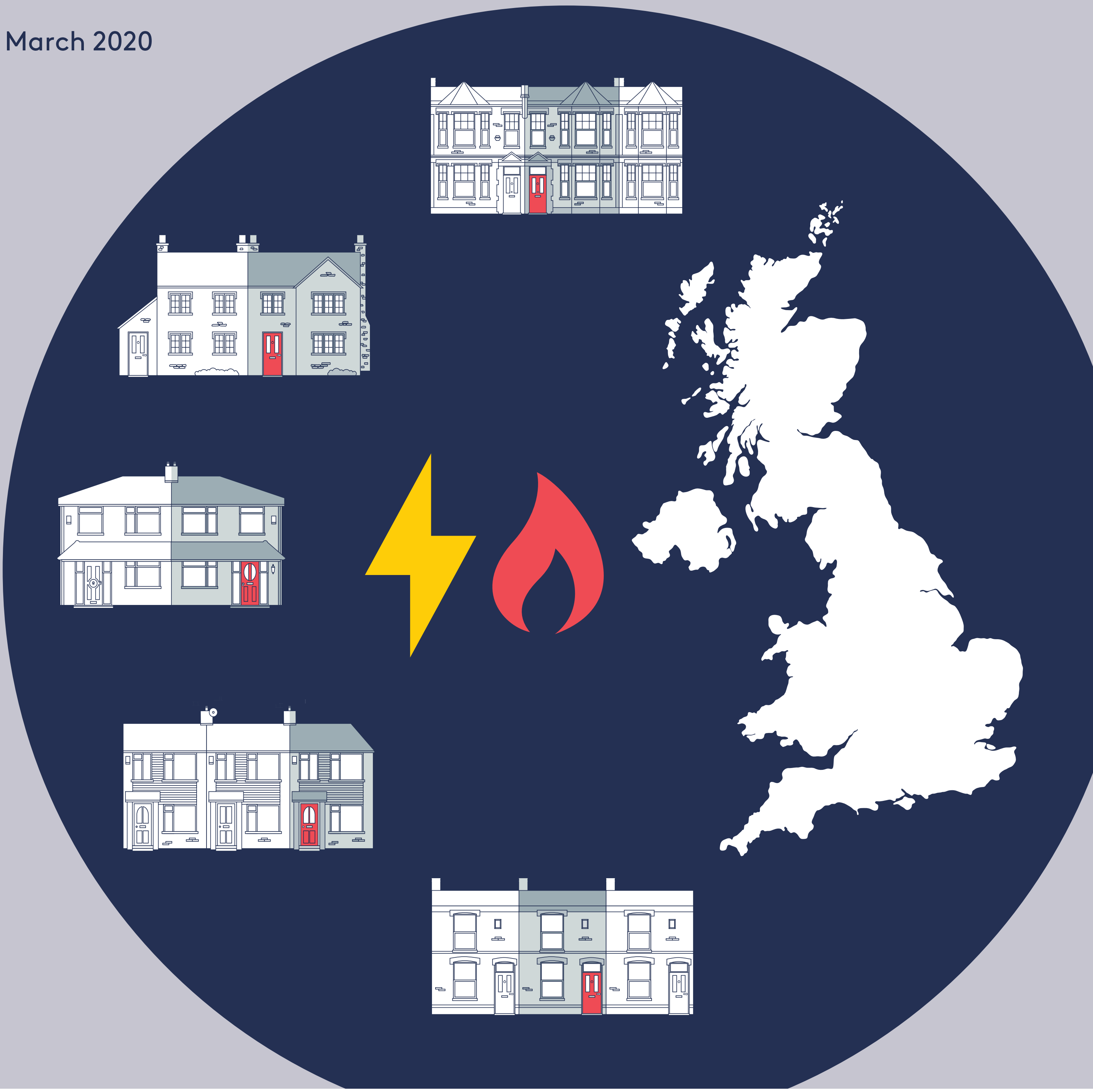
Distributional impacts of a carbon tax in the UK

Report 1: Analysis by household type

March 2020



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About this report

This report has been written to inform the Zero Carbon Commission and the Zero Carbon campaign.
See www.zeroc.org.uk

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Declaration of conflict of interest

All of the authors declare financial support from Zero Carbon for the submitted work and Sam Fankhauser is a member of the Zero Carbon Commission. Josh Burke and Sam Fankhauser declare financial support from the Grantham Foundation and the ESRC through the Centre for Climate Change Economics and Policy for the submitted work; Alex Kazaglis, Louise Kessler, Naina Khandelwal, Julia Bolk and Peter O'Boyle declare financial support from Vivid Economics for the submitted work. The authors declare no other relationships or activities that could appear to have influenced the submitted work. All of the views expressed in this work are those of the authors and are independent of the funding institutions.

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This report is intended to inform decision-makers in the public, private and third sectors. It has been reviewed by internal and external referees before publication.

Contents

Executive summary

Main messages

- Carbon pricing is essential for effective climate action. It is a powerful fiscal and environmental tool that encourages emissions abatement where it is cheapest and sends a clear price signal that the polluter must pay.
- The UK's transition to net-zero greenhouse gas emissions must be distributionally fair, and policies must be designed to mitigate undesirable distributional impacts.
- The current economic framework for decarbonisation in the UK is inefficient and uneven. A broader-based carbon tax consistent with net-zero greenhouse gas emissions would be desirable.
- Without mitigation measures, a carbon tax on energy fuels is regressive, hitting low-income households disproportionately.
- Judicious use of carbon tax revenues – where economic 'losers' are compensated – can help ensure distributional fairness and protection for fuel-poor households.
- It is therefore possible to design a recycling scheme that leaves fuel-poor households better off while driving the transition to net-zero emissions in the UK by 2050.

High-level recommendations

- The carbon tax level needs to be raised. A carbon tax consistent with net-zero emissions by 2050 would start at £50 per tonne of carbon dioxide.
- Conventional fiscal thinking that sees all revenue treated as general tax must change to ensure that the impacts of carbon pricing are distributed fairly and that the policy becomes more politically and socially acceptable. Carbon tax revenues should be explicitly used to correct undesirable distributional outcomes.
- Interventions focused on improving energy efficiency can make a substantial difference to the distributional impact of carbon pricing. For example, we show that using 33 per cent of revenues for energy efficiency can ensure fuel-poor households are not adversely affected by carbon taxation.
- Compensatory policies should at least in part pre-empt and cover any increases in energy bills arising from the carbon tax. This is necessary to avoid any transitionary periods where high carbon taxes increase energy bills before energy efficiency improvements are implemented.
- When assessing the impact of carbon taxation, government must also consider 'horizontal' effects – the distributive effects between households with similar incomes – which hitherto have been largely neglected. Assessing these effects will ensure that carbon pricing can be designed to prevent a rise in fuel poverty where there is within-income-decile variation in expenditure on energy.

Now is an opportune time for the UK to reconsider how it prices carbon, in a way that ensures distributional fairness

The UK Government has committed to reducing greenhouse gas emissions to net-zero by 2050 and is also facing the implications of leaving the European Union. This confluence presents an opportunity to reconsider options for pricing carbon, a policy that is shown to reduce emissions.

Carbon pricing encourages emissions abatement where it is cheapest and sends a clear price signal that the polluter must pay. The latter is particularly important as it is poor people and communities that are most vulnerable to the societal and economic impacts of climate change and pricing carbon is a way of ensuring that the costs are not borne entirely by those who are affected rather than those who are causing the impacts through greenhouse gas emissions.

However, carbon pricing is often hard to implement as it is more transparent than other policies about its economic winners and losers. Therefore in its design of a carbon tax the UK must carefully consider how costs and benefits are distributed across society, to achieve both immediate political feasibility and the durability of carbon policy over time. With the new net-zero target there is an important opportunity to scrutinise conventional fiscal thinking – especially that all revenue is treated as general tax – to ensure distributional fairness.

Defining what is 'equitable' is a political judgment. *Fuel poverty* is one benchmark. Through this lens, an equitable policy would see energy price rises for fuel-poor households offset by compensatory measures. This would help to alleviate the 'regressive' nature of carbon tax policies whereby the impacts often fall disproportionately on poorer households.

The UK's existing approach to pricing carbon has stalled decarbonisation across a number of sectors, including housing

Currently, different sectors experience different carbon prices, some explicit and some implicit and, in some cases, overlapping policy instruments. A lack of harmonisation of effective pricing across the economy has likely resulted in abatement inefficiency.

Decarbonisation of residential buildings is proving especially slow. As the majority of homes in the UK are heated by natural gas, it is particularly important that the carbon content of this fuel is appropriately priced. At the moment gas is artificially cheap for sound social reasons and political expediency, being subject to a reduced rate of VAT.

'Horizontal inequities' have largely been overlooked in carbon tax design

The ways in which households that are similar in income otherwise differ can be described as 'horizontal inequities' – they include number of occupants, location type and building characteristics. Evidence shows that horizontal inequities in relation to carbon tax impacts have a particularly strong effect when considering differences in geographical location. For example, a carbon tax is most regressive for households in low-density rural and isolated locations, when applied to housing and to transport.

Government must assess these horizontal effects, which hitherto have been largely neglected, to ensure that carbon pricing can be designed to prevent a rise in fuel poverty.

Our modelling for different UK households shows the effect of a carbon tax to be minimal after financial compensation is received, net of insulation costs

Any carbon tax must be designed such that regressive effects are limited. The most common ways to redistribute carbon tax revenues back to targeted low-income and/or fuel-poor households are through direct financial compensation for households and by providing a stimulus for energy efficiency improvements.

We tested whether there is a recycling scheme that leaves fuel-poor households better off while driving the transition to net-zero emissions by 2050.

We modelled the effect of a carbon tax of £50 per tonne of carbon dioxide in 2020, rising to £75 in 2030,[1] on five different types of household, from 2020–30. The household 'archetypes' were selected to represent a variety along two dimensions that are particularly important for carbon tax impacts: heating fuel and income level. We also integrated energy efficiency support into the model, to examine how revenue recycling options impact these different household types.

1. These tax rates were proposed by the Grantham Research Institute in an earlier report, *How to price carbon to reach net-zero emissions in the UK* (May 2019).

The five household archetypes are:

1. Household with electricity and gas (dual-fuel); annual income £57,000
2. Household with electricity only; annual income £29,000
3. Household with off-gas-grid oil for heating that switches to a heat pump, and electricity; annual income £11,000 and fuel-poor
4. Household with electricity and gas (dual-fuel); annual income £9,000
5. Household with electricity and gas (dual-fuel), with large energy expenditure; annual income £26,000 and fuel-poor.

Our modelling sees the carbon tax levied on domestic gas, electricity and oil, and the impact on energy bills assessed in a) 2020, without energy efficiency support or direct financial compensation, and in b) 2030, with energy efficiency support or direct financial compensation or both.

Key findings on policy design

- Our results show that rising energy costs, rather than the carbon tax, are generally the largest driver of bill increases. While energy bills increase by 2–7 per cent for fuel-poor homes and by 10–12 per cent for non-fuel-poor households between 2020 and 2030, the carbon tax accounts for 0–7 percentage points of the increase for all five household types after compensation.
- Households' annual energy bills increase by differing amounts according to the type of fuel used for space and water heating. For example, the carbon tax impact is greatest for dual fuel bills, while for households that use electricity for space and water heating, the impact of the carbon tax is much smaller.
- The net impact of the carbon tax policy is limited for most households after they receive direct financial compensation and/or energy efficiency support.
- Fuel-poor households – in our case studies, off-gas-grid households and low-income, high energy expenditure households – experience minimal increase in their energy bills, as they are targeted for heat pump installation and compensation for solid wall insulation, respectively, by the policy.
- Households that install solid wall insulation require greater compensation due to the high upfront costs of installation but these costs are more than offset by the incurred energy savings.
- The adoption of energy efficiency improvements and low-carbon heating (along with electricity sector decarbonisation) decreases residential gas emissions by 9 per cent and residential electricity emissions by 43 per cent between 2020 and 2030.

See Figure 1 on p6 for a visual summary of our results.

Conclusions: Carbon pricing in the energy sector will cut emissions effectively in the UK while generating significant revenue from 2021–30, providing finance to fund the transition and to ensure it is equitable

The anticipated revenue raised by implementing these policy changes will depend on households' behavioral responses to higher prices. If households do not change the quantity of energy they consume, we estimate that this policy package will raise significant revenue. The UK carbon tax on domestic gas and electricity would generate revenue projected to be £57 billion over the period 2021–30.[2] We have demonstrated that recycling the revenue to pay for energy efficiency can mitigate any bill increases arising specifically from the carbon tax.

Of the £57 billion, £27.1 billion (47 per cent) is needed to compensate all households. This can be split between fuel-poor households, which accounts for £18.8 billion. In this scenario the net impact of the carbon tax is zero. £8.2 billion is then allocated to non-fuel-poor households and used to provide

2. This revenue is collected from all gas- and electricity-fuelled households in the UK. Including other fuels, this revenue would be much higher.

financing for energy efficiency measures that have a long payback such as solid wall insulation and heat pump installation. The net impact on non-fuel-poor households would amount to £216 per household per year on average.

Our modelling clearly demonstrates that using the revenues for energy efficiency support can be a powerful means to offset some of the regressive social impacts of carbon taxes in the UK, particularly for fuel-poor homes.

Once tax revenues have been used to compensate households, £29.9 billion is left over. This leaves significant fiscal headroom to increase public acceptability of carbon pricing through appropriate redistribution of the revenues, either to industry where genuine competitiveness concerns exist, to help fund research into, and the development of, new low-carbon technologies, to further reduce energy bills for non-fuel-poor homes or to pre-empt increases in energy bills arising from the carbon tax before energy efficiency improvements are implemented. The appropriate balance will depend on the political context.[3]

Our study also recognises that the salience of carbon pricing varies from sector to sector and therefore must be supported by complementary policies. The appropriate balance between regulation, taxes and subsidies will need careful thought.

Contribution to the debate

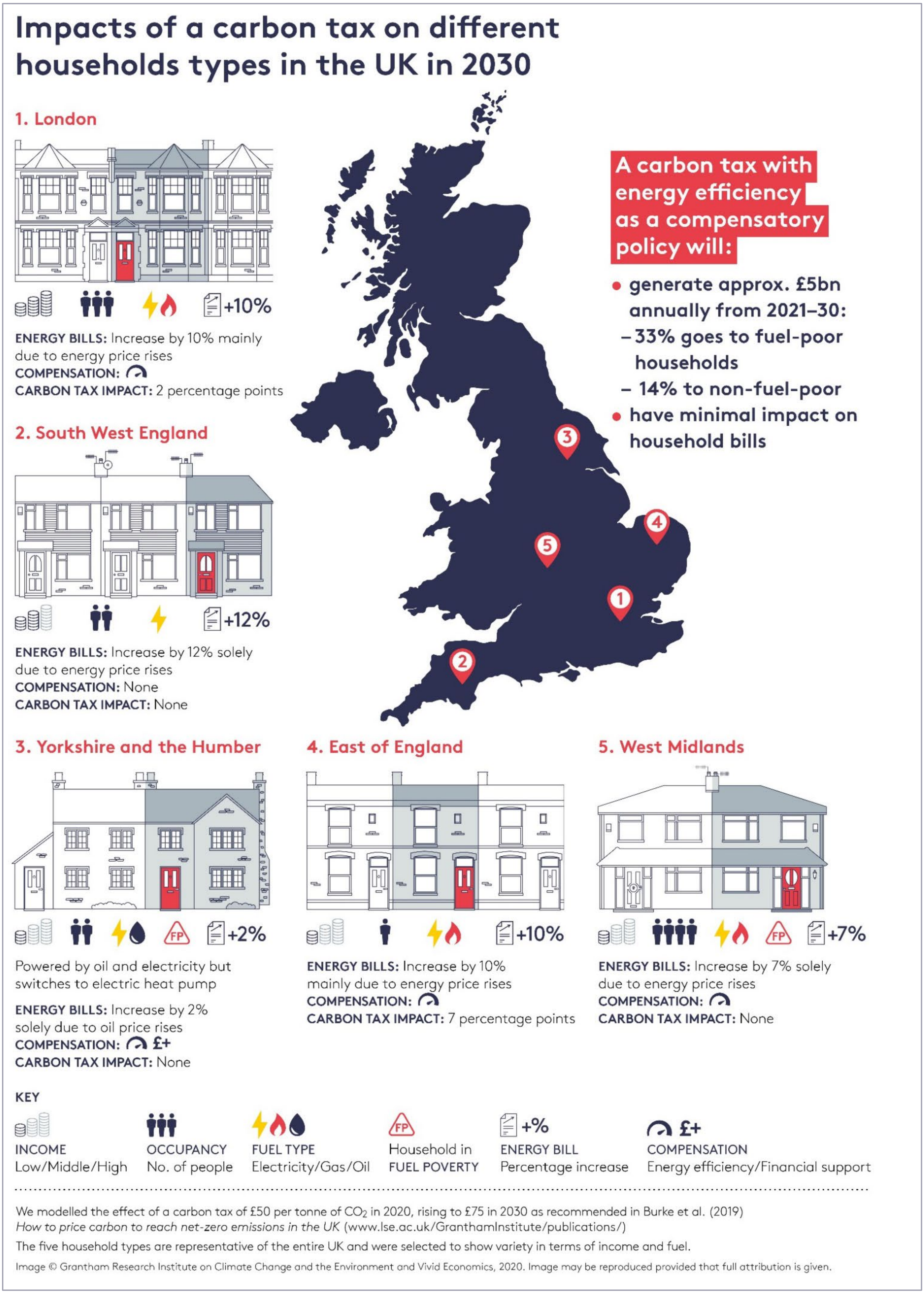
It is important to recognise some limitations to our approach. We do not have data on price elasticities of energy across the distribution of expenditure, which are important when trying to understand the distributional effect of the carbon price policy we outline. That said, it is likely that elasticities are lower in fuel-poor homes and therefore we are more likely to accurately capture costs for these households. However, this limitation may result in an overstatement of the costs of the policy for wealthier, non-fuel-poor households. This approach does also introduce some inconsistency in our analysis, since in our compensatory package we use the revenue after we account for the modelled reduction in energy demand for the implementation of energy efficiency measures.

This report aims to inform the debate about how to design carbon taxes to increase public acceptability. The numbers presented are helpful to provide a snapshot of the effect on consumers today and in 2030. The numbers are a static representation of cost and revenue and must be revised over time, to reflect the dynamic nature of economies and allowing for behaviour change, technological and process innovation.

We use simple and transparent assumptions, which show that the impacts on bills and revenues raised are not trivial and therefore warrant further analysis to fully understand the impacts and substitution effects of different carbon prices imposed on households.

3. Our companion report, *Distributional impacts of a carbon tax in the UK: Report 2 – Analysis by income decile,* looks further at how end users can be compensated through a carbon dividend.

Figure 1. Summary of case study findings



1. Introduction

The challenge of net-zero emissions

In June 2019 the UK government set itself an unprecedented challenge in legislating to reach net-zero greenhouse gas emissions by 2050. The UK was the first major economy to set a target of this magnitude and ambition, although several countries have since followed suit. The UK now faces the task of reaching that goal in reality. At the same time, the UK, having left the European Union on 31 January, must revisit EU-level climate policies such as the EU emissions trading system (EU ETS).

The confluence of the new net-zero target and Brexit presents an opportunity for the UK to reconsider its options for pricing carbon, with the possibility of widening the coverage, strengthening the price signal and incorporating lessons from successful pricing schemes around the world (Burke et al., 2019).

Under a net-zero target, a more emphatic use of carbon pricing is necessary to induce emissions reductions in an efficient way. Carbon pricing is a powerful fiscal and environmental policy tool (Vogt-Schilb et al., 2019) that encourages abatement where it is cheapest and sends a clear price signal that the polluter must pay. However, carbon pricing is often hard to implement as it is more transparent than other policies about its economic winners and losers. Thus, carbon prices are often too low to be truly effective, many sectors are not covered, and in those that are, significant exemptions dilute policy efficacy.

Designing an efficient and effective carbon tax policy for a net-zero world therefore requires careful consideration of how costs and benefits are distributed across society in order to achieve both immediate political feasibility and the durability of carbon policy options over time (Jenkins, 2019). The failure to do this is one of the reasons why governments around the world frequently fall short in their efforts to put an adequate price on carbon.

Underpinning carbon pricing with equity and fairness

The UK is beginning to experience the societal and economic impacts of climate change. Heavier rainfall is leading to the higher likelihood of surface water and river flooding, and heatwaves are becoming more frequent. Poor people and communities are most vulnerable to these impacts; it is widely recognised that it is unfair for the costs of climate change to be borne entirely by those who are affected by the impacts rather than those who are causing the impacts through greenhouse gas emissions. Economists therefore advocate putting a price on emissions through a tax or emissions trading. This is consistent with the 'polluter pays' principle and ensures that low-emissions goods and services can compete on a level playing field without their high-carbon rivals enjoying the advantage of an implicit subsidy.

Equity and fairness also means giving those being taxed an opportunity to participate in the decision-making process. To do so, consumers need to fully understand the policy and have a chance to express their views. This report can contribute to this process by informing consumers about the impacts of carbon tax policy and the role of carbon taxes in achieving net-zero greenhouse gas emissions.

While carbon pricing is necessary to reach net-zero emissions, any regressive impacts on households need to be mitigated to ensure fairness and political acceptability. Her Majesty's Treasury is currently undertaking a review of how the transition to net-zero will be funded and where the costs will fall. That review presents an opportunity to ensure that UK carbon policy is underpinned by principles of equity and fairness. In addition to ensuring a just transition, doing so will help to avoid resistance and backlash from those who would otherwise lose out (Gambhir et al., 2018).

Defining what is 'equitable' is a political judgment. This report uses *fuel poverty* as the benchmark and looks at how energy price rises for fuel-poor households can be offset by complementary measures. These compensatory policies have to address both *vertical inequities* – between high- and low-income households, and *horizontal inequities* – where income levels are similar but other household characteristics differ. Judicious use of the revenues is thus of equal importance to the price level. Higher carbon taxes will generate significant revenues and it is important to assess how best to use them.

Now that the Government has committed to a net-zero target, there is an important opportunity to scrutinise conventional fiscal thinking – especially that all revenue is treated as general tax – to ensure distributional fairness, greater political acceptability and the durability of the measure. For example, tax revenues could be recycled to finance energy efficiency improvements, which reduces energy bills, or cushion the social or economic impact of the tax by lowering other taxes or offering direct financial compensation to households. Recycling revenue in these ways would provide a progressive means to achieve an accelerated and just transition to a net-zero economy.

Project objectives

The main objectives of this study are:

- **To assess the impacts** of a net-zero-consistent carbon tax on different household types in the UK.
- **To design a carbon tax scheme** that could be progressive overall, by considering alternative uses of carbon tax revenues.

This work informs two related processes:

(i) The UK public debate on carbon pricing for net-zero, including HM Treasury's review of how the transition to net-zero will be funded and where the costs will fall.

(ii) The design of the UK's post-Brexit carbon pricing regime.

The report directly informs – but is not influenced by – the Zero Carbon[4] campaign and the work of its Commission.

Approach

This project covers two main workstreams, the findings of which will be released in two separate reports.

- The first workstream is a case study analysis that models the impact of carbon taxation across different household types with compensatory policies focussing mainly on energy efficiency measures. This is the focus of the current report.
- The second workstream models the impact of a range of carbon tax scenarios (including different tax rates, border carbon adjustments and compensatory policies) on energy, food and transport bills across income deciles. Compensatory policies compare the effectiveness of carbon dividends and energy efficiency measures in ensuring equity (*Distributional impacts of a carbon tax in the UK, Report 2: Analysis by income decile* [Burke et al., 2020]).

Structure of the report

Section 2 outlines the main barriers to efficient carbon pricing in the UK. This is followed in Section 3 by a description of the scenarios, the methodology used and the results of our analysis, including a detailed assessment of the impact of a net-zero-consistent carbon tax by household archetype. Section 4 concludes and presents our high-level recommendations.

Full details of our methodology are provided in the Appendix.

4. The Zero Carbon campaign was set up by Stephen Fitzpatrick, chief executive of Ovo Energy, to campaign for the UK to introduce a 'General Carbon Charge' that would account for carbon emissions within the price of goods and return the money raised to citizens through a 'carbon dividend'. See www.zeroc.org.uk/

2. Failings of the current approach

In this section we draw on the existing literature to outline the importance of carbon pricing in emissions abatement and the barriers that need to be overcome to make the design more efficient and reduce the regressivity of its impacts.

The importance of a clear price signal

A clear carbon price signal is shown to reduce emissions. This is true of longstanding schemes in the Nordic countries and especially true of the UK power sector. A recent report from Ofgem (2019) estimates that between 2010 and 2018 in the UK carbon pricing was the single most effective electricity decarbonisation policy, reducing emissions significantly more, and at far lower cost, than alternative policies such as subsidies, air quality directives and demand-side policies. However, at present, the UK's carbon pricing is inconsistent across the economy.

A lack of harmonisation is stalling decarbonisation

Different sectors experience different effective carbon prices and – in some cases – overlapping policy instruments (Day and Sturge, 2019; Advani et al., 2013). The UK has multiple carbon prices, some explicit and some implicit. They include, but are not limited to, the EU ETS price, the Carbon Price Floor, the Climate Change Levy and Fuel Duty (Helm, 2017). For example, UK air transport faces an effective carbon price of ~£150 per tonne of CO_2, whereas rail transport pays an effective price of ~£250 per tonne of CO_2. Within these two extremes, the majority of polluting activities face negative effective carbon prices, otherwise known as *implicit subsidies* (Vivid Economics and ODI, 2019).

A lack of harmonisation of effective pricing across the economy has stalled decarbonisation across many sectors and has likely resulted in abatement cost inefficiency (Newbery et al., 2018), as conventional economic theory suggests a single carbon price for all uses at all places and times (Stiglitz, 2019). Indeed, sectors that have been faced with uneven, small or no fiscal penalty – and that are large sources of pollution – have had little incentive to abate. This is true of sectors such as agriculture, air transport and, importantly, residential gas.

The low price of domestic gas comes at an environmental cost

Progress in reducing emissions from residential buildings has stalled for many reasons, but an insufficient and uneven carbon price that has failed to encourage zero-carbon solutions is an important factor. As the majority of homes in the UK are heated by natural gas, it is particularly important that the carbon content of this fuel is appropriately priced. At the moment it is instead artificially cheap (Oxford Energy, 2016) because it is subject to a reduced rate of VAT – 5 per cent instead of 20 per cent. The price therefore does not internalise or reflect the carbon content of the fuel.

Although there is a clear economic and environmental rationale for internalising the cost of carbon within gas, the failure to do so is a choice borne out of sound social reasons and political necessity – raising fuel costs can disproportionately affect those least likely to be able to absorb additional financial burdens. Because of these undesirable redistributive effects and the political barriers that ensue, it can be sensible to consider the importance of 'second best' solutions and implement differential pricing to maximise public acceptability and political feasibility (Burke et al., 2019b).

Regressivity of carbon taxes

Impacts on poorer households

The impacts of carbon tax policies often fall disproportionately on poorer households and are thus described as 'regressive'. Studies have shown this to be true for the UK (Dresner and Ekins, 2006; Callan et al., 2009; Feng et al., 2010; Gough et al., 2011). There are three reasons for this:

- Firstly, while wealthier households produce more carbon emissions in absolute terms (due to greater overall consumption), carbon-intensive spending as a share of income is significantly higher for poorer households (Gough et al., 2011).

- Secondly, as carbon pricing increases the costs of carbon-intensive commodities, firms tend to pass these costs through to consumers via higher prices. Lower income households may have limited ability to offset higher energy costs through substituting poorly insulated homes or low-energy-efficient products for superior alternatives (Berry, 2019).
- Thirdly, although higher prices – stemming from the carbon tax – should in theory reduce consumption, more expensive energy may mean that households respond by depriving themselves of energy services.[5] Reduced purchasing power combined with low income and high bills may prevent households from meeting their energy needs. Households that experience this can be defined as 'fuel-poor' (Hills, 2012).

Differences in impact between households of similar income

The ways in which households with similar incomes otherwise differ can be described as 'horizontal effects'. These differences include composition, tenure and location, and they can determine the extent to which households are affected by carbon taxes and if they are classified as fuel-poor.

While these issues have not always be considered in relation to carbon taxes, they have recently garnered more attention. The Hills Review of fuel poverty, for example, recommends that the size and composition of a household should be considered when determining what constitutes reasonable costs for keeping a home warm and by extension, if a household is fuel-poor. This is because a large household may have to spend more than a small household on consumer items in order to achieve an equivalent standard of living. It should also be recognised that a smaller amount of additional income is required to support an additional child than an additional adult (Hills, 2012). Further, there is evidence that distributive effects of carbon taxes within income groups could be larger in magnitude than across groups of different income (Douenne, 2018). The existence of horizontal effects means that there will be adverse impacts on some households from revenue recycling policy instruments that target household groups based on income alone.

Horizontal effects related to differences in geographical location are particularly strong. For example, a carbon tax is most regressive for low-density rural and isolated households, when applied to both housing and transport. Compared with urban and suburban inhabitants, rural residents have a relatively high demand for transport but less access to public transport, and they devote a larger proportion of their income to paying the carbon tax for private transport because of inadequate alternatives and greater distances between destinations (Berry, 2019). Rural households also pay a higher share of their income on carbon taxes than urban and suburban households due to their comparatively high demand for heating and electricity. This is because rural houses tend to be bigger and more exposed and so require more heating (Feng et al., 2010). Moreover, because income levels are lower on average in rural areas, the proportion rural inhabitants spend overall across transport and energy as a percentage of income is far greater compared with urban and suburban residents.

Addressing the regressivity of carbon taxes through revenue recycling

Revenue recycling can help to reduce the potentially regressive effects of carbon pricing by redistributing carbon revenues back to targeted low-income and/or fuel-poor households. There are several revenue recycling options in operation within the 28 jurisdictions that currently have a carbon tax, each with its own advantages and disadvantages. The two most common options are direct financial compensation for households and providing a stimulus for energy efficiency improvements in households (see Figure 2.1). In this report we focus on energy efficiency improvements as an effective way to alleviate fuel poverty concerns. The companion report looks at the advantages and disadvantages of wider revenue recycling options (see Burke et al., 2020).

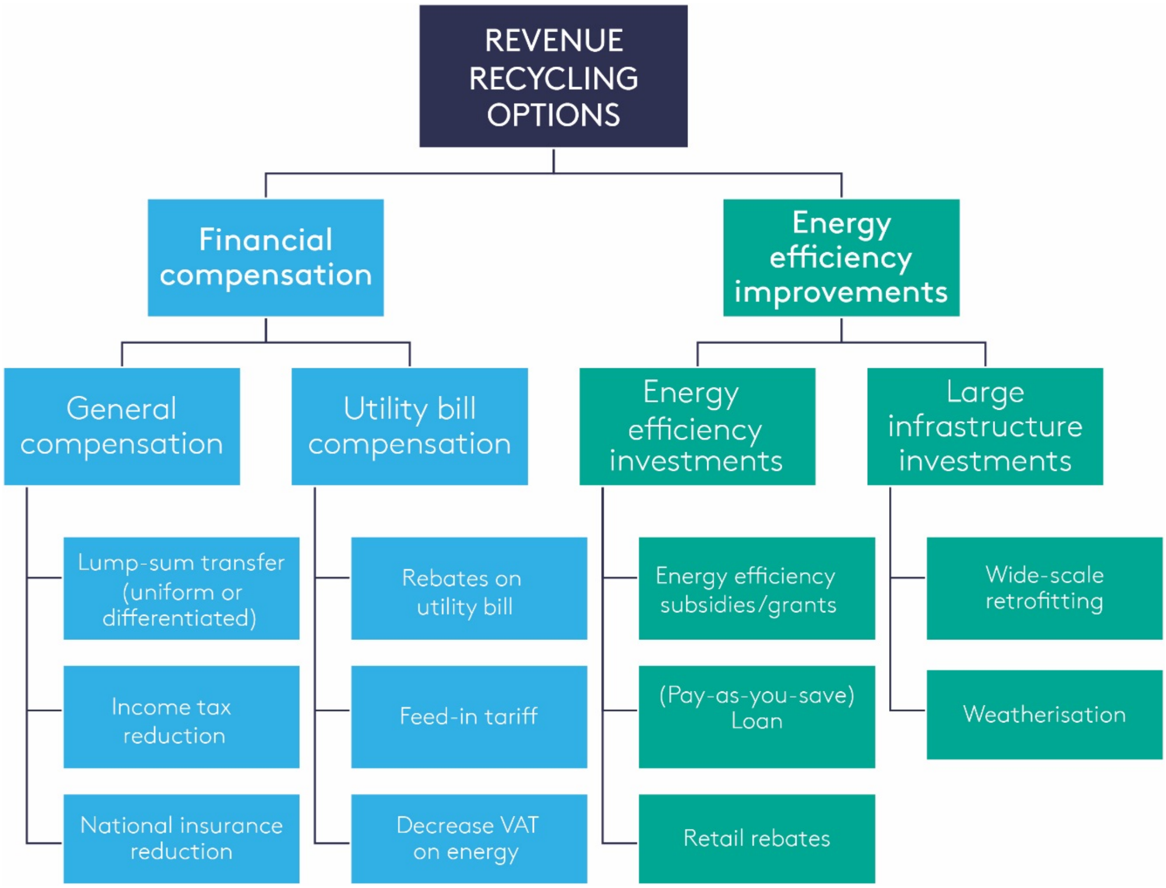
Direct financial compensation options can take the shape of lump-sum payments to all households (a flat transfer) or be based on specific characteristics (differentiated across income deciles, size-based,

5. It is important to be cautious over the interpretation of the desired effect of the tax. If it has been observed, i.e. energy consumption has gone down, attributing this solely to the adoption of improved energy behaviour (e.g. switching off lights) could be misleading as it may in fact be because households simply deprive themselves of energy services to save money.

geography-based, climate-based). In the UK options could include tax or national insurance reductions, utility bill compensation through rebates on the bill, or a VAT reduction for energy.

Energy efficiency investments can be incentivised and achieved through direct grants and subsidies, pay-as-you-save loans, and retail rebates on low-carbon energy efficiency appliances. Governments may also decide to invest in large programmes of wide-scale retrofitting.

Figure 2.1. Revenue recycling options within two categories: direct financial compensation and energy efficiency improvements



Note: Weatherisation, or weather-proofing, is the process of installing features to protect a building and its interior from the elements to reduce energy consumption and optimise energy efficiency.
Source: Authors

Direct financial compensation – impacts dependent on policy design

Direct financial compensations are transparent and have direct financial benefit, but their distributional impact heavily depends on the design of the policy. A flat transfer consists of the same amount being transferred to every household, increasing the equity and acceptability of the policy tool without improving the regressivity (Berry, 2019; Bourgeois et al., 2019). It is also a costly recycling policy as it targets all households. A differentiated cash transfer has a larger positive impact on the distributive effect but only when it is targeted correctly.

Transfers based on the size, geographical location or climate zone of the household have the same effects as flat transfers, as the cash transfers are designed not to vary significantly between income deciles (Berry, 2019). Income-based transfers are cheaper and more effective solutions.

Compensating customers through utility bill assistance[6] can decrease or remove the incentive to reduce energy consumption and hence emissions (International Council on Mining and Metals, 2013). It is important to design any utility bill compensation in such a way that it targets appropriate groups. For example, linking rebates to gas bills would leave out households that use wood or oil for heating – this is more likely to be the case for isolated rural households and as a result this group could be overlooked.

Decreasing the VAT charged on the domestic consumption of energy, another option, can be inefficient if goods and services consumed by low-income households are already VAT-exempt (Advani et al., 2013).

Energy efficiency policies – creating household savings but possibly with a time lag

Energy efficiency may reduce regressivity by increasing total energy savings and thereby lowering bills. For example, the Committee on Climate Change (CCC) found that household bills in 2016 were lower than bills in 2008 – by about £115 in real terms – and that this was because reductions in energy use have more than offset higher prices resulting from low-carbon policies and network costs (CCC, 2017).

Furthermore, energy efficiency policies provide households with opportunities to save more than the cost of installing the measures (Wiese et al., 2018). Pay-as-you-save loans also provide the right incentive for reducing energy consumption by enabling customers to pay back loans for energy efficiency improvement installation which themselves generate savings over the payback period. One study also finds that energy efficiency subsidies achieve greater energy savings and are more likely than direct financial transfers to reduce the proportion of people suffering from fuel poverty (Bourgeois et al., 2019).

However, because energy retrofits may take time there may be a temporary fuel poverty problem when prices are high but benefits have not yet had an impact. The interplay between the timing of the energy retrofit works and the trajectory of the carbon tax must be considered when evaluating the real monetary impact on households. Those advocating for compensatory policies that focus on energy efficiency must acknowledge that depending on the date and the speed at which effective retrofits can be implemented, households may experience negative monetary impacts for a while after (Douenne, 2018). Ideally, these adaptive investments could be conducted before the carbon tax is implemented or significantly increased.

Revenue recycling – increasing horizontal inequity if not designed well

As households differ on many dimensions other than income, some revenue recycling options can in fact increase horizontal inequity. If a policy does not distinguish between households that have similar incomes but different compositions or location characteristics, it lumps these together and creates a 'hidden group' of untargeted recipients. Furthermore, a revenue recycling option based on either social benefits or income tax leaves out poor households that do not receive government transfers or ones that do not earn income respectively (Browne et al., 2013; Cronin et al., 2019).

Testing these observations

In the next section, we test the conclusions from the literature outlined above by integrating energy efficiency support into our carbon tax modelling. The model assesses the issues raised in the literature, such as the effect suffered as a result of income differentials between households and temporal concerns, by modelling the effect of carbon tax on five different 'archetypal' households over a 10-year period. It also integrates energy efficiency support into the model in order to examine how revenue recycling options impact these different household types. This provides evidence for how revenue recycling may help alleviate regressive effects on carbon pricing in a heterogeneous population.

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6. The UK government currently provides some utility bill assistance in the form of Cold Weather Payments, which are available to people receiving certain benefits or support for mortgage interest, and if the average temperature is recorded as or forecast to be 0°C or below for seven days consecutively. See www.gov.uk/cold-weather-payment. Additionally, the Government's Warm Home Discount Scheme legally obligates particular energy suppliers to contribute £140 towards the electricity bill of eligible groups between September and March. Eligible groups include those who receive the Guarantee Credit element of Pension Credit and/or those who are on a low income and meet their energy supplier's criteria for the scheme. See www.gov.uk/the-warm-home-discount-scheme

3. How a carbon tax impacts on different household archetypes in the UK: scenarios and results

This section presents the scenarios used to assess the impact of a carbon tax on households' energy bills in the UK, including cases where carbon tax revenues are used to support energy efficiency improvements. The aggregate and then household-level results are then described, along with a summary of our overall findings from the case study analysis.

Case study selection

We have selected five case studies to represent the impact of a carbon tax on different representative archetypes of UK household. The household archetypes represent a variety of situations along two dimensions that are particularly important for carbon tax impacts: **heating fuel** and **income level**.

1. Household with electricity and gas (dual-fuel); annual income £57,000
2. Household with electricity only; annual income £29,000
3. Household with off-gas-grid oil for heating that switches to a heat pump, and electricity; annual income £11,000 and fuel-poor
4. Household with electricity and gas (dual-fuel); annual income £9,000
5. Household with electricity and gas (dual-fuel), with large energy expenditure; annual income £26,000 and fuel-poor.

The incomes include income for the whole household from all sources, including benefits, savings and investments.

Scenario details

Our modelling sees a carbon tax initiated in the year 2020 and the impact on the energy bills assessed a) in 2020, without energy efficiency support; and b) in 2030, with energy efficiency support and additional payments for fuel-poor households.

The tax is levied on three major domestic fuels: gas, electricity and oil. Border carbon adjustments on gas and electricity imports are not considered in Report 1 (this report) as they are modelled in Report 2. The current carbon tax on electricity is replaced with the assumed tax rates in 2020 and 2030.

The choice of the year 2020 for the initiation of the carbon tax is illustrative: it serves only to provide a 'baseline' energy bill for each household type without the realisation of energy efficiency savings.

Four key energy efficiency improvements are considered: solid wall insulation, cavity wall insulation, loft wall insulation and heat pump installation.

We look at households that have an uninsulated cavity wall or solid wall, and also uninsulated lofts. Heat pumps are only installed in households that receive solid wall or cavity wall insulation. Other energy efficiency improvements such as efficient lighting or appliances are assumed to have no additional costs as they are replaced at the end of their lifetime and are therefore excluded from this economic analysis.

For fuel-poor households, the cost of all energy energy efficiency improvements are covered by the policy. Non-fuel-poor households are only covered for solid wall insulation and heat pumps because of the long payback time of these ivestments. This is summarised in Table 3.1 below.

Table 3.1. Energy efficiency support for fuel-poor and non-fuel-poor households					
	Solid wall insulation	Cavity wall insulation	Loft wall insulation	Heat pumps	Carbon tax
Fuel-poor households	✓	✓	✓	✓	✓
	Total costs of energy efficiency improvements and carbon tax net of energy savings covered by the carbon tax policy				
Non-fuel-poor households	✓ Total cost covered by the carbon tax policy	✗ Paid for by households	✗ Paid for by households	✓ Total cost covered by the carbon tax policy	✗ Paid for by households

To determine the financial compensation required at the household level, carbon tax revenues, energy efficiency costs and energy savings are estimated at an aggregate country level.
Estimates of total and net costs (including energy savings) of energy efficiency improvements are calculated over the period 2020–2030. This provides changes in gas and electricity consumption induced by energy efficiency installations alongside broader decarbonisation of the electicity mix. Carbon tax revenues are then based on this changed energy consumption and grid emissions intensity. Net costs and revenue streams help determine the amount of financial compensation available at an aggregate level and therefore at a household level.

All monetary figures are presented in pounds sterling, 2018 prices, unless otherwise stated.
The UK Consumer Prices Index including owner occupiers' housing costs (the 'CPIH') (Office for National Statistics, 2018) is used to convert monetary figures to 2018 prices.

The methodology, including a summary of the key assumptions we make, is detailed in the Appendix.

Domestic gas and electricity prices in 2020 and 2030 are assumed to increase as detailed in the Committee on Climate Change's *Energy Prices and Bills Report 2017* (CCC, 2017). These projections are based on the assumption that 75 per cent of generation will come from low-carbon sources in 2030, and forecasts that gas prices will rise from 5.29 pence/kWh in 2020 to 6.24 pence/kWh in 2030 and electricity prices from 17.40 pence/kWh in 2020 to 21.28 pence/kWh in 2030 (ibid.).

Aggregate-level results

Projected energy efficiency investments costs, savings and carbon tax revenues (2020–2030)
Table 3.2 shows projected costs of energy efficiency improvements, associated energy efficiency savings and carbon tax payments for households whose main fuel is either gas or electricity. Results are shown for English households registered as 'fuel-poor' and 'non-fuel-poor' in the Fuel Poverty Database (BEIS, 2017) but the chosen household archetypes are representative of the UK as a whole. We did not model the impact of energy efficiency support on energy bills and carbon tax payments for the 'other category', which covers households whose main fuel is oil, biomass or waste, as these represent less than 7 per cent of households in England.[7]

7. The data do not distinguish between oil, biomass and waste within the 'other' category so this has not been modelled.

Table 3.2. Costs of energy efficiency (EE) improvements, associated savings and carbon tax payments, 2020–2030					
Main fuel type	Fuel-poor/ non-fuel-poor households	No. of households	Costs of EE and heating improvements (including low-carbon heating) (£m)	EE and low-carbon heating savings (£m)	Carbon tax payments (£m)
Gas	Fuel-poor	1,992,676	13,228	494	4,903
	Non-fuel-poor	17,790,504	5,582	732	42,809
	All households	19,783,180	18,810	1,226	47,712
Electricity	Fuel-poor	373,653	1,720	840	317
	Non-fuel-poor	1,455,970	2,600	1,593	1,114
	All households	1,829,623	4,321	2,433	1,431
Total gas and electricity households	Fuel-poor	2,366,329	14,948	1,334	5,220
	Non-fuel-poor	19,246,474	8,182	2,325	43,923
	All households	21,612,803	23,130	3,658	49,143
Other (oil, biomass, waste energy)	Fuel-poor	165,866	1,320		
	Non-fuel-poor	1,418,228	6,758		
	All households	1,584,094	8,078		
Total	Fuel-poor	2,532,195	16,268		
	Non-fuel-poor	20,664,702	14,941		
	All households	23,196,897	31,209		

Source: Authors

Under this model, the total costs of energy efficiency improvements in England over the next decade amount to £3.1 billion per year, including £1.6 billion per year for fuel-poor households.

This calculation is based on a series of assumptions pertaining to households' current level of energy efficiency as well as maximum installation rates over the next decade. These projections rely on the assumption that energy efficiency improvements are undertaken as a priority in fuel-poor households (see Table A7 in the Appendix for details).

The projected carbon tax revenue from gas and electricity-fuelled households for the whole of the UK would amount to £57 billion over the period 2021–2030.

When accounting for 'other' households that are not currently modelled, the revenues are likely to be marginally higher. This calculation assumes that the energy efficiency investments described in Table A7 are undertaken.

The energy efficiency and low-carbon heating cost estimates we present in this report are not directly comparable to estimates presented in the Committee on Climate Change's report to government, *Net Zero – The UK's contribution to stopping global warming* (CCC, 2019). The CCC estimates the annual costs for switching to low-carbon heating will be in the order of £15 billion and for energy efficiency £7 billion (ibid.). The CCC's estimates are for all buildings in the UK between 2030 and 2050, whereas the estimates we present in this report are only for residential buildings in England between 2020 and 2030. Additionally, the CCC annualises costs over 20 years with the cost of capital at 3.5 per cent for public and 7.5 per cent for commercial costs, whereas our estimates represent costs over a 10-year period between 2020 and 2030 with zero costs of capital, since these are assumed to be funded by carbon tax revenues.

Carbon revenue recycling

Based on projected carbon revenues, the proposed compensation policy would mean that all fuel-poor households would be compensated for both the costs of energy efficiency investments and the carbon tax, whereas non-fuel-poor households would receive financial compensation only for solid wall insulation and heat pumps. This is detailed further in Box 3.1.

Box 3.1. Proposed financial compensation policy

- Projected revenue from the carbon tax amounts to £57 billion over the period 2021–2030. This covers all gas- and electricity-fuelled households in the UK.
- Fuel-poor households are compensated for the total costs of energy efficiency investments and carbon taxation with net energy savings of £18.8 billion.[8]
- Non-fuel-poor households receive energy efficiency support for the costs of solid wall insulation and heat pumps installation (£8.2 billion).
- This leaves £29.9 billion which can be allocated in different ways, e.g. to mitigate the impacts of a carbon tax on households which are not fuel-poor, to pay for future energy efficiency improvements, to provide concessionary finance or to be invested in green infrastructure.
- This policy would come in addition to the existing Warm Home Discount Scheme [see footnote 6].
- Remaining funds from carbon revenues can pay for existing commitments such as the ECO.[9]

The net impact on non-fuel-poor households would amount to £216 per household per year on average over the period (see Table 3.3).

Table 3.3. Projected net impacts on fuel-poor and non-fuel-poor households

Fuel-poor/ non-fuel-poor household	No. of households	Average net impact pre-compensation *£/household/year*	Proposed financial compensation *£/household/year*	Average net impact post compensation *£/household/year*
Fuel-poor	2,366,329	-£796	£796	£0
Non-fuel-poor	19,246,474	-£259	£43	-£216

Notes: Analysis based on gas- and electricity-fuelled households in England. Net impact only covers the costs of energy efficiency and carbon tax payments; a negative figure implies costs to households. Increases in energy prices are not considered. Source: Authors

Projected decarbonisation benefits for the residential sector over the period 2020–2030

The analysis suggests that adoption of energy efficiency improvements and low-carbon heating decreases residential gas emissions by 9 per cent and residential electricity emissions by 43 per cent between 2020 and 2030.

The higher emissions reduction from electricity relative to gas results from decarbonisation of the electricity sector and the adoption of energy efficiency measures. The CCC recognises that switching homes to electric heating to reach net-zero will remain a challenge, cost-wise. In light of this, it recommends deployment must begin before 2030 with a continued role for the taxpayer in funding the low-carbon heating transition, along with addressing fuel poverty as a priority (CCC, 2019). Our analysis

8. Other government policies affecting fuel poverty are not considered in this analysis, therefore it is assumed if a household is fuel-poor in 2020, it is also fuel-poor in 2030.

9. The ECO is a government energy efficiency scheme requiring obligated suppliers to promote measures to improve the ability of low-income, fuel-poor and vulnerable households to heat their homes.

shows that a carbon tax on the residential sector could significantly encourage this energy efficiency and heating transition while addressing fuel poverty, and would lead to emissions reductions that would help the UK meet its net-zero target (see Table 3.4).

Table 3.4. Gas consumption (GC), electricity consumption (EC), emissions and carbon tax paid by the residential sector, 2021–2030

		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total	% change
Carbon tax	£/tCO_2	54	56	58	61	63	65	68	70	73	75		39%
Gas households	GC (TWh)	337	333	330	326	323	319	316	313	309	306		-9%
	EC (TWh)	58	59	60	61	62	63	63	64	65	66		14%
Electricity households	EC (TWh)	17	16	16	16	16	15	15	15	15	15		-12%
Total gas + electricity households	GC (TWh)	337	333	330	326	323	319	316	313	309	306		-9%
	EC (TWh)	74	75	76	77	77	78	79	79	80	80		8%
	Emissions from GC (MtCO_2)	69	68	67	66	66	65	64	64	63	62		-9%
	Emissions from EC (MtCO_2)	14	14	13	12	12	11	10	10	9	8		-43%
	Carbon tax paid on GC (£m)	3,725	3,825	3,927	4,033	4,142	4,255	4,370	4,490	4,613	4,684	42,063	26%
	Carbon tax paid on EC(£m)	767	762	754	744	730	714	693	670	642	603	7,079	-21%
	Total carbon tax paid (£m)	4,492	4,587	4,682	4,777	4,873	4,968	5,064	5,159	5,255	5,287	49,143	18%

Source: Authors

Household-level case studies

Case study 1: High-income, dual-fuel household

Location: London

Fuel and power sources: Connected to the gas grid: uses gas for space heating and hot water. Uses electricity for other power needs, including lighting and appliances. Fuel sources remain the same but the model assumes a decline in grid carbon intensity

Building features: Mid-terrace, with uninsulated solid walls and an uninsulated loft (with insulation less than 125mm thick, classed as 'uninsulated' as significantly less than the minimum of 270mm required by Building Regulations)

No. of occupants: Three

Tenure: Owner-occupied

Annual income in 2017: £57,873. Not considered to be in fuel poverty

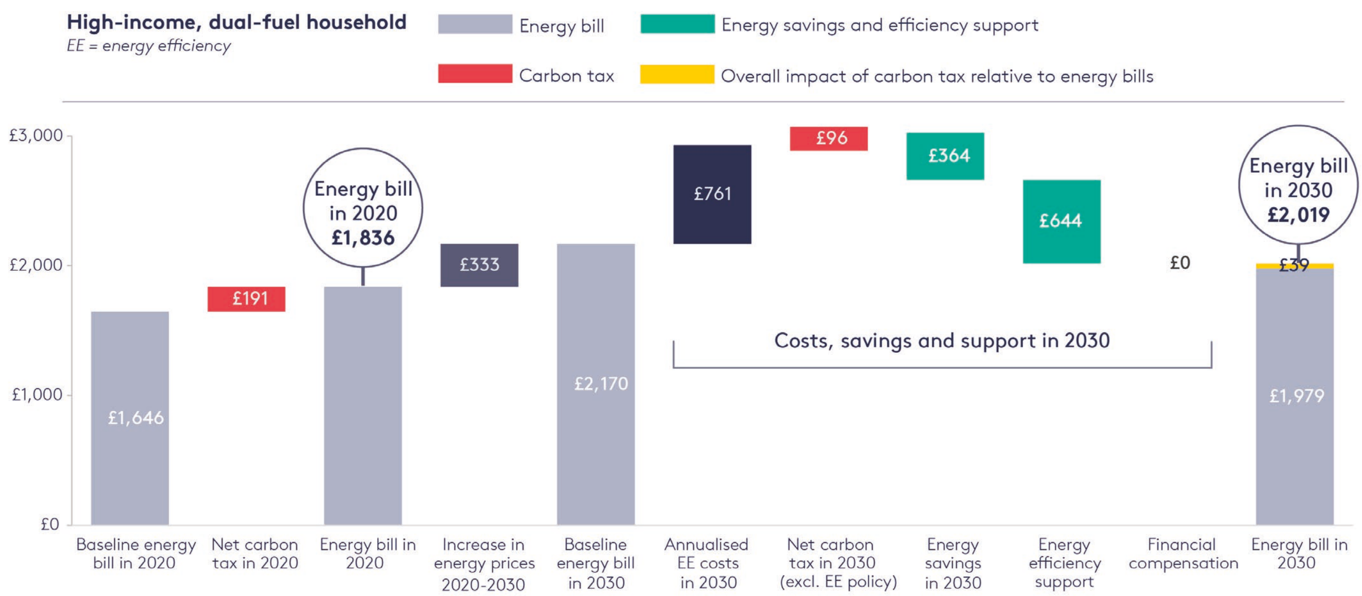
Total energy bills in 2017: £1,479. Not eligible for Warm Home Discount

The following assumptions are applied:

- Fuel mix remains the same to 2030
- Carbon tax of £50 per tonne of CO_2 is imposed in 2020 and £75 per tonne of CO_2 in 2030
- Solid wall and loft insulation are installed between 2020 and 2030
- Household receives energy efficiency support for the costs of solid wall insulation from carbon tax proceeds.

The results of our modelling for this household are shown in Figure 3.1.

Figure 3.1. Energy bill for a high-income, dual-fuel household



Notes: Energy efficiency improvement costs are annualised over 12 years and include financing costs at 5 per cent interest rate. Energy savings include reduced energy and carbon tax costs. Assumptions on increases in energy prices are taken from the CCC's projections (Committee on Climate Change, 2017). 'Baseline energy bills' and 'increase in energy prices 2020–2030' include the ETS and the Carbon Floor Price, but our modelling assumes this is replaced by the proposed carbon tax and displays carbon taxes in 2020 and 2030 net of the replaced policy. Source: Authors

The energy bill of the household in case study 1, which is typical for an average inefficient dual-fuel household, will increase by 10 per cent between 2020 (post carbon tax implementation) and 2030 (post carbon tax implementation and energy efficiency support).

Almost all of this increase comes from the increase in energy prices during the period, with the net impact of the carbon tax being around 2 percentage points, equivalent to just £39. The revenue from the carbon tax is used to support 100 per cent of the solid wall insulation costs in this case. Energy efficiency savings are higher than the increase in carbon tax costs in 2030, where the tax rate is higher in 2030 than in 2020, but is levied on the reduced energy consumption.

Case study 2: Middle-income household with electricity only

Location: South West England

Fuel and power sources: Electricity is used for both heating and other power needs, including lighting and appliances. Fuel sources remain the same but the model assumes a decline in grid carbon intensity

Building features: End of terrace with uninsulated cavity walls and an uninsulated loft (with insulation less than 125mm thick)

No. of occupants: Two

Tenure: Owned by housing association

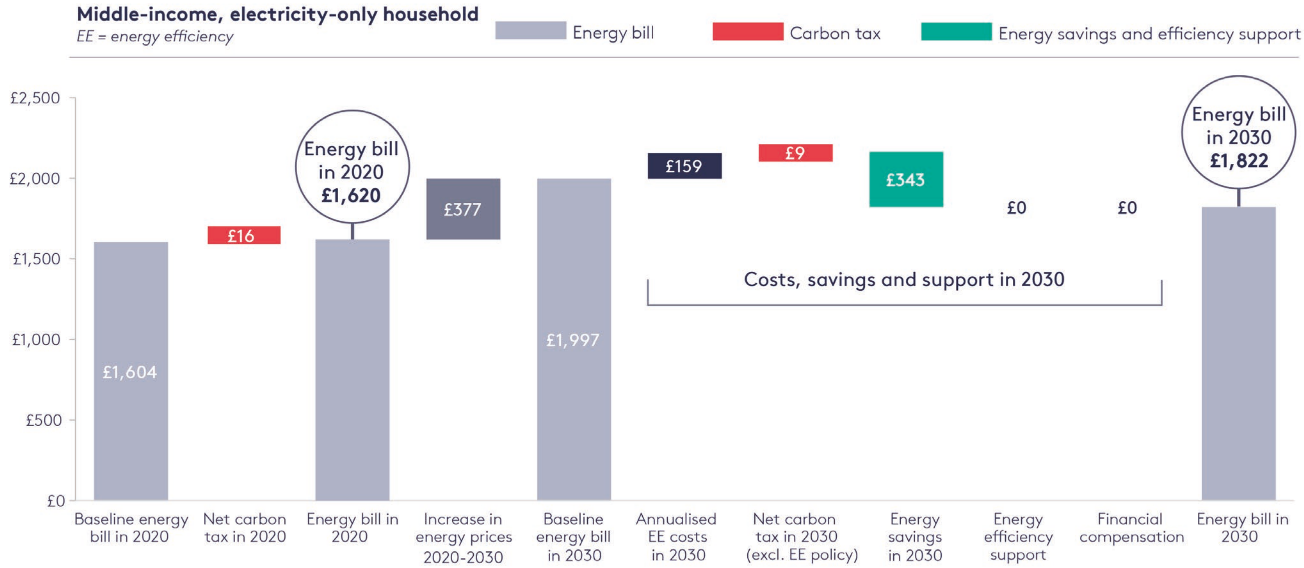
Annual income in 2017: £29,354. Not considered to be in fuel poverty

Total energy bill in 2017: £1,421. Not eligible for Warm Home Discount

The following assumptions are applied:

- Fuel mix remains the same to 2030
- The carbon content of electricity is projected to decrease from 200g CO_2/kWh in 2020 to 100g CO_2/kWh in 2030
- Carbon tax of £50 per tonne of CO_2 is imposed in 2020 and £75 per tonne of CO_2 in 2030
- The costs of cavity wall and loft insulation are covered by the household and are installed before 2030
- Household receives no financial compensation.

Figure 3.2. Energy bill for an electricity-only household



Notes: Energy efficiency improvement costs are annualised over 12 years and include financing costs at 5 per cent interest rate. Energy savings include reduced energy and carbon tax costs. Assumptions on increases in energy prices *are taken from the CCC's projections (Committee on Climate Change, 2017). 'Baseline energy bills' and 'increase in energy prices 2020–2030' include the ETS and the Carbon Floor Price, but our modelling assumes this is replaced by the proposed carbon tax and displays carbon taxes in 2020 and 2030 net of the replaced policy. Source: Authors*

The energy bill of the household in case study 2, which is typical for an inefficient electric-heating household, will increase by 12 per cent between 2020 (post carbon tax implementation) and 2030 (post carbon tax implementation and energy efficiency support).

All of this increase is driven by the increase in energy prices during the period. The energy efficiency insulation measures result in a substantial increase in energy savings, which more than offsets the annual costs of cavity wall insulation. The absolute carbon tax paid in 2030 is less than the amount paid in 2020 due to decarbonisation of the electricity sector and energy efficiency savings, even though the tax rate is increased over the decade. The impact of the carbon tax and energy efficiency support leads to a reduction in the average bill without these recycling policies in 2030. The household requires no financial compensation from the Government due to returns on investment from cavity wall and loft insulation, which are proportional to initial losses.

Case study 3: Low-income, off-gas-grid household, which switches to an electric heat pump

Location: Yorkshire and the Humber

Fuel and power sources: Oil is the main heating source. Uses electricity for other power needs, including lighting, appliances and cooking

Building features: Semi-detached with uninsulated solid walls, no loft insulation

No. of occupants: Two

Tenure: Private-rented

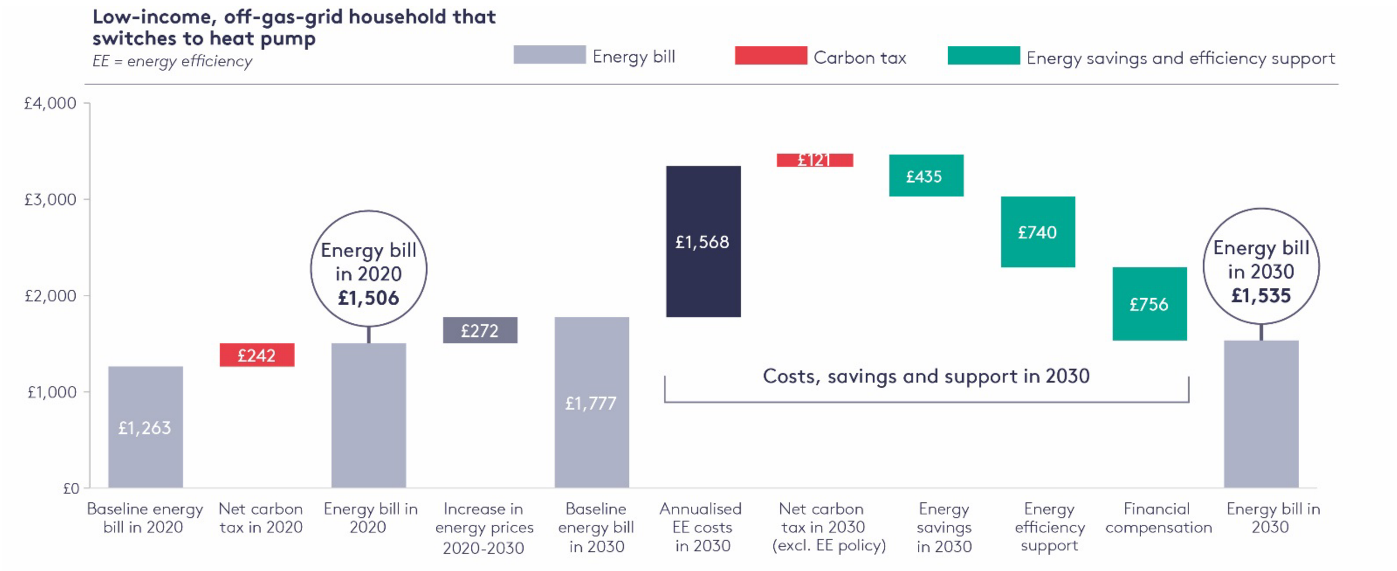
Annual income in 2017: £11,444. Considered to be in fuel poverty

Total energy bills in 2017: £988. Eligible for a £140 Warm Home Discount annually

The following assumptions are applied:

- Fuel mix changes from oil to electricity between 2020 and 2030
- Carbon tax of £50 per tonne of CO_2 is imposed in 2020 and £75 per tonne of CO_2 in 2030
- Solid wall insulation is installed before 2030
- Switch from oil to a heat pump is made before 2030
- Household receives financial compensation which covers the net costs of energy efficiency investments and carbon taxation.

Figure 3.3. Energy bill for an off-gas-grid household switching to an electric heat pump



Notes: Energy efficiency improvement costs are annualised over 12 years and include financing costs at 5 per cent interest rate. Energy savings include reduced energy and carbon tax costs. Heat pump costs are annualised over 10 years and include financing costs at 5 per cent interest rate. Energy efficiency support excludes the costs of heat pump, where net costs of heat pump are included in the financial compensation. Assumptions on increases in energy prices are taken from the CCC's projections (Committee on Climate Change, 2017). Baseline energy bills' and 'increase in energy prices 2020–2030' include the ETS and the Carbon Floor Price, but our modelling assumes this is replaced by the proposed carbon tax and displays carbon taxes in 2020 and 2030 net of the replaced policy.
Source: Authors

The energy bill of the household in case study 3, which is typical of an inefficient oil-heating household, will experience a minimal 2 per cent increase between 2020 (post carbon tax implementation) and 2030 (post carbon tax implementation and energy efficiency support).

This calculation is based on the central estimate of oil price projections. The energy efficiency savings incurred more than offset the carbon tax costs imposed in 2030. The absolute carbon tax paid in 2030 is significantly less than the amount paid in 2020 due to a switch from carbon-intensive oil heating to an electric heat pump. To protect the fuel-poor household from the rising costs of energy efficiency policy, low-carbon heating and carbon tax, the Government compensates for any net costs borne by the household with financial compensation. After the compensation, the carbon tax has minimal impact on this household.

Case study 4: Low-income, dual-fuel household

Location: East of England

Fuel and power sources: Connected to the gas grid: uses gas for space heating and hot water. Uses electricity for other power needs, including lighting and appliances. Fuel sources remain the same but the model assumes a decline in grid carbon intensity

Building features: Mid-terrace, uninsulated solid walls, uninsulated loft (with insulation less than 125mm thick)

No. of ccupants: One

Tenure: Owned by local authority

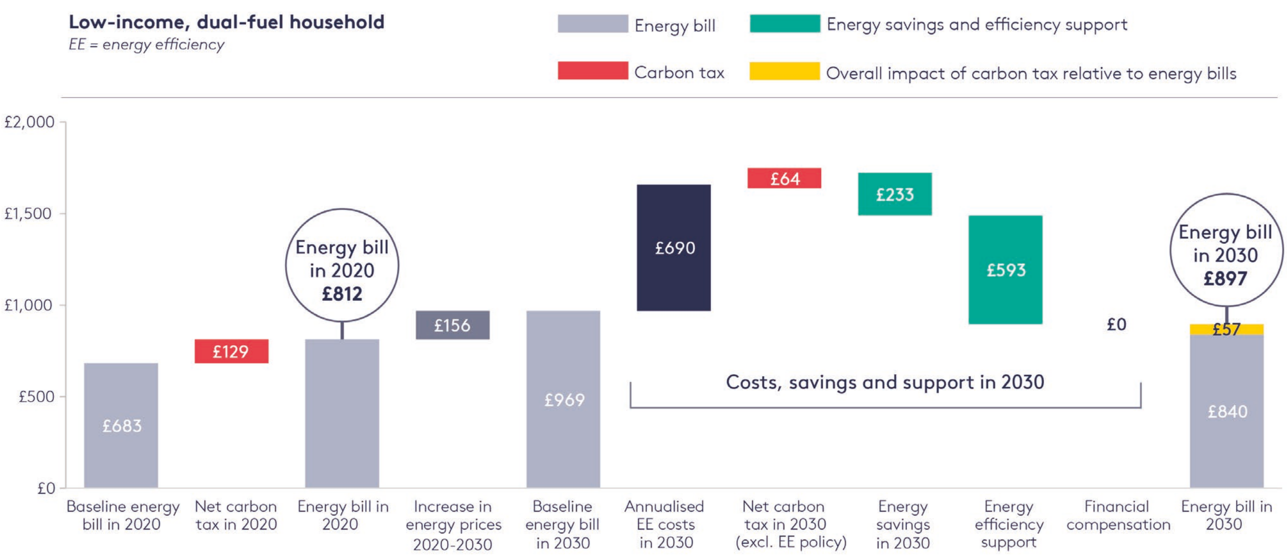
Annual income in 2017: £8,808. Not considered to be in fuel poverty

Total energy bill in 2017: £754. Eligible for a £140 Warm Home Discount annually

The following assumptions are applied:

- Fuel mix remains the same to 2030
- Carbon tax of £50 per tonne of CO_2 is imposed in 2020 and £75 per tonne of CO_2 in 2030
- Solid wall and loft insulation are installed before 2030
- The costs of solid wall insulation are covered by the carbon tax proceeds rather than the household
- The costs of loft wall insulation are covered by the household.

Figure 3.4. Energy bill for a low-income, dual-fuel household



Notes: Energy efficiency improvement costs are annualised over 12 years and include financing costs at 5 per cent interest rate. Energy savings include reduced energy and carbon tax costs. The increase in bills from increase in energy prices includes a £140 rebate from the Warm Home Discount scheme. Assumptions on increases in energy prices are taken from the CCC's projections (Committee on Climate Change, 2017). Baseline energy bills' and 'increase in energy prices 2020–2030' include the ETS and the Carbon Floor Price, but our modelling assumes this is replaced by the proposed carbon tax and displays carbon taxes in 2020 and 2030 net of the replaced policy.
Source: Authors

The energy bill of the household in case study 4, which is typical of an inefficient low-income, dual-fuel household, will increase by 10 per cent between 2020 (post carbon tax implementation) and 2030 (post carbon tax implementation and energy efficiency support).

Almost all of this is attributed to the increase in energy prices during the period, with the net impact of the carbon tax around 7 percentage points, equivalent to just £57. The energy savings from solid wall and loft insulation more than offset the carbon tax imposed in 2030. The household receives energy efficiency support to cover the net costs of solid wall insulation.

Case study 5: Low-income, dual-fuel, high energy expenditure household

Location: West Midlands

Fuel and power sources: Connected to the gas grid: uses gas for space heating and hot water. Uses electricity for other power needs, including lighting and appliances. Fuel sources remain the same but the model assumes a decline in grid carbon intensity.

Building features: Semi-detached with uninsulated solid walls and an uninsulated loft (with insulation less than 125mm thick)

No. of occupants: Four

Tenure: Owner-occupied

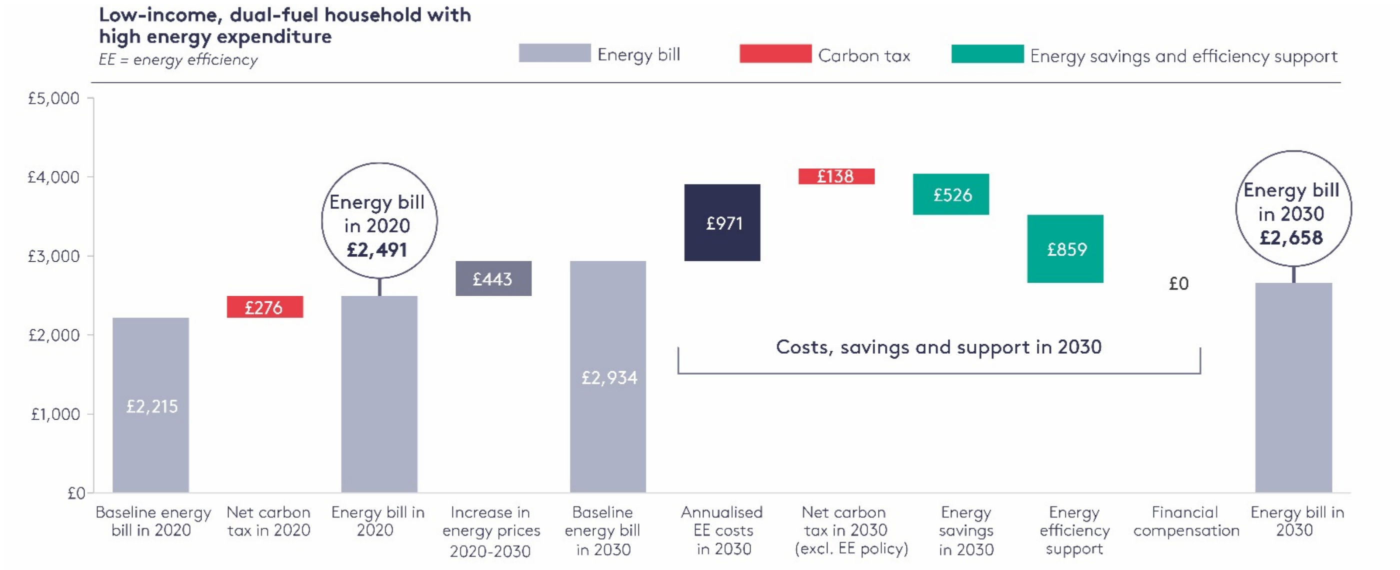
Annual income in 2017: £25,892. Considered to be in fuel poverty

Total energy bills in 2017: £1,993. Not eligible for Warm Home Discount

The following assumptions are applied:

- Fuel mix remains the same to 2030
- Carbon tax of £50 per tonne of CO_2 is imposed in 2020 and £75 per tonne of CO_2 in 2030
- Solid wall and loft insulation are installed before 2030
- Household receives energy efficiency support which covers the net cost costs of energy efficiency investments.

Figure 3.5. Energy bill for a low-income, dual-fuel, high energy expenditure household

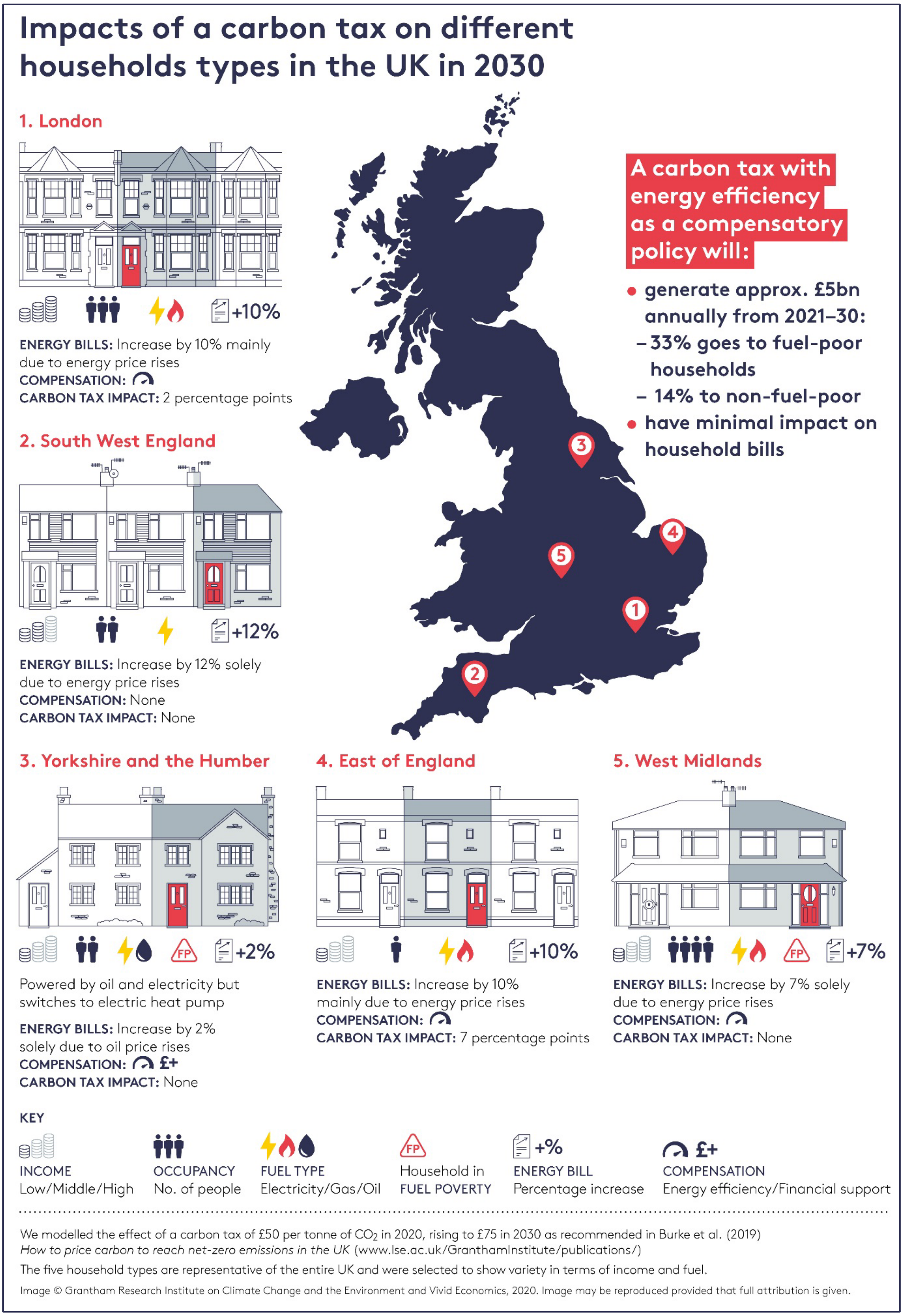


Notes: Energy efficiency improvement costs are annualised over 12 years and include financing costs at 5 per cent interest rate. Energy savings include reduced energy and carbon tax costs. Energy savings include reduced energy and carbon tax costs. Assumptions on increases in energy prices are taken from the CCC's projections (Committee on Climate Change, 2017). Baseline energy bills' and 'increase in energy prices 2020–2030' include the ETS and the Carbon Floor Price, but our modelling assumes this is replaced by the proposed carbon tax and displays carbon taxes in 2020 and 2030 net of the replaced policy. Source: Authors

The energy bill of the household in case study 5, which is typical of an inefficient, low-income, high energy expenditure household, will increase by 7 per cent between 2020 (post carbon tax implementation) and 2030 (post carbon tax implementation and energy efficiency support).

All of this increase is due to energy price increases during the period. The energy savings from solid wall and loft insulation more than offset the effects of the carbon tax imposed. To protect the fuel-poor household from the rising costs of energy efficiency policy and the carbon tax, the Government compensates for any net costs borne by the household in the form of energy efficiency support. After the compensation, the carbon tax reduces the energy bill without these recycling policies.

Overarching findings from the case study analysis



The net impact of the carbon tax policy is minimal for most households after they receive financial energy efficiency support, net of insulation costs.

For most household archetypes, energy savings from energy efficiency (and low-carbon heating where applicable) are greater than the carbon tax imposed in 2030. This implies, in general, that even under a higher carbon tax on energy, households do not require compensation in excess of the support for solid wall insulation costs once energy savings start to have an effect. However, compensatory measures, especially for fuel-poor households, need to be considered in the years before energy efficiency installation measures are adopted.

Fuel-poor households – off-gas-grid households and low-income, high energy expenditure households – experience mininal increase in their energy bills, as targeted by the policy.

Off-gas-grid households switch from carbon-intensive oil heating to electric heat pumps, and therefore pay a significantly lower amount of carbon tax after switching, compensating for the net costs of energy efficiency and low-carbon heating measures. Similarly, low-income, large energy consuming households receive energy efficiency support for the net costs of energy efficiency insulation measures.

Households with solid wall insulation require greater compensation due to the high upfront costs of installation (£6,709 for solid wall insulation compared with £744 for cavity wall and £1,220 for loft insulation).

Costs of cavity wall and loft insulation are more than offset by the incurred energy savings. The average savings on bills from energy efficiency are about £200, which are in line with the Committee on Climate Change's average saving estimate of £150 (Committee on Climate Change, 2019).

Under the proposed carbon tax scenario, the differences in the average energy bill increase among the case-study households arise from differences in fuel used for space and water heating.

Electricity and gas prices both rise over the decade, with electricity prices experiencing a slightly higher increase than gas. In addition, dual-fuel households pay a much higher carbon tax in 2030 than electrically-heated households as the electricity sector strives towards decarbonisation beween 2020 and 2030, lowering the carbon content of electricity consumed and thus carbon tax payments. The differences in impacts for different household archetypes are summarised in Table 3.5.

Table 3.5. Energy bill impacts for household archetypes

Household archetype	Net carbon tax in 2020 (£)	Energy bill in 2020 (£)	Baseline energy prices increase from 2020 to 2030* (£)	Net carbon tax in 2030 (£)	Annualised energy efficiency costs in 2030 (£)	Energy savings and compen-sation in 2030** (£)	Energy bill in 2030 (£)	Energy bill increase from 2020 to 2030 (%)	Energy bill increase coming from carbon tax policy package (percentage points)
Dual-fuel household (high income)	£191	£1,836	£333	£96	£761	-£1,009	£2,017	10%	2 pp.
Household with electric heating	£16	£1,620	£377	£9	£159	-£343	£1,822	12%	-10 pp.
Off-gas-grid household which switches to a heat pump	£242	£1,506	£272	£121	£1,568	-£1,931	£1,535	2%	0 pp.

Table 3.5. Energy bill impacts for household archetypes									
Dual-fuel household (low income)	£129	£812	£156	£64	£690	-£827	£897	10%	7 pp.
Low-income, high energy expenditure household	£276	£2,491	£443	£138	£971	-£1,385	£2,658	7%	0 pp.

*Note: *Baseline energy prices include current and projected policy of ETS and Carbon Price Floor on electricity. **Energy savings include reduced energy and carbon tax costs. Source: Authors*

4. Conclusions and recommendations

This study has assessed the impact of imposing a carbon tax of £50 per tonne of carbon dioxide in 2020, increasing to £75 per tonne of carbon dioxide in 2030, across five different household archetypes. More specifically, we have tested whether there is a recycling scheme that leaves fuel-poor households better off while driving the transition to net-zero emissions by 2050.

Energy bills, revenue-raising and recycling

Our results show that rising energy costs, rather than the carbon tax, are generally the largest driver of bill increases. While energy bills increase by 2–7 per cent for fuel-poor homes and by 10–12 per cent for non-fuel-poor households between 2020 and 2030, the carbon tax accounts for just 0–7 percentage points of the increase for all five household types after compensation. The anticipated revenue raised by implementing these policy changes will depend on households' behavioral responses to higher prices. If households do not change the quantity of energy they consume, we estimate that this policy package will raise significant revenue. The study projects £57 billion of revenues would be generated from the carbon tax on gas and electricity between 2021 and 2030, and this could increase if other sources of emissions were taxed.

We have demonstrated that recycling the revenue to pay for energy efficiency can mitigate any bill increases arising specifically from the carbon tax. Of the £57 billion, £27.1 billion (47 per cent) is needed to compensate all households. This can be split between fuel-poor households, which accounts for £18.8 billion, ensuring that all fuel-poor households are compensated for both the costs of energy efficiency investments and the carbon tax. In this scenario the net impact of the carbon tax is zero. The remaining £8.2 billion is then allocated to non-fuel-poor households and used to provide financing for energy efficiency support that has a long payback such as solid wall insulation and heat pump installation. The net impact on non-fuel-poor households would amount to £216 per year household per year on average.

Clearly this demonstrates that using the revenues for energy efficiency support can be a powerful means to offset some of the regressive social impacts of carbon taxes in the UK, particular for fuel-poor homes.

This then leaves £29.9 billion, which can be allocated in different ways, such as to mitigate the impacts of a carbon tax on households that are not fuel-poor, to pre-empt increases in energy bills arising from the carbon tax before energy efficiency improvements are implemented, or to be invested in green infrastructure.

Due to the planned decarbonisation of the power sector, the carbon tax burden for households heated with electricity is significantly lower than for households heated with gas or solid fuel. The latter households pay on average a higher price for the energy that they consume, which means that energy efficiency investments can lead to significant savings on their energy bills.

It is important to recognise some limitations to our approach. We do not have data on price elasticities of energy across the distribution of expenditure, which are important when trying to understand the distributional effect of the carbon price policy we outline. That said, it is likely that elasticities are lower in fuel-poor homes (Advani and Stoye, 2016) and therefore we are more likely to accurately capture costs for these households. However, this limitation may result in an overstatement of the costs of the policy for wealthier, non-fuel-poor households. This approach does also introduce some inconsistency in our analysis, since in our compensatory package we use the revenue after we account for the modelled reduction in energy demand for the implementation of energy efficiency measures.

This report aims to inform the debate about how to design carbon taxes to increase public acceptability. The numbers presented are helpful to provide a snapshot of the effect on consumers today and in 2030. The numbers presented are a static representation of cost and revenue and must be revised over time, to reflect the dynamic nature of economies allowing for behaviour change and technological and process innovation.

We use simple and transparent assumptions, which show that the impacts on bills and revenues raised are not trivial and therefore warrant further analysis to fully understand the impacts and substitution effects of different carbon prices on households. This said, this compensatory policy alone does not provide a sufficient means to increase the acceptability of carbon taxes.

Enhancing public and political acceptability

Understanding voter aversion is critical for navigating the political economy of carbon tax policy. Carratini et al. (2019) offer additional and pragmatic ways in which this can be done. This includes phasing in carbon taxes over time and clearly communicating how the revenue will be used.

Moreover, our study also recognises that the salience of carbon pricing varies from sector to sector and therefore must be supported by complementary policies. The appropriate balance between regulation, taxes and subsidies will need careful thought. But carbon pricing will be central to achieving net-zero emissions and not only provides an efficient mechanism by which to do this, but also the financial means to fund the transition and ensure it is equitable. Our study presents insights into how governments may wish to do this.

High-level recommendations

- The carbon tax level needs to be raised. A carbon tax consistent with net-zero emissions would start at £50 per tonne of carbon dioxide.
- Conventional fiscal thinking that sees all revenue treated as general tax must change to ensure that the impacts of carbon pricing are distributed fairly and that the policy is more politically and socially acceptable. Carbon tax revenues should be explicitly used to correct undesirable distributional outcomes.
- Interventions focused on improving energy efficiency can make a substantial difference to the distributional impact of carbon pricing. For example, we show that using 33 per cent of revenues for energy efficiency can ensure fuel-poor households are not adversely affected by carbon taxation.
- Compensatory policies should at least in part pre-empt and cover any increases in energy bills arising from the carbon tax. This is necessary to avoid any transitionary periods where high carbon taxes increase energy bills before energy efficiency improvements are implemented.
- When assessing the impact of carbon taxation, government must also consider horizontal effects – the distributive effects between households with similar incomes – which hitherto have been largely neglected. Assessing these effects will ensure that carbon pricing can be designed to prevent a rise in fuel poverty.

Appendix: Methodology

Key inputs

The key assumptions of our modelling exercise are summarised in Table A1, followed by a brief explanation.

Table A1. Key input assumptions

Level of analysis	Category	Description
Household-level Aggregate-level	Carbon tax	• A £50/tCO_2 carbon tax is introduced in 2020 increasing to £75/tCO_2 in 2030, as per earlier recommendations published by the Grantham Research Institute to achieve net-zero emissions in 2050 (Burke et al., 2019).
Aggregate-level	Energy efficiency installations over the period 2020–2030	• The maximum rate of energy efficiency installations is assumed over the period 2020–2030, as per the Committee on Climate Change's projections (CCC, 2016). • The maximum rate of heat pumps installations by 2030 is based on the CCC's accelerated electrification scenario CCC, 2019); an additional constraint is added that heat pumps are only installed in households that receive solid wall or cavity wall insulation. • We assume that installations are undertaken as a priority in fuel-poor households.
Household-level Aggregate-level	Energy prices over the period 2020–2030	• Electricity and gas prices in 2020 and 2030 are taken from the CCC's projections (CCC, 2017). • Domestic oil prices in 2020 and 2030 are assumed to increase in line with the Department for Business, Energy and Industrial Strategy (BEIS) projections of fossil fuel prices (BEIS, 2018). • Energy price forecasts are assumed consistent with net-zero carbon tax trajectory in the residential sector.
Household-level Aggregate-level	Decarbonisation of the UK economy	• The decarbonisation of the UK electricity sector is assumed to follow projections from the CCC's Fifth Carbon Budget, from levels of 200g CO_2 per kWh in 2020 to 100g CO_2 per kWh in 2030 (CCC, 2015).
Household-level Aggregate-level	Financial compensation policy	• Fuel-poor households are compensated for the net costs of energy efficiency installations and carbon tax payments. • Non-fuel-poor households are compensated for the net costs of solid wall insulation and heat pump installations.

Source: Authors

Key outputs of the modelling exercise

At the aggregate level

- An estimate of the total costs of energy efficiency improvements over the period 2020–2030 in England
- An estimate of the net costs of energy efficiency improvements over the period 2020–2030 in England (taking into account energy savings)
- An estimate of the change in gas and electricity consumption induced by these energy efficiency installations
- An estimate of the carbon tax revenue from gas- and electricity-fuelled households in England.

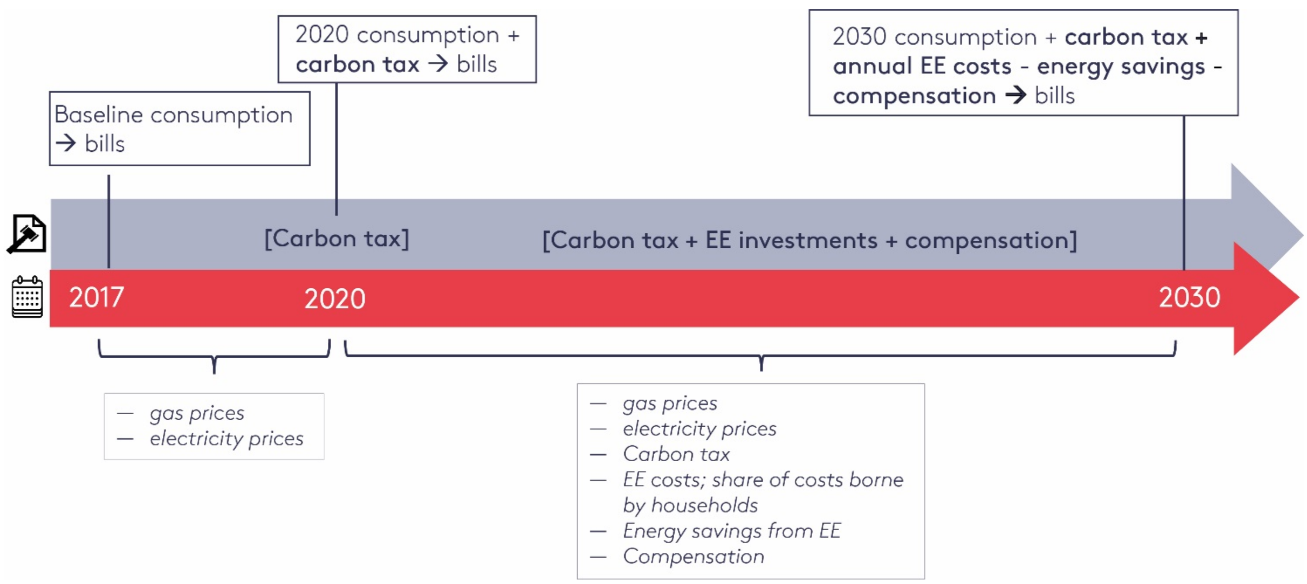
At the household level (case study analysis)

- An estimate of the annualised costs of energy efficiency improvements in 2030
- An estimate of the impacts of energy efficiency improvement on energy bills in 2030
- An estimate of the impact of carbon taxation on the household's 2020 and 2030 energy bills.

Detail of our approach

Figure A1 shows the timeline of the assessment of the impact of a carbon tax on households' energy bills in the UK, including cases where carbon tax revenues are used to support energy efficiency improvements or to cushion the impact of the carbon tax.

Figure A1. Assessment timeline



Note: Energy efficiency (EE) investments are complemented with a heat pump installation in one of the case studies. Source: Authors

The baseline energy consumption for each case-study household is derived from the Department for Business, Energy and Industrial Strategy's fuel poverty database (BEIS, 2017). The database provides fuel costs by purpose, i.e. costs of space heating, costs of heating water, costs of cooking and costs of lighting and appliances. Fixed and unit energy prices by fuel, region and payment type are used to back-calculate energy consumption for each household type in 2017. The energy consumption for a 'typical' household archetype is then averaged over all the households in the database with the selected household characteristics.

The 2017 baseline energy consumption is multiplied by 2020 energy prices to give the total energy bill in 2020 without the carbon tax for each household archetype. The carbon content of each fuel is estimated using fuel emissions intensity, which is then multiplied by the carbon tax rate assumed on domestic energy consumption in 2020. This gives the final energy bill in 2020 with carbon tax for each household archetype.

The 2017 baseline energy consumption is multiplied by 2030 energy prices to give the total energy bill in 2030 without a carbon tax or energy efficiency savings for each household archetype. Annualised energy efficiency costs (along with annual heat pump costs where applicable) borne by households are calculated using installation costs of energy efficiency measures and assumptions on financing costs. Energy savings from energy efficiency adoption (and heat pumps) are then estimated on space and water heating consumption, to give the final energy consumption in 2030. The reduced energy consumption is used to calculate fuel costs with 2030 prices as well as the carbon tax rate assumed on domestic energy consumption in 2030. The final energy bill is calculated as the sum of fuel costs, carbon tax and annual energy efficiency costs (and heat pump costs) minus the energy savings calculated in monetary terms.

The detailed assumptions on key variables used for the assessment are given below.

Household archetypes

BEIS's fuel poverty dataset (BEIS, 2017) is used to construct different household archetypes for assessment. The dataset is a random sample of households in England,[10] which provides baseline information on energy consumption and fuels used, along with information on other household characteristics such as income, number of occupants, region, building type, insulation type, and Energy Performance Certificate (EPC) rating. A number of characteristics are identified to construct each of the five household types, as detailed in Table A2.

Table A2. Household archetypes

Household archetype	Description	Household characteristics
1. Dual-fuel household (high income)	A household connected to the gas grid and uses gas for space heating and hot water and uses electricity for most other power needs, for example, lighting and appliances.	**Fuels:** Gas (space heating, water heating, 61% for cooking) and electricity (lighting and appliances and 38% for cooking) **Fuel poverty flag:** Not in fuel poverty **FPEER rating** [see Notes]**:** D, E, F, G **Tenure:** Owner occupied **Wall type:** Solid wall uninsulated **Loft insulation:** Under 125mm **Heat to group eligibility:** Not eligible **Warm Home Discount:** Not eligible **ECO eligibility:** Not eligible
2. Household with electric heating	A household that uses electricity as its main heating source and for other power needs, for example, lighting and appliances.	**Fuel:** Electricity **Fuel poverty flag:** Not in fuel poverty **FPEER rating**: D, E, F, G **Tenure**: Owned by a housing association **Wall type**: Cavity uninsulated **Loft insulation**: Under 125mm **Heat to group eligibility**: Not eligible **Warm Home Discount**: Not eligible **ECO eligibility**: Not eligible

10. The fuel poverty dataset is based on the English Housing Survey and therefore only provides information on households in England. As a result, this analysis is representative of households in England, rather than the UK as a whole.

Table A2. Household archetypes

3. Off-gas-grid household that switches to a heat pump	A household that currently uses oil for heating purposes and switches to using an electric heat pump.	**Fuels:** 'Other', i.e. oil for heating, and electricity for other power needs **Fuel poverty flag:** In fuel poverty **FPEER rating**: D, E, F, G **Tenure**: Owner-occupied **Wall type**: Solid wall uninsulated **Loft insulation**: 125mm or more **Heat to group eligibility**: Eligible **Warm Home Discount**: Eligible **ECO eligibility**: Eligible
4. Dual-fuel household (low income)	A household connected to the gas grid and with electricity, in a dwelling owned by the local authority.	**Fuels:** Gas (space heating, water heating, 61% for cooking) and electricity (lighting and appliances and 38% for cooking) **Fuel poverty flag:** Not in fuel poverty **FPEER rating**: D, E, F, G **Tenure**: Local authority **Wall type**: Solid wall uninsulated **Loft insulation**: Under 125mm **Heat to group eligibility**: Not eligible **Warm Home Discount**: Eligible **ECO eligibility**: Not eligible
5. High energy-expenditure household (low income)	A household with energy consumption significantly greater than the average consumption in the UK.	**Fuels:** Gas (space heating, water heating, 61% for cooking) and electricity (lighting and appliances and 38% for cooking) **Fuel poverty flag:** In fuel poverty **FPEER rating**: D, E, F, G **Tenure**: Owner-occupied **Wall type**: Solid wall uninsulated **Loft insulation**: Under 125mm **Heat to group eligibility**: Eligible **Warm Home Discount**: Not eligible **ECO eligibility**: Not eligible

Notes: Building on the Standard Assessment Procedure (SAP) for measuring energy performance of domestic properties, the Fuel Poverty Energy Efficiency Rating (FPEER rating) is a measure of the energy efficiency of a property, taking into account policy measures that directly affect household energy costs (such as the Warm Home Discount). The energy efficiency rating from 0 (lowest) to 100 (highest) is translated into an energy efficiency 'band' from G (lowest) to A (highest). The Help to Heat Group refers to UK households that are eligible to receive heating related benefits from their distribution networks as a result of meeting certain criteria, including income thresholds or benefits. The ECO is a government energy efficiency scheme requiring obligated suppliers to promote measures to improve the ability of low-income, fuel-poor and vulnerable households to heat their homes.

Source: Authors

Energy consumption
We take the 2017 energy consumption from the UK Fuel Poverty Dataset, where gas and electricity consumption are clearly marked in the database and oil consumption is taken as the 'other' category under main fuel type.

The following energy consumption changes are considered over time:

- Structural changes: Decarbonisation of the UK electricity sector between 2020 and 2030 is assumed in line with Committee on Climate Change projections in the Fifth Carbon Budget (CCC, 2015), which implies changes to the average carbon intensity of electricity produced between 2020 and 2030.
- Changes from energy efficiency (and heat pump where applicable) adoption: The analysis models changes in energy consumption (or energy savings) from better insulated homes (or from switching to a heat pump) as well as a slight rebound effect from energy efficiency adoption.
- Income effect: The income effect, defined as change in energy demand caused by change in a household's purchasing power resulting from an increase in real income, is not included in the assessment of the impact on the energy bills.
- Price effect: Households' response to a carbon tax is captured in their adoption of energy efficiency investments and no additional effect is assumed.

Energy prices
We derive the 2017 energy prices for electricity and gas from BEIS annual estimates of electricity and gas bills (BEIS, 2019). The fixed and variable unit costs are given by region and payment type, which are used to back-calculate energy consumption from fuel costs in the Fuel Poverty Dataset. The 2017 oil prices are obtained from the price quotes in the UK Consumer Price Index 2017, given by region[11] (ONS, 2019).

Domestic gas and electricity prices in 2020 and 2030 are assumed to increase in line with the CCC's Energy Prices and Bills 2017 (Committee on Climate Change, 2017). The CCC's electricity costs projections rely on the assumptions that 75 per cent of generation will come from low-carbon sources in 2030, implying that average electricity prices will be around £46/MWh higher as result of these low-carbon policies, compared with an estimated premium of £16/MWh in 2016 and £28/MWh in 2020. The CCC's projections of electricity and gas price components are summarised in Table A3. We assume domestic oil prices (pre-carbon tax) increase in line with BEIS projections of fossil fuel prices (BEIS, 2018).

Table A3. Energy prices in 2020 and 2030

Fuel	2020 (pence/kWh)	2030 (pence/kWh)
Gas	5.04	5.94
Electricity	17.40	21.43
Oil	0.54 (p/bbl)	0.64 (p/bbl)

Note: Both gas and electricity prices are represented in 2018 prices. Electricity prices do not include carbon tax component as projected by the CCC
Source: Authors based on CCC (2017)

Carbon tax
A carbon tax is initiated in the year 2020, jointly levied on the carbon content of gas, electricity and oil consumed by households. A starting price of £50 per tCO_2 is assumed in 2020, rising to £75 per tCO_2 in 2030, in line with previous recommendations from the Grantham Research Institute on domestic carbon taxes required to reach net-zero emissions in the UK (Burke et al., 2019a).

The carbon tax on gas and oil is levied at the point of consumption, i.e. households directly pay for the tax based on the carbon content of the gas and oil they consume. However, the carbon tax on electricity

11. The UK CPI November 2017 release is used as approximation for oil prices in 2017.

is imposed at the generation level, so is only paid by generators that are carbon-intensive. This implies the carbon tax is levied on the marginal emissions intensity of electricity produced. We assume these carbon tax costs are fully passed on from generators to suppliers but the cost pass-through from suppliers to households is not full, as suppliers pass on the costs based on the average emissions intensity of electricity.[12] This implies that households face a carbon tax imposed on the average emissions intensity of electricity, and the reduced demand for carbon-intensive power generation at the supplier level incentivises cleaner generation.

The emissions intensity of gas is taken to be 0.18kg CO_2 per kWh from the UK Government's *Greenhouse gas conversion factors for company reporting* (Hill et al., 2019). This factor is divided by the assumed average gas boiler efficiency of 90 per cent to obtain the output emissions intensity of gas consumed. The average emissions factor of electricity is assumed to change in line with UK electricity sector decarbonisation projections in the CCC's Fifth Carbon Budget, from levels of 200g CO_2 per kWh in 2020 to 100g CO_2 per kWh in 2030 (CCC, 2015). The emissions intensity of oil is taken to be 0.25kg CO_2 per kWh from Hill et al. (2019). This factor is divided by the assumed average oil boiler efficiency of 90 per cent to obtain the output emissions intensity of oil consumed.

Table A4. Projected carbon intensities and carbon taxes

		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Average carbon intensity of electricity	kg tCO_2 /kWh	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.10
Average carbon intensity of gas-fuelled heat	kg tCO_2 /kWh	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Carbon tax	£/tCO_2	54	56	58	61	63	65	68	70	73	75

Source: Authors

Energy efficiency and heat pump costs and savings

Energy efficiency installation costs for all the three energy efficiency measures are derived from the CCC's *Analysis on abating direct emissions from hard-to-decarbonise homes* (Element Energy and UCL IEDE, 2019). That report provides costs breakdown by property type and property size, which we apply to the case study households as relevant. There are no operating costs in this case and no technology improvements are assumed between now and 2030. The costs of energy efficiency improvements borne by households are annualised assuming a 12-year loan term with an annual interest rate of 5 per cent.

Energy efficiency savings are also taken from the CCC's *Analysis on abating direct emissions from hard-to-decarbonise homes* (Element Energy and UCL IEDE, 2019), which assumes energy savings of 15 per cent from solid or cavity wall insulation and savings of 10 per cent from loft wall insulation. The saving estimates are based on real observed case studies as well as modelling exercises, and therefore reflect typical observed savings, including the rebound effect. These factors are applied to space and water heating consumption after energy efficiency measures are adopted.

An air source electric heat pump is assumed to be installed in households, costs of which are taken from the CCC's report *Net Zero – The UK's contribution to stopping global warming* (CCC, 2019). Similar to energy efficiency measures, no operating costs and technology improvements are assumed between now and 2030. The costs of installing a heat pump are annualised assuming a 10-year loan term with an annual interest rate of 5 per cent.

12. Energy suppliers would have a good case for compensation, as they would be unable to substitute away to other energy generators if the marginal generator of electricity is gas in 2030. A proportion of the remaining carbon tax revenues can be used to compensate these suppliers.

Energy savings from switching to a heat pump are calculated by dividing the space and water heating consumption by the assumed efficiency of the system, taken to be 275 per cent (Sheikh and Callaway, 2019). This gives the additional electricity consumption requirement, with the original fuel demand for space and water heating reducing to zero.

Table A5. Energy efficiency costs and savings

Energy efficiency improvement	Average cost	Source	Expected energy savings	Source
Solid wall insulation	£6,709	1	15%	1
Cavity wall insulation	£744	1	15%	1
Loft insulation (under 125mm)	£1,220	1	10%	1
Switch from direct electric heating / oil heating / a gas boiler to a heat pump	£6,500	2	Assume that the efficiency of a heat pump is 275%	3

Note: Costs of energy efficiency improvements averaged over all house types (unweighted)
Sources: 1. Element Energy and UCL IEDE (2019) 2. CCC (2019) 3. Sheikh and Callaway (2019)

Energy efficiency improvements over the period 2020–2030

Table A6 provides projected rates of energy efficiency and heat pump installations between 2020 and 2030 in the UK.

Table A6. Projected rates of energy efficiency and heat pumps installations, 2020–2030

Type	Projected rate of installation	Source
Solid wall insulation	The CCC projects that solid wall insulation rates will average 145,000 installations per year	1
Cavity wall insulation	The CCC projects that cavity wall insulation rates will average 190,000 installations per year	1
Loft insulation	The CCC projects that loft insulation rates will average 100,000 installations/year	1
Heat pumps	The maximum rate of heat pumps installations by 2030 is based on the CCC's accelerated electrification scenario; an additional constraint is that heat pumps are only installed in households that receive solid wall or cavity wall insulation	2, 3
	The suitability factor of heat pumps for households with oil heating is 70%	4
	The suitability factor of heat pumps for households with gas heating is 70%	4
	The suitability factor of heat pumps for households with direct electric heating is 40%	4

Sources: 1. CCC (2016) 2. Vivid Economics and Imperial College London (2019) 3. Committee on Climate Change (2019) 4. Element Energy and NERA Economic Consulting (2011)

Table A7 shows detailed projections of energy efficiency improvements in fuel-poor and non-fuel-poor households over the period 2020–2030. These projections rely on the assumptions that energy efficiency investments are undertaken as a priority in fuel-poor households. The projected costs of energy efficiency installations amount to £3.1 billion per year over the period 2021–2030, including £1.6 billion in fuel-poor households.

Table A7. Projected energy efficiency improvements, 2020–2030			
Type of energy efficiency improvement	Type of household	Projected no. of installations	Projected installation costs (£m)
Solid wall insulation	Fuel-poor	1,019,280	£6,839m
	Non-fuel-poor	430,720	£2,890m
	All	1,450,000	£9,729m
Cavity wall insulation	Fuel-poor	614,931	£457m
	Non-fuel-poor	1,285,069	£955m
	All	1,900,000	£1,413m
Loft insulation (under 125mm)	Fuel-poor	1,000,000	£1,220m
	Non-fuel-poor	-	-
	All	1,000,000	£1,220m
Switch from direct electric heating to a heat pump	Fuel-poor	95,204	£619m
	Non-fuel-poor	365,428	£2,375
	All	460,631	£2,994m
Switch from an oil boiler to a heat pump	Fuel-poor	116,106	£755m
	Non-fuel-poor	992,760	£6,453m
	All	1,108,866	£7,208m
Switch from a gas boiler to a heat pump	Fuel-poor	1,002,170	£6,514m
	Non-fuel-poor	357,602	£2,324m
	All	1,359,772	£8,839m
Total	Fuel-poor		£16,404m
	Non-fuel-poor		£14,998m
	All		£31,402m

Note: Numbers are for England only. Excludes financing costs. Fuel-poor households represent 11% of all households.
Source: BEIS Fuel Poverty Database; Authors

References

Advani A, Stoye G (2016) *Cheaper, Greener and More Efficient: Rationalising UK Carbon Prices*. https://doi.org/10.1111/1475-5890.12097

Advani A, Bassi S, Bowen A, Fankhauser S, Johnson P, Leicester A, Stoye G (2013) *Energy use policies and carbon pricing in the UK*. IFS Report R84. Institute for Fiscal Studies. https://www.ifs.org.uk/comms/r84.pdf

BEIS [Department for Business, Energy and Industrial Strategy] (2017) *Fuel Poverty Statistics: Detailed Tables, 2017 Contents*

BEIS [Department for Business, Energy and Industrial Strategy] (2019) *Statistical dataset: Annual domestic energy bills*

Berry A (2019) The distributional effects of a carbon tax and its impact on fuel poverty: A microsimulation study in the French context, *Energy Policy* 124: 81–94. doi: 10.1016/j.enpol.2018.09.021.

Bourgeois C, Giraudet L-G G, Quirion P (2019) *Social-environmental-economic trade-offs associated with carbon-tax revenue recycling*. https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2019/7-make-buildings-policies-great-again/social-environmental-economic-trade-offs-associated-with-carbon-tax-revenue-recycling/

Browne J, Dresner S, Ekins P, Hamilton I, Preston I, White V (2013) Designing carbon taxation to protect low-income households. https://www.jrf.org.uk/report/designing-carbon-taxation-protect-low-income-households

Burke J, Byrnes R, Fankhauser S (2019a) *How to price carbon to reach net-zero emissions in the UK*. London: Grantham Research Institute on Climate Change and the Environment. http://www.lse.ac.uk/GranthamInstitute/publication/how-to-price-carbon-to-reach-net-zero-emissions-in-the-uk/

Burke J, Byrnes R, Fankhauser S (2019b) *Global lessons for the UK in carbon taxes*. London: Grantham Research Institute on Climate Change and the Environment. http://www.lse.ac.uk/GranthamInstitute/publication/global-lessons-for-the-uk-in-carbon-taxes/

Burke J, Fankhauser S, Kazaglis A, Kessler L, Khandelwal N, Bolk N, O'Boyle P, Owen A (2020) *Distributional impacts of a carbon tax in the UK: Report 2 – Analysis by income decile*. London: Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy, London School of Economics and Political Science, and Vivid Economics. http://www.lse.ac.uk/GranthamInstitute/publications

Carattini S, Kallbekken S, Orlov A (2019) How to win public support for a global carbon tax, *Nature* (November): 289–291

Committee on Climate Change [CCC] (2016) *Meeting Carbon Budgets: Technical Report to Parliament 2016: Technical Annex 3: Buildings*. https://www.theccc.org.uk/wp-content/uploads/2016/07/2016-PR-Buildings-Tech-Annex.pdf

Committee on Climate Change [CCC] (2017) *Annex: Energy Prices and Bills - impact of meeting carbon budgets*. https://www.theccc.org.uk/wp-content/uploads/2017/03/Energy-Prices-and-Bills-Committee-on-Climate-Change-March-2017-Annex.pdf

Committee on Climate Change [CCC] (2019) *Net Zero: The UK's contribution to stopping global warming*. https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/

Cronin J A, Fullerton D, Sexton S (2019) Vertical and Horizontal Redistributions from a Carbon Tax and Rebate, *Journal of the Association of Environmental and Resource Economists* 6(S1): S169–S208. doi: 10.1086/701191

Day G, Sturge D (2019) *Rethinking Decarbonisation Incentives; Future Carbon Policy for Clean Growth*. Energy Systems Catapult and Energy Technologies Institute. doi: 10.1787/9789264289635-en

Douenne T (2018) *The vertical and horizontal distributive effects of energy taxes: A case study of a French policy*. FAERE. http://faere.fr/pub/WorkingPapers/Douenne_FAERE_WP2018.10.pdf

Element Energy and NERA Economic Consulting (2012) Achieving deployment of renewable heat. Final report for the Committee on Climate Change. http://www.element-energy.co.uk/wordpress/wp-content/uploads/2012/05/CCC-Renewable-Heat-final-report_06.05.11.pdf

Element Energy and UCL IEDE (2019) *Analysis on abating direct emissions from hard-to-decarbonise homes. A study for the Committee on Climate Change*. https://www.theccc.org.uk/publication/analysis-on-abating-direct-emissions-from-hard-to-decarbonise-homes-element-energy-ucl/

Feng K, Hubacek K, Guan D, Contestabile M, Minx J, Barrett J (2010) Distributional effects of climate change taxation: The case of the UK, *Environmental Science and Technology* 44(10): 3670–3676. doi: 10.1021/es902974g

Foster S, Tahir F, Orchard K, Walker I, Raslan R, Schwartz Y (2019) *Analysis on abating direct emissions from "hard-to-decarbonise" homes , with a view to informing the UK's long term targets: A study for the Committee on Climate Change* (July). https://www.theccc.org.uk/publication/analysis-on-abating-direct-emissions-from-hard-to-decarbonise-homes-element-energy-ucl/

Gough I, Abdallah S, Johnson V, RyanCollins J, Smith C (2011) *The distribution of total greenhouse gas emissions by households in the UK , and some implications for social policy*. Nef and CASE. http://sticerd.lse.ac.uk/dps/case/cp/CASEpaper152.pdf

HM Government (2018) *Fossil fuel price assumptions*. https://www.gov.uk/government/collections/fossil-fuel-price-assumptions

Helm D (2017) *Cost of Energy Review*. https://www.gov.uk/government/publications/cost-of-energy-independent-review

Hill N, Karagianni E, Jones L, MacCarthy J, Bonifaz E *et al*.(2019) *2019 Government Greenhouse Gas Conversion Factors For Company Reporting: Methodology paper* (August). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/829336/2019_Green-house-gas-reporting-methodology.pdf

Hills J (2012) *Getting the measure of fuel poverty. Final Report of the Fuel Poverty Review*. CASE. http://sticerd.lse.ac.uk/dps/case/cr/CASEreport72.pdf

International Council on Mining and Metals (2013) *Options in recycling revenues generated through carbon pricing*. https://www.icmm.com/website/publications/pdfs/climate-change/options-recycling-revenues-carbon-pricing

Jenkins J D (2019) *Why Carbon Pricing Falls Short And What to Do About It*. https://kleinmanenergy.upenn.edu/policy-digests/why-carbon-pricing-falls-short

Newbery D M, Reiner D M, Ritz R A (2018) *When is a carbon price floor desirable?* https://doi.org/10.17863/CAM.24678

Office for National Statistics [ONS] (2018) *Consumer Prices Index including owner occupiers' housing costs (CPIH) historical series*

Office for National Statistics [ONS] (2019) *Consumer price inflation item indices and price quotes*. https://www.ons.gov.uk/economy/inflationandpriceindices/datasets/consumerpriceindicescpiandretailpricesindexrpiitemindicesandpricequotes

Ofgem (2019) *Ofgem State of the Market 2019 Report, State of the Market 2019 Report*. http://www.spp.org/publications/QSOM_2014Spring.pdf

Oxford Energy (2016) *Decarbonising heat* (November): 1–3

Sheikh I, Callaway D (2019) Decarbonizing Space and Water Heating in Temperate Climates: The Case for Electrification, *Atmosphere*, 10: 435. doi: 10.3390/atmos10080435

Stiglitz J E (2019) Addressing climate change through price and non-price interventions, *European Economic Review* 119: 594–612. doi: 10.1016/j.euroecorev.2019.05.007

Vivid Economics and Imperial College London (2019) Accelerated electrification and the GB electricity system. Report prepared for Committee on Climate Change. https://www.theccc.org.uk/wp-content/uploads/2019/05/CCC-Accelerated-Electrification-Vivid-Economics-Imperial-1.pdf

Vivid Economics and ODI (2019) *Estimating Effective Carbon Prices: Accounting for Fossil Fuel Subsidies*. https://www.vivideconomics.com/wp-content/uploads/2019/08/Vivid-Economics-ODI-Estimating-Effective-Carbon-Prices-report-.pdf

Vogt-Schilb A, Walsh B, Feng K, Di Capua L, Liu Y, Zuluaga D et al. (2019) Cash transfers for pro-poor carbon taxes in Latin America and the Caribbean, *Nature Sustainability* 2(10): 941–948. https://doi.org/10.1038/s41893-019-0385-0

Wiese C, Cowart R, Rosenow J (2018) *Carbon leverage: Investing Europe's carbon revenues in energy efficiency*. RAP. https://www.raponline.org/knowledge-center/carbon-leverage-investing-europes-carbon-revenues-in-european-energy-efficiency/

This report presents the results of a case study analysis that models the impact of carbon taxation across different household types in the United Kingdom, with compensatory policies focussing mainly on energy efficiency measures.

It is one of two reports that informs:

(i) The UK public debate on carbon pricing for net-zero, including HM Treasury's review of how the transition to net-zero will be funded and where the costs will fall.

(ii) The design of the UK's post-Brexit carbon pricing regime.

The companion report, *Distributional impacts of a carbon tax in the UK: Report 2 – Analysis by income decile*, looks further at how end users can be compensated through a carbon dividend.

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