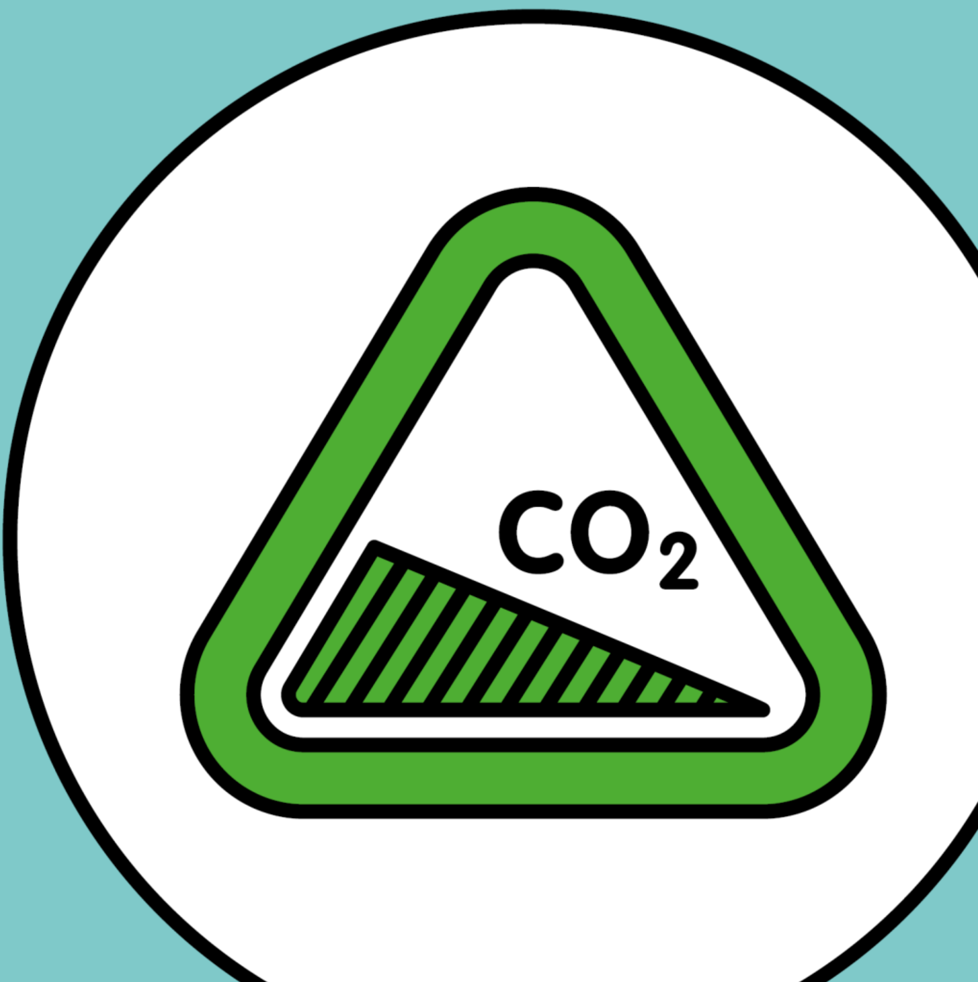
CATAPULT
Energy Systems

Living Carbon Free

Exploring what a net-zero target means for households



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1. Executive summary

The Committee on Climate Change (CCC) is assessing the impact of a target to reach net zero emissions. In this report, Energy Systems Catapult considers the implications for households of increased ambition across six activities: **heat, transport, electricity use, aviation, diet and waste**. For each activity, we explore possible actions for decarbonisation and, using pathways set out by the CCC, we show the emissions reduction that can be achieved under different ambition levels. We also share some illustrations of what a net zero future might look like for different groups.

Heat decarbonisation will require improvements to the fabric of our homes and adoption of low carbon heating systems such as heat pumps, district heating and hydrogen boilers. Smart control systems can ensure these solutions provide the experience households want, while local area planning will be essential to ensure a joined-up approach and avoid unnecessary cost.

Transport emissions can be reduced firstly by reducing overall distances travelled (e.g. through flexible working). Shifting to more sustainable modes of transport like buses and trains, or walking and cycling, would reduce energy use by private cars (and ease congestion and improve air quality). Making more efficient use of cars would help too, e.g. through carpooling. Finally, switching to electric (and potentially hydrogen) vehicles will be essential for net zero.

Electricity use for lighting and appliances (and heat and transport) will have to be fully decarbonised. That will require national solutions like large-scale renewables, nuclear, or gas with carbon capture and storage (CCS). But there will also be significant opportunities for households to participate and provide flexibility to the grid, e.g. through micro-generation and energy storage technologies, or smart appliances that offer demand side response as part of a future smart grid.

Aviation emissions have been steadily increasing over recent decades. Airlines can help curb emissions through more efficient aircraft and flight management, and accelerating deployment of advanced technologies like hybrid electric planes. Households can contribute by thinking more carefully about our growing demand for air travel (especially the most frequent flyers).

Diet change can help reduce emissions from agriculture, in addition to 'upstream' changes like improved farming practices. Reducing our meat and dairy consumption can have a particularly large impact due to the high global warming effect of the methane emissions involved.

Waste reduction, including food waste, can also help to avoid emissions arising from landfill.

To meet an 80% target, most scenarios require high ambition on electricity and waste, but many households might still be reliant on (hybrid) petrol cars and gas boilers, eat as much meat and dairy as today, and fly more every year. Achieving net zero will require households to engage more profoundly in the transition around heat, transport, aviation and diet. This is a challenge but also an opportunity: many of the actions would have co-benefits such as reduced congestion, improved air quality, expansion of green spaces and improved physical and mental health.

As the CCC's analysis shows, even net zero scenarios include some remaining household emissions, e.g. in diet and aviation. Negative emissions (removing carbon from the atmosphere) would therefore be required. But methods for achieving this have their limits, so the more we can curb emissions directly, the less we will have to rely on these.

Care has to be taken when setting policy to drive a transition to net zero, to ensure the least well off are not disproportionately affected, particularly in the case of low carbon heating.

2. Introduction

The UK Climate Change Act 2008 set a legally binding target of reducing greenhouse gas (GHG) emissions by 80% by 2050 compared to a 1990 baseline. This was seen as a proportionate UK response to a global effort to prevent temperatures rising beyond 2°C above pre-industrial levels.

Since that time, improved scientific understanding of the risks of climate change means attention has shifted to a more ambitious target of limiting warming to 1.5°C. To succeed, we need to eliminate *net*[1] GHG emissions globally by the second half of the century.

The UK Government has asked the Committee on Climate Change (CCC) to advise on an appropriate target date for the UK to achieve net zero emissions, and whether this requires accelerated reductions between now and 2050.

In this supporting analysis, Energy Systems Catapult (ESC) has explored net zero from the point of view of households. Even under the current level of ambition, many aspects of our day to day lives will change as we adopt low carbon energy technologies such as electric vehicles or heat pumps. Here we look at these opportunities and challenges to understand what households can do to support the stretch from an 80% reduction to a net zero target.

Counting Carbon

As part of a global economy, many of the goods and services we consume in the UK are imported from overseas, while many of the goods and services produced by our national economy are destined for consumers elsewhere. Allocating responsibility for the emissions associated with these activities can be done in two ways.

The production perspective puts responsibility for emissions onto the country where they physically arise. This could occur when heating homes with gas, fuelling cars with petrol or when emissions arise during industrial production of goods and services - even when some of those goods are exported overseas. At the same time, this approach ignores emissions arising overseas in the production of goods and services that are imported to the country.

The consumption perspective places accountability on the final consumer not the producer. Regardless of where emissions physically occur along the global supply chain, responsibility is allocated to the country where the goods and services are ultimately destined to be consumed.

For a household looking to understand its emissions impact, the consumption perspective is a natural fit. For a national government interested in target setting, inevitably the focus is on territorial emissions over which that government has jurisdiction. Accordingly, the UK Climate Change Act adopts the production perspective.

Here we explore how UK households can play their part in meeting a national net zero target set on a production basis. But addressing climate change is a global challenge so it makes sense to keep track of the emissions from households on a consumption basis too[2]. At a national level, this can help to ensure we don't solve the UK emissions challenge by simply offshoring our emissions intensive activities like heavy industry and food production. At a household level, it would help us all understand the true impact of our activities and allow us to identify opportunities to make more sustainable choices.

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[1] Achieving net zero means balancing any remaining emissions with an equal quantity of carbon removed from the atmosphere.
[2] DEFRA, UK's carbon footprint, https://www.gov.uk/government/statistics/uks-carbon-footprint

Household emissions

The CCC have provided analysis of the potential for emissions reduction in different sectors of the economy. Here we have considered the implications for households across a set of six activities:

- **Heat** (emissions from energy for space and water heating in residential buildings)
- **Transport** (emissions from cars, buses, trains, excludes commercial fleets, goods vehicles)
- **Electricity use** (emissions from generation of electricity for domestic consumption)
- **Aviation** (emissions from domestic and international air travel, excluding business travel)
- **Diet** (aligned with emissions from UK agriculture and land use)
- **Waste** (emissions from waste management, excluding share from commercial waste)

Most of these activities map well with a production perspective, as they relate to emissions which are domestic by their nature. The exception is diet, where the CCC advice relates to UK agriculture and land use emissions, even though we know that food products are extensively imported and exported as part of a global market. We have tried to give a general sense of how actions by UK households could contribute to UK (and global) emissions reductions.

We have disregarded emissions arising from energy use for commercial and industrial purposes. From a consumption perspective, these emissions occur due to household demand for goods and services, but for our purposes we have treated these as out of scope.

The six activities above are explored in the following sections. For each one we examine:

- **The story so far** (changes in emissions between 1990 and 2017)
- **Actions for decarbonisation** (including upstream as well as household level actions)
- **Current and future ambition** (remaining emissions in an 80% reduction case and beyond)

On this final point, we have used the CCC's own analysis of what can be achieved in each category assuming different levels of ambition. This includes:

- **Core** scenario – made up of low-cost low-regret options that make sense under most strategies to meet the current 80% 2050 target. They also broadly reflect the Government's current level of ambition.
- **Further Ambition** scenario – includes more challenging options, and on current estimates generally more expensive than the Core options. Further Ambition gets us to 96% reduction.
- **Net-zero** – the CCC highlight several more 'Speculative' options which could be used to achieve a net-zero target, on top of the Further Ambition measures. The approach represented here assumes some of the CCC's Speculative demand and land-led measures are used to achieve 100% emissions reduction. (The extra 4% could instead be achieved through e.g. further greenhouse gas removals).

The table and figure below show household emissions for each activity in 1990, 2017, and in the **Core**, **Further Ambition** and a demand-led **Net-zero** future. The emissions are calculated on a *per household* basis (assuming 35 million households in 2050 compared to around 29 million today) [3].

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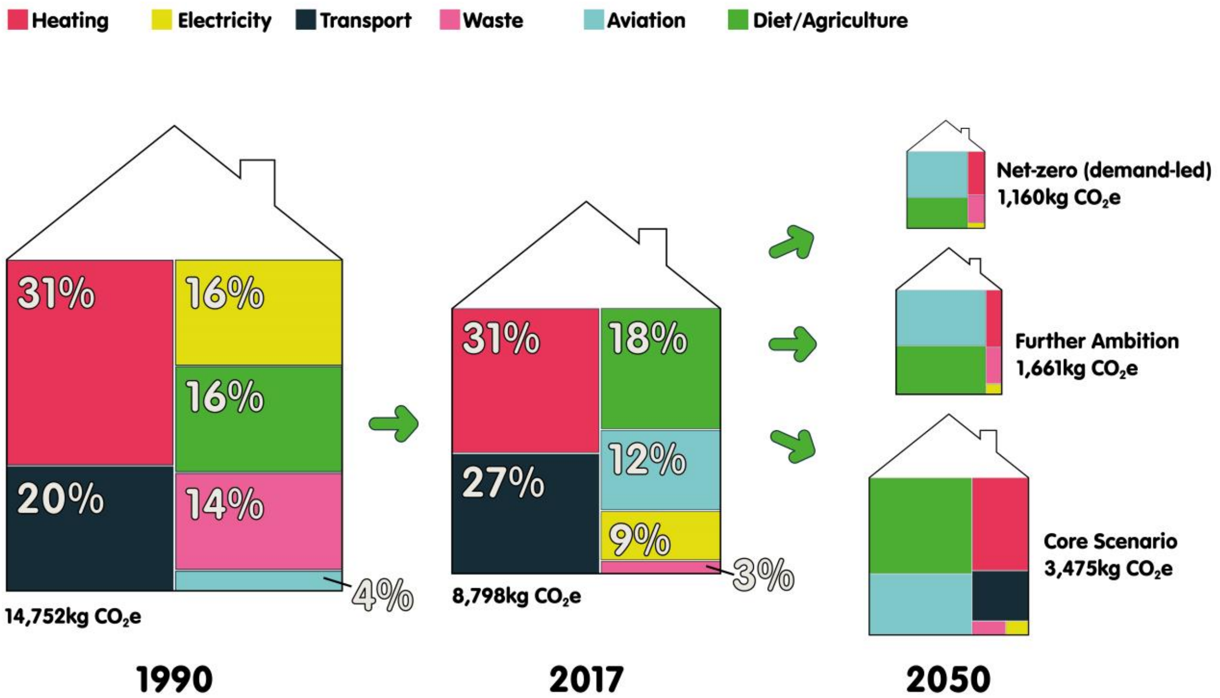
[3] Historical household emissions from heating and electricity determined from domestic energy consumption and associated GHG conversion factors and average national supply intensities. Household transport and aviation emissions determined from statistics on national GHG emissions from all modes of transport with a proportion removed for business, commercial, and industrial use. Waste emissions determined by attributing an appropriate proportion of UK waste management GHG emissions to households and the proportion of agriculture emissions were used as a proxy for diet emissions. Sources include: BEIS, ECUK tables 3.01, 3.02, 3.23; Final UK greenhouse gas emissions national statistics 1990-2017 Table 3. Defra/DECC, GHG Conversion Factors for Company Reporting, Tables 1c, 1d, 9c. CCC, Reducing UK emissions – 2018 Progress Report to Parliament, 2018, Supporting data Table 2.2. DfT, National Travel Survey, Tables NTS0410, TSGB0208 (AVI0108). CAA, 1991 Passenger Survey Report - Gatwick, Heathrow, Luton, Stansted & London City. DCLG, Household projections for England and local authority districts.

Table 1: UK average household emissions across the six activities. Based on ESC analysis.

				2050		
kgCO₂e	**1990**	**2017**		**Core Scenario**	**Further Ambition**	**Net-zero (demand-led)**
Heating	4,535	2,745		692	138	138
Transport	2,952	2,376		371	-	-
Electricity	2,358	755		59	25	25
Aviation	533	1,027		911	724	537
Diet / Agriculture	2,324	1,591		1,343	686	371
Waste	2,050	305		100	87	87
TOTAL	**14,752**	**8,798**		**3,475**	**1,661**	**1,160**

Figure 1: Infographic of UK average household emissions (with historical shares)



3. Heat

The energy used to provide heating and hot water in our homes so people can get clean and be comfortable.

The story so far

The UK has a relatively old housing stock with over a third of homes built before the Second World War. This is one reason why ours is among the least efficient housing stocks in Europe[4].

Between 1990 and 2017 the UK housing stock has grown from 23 to 27 million households. Estimates suggest that average winter indoor temperatures have also increased (but may be levelling out)[5].

Fortunately, new homes added in that time have been constructed to a higher thermal efficiency. Progress has been made to improve existing buildings too, through measures such as loft and cavity wall insulation and double glazing. Boiler technology has also improved, with more efficient condensing boilers now the norm. Finally, there has been considerable progress in decarbonising the electricity mix, reducing emissions for the 7% of households currently using electric heating.

All these factors mean that despite growth in the number of households, and in the number heated by fossil natural gas (up from 14 to 24 million), absolute emissions from home heating have fallen.

In per household terms, the average emissions from heating fell from 4,535 to 2,745 kg CO_2e from 1990 to 2017. Figure 2 shows where progress has been made and offers an illustrative guide to future measures.

Figure 2: Much of the remaining challenges are more difficult and expensive[6] (Image: ETI)

[4] Association for the Conservation of Energy (2015) The cold man of Europe – 2015.
[5] DECC, UK Housing Energy Fact File 2013, (estimate from Graph 6o).
[6] Note: the switch from boilers to low carbon heating relates to energy not capacity.

Actions for decarbonisation

Heating demand in the UK will evolve due to an increasing population, housing stock replacement, building regulations for new homes and the impact of climate change on our weather. Changing comfort expectations and bathing behaviour also come into play, and while low carbon alternatives can certainly meet these needs, there are three consumer challenges to bear in mind:

- People will want solutions that are as good as or better than what they have, but the 'best' solution will vary from place to place and home to home;
- People want control over how much time, effort, money they spend getting the outcomes they want, and everyone prefers something different;
- People need to know how strategic decisions for their local area will affect the low carbon solutions available to them, so they can prepare their homes for the transition.

Technically, we must continue to improve the efficiency of our homes (particularly the hard to treat aspects) and support the adoption of low carbon heating systems in place of natural gas.

Improvements to the fabric of our homes (insulation, draught proofing, new windows) can reduce the rate of heat loss from the building, therefore reducing the amount of energy required to maintain a comfortable temperature. The retrofit measures deployed so far have been relatively simple and economic to adopt. Further improvements may require more investment and could be more disruptive, but their installation can be combined with other home improvements. People will need to be reassured that the benefits from energy savings and a more comfortable living environment outweigh the costs. Some households may need financial support for these upgrades.

Low carbon heating systems will have to replace the natural gas boilers used in most homes today. Heat pumps, district heating and hydrogen boilers are all examples of the types of heat system that could be used (the first two are used extensively around the world already).

Electric heat pumps operate best when left to run uninterrupted through the day. However, we often need heat at certain times, typically when we get up in the morning or settle in for the evening. Rather than installing super-sized heat pumps and operating these inefficiently by trying to follow demand, smaller heat pumps could be coupled with simple thermal storage. The storage can be charged up when electricity is cheap (e.g. overnight) and discharged during periods of peak demand to supplement the constant output from the heat pumps. In this way, households can help balance the wider system and reduce overall cost.

District heating networks are likely to be introduced or expanded across urban areas with high concentrations of housing. Heat is generated at energy centres and distributed through pipes to homes and businesses. In each building, a heat exchanger transfers the heat from the network to the building's hot water system. Many heat networks today rely on natural gas. To support decarbonisation, new and expanded heat networks will have to rely on low carbon sources. Fortunately, new heat sources can be added according to local circumstances without disrupting the end user. For example, low carbon electricity can be used to extract heat from local water sources via heat pumps, or 'waste heat' could be recovered from industrial facilities.

Hydrogen boilers would deliver the same level of service as householders get from their current natural gas boilers. With the exception of a few safety considerations, they can be installed as a direct replacement, and it is anticipated that existing gas networks can be repurposed to enable distribution to individual homes. Perhaps the greater challenge is that new infrastructure would be required to support low carbon hydrogen production.

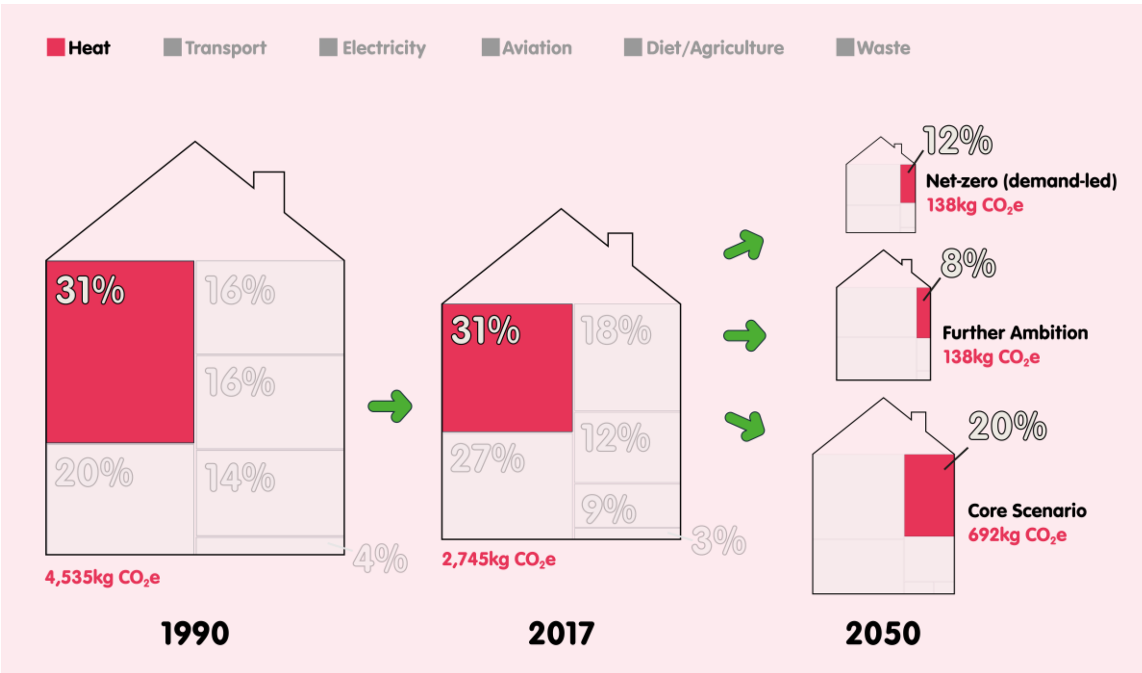
A further option is to install **hybrid heating** systems, where a heat pump can provide the majority of the heat, but during extreme cold weather events (or when electricity costs are very high), the system can switch over to using a gas boiler. Many 80% scenarios see a role for hybrid solutions like this, but more ambitious targets would leave no room for natural gas even for occasional use, so any hybrid systems would have to use hydrogen boilers.

This multi vector approach, although coming with a higher initial cost, may allow service providers to operate the whole system more efficiently.

Smart control systems can be installed to complement these low carbon heating technologies, and early trials indicate that people enjoy having improved control over their heating[7]. With smart controls, people can schedule warmth by time of day and temperature in each room of the house, with the system automatically taking the required actions (e.g. turning on the boiler) to reach the set temperature according to the schedule. People could also then monitor their heat usage via an app to help understand which energy provider and tariff structure would best meet their needs.

Local area planning will be essential to ensure a joined-up approach and avoid the cost of supporting more infrastructure than necessary[8]. As part of an optimal approach to decarbonising heat across the country, it will often be best to make strategic choices for entire geographical areas. For example, some gas networks may be converted to hydrogen enabling households to continue to use boilers, while other areas may see gas networks retired in favour of district heat networks or upgraded electricity networks to support heat pumps. While this may limit the choice of solutions for individual homes, this kind of local area planning will help us transition to low carbon heat in the most cost-effective way overall.

Figure 3: Infographic of UK average household emissions for heating



[7] ESC, 2019, "Smart Energy Services for Low Carbon Heat" https://es.catapult.org.uk/wp-content/uploads/2019/03/20190320-SSH2-Insight-Report-FINAL.pdf

[8] ESC, 2018, "Local Area Energy Planning key to minimising decarbonisation costs", https://es.catapult.org.uk/news/local-area-energy-planning-key-to-minimising-decarbonisation-costs/

Current and future ambition

There is no ‘one-size-fits-all’ solution to the challenges posed by the decarbonisation of heat across different home types, sizes, locations and occupants. Existing pathways from the CCC and others show that meeting our emission targets will require a mix of heating solutions including heat pumps, district heating, gas boilers, hydrogen boilers and hybrid systems. Even then, the reductions that can be achieved will vary between households. Many homes will move onto near zero carbon heating solutions, while some hard-to-treat homes could continue to be responsible for significant emissions.

In the CCC **Core** scenario, average household emissions for heating come down from 2,745 to 692 kg CO_2e between 2017 and 2050. This is consistent with an 80% economy wide reduction target that would see many homes continuing to rely on natural gas boilers e.g. as part of a hybrid system with electric heat pumps.

As part of the **Further Ambition** and **Net-zero** cases, the CCC believe average emissions need to be brought down to 138 kg CO_2e per household. This would require natural gas heating to be all but eliminated, either through a switch to hydrogen in the gas network, or a transition to alternative non-gas solutions.

4. Transport

The vast majority of households have a need for mobility to enable us to commute to work, go shopping or visit friends and family. For most of us, this involves a mixture of different modes of transport including walking, cycling, driving or public transport.

The story so far

Between 1990 and 2017, emissions from UK surface transport have increased in absolute terms. Allowing for growth in the number of households, the average per household emissions fell from 2,952 to 2,376 kg CO_2e.

Clearly different modes of travel have very different implications for emissions, with private cars responsible for the majority. In 1990, in the UK we travelled a total of 588 billion kilometres by car. By 2017 that had risen to 670 billion kilometres[9]. Improvements in vehicle fuel efficiency have prevented emissions from growing at the same rate, but internal combustion engines continue to dominate the vehicle fleet.

Actions for decarbonisation

Achieving a net zero target will require significant changes to how we move around. This will require both comprehensive decarbonisation of cars and vans and rethinking how we get around in the first place. Our mobility needs are diverse, and depend on proximity to the workplace, schools and amenities and many other factors. The solutions available to us will also vary depending on whether we live in an urban city centre, the outskirts of a small town or in an isolated rural area. For example, people living in cities and towns make fewer and shorter car journeys.

Reducing overall distance travelled would mean less pressure for new transport infrastructure, thus reducing indirect emissions from extraction and processing of raw materials. Reducing travel distance could be achieved through more flexible working patterns allowing people to work from home (or closer to home in 'shared working' spaces), supported by greater use of virtual rather than physical meetings. Those living in urban areas generally travel the shortest distances so, in principle, increased urbanisation of the UK population could support this transition (relative to an alternative future with more suburban or rural living).

Shifting to more sustainable modes of transport could be a cost-effective alternative to private car ownership, depending on location. In its simplest form, modal shift could mean more walking and cycling. People could also gain health benefits from a more active lifestyle. For longer journeys or in adverse weather conditions, many of us would require some form of public transport. This can involve increased physical activity too, from walking or cycling to the local bus stop or train station.

Travel time has been found to be the biggest factor when it comes to deciding to use public transport[10]. A more efficient and extensive public transport system would therefore ease the switch away from private car use. Mode switching will probably be easier for people living in cities and towns where investment in public transport is easier to justify. Given that there are still a significant number of journeys done by car in urban areas, there is a large opportunity for mode switching to have a significant impact on transport emissions. This would provide the further benefits of reduced congestion and improved air quality.

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[9] HM Govt, tsgb01 https://www.gov.uk/government/statistical-data-sets/tsgb01-modal-comparisons

[10] A.H.M. Mehbub Anwar, Jie Yang, Examining the Effects of Transport Policy on Modal Shift from Private Car to Public Bus, Procedia Engineering, Volume 180, 2017, Pages 1413-1422, ISSN 1877-7058, https://doi.org/10.1016/j.proeng.2017.04.304.

Those living in more rural areas have fewer public transport options than those in urban areas but could still take advantage of park and ride schemes for journeys into city centres, for example.

Using vehicles more efficiently would also help reduce emissions. This is most significant while we continue to drive fossil fuel vehicles, but even in the case of electric vehicles, more efficient use would mean less overall electricity generation required to charge them. Increasing the average occupancy rate of cars, e.g. through carpooling to work, would reduce the number of individual vehicle journeys (and reduce congestion along the way). Car sharing schemes could offer flexibility for those who are able to travel primarily by public transport but may have the occasional need for a private vehicle.

Switching to new vehicle technologies will be essential. Electric vehicles on the market today offer an average range of around 240 kilometres[11], which is more than sufficient for most car journeys. For example, in urban areas the average distance per trip is only 13 kilometres. Even for those living in more isolated rural dwellings the average trip is only 18 kilometres.

Of course, range requirements are not determined by average distances but by occasional longer journeys. This explains the high average range of electric vehicles currently on the market, which might be sufficient to support a typical weekend getaway. The average range of new electric vehicles will continue to increase as battery costs come down, ensuring more households can find a solution that suits all of their needs.

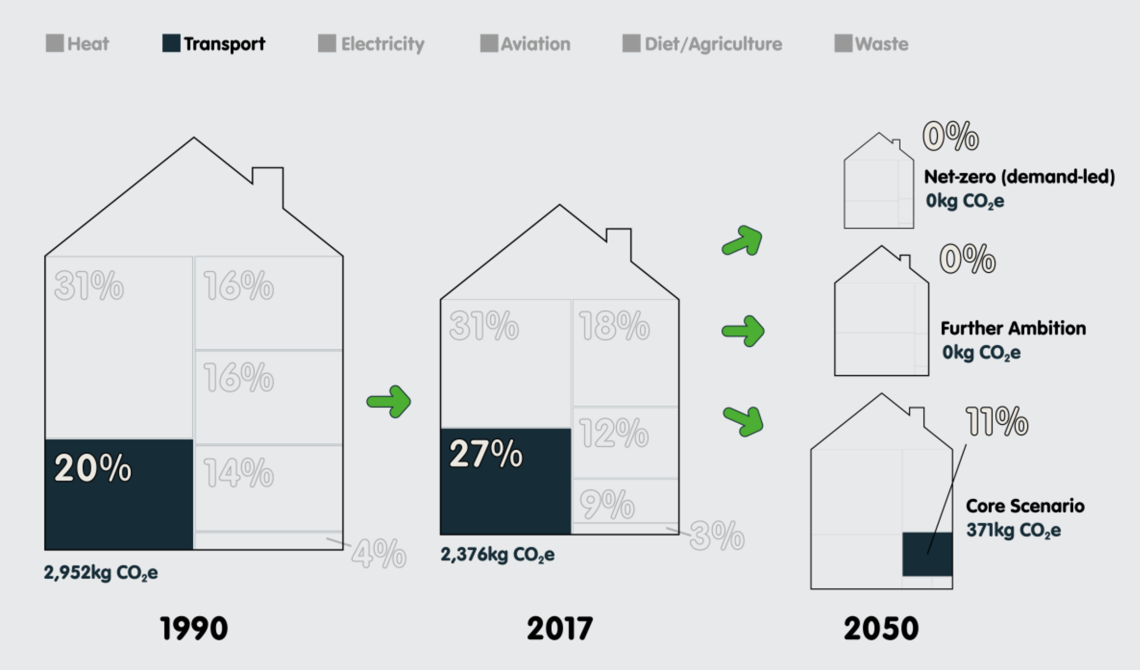
For very long trips, like the annual family holiday, rapid charging units at service stations can already provide an 80% charge in under 30 minutes. Some households will opt for vehicles with a much larger than average range, making a cross-country trip with one or two recharging stops a viable option. As new business models emerge to facilitate an electric vehicle transition, other households might rely on a short-range vehicle for day-to-day use, while taking advantage of car hire schemes to take a long-range model for occasional longer journeys.

Aside from fast charging stations, all EV owners will require an everyday charging facility. Those with off-street parking will be able to install a charging point of their own. For others who use on-street parking, public charging points will have to be rolled out extensively across the UK if an all-electric vehicle fleet is to be realised. In many cases, workplace charging will offer an alternative or complementary opportunity to recharge.

There are certain hours when we need our vehicles out on the road, but usually they remain parked for more than enough hours to ensure a full charge every day, meaning we have some flexibility around when we choose to recharge them. Households can support load balancing here by opting for smart charging. This can ensure their vehicles avoid recharging at times of high demand, minimising the need for additional peak generation which can be costly (and carbon intensive when provided by natural gas turbines).

[11] (150 miles), value obtained from https://www.nimblefins.co.uk/average-electric-car-range and excludes Tesla

Figure 5: Infographic of UK average household emissions for transport



Current and future ambition

The CCC's **Core** scenario assumes the majority of the road transport fleet is electrified by 2050. This would lead to a reduction in emissions from transport for the average household from 2,376 to 371 kg CO_2e between 2017-2050.

In CCC's latest analysis, **Further Ambition** and **Net-zero** scenarios assume *all* cars will have to be fully electric (or hydrogen) by 2050, meaning household emissions from transport are effectively eliminated. To achieve this, all new car sales from 2035 will have to comply with this, allowing a 15-year period for any remaining fossil fuel vehicles to retire.

5. Electricity use

Electricity provides households with energy for lighting, appliances, cooking, water heating and sometimes space heating. There is considerable variation in consumption between household types, especially due to heating - 25% of flats use electricity for heat compared to only 4% of houses (emissions from electricity for heat are treated in the heat category).

The story so far

Historically, electricity has been generated on a large scale at a distance from the consumer. In 1990, power plants burning coal and oil accounted for almost 80% of the UK electricity mix. Low carbon sources including nuclear and hydro power contributed the remaining 20%.

Emissions from electricity fell through the 1990s as a fleet of gas power plants was installed in place of coal and oil plants. In the last decade even more coal has been displaced, this time with renewables such as wind power, solar photovoltaics (PV) and biomass combustion.

These changes have brought about a dramatic reduction in the emissions intensity of electricity generation from 770 to 263 grams of CO_2 per kilowatt-hour between 1990 and 2017.

On an annual basis, excluding electricity for heat, average household emissions have fallen from 2,358 to 755 kg CO_2e.

Actions for decarbonisation

To continue these reductions in emissions, nearly all of our electricity will have to be generated from some mixture of renewables, nuclear, or gas with carbon capture and storage (CCS).

Nuclear and gas CCS would not require backup, but these require significant levels of planning and investment and both have suffered cancellations in recent years. Even if nuclear and CCS do emerge in the longer term, the recent and rapid deployment of renewables can be expected to continue until these become a more dominant feature of our electricity system. To accommodate these without relying on gas will require alternative approaches to providing backup, flexibility and other system services.

There are numerous large-scale solutions to this, such as interconnectors between the UK and Europe, or grid-scale energy storage. But there will also be significant opportunities for households to participate as part of a future smart grid.

Micro-generation technologies offer households the opportunity to participate directly in the switch to low carbon electricity generation. Rooftop solar PV in particular has been adopted by around a million UK households in the last decade. The rate of deployment slowed once financial incentives were withdrawn, but as costs continue to decline many more households may consider adopting PV in future.

Domestic battery storage could complement solar PV, allowing electricity to be stored up while demand is lower and used when it is higher. The economic case for such integrated systems in the home will depend on wider electricity system decisions beyond the control of households. For example, larger PV systems or 'solar farms' are generally more cost-effective than rooftop systems (indeed larger systems account for 80% of PV capacity in the UK today). If more solar farms were deployed in the UK these might provide such abundant electricity on sunny days that it becomes less attractive for households to install their own systems. Similarly, if storage becomes an economically effective way of smoothing supply and demand, commercial parties may succeed in doing this at a larger scale, limiting the financial benefit of integrated household systems.

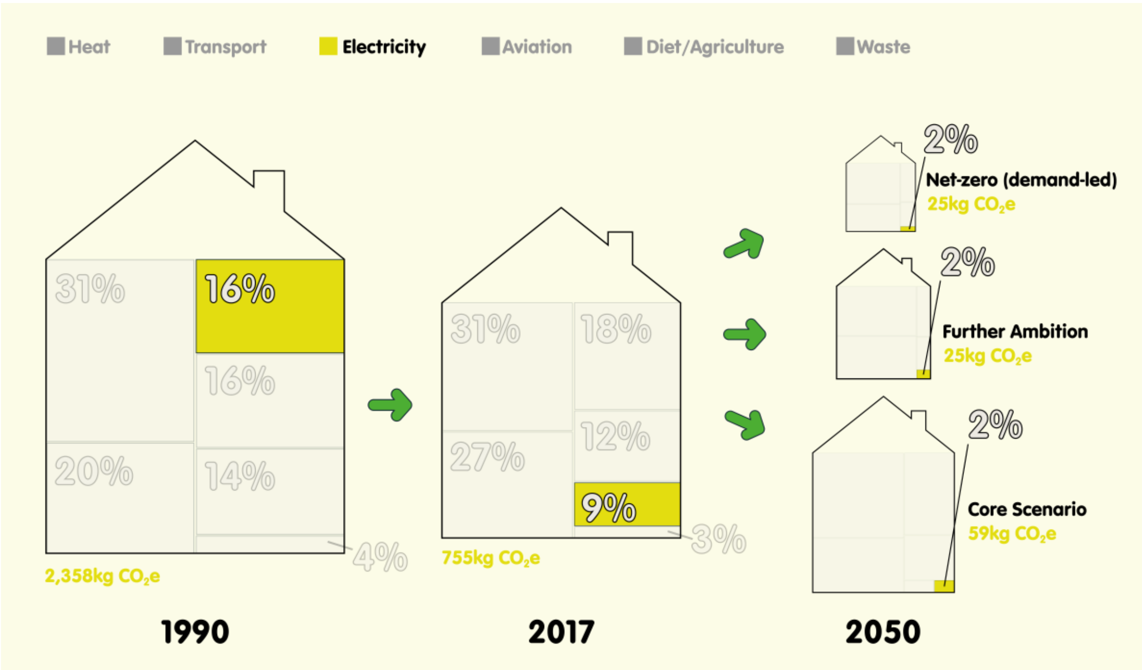
Whether or not households integrate micro-generation and storage technologies, the earlier discussions on heat and transport make it clear that decarbonisation of those activities is expected to rely significantly on electrification. Where this is the case, households can play a more active role in supporting the smooth running of a low carbon electricity grid through the smart operation of heat pumps, electric vehicle charging and other electrical appliances.

Smart appliances could respond to the needs of the grid, reducing consumption of electricity during peak times. For example, dishwashers and washing machines might be set up in the evening and operated overnight when electricity demand is low. Similarly, fridges and freezers could be cooled to the lower end of an acceptable temperature range when the hour of peak demand is approaching, allowing them to stay with this range without consuming further electricity over the peak hour. More generally, all appliances should continue to adhere to increasing efficiency requirements, minimising overall electricity demand.

With smart systems in the home and across the grid, all of this can be automated based on price signals driven by supply and demand (though this will likely require changes in market design or new markets in flexibility). Some households might choose a tariff taking advantage of smart systems to offer overall lowest cost, with others opting to pay a premium for the freedom to use electricity whenever they like. New business models might offer households the chance to buy the outcomes rather than units of energy, leaving their service provider to make sure their home is comfortable, water hot, and car charged without using electricity when it doesn't suit the network.

Beyond simply foregoing EV charging during periods of high demand, some innovators are experimenting with vehicle-to-grid technology, where car batteries are capable of discharging electricity back onto the grid in response to a sufficiently high price signal. This could mean some drivers returning home at peak times and plugging in their EV to sell their remaining electricity onto the grid, before recharging in the early hours ready for the next day.

Figure 4: Infographic of UK average household emissions for electricity



Current and future ambition

Even with existing ambition, decarbonising the overall energy system has to begin with rapid decarbonisation of the electricity sector. This is essential to ensure that the electrification of heat and transport (and industry) can deliver genuine emissions reductions.

In previous analysis, the CCC suggested 75% of generation should be from low carbon sources by 2030 to keep on track with existing legislative targets. Unabated gas would make up the remaining 25%, providing backup, flexibility and other essential system services, but would mean some emissions remain. Thereafter, the proportion of low carbon generation would continue to increase, taking advantage of new capacity as well as increasing smart system flexibility to push out unabated gas from the mix. Hydrogen could eventually replace natural gas for peak power capacity.

By 2050, the CCC's **Core** scenario sees emissions from electricity reduced to a small residual. In household terms, this means a drop from 755 to 59 kg CO_2e per household per year.

In the **Further Ambition** and **Net-zero** scenarios, the CCC believe this can be squeezed further, down to 25 kg CO_2e. The residual emissions are from carbon capture and storage facilities operating as part of a fully decarbonised electricity supply.

6. Aviation

For many households, international aviation offers the chance to explore different parts of the globe, while domestic aviation has become a more popular means of getting across the UK.

The story so far

Like the rest of the world, the UK has experienced a boom in air travel with overall passenger journeys growing from around 100,000 to 280,000 journeys per year between 1990 and 2017[12]. As a result, and despite improvements in energy efficiency, aviation emissions have grown considerably.

Discounting flights taken for business purposes, we estimate that average household emissions from recreational flights almost doubled from 533 to 1,027 kg CO_2e over this period. In reality, a small proportion of households are responsible for the majority of flights (see below).

Actions for decarbonisation

Low carbon alternatives look more technically challenging for aviation than for other large sources of emissions like home heating, road transport or electricity generation. In practice this means aviation is expected to still produce significant carbon emissions in 2050.

To achieve net zero, these emissions would need to be offset elsewhere (see carbon offsetting later). To avoid relying too heavily on emissions offsetting, aviation emissions would have to be contained where possible. There are a number of ways the aviation industry can tackle emissions.

More efficient aircraft and flight management including efficient flight profiles, improved co-ordination of flight landings and improved occupancy rates, could lead to a 42% energy efficiency improvement by 2050 (from 2015 levels) [13].

Ground based emissions occur in preparation for take-off and after landing, e.g. taxiing to and from the runway. Rethinking how these steps are performed could enable some of the energy requirement to be delivered by electrical ground-based systems rather than by burning jet fuel.

Biofuels produced from sustainably grown biomass could in principle displace some of the fossil fuel used in aviation. But land constraints will likely limit the volume of biomass that can be grown sustainably, and it may be more valuable if used elsewhere in a low carbon economy.

Advanced aviation technologies might include hybrid planes combining an electric motor with a traditional jet engine system or possibly fully electric planes for short-haul flights. There is some debate around the potential of hybrid planes to reduce the fuel-based emissions of aviation. The debate centres around the additional weight and complexity added to the system. Currently, fully electric planes are limited by the low energy density of electric batteries.

Even if hybrid or fully electric planes became commercially viable in the coming decades, the long lifetime of existing aircraft (up to 30 years) means it will take even longer for these new technologies to penetrate the market. This is likely to limit the role of such advanced technologies in reducing aviation emissions out to 2050.

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[12] DfT, 2018, "TSGB0201 (AVI0101): Air traffic at UK airports", https://www.gov.uk/government/statistical-data-sets/tsgb02
[13] European Commission, 2018, "A Clean Planet for all: A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy"

Managing demand

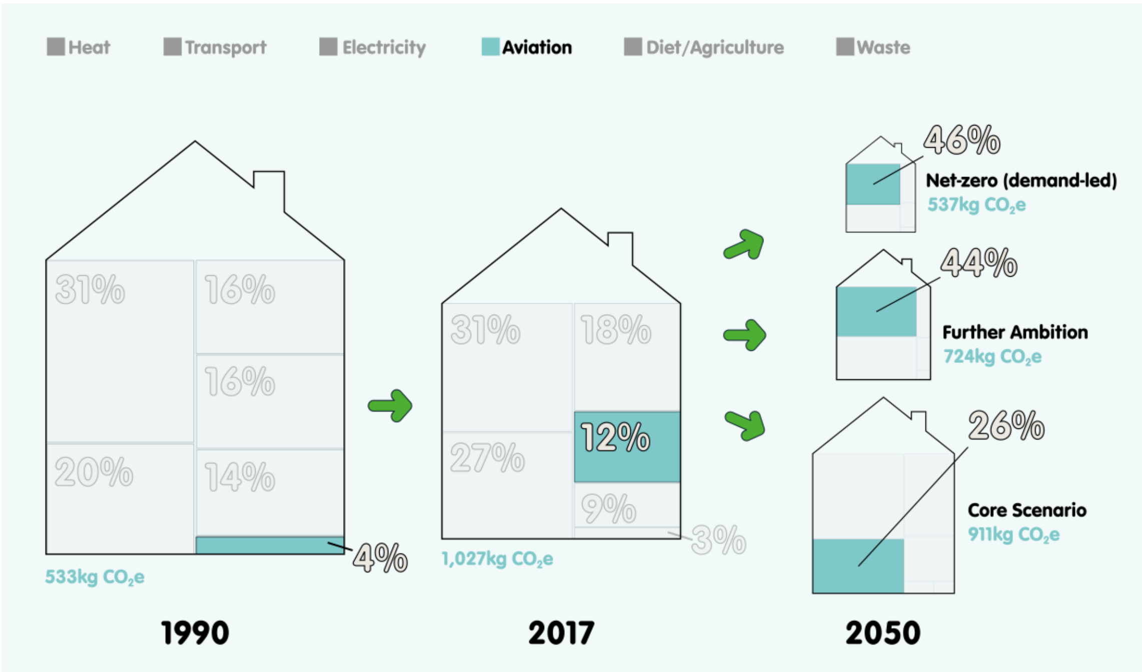
While technological measures can help reduce emissions per journey, the historical trend of increasing journeys is forecast to continue in the long term, cancelling out any reductions overall. But forecasts are not a foregone conclusion, and as individuals we can make informed choices about air travel in the context of the climate challenge.

Demand for many domestic and short-haul flights could be reduced by consumers changing their mode of travel, i.e. taking long-distance trains. This would occur if these modes of travel were made more appealing than flying. There are many factors which could cause this change in perception, from the price to the level of comfort to the environmental impact.

International flights account for a larger share of UK aviation emissions. Realistically, long-haul flights cannot be reduced through modal shifting. If emissions are to be curbed, aside from the technological approaches mentioned above, overall demand will have to be addressed.

A government survey conducted in 2014 found that in the previous year just 15% of people were responsible for 70% of all flights[14]. Moreover, 50% of those surveyed had not flown at all in that period. This suggest that measures to curb aviation demand by incorporating the cost of carbon would be felt most keenly by a small community of 'frequent flyers'.

Figure 7: Infographic of UK average household emissions for aviation



Current and future ambition

As part of the CCC **Core** scenario with an 80% emissions target, the ambition for aviation is to ensure that 2050 emissions are kept to 2005 levels. Allowing for population growth, average household emissions would have to be reduced slightly from 1,027 to 911 kg CO_2e between 2017

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[14] DfT, 2014, "Public experiences of and attitudes towards air travel", https://www.gov.uk/government/statistics/public-experiences-of-and-attitudes-towards-air-travel-2014

and 2050. Given improvements in technological and operational efficiencies, the CCC suggest this target could allow for a 60% growth in demand (versus 2005).

In the **Further Ambition** scenario, annual aviation emissions are reduced to 724 kg CO_2e per household, with growth in passenger journeys limited to 40% above 2005 levels.

In the **Net-zero (demand-led)** case, where households contribute directly to further emissions reductions, average household emissions are reduced to 537 kg CO_2e. To achieve this, demand would have to be limited to just 20% above 2005 levels.

Given that demand over the last decade or so has already exceeded this (25% above 2005 levels), this would now require an overall reduction in journeys compared to today.

Importantly, even this more ambitious demand reduction scenario would still leave significant emissions associated with aviation, requiring offsets elsewhere in the economy (see later).

7. Diet/Agriculture

In a global economy, where much of the food we consume is imported from overseas, and much of the food we produce is exported to other countries, the relationship between our dietary choices and UK agriculture emissions is not strictly one-to-one. In fact, only 36% of the emissions associated with the UK diet relate to UK agriculture[15]. Care needs to be taken to ensure that efforts to reduce agriculture emissions in the UK do not simply lead to offshoring of food production to other countries.

Still, as part of a net zero target, emissions from UK agriculture will have to be tackled and the choices we make as consumers can make a significant difference in addition to upstream measures taken within the sector.

The story so far

Aggregate emissions from the agriculture sector fell from 55 to 46 **Mt** CO_2e between 1990 and 2008, and have remained stagnant since then, accounting for 10% of UK emissions today [16].

The majority of agriculture emissions are in the form of methane and nitrous oxide. Both of these gases are relatively single source with 90% of nitrous oxide emissions produced directly from nitrogen fertiliser application and 90% of methane emissions from livestock[17].

Consumer diets have changed a lot over the years. Factors such as convenience, price, health and ethics have all played a part in changing what we eat. Increasingly, the environmental impact of food has become an important factor for many consumers, contributing to the current movement towards low meat, vegetarian and vegan diets. One UK survey suggests 12.5% of respondents are now vegetarian or vegan and 21% consider themselves as flexitarians (they are conscious of the amount of meat and/or dairy they consume) [18].

Despite these trends it is difficult to predict how social factors will influence diet in the coming decades as there are potential countervailing factors involved.

Although the mapping of UK agriculture emissions against consumer diets is challenging, taking these sectoral emissions on a *per household* basis for indicative purposes would imply a shift from 2,324 to 1,591 kg CO_2e from 1990 to 2017.

Actions for decarbonisation

CCC analysis suggests it is possible to achieve deep emissions reductions in the agriculture sector while maintaining current levels of food production per capita.

Improved farming practices in relation to soil and livestock management could deliver reductions of up to 9 Mt CO_2e by 2050[19], even with current patterns of land use. This can include measures

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[15] Henri de Ruiter, Jennie I. Macdiarmid, Robin B. Matthews, Thomas Kastner and Pete Smith, 2016 " Global cropland and greenhouse gas impacts of UK food supply are increasingly located overseas", https://royalsocietypublishing.org/doi/10.1098/rsif.2015.1001

[16] BEIS, 2019, "Final UK greenhouse gas emissions national statistics: 1990-2017"

[17] Defra et. al, 2017, "Agriculture in the United Kingdom", "https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/741062/AUK-2017-18sep18.pdf

[18] Waitrose and Partners, "Food and Drink report: 2018-2019", https://www.waitrose.com/content/dam/waitrose/Inspiration/Waitrose%20&%20Partners%20Food%20and%20Drink%20Report%202018.pdf

[19] CCC, Land Use: Reducing emissions and preparing for climate change, 2018, https://www.theccc.org.uk/wp-content/uploads/2018/11/Land-use-Reducing-emissions-and-preparing-for-climate-change-CCC-2018.pdf

that maintain or increase levels of carbon in the soil, reduce nitrous oxide emissions by managing soil nitrogen levels and reduce methane emissions from rearing livestock.

Reduced meat and dairy consumption can make a significant impact in reducing emissions from our diet. Particularly large reductions could be made through reducing the number of ruminant animals, such as cows and sheep, which release large volumes of methane when they digest food (methane has a global warming potential 28 times greater than CO_2). Meat and dairy production also require a large area of land to graze the animals and to produce crops for the animals to eat, relative to growing plant-based foods directly for human consumption. Reducing meat and dairy consumption can therefore free up land for increased afforestation, peatland restoration, and the growing of energy crops (see Carbon offsetting).

Reduced meat and dairy would not only reduce UK emissions and free up land, but it would also make us healthier. Compared to the average diet today, the government's nutritional guidelines[20] for healthy eating implies an 89% reduction in beef consumption, a 63% reduction in lamb consumption and a 20% reduction in dairy consumption in the UK. It has been suggested that by transitioning from a high meat diet to a low meat diet it is possible for a single person to reduce their dietary emissions by 35%.[21]

Not all of the beef and lamb consumed in the UK today is produced here, therefore the changes may not directly translate into UK emission reductions. Still, even where these are not captured in the UK accounts, they would lead to real emissions reductions and land-use improvements elsewhere in the world.

Alternative meat and dairy products could be one aspect of how we reduce traditional meat and dairy consumption. The two main factors which people consider with these products is their protein content or their similarity to the traditional products. There are already some alternatives widely available on the market such as tofu, soya milk or Quorn. Less familiar alternatives include protein derived from insects, and others which are still in the developmental stages such as laboratory-grown meat.

The potential of each substitute to reduce emissions has to be closely assessed. However, if each of these new products is sustainably sourced and consumed in moderation, they will have a smaller environmental impact than their traditional counterparts. The potential contribution of alternative products in reducing emissions is dependent on the openness of consumers to trying these out. In the case of lab grown meat, it will also depend on affordability, though production costs have fallen substantially from £215,000 to roughly £8 per burger patty between 2013 and 2018[22].

Reducing food waste is a key contribution that individual consumers can make to reducing emissions. Currently, a significant share of agricultural land is devoted to the production of food that ends up being thrown away, often still in an edible state. Around 10 million tonnes of food

[20] Public Health England, 2018, "The Eatwell Guide", https://www.nhs.uk/live-well/eat-well/the-eatwell-guide/
[21] Peter Scarborough et al., 2014, "Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK", https://link.springer.com/article/10.1007/s10584-014-1169-1

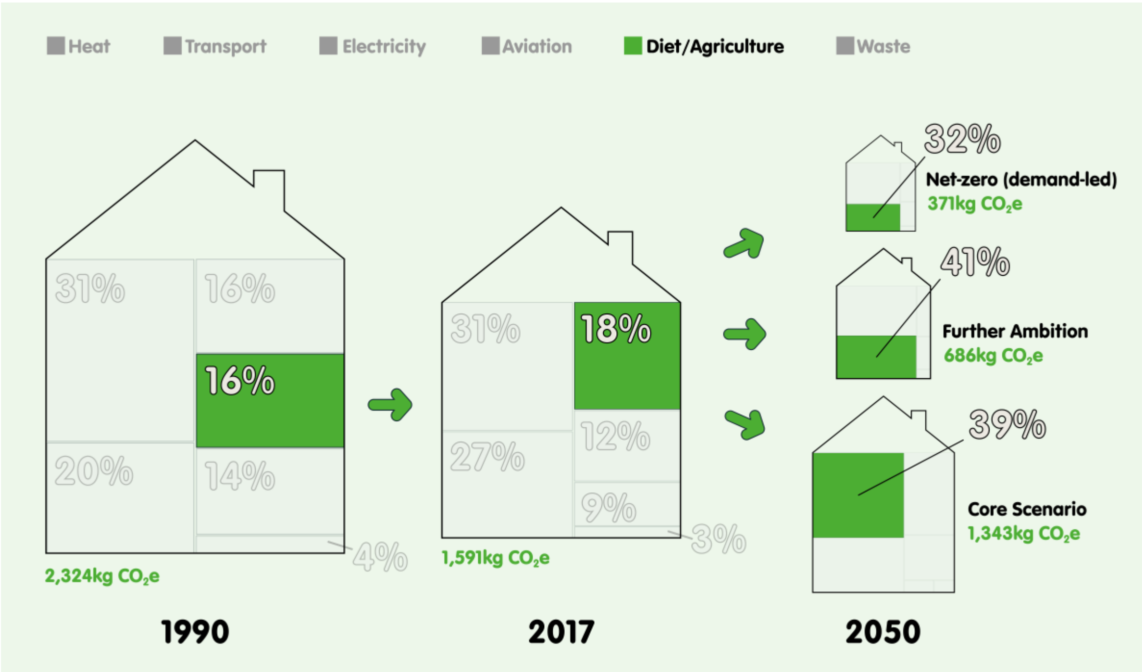
[22] Adam Smith Institute, 2018, "Briefing paper: The prospects for lab grown meat", https://www.adamsmith.org/research/dont-have-a-cow-man-the-prospects-for-lab-grown-meat

that leaves the farm is wasted each year[23], with 70% of this being binned within households[24]. This equates to consumers spending 14% of their weekly food shop on food which goes in the bin[25].

According to WRAP (Waste and Resources Action Programme), food waste can be prevented by buying the right amount, keeping what has been bought at its best and consuming what has been bought[26]. Government and industry can act together to provide better household education, clearer packaging (e.g. removing best before dates, letting the consumer be the judge) or more appropriate portion sizes. The UK government estimates food waste could be reduced by up to 60% through these measures[27].

Again, not all wasted food will have been grown in the UK, so the benefits of reducing these unnecessary emissions extend globally.

Figure 8: Infographic of UK average household emissions for diet/agriculture



Current and future ambition

As part of its **Core** scenario for an 80% emissions reduction, the CCC assumes a small reduction in UK-wide emissions from agriculture, from 46 to 38 **Mt** CO_2e in 2050.

The **Further Ambition** scenario sees agriculture emissions reduced to 26 **Mt** CO_2e in 2050. This assumes a 20% reduction in consumption of lamb, beef and dairy, replaced by an increase in

[23] House of Commons Environment, Food and Rural Affairs Committee, 2017, "Food waste in England: Eighth Report of Session 2016-7" https://publications.parliament.uk/pa/cm201617/cmselect/cmenvfru/429/429.pdf

[24] Defra, 2014, "Food Statistics Pocketbook 2013" https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/315418/foodpocketbook-2013update-29may14.pdf

[25] Defra, 2017, "Food Statistics Pocketbook 2016", https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/608426/foodpocketbook-2016report-rev-12apr17.pdf

[26] WRAP, 2019, "Love Food, Hate Waste Campaign", https://www.lovefoodhatewaste.com/what-to-do

[27] House of Commons Environment, Food and Rural Affairs Committee, 2017, "Food waste in England: Eighth Report of Session 2016-7" https://publications.parliament.uk/pa/cm201617/cmselect/cmenvfru/429/429.pdf

consumption of pork, poultry and plant-based proteins (still well short of the government's healthy eating guidelines).

The **Net-zero (demand-led)** case assumes further dietary change allowing an overall reduction down to 15 Mt CO_2e (the Net-zero scenario also assumes negative emissions of 18 Mt CO_2e from land use change such as afforestation and peatland restoration, giving an overall negative footprint for this sector. Negative emissions are discussed later in the carbon offsetting section).

As set out earlier, the significant level of food imports and exports makes it difficult to directly map emissions from UK agriculture onto UK consumer diets. For illustration though, sharing out UK agriculture emissions on a *per household* basis would imply a shift from 1,591 kg CO_2e per household today, down to 1,343 kg CO_2e in **Core**, 686 kg CO_2e in **Further Ambition**, or 371 kg CO_2e in **Net-zero**.

8. Waste

How we deal with household waste including food waste and plastic packaging, has an important bearing on emissions. Waste disposal can be a source of emissions and can also generate energy.

The story so far

It is important to distinguish between biodegradable waste like food and paper and non-biodegradable waste like plastic packaging.

Biodegradable waste, when sent to landfill, decomposes and produces methane which is responsible for over 90% of all emissions from the waste management sector. A central goal of waste management has therefore been to reduce biodegradable waste sent to landfill through separate food waste collections and paper recycling. These and other measures have helped to reduce emissions from waste by 70% since 1990. On a per household basis, emissions fell from 2,050 to 305 kg CO_2e from 1990 to 2017.

Actions for decarbonisation

Across all types of waste, the primary action for reducing emissions is clearly to reduce the levels of waste being produced.

Reducing biodegradable waste like food can make a significant contribution to reducing emissions. In 2017 there was an estimated 10 million tonnes of food and drink waste, 60% of which could have been avoided[28]. While some food waste is produced upstream of the household i.e. in supermarkets, there are still actions that can be taken by individuals to reduce their own food waste, during planning, shopping, storage, preparation and consumption of food[29].

Dealing with unavoidable biodegradable waste might include composting for some households. If properly managed this will then produce CO_2 (rather than more harmful methane) and the product from composting can be used as fertiliser in gardens.

It will be more difficult for some households to compost their waste. In these cases, a separate food waste collection (which can then be processed elsewhere to produce fertiliser) would help these households to prevent their food waste from reaching landfill. Progress will rely on local authorities providing this option more comprehensively than at present. Once the food waste is collected, it can be treated most appropriately through use of anaerobic digestion[30].

To reduce non-biodegradable waste such as paper and plastics, households can reduce, reuse, recycle. Reducing unnecessary consumption of material goods avoids emissions occurring both upstream during production and downstream from waste disposal. This can include choosing products which have less packaging e.g. buying in bulk.

Reuse could mean buying used products or reusing products multiple times. Maintenance and repair of e.g. clothing, tyres and appliances means they will not need to be replaced as frequently. Donating rather than disposing appliances, tools and clothes allows others the option of reuse.

[28] WRAP, “Estimates of Food Surplus and Waste Arisings in the UK”, January 2017, p13

[29] Karolin Schmidt, Ellen Matthies, Where to start fighting the food waste problem? Identifying most promising entry points for intervention programs to reduce household food waste and overconsumption of food, Resources, Conservation and Recycling, Volume 139, 2018, Pages 1-14

[30] Energy Technologies Institute ‘Executive Summary – Technology Assessment’, https://www.eti.co.uk/search?size=10&from=0&_type=all&publicOnly=false&query=executive+summary+technology+assessment

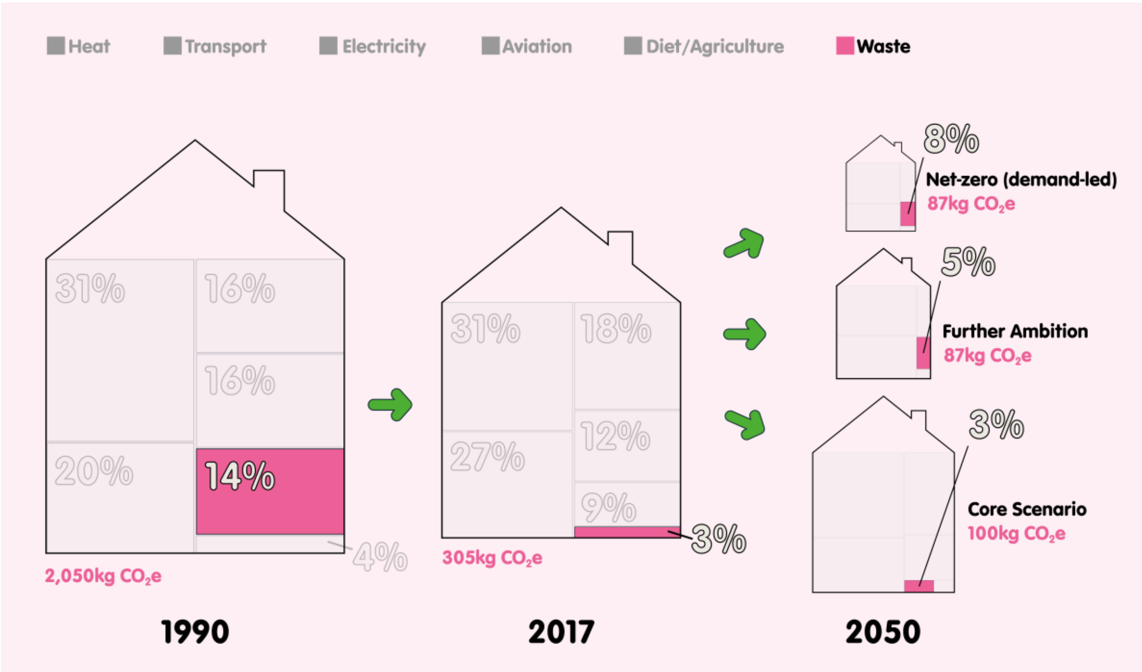
After reducing and reusing goods to avoid waste, recycling should be the last of the three methods households use to reduce waste emissions. The level of recycling will be dependent on the extent of the recycling facilities available.

Dealing with the remaining non-biodegradable waste also requires action to avoid landfill. In this case, the waste can be used by Energy from Waste facilities using incineration or gasification. Since this type of waste contains plastics derived from fossil fuels, burning this waste for energy recovery results in CO_2 emissions. In future, carbon capture and storage technology (considered vital for reducing emissions from heavy industry for example) could potentially be applied to Energy from Waste facilities located near to industrial CCS hubs.

It may not be economic to apply CCS technology to every such facility across the country though, due to distance from the industrial hubs where CCS infrastructure is likely to be concentrated. So, however successful these technological efforts are, it is better to avoid this waste from arising in the first place. This would consequently reduce the emissions arising upstream in the manufacture of plastics (and the extraction of the raw materials).

Households can most actively participate in reducing household waste through the familiar guidance to reduce, reuse, recycle and through their collective purchasing power and the influence they exert on supermarkets and other major retailers. Subsequent actions including energy recovery are mostly influenced by government policy and local councils.

Figure 6: Infographic of UK average household emissions for waste



Current and future ambition

In its existing analysis for a **Core** 80% reduction target, the CCC has advised that emissions from waste should be rapidly reduced. For example, this would include a ban on biodegradable waste being sent to landfill by 2025. By 2050, some residual household emissions from waste would persist, due to wastewater treatment, biological treatment, and ongoing emissions from legacy landfill sites. These are estimated at 100 kg CO_2e per household per year.

The CCC's **Further Ambition** and **Net-zero** scenarios see only limited scope for further reduction in this sector: down to 87 kg CO_2e.

9. 'Negative' emissions

Across many of the activities explored above, even in the CCC's net zero scenario, emissions are not eliminated entirely. Instead, residual emissions from activities like aviation and agriculture would be offset by **negative emissions** (removing carbon from the atmosphere). Various approaches to negative emissions have been proposed, all of which have their limitations[31].

Methods relying on land use change include afforestation, habitat restoration and soil carbon sequestration. With afforestation for example, CCC has recommended that up to 1.5 million hectares of new woodland should be planted to sequester carbon by 2050[32]. At the same time, we can increase the amount of wood used in construction, locking in carbon through the built environment. These land-based approaches could have many co-benefits including:

- improved mental and physical health as we take advantage of expanded, better quality and more accessible green spaces[33];
- improved biodiversity due to the increase in well managed woodland and other habitats;
- flood prevention in towns downstream, through strategic planting of trees on floodplains[34].

Land use change has its limits though, so most scenarios that rely on extensive negative emissions require additional methods. One approach is to use sustainably grown biomass for energy, with carbon capture and storage (BECCS). Here atmospheric carbon is locked into plant matter as it grows, this biomass is then converted to energy e.g. electricity, heat or hydrogen, and the released carbon is captured and piped into a suitable underground geological formation for permanent storage.

More speculatively, some technologies have been proposed for direct air carbon capture and storage (DACCS). This would instead use low carbon energy to draw in and capture atmospheric carbon directly, followed by permanent storage.

At a national level, it will be necessary to employ negative emissions to some extent to counter residual emissions, but there are different ways this might be implemented. It could be that the industries/businesses responsible for producing emissions are asked to take responsibility for offsetting these, ensuring net zero is delivered on a sector-by-sector basis.

This may be seen as a fair way of paying for the costs of reaching net zero. Households would tend to see an increase in the price of carbon-intensive goods and services, relative to low carbon alternatives. Households would still be free to purchase these goods and services, but the relative prices of high and low carbon choices are likely to influence their decisions. For many of us, changes in prices, availability and quality are likely to act as an incentive to shift to more sustainable purchases.

Given the limits of land use change and the immaturity of BECCS and DACCS, carbon offsetting should not be seen as a panacea, but as something we should pursue in parallel with deep decarbonisation of the activities we undertake as a society.

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[31] Royal Society, 2018, "Greenhouse gas removal", https://royalsociety.org/topics-policy/projects/greenhouse-gas-removal/
[32] Committee on Climate Change, November 2018. *Land use: Reducing emissions and preparing for climate change*
[33] Houses of Parliament, Parliamentary Office of Science and Technology, October 2016. *Green Space and Health*
[34] Simon J. Dixon, David A. Sear, Nicholas A. Odoni, Tim Sykes, Stuart N. Lane, February 2016. *The effects of river restoration on catchment scale flood risk and flood hydrology,* Earth Surface Processes and Landforms. Volume 41, Issue 7.

10. Household scenarios

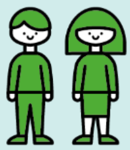
The previous sections give a sense of the effort required across the UK in different emissions categories. For individual households with different circumstances, needs and preferences, the specific activities they feel able and willing to undertake will vary considerably. For instance, with heating, some people spend less time at home than others and find cooler temperatures more comfortable; with transport, some live close to work and are fit enough to walk; with diet, some choose to be vegan or vegetarian and enjoy cooking, and so on.

It is impossible to accurately predict how society's needs and preferences will evolve over the coming decades. Instead, based on studies of how different consumer groups go about their lives today[35,36,37,38], combined with the actions for decarbonisation explored above, this section illustrates three different households in 2050 and how they might go about their lives in a net-zero future. The households include:

- **A young working couple** in a rented home. Born in the 2020s, they will grow up in a world where low carbon solutions are more commonplace.
- **A young family** living in their own home. The adults in this family are today's children who will come of age during the low carbon transition.
- **An elderly man** living on his own. Currently middle-aged, many in this generation will have a fairly settled way of life and may fear some of the changes entailed by a low carbon transition.

Young working couple

Meet Anita and Rupert, they are both in their late twenties and live in a two-bedroom rental flat in a city centre. Anita is an architect and Rupert works in human resources. They cycle or use the tram to get to work. They met while studying at university. Since they were not originally from the city, they spend some of their free time at weekends visiting their friends and family in different parts of the UK.



Like other young professionals in 2050, Anita and Rupert are very much a service-oriented couple. They rent their home, so their landlord is responsible for the property. They preferred this home to the others they looked at because its running costs were lower and simpler to predict. They pay for their energy as one service amongst many (e.g. internet, entertainment, security, cleaning, rent). The zero-carbon home is the norm for them, much as gas central heating was for their parents.

Heating

Anita and Rupert live on a district heat network, so their space heating and hot water are available on demand. Maintenance of the heating and overall energy efficiency of the property is delegated by the landlord to an energy service provider, from whom the couple have selected an energy plan.

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[35] Households energy usage (2018), ETI, https://www.eti.co.uk/search?size=10&from=0&_type=all&publicOnly=false&query=segmentation

[36] Energy Systems Gateway work, Trial Winter 2017/18

[37] Pullinger et al "Final report of the ARCC-Water/SPRG Patterns of Water projects March 2013" http://eprints.soton.ac.uk/359514/1/datastream_publicationPid%253Duk-ac-man-scw_187780%2526datastreamId%253DFULL-TEXT.PDF

[38] Analysis of National Travel Survey Data to Inform Estimates of Heat Demand assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/729521/national-travel-survey-2017.pdf

Anita and Rupert don't really think too much about their use of energy. They work full time at their offices. At weekends, social interaction and other interests take them out of the home. When they are home, they prefer warm temperatures in the parts of the home that they use.

The couple's hot water use is a little unpredictable, as Rupert sometimes showers at the gym or at work if he cycles in. By contrast, Anita prefers to go home for a shower even after the gym. Her showers vary in length according to time constraints.

Having enough heat and hot water without having to plan in advance is very important to them, and the flexible plan they chose from the energy service provider reflects this. The responsiveness of the district heat network is key to ensuring the couple have the heat they want when they want it.

Surface Transport

Anita and Rupert live in rental accommodation close to their places of work in the city centre. Renting means that they can move home relatively quickly if employment changes. They live car-free as their short commutes are regular and consistent, so can be done with urban public transport. Weather permitting, Rupert will often cycle. As they are in full time work, they do most of their recreational travelling at weekends, mainly meeting up with friends across town. This makes public transport an ideal and frequently used option for this couple.

Electricity

Anita and Rupert have a smart service plan that saves them money by allowing their service provider to remotely communicate with smart appliances in their home to assist in balancing the low carbon grid. For example, their fridge-freezer can avoid consuming electricity during peak times while still maintaining a safe operating temperature. They are also happy to load up the dishwasher in the evening and let it come on during the night.

The smart plan is designed to meet their needs, not the other way around, so they still use their appliances and devices when they want to, for example when entertaining. They accept that this may add a supplement to their monthly bill if it happens to be during a period of high demand. As part of managing this, the energy service provider has installed some domestic battery storage in the property to reduce the property's reliance on the network during peak times.

Aviation

Despite improved aircraft efficiency and flight management compared to today, aviation in 2050 still relies on fossil fuel. With most other aspects of their lives supported by low carbon solutions, Anita and Rupert are well aware of the environmental impact of flying and yet, with an entire globe to explore, they find it hard to resist the pull of foreign travel altogether.

In an effort to limit their impact, the couple save up for one foreign holiday each year, staying out for an extended period to see as much as they can of the local area as part of that one trip. They are accepting of the carbon offsetting fee charged by the airline as part of the ticket price (and glad that they don't travel often enough to incur frequent flyer charges).

Diet and Waste

Anita is a vegetarian and loves to try new recipes. Rupert eats meat, but generally only when eating out. When at home he is happy to share vegetarian dishes with Anita. Since they have no garden to allow composting, all their food waste is bagged and deposited for communal waste collection, alongside recycling and general waste.

Family of 4 (2 adults and 2 children under 16)

Meet the Jagpal-Smiths. Harrison and Scarlett live with their two children Arthur and Gabi. They live in a suburban area, near other families and amenities. Harrison is an account manager and often works at home. He takes the train to the office when needed. Scarlett is a part time teacher at the local secondary school so uses the family car to get to work. She takes Arthur to school in the car on her working days and car shares with two other members of staff. On her non-working days, she volunteers on the walking bus that Gabi uses to go to school.

Like many other young families, Harrison and Scarlett chose their home because it was close to essential amenities like schools, shops, cafes, doctors etc. Town planning has encouraged independent communities, reducing the need for car travel and enabling more transport by foot or bicycle as well as public transport.

Heating

The Jagpal-Smiths are comfort-focused, keeping the children warm is more important than the cost of energy. They spend plenty of time at home and have been willing to invest in their property and in new technologies to provide the level of comfort they want. As part of a comprehensive overhaul previously, the family were able to greatly improve the energy efficiency of the home, and now a heat pump meets their needs for consistent heat throughout the day.

The family's hot water needs are relatively consistent and predictable. Harrison, Scarlett and teenager Arthur mostly shower in the morning, each day. Gabi still has a bath each evening.

A large hot water storage tank ensures that peaks in demand can be accommodated without relying on an excessively large heat pump or secondary heating system.

Surface Transport

Scarlett relies on her car for the short commute to work and for the many short trips to the children's clubs and social events. She also shares transport with other parents (just as most parents do now). When she is not at work Scarlett volunteers with the supervised walking bus that ensures Gabi and her classmates get to school safely on foot. Harrison walks to the station and takes the train to the office three times a week. On the other days he works from home.

Though this household makes many trips per week, town planning has created geographically compact communities and their journeys are typically short. They can comfortably rely on a combination of their electric vehicle, public transport, and the walking bus.

The Jagpal-Smiths frequently go on holidays and trips within the UK to visit family or theme parks. For longer trips they use an integrated travel service which involves train travel and then the use of an electric hire car for the duration of the holiday, booked as a package.

Electricity

Scarlett and Harrison had their home equipped with solar panels as part of the earlier retrofit. Scarlett enjoys knowing her EV is being charged from their own electricity during the day. A smart charger ensures that - even when the sun is not shining – charging occurs when this is least expensive. She also has the advantage of being able to charge her EV when she is at work.

The family have invested in smart appliances that are capable of avoiding energy use at peak times, but they frequently forego this capability to meet the needs of their young family.

Aviation

Harrison is required by his company to take occasional business trips abroad (although the company's corporate social responsibility policy aims to limit air travel to only the most essential trips). For the Jagpal-Smiths, family holidays are rarely taken abroad. Instead, most of their holidays are spent at one of the UK's resurgent seaside resorts, taking advantage of a good range of all-weather venues and activities.

Diet and Waste

The family enjoy a wide range of foods, but meat is only eaten twice a week due to its cost and environmental impact. Harrison is mostly responsible for grocery shopping which is delivered each week while he is working at home. He chooses some groceries based on their carbon rating as well as nutritional information. They grow some vegetables in their garden and are careful to compost food waste where possible to feed back into the soil.

After completing a school project on the theme, Arthur has become the resident recycling and waste reduction expert, encouraging dad to take packaging into account in his grocery shopping.

Single elderly homeowner

Meet Ian, he's 75 years old and is a retired project manager living in a rural village. He still lives in the 1920's three-bedroom detached home that he shared with his wife and children. Being off the gas grid, he installed a heat pump to save money with escalating oil prices and has insulated his home. His three children live in different parts of the UK, so he spends a lot of his time staying with them but is still home quite a lot of the time.

Heating

Ian likes to conserve energy resources and thinks carefully about how he heats the home. Until he retired a decade ago, the home was heated by an oil boiler. Ian had spent a lifetime trying to limit energy use by engaging in energy-saving behaviours like avoiding heating rooms when not in use.

When he retired, Ian invested in a home retrofit to improve the energy efficiency of his home and allow him to replace the aging oil-boiler with a ground source heat pump. He hates to waste energy and thinks it is extravagant to overuse heating, so it took him some time to get comfortable with leaving his heat pump on continuously to provide a constant level of heat, rather than switching it on and off for instantaneous comfort.

Ian had a large hot water tank installed alongside the heat pump. This ensures his system can take advantage of cheap electricity at times of high supply and low demand, with the heat then released when needed to supplement the continuous output from the heat pump. The tank also provides sufficient hot water for use in the kitchen and bathroom.

Surface Transport

Ian is at home for most of the day. Like many retired people he makes fewer trips than other household groups. When he does travel, Ian relies on his EV which he charges overnight in the driveway. As he gets older, he is worried that he may no longer be able to drive. Unlike elderly people living in urban areas where public transport can ensure continued independence, Ian is worried that his rural setting will leave him isolated.

Although he has not shown too much interest until now, Ian is learning about the latest autonomous vehicle technology from his son. He hopes that this could be the solution to his mobility needs but has not yet decided whether he will buy a private car with some autonomous capability or rely on the fully autonomous vehicles that provide mobility on demand.

Electricity

Ian's choice of an electric heat pump and electric vehicle means his home places a higher demand on the electricity distribution network than before. With so many of his rural neighbours following the same path, the local distribution network has been upgraded to cope with the increased demand. Apart from ensuring his EV is plugged in to charge overnight, Ian is not too hands-on with managing his electricity use.

Aviation

Ian is not a regular flyer these days. Instead, he is going on a three-week cruise with his sister Samantha. They are traveling to the dock by train and then cruising around the Mediterranean.

Diet and Waste

Ian has reduced his meat consumption due to suffering with angina. He mainly eats ready meals, generating a lot of packaging waste, but does check the carbon rating on the product when making purchasing decisions to limit his impact. Ian saves any food scraps for the compost bin where appropriate, but non-compostable food waste is collected by the locally authority along with his recycling and other household waste.

11. Commentary

Household diversity and distributional impacts

In this analysis we have focused on assessing the actions and emissions for an average household. As the scenarios illustrate though, we have a wide range of household types across the UK and the carbon footprint of each is correspondingly diverse. Policy and other mechanisms to encourage a low carbon transition must be sensitive to the specific challenges and opportunities that arise due to location, building type, income etc.

For example, the richest 10% of households have an overall carbon footprint *three times* the size of the poorest 10%[39]. The disparity is less pronounced for home heating, where the richest emit just twice as much as the poorest. But for private transport it is seven times as much, and international aviation ten times as much.

With aviation demand dominated by a small community of frequent flyers, pricing in carbon here would mean the cost was mostly borne by those able to pay.

For private transport, as we shift to an electric vehicle future, the purchase of new vehicles will tend to be by wealthier households, as is the case today. Over time, as they enter the second-hand market these vehicles will become affordable for other households. But other challenges may arise around charging points: wealthier households are more likely to have access to private off-street charge points (in driveways), so close attention will have to be paid to ensure sufficient on-street charge points, for example.

For heating, the fact that emissions are less diverse across income groups is indicative of the high relative expenditure of lower income households on this essential service (which pushes many homes into fuel poverty today). With significant capital expenditure potentially required for home retrofits and low carbon heating systems, authorities will have to be conscious of the challenges this could present for low income households. At the same time, a coordinated transition to decarbonised heat can be planned alongside more wide-ranging improvements in living conditions, raising the quality of life and health of millions of UK households by treating damp and draughts etc as well as reducing bills.

The rate of change

In scenarios consistent with an 80% reduction by 2050, parts of the energy system would remain reliant on unabated fossil fuels. Aviation and shipping are obvious examples, but also heavy-duty road vehicles, industry, hard-to-treat buildings, even peak electricity generation from gas turbines.

In the CCC’s **Further Ambition** or **Net-zero** scenarios, these sectors would require far more comprehensive decarbonisation by 2050, and this cannot be achieved through a last-minute technological overhaul in the late 2040s. Achieving net zero by around 2050 requires accelerated adoption of key technologies to ensure they can be commercialised and scaled up in time.

An accelerated reduction pathway is not just a means-to-an-end. Early action on decarbonisation is also desirable in itself in relation to limiting climate change, since it is our *cumulative emissions* over time that drive the concentration of carbon in the atmosphere[40].

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[39] Centre for Sustainable Energy, 2013, “The Distribution of household CO_2 emissions in Great Britain”

[40] Bill McKibben: Winning slowly is the same as losing, https://www.rollingstone.com/politics/politics-news/bill-mckibben-winning-slowly-is-the-same-as-losing-198205/.

Whereas current pathways allow some decisions to be deferred to the 2030s or 2040s, in an accelerated net zero pathway these decision points will necessarily be brought forward. For example, if petrol and diesel vehicles need to be removed from our roads entirely by 2050, the average lifetime of a car means that sales of these vehicles will need to end by around 2035, which is ahead of current government ambition.

Similarly, if the average age of a gas boiler is around 15 years, then most households can expect their boiler to need replacement between now and 2030. Under many pathways aligned with current (80%) ambition, the majority could choose to install a new gas boiler, deferring the low carbon step for another 15 years. With a more accelerated timetable for decarbonising heat, clear guidance and support would be needed to enable more of these households to adopt low carbon options sooner (along with the local area planning to ensure this is done in a coordinated way).

12. Summary

Current UK ambition is to reduce GHG emissions by 80% in 2050 compared to a 1990 baseline. In light of the latest climate science, the UK Government has asked the CCC for advice on the implications of a target to achieve 'net zero' emissions (100% reduction). In this report we have explored the implications of a more ambitious target at the household level.

With the current target, it is possible that some homes could continue to rely on petrol/diesel cars and gas boilers (albeit more efficient, hybrid versions). The budget could also accommodate continued expansion of air travel, meat and dairy consumption, as well as fossil fuel use in the production of goods and services we rely on.

Achieving a net zero target would require households to engage more profoundly in the transition. This is a challenge but also an opportunity since many of the steps involved would bring a number of co-benefits such as reduced congestion, improved air quality, expansion of green spaces and improved physical and mental health.

Electricity generation must be near fully decarbonised in any pathway. Households can play their part through the adoption of micro-generation and storage technologies, or smart appliances that can help balance the grid.

For transport, unlike current ambition pathways, hybrid electric petrol/diesel cars will not be sufficient. Increased ambition will require a decisive shift towards fully electric/hydrogen vehicles.

Similarly, for heat, hybrid approaches that rely on continued use of natural gas will not be enough. Net zero will require even most hard-to-treat buildings to adopt low carbon alternatives. Policymakers will need to take care to ensure the least well off are supported in this transition.

With aviation, the biggest emitters today tend to be the wealthiest households, meaning emissions could be tackled through e.g. a levy on frequent flyers.

Emissions from agriculture could be reduced considerably if we shifted our diets in line with guidance for healthy eating, in particular by reducing consumption of meat and dairy. Reducing food waste would also make an important difference here, and in reducing emissions from landfill.

Even with the CCC's most ambitious scenario, it is assumed that there will still be some emissions remaining, especially those associated with aviation and diet. As a result, we will have to rely on carbon offsetting to reach net zero. But approaches for achieving negative emissions are limited in scope, so the more we can reduce emissions directly, the more confidence we can have in our ability to meet the target.

Energy Systems Catapult supports innovators in unleashing opportunities from the transition to a clean, intelligent energy system.

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