REDUCING CO_2 EMISSIONS IN A TYPICAL 60 YEARS OLD DETACHED HOUSE IN LONDON

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INTRODUCTION

In this paper an attempt has been made to provide the best options for renewable energy and low carbon technologies to reduce CO_2 emissions from a detached house built in 1950 and located in London. The options for energy efficiency measures—photovoltaics, solar thermal, wind turbine, ground source heat pump, Gas CHP—have been evaluated on the basis of energy and CO_2 savings and technical viability. The main conclusions derived from this study are summarised in this paper.

KEYWORDS

CO_2 emissions, renewable energy, low carbon technologies, solar thermal

1. BACKGROUND

Energy-efficient buildings are needed to tackle climate change, which is considered to be one of the greatest threats to the planet, a cause of rising fuel bills, and a threat to living standards and health. The UK Government passed the Climate Change Act in 2008 to try and reduce its greenhouse gas emissions through legislative measures. Under this long-term legally-binding framework, the Government is committed to an 80% reduction in CO_2 emissions by 2050 against 1990 levels and a 30% reduction by 2020 [1]. There has been a lot of attention to energy use in new buildings through regulation and exemplars. However, improving new buildings only addresses part of the problem. Approximately 60% of the 2050 building stock has already been built, and nearly half of these buildings were built before 1985, when the energy efficiency requirements were introduced.

Renewable energy is the term used to describe the energy flows that occur naturally and continuously in the environment. Most renewable energy comes either directly or indirectly from the sun [2]. Sunlight, or solar energy, can be used directly for heating and lighting homes and other buildings, for generating electricity, for hot water heating, solar cooling, and a variety of commercial and industrial uses. In contrast to use of fossil fuels such as coal and gas, these energy sources are effectively inexhaustible. Use of various forms of renewable energy also does not produce the CO_2 emissions that cause climate change. After maximising energy efficiency measures, use of renewable energy can offer a means to further reduce the CO_2 emissions generated by houses. In order to get the maximum benefits from any renewable technology, it is essential to make the house as energy efficient as possible, by measures such

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TABLE 1. Description of dwelling and household.

Dwelling type	Detached
Total floor area	128 m^2
No of occupants	4
External walls	Uninsulated cavity walls
Window area	Single glazing
Heating system	Gas central heating
Boiler type	Old gas boiler (efficiency 60%)
Hot water system	Hot water storage tank with losses of 200W, heating by gas boiler
Lights	Conventional incandescent lighting

as installing high levels of insulation and double glazing. Space heating is the most significant component (more than half) of carbon emissions from home energy use, followed by water heating (at around a fifth). However, it should be noted that lighting and electrical appliances taken as a whole (excluding cooking, which can be based on other fuels) constitute another fifth. This would indicate that while building thermal efficiency, heating and hot water appliance efficiency and controls are the most important issues to focus upon. Full consideration should also be given to lighting and electrical appliance efficiency and use. Micro-generation (renewable energy sources used at household level) has the potential for significant carbon reduction impact across all end uses.

There are a variety of technologies that have been developed to take advantage of solar and wind energy [2, 3]. These include: photovoltaic systems; solar thermal; solar electricity; passive solar heating and day-lighting; and solar process space heating and cooling. Other energy efficient technologies include cavity wall insulation, double-glazed windows, replacement of boilers, low energy lights, and A-rated appliances. In March 2011, the UK Government (www.energysavingtrust.org.uk) announced the details of the Renewable Heat Incentive (RHI), which is the first of its kind in the world. The incentive is designed to provide financial support that encourages individuals, communities, and businesses to switch from using fossil fuel for heating to renewables such as wood fuel. This paper is based on a report that has been commissioned to carry out a pre-feasibility study to investigate the options for renewable energy and low carbon technologies of a detached house built in 1950 located in London. The total floor area of the house is 128 m^2 with a floor to ceiling height of 2.5 m. Other details are given in Table 1. The primary aim is to reduce CO_2 emissions from the house. The potential options are evaluated on the basis of the analysis of energy, carbon, and cost savings.

2. METHODOLOGY

2.1 Description of Technologies

Solar Photovoltaic

Solar photovoltaic (PV) (Fig.1) technology converts the energy in sunlight into electricity. PV systems are low maintenance as they have no moving parts and panels generally have 25-year warranties. The PV systems should be located in an unshaded area. Although PV is one of

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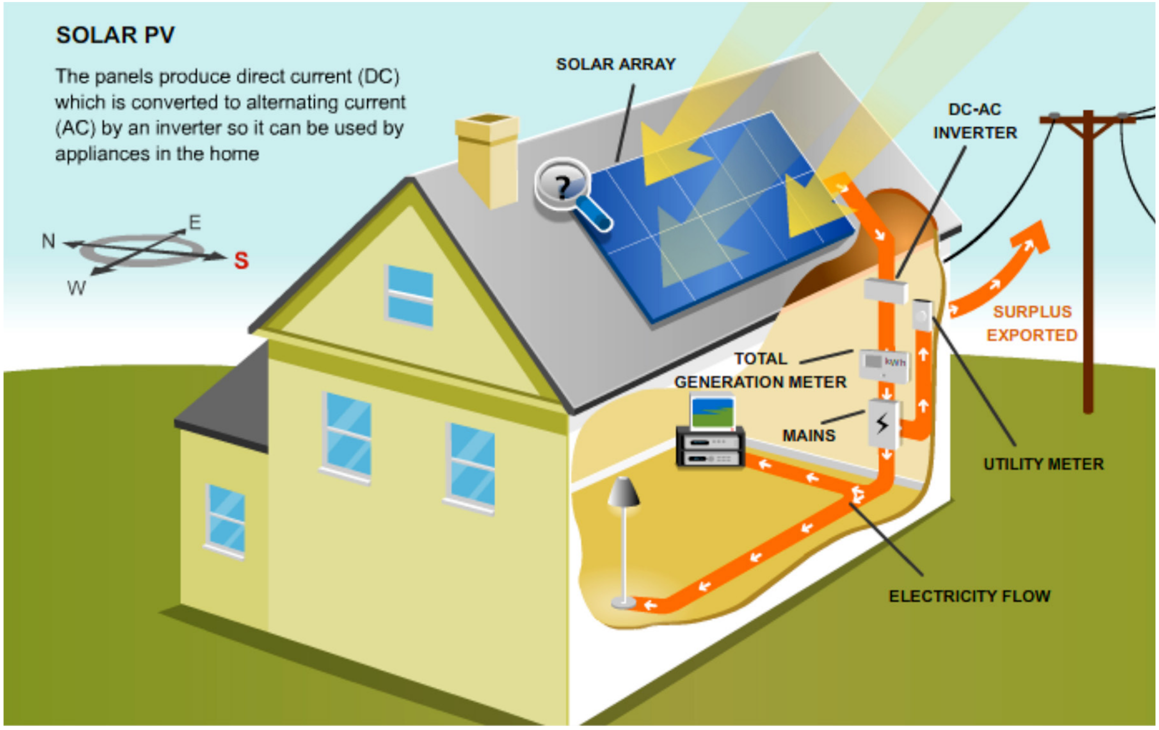
FIGURE 1. Solar photovoltaic.



the more expensive renewable energy technologies, its cost is set to reduce significantly in the future as the PV market expands. Current domestic prices are around £6000 for an installed 1 kWp system and grants for just under 50% of this cost are currently available. A system of this size would be expected to generate 750 kWh of electricity per year.

Solar Thermal

Solar thermal (Fig. 2) uses heat from the sun to warm up a liquid that is pumped through a panel on the roof. In the most common kind of system, this liquid then goes through a coil in a hot water cylinder where the heat is transferred to water. In a residential block, a communal hot water system with a heat metering system can be implemented, although additional room for a plant room would be required. Solar thermal technology is a cost effective way to reduce carbon emissions, especially if it is replacing electrical water heating. A system to provide 50–70% of the hot water needs for a four-bed house costs in the region of £2,500.

Wind Turbine

Wind power generation converts the kinetic energy in wind to mechanical energy, which in turn is used to generate electricity. Turbines (Fig. 3) should be sited away from obstacles that could disrupt the wind pattern, such as buildings and trees. It is important to have contact with the planners at the earliest possible stage and to involve the public in the consultation process. Although the initial capital outlay can be quite high, a well-positioned wind turbine can recoup this cost relatively quickly. Installed costs are size dependent: £500/100W for small, battery charging turbines; £3000/kW for medium sized, grid-connected turbines; and £700/kW for large 2MW turbines.

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FIGURE 2. Solar thermal.

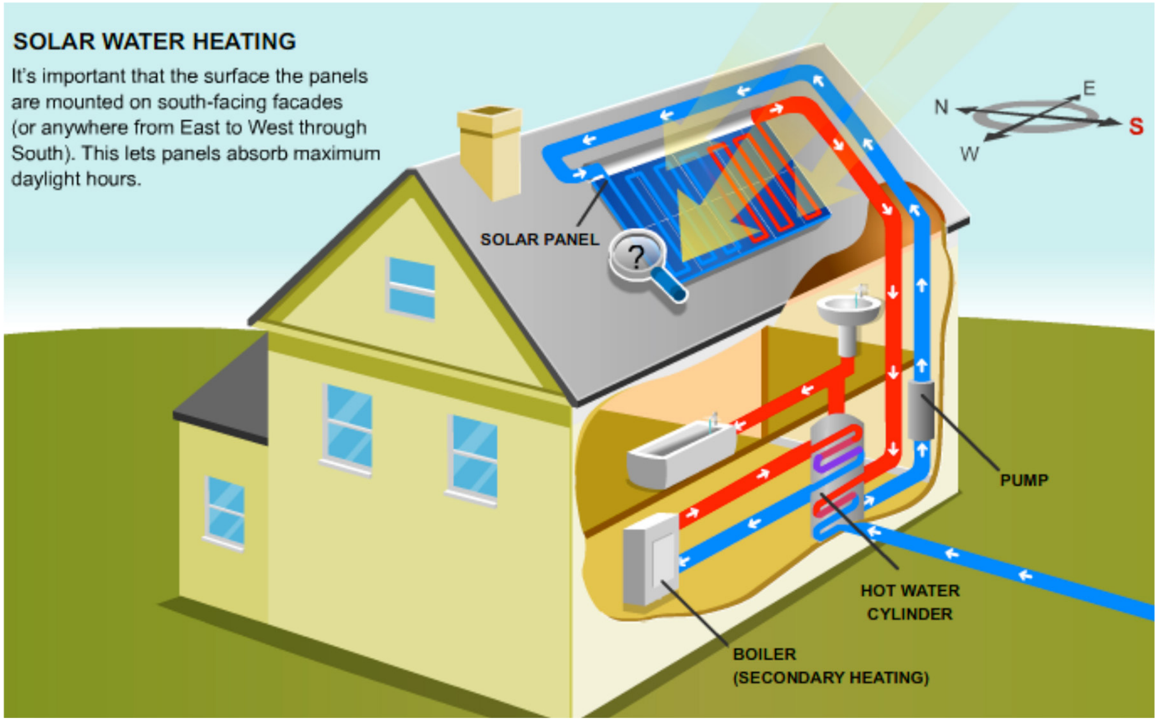
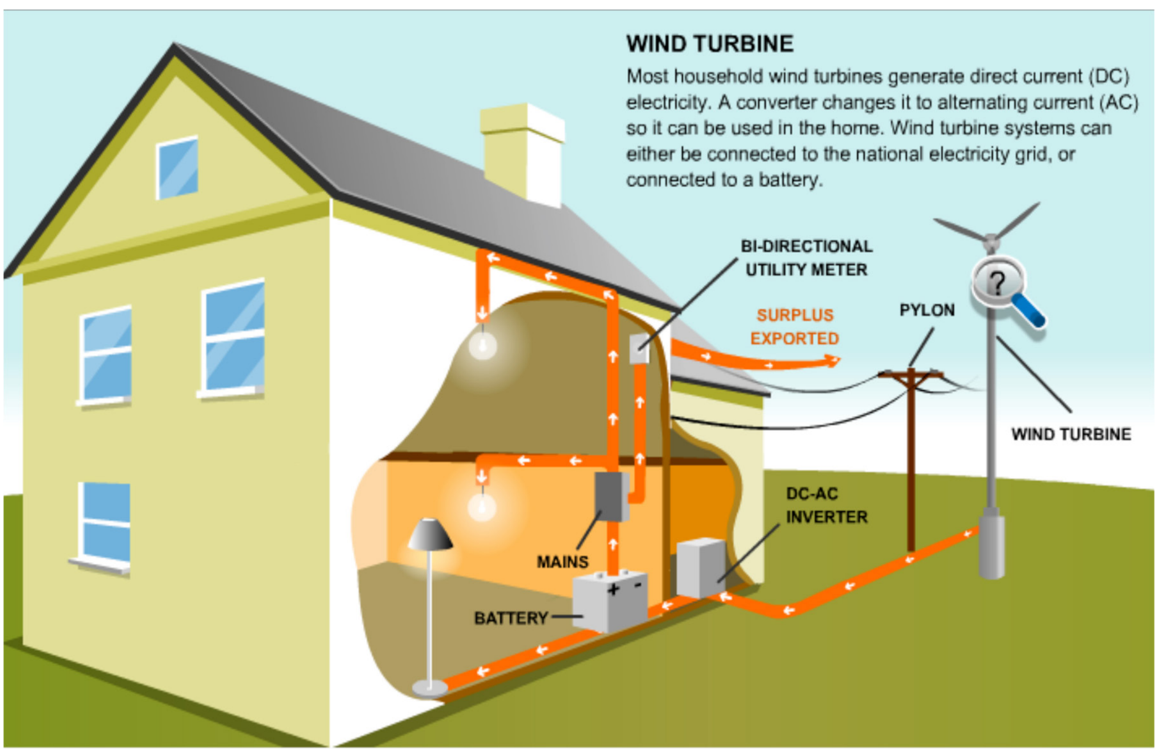


FIGURE 3. Wind turbine.



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Ground Source Heat Pumps (GSHP)

Ground source heat pumps (GSHP) (Fig. 4) use heat from a few meters below the ground that can be sourced to provide space heating in the home, and in some cases help pre-heat water for the central heating system. GSHP technology is a very efficient method of low grade heating; for every 1 kWh of energy used to pump the fluid around the system, 2.5–4 kWh of heat are produced. If coupled with a renewable electricity generator, the system becomes essentially carbon neutral. A professional installation of a GSHP costs between £800 and £1,200 per kW of peak heat output, which does not include the cost of the distribution system.

Combined Heat and Power (CHP)

A combined heat and power (CHP) (Fig. 5) unit simultaneously produces both heat and electricity from the same fuel. CHP is a suitable technology for most developments with a high heat load, such as care homes, hospitals, and hotels. A CHP unit must be sized to the predicted heat requirements, usually of the summer months. A 5.5kWe/12.5kWh unit would cost around £12,000 fully installed (about £1,000/kWh) and a 12 kWe/30kWh unit about £21,000 (about £700/kWh).

Energy Efficient Technologies

Insulating wall cavities helps to retain warmth, save energy, and reduce condensation. Energy efficient windows help reduce heat loss, leading to fewer draughts and cold spots. Replacing the boiler with an A-rated efficient condensing boiler will help to reduce energy bills and CO_2

FIGURE 4. Ground source heat pump.

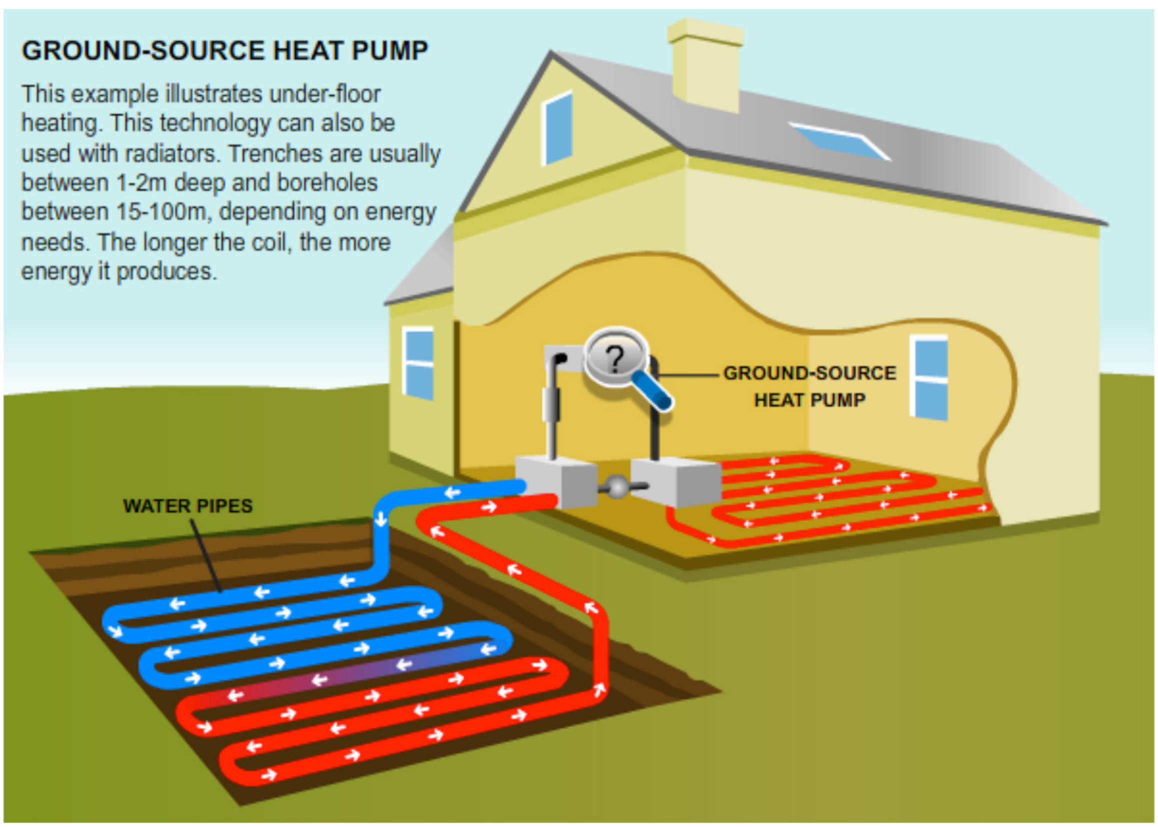

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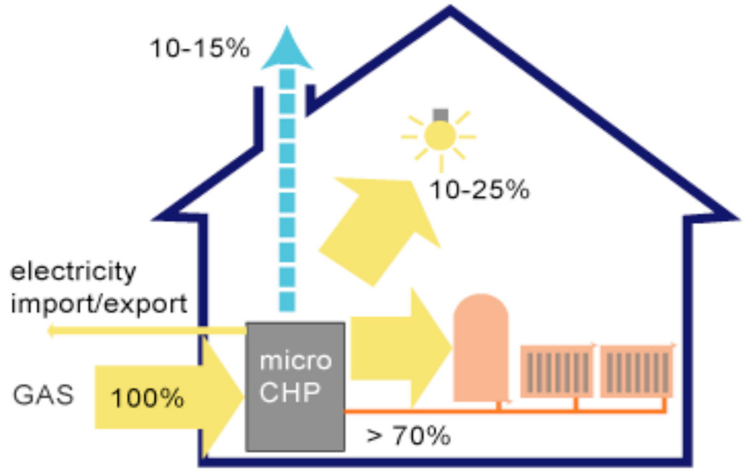
FIGURE 5. Combined heat and power.



emissions. Low energy lights and A-rated appliances are also useful in reducing energy bills and CO_2 emissions.

2.2 Description of Models

House Model

The house energy model uses a single zone steady state approach to calculate the energy demand and CO_2 emissions. The monthly ambient temperature and average daily solar radiation on a horizontal surface is obtained from climate data. U-value of the elements is obtained from SAP 2009 to calculate the fabric heat loss. The monthly average daily solar irradiation on walls of the house is obtained from the PV model. These values, together with the window area, are used to calculate the solar gains. Similarly, the internal gains from lighting, appliances, and occupants are assumed in the model. Thus, the average monthly energy consumption (gas and electricity) is determined. Using fuel conversion factors, the total CO_2 emissions from the house is obtained. The main limitations of this model are that it assumes 100% solar gains from windows, which in practice will not be so, and this will have an impact on the actual energy demand of the house.

PV Model

This model can be described as a succession of three basic steps (www.retscreen.net): (i) calculation of hourly global and diffuse irradiance on a horizontal surface for all hours of an "average day" having the same daily global radiation as the monthly average; (ii) calculation of hourly values of global irradiance on the tilted (or tracking) surface for all hours of the day; and then (iii) summation of the hourly tilted values to obtain the average daily irradiance in the plane of the PV array. The energy available to the grid is what is produced by the array reduced by inverter losses.

Solar Thermal Model

The climate data is used to calculate the monthly average daily irradiance in the plane of the solar collector, which is used to calculate the collector efficiency and solar energy [4]. This model calculates the fraction of the hot water load that is provided by the solar heating system. Once this is calculated, the amount of renewable energy that displaces the conventional energy for water heating can be determined. The method enables the calculation of the

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monthly amount of energy delivered by hot water systems with storage, given monthly values of incident solar radiation, ambient temperature, and load. The main limitation of this model is it assumes that daily volumetric load is constant over the season of use.

Wind Model

The wind model is used to evaluate the total energy production from a domestic small-scale wind turbine. Wind speed is obtained from climate data and wind turbine maximum power is assumed based on the average energy consumption of the house. Wind speed distribution is calculated as a probability density function. This can be used to calculate the energy generated at a certain wind speed and the summation of all these values will give the total energy generated by the wind turbine. The main limitation is that it does not take into account the nature of the site—urban or rural—or the obstructions due to nearby buildings which might have a significant impact on wind speed. The actual overall electricity generation might be quite low as compared to that calculated by the model.

Heat Pump Model

This model takes into account the building heating energy requirement and the co-efficient of performance of the heat pump to determine the electricity use. By specifying the COP and knowing the building heating energy requirements, the electricity that can be generated from the heat pump can be calculated.

Gas-CHP Model

The specified heat to power ratio and building heating and hot water energy requirements are utilised to calculate the electricity generation from the CHP unit. The gas used by the CHP to deliver the electricity and heat requirement of the building is obtained by adding the energy requirement and electricity generation together divided by the efficiency of the unit.

3. RESULTS AND DISCUSSION

3.1 Results for Existing House

The house model has been used to determine the energy used by the existing house and the total CO_2 emissions from the house based on the information provided in Table 1. The U-values of 1.6 W/m^2K and 4.8 W/m^2K for external walls and windows respectively have been obtained from SAP 2009. The monthly average solar irradiations on the walls have been calculated from the PV model. The fuel price of 3.10p/kWh for gas and 11.46p/kWh for electricity, including additional standing charges of £106 for gas, have been taken from SAP 2009 to calculate the energy bills for the household. The total gas and electricity used by the house, the energy bills, and the CO_2 emissions for the house are summarised in Table 2.

TABLE 2. Breakdown of total energy use, fuel bill, and CO_2 emissions.

Energy consumption	Total energy use (kWh/yr)	Fuel bill (£/yr)	CO_2 emissions (tonnes/yr)
Gas (space heating, hot water and cooking)	42967	1,438	7.95
Electricity (Lighting and appliances)	3716	426	2.00
Total	46682	1,864	9.95

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It can be seen from Table 2 that the gas consumption of the house is 42967 kWh/yr, thus leading to a CO_2 emission of 7.95 tonnes, or 79.9% of the total CO_2 emissions. According to Lynus (2007), the gas and electricity consumption for an average three-bed detached house in the UK is 27000 kWh/yr and 3300 kWh/yr respectively. Thus, although the electricity consumption of 3716 kWh/yr for the house seems reasonable, the gas consumption is too high and not plausible. The total CO_2 emissions of the household is 9.95 tonnes, which is again way too high compared to 6.20 tonnes for average emission from a household of the same size and age, as per www.defra.gov.uk [5].

3.2 Effects of Energy Efficiency Measures

A number of energy efficiency measures have been taken into account for reducing the energy demand and CO_2 emissions of the existing household. These include cavity wall insulation, double-glazed windows, replacing the old gas boiler with a new A-rated condensing boiler, low energy lighting, and replacing the C-rated appliances with A-rated high efficient ones. The improved U-values of 0.35 W/m^2K and 1.6 W/m^2K for external walls and windows respectively have been used in the house model to get the revised energy use and CO_2 emissions. A boiler efficiency of 87% has been adopted. All these values have been obtained from SAP 2009. It is assumed that out of the total electricity consumption of 3716 kWh, 30% [6] (1115 kWh) is spent on lighting and the rest (2601 kWh) on running the appliances in the house. Based on the assumption that using low energy compact fluorescent lights (CFLs) will reduce the lighting energy consumption by 75% [7] and A-rated appliances will use 50% less energy than the C-rated appliances, the total electricity consumption will be reduced to 1580 kWh/yr. This value is adopted in the house model. The energy, cost savings, and CO_2 emissions resulting from the energy efficiency measures are presented in Figures 6, 7, and 8. The energy demand and CO_2 emissions are reduced by 68% and 66.7% respectively. Installation costs are £500 for cavity wall insulation, £2,000 for double glazed windows, £2,500 for boiler replacement, and £2,000 for replacing the appliances.

3.3 Effects of Photovoltaics

When considering a residential solar PV installation, it is important to take into account the available roof area of the house. To maximise the amount of solar energy falling on the array, the orientation and tilt of the array is taken to be due south and 30 degrees respectively, as is optimum for UK location. As a general rule of thumb, a PV installation of 1 kW peak power will require an area of 8 m^2 for the array and generate approximately 750 kWh/yr [8]. To offset the electricity use in the existing house would require a PV array with an area of about 24 m^2, costing around £15000. Therefore, an array of 24 m^2 is used in the PV model (Table 3).

The module characteristics are obtained from manufacturer's test data and these values are used in the PV model to obtain the electricity generation from PV

FIGURE 6. Energy demand.

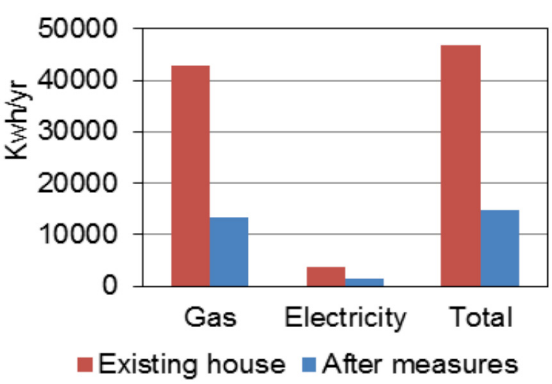

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FIGURE 7. Cost savings.

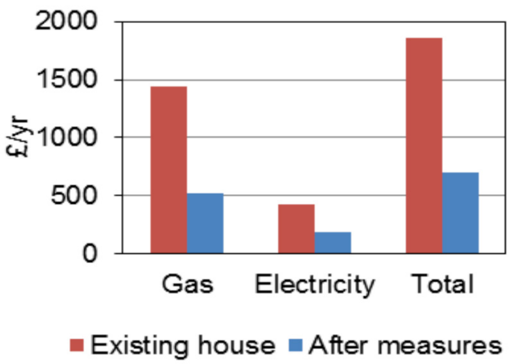
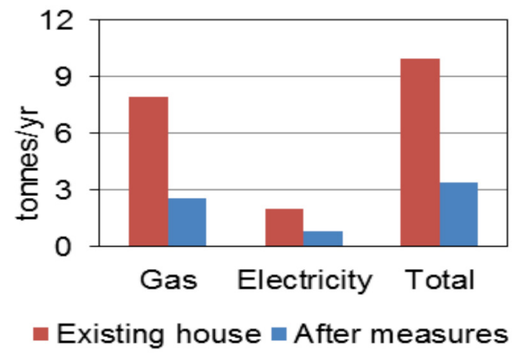


FIGURE 8. CO_2 emissions.



installation and income due to grid export. A total of 79.9% of the household's electricity usage will be generated by the PV, equivalent to 2970 kWh/yr. The money saved on energy bills is £340/yr and the income from grid export is £306/yr. Solar electricity systems do not release CO_2, reducing CO_2 emissions by 16%. Although solar electricity is an expensive option, once installed the systems last for a minimum of 20 years and require little maintenance. PV systems are suitable in most situations. The key considerations are the orientation of available roof space and any shading from trees, buildings, or chimneys. Even partial shading of a PV array should be avoided, since yield will fall by more than the area shaded due to the electrical arrangement of the modules.

TABLE 3. Details of Photovoltaics.

Area	24 m^2
Capital cost	£15,000
Output	2970 kWh/yr
Financial saving	£340 per year
CO_2 saving	1.6 tonnes per year

3.4 Effects of Solar Thermal

The energy required for hot water for the existing house is 4199 kWh/yr. A good rule of thumb for solar water heating systems is to allow 1 m^2 of solar collector per occupant of the house, and 40 litres of dedicated solar storage per occupant [8]. Therefore, a solar collector area of 4 m^2 is considered for 4 occupants in the solar thermal model (Table 4). The collector position to give optimum all year round energy collection is roughly south facing and at a tilt of 30° to the horizontal. These values are used in the solar thermal model to obtain the heat supplied by the solar water system. The solar thermal fulfills 41% of the annual hot water requirements (1729 kWh/yr). The costs for a typical solar water heating system are around £3,000 depending on variants such as size, quality of panel, individual contractors, and ease of integration into the current heating system. Solar thermal provides cost savings of £128/year and a 9.5% reduction in CO_2 emissions. Once installed, solar thermal requires very little maintenance, providing free hot water created by the sun's energy for over 20 years and adding value to the property. Solar thermal systems are suitable in most situations. Similar to photovoltaics, the key considerations are the orientation of available roof space and any shading from trees, buildings, or chimneys. Even slight shading should be avoided to get the best performance.

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TABLE 4. Details of solar thermal.

Area	4 m^2
Capital cost	£3,000
Output	1728 kWh/yr
Financial saving	£128 per year
CO_2 saving	0.95 tonnes per year

TABLE 5. Details of wind turbine.

Capacity	1.5 kW
Capital cost	£2,500
Output	2830 kWh/yr
Financial saving	£325 per year
CO_2 saving	1.5 tonnes per year

3.5 Effects of Wind Turbine

Of all renewable energies, wind power holds the most promise to make a significant impact in reducing carbon output. The installed costs of small-scale turbines are around £2,500 for 1.5 kW (Table 5). A building-mounted wind turbine with a maximum power output of 1.5 kW is considered to offset the electricity consumption in the house. This value is used in the wind model to obtain the annual electricity generation by the turbine. The use of the wind turbine helps to generate 76% of household electricity with a 15% reduction in CO_2 emissions and cost savings of £325/year. The average wind speed obtained from climate data is 5 m/s for London. However, the average wind speed in most of England is nearer 4 m/s, and in urban areas it is often less than 3 m/s. This illustrates why a small, building-mounted wind turbine is not a cost effective improvement measure and is very unlikely to significantly offset the electricity demand of the house. For the majority of property owners living in urban areas, installing wind turbines on or close to buildings with overall wind speeds of less than 5m/s is probably not a realistic proposition.

3.6 Effects of Ground Source Heat Pump

A ground source heat pump (GSHP) having a 3.2 co-efficient of performance [9] is used in the heat pump model. Because GSHPs raise the temperature to around 40°, they are most suitable for under-floor heating systems or low-temperature radiators, which require temperatures between 30° and 35°. The GSHP system is inadequate in itself for directly heating hot water output. Hot water for taps needs to be stored at 60° whereas for domestic GSHPs the maximum water storage temperature obtainable is 50°. If the heat pump is providing hot water this could limit the overall efficiency. Therefore, in this model, it is assumed that the GSHP will provide only the space heating energy requirements of the building. The energy required for space heating the house is 20831 kWh/yr, which will be delivered by the heat pump with a standard grid electricity usage of 6510 kWh/yr (Table 6). Thus, the total electricity consumption will be 10225 kWh/yr and gas consumption (hot water) 6998 kWh/yr. Therefore, using the heat pump reduces energy consumption by 63%. The total CO_2 emissions are reduced by 31% from 9.9 tonnes for the original house to 6.8 tonnes using a heat pump. The cost savings per year is £368. The Energy Saving Trust (EST) states that the costs of installing a typical ground source system range from about £7,000 to £13,000. Approximately 200 m^2 of trench would be needed for a horizontal ground loop for a typical domestic installation. A typical domestic unit measures approximately 170cm high × 60cm wide × 60cm deep; about the size of a small fridge. As this house is currently heated by gas, the financial and carbon savings that one could expect from switching to a heat pump are relatively low, compared to the savings that can be achieved by switching from other fuels (such as oil) to a heat pump. Hence, the option of upgrading to a condensing boiler is much more viable

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for this house. Heat pumps are most suitable for new build installation, as the dwelling can be designed for low-temperature systems (like under-floor heating) and have high levels of insulation to reduce the heating requirement and therefore the size and cost of the system. Ground source heat pumps (GSHP) require a significant area of adjacent land, so are not likely to be suitable for urban locations such as this house.

3.7 Effects of Gas CHP

Since the house is currently heated by gas, installation of a micro CHP heating system may be considered. The main output of a micro-CHP system is heat, with some electricity generation, at a typical ratio of about 6:1 for domestic appliances [6]. The Baxi Ecogen high efficiency boiler uses technology called a Stirling engine. As soon as heat is demanded, a magnetic piston drives up and down within a generator coil to produce 6 kW of heat and 1 kW of electricity per hour. If the heat demand goes above 6 kW, the supplementary burner will fire up and can offer an additional 18 kW of heat. As heat demand falls within the home, the boiler modulates down to as low as 3 kW, while still generating electricity [10]. Therefore, a heat-to-power ratio of 6 and efficiency of 90% is used in the CHP model (Table 7). The CHP unit uses 31655 kWh/yr of natural gas to meet the space heating and hot water requirements of the house and in addition to generating 4070 kWh/yr of electricity. The energy use reduces by 32% from 46682 kWh/yr to 31655 kWh/yr. The total CO_2 emissions reduce by 43% from 9.9 tonnes/yr to 5.6 tonnes/yr. The energy bill for gas per year comes out to be £1,087. Thus, a savings of £775/yr is achieved by the installation of CHP. In addition, a surplus electricity of 355 kWh/yr can be sold to the grid leading to an income of £40/yr. Gas CHP is suitable for a wide range of scenarios. The only limiting factor is the high installation cost, which is around £4000–£6000.

3.8 Comparison of Technologies in Terms of Carbon Cost Effectiveness

The capital costs of improvement measures vary considerably, from almost nothing for a compact fluorescent lamp to several thousand pounds for solar thermal and up to £10,000 for micro-CHP. Improvement measures also have different effects; some may reduce the CO_2 emissions associated with energy use in a dwelling only slightly, while others may deliver large reductions of many tonnes over their lifetimes. To complicate matters further, measures have different lifetimes—a low energy lamp may last 5 years, a new boiler may last 15 years and insulation may last 60 years or more. It is helpful to know which measures represent the best

TABLE 6. Details of ground source heat pump.

COP	3.2
Capital cost	£7,000–£13,000
Output	20830 kWh/yr
Electricity used	6510 kWh/yr
Financial saving	£368 per year
CO_2 saving	3.1 tonnes per year

TABLE 7. Details of ground source heat pump.

Heat to power ratio	6.1
Capital cost	£4,500
Thermal efficiency	90%
Thermal output	25029 kWh/yr
Electrical output	4070 kWh/yr
Gas used	31655 kWh/yr
Financial saving	£775 per year
CO_2 saving	4.8 tonnes per year

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investment, so that when planning for installation of measures for house improvement we need to consider not only the capital costs of the improvement options, but also by how much each measure is likely to reduce both fuel costs and CO_2 emissions over its life. All the technologies except energy efficiency technologies have been compared in terms of their carbon cost effectiveness. This is because each energy efficiency measure has a different lifetime, for example insulation lasts for 60 years whereas a boiler lasts for 10 years, thus making it difficult to compare.

The 'carbon cost effectiveness' of an improvement measure is the capital cost of the measure minus the fuel cost savings that it will deliver, per tonne of CO_2 emission saved, during the lifetime of the measure. The carbon cost effectiveness of the renewable technologies option stated for this house is calculated using the installation costs, fuel cost savings and assuming the average lifetime of all the technologies as 20 years. Some measures may be said to 'pay for themselves'—they reduce fuel costs over their lifetimes by more than their initial capital costs. Other measures involve substantial costs and deliver significant carbon dioxide emissions reduction. The least carbon cost effective measures may cost several thousand pounds per lifetime tonne of CO_2 saved.

4. CONCLUSIONS

In this paper an attempt has been made to provide the best options for renewable energy and low carbon technologies to reduce CO_2 emissions from a detached house built in 1950 located in London. The options for energy efficiency measures—photovoltaics, solar thermal, wind turbine, ground source heat pump, and Gas CHP—have been evaluated on the basis of energy and CO_2 savings and technical viability. The main conclusions derived from this report are summarised below:

- To ensure that we get the most out of the renewable technologies, it is important to make the house as energy-efficient as possible by installing all the energy efficiency measures. The wall insulation, double glazed windows, replacement of boiler and appliances and low energy lighting must be undertaken for this house as these measures alone contribute to a 66.7% reduction in CO_2 emissions. The cost savings by using energy efficiency measures is £1,162/yr, which is significant.
- Electricity generation from photovoltaics in order to meet the electricity demand is one of the technologies that can be considered for this house. This will lead to 79.9% of the electricity demand being met by the PV system with a 16% reduction in CO_2 emissions and fuel cost savings of £340/yr. This option is technically viable for this house although it is least carbon cost effective as compared to the other technologies.
- The hot water requirements of the house can be fulfilled by the installation of a solar thermal system. This will meet 41% of the hot water requirements of the house, contributing to 9.5% reduction in CO_2 emissions and fuel cost savings of £128/yr.
- Wind turbines are the most carbon cost effective technology, producing a 15% reduction in CO_2 emissions and cost savings of £325/yr. Unfortunately, a domestic small scale wind turbine would not be suitable for this house, as the average wind speed in this area is likely to be below 5m/s and, hence, not technically viable.
- A ground source heat pump (GSHP) reduces CO_2 emissions by 31% and results in a cost savings of £368/yr, which is quite significant. However, a GSHP is most suitable

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for under-floor heating system, and this house has radiators. Therefore, it is not a technically feasible option for this house.

- Installing a gas-CHP is another option that can be considered for this house. It is the second most carbon cost effective, resulting in a 43% reduction in CO_2 emission and fuel cost savings of £775/yr, which is the second highest amongst all the technologies. This will also help to meet both the electricity and heating requirements of the house.

Thus, the recommended options are energy efficiency technologies, photovoltaics, solar thermal, and gas CHP. Other options not evaluated in this report could be considered for this house, including air source heat pump and a biomass CHP.

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