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Forecasting how residential urban form affects the regional carbon savings and costs of retrofitting and decentralized energy supply

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HIGHLIGHTS

- An innovative model for testing combinations of spatial planning and decentralised energy supply.
- An improved method of modelling the spatial variability of energy consumption per dwelling type.
- Shows how spatial planning would affect the future carbon reduction of decentralised supply.
- Forecasts the future carbon reduction and costs of retrofitting and decentralised supply.
- A method of forecasting how residential space would affect the suitability of decentralised supply.

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ABSTRACT

Low carbon energy supply technologies are increasingly used at the building and community scale and are an important part of the government decarbonisation strategy. However, with their present state of development and costs, many of these decentralised technologies rely on public subsidies to be financially viable. It is questionable whether they are cost effective compared to other ways of reducing carbon emissions, such as decarbonisation of conventional supply and improving the energy efficiency of dwellings. Previous studies have found it difficult to reliably estimate the future potential of decentralised supply because this depends on the available residential space which varies greatly within a city region. To address this problem, we used an integrated modelling framework that converted the residential density forecasts of a regional model into a representation of the building dimensions and land of the future housing stock. This included a method of estimating the variability of the dwellings and residential land. We present the findings of a case study of the wider south east regions of England that forecasted the impacts of energy efficiency and decentralised supply scenarios to year 2031. Our novel and innovative method substantially improves the spatial estimates of energy consumption compared to building energy models that only use standard dwelling typologies. We tested the impact of an alternative spatial planning policy on the future potential of decentralised energy supply and showed how lower density development would be more suitable for ground source heat pumps. Our findings are important because this method would help to improve the evidence base for strategies on achieving carbon budgets by taking into account how future residential space constraints would affect the suitability and uptakes of these technologies.

1. Introduction

The UK Climate Change Act 2008 has legislated for decarbonisation by implementing a system of 5-year carbon budgets to achieve an 80% reduction in targeted greenhouse gas emissions by 2050 relative to 1990 levels. The "Low Carbon Transition Plan" implemented in 2009 includes increasing the proportion of gas, nuclear and renewable energy supply and reducing the proportion of the more polluting fuels such as coal. The national demand for electricity may double by 2050, due to population growth and the electrification of heating and road transport. Hence there is a daunting

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amount of investment needed in energy supply infrastructures, including replacing a quarter of power capacity by 2020 for security of supply, and a target of 30% of electricity in 2020 to come from renewable sources.

Buildings account for over 40% of all CO_2 emissions and there have been various initiatives to improve their energy efficiency. The requirement for energy conservation was first introduced into the UK building codes in 1976 as 'Part L' of the Building Regulations and since then there has been only a step by step increase in energy efficiency standards. Also, around two-thirds of dwellings that currently exist were built prior to 1976. Consequently much of the UK housing stock has been built with low energy efficiency performance. In recent years there have been a number of government schemes to incentivise retrofitting, most recently the 'Green Deal'. This provided subsidised loans for energy efficiency improvements but it had low uptake from households and the scheme closed in 2015.

The Code for Sustainable Homes (CfSH) initiative [1] was introduced in 2006 to achieve a progressive step-change in building practice with the aim of all new dwellings being 'zero carbon' by 2016 ('Level 6'). Developers were allowed discretion on how to achieve the required level of CfSH, such as energy efficient building fabric, decentralised supply technologies, and 'allowable' solutions such as bio-fuel carbon offsets or contributions to offsite electricity generation [2]. This would typically include discussions with the local planning authority, which have responsibility for sustainable development [3]. The UK government recently withdrew the CfSH and in March 2015 announced a new National Technical Standard that will be more easily attainable with the aim of simplifying and speeding up the development process. This new technical standard will be broadly equivalent to CfSH Level 4 which was the greatest reduction in CO_2 emissions achievable by energy efficient building fabric alone.

These building standards for homes do not take into account transport, which accounts for a similar magnitude of CO_2 emissions per capita to the buildings. Car travel varies considerably between different area types with people in rural areas travelling around twice as far per year by car than those who live in urban conurbations [4]. Therefore, location of development is an important factor affecting the overall energy consumption and carbon emissions of a household.

The UK Future of Heating government report [5] proposed that decentralised energy supply will make a substantial contribution to future CO_2 reduction, with heat pumps and hybrid boilers supplying the majority of future domestic heating. The strategy for meeting future carbon budgets in the Committee on Climate Change (CCC) advisory reports to the UK government relies heavily on these decentralised technologies for domestic buildings [6]. However, their report on low carbon heat scenarios [7] and the DECC government consultation on a domestic renewable heat incentive scheme [8] both identified cost effectiveness and uncertainty about whether properties have the space required for installation as important barriers to the uptake of these technologies.

Evidence for these strategies is from methods that can be broadly divided into either techno-economic energy system models or more 'bottom up' building stock energy models. The RESOM model is an example of an energy system model and was used to provide evidence for the Future of Heating report [9]. It disaggregated dwellings into standard dwelling typologies and whether they would be in rural or urban areas but with no explicit representation of the variability of their plot size or floor space. MARKAL is a widely used energy system model [10] and Dodds [11] found that adding extra dwelling typologies made relatively little difference to its forecasts because it operates at an aggregate scale. He concluded that these energy system models need to be combined with building stock models to account for the spatial variability of urban form.

There are numerous examples of building stock energy models [12,13]. These use typologies that correspond with national housing survey data classifications such as dwellings types, age bands, building fabric and heating systems [14]. These models have been developed to estimate energy demands and consumption for the building stock at regional scale. These models distinguish between dwelling types but not how they vary on outdoor space or how floor space varies spatially within the region per dwelling type. Their land and floor space can vary greatly, which affects energy consumption and their potential for decentralised energy conversion. This is partly due to differences in household preferences and wealth and also the differences in land values between areas. An increase in land value due to regeneration or improved access to jobs and services creates development pressures for higher density. This transformation through property conversions and redevelopment further increases the diversity of the housing stock. It would be advantageous for urban energy models to represent this variability [15].

Pereira & Assis [16] showed how changes in household energy consumption are spatially correlated with changes in income, and numerous studies have shown that human factors account for a substantial amount of the variability of energy use [17–19]. Greater affluence tends to increase the demand for floor space and may diminish the financial motivation to reduce energy consumption. Conversely, people on low incomes may be less likely to adopt energy supply technologies [20]. Governance and community involvement will be important for the implementation of distributed energy systems [21].

There are clearly interrelationships between the availability of space and the suitability of decentralised technologies. A study by Blum et al. [22] estimated the potential CO_2 reduction of ground source heat pumps (GSHP). This was based mainly on regional household energy demands and soil conditions but not the availability of residential space. GSHP have lower capital costs if there is sufficient outdoor space for horizontal loops but they can also be installed as more expensive vertical loop systems so long as there is enough access space for installation [23]. The Future of Heating report suggests that GSHP will initially be more suitable for dwellings off the gas grid in outer areas because these have more space available and replacing their carbon intensive heating systems would have environmental benefits. However, heat pumps are low temperature systems that are more suitable for well insulated properties. Ground source heat pumps may be most suitable for new build because if installed as part of the construction process and if the new dwellings have under floor heating they can operate at a more efficient temperature. Micro-CHP may be a suitable alternative in areas with insufficient space for heat pumps so long as there is sufficient indoor space for the equipment. However gas-fuelled CHP systems only achieve a relatively small reduction in carbon emissions and their cost effectiveness depends on the temporal balance of the demand for heat and power and is greater if the power is fully utilised within the dwellings [24].

The above examples illustrate that the suitability of decentralised energy technologies needs to be considered at the building-scale because their cost effectiveness will depend on the combination of energy demand and built form characteristics. However, decisions on policy support such as public subsidies, regulations and research and development are taken at national scale. This poses a difficult challenge because these strategies have a long time horizon and so rely on forecasts.

Forecasting the future urban densities is best done using a socio-economic urban model, such as land use and transport interaction (LUTI) models which are static aggregate models of