The remaining potential for energy savings in UK households

Jan Rosenow [a b c], Pedro Guertler [d], Steven Sorrell [a], Nick Eyre [b]

[a] Centre on Innovation and Energy Demand, Sussex Energy Group, University of Sussex

[b] Environmental Change Institute, University of Oxford

[c] The Regulatory Assistance Project, Rue de la Science 23, 1040 Brussels, Belgium

[d] E3G, 47 Great Guildford St, London SE1 0ES, United Kingdom

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Abstract

Progress on improving energy efficiency of UK homes has stalled in recent years and the question arises how much more potential for further energy savings exist across the housing stock. Whilst there are some high-level estimates of the potential for buildings energy efficiency in the UK, a more granular assessment is needed to understand exactly where this potential lies and what form it takes. Our analysis fills this gap. It is based on the best available evidence on the remaining potential for energy efficiency improvements within UK residential buildings. Using UK government criteria for investment appraisal, we demonstrate that there is a significant resource of untapped energy-saving opportunities in UK homes. Specifically, our estimates suggest that: one quarter of the energy currently used in UK households could be cost effectively saved by 2035; and this could increase to one half if allowance is made for falling technology costs and the wider benefits of energy efficiency improvements. However, these estimates are sensitive to the assumptions made about capital,

energy and carbon costs, and capturing this potential will require both significant policy change and large-scale investment.

1 Introduction

Improved energy efficiency has played a pivotal role in reducing the UK's energy use and carbon emissions. On a temperature corrected basis, total UK household energy use decreased by 19 percent between 2002 and 2016, despite a 12 percent increase in the number of households and a 10 percent increase in population (BEIS 2016a). Per-household energy consumption fell by 37 percent between 1970 and 2015, with most of this decrease (29 percent) occurring since 2004 (ibid). Energy efficiency improvements in individual households have offset the 46% increase in the number of households, the 5.6^{o}C increase in average internal temperatures and the rapid growth in appliance ownership over this period, with the result that total household energy consumption has increased by only 7 percent in 45 years.

Although rising energy prices and the 2008 recession contributed to recent trends, the bulk of the reduction in per-household energy consumption can be attributed to public policies to improve energy efficiency. Of particular importance have been the major home insulation programmes funded by successive 'supplier obligations' such as the Carbon Emissions Reduction Target (CERT - 2008 to 2012) and the Energy Company Obligation (ECO – 2013 onwards) (CCC 2017; CEBR 2011; DECC 2015; Odyssee 2017; Rosenow 2012). These imposed energy and carbon saving targets on electricity and gas suppliers and allowed them to recover the costs through a levy on household energy bills. Also important were the requirement for condensing boilers within the UK Building Regulations and the progressive tightening of EU standards on the energy efficiency of electrical appliances (CEBR 2011). Evaluations of these policies have shown them to be highly cost-effective, both in terms of the cost savings to participating households and in terms of broader societal welfare (Lees 2006, 2008; Rosenow and Galvin 2013). This experience supports the argument that market forces alone cannot deliver all cost-effective investment in residential buildings, owing to multiple and overlapping market failures. Instead, policy intervention can be used to improve economic efficiency.

The UK Climate Change Act (2008) establishes a long-term target of reducing greenhouse gas (GHG) emissions to 80 percent below 1990 levels by 2050. To meet this target, the government has established five-yearly carbon budgets which restrict the amount of greenhouse gases UK can legally emit in each five-year period. In October 2017, the government published its Clean Growth Strategy (BEIS, 2017a) that set its approach to meeting the 4th (2023-2027) and 5th (2028-2032) carbon budgets and to ensuring that the UK maximizes the economic and environmental benefits of green technology. However, the full set of policies to deliver on those carbon budgets has yet to be developed (CCC, 2018). Since residential buildings account for approximately one quarter of UK carbon emissions, the remaining potential for improving the energy efficiency of those buildings is of considerable importance. Accurately assessing and effectively unlocking this potential will be critical to ensuring the UK follows the most cost-effective path to meeting its targets. Underestimating and neglecting this potential could cost the UK billions in unnecessarily high energy bills and higher cost energy supply.

In the past, multiple studies have indicated a large potential for improved energy efficiency in UK residential buildings. And this remains the case, despite the substantial improvements over the last 15 years. For example, in its impact assessment for the 5th Carbon Budget, the UK government concluded that residential buildings had the highest technical potential for carbon abatement across the economy, offering 32% of the total (DECC 2016a). Much of this is due to the potential for improved energy efficiency. The government's analysis is corroborated by other studies, including the Infrastructure Transitions Research Consortium (ITRC 2016) whose evidence fed into the National Needs Assessment.[1]

However, a more granular assessment is needed to understand exactly where this potential lies and what form it takes. Our analysis fills this gap. It is based on the best available evidence on the remaining potential for energy efficiency improvements within UK residential buildings. Using UK government criteria for investment appraisal, we demonstrate that there is a significant resource of untapped energy-saving opportunities in UK homes. Specifically, our estimates suggest that: **one quarter** of the energy currently used in UK households could be cost effectively saved by 2035; and this could increase to **one half** if allowance is made for falling technology costs and the wider benefits of energy efficiency improvements. However, these estimates are sensitive to the assumptions made about capital, energy and carbon costs, and capturing this potential will require both significant policy change and large-scale investment.

The paper is structured as follows. The following section presents our methodology for estimating the remaining technical and economic potential for energy efficiency measures in UK households, while Section 3 summarises the data sources employed and the assumptions made. Section 4 presents the results of the modelling exercise as three scenarios with varying levels of ambition, and indicates the potential development of energy and cost savings over time. Section 5 discusses some of the uncertainties in the analysis, as well as the type of measures required to unlock the identified potential. Section 6 concludes with some policy recommendations.

[1] The National Needs Assessment brought together a coalition including industry, investors, environmental, legal and professional bodies, and politicians and opinion formers to deliver a 35 year view of the changing demands on infrastructure services.

2 Methodology

We estimate the *lifetime energy savings* associated with different levels of deployment of energy efficiency technologies in UK households over the period to 2035, together with the *net present value* of those energy savings. In valuing these energy savings, we consider both the avoided energy costs and the wider benefits of reduced energy consumption, such as reduced greenhouse gas emissions and improved air quality.

Our estimates for the technical and economic potential of different types of energy efficient technology are based upon analyses by the UK Committee on Climate Change (CCC), while our estimates of the costs and benefits associated with those technologies are informed by policy appraisal guidance (called the Green Book) provided by the UK Treasury and UK Department of Business, Energy and Industrial Strategy (BEIS, 2015). In particular, our calculation of the costs and benefits of energy savings employ a spreadsheet toolkit provided by the Interdepartmental Analysis Group (IAG, 2015). Hence, our analysis does not rely on new modelling tools, but instead explores the implications of the assumptions and tools employed by UK government departments and UK government agencies.

We model four groups of technologies: heating efficiency; appliance efficiency; heat networks; and individual low-carbon heating systems. Heating efficiency encompasses building fabric, heating controls and efficient boilers. Efficient appliances include fridges and freezers, washing machines, dryers, ovens, televisions and lighting.[2] Heat networks include schemes in high density areas that are powered from a number of sources (e.g. gas-fired combined heat and power, industrial waste heat, energy from waste). Finally, low carbon individual heating systems include air-source and ground-source heat pumps (with and without heat storage) and biomass boilers. Heat networks and low carbon heating systems are included in the analysis,

[2] Strictly speaking lighting is not an appliance but for the purpose of this exercise it has been included in the appliances category.

since they can significantly reduce final energy demand as well as carbon emissions[3]. For example, heat networks may be driven by gas-fired combined heat and power (CHP) schemes that are more efficient than separate provision of electricity and heat. Similarly, they may be driven by waste heat from power plants and industrial facilities, or by latent heat from sewage or rivers.

All scenarios are modelled relative to a baseline scenario. The baseline shows total household energy demand increasing to 2035, owing to the assumption of no energy efficiency improvements in the existing stock (27 million dwellings), together with the construction of five million new dwellings over that period. The baseline scenarios published by the UK government and CCC include the impact of replacing existing boilers with more efficient condensing boilers when the former are retired. Here, these energy savings have been removed from the baseline and shown separately within our constructed scenarios. The latter also include the energy savings from energy efficiency measures, together with those from deploying heat pumps and heat networks in new dwellings - relative to the use of gas heating in the baseline scenario.

We develop three scenarios representing progressively more ambitious levels of technology deployment. These are termed the *limited ambition*, *cost-effective* and *technically possible* scenarios respectively. Each scenario assumes a different level of technology deployment in existing buildings, but the energy performance of new buildings is assumed to be the same. The first two scenarios use the same assumptions for the capital cost and lifetime of different energy efficiency measures, together with the level of adoption of various behavioural measures, while the third scenario assumes the adoption of all technically feasible measures, regardless of costs. Supply chain constraints are not considered in any of the scenarios. The assumptions underlying each scenario are as follows:

[3] Some low carbon heating options increase energy demand while reducing emissions, while others reduce both. Their net effect in the scenarios assessed in this paper is to reduce energy demand, as can be seen in Figures 2 and 3.

1. *Limited ambition*: This includes all energy efficiency measures that can be installed by 2035 based on a continuation of current policy deployment projections as set out in formal policy appraisals. This level of deployment is broadly consistent with the UK Government's central projections for energy and emissions, published in 2016 (DECC 2016c).[4] Equipment is not replaced before the end of its natural life. On the whole in this scenario, estimated energy cost savings (based on BEIS' central scenario for energy prices), discounted over the lifetime of the measures, exceed the associated capital costs. We use a discount rate of 3.5% in line with official guidance (BEIS, 2015). In that year, the Committee on Climate Change (2016b) estimated that 85% of the carbon savings in buildings from the government's projections were 'at risk' (i.e. may not materialise) owing to low take-up of measures, less than full implementation of policies or poor enforcement of standards.
2. *Cost-effective*: This includes all energy efficiency measures deployable to 2035 that are estimated to be cost-effective according to criteria used by the UK government to appraise public policies and projects (DECC/BEIS 2015). The level and rate of deployment is based closely on the CCC's central scenario for meeting the 5th Carbon Budget, which means technologies are deployed at a rate informed by their historical deployment and follow a traditional S-curve trajectory for market diffusion. The cost-effective scenario uses a discount rate of 3.5% and accounts for energy cost savings in the same way as the 'limited ambition' scenario, but also places a monetary value on improvements in comfort and air quality, as well as on reductions in greenhouse gas emissions. Measures are cost effective when the discounted sum of these private and social benefits exceeds the associated capital and other costs. This level of deployment is broadly consistent with an overall approach taken across all sectors of the economy that meets the 5th Carbon Budget at least cost. For illustration, we also estimate the value of some additional benefits from energy efficiency measures, such as the improvements in health that result from warmer and drier homes, but we do not include these in our assessments of cost effectiveness.

[4] A 2016 version of the Updated energy and emissions projections was published in March 2017, where final energy demand in the residential sector in 2035 is 2.9% higher than in the 2015 version, mainly owing to lower than previously projected savings from efficient electrical appliances.

3. *Technically possible*: This includes all of the measures examined (all of which are currently available and applicable to today's housing stock) without regard to their cost effectiveness. This does not include the possible future deployment of new technologies, although experience suggests that new technologies will emerge and open up further energy-saving opportunities. In order to decarbonise the housing stock by 2050 a large share of this technical potential will need to be delivered.

3 Data and assumptions

This section summarises the sources and assumptions used for: a) the potential energy savings associated with energy efficiency improvements; c) the capital cost of those improvements; and d) the social benefits of those improvements, expressed in monetary terms.

3.1 Energy savings from energy efficiency improvements

Estimates of potential energy savings are based upon estimates of the remaining potential for installing different types of energy efficiency measure within UK residential buildings. Our primary source for estimates of the technical and economic potential for improved energy efficiency is the 'Fifth Carbon Budget Dataset' provided by the CCC (2016a). This dataset combines information from a variety of sources. For its 'central scenario' (which meets the 4th and 5th carbon budgets), the CCC estimate the annual deployment of different technologies in existing and newly built dwellings between now and 2035, together with the associated energy and emission savings. We use this data to estimate the impact of alternative scenarios for the scale and mix of technology deployment over time.

We supplement the CCC dataset with additional sources, such as those providing estimates of the remaining technical potential for efficiency improvements, together with government policy impact assessments. Table 1 summarises our assumptions for the remaining number of each type of measure, and the fuel and electricity savings associated with each. The fuel and electricity savings are based principally on a study by Element Energy (2013) and assume that all technical potential is fulfilled and are thus incremental for every measure across the existing housing stock. The energy savings associated with district heating are scaled from the CCC dataset to match the potential for heat supplied through heat networks, in this way (perhaps crudely) that the same proportionate mix of district heat sources applies at larger scale (including for waste heat as a source).

Table 1: Estimates of the remaining number of measures available for improving the energy efficiency of existing UK housing stock

Measure	Number of measures*	Electricity savings (TWh)	Fuel savings (TWh)	Sources and assumptions
Cavity wall insulation	5.2m	0.5	9.7	DECC (2016b)
Loft insulation (lofts with 125mm insulation or less to 270mm insulation)	7.1m	0.2	2.2	
Solid wall insulation	7.6m	1.6	21.4	
Floor insulation	19.5m	0.9	12.8	Element Energy & EST (2013) minus the number installed in 2014-2015 (BEIS, 2016a)
Enhanced double glazing (majority is replacement of pre-2002 double-glazing)	17.9m	2.0	20.3	
Other fabric measures (includes insulated doors, draught proofing, and improved hot water tank insulation)	39.7m [total number of opportunities for each measure across all homes]	1.3	17.1	
Boiler upgrades (from non-condensing to condensing)	11.7m	0.6	33.8	Element Energy & EST (2013) minus the number installed in 2014-15 (HPM Magazine 2016)
Heating controls and upgrades (number of properties receiving single measure or combination of measures)	12.4m	0.1	3.2	Sum total of opportunities in homes missing one or more of: thermostatic radiator valves, timer, thermostat and cylinder thermostat (Element Energy, 2013), minus the number installed in 2014-2015 (BEIS, 2016a)
Heat networks (2050 heat supplied)	40 TWh	-3.0	29.4	DECC (2013) and mid-point of central and high 2050 estimate in Element Energy (2015)
Heat pumps	23.0m; consisting of 5.8m in off-gas areas / non-gas heated properties and remainder replacing gas boilers (showing gas savings incremental to	-37.0	148.6	Frontier Economics & Element Energy (2013)

Measure	Number of measures*	Electricity savings (TWh)	Fuel savings (TWh)	Sources and assumptions
	earlier boiler upgrades)			
Efficient lighting (lamps) (from incandescent to compact fluorescent, and from halogens to LEDs)	321.6m	6.4	-4.6	Element Energy & EST (2013), minus the number installed in 2014-15 (CCC, 2016)
Cold appliances (A+++)	37.1m	7.1	-3.8	
Wet appliances (number of appliances where replacement with A+++ washing machines, A-rated tumble driers, and A+ dishwashers)	39.2m	2.8	-0.1	
Efficient ovens (A+)	15.1m	0.9	-0.5	
Efficient televisions (A++)	51.8m	6.0	-3.5	

* TWh for heat networks as number of measures not appropriate as a metric

3.2 Costs and lifetimes of energy efficiency improvements

Tables 2-4 summarise our assumptions for the capital cost and lifetime of each measure. The assumptions for capital costs are derived from a variety of sources (ACE 2016; BEIS 2016b; CCC 2015, 2016b). We assume that the capital cost of solid wall and floor insulation fall at the rates set out in Guertler (2014) – leading to a 30% reduction by 2030. Assumptions about the lifetime of different technologies are taken from Ofgem (2015) and are consistent with those used in the most recent supplier obligation. We assume, as households would replace them anyway, that energy-efficient electrical appliances and replacement condensing gas boilers involve no additional capital cost.

For heat networks, we rely upon a study for the CCC by Foster *et al*. (2015) which provides estimates of the levelised cost of delivered heat (£/MWh). From this, we isolate the capital costs of the central plant and network and express the sum of these in levelised form (Table 3). For heat pumps and biomass boilers, we adopt capital cost estimates from the CCC (2015; 2016b) and assume that these fall by 20% by 2030 (Table 4) – which is broadly in line with the reductions assumed by DECC (2016d, 2016e) in their 'mass market' scenario.

In addition, Table 5 presents our assumptions for the take-up of behavioural measures to save energy in both the cost-effective and limited ambition scenarios. While public campaigns to increase their prevalence and persistence are likely to carry a cost, this has not been estimated here.

Table 2: Assumed capital cost and lifetime of energy efficiency measures

Efficiency measure	Installed cost per dwelling (£)	Lifetime (years)+
Solid wall insulation - External	8,500	36
Solid wall insulation - Internal	8,500	36
Cavity wall insulation - Easy to treat	500	42
Cavity wall insulation - Hard to treat	1,300	42
Cavity wall - Treat with solid wall insulation rather than insulating cavity	8,500	36
Loft insulation 50-125mm to 270mm	400	42
Loft insulation 125-200mm to 270mm	400	42
Suspended timber floor insulation	2,000	42
Solid floor insulation	3,000	42
Single to double glazing (average per property)	5,000	20
Pre 2002 double glazing to improved double glazing	5,000	20
Insulated doors (one per building)	500	15
Draught-stripping	100	10
Boiler upgrade	0*	12
Heating controls - Full	250	12
Heating controls - timer + thermostatic radiator valve	250	12
Heating controls - thermostatic radiator valve only	200	12
HW cylinder thermostat	50	12
Hot water tank insulation from none to 80mm	50	10
Hot water tank insulation from jacket to 80mm	50	10
Hot water tank insulation from foam to 80mm	50	10
Efficient lighting	0*	5.5 for CFLs; 27.4 for LEDs
Efficient cold appliances	0*	12.5
Efficient wet appliances	0*	12
Efficient ovens	0*	12
Efficient televisions	0*	7.5

Note: We assume that replacement lighting, boilers and appliances involve no additional capital cost, since inefficient lighting and boilers will no longer be available and inefficient appliances are replaced at the end of their lives.

Sources: ACE 2016; BEIS 2016b; CCC 2015, 2016b DECC (2014a); Ofgem (2015)

Table 3: Assumed capital cost and lifetime of heat networks

Heat network technology	Levelised capital cost of plant and network (£/MWh of delivered heat)	Lifetime (years)
Low temperature waste heat from industry/power sector + heat pump	37.0	40
High temperature waste heat from industry/power sector	30.0	40
River source heat pump	46.5	40
Sewage source heat pump	42.0	40
Gas combined heat & power (CHP)	41.5	40
Biomass boilers	33.0	40
Energy from waste	30.0	40
Gas peak load boilers	41.5	40

Sources: Element Energy (2015); Foster *et al*. (2015)

Table 4: Assumed capital cost and lifetime of low carbon heating systems

Building type	Individual low carbon heating system	Installed cost per dwelling (£)	Lifetime (years)
Existing building	Air source heat pump (ASHP), air-to-water (ATW), no storage	7,000	15
	ASHP, ATW, storage	8,000	15
	Ground source heat pump (GSHP), ATW, no storage	14,000	20
	GSHP, ATW, storage	16,000	20
	Biomass boilers on biomass wood/biomass pellets	5,520	20
New building	GSHP no storage from 2025	10,500	17.5
	GSHP with storage from 2025	12,000	17.5

Sources: Ofgem (2015); CCC (2015; 2016b)

Table 5: Assumptions for behavioural measures

Behavioural measure	Number of households undertaking measure in 2015 (million)	Number of households undertaking measure in 2035 (million)	Electricity saving in 2035 (TWh)	Fuel saving in 2035 (TWh)
Turn down thermostat by 1°C	7.5	15.0	0.3	8.3
Turn off lights when not in use	1.1	7.8	0.4	-0.3

Source: CCC, 2016a

3.3 Monetary benefits of energy efficiency improvements

A wide range of benefits are associated with energy efficiency improvements in residential buildings, many of which are difficult to quantify and value. For the cost effective scenario, we estimate the present value of benefits in the form of energy cost savings, GHG emission reductions, improved air quality and improved thermal comfort. Our estimates follow Treasury guidance (DECC/BEIS 2015) for policy appraisal and are compiled with the help of a toolkit from the Interdepartmental Analysts Group (IAG 2015). We add these benefits to the energy cost savings to determine whether investments are cost-effective from a broader, social perspective.

For illustrative purposes, we also estimate some wider benefits that do not form part of formal policy appraisals, although they are sometimes included in annexes to policy impact assessments. These benefits include the improved health of homeowners and electricity system benefits such as avoided network investment. We also consider some potential macroeconomic benefits, including the contribution of the capital investment to economic output and employment. However, we do not use these wider benefits in our assessment of cost-effectiveness owing to the uncertainties associated with each.

Benefits are discounted over the lifetime of the relevant technologies - which for fabric improvements installed in 2035 extends as far as 2076. We input the estimated savings in fuel and electricity consumption into the IAG's spreadsheet toolkit and use this to calculate the present values of benefits over the period 2016-2076. The following sections provide more detail on individual assumptions.

3.3.1 Valuing energy savings

For the cost-effective scenario, we value changes in energy consumption at the *long run variable cost* of the relevant energy commodity, rather than the retail price. The long-run variable cost excludes: a) fixed costs that will not change with a small change in energy use; b) greenhouse gas costs since these are valued separately; and c) taxes, margins and other components that simply reflect transfers between different groups (DECC/BEIS 2015). Our assumptions for these costs are consistent with the central scenario for energy prices published by the UK government in 2015 (IAG 2015). For simplicity, we ignore broader market impacts (e.g. lower energy prices), since these can only be captured with a macroeconomic model.

Since investments in improved energy efficiency reduce the variable cost of energy services such as heating and lighting, they encourage increased consumption of those services. This is normally referred to as the direct rebound effect (Chitnis and Sorrell 2015; Sorrell et al. 2009). We assume a direct rebound effect of 15 percent for fabric improvements and heating system upgrades, in line with the estimates used by the UK government in impact assessments (DECC 2014b). This implies that only 85 percent of the potential energy savings from these improvements are achieved in practice.

We discount the estimated monetary benefits at a rate of 3.5% for the first 30 years, followed by 3% for the next 45 years. This represents a social discount rate that is relevant for policy appraisal and hence is lower than the implicit discount rates applied by consumers for energy efficiency investments.

3.3.2 Valuing reduced greenhouse gas emissions

Our estimates of the greenhouse gas reductions associated with energy savings are based upon standard emission factors (100-year GWP) for the relevant energy commodities, together with assumptions about future changes in the electricity generation mix. These reductions are then assigned a monetary value. In accordance with UK government practice, the carbon emissions associated with electricity consumption are valued differently from those associated with fuel consumption, since the former are covered by the EU emissions trading system (EU ETS). Traded sector emissions are initially assigned a low value (£4/tCO_{2e} in 2016) to reflect the low price of EU ETS allowances, while non-traded emissions are assigned a much higher value (£64/tCO_{2e} in 2016). Following UK government practice, these values are assumed to converge by 2030 (at £77/tCO_{2e}) to reflect the growth of a global carbon market (BEIS 2015) - although in practice, EU-ETS allowance prices appear unlikely to rise to that level.

3.3.3 Valuing improved air quality

Energy efficiency measures in residential buildings should improve local and regional air quality. This is due to fewer nitrogen oxides (NOx) and particulate matter (PM) being emitted from both fossil-fuel electricity generation and from the direct combustion of fuels in buildings. The IAG spreadsheet uses standard emission factors to estimate the size of these reductions over time, allowing for changes in the electricity generation mix. The avoided damage associated with these emissions is then valued at £1052/tonne for NOx and £30,225/tonne for PM (DECC, 2016d).

3.3.4 Valuing improved thermal comfort

Improved comfort is an important benefit of and motivator for undertaking fabric and heating improvements. Where buildings are under-heated, energy efficiency improvements can allow occupants to increase indoor temperatures without using additional energy. In addition, draught-proofing can make buildings feel more comfortable even if indoor temperatures remain unchanged. As simple approximation for the value of these benefits is to use the market value of the energy savings that homeowners are willing to forego for improved comfort. These foregone energy savings represent the direct rebound effect mentioned above. We therefore use the retail price of energy to value improved comfort, rather than the long run variable cost of energy. There are potential overlaps between the value of thermal comfort and the value of health benefits associated with higher internal temperatures (below), but at present we treat these separately.

3.3.5 Valuing health benefits

Energy efficiency measures that lead to higher indoor temperatures may also deliver important health benefits such as lower rates of respiratory illness and fewer winter deaths. The UK Government's Impact Assessment of the last phase of the Energy Company Obligation includes an estimate of the monetary value of health impacts, but this is excluded from their net present value calculations owing to the potential overlap with comfort benefits. However, the Government is refining its approach to quantifying these benefits, with the aim of including them in future assessments.

For the purpose of this paper, we estimate health benefits by taking the midpoint between: a) a lower set of estimates derived from the impact assessment of the 'ECO Help to Heat' scheme (BEIS 2016b); and b) a higher set of estimates derived from the 2013 Fuel Poverty Strategy for England (DECC 2013b). The resulting figures are applied to cavity, loft and solid wall insulation, and boiler upgrades only on the basis of the average health benefits per kWh saved.

3.3.6 Valuing benefits to the electricity system

Reductions in electricity consumption can deliver benefits to the electricity system including avoided line losses, avoided expenditure on both generation capacity and electricity networks and reducing the need for some categories of reserve. However, these benefits are uncertain and they can be very context specific. In the absence of reliable estimates for the UK, we employ per kWh estimates (Table 5) from a US case study (Lazar and Colburn 2013) and multiply these by our estimated electricity savings to obtain an estimate of the total benefit to the electricity system.

Table 6: Estimates of electricity system benefits from end-use electricity savings

Electricity system benefit	p/kWh of saved electricity
Avoided line losses	0.8
Avoided generation capacity costs	0.3
Avoided transmission capacity costs	0.2
Avoided distribution capacity costs	1.5
Minimising reserve requirements	0.1

A study from Germany (Neme et al. 2014) provides even higher values in the range of € 0.11-0.15 per kilowatt-hour (in levelized costs). The study quantified the impact of efficiency investments on the costs associated with each of the different components of electric system (generation, transmission and distribution), as well as its combined or total impact on the German electric system. Most of the benefits identified in the study were associated with the reduced need for investment in renewable energy production in a more efficient power system that is subject to long-term targets for a high share of renewable energy generation.

Many of those benefits are, of course, associated with reduced peak load as well as a reduction in overall electricity consumption. In addition, more efficient and smarter appliances are able to provide demand response services and could provide further benefits if part of a demand response programme. In the absence of data and the need to make a lot of assumptions we have not quantified those effects in this study and future research should investigate more precisely how improved energy efficiency of the building stock would contribute to cost reductions in this area.

3.3.7 Valuing macroeconomic impacts

Investments in energy efficiency can have complex impacts on economic activity and employment. For example, there will be increased activity by manufacturers of energy-efficient technologies (e.g. heat pumps), as well as by suppliers of those firms. The former is a *direct* impact of the energy efficiency investment, while the latter is an *indirect* impact. There may also be *induced* impacts as a result of increased expenditure by both the additional employed workers (direct and indirect) and by consumers whose real income has increased as a result of the energy efficiency improvements (Blyth et al. 2014; Rosenow et al. 2014). This increased spending may increase sales and hence economic activity in many sectors in the economy. However, these gains may be partly offset by *displaced* activity in other sectors- for example, in the energy supply sector as a result of reduced energy demand. Similarly, if the investment is funded through a levy on domestic energy bills, the resulting reduction in household expenditure could have negative economic effects.

For simplicity, we confine attention to the impact of energy efficiency investments on overall economic activity, and estimate this in a relatively crude way. We use gross value added (GVA) as a metric for describing the contribution to gross domestic product (GDP, as measured by the production method, rather than income or expenditure methods[5]) resulting from energy efficiency investments. GVA is defined by the ONS (2016) as the total value of output of goods and services produced less the intermediate consumption (goods and services used up in the production process in order to produce the output). It is the main component of GDP as measured by the production method.

To estimate GVA, we take values from ONS (2015) of the ratio of GVA to turnover in the relevant industry sectors, averaged over three-years (2010 to 2012). This gives a ratio 39.8% for the efficiency activities and 46.3% for the heat activities. In order to calculate a figure for GVA we use the installed costs of the different technologies, indicated earlier in the paper, as a proxy for turnover.

4 Results

In this section, we summarise the results of modelling the potential for energy efficiency improvements within UK residential buildings in the period to 2035. First, we show the level

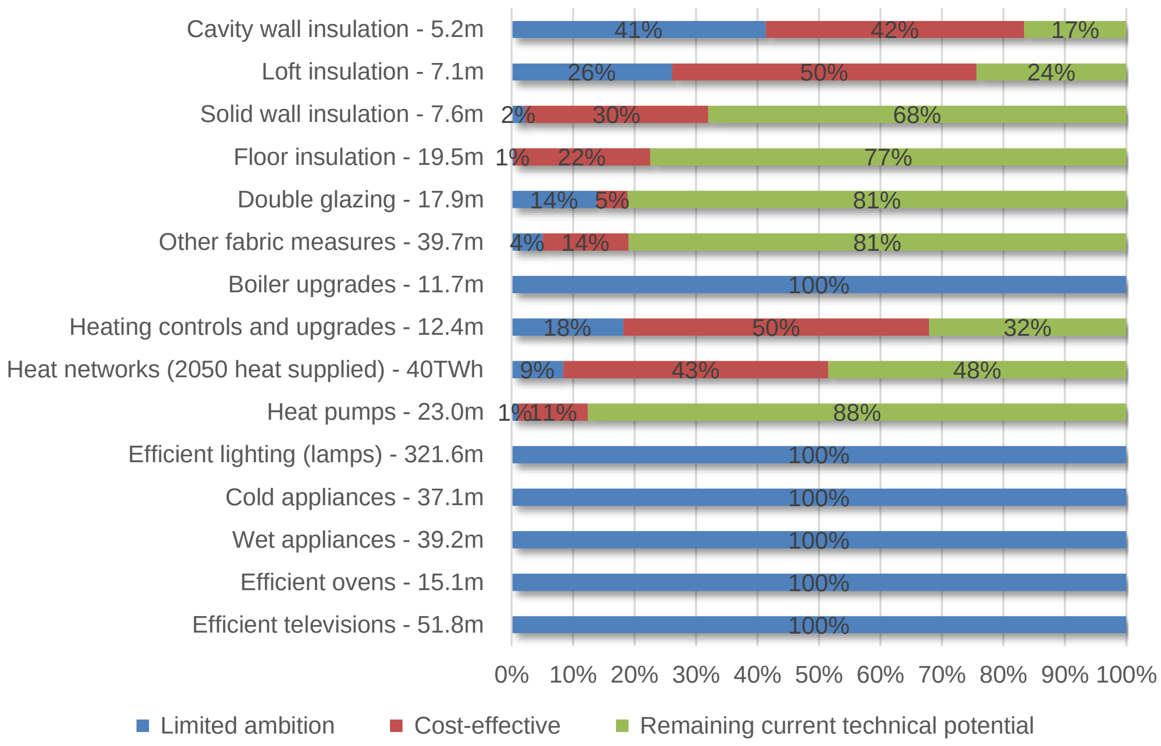
[5] Whereby GDP is the sum of all GVA from industries, plus taxes on products and imports, less subsidies on products not allocated to industries.

of deployment of each technology within each of our scenarios and the associated energy savings. Second, we model a plausible pathway over time for delivering all cost-effective energy savings in the period to 2035. Third, we calculate the costs and benefits of this scenario, including both ‘narrow’ and ‘wide’ benefits.

4.1 Potential for individual measures

Figure 1 illustrates our estimates of the potential scale of installations of 15 different measures within the present housing stock by 2035. Figure 1 also indicates the estimated fraction of the technical potential that could be delivered under the ‘limited ambition’ and ‘cost-effective’ scenarios, together with the fraction that would remain unexploited. The figure illustrates that the cost-effective scenario exhausts most of the modelled technical potential for cavity loft insulation and boiler upgrades, and all of the potential for efficient lighting and appliances. However, only one third of the technical potential for solid wall insulation is achieved (2.4 million dwellings out of a total of 7.6 million with solid walls), and only 12% of the potential for heat pumps (2.7 million dwellings).

Figure 1: Proportion of the technical potential in the existing housing stock that is achieved by 2035 in the 'limited ambition' and 'cost-effective' scenarios



Note: Diagram indicates the relevant number of measures, as defined in Table 1

4.2 Energy savings in existing building stock

Figures 2 and 3 illustrate the resulting estimate for the potential reduction in household energy consumption by 2035 for each of our scenarios. These estimates refer solely to energy use in existing buildings and are expressed as a percentage of energy consumption in 2015. The modelling suggests that energy savings equivalent to more than half of current household energy consumption could be achieved through a combination of energy efficiency improvements, heat pumps and the development of heat networks. This represents the technical potential for existing buildings with currently available technology.

Using UK government criteria for investment appraisal and taking into account broader social benefits, we estimate that half of this investment would be cost-effective in the period to 2035 (the 'cost-effective' scenario), and would lead to a 25% reduction in energy consumption. At current energy prices (Ofgem 2017), this equates to energy cost savings of approximately £270 per household per year – split between a 36% saving on heating fuels and a 15% electricity saving. In contrast, if cost effectiveness is evaluated solely on the basis of energy savings to households (the 'limited ambition' scenario), a 12% reduction in energy consumption could be achieved. Hence, taking a broader view of the costs and benefits of energy efficiency investments leads to a doubling of the estimated cost effective potential - with the majority of this additional potential deriving from the value placed on carbon emissions (see below). Notably, most low carbon heating investments only appear cost effective over this time period when these broader benefits are taken into account.

The measures offering the greatest technical potential for energy savings over this period are low carbon heating systems, building fabric improvements and upgrades to condensing boilers (Figure 3). These contribute reductions in energy consumption of 28%, 15% and 7% respectively compared to the 2015 baseline. But while boiler upgrades are fully exploited in all scenarios by 2035, the limited ambition scenario includes only 4% of the potential from low carbon heating and 13% of the potential from building fabric improvements - since both of these are relatively expensive measures. Including the wider benefits of energy savings (the cost-effective scenario), increases these figures to 25% and 40% respectively.

Figure 2: Estimated potential for energy savings in existing residential buildings by 2035 (percentage of energy consumption in 2015)

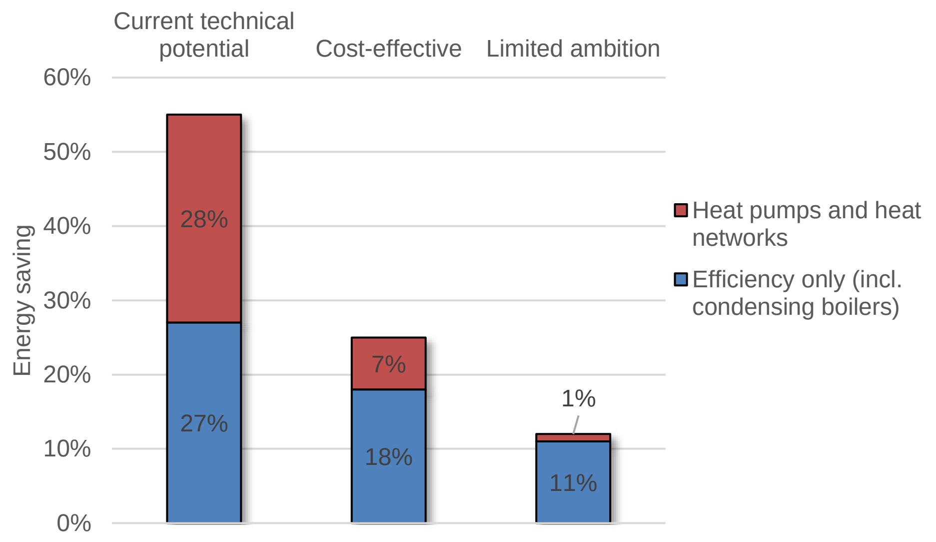
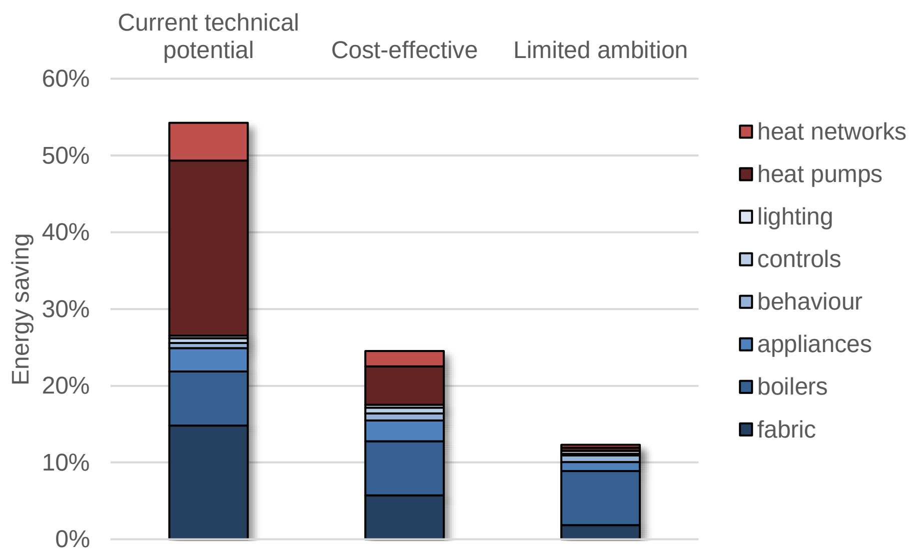


Figure 3 Estimated potential for energy savings in existing residential buildings by 2035, broken down by type of measure (percentage of energy consumption in 2015)



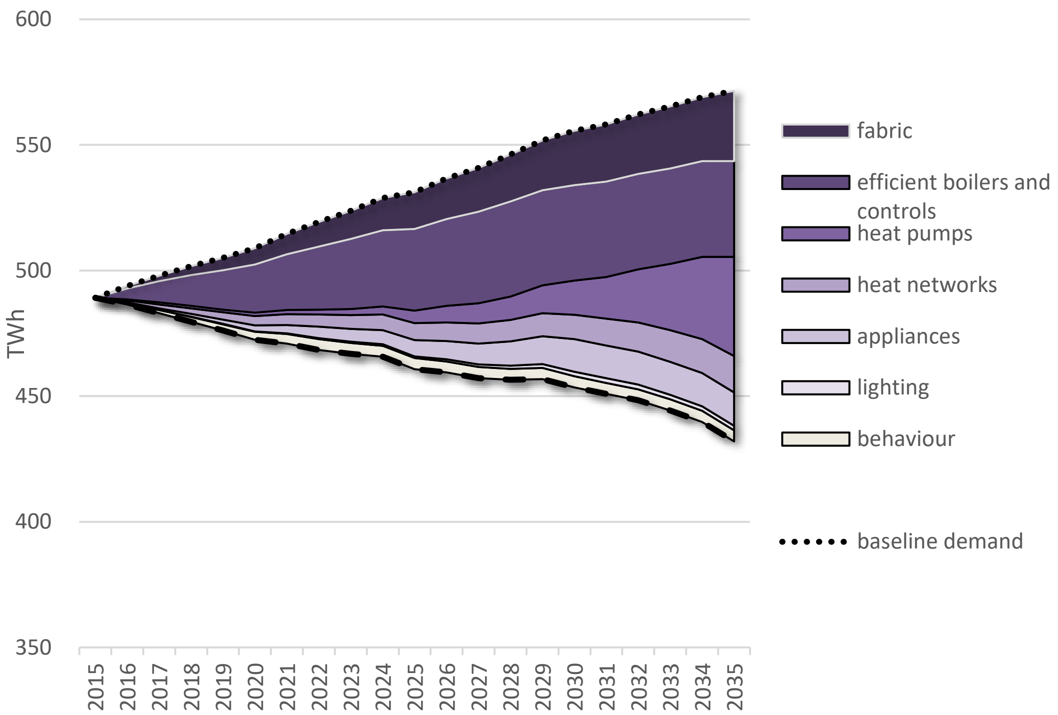
4.3 Energy savings in the future housing stock

The energy savings of the 'cost-effective' scenario can be achieved in a more or less linear fashion over time, although supply chain constraints will mean that initially the roll-out rate will be at lower levels. If progress stalls in earlier years, however, it may be difficult to recover this potential in later years.

Figure 4 compares the estimated energy consumption in the ‘baseline’ and ‘cost-effective’ scenarios, and illustrates the contribution of seven categories of measure to the total energy savings. In this figure, energy savings are measured relative to the baseline scenario rather than to 2015, and therefore include savings in both existing and new buildings. The figure indicates that around 47% of the total savings by 2035 are achieved through building fabric improvements, boiler replacements and upgrades of heating controls within existing homes. A further 36% is achieved through heat pumps (half of which are in newly built homes) and heat networks (with nearly all savings in existing homes). Energy efficient appliances and lighting provide 11% of the total savings and behavioural measures in existing buildings the remaining 6%. Thus, around two thirds of the energy savings can be achieved by ‘traditional’ energy efficiency measures. However, to achieve deeper reductions in both energy consumption and carbon emissions, it is necessary to invest in new heating technologies such as heat pumps and heat networks.

In total, the analysis suggests that household energy consumption in 2035 can be cost-effectively reduced by around 140 TWh per year (Figure 4), which is equivalent to ~28% of consumption in 2015. Put another way, these energy savings are equivalent to the annual output of six nuclear power stations the size of Hinkley Point C (CCC 2016c) - although they represent savings in both fuel (124 TWh, a 36% saving) and electricity (16 TWh, a 15% saving).

Figure 4: Total household energy demand in the baseline and 'cost-effective' scenarios (includes new build from 2015)

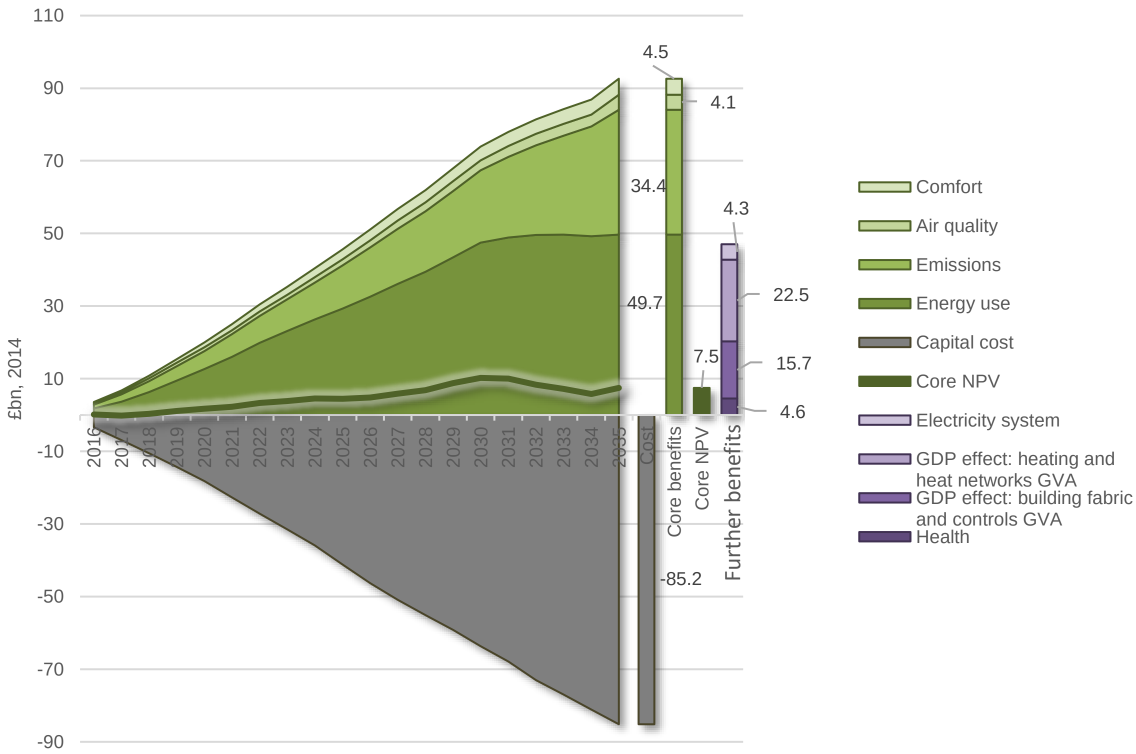


From a policy perspective, it is also important to understand the costs and benefits of this scenario. These are explored in the next section.

4.4 Costs and benefits over time

The estimated costs and benefits associated with the cost-effective scenario are shown in green in Figure 4. Taken together, we estimate the net present value (discounted benefits minus discounted costs) of this scenario to be approximately £7.5 billion. Energy cost savings account for 54% of the benefits in this scenario, with the broader, social benefits accounting for the remainder. Hence, the value placed upon those external benefits can have a significant influence on assessed cost-effectiveness. Greenhouse gas savings account for 37% of the total benefits, while air quality and comfort improvements together account for less than 10%. Hence, the NPV will be sensitive to the assumptions made for the variable cost of energy and the value of GHG emissions, together with the capital cost of the relevant investments.

Figure 3: Cumulative present values of investment in the housing stock in the 'cost-effective' scenario



Sources: own calculations based on IAG (2015)

The 'wider' benefits of this scenario are shown in purple. These are less certain and are not necessarily additional because of uncertainties around alternative uses of the funds and the associated GDP effects. Their net value depends on the composition of other investments in the economy. These benefits are dominated by the (partially assessed) impact of the energy efficiency investments on GDP, which account for 81% of the total.

5 Discussion

Current UK policy is geared towards delivering the 'limited ambition' scenario by 2035, but much of this delivery is uncertain and at risk. In terms of the UK's carbon emissions targets, achieving the 'cost-effective' scenario is consistent with meeting the 5th Carbon Budget as well as staying on track to the deeper emissions cuts necessary by 2050, but will require a large increase in the pace of delivery.

The different scenarios deliver significant reductions in carbon emissions from domestic buildings and contribute to the Climate Change Committees carbon budgets. The associated reductions in direct emissions (excluding electricity) by 2030 compared to 2015 are 10% for the limited ambition scenario, 16% for the cost-effective scenario and 75% for the technical potential scenario. Last year's progress report by the Climate Change Committee wants to see a 20% fall in emissions from buildings (including non-residential) by 2030 compared to 2016 to stay on their cost-effective path to 2050. This means that energy efficiency could deliver a significant share of the required reductions in carbon emissions.

For 2050, going further and capturing most of the technical potential will also be necessary. We anticipate that much of this will be more cost-effective than reducing emissions in electricity supply, industry and transport. Also, a combination of rising energy prices and technological improvements will push the envelope of what is cost-effective in the future.

However, it is clear that the scale of the task is immense. Millions of properties will need to receive measures and this requires developing a supply chain that can deliver at scale and to high quality. For example, the rate of installation of heat pumps will need to increase from around 20,000 per year at present to over one million per year in the 2030s (CCC, 2018). It is also important to treat energy efficiency opportunities in a similar manner to low carbon energy supply. The simplistic assumption that deployment can be left to 'the market' because householders benefit from the energy savings is incorrect. Energy efficiency delivers significant social benefits ('positive externalities') that are not captured by individual households. Hence, even in a well-functioning market, investment in energy efficiency will be less than socially optimal unless these externalities can be reflected through public policy. Figure 2 also shows that the technical potential is significantly larger than the current cost-effective potential. But experience with mass market, low carbon technologies (most obviously solar photovoltaics) shows that increased deployment leads to falling costs and improving performance which makes such technologies increasingly cost-effective. Again, these ‘learning economies’ have wider social benefits that are not captured by individual investors. Policy support for deployment can therefore be justified and will bring the cost-effective potential closer to the technical potential. In short, the main rationales for policy support for low carbon energy supply are equally relevant to energy efficiency, but are given insufficient weight in current UK Government policy.

In its 2017 Clean Growth Strategy (BEIS, 2017a), the UK government set out a range of policies, proposals and intentions to reduce UK carbon emissions and to build a greener economy. But many of these proposals are lacking in either detail or ambition, and at the time of writing the ‘firm’ policies that have been announced are insufficient to deliver on the fourth and fifth carbon budgets (CCC, 2018). For households, the Strategy set out an aspiration to upgrade as many homes as possible to Energy Performance Certificate (EPC) Grade C by 2035, provided this is “practical, cost-effective and affordable" (BEIS, 2017). With 19 million homes (70%) currently below this standard, achieving this aspiration would go a long way towards delivering the energy savings identified above, together with the associated private and social benefits. But much hinges upon how the ‘cost effective and affordable’ caveat is interpreted – and in particular, whether the broader social benefits of energy efficiency investments are recognized. For example, the government is currently consulting on energy efficiency standards for the private rental sector (BEIS, 2017b), but the proposals include a £2500 cap on the costs incurred by landlords. This would greatly restrict the level of investment and hence the amount of energy savings achieved, as well as failing to remove many tenants from fuel poverty (ACE, 2017). If similar restrictions are placed upon other policy initiatives, the UK will run the risk of either missing its 4^{th} and 5^{th} Carbon Budgets or relying upon traded or banked carbon credits to comply - which in turn would make it much harder to deliver deeper emission reductions in the future.

This paper has deliberately not attempted to develop policies for delivering on the potential we identified. An interesting and important questions is how energy efficiency at scale can and should be funded, how much will be public and how much private investment, and whether public investments should be funded through energy bills (for example and Energy Efficiency Obligation) or general taxation (for example a loan or grant programme). A recent working paper by the UK Energy Research Centre looks at some of those questions in more detail (Barrett et al. 2018).

6 Conclusions and policy recommendations

It is clear that there remains large untapped potential for energy efficiency improvements within UK housing. Using the best available evidence, our analysis demonstrates that:

- one quarter of the energy currently used in UK housing could be cost-effectively saved by 2035;
- allowing for falling equipment costs and including the wider, social benefits of energy efficiency improvements, it should be possible to cost-effectively reduce energy demand in UK homes further. Technically, energy demand of UK homes could be halved. With innovation in technology and delivery, appropriately supported by public policy, it is likely that more ambitious reductions can be achieved.

The evidence shows that the benefits of improved energy efficiency in UK homes are considerable and justify significant investment from both the public and private sectors. In addition to energy savings, upgrading homes delivers a wide range of persistent benefits to the economy and society, such as improved health, better comfort, increased productivity, more skilled employment and reduced investment in electricity networks – all of which are hallmarks of a modern, low carbon infrastructure. These in turn can contribute to broader policy objectives, such as relieving pressure on the NHS, supporting households struggling to make ends meet, delivering more cohesive communities and reducing fuel poverty. These benefits reduce the cost of the transition to a low carbon economy. More so than carbon abatement in other sectors, the benefits from investing in homes accrue directly to people everywhere in the UK.

To leverage the necessary private investment for these benefits to be captured, there needs to be significant policy change and public investment. The ambitions set out in the Clean Growth Strategy need to be backed up with strong policies in a range of areas, including: an effective energy efficiency programme for the 'able to pay' sector; more ambitious standards for private rented buildings; regulations that ensure new buildings meet high standards of energy efficiency and are suitable for low carbon heating; and greater support for the deployment of heat pumps, particularly in dwellings that do not have access to natural gas. To achieve the necessary cross-departmental focus, UKERC (2017) has proposed an Energy Efficiency White Paper that, amongst other things, would review the relevant cost benefit, tax and accounting frameworks, establish a dedicated heat regulator, set out the contribution of energy efficiency to achieving climate targets and propose a policy mix that will deliver this deployment. The proposed National Infrastructure Assessment plan for 2018 also provides an opportunity to ensure that energy efficiency and low carbon heat are central to future plans for UK infrastructure.

The best available evidence shows that upgrading the UK's existing buildings can provide substantial energy savings while delivering large benefits to society. It should therefore be a central component of the low carbon energy transition.

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