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Distributional impacts analysis of engineered Greenhouse Gas Removal technologies in the UK:

Report prepared for the National Infrastructure Commission

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About this report

This report has been written by Anne Owen, Josh Burke and Esin Serin to inform the National Infrastructure Commission's study on Greenhouse Gas Removal. For more information on that study, see: **www.gov.uk/government/publications/national-infrastructure-strategy/nic-greenhouse-gas-removal-technologies-study-terms-of-reference**

About the authors

Dr Anne Owen is a University Academic Fellow in End-Use Energy Demand and holds an Engineering and Physical Sciences Research Council (EPSRC) Fellowship award.

Josh Burke is a Senior Policy Fellow at the Grantham Research Institute on Climate Change and the Environment.

Esin Serin is a Policy Analyst at the Grantham Research Institute on Climate Change and the Environment.

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Contents

Summary

Main messages

- Most pathways to net-zero in the UK include the deployment of greenhouse gas removal (GGR) technologies.
- How the costs of deploying GGR technologies are apportioned between sectors significantly impacts the distribution of costs between income groups in the UK.
- Funding GGR via sectors that will have large residual emissions in 2035 and 2050 would increase household costs associated with aviation and land use the most.
- The costs of GGR policy would only exceed 1% of income for income deciles 1–7 in 2050 if GGR deployment costs were very high (£400 per tonne of carbon dioxide-equivalent). Overall, lower-income groups would be disproportionately affected, but the implications differ for each sector.
- As higher-income households have much larger carbon footprints derived from aviation than lower-income households, passing on GGR costs via aviation has the potential to curb emissions while having minimal impacts on social welfare.
- Regarding the impact on food costs, it is important to understand demand changes in the short and long terms in response to changes in price. This will vary between food and income groups and will determine overall equity.
- Any rises in household energy costs associated with the use of GGR technologies would further entrench inequality, as low-income households currently pay disproportionately more towards low-carbon policy costs in the UK.
- This report only considers costs to households from the domestic deployment of GGR technologies. Many goods and services bought by UK households have their supply chain located abroad and there will be further costs associated with imported goods that have been impacted by GGR deployment elsewhere.

GGR technologies and net-zero in the UK: evaluating the distribution of costs

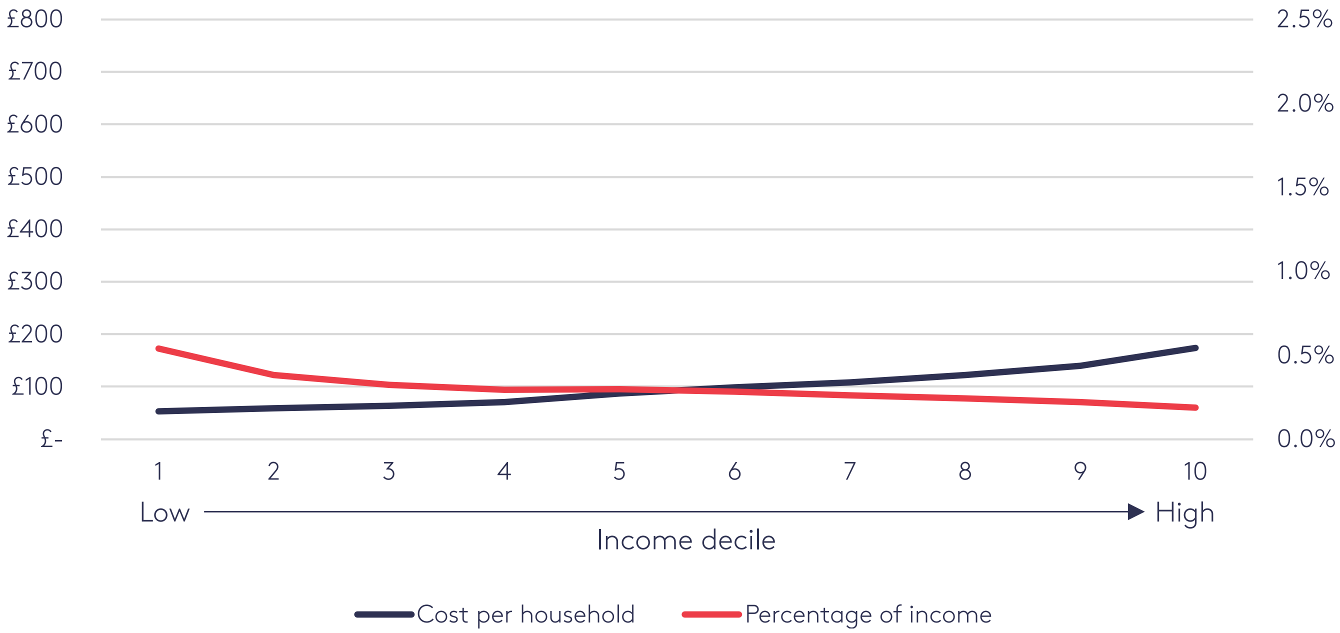
The UK government's net-zero commitment assumes the use of Greenhouse Gas Removal (GGR) technology. Quantifying where the costs of funding these technologies fall – and their magnitude – can provide greater insight into the efficiency and effectiveness of government policies. The aim of this study is to provide information and analysis to the National Infrastructure Commission (NIC) to support its evaluation of the potential distributional impact on equivalised households if costs for deploying and operating GGR technologies are placed on different sectors of the economy. Discussion of engineered GGR throughout this paper solely refers to Direct Air Capture and Bioenergy with Carbon Capture and Storage.

Distributional impacts in 2050

The charts below illustrate the outputs of our distributional impacts model for 2050. The left-hand axis shows the absolute impact, measured in pounds Sterling, and the right-hand axis shows the relative impact, measured as a percentage of income. Households have been equivalised (taking account of differences in size and composition). In the low GGR cost scenario for 2050, the results illustrate that lower-income households experience lower absolute impacts, but higher relative impacts compared with high-income households. GGR costs make up over 0.54% of income for the lowest-income decile (decile 1) versus 0.19% for the highest-income decile (decile 10). This suggests a regressive trend, as the proportional spend on GGR technologies for income decile 1 is more than double that of income decile 10.

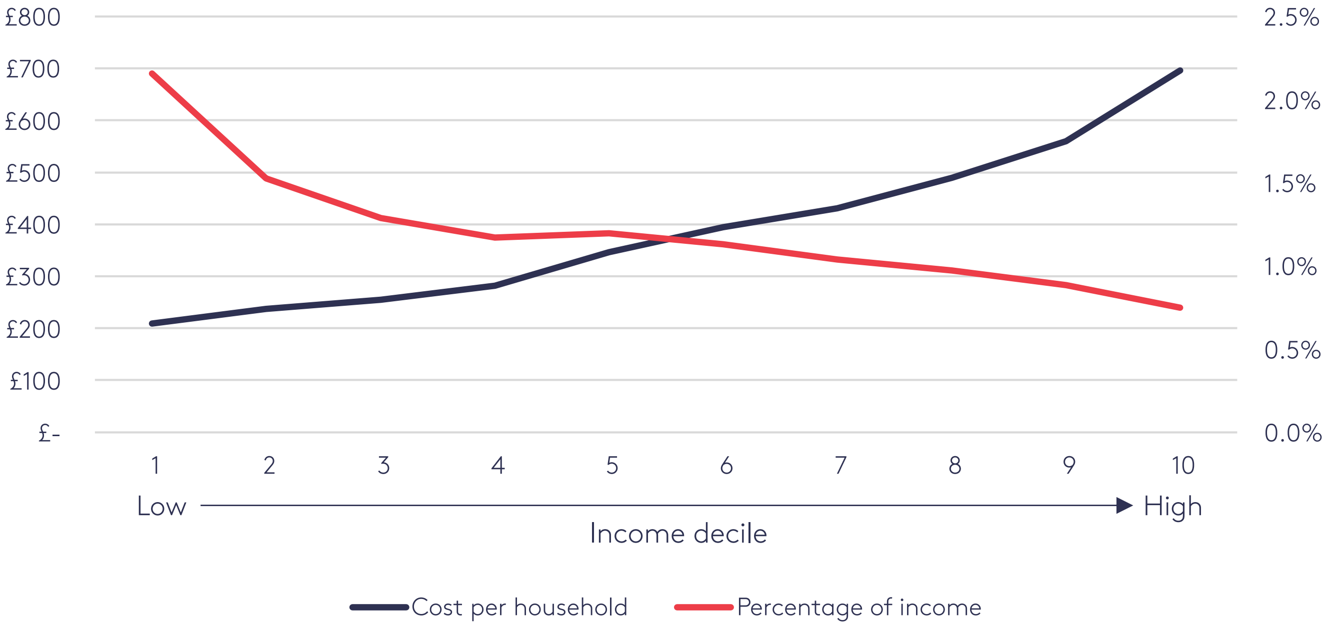
This trend persists under a high GGR cost scenario in 2050, but we see a more pronounced set of results as the cost and scale of GGR increase. The relative cost of GGR exceeds 1% of household income for the first time and this is the case for deciles 1–7. The share is particularly high for the lowest-income decile, at 2.16%. This reflects an absolute annual impact of £209 for decile 1 and £697 for decile 10. However, these values represent a very high upper bound estimate. Further analysis is needed to understand how consumers change their consumption in response to changes in price given the effects of different deployment rates of GGR on households' expenditure and income. Moreover, as the numbers used in this analysis are a static representation of cost, they must be revised over time to reflect the dynamic nature of economies and allow for technological and process innovation.

Figure S1: Annual impact of a GGR cost of £100/tCO_2e on equivalised households in the UK, by income decile in 2050



Note: Model assumptions: 1) Balanced net-zero, 2) Own costs chosen (£100/tCO_2e), 3) Committee on Climate Change total abated emissions chosen, 4) 2050 residual shares chosen, 5) Costs met by households, government, cap and exports, 6) Households pay for net-zero only. (See Table 2.1 for further details.)

Figure S2: Annual impact of a GGR cost of £400/tCO_2e on equivalised households in the UK, by income decile in 2050



Note: Model assumptions as above.

1. Introduction

The role of Greenhouse Gas Removals in achieving net-zero

Global net-zero emissions are essential to keep global warming to 1.5 degrees Celsius and limit the worst impacts of climate change. The *Special Report on Global Warming of 1.5 °C* by the Intergovernmental Panel on Climate Change (IPCC) concluded that "limiting temperature rise to around 1.5 degrees implies reaching net-zero emissions of CO_2 by mid-century" (IPCC, 2018).

More action is required by high-income countries such as the UK if the Paris Agreement targets are to be achieved. The UK government has set itself an unprecedented challenge in legislating to reach net-zero greenhouse gas emissions by 2050; it now faces the task of reaching that goal.

The net-zero commitment by the UK assumes the use of greenhouse gas removal (GGR) technologies and all the net-zero scenarios produced by the Climate Change Committee (CCC) include varying amounts of GGR deployment. This is consistent with almost all modelled emissions scenarios that align with the Paris Agreement's target of limiting global temperature increase to well below 2°C. The IPCC makes a strong case for negative emissions, and 87% of its Integrated Assessment Model (IAM) pathways that limit warming to 1.5 or 2°C rely on negative emissions (Obersteiner et al., 2018).

Despite the prevalence of GGR technology in Paris-consistent scenarios, and the UK's own net-zero technological pathway, there is neither sufficient regulatory support for emerging technologies in the UK, nor an understanding of how they might be funded and who will bear the cost.

As the UK looks ahead to meeting its net-zero target – with GGR playing a role – it is important to understand how the costs of funding these technologies are distributed across society. Depending on the sectors on which the costs are placed, and in the absence of measures to mitigate socially regressive impacts, there is a risk that the cost as a proportion of income will be higher for those in the lower deciles than those in the higher deciles. The UK, as a leader on net-zero policy, is well placed to contribute to the development of policy frameworks for GGR technologies and an understanding of the distributional impacts of deploying GGR as part of the transition to net-zero.

Objectives and scope of this study

The UK Government has requested that the National Infrastructure Commission (NIC) conduct a study into engineered GGR technologies and the potential impacts of their deployment on UK income and expenditure deciles. The aim of this study is to provide information and analysis to the NIC to support its evaluation of the potential distributional impacts on UK income and expenditure deciles if costs for deploying and operating GGR technologies are placed on different sectors of the economy. Discussion of engineered GGR throughout the paper solely refers to Direct Air Capture (DAC) and Bioenergy with Carbon Capture and Storage (BECCS). The full terms of reference can be found **here**.

The analysis consists of three components:

- The consumption (in pounds Sterling) of UK produced goods/services by households in 2018, 2035 and 2050.
- The carbon intensity of household consumption in 2018, 2035 and 2050.
- The magnitude of the impact to households (in pounds and as a percentage of income/expenditure) in 2018, 2035 and 2050.

For the analysis examining the magnitude of the impact to households, we present results for one GGR deployment scenario in 2035 and 2050 with price sensitivities to highlight the different distributional impacts across income deciles 1–10. The study aims to help policymakers identify the distributional impacts of different GGR deployment scenarios using a range of GGR deployment rates and costs.

Structure of the report

Section 2 outlines the analytical approach and the assumptions used in the report's deployment scenario, including a detailed description of the key data sources. Section 3 describes the results of our analysis including an assessment by income decile. Section 4 discusses the implications of the results and areas for further research. Full details of our methodology and results of our analysis by expenditure deciles are provided in the Appendices.

2. Analytical approach and assumptions

Overview

For this analysis, the costs of greenhouse gas removal (GGR) technologies employed by UK industries are assumed to be directly passed on to the consumers of the goods and services provided by these industries. If GGR technologies are costed at a price-per-tonne of abated carbon, the cost to the consumer will be determined by the portion of their associated carbon footprint that is sourced and can be traced back to domestic (UK) industries. Put another way, we only look at emissions from goods and services produced in the UK.

Determining the distributional costs to UK households in 2035 and 2050 requires the following data:

- A model capable of tracing the UK industrial emissions to the point of consumption by UK households, UK Government, UK capital expenditure and exports
- Estimated household consumption in 2035 and 2050
- Estimated greenhouse gas emissions by UK industries in 2035 and 2050
- Estimated cost-per-tonne for GGR technologies in 2035 and 2050
- Estimated abatement potential by GGR technologies in 2035 and 2050

As the CCC's recommended Sixth Carbon Budget pathway stipulates a 78% reduction from 1990 levels in UK territorial emissions by 2035, in 2035, we use the CCC's estimates for the removal of small quantities of emissions, but not all, leaving 965 $MtCO_2e$ of residual emissions (CCC, 2020). In 2050, we model the removal of all residual emissions[1] to achieve net-zero.

Developing a single robust cost estimate for GGR technologies is challenging due to the immature nature of related technologies and the large uncertainty over the cost and scale of GGR deployment. In our analysis, we have therefore used a lower and upper bound range of £100 and £400 per tonne of CO_2e abated (as an average cost across all GGR technologies).

Key data sources

Three key sources of information underpin the analysis:

- The UK's national carbon footprint account and UKMRIO database.
- The living costs and food survey.
- The CCC's Sixth Carbon Budget dataset.

UK's national carbon footprint account

The UK's carbon footprint is an official statistic calculated annually by the University of Leeds (Defra, 2021). The latest carbon footprint to have been reported is that for 2018, calculated in 2021. The calculation uses an environmentally-extended multiregional input-output (MRIO) framework (known as the UKMRIO). This MRIO framework is a macroeconomic model that traces transactions between UK industries and between other industries located anywhere in the world. Using linear algebraic functions, it is possible to calculate the increase in industrial output required by all industries if demand for a particular good or service increases by £1, and hence the associated emissions increase (for further detail please see Appendix 1). Production-based industrial emissions are reallocated to final demand consumption. The consumption-based emissions account includes both the direct and indirect carbon associated with the full supply chain of goods and services consumed in one year. The UKMRIO disaggregates final demand by UK households, UK government, UK capital investment and exports to final demand in other countries.

The UKMRIO framework can be used to estimate footprints for 2035 and 2050 by changing some of the model elements. Replacing emissions by UK industries and household spend data with estimates for 2035 and 2050 will give future carbon footprint scenarios. For this study we have disaggregated total household spend into households grouped by income and expenditure.

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[1] Emissions not abated

The Living Costs and Food Survey

Disaggregating the national carbon footprint by equivalised[2] household income and expenditure decile and by region requires data on the expenditure of different types of households. Since 1957, the Office for National Statistics (ONS) has surveyed UK households annually on their weekly expenditure (UK Data Service, 2021). In 2008, this survey became known as the Living Costs and Food Survey (LCFS). The LCFS achieves a sample of around 6,000 UK households and is used to provide information on retail price indices, National Account estimates of household expenditure, the effect of taxes and benefits, and trends in nutrition. As well as providing information on household spend on more than 300 different product types, additional information is collected such as the composition, age, sex and occupation of household members; total household income; and the household's location, tenure, and dwelling type. We have used the LCFS data for spend in 2018 to develop an expenditure profile for 10 household income groups and 10 household expenditure groups. We can use this data to disaggregate the total household footprint calculated by the UKMRIO and make changes to spends in some of the categories to reflect future spend patterns.

The Climate Change Committee's Sixth Carbon Budget advice

The assumptions for modelling the distributional impacts of GGR deployment across sectors are underpinned by the CCC's Sixth Carbon Budget. For each of the CCC's five net-zero scenarios (Balanced Net-Zero, Headwinds, Widespread Engagement, Widespread Innovation, Tailwinds), the following data have been extracted:

- Energy demand for 2018, 2035 and 2050.
- Residual emissions by sector in 2018, 2035 and 2050.
- Quantity of emissions removed by different GGR technologies in 2035 and 2050.

We use the energy demand data to adjust the household consumption figures to reflect changes in demand for fuel in 2035 and 2050, and make no other changes to household spend. We use the residual emissions data to replace the UK industrial emissions in the UKMRIO framework. The potential volume of emissions that can be removed by GGR technologies form inputs to the next stage in the model.

Assumptions in the deployment scenario

While the Distributional Model underlying this analysis provides the capability to switch between all five of the CCC's net-zero scenarios, the 'balanced net-zero' pathway is chosen to define the deployment scenario in this report (from here on referred to simply as the 'deployment scenario'). The structure of the Distributional Model can be found in Appendix 2 and the key assumptions that underpin the deployment scenario (drawn from the CCC) in Appendix 3.

In the deployment scenario all CCC default settings are used where applicable in the model steps, except for the cost estimates. Here we use a low and a high scenario, where the average abatement cost of all GGR technologies is £100 per tonne in 2035 and 2050 (low) or £400 per tonne in 2035 and 2050 (high).

In steps 4–6, the deployment scenario assumes that GGR deployment in 2035 and 2050 is allocated to sectors based on their proportion of residual emissions in 2050, that the cost falls on both UK households and the Government, but consumers are liable only for the cost of achieving net-zero emissions in the UK, and not more than that (i.e. there is no requirement for them to fund net-negative emissions[3]).

The chosen assumptions for each of the six steps are detailed in Table 2.1.

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[2] Using data on household composition, household spends are equivalised using the modified OECD scale, where the reference case (weight = 1) is a two-adult household with no children.

[3] Several of the CCC scenarios for net-zero achieve net-negative emissions, where gross negative emissions match or exceed gross positive emissions.

Table 2.1: Assumptions in the deployment scenario

Step	Assumptions
Step 1: CCC scenario	Balanced net-zero
Step 2: GGR cost	Low: £100/tCO_2e High: £400/tCO_2e
Step 3: Scale of GGR deployment	Use emissions removed from CCC
Step 4: Sectoral apportionment	Split 2035 and 2050 by 2050 residual shares
Step 5: Share of costs	Costs met by UK households, government, capital and exports
Step 6: Cost of net-zero	Households pay only for net-zero (not beyond)

Results reflect upper bound estimates of the distributional impacts

We use simple and transparent assumptions to examine the magnitude of impact on consumer bills and the numbers we present are helpful to provide a snapshot of the effect on consumers in 2035 and 2050.

However, the results are likely to reflect upper bound estimates of the distributional impacts because we make the following assumptions:

- The change in price does not lead consumers to change their consumption habits.
- The proportion of UK goods and services remains constant, i.e. consumers do not switch to purchasing more imported goods in response to a price change on UK produced goods and services.
- There is full cost pass-through, whereby firms pass all the cost on to consumers of the goods or services it produces, i.e. firms do not absorb any costs or change their production processes in response.

However, the upper bound estimates may be moderated as we only track increased costs due to domestic policy. It is highly likely that goods for which the supply chain sits abroad will also increase in price due to low costs of carbon policies such as GGR deployment in those respective countries. Thus, consumers may experience higher future product prices and higher overall household bills when accounting for imports from countries in which GGR technologies have been deployed.

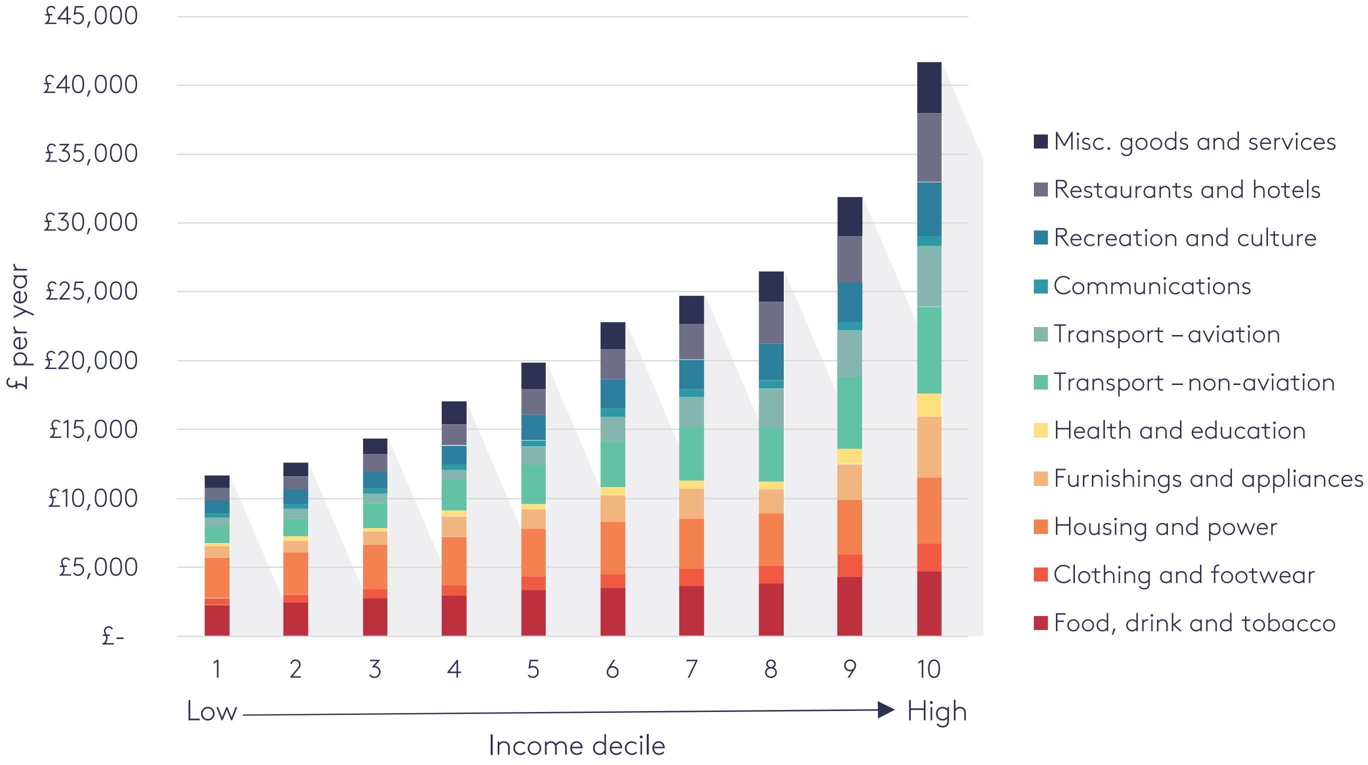
3. Analysis

UK household expenditure on UK-produced goods and services

This section includes two charts presenting UK household expenditure. The first chart (Figure 3.1) illustrates changes in 2018 household expenditure by income deciles 1–10 for 11 expenditure categories of interest. Figure 3.2 then examines changes in total expenditure by UK households for the same categories across three years (2018, 2035 and 2050) for the deployment scenario (aligned with the CCC's balanced net-zero pathway, as explained in Section 2).

There is a clear disparity in expenditure across income deciles, with households in income decile 1 spending £11,678 per year, compared with income decile 10, which spends almost four times as much (£41,676). Overall, there is a fairly linear relationship between total household expenditure and income decile with incremental increases. Only the expenditure of the highest-income decile increases by a notably larger margin from the previous decile. Broadly speaking, housing and power, transport (aviation and non-aviation), and food, drink and tobacco make up the largest areas of expenditure across all income deciles. The share of total expenditure for income decile 1 is highest for housing and power. In contrast, the highest share of total expenditure for income decile 10 is on non-aviation transport.

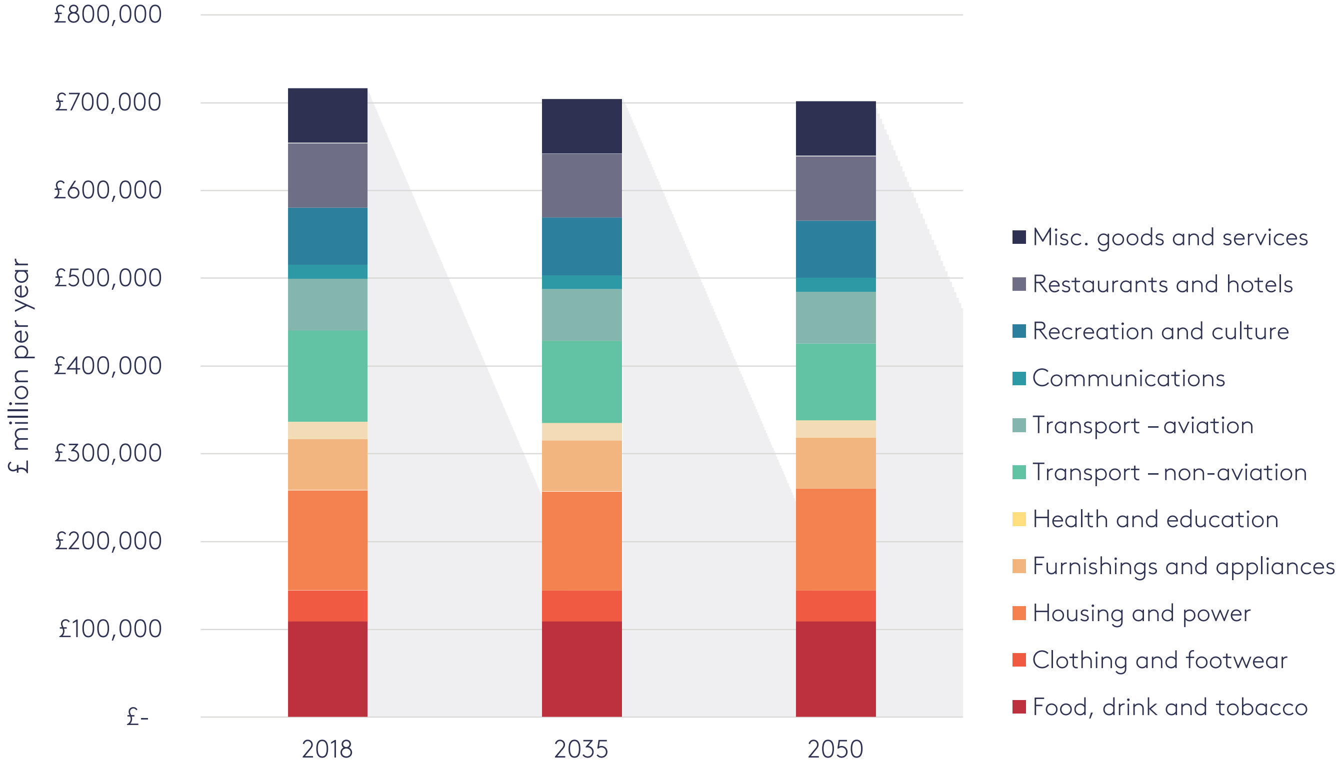
Figure 3.1: UK equivalised household expenditure in 2018, by income decile



Source: Authors

In Figure 3.2, the only categories of household expenditure that change in 2035 and 2050 are in the fuel sectors and those changes are based on the CCC's future energy demand scenarios. We observe little change overall in total household expenditure across the different years and we assume this also holds across income distribution. In all three years, transport (aviation and non-aviation combined) takes the highest share of spending, followed by housing and power, and food, drinks and tobacco.

Figure 3.2: UK total household expenditure in the deployment scenario, 2018, 2035 and 2050



Source: Authors

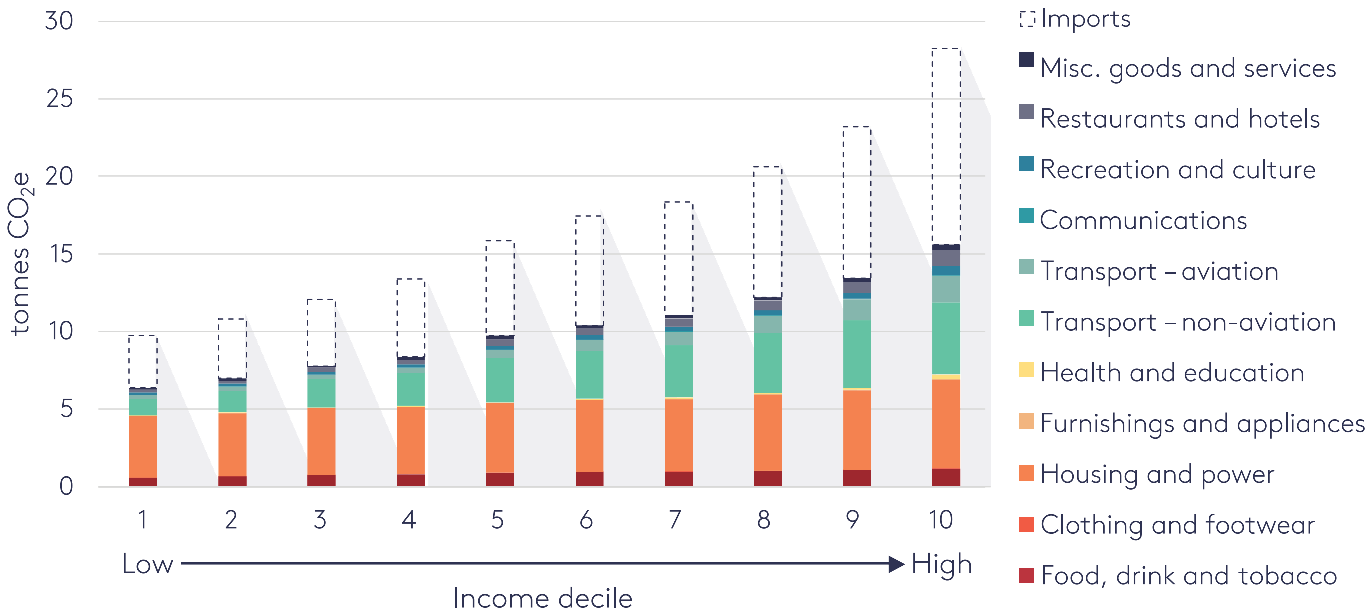
Equivalised household carbon footprints (tonnes CO_2e)

The following analysis examines the carbon intensity of household consumption based on the same consumption categories as the previous section. Figures 3.3, 3.4 and 3.5 present changes in household carbon footprint by income deciles for the years 2018, 2035 and 2050, respectively. Figure 3.6 presents changes in an average two-adult household carbon footprint for the same years in the deployment scenario.

Figure 3.3 illustrates a fairly linear relationship between household carbon footprint and income in 2018. Across the 11 sectors of interest, we calculate that in 2018 the highest-income decile will emit nearly three times more carbon dioxide equivalent (CO_2e) than decile 1. Compared to past studies examining the carbon footprint of UK income deciles, Figure 3.3 illustrates that the disparity in carbon footprint has reduced very slightly over time (Gough, 2011).

The main difference in emissions by equivalised income decile is in the sectors of health and education, transport, and restaurants and hotels. High-income households tend to use more emissions-intensive transport – such as aviation – than lower-income households. This is evidenced by the highest-income households emitting seven times as much CO_2e from aviation as the lowest-income households. Measures to address the carbon footprint of transport and particularly aviation would therefore not necessarily be regressive as the share of income spent on transport increases with income. In contrast, measures to reduce emissions from housing and power would be far more regressive, hitting low-income households disproportionately, as income decile 10's emissions from housing and power are only 1.4 times those of income decile 1, the lowest ratio of all the categories.

Figure 3.3: UK equivalised household carbon footprint in 2018, by income decile

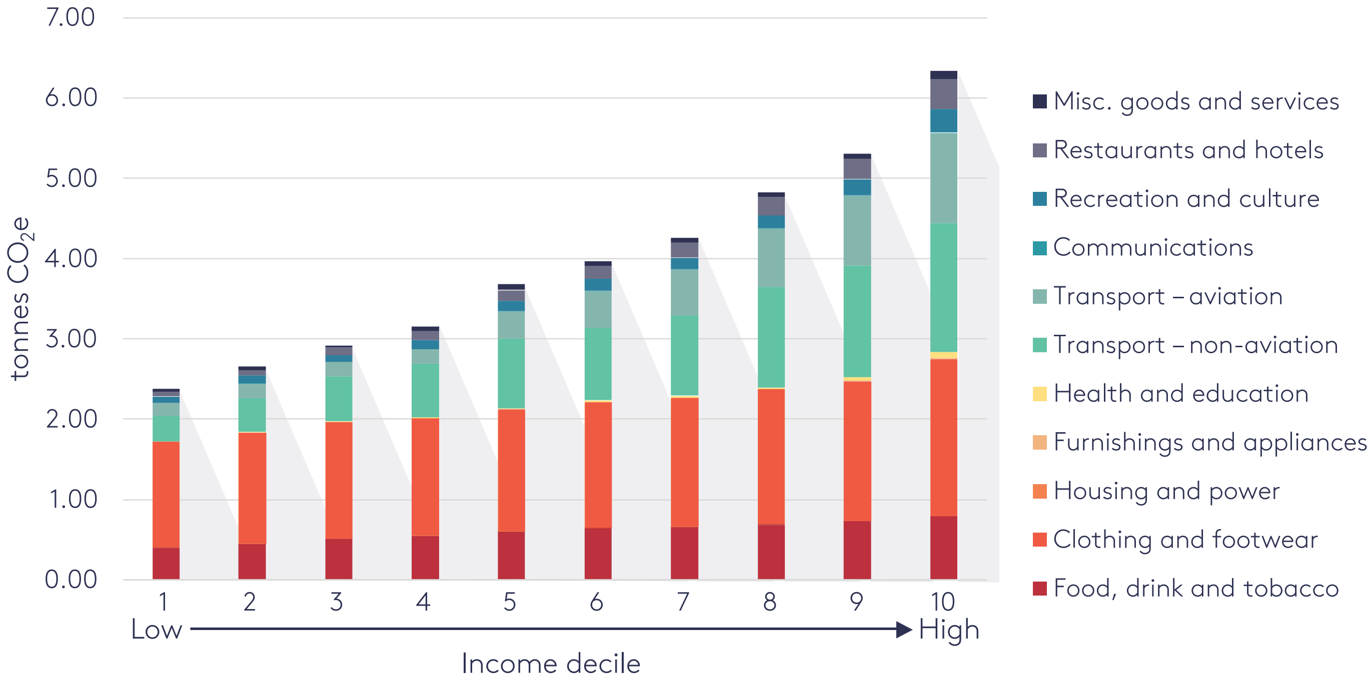


Note: Imports has an empty box with a dashed line to separate the category as we do not consider imports in the rest of the analysis. Source: Authors

Figures 3.4–6 take into account the expected carbon intensity of goods/services in 2035 and 2050 under the deployment scenario. The CCC's Sixth Carbon Budget projections of future energy demand are used to adjust the household consumption figures to reflect changes in demand for fuel in 2035 and 2050.

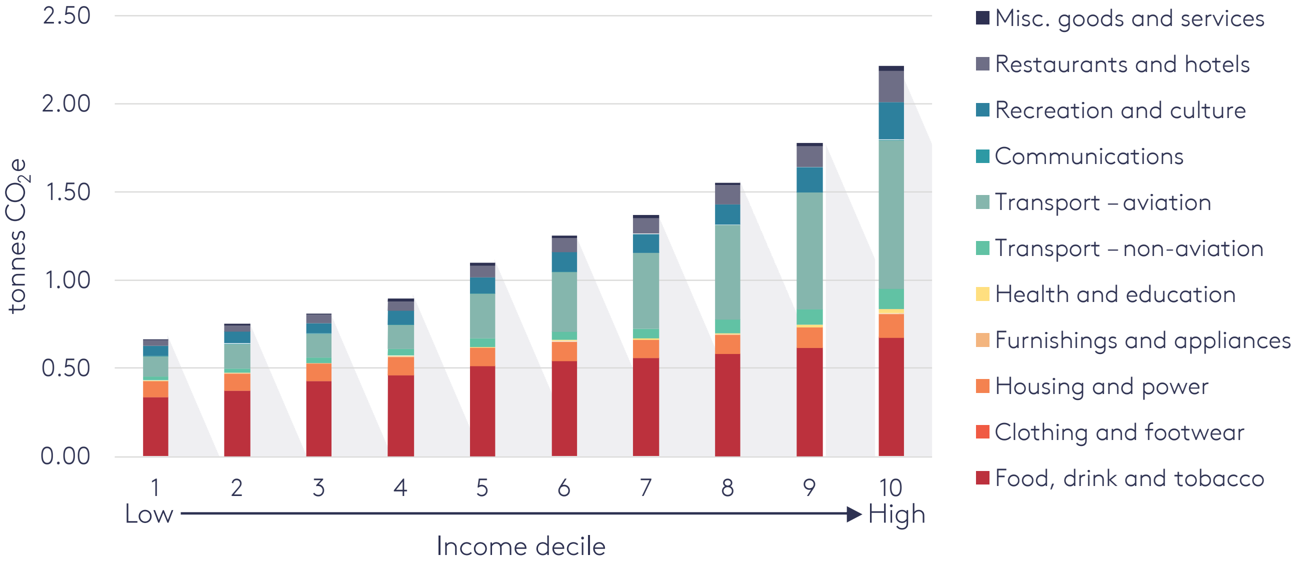
Figures 3.4 and 3.5 also illustrate a fairly linear relationship between household carbon footprint and income, but we observe that household footprints fall considerably across all income deciles between 2018 and 2050.

Figure 3.4: UK equivalised household carbon footprint in the 2035 deployment scenario, by income decile (imports excluded)



Source: Authors

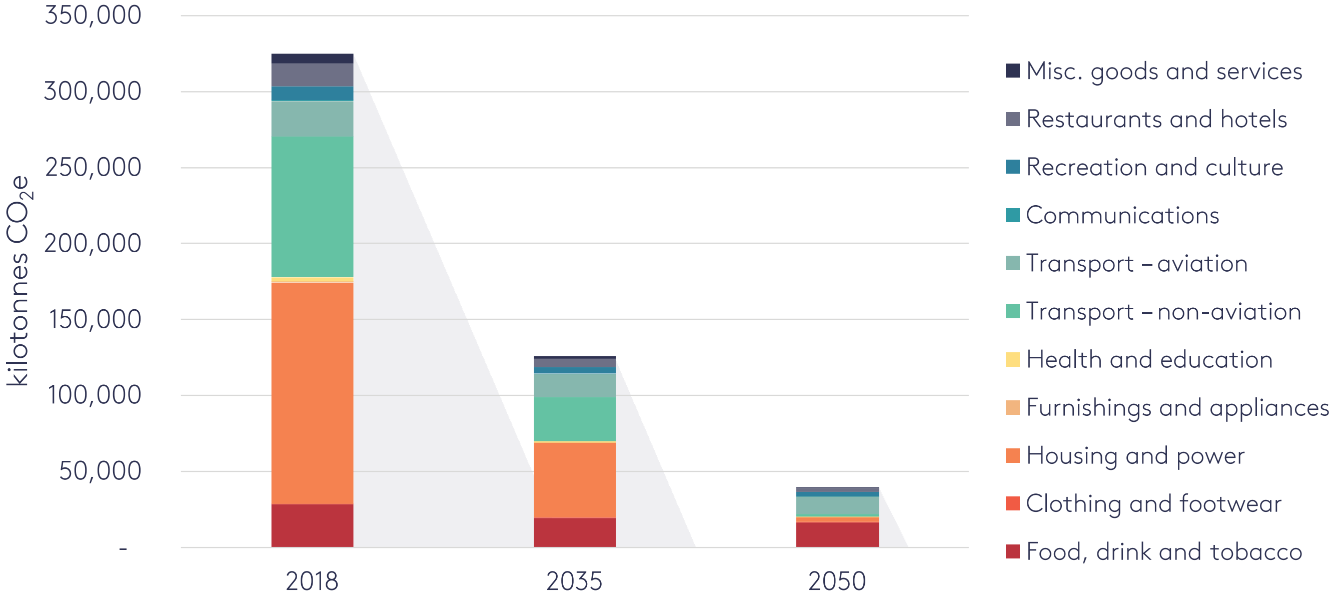
Figure 3.5: UK equivalised household carbon footprint in the 2050 deployment scenario, by income decile (imports excluded)



Source: Authors

Unlike household expenditure, which is expected to remain largely constant to 2050, household carbon footprints under the Balanced Net-Zero pathway clearly decrease over time. This demonstrates a decoupling of household expenditure from household carbon footprint. Here, we show that the total emissions associated with households (excluding imports) reduces by 38% between 2018 and 2035 and by a further 27% between 2035 and 2050. Between 2018 and 2050 the total emissions associated with households decreases by approximately 55%. Although the largest share of household carbon footprint can be attributed to housing and power in both 2018 and 2035, by 2050 it is no longer the biggest source of household emissions. Instead, by 2050 food, drinks and tobacco and aviation contribute the largest shares. This trend reflects the increasing decarbonisation of the power and heating sector and larger shares of residual emissions in the land use and aviation sectors. This is an expected result, given these are particularly hard-to-abate sectors, where low-carbon solutions or GGR technologies may still not be economically viable in 2050, or significant behavioural changes will be needed.

Figure 3.6: UK household carbon footprint in the deployment scenario, 2018, 2035 and 2050 (imports excluded)



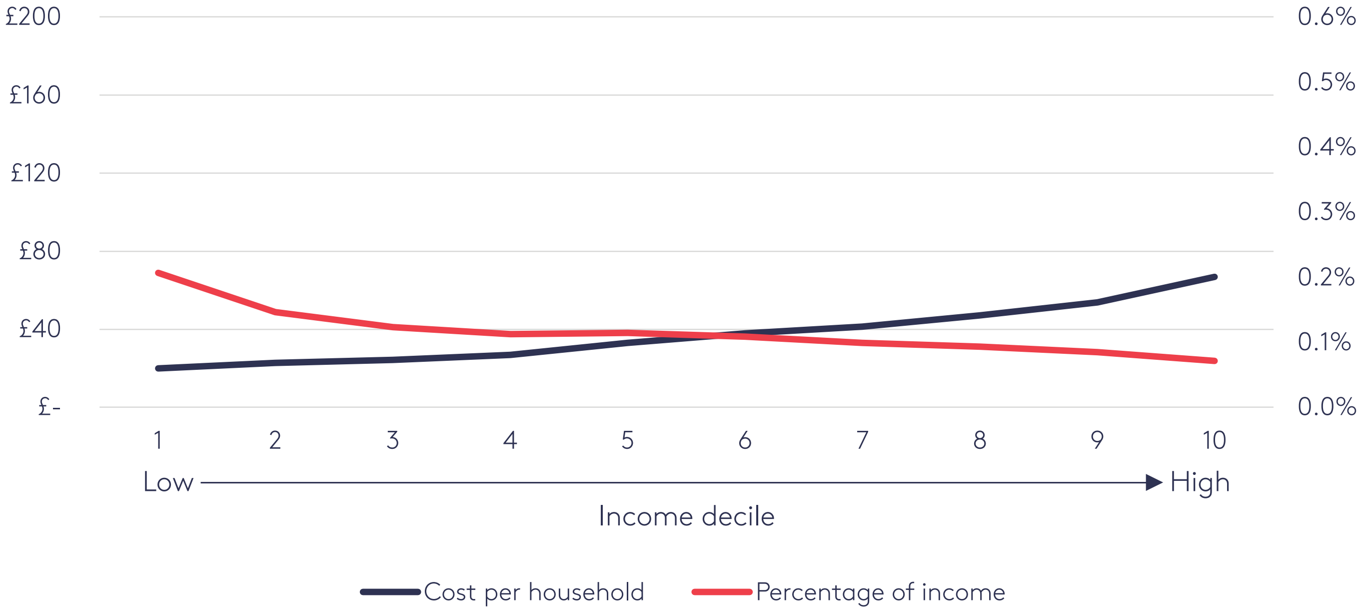
Source: Authors

Magnitude of distributional impacts

Income decile results – deployment scenario with low-cost GGR

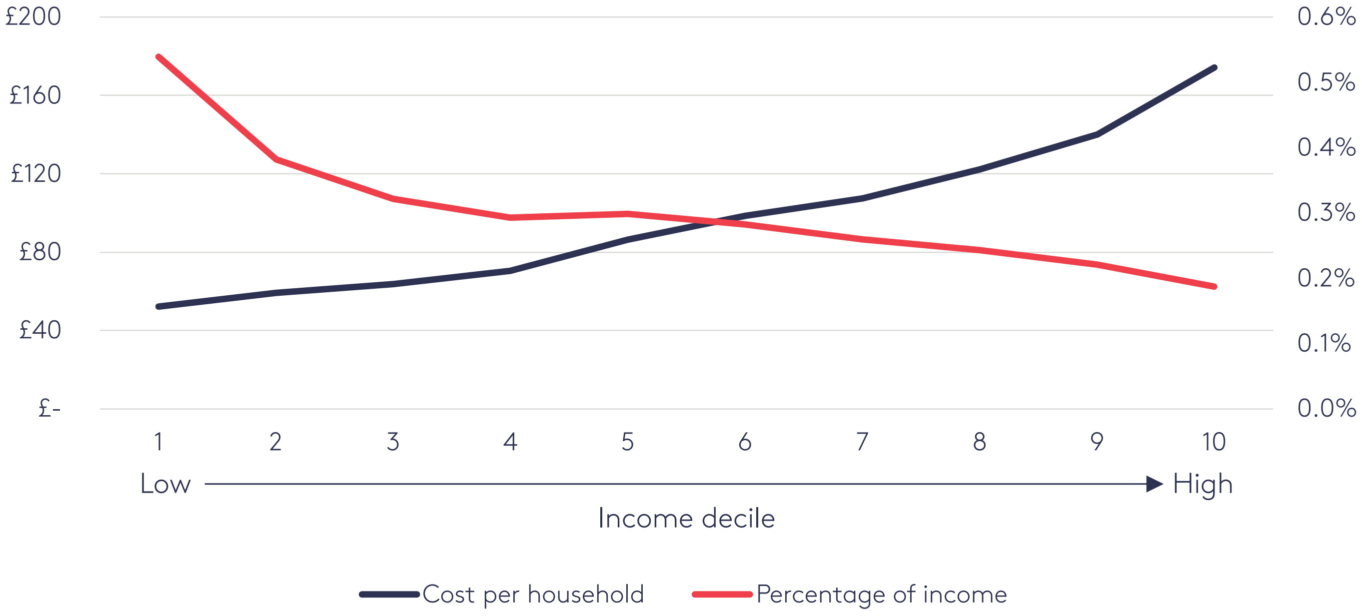
Figures 3.7 and 3.8 illustrate the distributional impacts of the low-cost GGR scenario on income deciles 1–10 in 2035 and 2050. The left-hand axis shows the absolute impact, measured in pounds, and the right-hand axis shows the relative impact, measured as a percentage of income.

Figure 3.7: Annual impact of a GGR cost of £100/tCO_2e on equivalised households, by income decile in 2035



Note: Model assumptions: 1) Balanced net-zero, 2) Own costs chosen (£100/tCO_2e), 3) Committee on Climate Change total abated emissions chosen, 4) 2050 residual shares chosen, 5) Costs met by households, government, cap and exports, 6) Households pay for net-zero only. (See Table 2.1 for further details.) Source: Authors

Figure 3.8: Annual impact of a GGR cost of £100/tCO_2e on equivalised households, by income decile in 2050



Note: Model assumptions as above. Source: Authors

In the low-cost scenario, we assume that the cost of all GGR technologies is £100/tCO_2e in 2035 and 2050. Under this assumption, although the distribution is relatively flat in 2035, we observe a regressive impact. This occurs when lower-income households pay larger percentages of their incomes in taxes or policy costs compared with higher-income households. In our analysis, the cost of GGR constitutes 0.21% of the lowest-earning decile's income, and just 0.07% of the highest-earning decile. This translates to £20 in absolute terms for the lowest-income decile, and over £67 for the highest-income decile, representing a broadly linear relationship between income decile and the average cost from GGR per equivalised household.

This regressive trend becomes even more pronounced in 2050, with the gap between absolute and relative cost growing larger. This means that the proportion of income decile 1 spends on GGR more than doubles. In 2050, GGR costs constitutes over 0.5% of the income for the lowest-income decile versus about 0.2% for the highest-income decile. This means the difference in the proportion of affected income between the highest and lowest earning deciles is 0.3% in 2050, up from 0.13% in 2035. The cost per equivalised household increases to around £52 for the lowest-income decile, and to £174 for the highest-income decile. To put these costs into perspective, for decile 1 this is equivalent to three-quarters of a full tank of petrol for an average family-sized car; for income decile 10, the additional annual costs of paying for GGR are equivalent to a flight from London to Morocco.

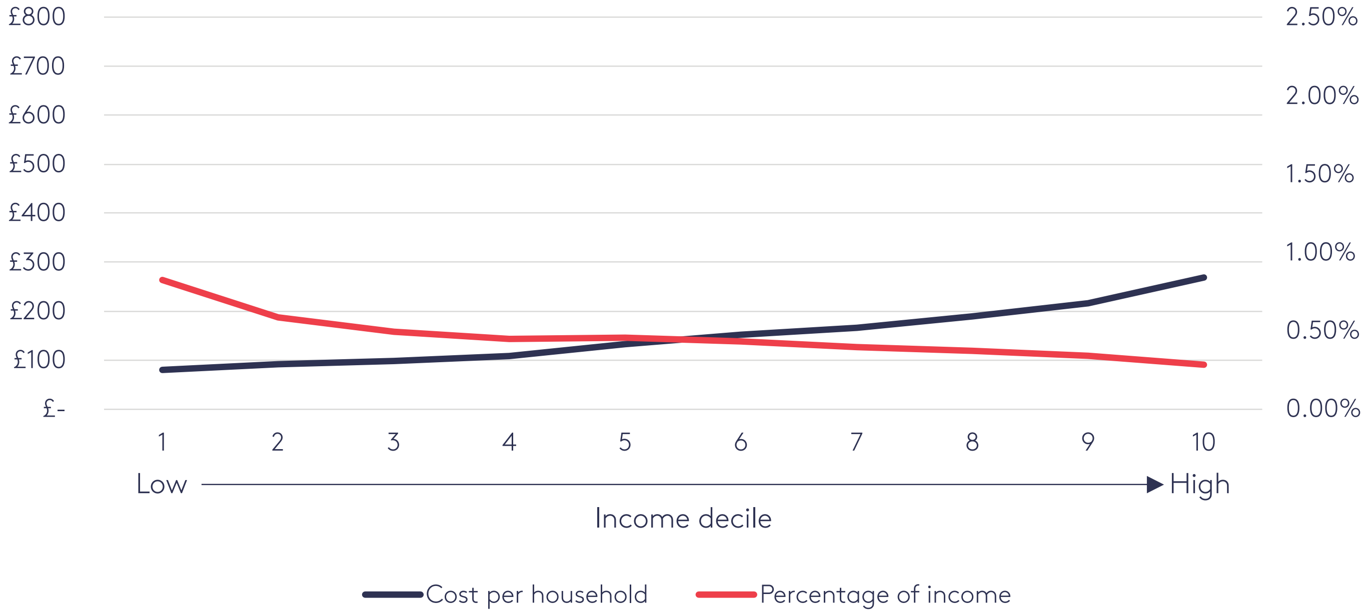
Income decile results – deployment scenario with high-cost GGR

In the high GGR cost scenario we use a price of £400/tCO_2e for all GGR technologies. This value is held constant in 2035 and 2050.

In 2035, we observe that the cost of GGR has a more severe regressive impact on low-income households, where it constitutes around 0.8% (almost £80) of the lowest-earning decile's income, compared with almost 0.3% (£267) of the highest-earning decile's. That means the lowest-earning decile spends 0.5% more of their income on GGR costs than the highest-earning decile, where the equivalent difference is 0.13% in the low GGR cost scenario described above.

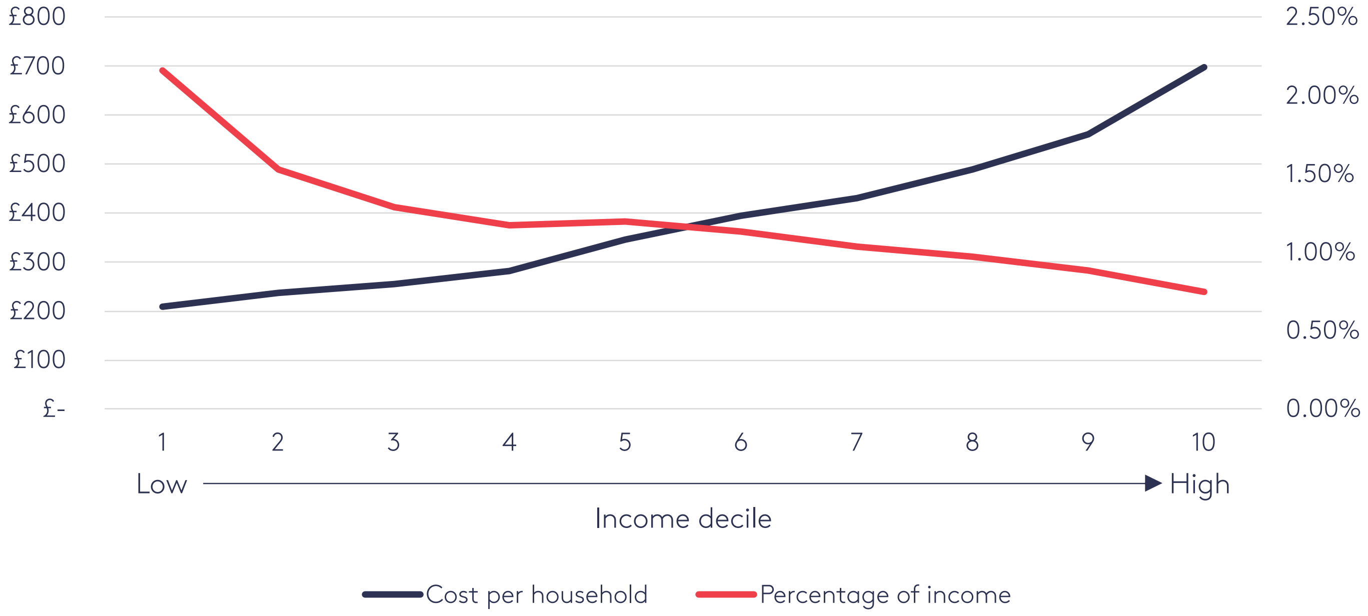
In 2050, we see that the cost of GGR exceeds 1% of household income for the first time. The cost of GGR represents over 1% of household income for seven of the 10 household income deciles, and the share is particularly high for the lowest-income decile, at 2%. GGR costs also translate into much higher values in absolute terms across all income deciles here compared with the same scenario in 2035, as well as both years of the low GGR cost scenario. For instance, the £209 facing the lowest-income decile in this scenario is more than the £174 facing the highest-income decile in the £100/tCO_2e scenario for the year 2050. For income decile 10, the cost impact of GGR is £695. For income decile 1, these costs are approximately equivalent to a flight from London to Moscow and for income decile 10, to a flight from London to Wellington, New Zealand.

Figure 3.9: Annual impact of a GGR cost of £400/tCO_2e on equivalised households, by income decile in 2035



Note: Model assumptions as above. Source: Authors

Figure 3.10: Annual impact of a GGR cost of £400/tCO_2e on equivalised households, by income decile in 2050

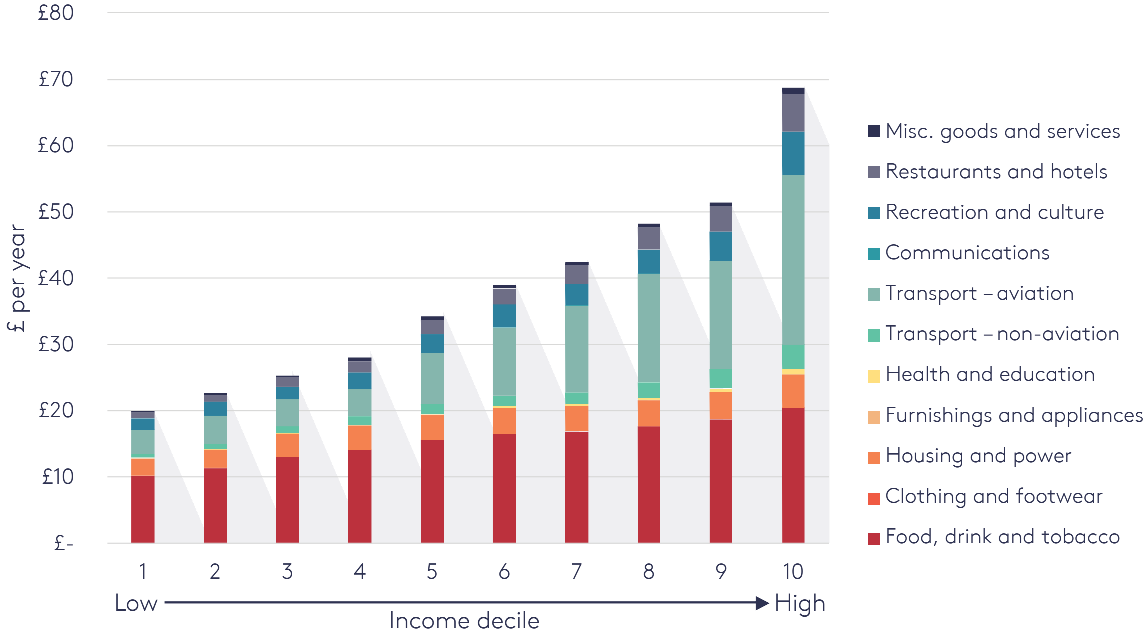


Note: Model assumptions as above. Source: Authors

Cost impact for each income decile, split by product – deployment scenario with low cost GGR

The total costs to equivalised households shown in charts 3.7–10 are now broken out into 11 product categories. The pass-through of GGR costs to products is directly affected by how the GGR costs are apportioned at the sectoral level. As the deployment scenario in this analysis attributes the costs of GGR to the sectors with large residual emissions (i.e. aviation and land use) we therefore see expected increases in the costs of food, drink and tobacco and of aviation. It is important to understand how these costs are passed through to specific products and income deciles as this will determine the extent to which higher prices are regressive or progressive. This is discussed further in Section 4.

Figure 3.11: Annual product impact of a GGR cost of 100/tCO$_2$e on equivalised households, by income decile in 2035

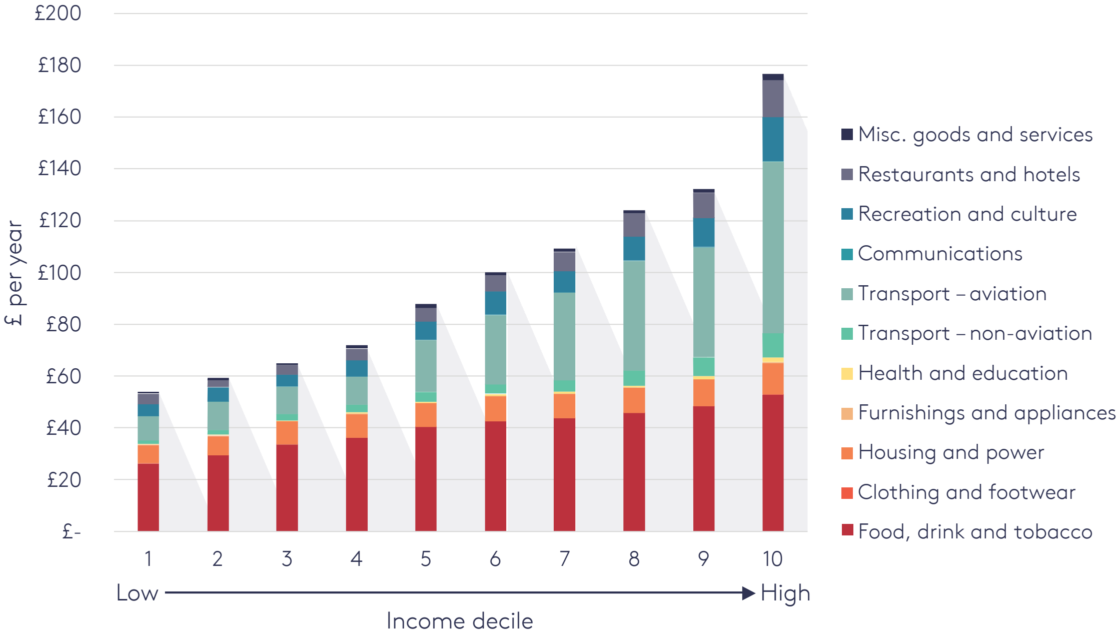


Note: Model assumptions as above. Source: Authors

Figure 3.11 illustrates that if the GGR technologies are funded via the sectors with large residual emissions, consumers will face higher prices for aviation and food, drink and tobacco. For income decile 1, the total economic impact is £20, with increases in the cost of food and non-alcoholic drinks accounting for approximately 50% of the total costs. This is far by the largest share of total costs. In contrast, for income decile 10, of the £68 total cost, the largest share is attributable to aviation (37%), followed by food, drink and tobacco (30%).

Examining the increases in product prices for 2050, we observe the same pattern of results. In both charts, food, drink and tobacco make up the largest share of costs for income deciles 1–9, while for decile 10 aviation takes this role. In 2050 we also observe a much greater range of costs (for income deciles 1–10), at £123 compared with a range of £48 in 2035.

Figure 3.12: Annual product impact of a GGR cost of £100/tCO$_2$e on equivalised households, by income decile in 2050

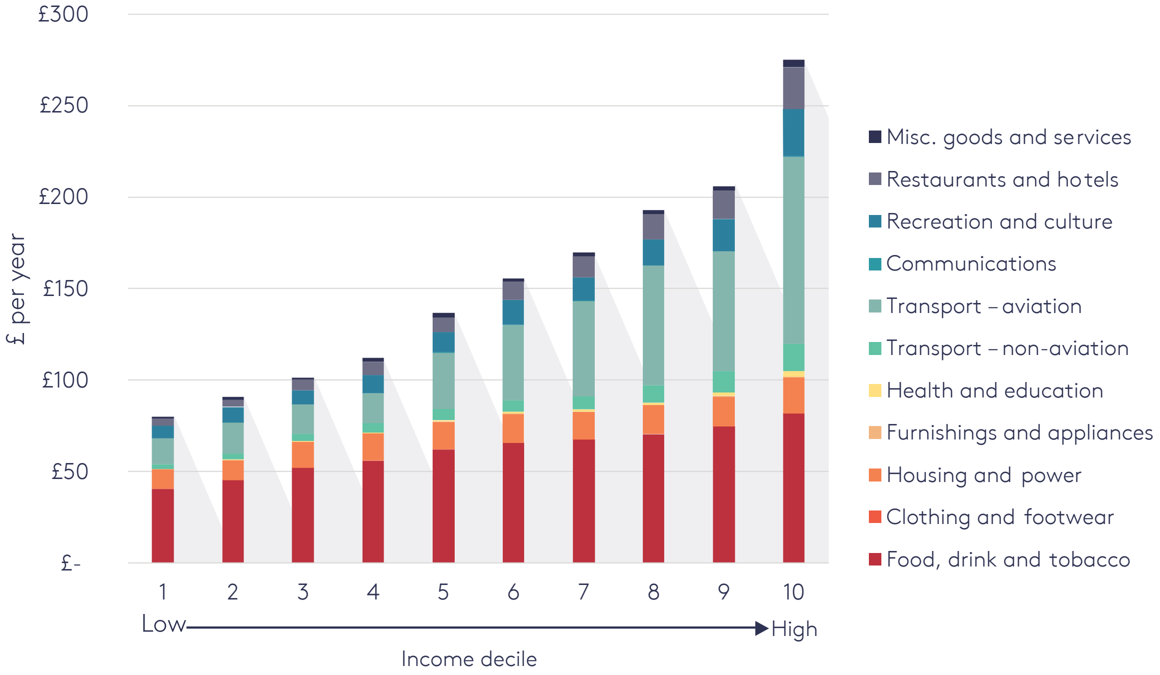


Note: Model assumptions as above. Source: Authors

Cost impact for each income decile, split by product – deployment scenario with high-cost GGR

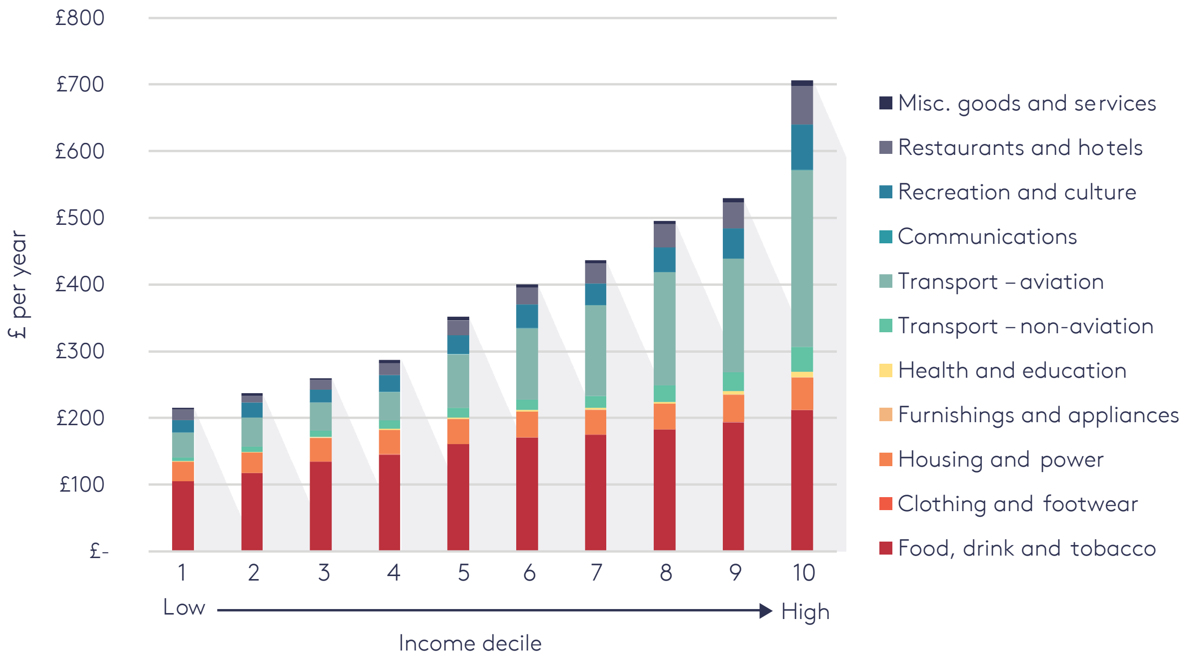
Figures 3.13 and 3.14 examine the impact on equivalised households in 2035 and 2050 when the cost of GGR is assumed to be £400/tCO_2e. In both the high-cost scenario charts below we observe the same pattern as the low-cost scenario. For example, for deciles 1–9 costs associated with food, drink and tobacco make up the largest share of total costs, and for income decile 10 aviation remains the largest share of total costs. For income decile 1, aviation only accounts for 18% of total costs, whereas this is double at 38% for income decile 10.

Figure 3.13: Annual product impact of a GGR cost of £400/tCO_2e on equivalised households, by income decile in 2035



Note: Model assumptions as above. Source: Authors

Figure 3.14: Annual product impact of a GGR cost of £400/tCO_2e on equivalised households, by income decile in 2050



Note: Model assumptions as above. Source: Authors

In the high-cost scenario, the total economic impact to income decile 1 is £80 in 2035 and £215 in 2050. For income decile 10, the total economic impact is £274 in 2035 and £707 in 2050.

Compared with aviation and food, drink and tobacco, additional costs to housing and power are much more equal across the income deciles. These additional costs are partly derived from placing GGR costs on the land use sector, which raises the cost of timber used in household construction. For lower-income households this amount will represent a much larger proportion of total income and therefore has the potential to be particularly regressive.

4. Discussion

The importance of equitable policy design

Designing efficient and effective climate policy for a net-zero world requires careful consideration of how costs and benefits are distributed across society in ways that determine both the immediate political feasibility and the durability of policy options over time. As recent protests in Chile and France and unrest in North Africa in 2011 demonstrate, consumers are extremely sensitive to changes in the cost of vital provisions such as transport and food. By looking at the impacts at different levels of household income, this analysis allows policymakers to conceptualise where and how these costs will fall, providing greater insight into the equity of government policies.

Understanding the distributional nature of impacts is particularly important as, to date, little empirical evidence exists on how different forms of policy support impact public perceptions of GGR technologies. However, a study by Bellamy (2018) found that guarantees of higher prices for producers selling energy derived from BECCS were strongly opposed by the public, owing to participants' knowledge of the high costs imposed on taxpayers by this mechanism.

Sectoral implications

How the costs of deploying GGR technologies are apportioned between sectors is particularly important if, as in this study, the costs of GGR are passed through to consumers via higher prices for goods and services within these sectors. For example, if the costs of GGR are apportioned based on residual emissions, aviation and the land use sector will be disproportionately affected, as we show in Figures 3.11 and 3.14.

However, because the demand elasticities for food and aviation differ across households at different levels of income, the impacts are likely to be different between income deciles. As higher-income households have much larger carbon footprints deriving from aviation than lower-income households, passing on GGR costs via the aviation sector has the potential to curb carbon dioxide emissions with minimal impacts on social welfare, as income elasticities decline with rising income level. Therefore, across deciles air travel is a 'luxury' good as opposed to a necessity (i.e. income elasticity is above 1 [Fouquet, 2020]).

Regarding food, it is important to understand short- and long-term demand changes in response to changes in cost. Research by the Department for Environment, Food and Rural Affairs suggests that an increase in the price of non-food items and the resultant decrease in real income leads households to reduce their food consumption (Defra, 2011). For most foods, including fish, fruit, nuts and vegetables, consumers appear to buy products out of habit and continue to do so even when prices rise, making the effort to look for cheaper alternatives only in the long run.

Alternatively, if GGR technologies were funded via the sectors in which they were produced (e.g. BECCS power in the power sector), passing on higher costs to consumers in the form of higher energy prices would hit low-income households disproportionately and exacerbate existing inequalities. Low-income households already pay disproportionately more towards low-carbon policy costs in the UK.

Understanding and accounting for these dynamics is critical to fully understanding the distributional implications of policy design, particularly how spending on critical commodities as a proportion of income varies between different income groups. While this is outside the scope of this work, it could be an area for further exploration.

More generally, further analysis is needed to fully understand the substitution effects of different deployment rates of GGR on households' expenditure and income. As the numbers are a static representation of cost, they must be revised over time to reflect the dynamic nature of economies and allow for technological and process innovation.

Future spend scenarios

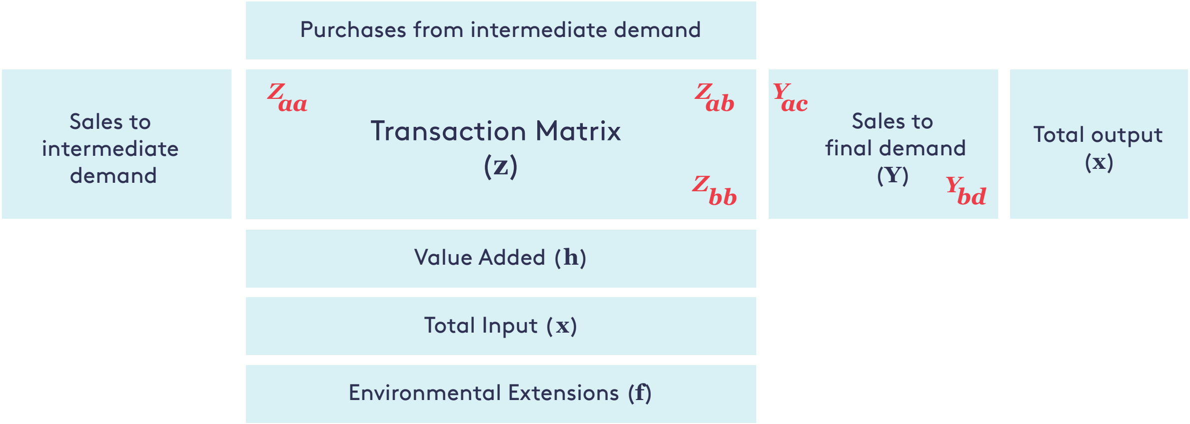
Further work could also focus on reflecting the full extent of behaviour change potential in this type of analysis. While the Distributional Model translates the CCC's energy demand figures for 2018, 2035 and 2050 into changes in fuel-related household expenditure for the respective years, information is not available on how households would modify their future expenditure for other categories of interest. This means behavioural changes due to social, environmental or cultural reasons (e.g. dietary habits, fashion trends) are excluded from the current analysis.

Appendix 1: Methodology

Input-output analysis to calculate carbon footprints

For household carbon footprints calculated using input-output analysis, environmental economists have adopted input-output models (IOM) for their ability to make the link between the environmental impacts associated with production techniques and the consumers of products. The Leontief Input-Output model (Figure A1) is constructed from observed economic data and shows the interrelationships between industries that both produce goods (outputs) and consume goods (inputs) from other industries in the process of making their own product (Miller and Blair, 2009).

Figure A1: Basic structure of a Leontief Input-Output Model



Consider the transaction matrix $\mathbf{Z}$: reading across a row reveals which industries a single industry sells to and reading down a column reveals who a single industry buys from. A single element, $\mathbf{z_{ij}}$, within $\mathbf{Z}$, represents the contributions from the ith sector to the jth industry or sector in an economy. For example, $\mathbf{z_{aa}}$ represents the ferrous metal contribution in making ferrous metal products, $\mathbf{z_{ab}}$, the ferrous metal contribution to car products and $\mathbf{z_{bb}}$the car production used in making cars. Final demand is the spend on finished goods. For example, $\mathbf{y_{ac}}$is the spend on ferrous metal products by households as final consumers whereas $\mathbf{y_{bd}}$ is the spend on car products by government as final consumers. The total output ($\mathbf{x_i}$) of a particular sector can be expressed as:

$$\mathbf{x_i = z_{i1} + z_{i2} + \ldots + z_{ij} + y_i} \qquad (1)$$

where $\mathbf{y_i}$is the final demand for that product produced by the particular sector. If each element, $\mathbf{z_{ij}}$, along row i is divided by the output $\mathbf{x_i}$, associated with the corresponding column j it is found in, then each element in $\mathbf{Z}$ can be replaced with:

$$\mathbf{a_{ij}} = \frac{\mathbf{z_{ij}}}{\mathbf{x_j}} \qquad (2)$$

to form a new matrix $\mathbf{A}$.

Substituting for (2) in equation (1) forms:

$$\mathbf{x_i = a_{i1}x_1 + a_{i2}x_2 + \cdots a_{ij}x_i + y_i} \qquad (3)$$

Which, if written in matrix notation is $\mathbf{x} = \mathbf{Ax} + \mathbf{y}$. Solving for $\mathbf{y}$ gives:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{y} \qquad (4)$$

where $\mathbf{x}$ and $\mathbf{y}$ are vectors of total output and final demand, respectively, $\mathbf{I}$ is the identity matrix, and $\mathbf{A}$ is the technical coefficient matrix, which shows the inter-industry requirements. $(\mathbf{I} - \mathbf{A})^{-1}$ is known as the Leontief inverse (further identified as $\mathbf{L}$). It indicates the inter-industry requirements of the ith sector to deliver a unit of output to final demand. Since the 1960s, the IO framework has been extended to account for increases in the pollution associated with industrial production due to a change in final demand (Miller and Blair, 2009).

Consider, a row vector f of annual greenhouse gas emissions generated by each industrial sector:

$$\mathbf{e} = \mathbf{f}\hat{\mathbf{x}}^{-1} \quad (5)$$

is the coefficient vector representing emissions per unit of output. Multiplying both sides of (4) by $\mathbf{e}'$ gives:

$$\mathbf{e}'\mathbf{x} = \mathbf{e}'\mathbf{L}\mathbf{y} \quad (6)$$

and simplifies to $\mathbf{F} = \mathbf{e}'\mathbf{L}\mathbf{y}$ (7)

where $\mathbf{F}$ is the greenhouse gas emissions in matrix form, allowing consumption-based emissions to be determined. $\mathbf{F}$ is calculated by pre-multiplying $\mathbf{L}$ by emissions per unit of output and post-multiplying by final demand. This calculation shows how a unit change in final demand $\mathbf{y}$, increases the emissions by all industries to satisfy this change. We diagonalise emissions per unit of output and final demand to ensure that the result is a square matrix. This result format allows calculation of product footprints by summing the columns and calculation of emissions by source by summing the rows.

This system can be expanded to the global scale by considering trade flows between every industrial country in the world rather than within a single country. This type of system requires a multiregional input-output (MRIO) table. A MRIO is used for the calculation of the household income decile carbon footprints used in this study. The UKMRIO database is a 15-region system which models global trade by the UK, Brazil, Russia, India, China, South Africa, USA, Japan, Rest of the European Union, Rest of Europe, Rest of the OECD, Rest of Africa, Rest of Americas, Rest of Asia, and Rest of the Middle East. For this study, carbon footprints are reported showing the emissions that are sourced in the UK and the rest of the world. The UKMRIO is based on supply and use (input-output) tables from the Office for National Statistics (ONS), which describe inter-industry transactions between 112 sectors.

The UKMRIO database contains a single column $\mathbf{y_h}$ for expenditure by all UK households. The living costs and food survey is used to disaggregate this column into the expenditure by ten equivalised household income groups. This means that to find the carbon footprint of decile 1 ($\mathbf{F_1}$), we calculate:

$$\mathbf{F_1} = e'L\mathbf{y_1} \quad (8)$$

Where $\mathbf{y_1}$ is the expenditure by an equivalised two-adult household in the first income decile.

A note on household income groups, uncertainty and equivalisation

How representative are the income deciles used in the study?

The ONS uses household characteristics data to calculate the number of households in the whole of the UK that are representative of each of the single sample households who completed the living costs and food survey. The characteristics of an individual sample household are compared with total UK data taken from the Census. As an example, the first household in the 2018 household has a weight of 4,576, meaning that the ONS has concluded that there are 4,576 households in the UK of this type. The weights sum to 27 million – the number of UK households in 2018.

In this study, we weight the data accordingly so that we are in essence working with a model of 27 million data points. We split these 27 million data points into 10 equal sized income deciles, so the first decile represents 2.7 million households.

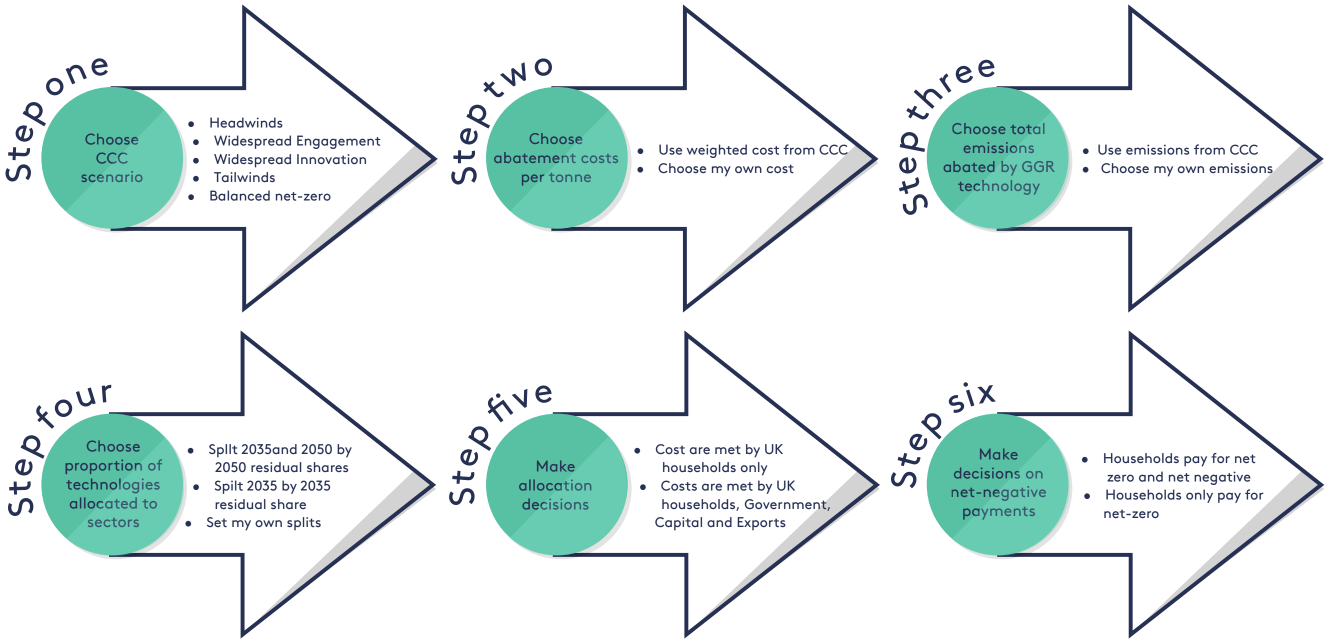
Has the household data been equivalised?

In this study we use a modified OECD equivalence scale as used by the UK Government, where the reference case (weight =1) is a two-adult household with no children. Each household in the Living Costs and Food Survey is assigned an equivalence factor. Households with a single adult score 0.67, each subsequent adult adds 0.33 and children under the age of 14 score 0.2. For example, a household of two adults and two children scores 1.4. Income and expenditure are divided by the equivalence factor to ensure that each survey is equivalent to a household of two adults and no children.

Appendix 2: Distributional Model structure

A macro-enabled Excel workbook (the Distributional Model) has been constructed for this project to enable the investigation of distributional costs to UK households associated with GGR technologies under a number of future scenarios. Data from the Sixth Carbon Budget dataset then feeds into the Distributional Model, which has inbuilt flexibility so that the assumptions can be changed in several steps. Figure A2 illustrates the six analytical steps within the model.

Figure A2: Analytical steps within the model



Step 1 allows the user to switch between all five of the Climate Change Committee's net-zero scenarios. Choosing a CCC scenario automatically changes inputs across a number of steps to present scenario-specific residual emissions, energy demand, weighted GGR cost estimates and quantity of GGR deployed per technology.

Step 2 allows scenario-specific weighted cost estimates from the CCC to be used for each GGR technology. Alternatively, other costs can also be chosen.

Step 3 provides the option of using the CCC's estimates for quantity of removal per GGR technology.

Step 4 allows the user to choose how the proportion of GGR technologies is allocated to each sector. This can be based proportionally on the residual emissions in either 2035 or 2050. For example, in a scenario where aviation accounts for 50% of residual emissions in 2035, 50% of abatement from GGR is allocated to this sector.

Step 5 allows the user to choose whether the costs are borne entirely by households or whether the government estate also bears the cost of GGR deployment for their emissions

Step 6 provides an opportunity to choose whether UK households are liable for achieving the cost only of net-zero. Alternatively, as CCC scenarios continue to become net-negative, there is an option to choose whether households are also liable for this additional level of greenhouse gas removal. This is a pertinent question given that the cost of going further than net-zero, i.e. net negative, may be absorbed either by government or other countries looking to offset their emissions.

Appendix 3: The Climate Change Committee's scenario assumptions

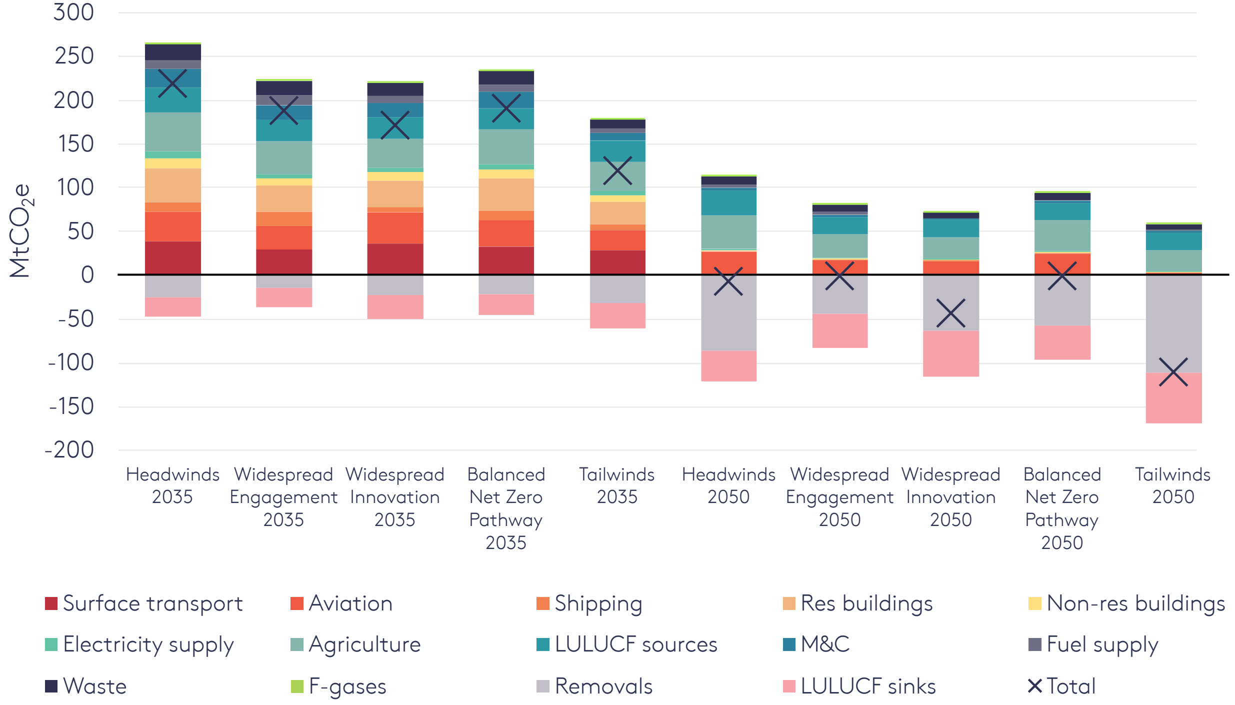
Table A1: Residual emissions by sector in 2035 and 2050

Region	Sector	Metric	Headwinds 2035	Widespread Engagement 2050	Widespread Innovation 2035	Balanced Net-Zero 2035	Tailwinds 2035	Headwinds 2050	Widespread Engagement 2050	Widespread Innovation 2050	Balanced-Net Zero 2050	Tailwinds 2050
UK	Surface transport	Emissions pathway CO_2e	38	29	35	32	28	1	1	1	1	1
UK	Fuel supply	Emissions pathway CO2e	10	12	8	8	6	3	3	-1	0	1
UK	Manufacturing & construction	Emissions pathway CO_2e	21	17	17	19	9	3	3	2	3	2
UK	Residential buildings	Emissions pathway CO_2e	39	30	30	37	26	0	0	0	0	0
UK	Non-residential buildings	Emissions pathway CO_2e	11	8	10	10	7	1	1	1	1	1
UK	Electricity supply	Emissions pathway CO_2e	8	5	5	6	5	2	1	1	1	1
UK	Agriculture	Emissions pathway CO_2e	44	37	33	39	33	38	27	24	35	24
UK	Aviation	Emissions pathway CO_2e	34	27	36	30	23	25	15	15	23	1
UK	Shipping	Emissions pathway CO_2e	11	16	7	11	7	1	1	1	1	1
UK	Waste	Emissions pathway CO_2e	18	16	14	16	10	9	8	7	8	6
UK	F-gases	Emissions pathway CO_2e	3	3	3	3	3	2	2	2	2	1
UK	LULUCF* sources	Emissions pathway CO_2e	29	24	25	24	24	28	20	20	20	20
UK	LULUCF sinks	Emissions pathway CO_2e	-22	-22	-28	-23	-29	-35	-39	-53	-39	-58
UK	Removals	Emissions pathway CO_2e	-26	-15	-23	-23	-32	-87	-45	-63	-58	-112
UK	Total	Emissions pathway CO_2e	219	188	172	191	119	-7	-1	-44	-1	-111
UK	Baseline	Emissions pathway CO_2e	0	0	0	0	0	0	0	0	0	0

Note: LULUCF= land use, land use change and forestry. Source: Sixth Carbon Budget (CCC, 2020)

Data from the CCC's Sixth Carbon Budget showing residual emissions by UK industrial sectors is used to generate alternative versions of e, the vector of emissions intensity by industry used in the UKMRIO framework. The CCC sectors are disaggregated by output to match the 112 sectors found in the UKMRIO.

Figure A3: Residual emissions per sector in 2035 and 2050



Note: LULUCF= land use, land use change and forestry

This requires five different corresponding energy demand scenarios, shown in Table A2.

Table A2: Energy demand assumptions

Scenario				2018	2035	2050
Headwinds	***Energy demand***	**Electricity demand**	*TWh*	352	420	548
		Gas demand	*TWh*	877	545	462
		Petroleum demand	*TWh*	736*	388	113
Widespread engagement	***Energy demand***	**Electricity demand**	*TWh*	352	452	610
		Gas demand	*TWh*	877	379	140
		Petroleum demand	*TWh*	736	338	68
Widespread Innovation	***Energy demand***	**Electricity demand**	*TWh*	352	479	679
		Gas demand	*TWh*	877	395	151
		Petroleum demand	*TWh*	736	360	67
Tailwinds	***Energy demand***	**Electricity demand**	*TWh*	352	487	617
		Gas demand	*TWh*	877	418	83
		Petroleum demand	*TWh*	736	274	12
Balanced net-zero	***Energy demand***	**Electricity demand**	*TWh*	352	458	612
		Gas demand	*TWh*	877	472	217
		Petroleum demand	*TWh*	736	346	105

*Note: *2020 baseline from CCC's Sixth Carbon Budget. Source: Sixth Carbon Budget (CCC, 2020), BEIS (2019a, b)*

The energy demand changes are used to make alternative versions of $\mathbf{y_h}$, the vector of spend by UK households used in the UKMRIO framework. Spend on electricity, gas and petroleum is adjusted in proportion to the 2018 figures.

Table A3: GGR deployment assumption

$MtCO_2$/yr in 2035	Balanced Net-Zero Pathway	Headwinds	Widespread Engagement	Widespread Innovation	Tailwinds
BECCS power	14.37	14.32	8.84	14.19	14.32
BECCS energy-from-waste	0.02	1.39	1.16	0.02	2.68
BECCS in industry	1.83	2.67	1.90	1.89	3.33
BECCS hydrogen	3.23	3.79	0.00	2.64	6.67
BECCS biofuels	2.52	3.25	2.44	2.06	2.06
BECCS bio-methane	0.30	0.29	0.28	1.43	2.56
DACCS	0.00	0.00	0.00	0.30	0.30
Total	*22.27*	*25.71*	*14.61*	*22.54*	*31.91*

$MtCO_2$/yr in 2050	Balanced Net-Zero Pathway	Headwinds	Widespread Engagement	Widespread Innovation	Tailwinds
BECCS power	19.11	38.70	30.25	15.95	38.70
BECCS energy-from-waste	7.48	10.10	0.93	5.49	6.96
BECCS in industry	3.06	4.34	3.09	3.38	3.23
BECCS hydrogen	14.29	23.00	0.00	11.84	36.02
BECCS biofuels	8.31	9.83	9.48	11.15	11.15
BECCS bio-methane	0.61	0.61	0.48	0.51	0.47
DACCS	5.00	0.00	0.00	14.53	14.53
Total	*57.85*	*86.59*	*44.22*	*62.86*	*111.07*

Source: Sixth Carbon Budget (CCC, 2020)

Table A4: GGR cost assumptions

Average abatement cost, £ per tonne	Balanced Net-Zero Pathway	Headwinds	Widespread Engagement	Widespread Innovation	Tailwinds
BECCS power	118.64	124.29	90.43	113.16	133.29
BECCS energy-from-waste	274.74	0.00	0.00	274.74	2.30
BECCS in industry	119.41	189.20	188.87	176.05	146.49
BECCS hydrogen	74.82	74.82	0.00	74.82	74.82
BECCS biofuels	73.30	72.19	54.99	76.74	76.74
BECCS bio-methane	74.27	74.27	74.27	66.54	65.59
DACCS	242.48	0.00	0.00	168.72	168.72
Weighted cost	**106.76**	**109.88**	**89.81**	**108.58**	**102.71**

Average abatement cost, £ per tonne	Balanced Net Zero Pathway	Headwinds	Widespread Engagement	Widespread Innovation	Tailwinds
BECCS power	99.98	111.62	105.41	108.74	152.35
BECCS energy-from-waste	161.60	132.71	132.71	133.53	133.32
BECCS in industry	126.26	193.45	195.83	187.75	145.77
BECCS hydrogen	60.80	73.36	0.00	60.80	68.82
BECCS biofuels	50.47	50.53	34.88	50.36	50.36
BECCS bio-methane	65.36	0.00	65.36	65.36	65.36
DACCS	179.42	0.00	0.00	122.10	122.10
Weighted cost	**99.05**	**100.29**	**96.75**	**98.5**	**109.31**

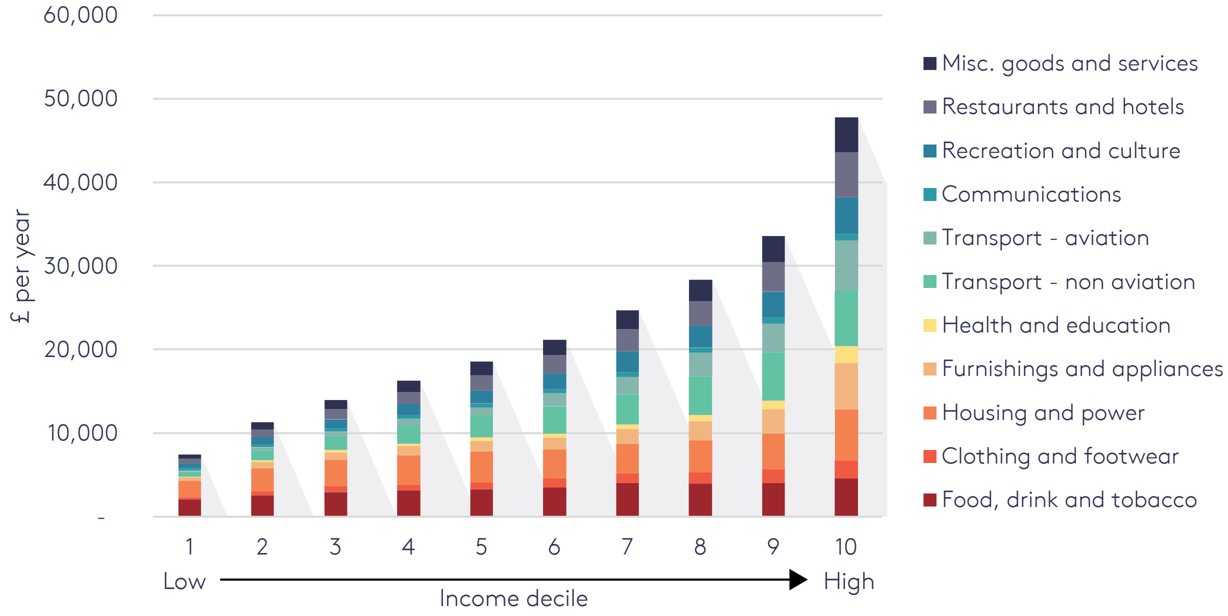
Source: Sixth Carbon Budget (CCC, 2020)

Appendix 4: Analysis results by expenditure decile

UK household expenditure (£) on UK-produced goods and services

Figure A4 illustrates changes in 2018 household expenditure by expenditure deciles, for 11 categories of expenditure.

Figure A4: UK household expenditure in 2018, by expenditure decile

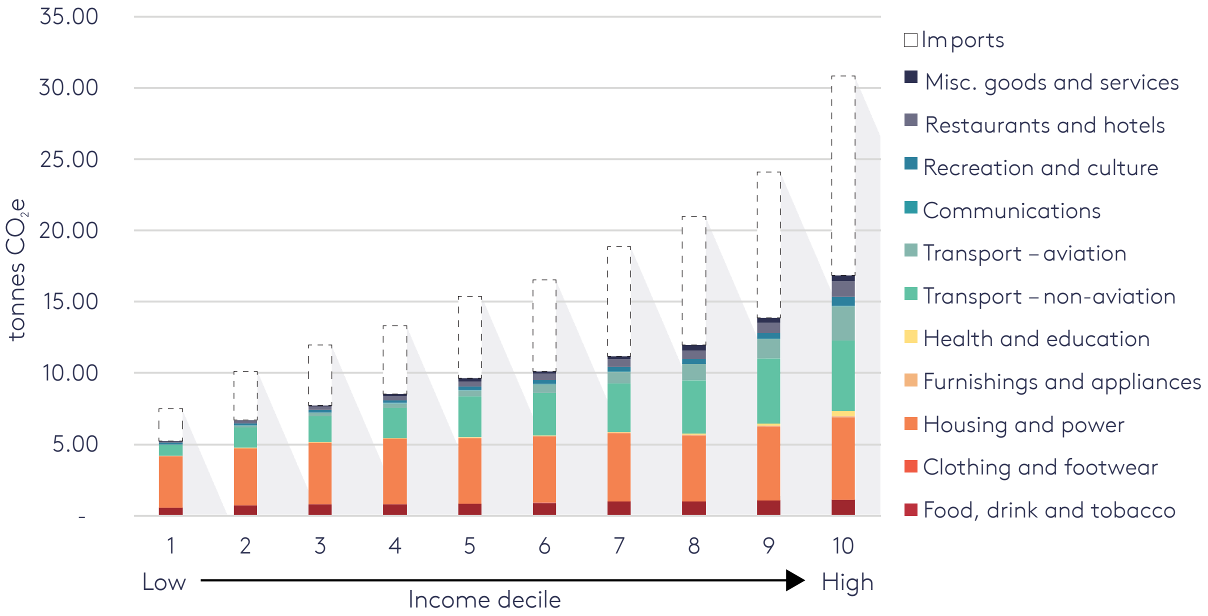


Source: Authors

Household carbon footprints (tonnes CO_2e)

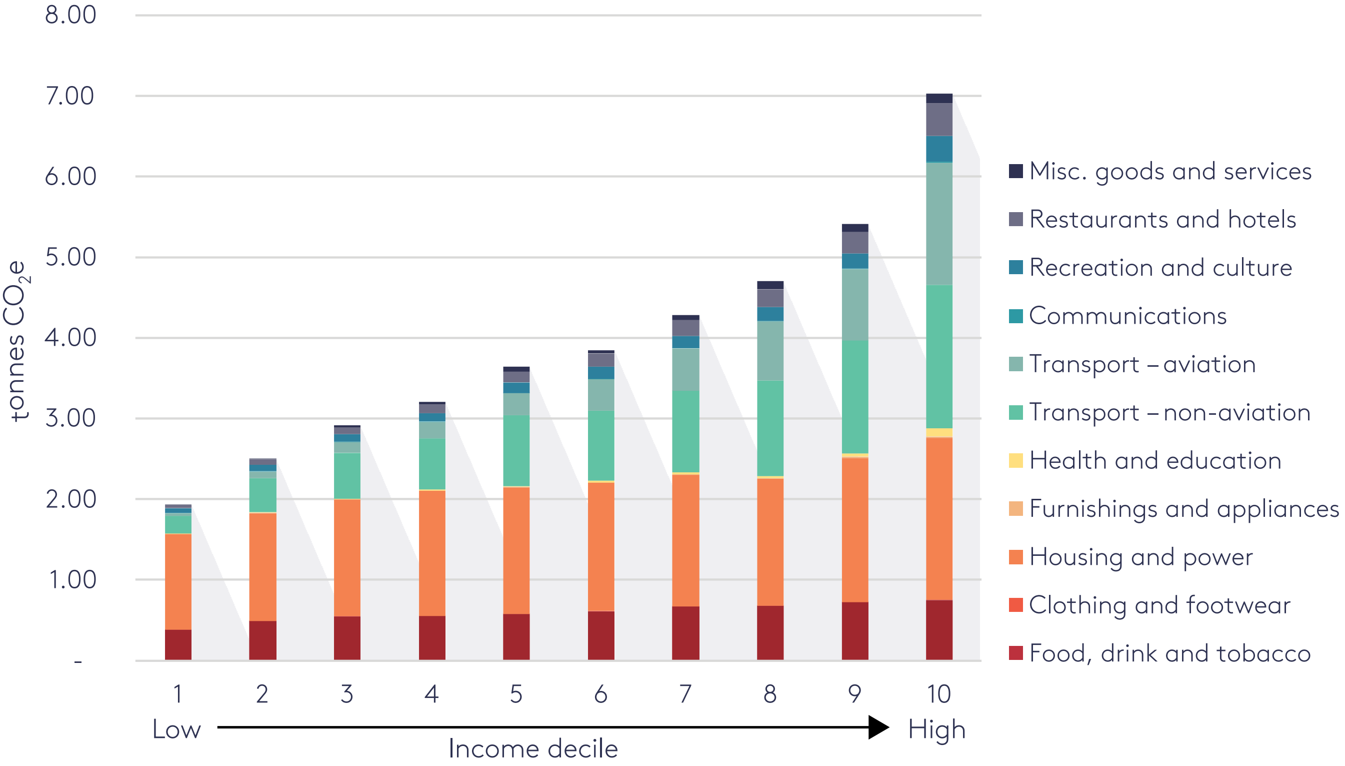
Figure A5 examines the carbon intensity of household consumption in 2018, again by expenditure deciles, and based on the same consumption categories as above. Figures A6 and A7 present changes in household carbon footprint in the deployment scenario by expenditure deciles for the years 2035 and 2050, respectively.

Figure A5: UK household carbon footprint in 2018, by expenditure decile



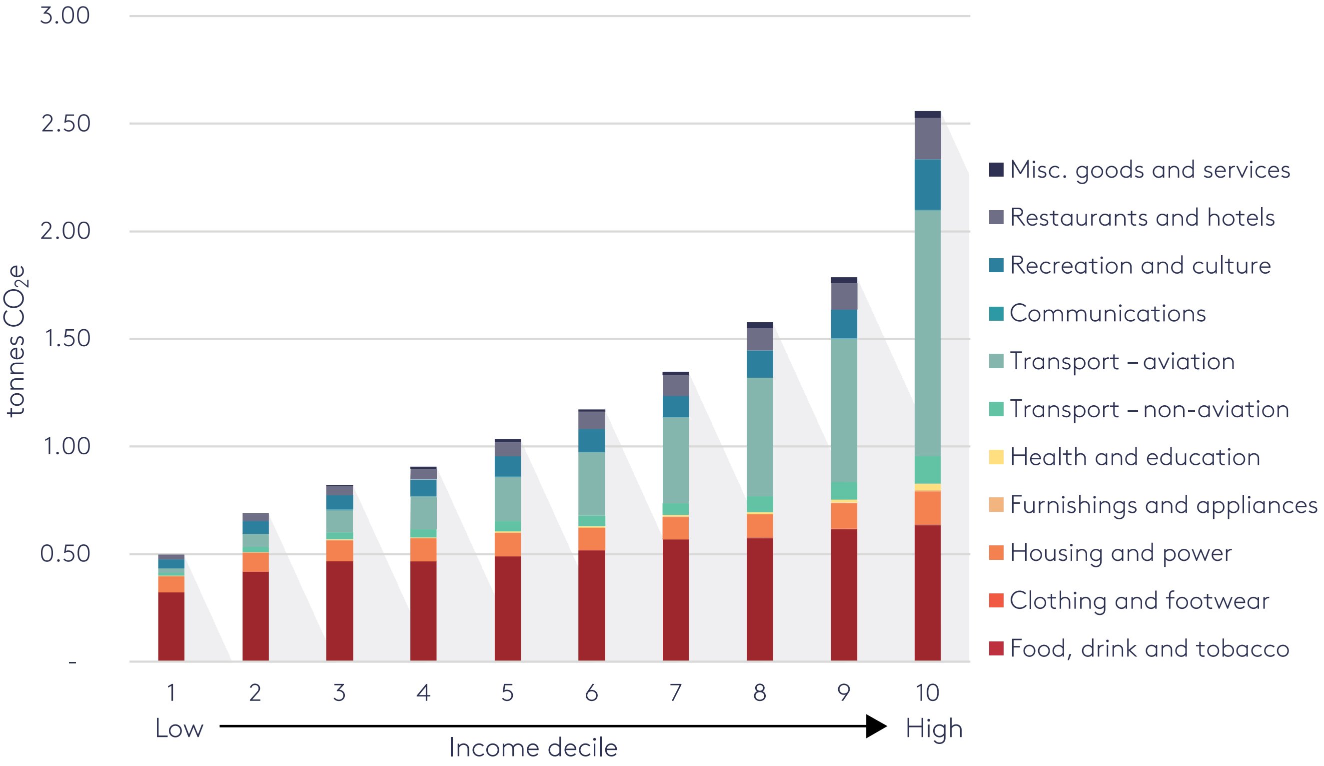
Source: Authors

Figure A6: UK household carbon footprint in the deployment scenario in 2035 by expenditure decile (imports excluded)



Source: Authors

Figure A7: UK household carbon footprint in the deployment scenario in 2050 by expenditure decile (imports excluded)



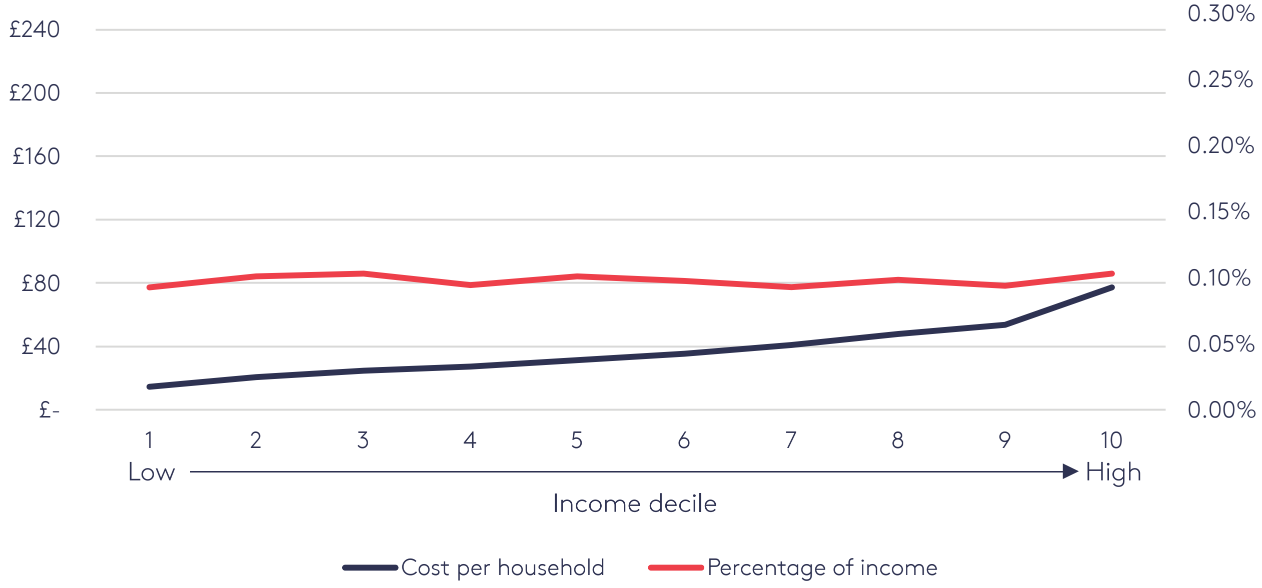
Source: Authors

Magnitude of distributional impacts

Expenditure decile results – deployment scenario with low cost GGR

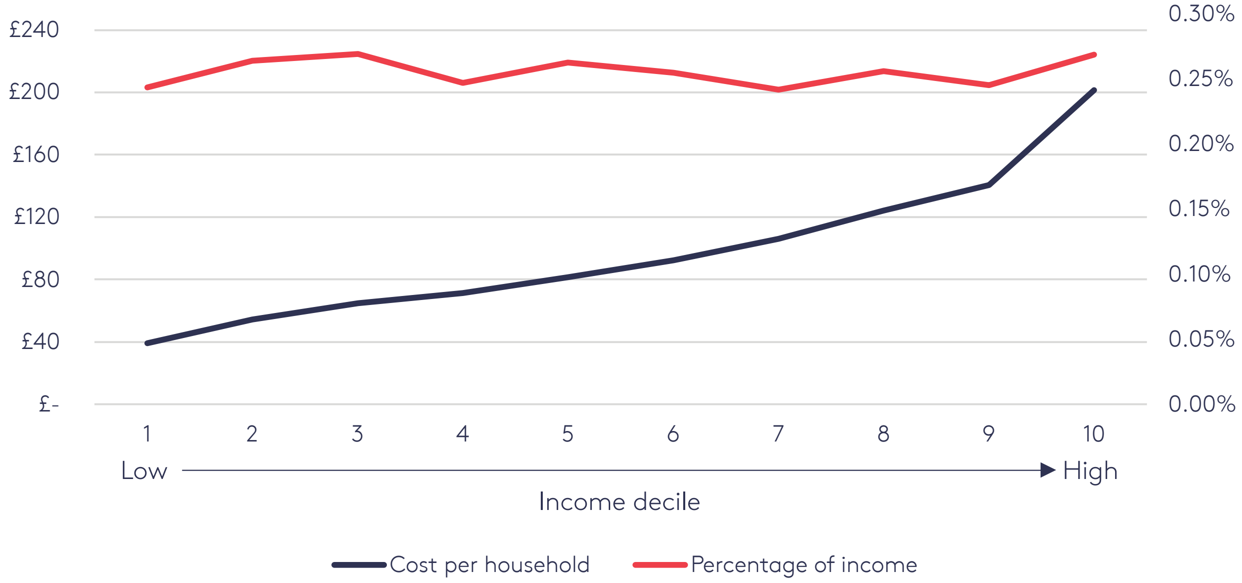
Figures A8 and A9 illustrate the distributional impacts of the low cost GGR scenario on expenditure in 2035 and 2050. In this scenario we assume that the cost of all GGR technologies is £100/tCO_2e in 2035 and 2050. The left-hand axes in the charts show the absolute impact, measured in pounds Sterling, and the right-hand axes show the relative impact, measured as a percentage of income.

Figure A8: Impact of a GGR cost of £100/tCO_2e on households, by expenditure decile in 2035



Note: Model assumptions: 1) Balanced net-zero, 2) Own costs chosen (£100/tCO_2e), 3) CCC total abated emissions chosen, 4) 2050 residual shares chosen, 5) Costs met by households, gov, cap and exports, 6) Households pay for net-zero only. Source: Authors

Figure A9: Impact of a GGR cost of £100/tCO_2e on households, by expenditure decile in 2050



Note: Model assumptions: 1) Balanced net-zero, 2) Own costs chosen (£100/tCO_2e), 3) CCC total abated emissions chosen, 4) 2050 residual shares chosen, 5) Costs met by households, gov, cap and exports, 6) Households pay for net-zero only. Source: Authors

Expenditure decile results – deployment scenario with high-cost GGR

In the high GGR cost scenario we use a cost of £400/tCO_2e for all GGR technologies, held constant in 2035 and 2050. Figures A10 and A11 below illustrate the distributional impacts of this scenario on expenditure deciles in 2035 and 2050. As above, the left-hand axes in the charts show the absolute impact, measured in pounds and the right-hand axes show the relative impact, measured as a percentage of income.

Figure A10: Impact of a GGR cost of £400/tCO_2e on households, by expenditure decile in 2035

Note: Model assumptions: 1) Balanced net-zero, 2) Own costs chosen (£400/tCO_2e), 3) CCC total abated emissions chosen, 4) 2050 residual shares chosen, 5) Costs met by households, gov, cap and exports, 6) Households pay for net-zero only. Source: Authors

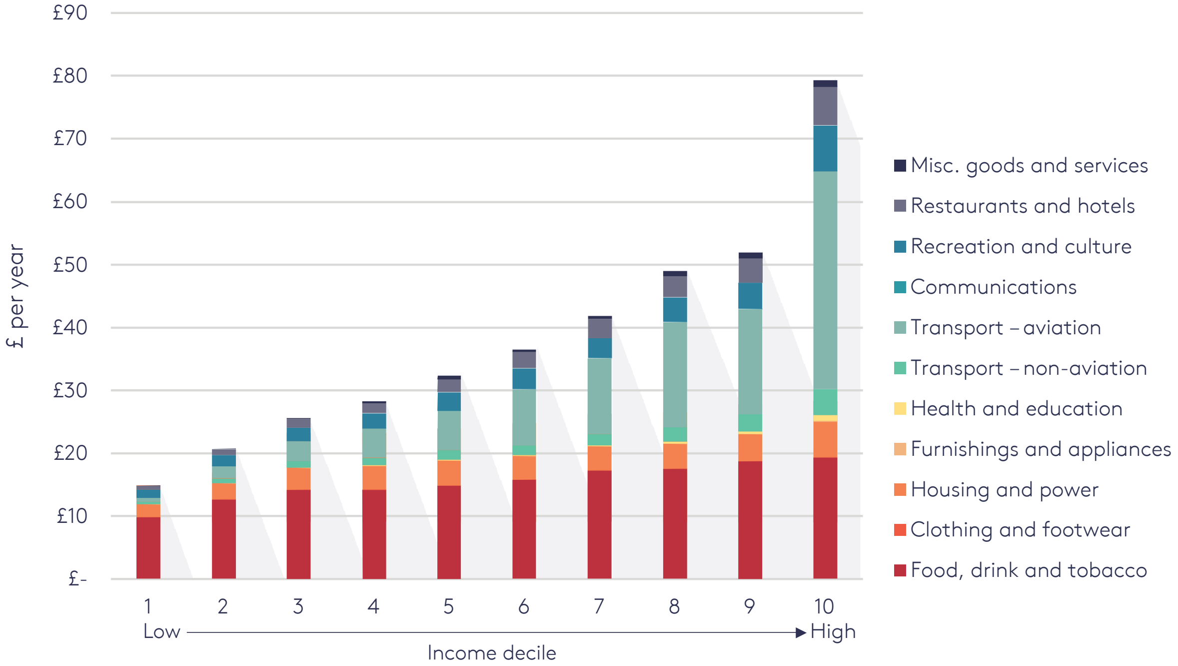
Figure A11: Impact of a GGR cost of £400/tCO_2e on households, by expenditure decile in 2050

Note: Model assumptions: 1) Balanced net-zero, 2) Own costs chosen (£400/tCO_2e), 3) CCC total abated emissions chosen, 4) 2050 residual shares chosen, 5) Costs met by households, gov, cap and exports, 6) Households pay for net-zero only. Source: Authors

Cost impact for each expenditure decile, split by product – deployment scenario with low cost GGR

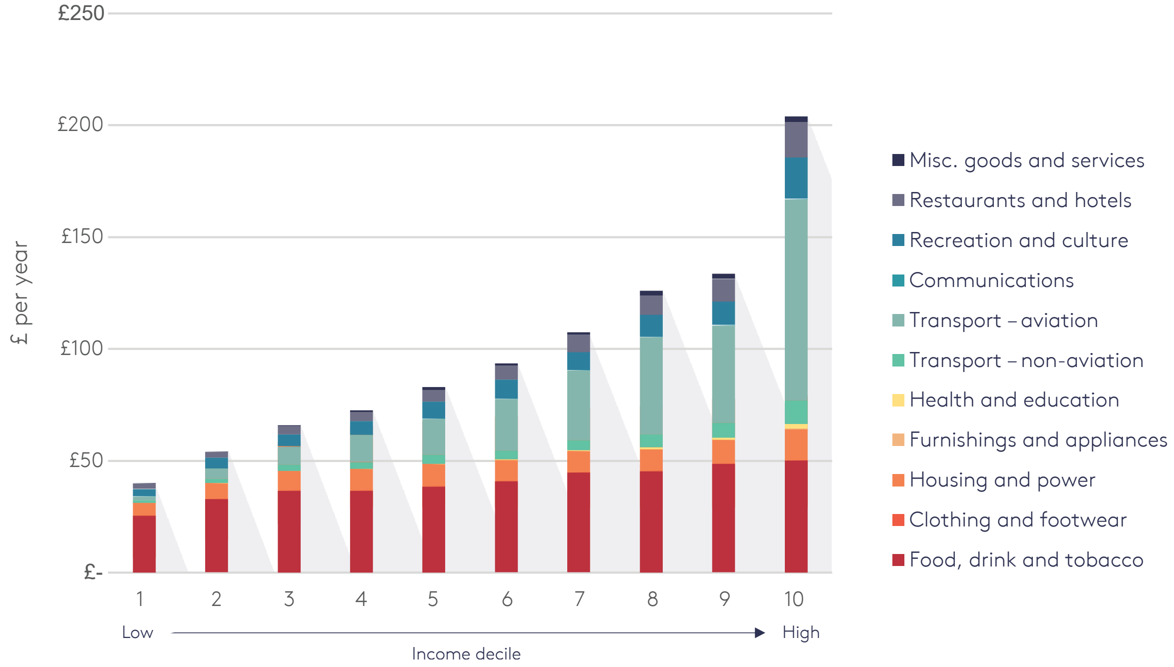
The total costs to households shown in charts A8–11 are now broken out into 11 products in the following charts.

Figure A12: Annual product impact of a GGR cost of £100/tCO_2e on households, by expenditure decile in 2035



Note: Model assumptions: 1) Balanced net-zero, 2) Own costs chosen (£100/tCO_2e), 3) CCC total abated emissions chosen, 4) 2050 residual shares chosen, 5) Costs met by households, gov, cap and exports, 6) Households pay for net-zero only. Source: Authors

Figure A13: Annual product impact of a GGR cost of £100/tCO_2e on households, by expenditure decile in 2050

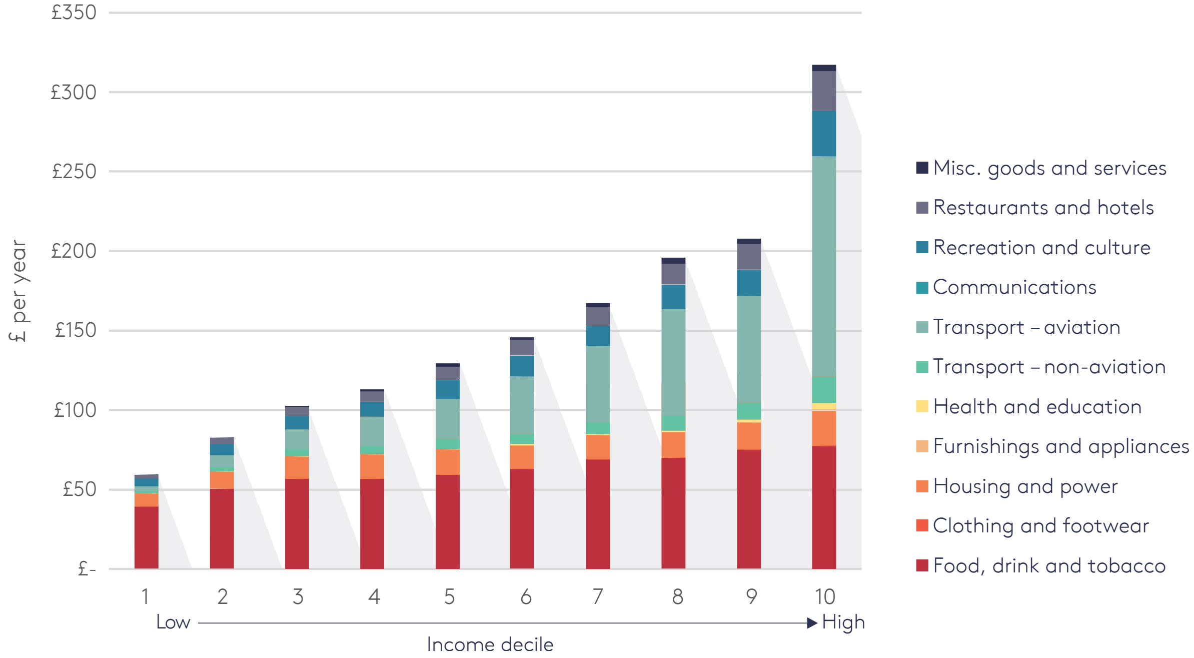


Note: Model assumptions: 1) Balanced net-zero, 2) Own costs chosen (£100/tCO_2e), 3) CCC total abated emissions chosen, 4) 2050 residual shares chosen, 5) Costs met by households, gov, cap and exports, 6) Households pay for net-zero only. Source: Authors

Cost impact for each expenditure decile, split by product – deployment scenario with high-cost GGR

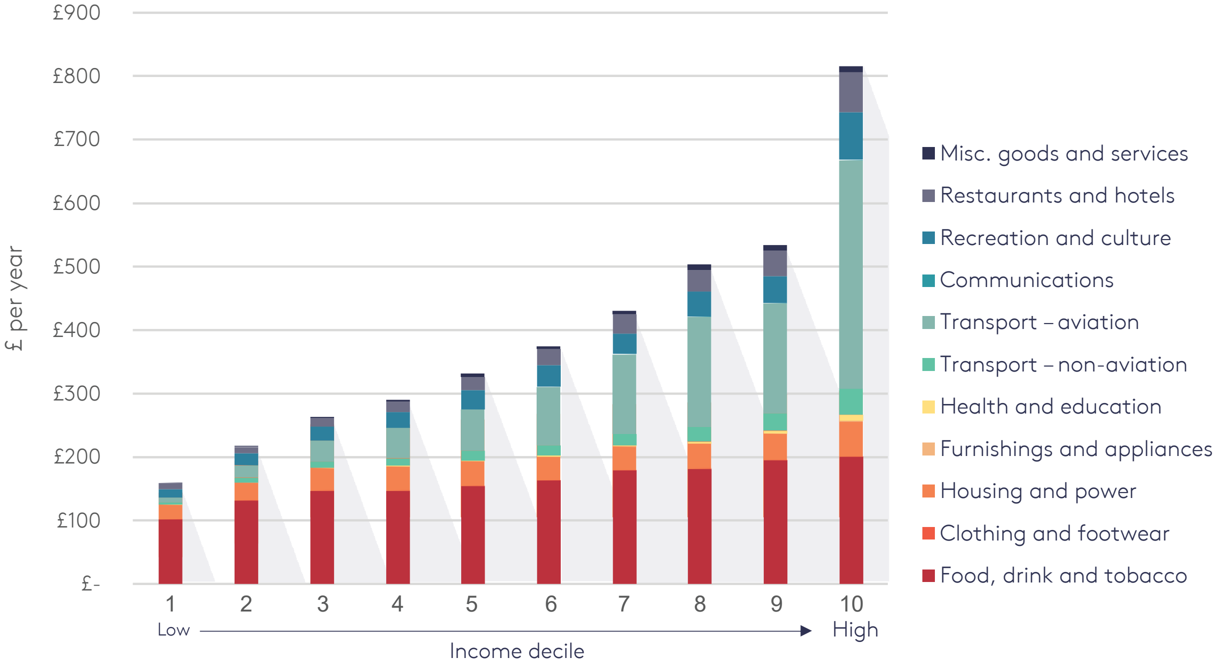
Figures A14 and A15 examine the impact on households in 2035 and 2050, when the cost of GGR is assumed to be £400/tCO_2e.

Figure A14: Annual product impact of a GGR cost of £400/tCO_2e on households, by expenditure decile in 2035



Note: Model assumptions: 1) Balanced net-zero, 2) Own costs chosen (£400/tCO_2e), 3) CCC total abated emissions chosen, 4) 2050 residual shares chosen, 5) Costs met by households, gov, cap and exports, 6) Households pay for net-zero only. Source: Authors

Figure A15: Annual product impact of a GGR cost of £400/tCO_2e on households, by expenditure decile in 2050



Note: Model assumptions: 1) Balanced net-zero, 2) Own costs chosen (£400/tCO_2e), 3) CCC total abated emissions chosen, 4) 2050 residual shares chosen, 5) Costs met by households, gov, cap and exports, 6) Households pay for net-zero only. Source: Authors

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