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Effect of heat-saving measures on the CO_2 savings attributable to micro-combined heat and power (μCHP) systems in UK dwellings

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Abstract

This paper considers the relationship between heat-saving and micro-combined heat and power (μCHP) technological interventions for reducing the carbon footprint of existing domestic dwellings within the UK housing stock. The relationship between the annual heat requirement of individual dwellings and the CO_2 savings attributable to different μCHP systems is investigated (by means of predictive modelling based on heat and power demand datasets recorded on a 1-min time base for nine dwellings). An assessment is made of the effects of various heat-saving measures upon the annual CO_2 savings predictions for candidate μCHP system implementations, when applied to 'domestic building variants' (as defined within the Carbon Vision TARBASE research programme). The increasing application of heat-saving interventions serves to reduce the CO_2 savings solely attributable to a μCHP system. The magnitude of this effect is a function of the μCHP system's electrical efficiency and electrical power output. For example, a 1 kW prime mover of 10% electrical efficiency is predicted to reduce annual CO_2 emissions by 72 kg CO_2 for a dwelling with an annual heat requirement of 11.9 MWh, but if the identified set of heat-saving measures is implemented first the demand falls to 5.0 MWh and the μCHP system will actually result in an emissions increase of 100 kg CO_2 p.a. By comparison, relative savings of 467 and 294 kg CO_2 p.a. are predicted if this dwelling is fitted with a 1 kW prime mover of 30% electrical efficiency. Still greater savings are predicted for higher power output systems of high efficiency, but a relatively large proportion of the generated electricity (44–75% depending on the heat and electrical demand of the dwelling) must then be exported.

Keywords: Micro-CHP; Domestic sector; Energy efficiency; CO_2 savings

1. Introduction

This investigation forms part of the Carbon Vision TARBASE research project which aims to identify technological intervention strategies for reducing the CO_2 emissions attributable to the existing UK built asset base (both domestic and non-domestic) by 50% by 2030. The interdependence of interventions applied to the building fabric, HVAC and end use equipment upon the on-site generation of heat and power are being researched.

The UK government has committed, through recent initiatives [1,2] to accelerate the adoption of demand-side technological interventions designed to minimise the CO_2 emissions attributable to the use of electricity and the attainment of thermal comfort in domestic dwellings. Similar commitments have been made by other EU countries; for instance the German government [3], over a 25 year period intends to upgrade all domestic housing constructed before 1984 to an 'exemplar' energy efficiency standard. Within the UK package of initiatives, the government also seeks to promote the deployment of micro-combined heat and power (μCHP) systems. These are being developed to employ heat engine or fuel cell technology and will enter the domestic gas boiler market. The market opportunity is large; the UK boiler market comprises some 17 m units with annual sales well in excess of 1 m [4].

Conceptually, μCHP systems offer significant opportunities for decarbonising the provision of heat and power to

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Nomenclature

a	constants for Eq. (1)—see Table 2
e	annual electrical demand of the stated dwelling (kWh)
e_{gen}	total amount of electricity generated by the stated μCHP system (kWh)
e_{exp}	electricity generated by the stated μCHP system that is exported from the dwelling (kWh)
P_{oe}	electrical output of the stated μCHP system (kW)
P_{ot}	thermal output of the stated μCHP system (kW)
q	annual thermal demand of the stated dwelling (space heat and hot water) (kWh)
RSq_{adj}	coefficient of determination
S_{CO_2}	annual CO_2 savings attributable to the stated μCHP system when compared to conventional supply arrangements
ζ_e	electrical efficiency of the stated μCHP system (%)

individual dwellings when compared to conventional arrangements. Recent studies have estimated the carbon abatement potential of the μCHP approach when considered in a single dwelling as 9–17% [5], 10–19% [6] and 20% [7]. The variation in the predicted CO_2 saving is largely a consequence of the prime mover technology, control method, the assumed carbon intensity of the displaced network electricity and the modelling approach adopted. The annual CO_2 saving due to a μCHP intervention in an individual dwelling is also a function of the discrete heat and power demands of the dwelling and how these change with time. As the future energy requirement for space heating falls, due to energy efficiency and/or climate change, the total annual run time available for a given μCHP system to operate will fall and μCHP will tend towards greater intermittency with attendant thermodynamic losses. The extent to which the CO_2 savings attributable to a μCHP system is thereby compromised will be a function of its electrical power output, electrical efficiency and controllability. The combined impact of energy efficiency measures and μCHP systems therefore needs to be better understood if the carbon abatement potential inherent in the μCHP approach is to be realised.

The implementation of highly distributed generation is being supported by institutional and governmental agencies due to its numerous potential benefits (e.g., reduced CO_2 emissions per kWh, lower utility bills, fuel diversification, deferred investment in distribution networks, protection against power outages, reducing the incidence of fuel poverty, fostering community participation and increasing understanding of energy generation and use at the household level). Some of these attributes are primary or imperative for the approach to be adopted, namely reducing operational energy costs and CO_2 emissions. The others may be considered as secondary and will only accrue as a consequence of a mass market for μCHP systems developing. The market for these systems therefore depends on developing preferred technology and fiscal frameworks which facilitate achieving the primary benefits of reduced CO_2 emissions and reduced operational costs.

By convention the CO_2 accounting method for network-connected micro-generation systems assumes that all of the electricity which is generated but not used instantaneously within the dwelling will be exported and used elsewhere and displace the equivalent quantity of centrally generated electricity. The CO_2 emissions savings credit is equivalent to the total electricity generated by the μCHP system. This accounting method does not therefore distinguish between electricity generated by the stated μCHP system that is used instantaneously in the dwelling and electricity that is exported from the dwelling. There are three associated implications:

(a) The μCHP control regime will only effect CO_2 emissions as a consequence of its role in determining the capacity factor and the number of 'switching events' per annum, i.e., how often it needs to be switched on and off.
(b) The application of heat-saving measures will serve to reduce μCHP system run time and increase the intermittency of the thermal demand profile, i.e., the number of switching events and hence reduce the CO_2 emissions savings attributable to a given μCHP system.
(c) The implementation of electricity-saving measures will have no effect on the predicted CO_2 emissions savings for a μCHP system.

μCHP is therefore an additive but complicating factor to the traditional approach of reducing CO_2 emissions via heat-saving and electricity-saving techniques. Also, the CO_2 savings attributable to μCHP systems will depend on the response of the electricity supply industry—with this becoming more influential as the μCHP penetration level increases.

The objective of this research is first to derive a relationship between annual thermal demands of the dwelling, operating parameters of μCHP systems and CO_2 emissions savings. This relationship will be derived using temporally precise demand data. Second, using this relationship, the effect of heat-saving interventions upon the CO_2 emissions savings attributable to a range of μCHP systems was investigated for a series of domestic building variants. This paper reports these CO_2 saving predictions and offers a brief commentary on the potential economic impacts of the observations; a full economic analysis lies beyond the scope of this paper.