in a CHP scheme and its economic value is dependant on the density of the buildings served. It is assumed here that the dwelling density is approximately 40 dwellings per hectare.

CHP modelling generally involves detailed computer simulations of the heat and electricity demands of a site so that the most appropriate capacity of CHP plant can be selected. For the purposes of this high level analysis it has been assumed that gas CHP units will supply 75% of the clusters' heat loads with the aid of hot water thermal stores as required. However, biomass CHP plants are not as flexible, in terms of operation, as gas CHP. Biomass CHP plants with hot water storage are therefore assumed to supply no more than 65% of the clusters' heat loads.

Large scale CHP plant will have certain environmental impacts on the local area which should be considered when planning developments. This are discussed further in Document DOC6, Background to the Study.

### 5.8.1 Gas CHP

Natural gas CHP technologies are available in capacities suitable for all the clusters considered. Gas CHP plant is available for the larger clusters powered by gas turbines or gas fired internal combustion engines.



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**Figure 7: Gas Fired CHP**

As natural gas fired engines have a higher electrical efficiency than biomass CHP and electricity is a more valued product than heat, gas engines have been considered for all the large clusters. For the smaller clusters gas engine technology is the only CHP option. It is assumed that in each scenario the CHP will supply of the order of 75% of the heat demand and that any extra heat required by a cluster is provided using gas boilers and any extra electricity required is supplied from the electricity grid. It is assumed that Good Quality

CHP<sup>4</sup> status is achieved on all the sites as it is assumed that all the useful heat generated will be used. For small scale gas engine CHP units, approximately two units of heat are produced for every unit of electricity generated. For large scale gas engine CHP units, approximately one unit of heat is produced for every unit of electricity generated.

Table 12 below shows the estimated capacity of gas engine CHP suitable for each cluster, the resulting estimated CO<sub>2</sub> savings and the estimated capital costs.

|  | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|--|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| % reduction in CO <sub>2</sub> emissions due to gas CHP                          | 11%       | 11%       | 13%       | 22%       | 21%       | 29%       | 30%       |
| CHP Electrical Capacity  | 4kW       | 12kW      | 50kW      | 330kW     | 790kW     | 6.2MW     | 18MW      |
| Estimated Capital Cost   | £79k      | £200k     | £530k     | £3.4M     | £6.3M     | £37M      | £100M     |
| Estimated additional capital cost per m <sup>2</sup> per % CO <sub>2</sub> saved | £9.3      | £7.9      | £5.3      | £3.7      | £3.5      | £2.       | £2.1      |

**Table 12: Potential CO<sub>2</sub> savings and associated extra capital costs of using gas CHP**

It should be noted that commercial energy service companies (ESCOs) may be interested in owning and / or operating schemes serving 1,000 or more dwellings i.e. Clusters 5, 6 and 7. Recent work in this area indicates that ESCOs may be able to contribute between 30% and 50% of the additional capital costs when serving schemes the size of Cluster 5 (1,000 dwellings) and contribute up to 100% of the additional cost when serving schemes the size of Cluster 7 (18,000 dwellings).

Gas CHP schemes serving less than 1,000 dwellings are generally less attractive to commercial ESCOs due to the lower profit margins of such schemes. Consequently such schemes tend to be owned and operated by not for profit ESCOs and social landlords.

### 5.8.2 Biomass CHP

Four different biomass CHP technologies have been considered for the cluster analysis:

- Indirect air turbine plant
- Biomass gasification plant
- Biomass fuelled organic rankine cycle (ORC) plant
- Biomass fuelled steam turbine plant

A brief description of each is provided below. Further information can be found in Document DOC6, Background to the Study.

#### Indirect Air Turbine

The indirect air turbine is a novel technology produced by Talbott Biomass Energy Ltd, which is currently being commercialised. The indirect air turbine has a net electrical generating capacity of 90kWe and produces 2.5 units of heat for every unit of electricity generated. It could be suitable for use in clusters of 200 dwellings and above.

<sup>4</sup> Good Quality CHP is a minimum standard of operation introduced by the UK government to improve the operational efficiency of CHP schemes.

### Biomass gasification CHP

Biomass gasification CHP technology is available from three companies in Europe, in modules of about 300kW electrical capacity. As the wood fuel for the gasifier is required to have a low level of moisture, heat from the CHP can be used to dry it. The net heat to electricity generation ratio for biomass gasification CHP, assuming onsite drying of the wood fuel, is approximately 1:1. It could be suitable for use in clusters of 400 dwellings and above.

### Organic Rankine Cycle CHP

The organic rankine cycle is similar to the steam turbine cycle but uses lower temperatures and pressures and so allows the production of cost effective small scale CHP units, available in modules of 500kW to 2,000kW. The heat to electricity generation ratio for ORC plant is about 5:1. ORC CHP technology is a mature technology with over 100 installations in Europe. It could be suitable for use in clusters of 1,000 dwellings and above.

### Steam turbines

Steam turbines are a mature technology which has been in use since the early 20<sup>th</sup> century and possibly earlier. Two types of steam turbines CHP units are available, those where the heat to electricity generation ratios can be varied and those where the quantity of electricity generated is fixed and a portion of heat, if any, is recovered. Steam turbine CHP plants are generally available with electrical capacities of 2MW and upwards. The heat to electricity generation ratios of steam turbine CHP plants when in full extraction i.e. heat generation mode is about 3:1. Steam turbine CHP plants are suitable for clusters of 10,000 dwellings and above.

As stated above, in each scenario it was assumed that the CHP plant would supply of the order of 65% of the heating demand and that any additional heat requirement would be provided using gas boilers. This is a level of heat supply which will generally result in there being little, if any, need to reject heat to the atmosphere. It will thus be noted that the maximum CO<sub>2</sub> savings estimated is 66%.

This level of savings could be increased by increasing the proportion of the heat demand supplied by the biomass CHP plants, however; it is likely that there will then be a need to reject significant quantities of heat. Whilst wood fuel is a very low carbon fuel this could be considered a poor use of a renewable biomass resource that is ultimately constrained by the available land area.

Tables 13 and 14 show the CO<sub>2</sub> savings and the total estimated additional capital costs of each biomass CHP technology, for each cluster.

|                          | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|--------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Indirect air turbine CHP | x         | x         | x         | 43%       | 41%       | x         | x         |
| Gasification CHP         | x         | x         | x         | 70%       | 65%       | 66%       | 66%       |
| ORC CHP                  | x         | x         | x         | x         | x         | 31%       | 31%       |
| Steam turbine CHP        | x         | x         | x         | x         | x         | x         | 37%       |

**Table 13: Biomass CHP CO<sub>2</sub> savings**

|                          | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|--------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Indirect air turbine CHP | x         | x         | x         | £3.4M     | £6.4M     | x         | x         |
| Gasification CHP         | x         | x         | x         | £4.0M     | £8.0M     | £44M      | £120M     |
| ORC CHP                  | x         | x         | x         | x         | x         | £34M      | £91M      |
| Steam turbine CHP        | x         | x         | x         | x         | x         | x         | £100M     |

**Table 14: Biomass CHP scheme additional costs**

Table 15 shows the normalised cost of CO<sub>2</sub> mitigation for each technology, for each cluster i.e. the additional capital cost per unit built area, per percentage reduction in CO<sub>2</sub> emissions achieved.

|                          | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|--------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Indirect air turbine CHP | x         | x         | x         | £2.0      | £1.8      | x         | x         |
| Gasification CHP         | x         | x         | x         | £1.4      | £1.4      | £1.2      | £1.1      |
| ORC CHP                  | x         | x         | x         | x         | x         | £1.8      | £1.8      |
| Steam turbine CHP        | x         | x         | x         | x         | x         | x         | £1.8      |

**Table 15: Normalised cost of CO<sub>2</sub> mitigation using various biomass CHP technologies**

Biomass CHP schemes tend to be more expensive than gas CHP schemes due to the more expensive capital and operating costs of the CHP technologies. Project experience indicates that ESCOs operating biomass CHP schemes serving 1,000 or more dwellings can be expected to contribute of the order of 20% of the additional capital required for a scheme.

## 6 Combinations of low and zero carbon individual technologies

Of the technologies investigated PV has the potential to provide the greatest level of CO<sub>2</sub> mitigation, although at high cost. It is recognised, however; that various combinations of renewable energy technologies might provide more optimal solutions, in terms of cost and CO<sub>2</sub> mitigation potential.

When reviewing the potential for using combinations of technologies, whether the technologies are “complementary” or “conflicting” is of prime importance and should be considered on both a building by building basis as well as a development wide basis. Complementary technologies are technologies which do not compete for available resource or to supply a form of energy for which there is a limited demand. An example of complementary technologies is biomass boilers and PV. Most combinations which feature more than one source of heat are examples of conflicting technologies.

Table 16 below indicates which local embedded energy generation technologies compliment large scale remote (sitewide) energy generation technologies and those which will conflict with sitewide energy generation technologies.

|                           |                          | Large Scale Remote Generation |                 |             |         |               |
|---------------------------|--------------------------|-------------------------------|-----------------|-------------|---------|---------------|
|                           |                          | Wind                          | Biomass Boilers | Biomass CHP | Gas CHP | Heat Networks |
| Local Embedded Generation | PV                       | ✓                             | ✓               | ✓           | ✓       | ✓             |
|                           | Solar Thermal            | ✓                             | ✗               | ✗           | ✗       | ✗             |
|                           | Wind                     | ✓                             | ✓               | ✓           | ✓       | ✓             |
|                           | Ground Source Heat Pumps | ✓                             | ✗               | ✗           | ✗       | ✗             |
|                           | Air Source Heat Pumps    | ✓                             | ✗               | ✗           | ✗       | ✗             |
|                           | Biomass Boilers          | ✓                             | ~               | ~           | ~       | ~             |
|                           | Gas CHP                  | ✓                             | ~               | ~           | ~       | ~             |
|                           | Biomass CHP              | ✓                             | ~               | ~           | ~       | ~             |

Legend: “✓” = complementary; “✗” = conflicting; “~” = integration possible if heat source is on a large enough scale and can be configured to export heat to a heat network

**Table 16: Complimentary and conflicting technology combinations**

The capital costs and CO<sub>2</sub> savings of the following combinations of technologies have been assessed:

1. Photovoltaics + ground source heat pumps
2. Small scale wind turbines + ground source heat pumps
3. Small scale wind turbines + large scale wind turbines + ground source heat pumps
4. Photovoltaic panels + biomass boilers
5. Photovoltaic panels + solar hot water

## 6.1 Photovoltaic Panels + Ground Source Heat Pumps

As discussed above, PV and ground source heating are complementary technologies as one generates electricity while the other generates heat. Table 17 shows the estimated CO<sub>2</sub> savings and the associated additional capital costs.

|  | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|--|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Maximum % reduction in CO <sub>2</sub> emissions due to PV + GSHPs               | 94%       | 94%       | 94%       | 88%       | 81%       | 80%       | 80%       |
| Estimated Additional Capital Cost  | £290k     | £880k     | £2.9M     | £15M      | £32M      | £210M     | £580M     |
| Estimated additional capital cost per m <sup>2</sup> per % CO <sub>2</sub> saved | £3.9      | £3.9      | £3.9      | £4.1      | £4.5      | £4.5      | £4.5      |

**Table 17: Potential CO<sub>2</sub> savings and associated extra capital costs of using PV panels and ground source heat pumps**

## 6.2 Small Scale Wind Turbines + Ground Source Heat Pumps

As wind turbines generate electricity and ground source heat pumps generate heat they are complementary technologies so both be used on a site. Table 18 shows the estimated CO<sub>2</sub> savings and the additional capital costs.

|   | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|---|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Maximum % reduction in CO <sub>2</sub> emissions due to small wind turbines + GSHPs | 35%       | 35%       | 30%       | 28%       | 25%       | 24%       | 24%       |
| Estimated Additional Capital Cost   | £140k     | £420k     | £1.0M     | £5.1M     | £10M      | £70M      | £190M     |
| Estimated additional capital cost per m <sup>2</sup> per % CO <sub>2</sub> saved    | £5.0      | £5.0      | £4.3      | £4.5      | £4.8      | £5.0      | £5.0      |

**Table 18: Potential CO<sub>2</sub> savings and associated extra capital costs of using small scale wind turbines and ground source heat pumps**

### 6.3 Small scale + large scale wind turbines + ground source heat pumps

The benefits, in terms of CO<sub>2</sub> savings and additional capital costs, of adding large scale wind turbines to the clusters provided with small scale wind turbines and ground source heat pumps is shown in Table 19 below.

|  | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|--|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Maximum % reduction in CO <sub>2</sub> emissions due to large wind turbines, small wind turbines + GSHPs | 35%       | 35%       | 30%       | 28%       | 27%       | 28%       | 28%       |
| Estimated Additional Capital Cost  | £140k     | £420k     | £1.0M     | £5.1M     | £11M      | £72M      | £200M     |
| Estimated additional capital cost per m <sup>2</sup> per % CO <sub>2</sub> saved                         | £5.0      | £5.0      | £4.3      | £4.5      | £4.6      | £4.5      | £4.3      |

**Table 19: Potential CO<sub>2</sub> savings and associated extra capital costs of using small scale wind turbines + large scale wind turbines + ground source heat pumps**

Note clusters 1, 2, 3 and 4 are too small to accommodate a large wind turbine.

### 6.4 Photovoltaic panels + biomass boilers

Photovoltaic panels and biomass boilers are complimentary technologies as described above. Table 20 below shows the estimated CO<sub>2</sub> saving and estimated additional costs of fitting the maximum area possible of PV panels and supplying heat from biomass boilers.

|   | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|---|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Maximum % reduction in CO <sub>2</sub> emissions due to PV panels + biomass boilers | 106%      | 106%      | 106%      | 100%      | 93%       | 93%       | 93%       |
| Estimated Additional Capital Cost   | £280k     | £840k     | £2.8M     | £14M      | £30M      | £200M     | £560M     |
| Estimated additional capital cost per m <sup>2</sup> per % CO <sub>2</sub> saved    | £3.3      | £3.3      | £3.3      | £3.5      | £3.7      | £3.7      | £3.7      |

**Table 20: Potential CO<sub>2</sub> savings and associated extra capital costs of using PV panels + biomass boilers**

## 6.5 Photovoltaic panels + solar hot water

Although solar hot water and PV panels will compete for available roof space so are not complimentary technologies, the combination has been included so that the estimated capital costs and CO<sub>2</sub> savings can be compared with the other combinations. It can be seen that the capital costs are little different from the example given in section 5.1 where PV installations are maximised, however; the CO<sub>2</sub> savings are markedly lower.

|   | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|---|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Maximum % reduction in CO <sub>2</sub> emissions due to PV panels + solar hot water | 66%       | 66%       | 66%       | 62%       | 58%       | 58%       | 58%       |
| Estimated Additional Capital Cost   | £240k     | £710k     | £2.3M     | £12M      | £26M      | £170M     | £480M     |
| Estimated additional capital cost per m <sup>2</sup> per % CO <sub>2</sub> saved    | £4.4      | £4.4      | £4.4      | £4.6      | £5.0      | £4.9      | £4.9      |

**Table 21: Potential CO<sub>2</sub> savings and associated extra capital costs of using**

As stated previously, the potential CO<sub>2</sub> savings reduce as the clusters increase in size due to the increasing number of non residential buildings which do not require as much domestic hot water as dwellings.

## 7 Summary and Conclusions

The purpose of this study was to explore the potential for the reduction of CO<sub>2</sub> emissions through the supply of low or zero carbon energy to a series of generic clusters of buildings. The previous sections of this document have provided information on the estimated maximum possible CO<sub>2</sub> savings achievable using a particular technology or combination of technologies and the estimated capital cost of installing those technologies.

Figures 8 and 9 below show the potential CO<sub>2</sub> savings of each technology for each cluster and the cost effectiveness of each technology or combination of technologies.

The results of the cluster analysis provide high level guidance as to which CO<sub>2</sub> reduction technologies might be most appropriate for the Ashford Growth Areas.

For ease of reference, we have compiled two matrices which allow easy access to the key results:

- Table A1, brings together the estimated CO<sub>2</sub> savings for each technology into a single table to allow potential solutions to be more easily compared.
- Table A2 summarises the potential CO<sub>2</sub> savings for each technology presented in Sections 5, 6 and 7 for the different cluster sizes.

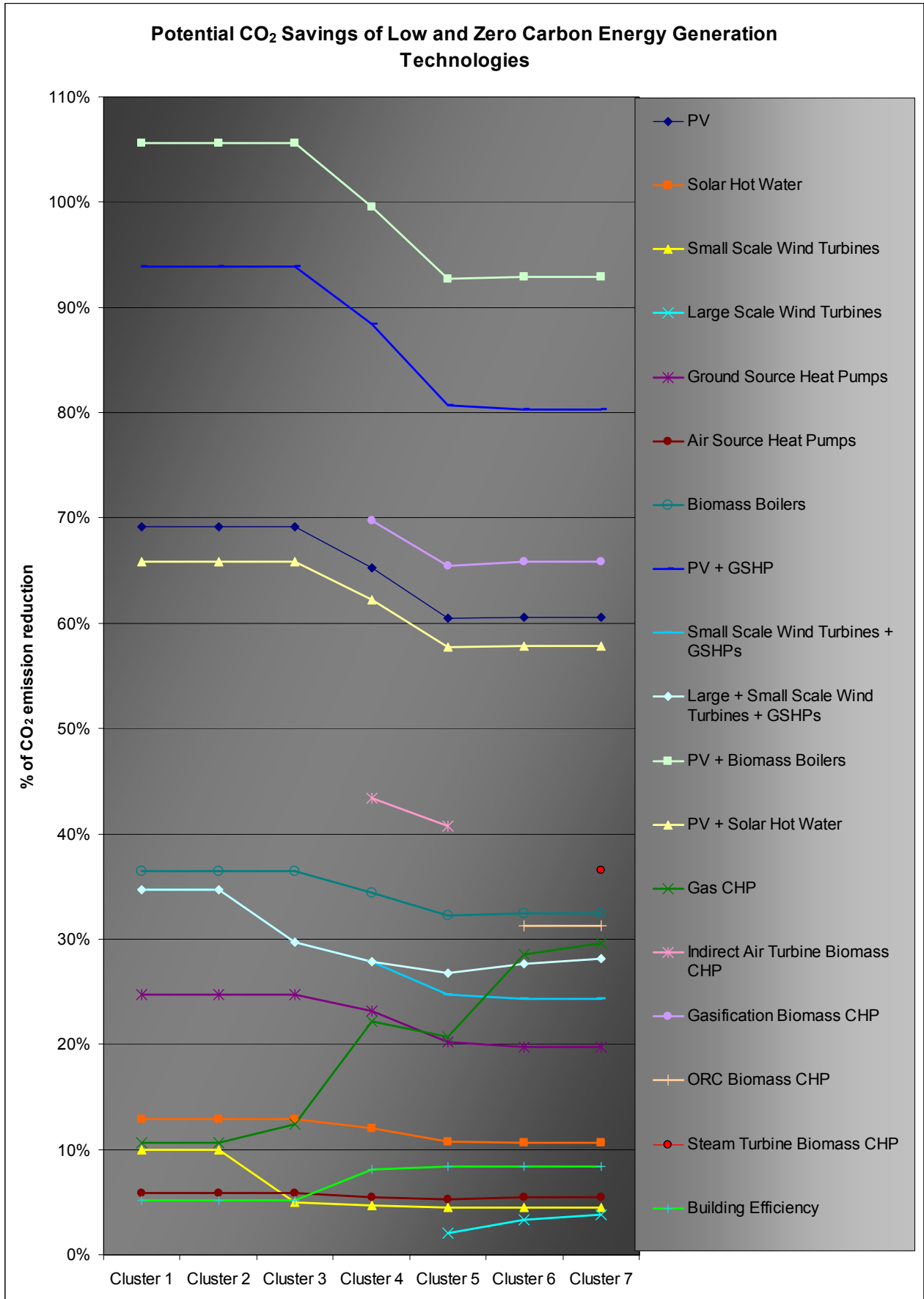
The cost effectiveness of the different technologies and combinations of technologies varies by an order of magnitude between the most cost effective and the least cost effective based on the normalised capital cost metric developed for this study.

These results also show the significance of the scale of development. As a rule large scale technologies become more cost effective with increasing size whilst standalone technologies are less well suited to larger developments where the demand profile is increasingly influenced by the demands of the non-residential buildings.

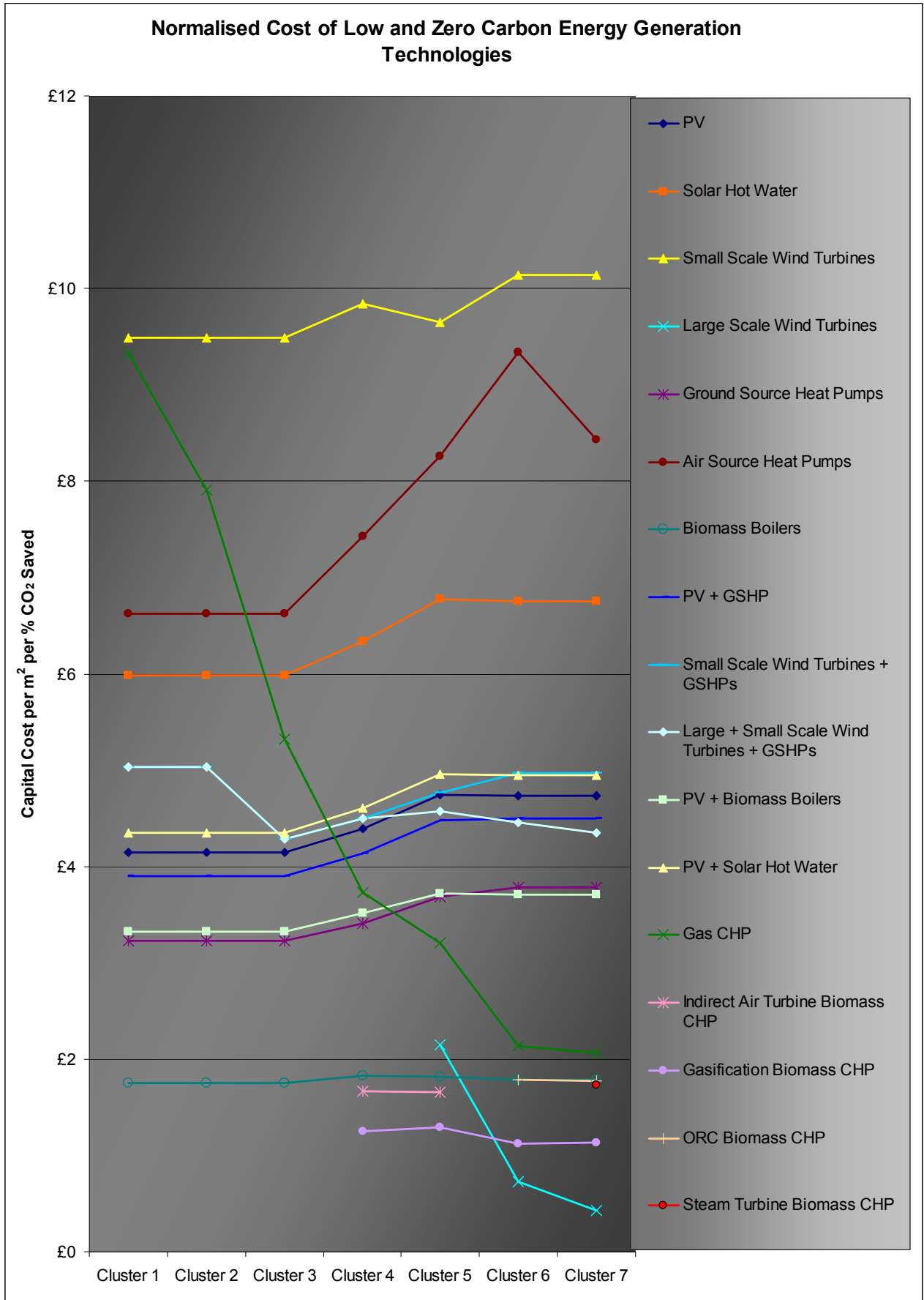
Technologies which should be considered in the first instance are: large scale wind turbines, CHP (biomass and gas fired) and biomass boilers.

Conversely the study has shown that some technologies are less cost effective and are less likely to feature in any developments in the Ashford Growth Area. These include micro wind, air source heat pumps and solar hot water.

In addition to this work, a group of Pilot Studies, modelled on types of development within the Greater Ashford Development Area, has been prepared. Details and results of these studies can be found in Document DOC3, Pilot Sites Study.



**Figure 8: Potential CO<sub>2</sub> savings of low and zero carbon energy generation technologies**



**Figure 9: Normalised cost of low and zero carbon energy generation technologies**

## **TABLES**

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## A1 Maximum CO<sub>2</sub> Savings Potential

|                                 | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|---------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Building Improvements           | 5%        | 5%        | 5%        | 8%        | 8%        | 8%        | 8%        |
| Photovoltaic Panels             | 69%       | 69%       | 69%       | 65%       | 60%       | 61%       | 61%       |
| Solar Hot Water Panels          | 13%       | 13%       | 13%       | 12%       | 11%       | 11%       | 11%       |
| Small Wind Turbines             | 10%       | 10%       | 5%        | 5%        | 4%        | 5%        | 5%        |
| Large Wind Turbines             | x         | x         | x         | x         | 2%        | 3%        | 4%        |
| Ground Source Heat Pumps        | 25%       | 25%       | 25%       | 23%       | 20%       | 20%       | 20%       |
| Air Source Heat Pumps           | 6%        | 6%        | 6%        | 5%        | 5%        | 5%        | 5%        |
| Biomass Boilers                 | 36%       | 36%       | 36%       | 34%       | 32%       | 32%       | 32%       |
| PV + GSHPs                      | 94%       | 94%       | 94%       | 88%       | 81%       | 80%       | 80%       |
| Small Wind + GSHPs              | 35%       | 35%       | 30%       | 28%       | 25%       | 24%       | 24%       |
| Small Wind + Large Wind + GSHPs | 35%       | 35%       | 30%       | 28%       | 27%       | 28%       | 28%       |
| PV + Biomass Boilers            | 106%      | 106%      | 106%      | 100%      | 93%       | 93%       | 93%       |
| PV + Solar Hot Water            | 66%       | 66%       | 66%       | 62%       | 58%       | 58%       | 58%       |
| Gas CHP                         | 11%       | 11%       | 13%       | 24%       | 23%       | 31%       | 32%       |
| Indirect air turbine CHP        | x         | x         | x         | 47%       | 44%       | x         | x         |
| Gasification CHP                | x         | x         | x         | 76%       | 71%       | 72%       | 72%       |
| ORC CHP                         | x         | x         | x         | x         | x         | 34%       | 34%       |
| Steam turbine CHP               | x         | x         | x         | x         | x         | x         | 40%       |

**Table A1: Estimated maximum CO<sub>2</sub> savings for each technology option for each cluster.**

As stated in Section 7, when considering which renewable energy technologies can be combined, consideration needs to be given to whether the technologies are complimentary.

The matter of complimentary technologies is also of importance when considering how the renewable energy technologies in each cluster will impact on neighbouring clusters, as shown in Table 16.

## A2 Normalised Capital Cost

Table A2 shows the capital cost per m<sup>2</sup> of building connected to a particular technology per percentage point of CO<sub>2</sub> savings achieved to allow comparison of the technologies on a financial basis.

|                                 | Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 | Cluster 6 | Cluster 7 |
|---------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Building Improvements           | -         | -         | -         | -         | -         | -         | -         |
| Photovoltaic Panels             | £4.1      | £4.1      | £4.1      | £4.4      | £4.7      | £4.7      | £4.7      |
| Solar Hot Water Panels          | £6.0      | £6.0      | £6.0      | £6.3      | £6.8      | £6.8      | £6.8      |
| Small Wind Turbines             | £9.5      | £9.5      | £9.5      | £10       | £10       | £10       | £10       |
| Large Wind Turbines             | *         | *         | *         | *         | £2.2      | £0.7      | £0.4      |
| Ground Source Heat Pumps        | £3.2      | £3.2      | £3.2      | £3.4      | £3.7      | £3.8      | £3.8      |
| Air Source Heat Pumps           | £6.6      | £6.6      | £6.6      | £7.4      | £8.3      | £9.3      | £8.4      |
| Biomass Boilers                 | £1.8      | £1.8      | £1.8      | £1.8      | £1.8      | £1.8      | £1.8      |
| PV + GSHPs                      | £3.9      | £3.9      | £3.9      | £4.1      | £4.5      | £4.5      | £4.5      |
| Small Wind + GSHPs              | £5.0      | £5.0      | £4.3      | £4.5      | £4.8      | £5.0      | £5.0      |
| Small Wind + Large Wind + GSHPs | £5.0      | £5.0      | £4.3      | £4.5      | £4.6      | £4.5      | £4.3      |
| PV + Biomass Boilers            | £3.3      | £3.3      | £3.3      | £3.5      | £3.7      | £3.7      | £3.7      |
| PV + Solar Hot Water            | £4.4      | £4.4      | £4.4      | £4.6      | £5.0      | £4.9      | £4.9      |
| Gas CHP                         | £9.3      | £7.9      | £5.3      | £3.7      | £3.5      | £2.2      | £2.1      |
| Indirect air turbine CHP        | *         | *         | *         | £2.0      | £1.8      | *         | *         |
| Gasification CHP                | *         | *         | *         | £1.4      | £1.4      | £1.2      | £1.1      |
| ORC CHP                         | *         | *         | *         | *         | *         | £1.8      | £1.8      |
| Steam turbine CHP               | *         | *         | *         | *         | *         | *         | £1.8      |

**Table A2: Estimated capital cost per m<sup>2</sup> of connected building per percentage unit of CO<sub>2</sub> saved**