Delivering Net Zero UK: A stocktake

Report

May 2024

Oxford Smith School of Enterprise and the Environment

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This report contains analysis cited in the Policy Brief ("*Getting a Good Deal on Net Zero*") and is accompanied by a Technical Annex. The Smith School team involved in the preparation of this report were Anupama Sen, Harry Lightfoot Brown and Sam Fankhauser. This report draws on multiple sources, including analysis from McKinsey & Company. We are grateful to the Children's Investment Fund Foundation for their support of this work. We are also extremely grateful to Dr François Lafond and Dr Emilien Ravigné for their detailed feedback on previous drafts.

The views expressed in this report do not necessarily represent those of the Smith School or any other individual, institution, or funder. It has been reviewed by at least one internal referee before publication.

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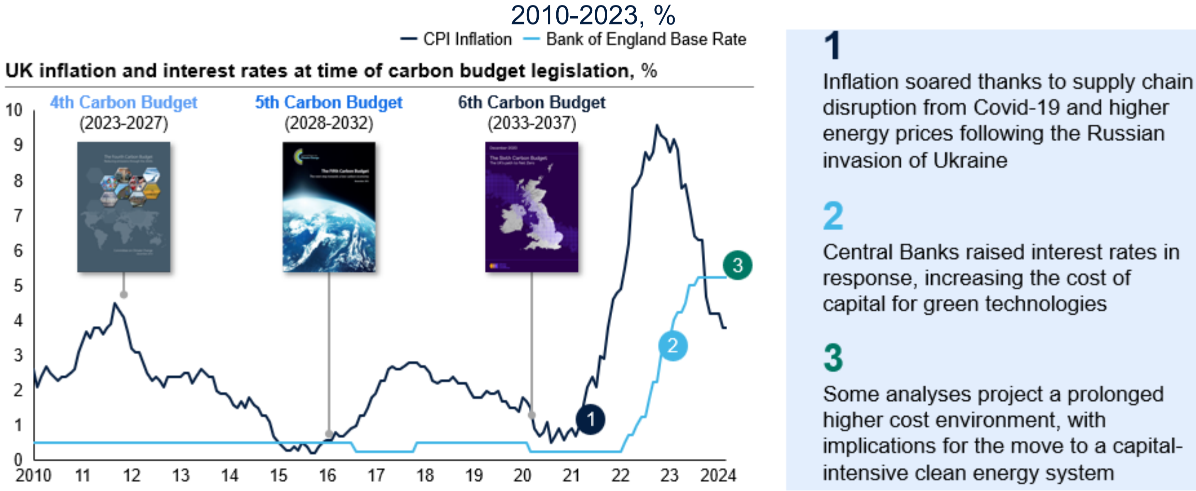
Executive summary

The world is at a fork in the road, with future pathways set to profoundly shape both the cost and impact of the energy transition. With the UK in a critical decade for climate action, this study broadly summarises two alternative future pathways: i) a return to a 'low cost' environment, with continued cost decreases in clean technologies and low financing costs, as the world experienced prior to 2022; ii) a 'higher for longer' cost environment, where cost decreases decelerate and financing costs remain above the post-2008 trend, as the world is currently experiencing.

In contrast to the stable expectations when the UK's Climate Change Committee (CCC) first published its recommendations on the carbon budgets, and despite the recent decline in inflation from its peak in 2022/23, the cost of financing over the remainder of this decade is uncertain (Figure 1). Clean technologies tend to be much more capital-intensive than their conventional alternatives and, as such, increasing financing costs disproportionately impact their total costs compared to conventional alternatives. It is therefore vital to understand the implications for reaching net zero in a potential higher-rate environment.

Figure 1: UK inflation and interest rates at time of carbon budget legislation
2010-2023, %



Source: Bank of England (2024)

This study updates cost estimates of the CCC Net Zero trajectory to 2030 in both a low and high cost environment. Sitting between the CCC's sixth and seventh carbon budget analyses, it explores the incidence of investment and cost across government, business and households, and quantifies the first-order regional employment and competitiveness impacts associated with a Net Zero scenario. It takes a relatively narrow view of the cost of the transition. A more complete assessment might account for co-benefits of decarbonisation including reduced air pollution and improved energy security, as well as longer-term secondary impacts such as potential comparative advantages for the UK as global supply chains decarbonise, but as the immediate implications for investment and cost are currently at the core of the public debate, this study primarily focuses on the nearer-term impacts.

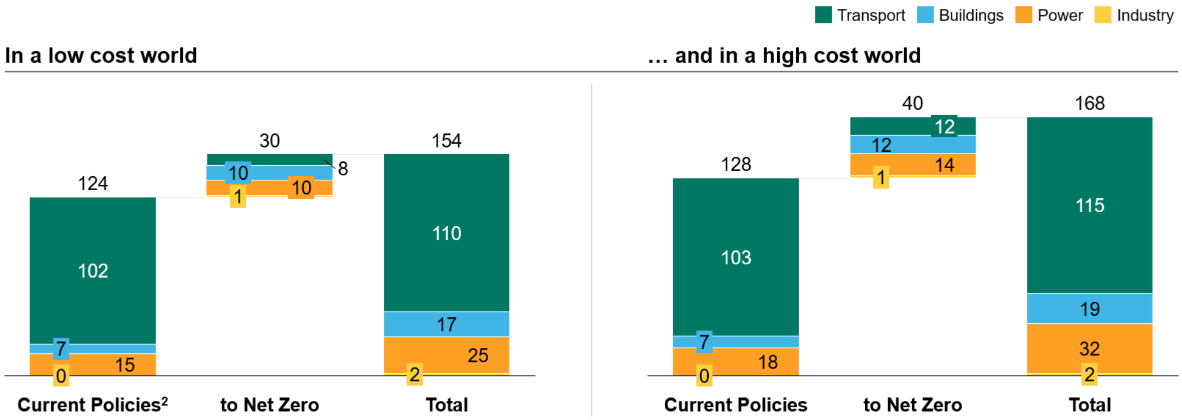
In comparing the financial costs of clean technologies with their conventional equivalents, this study approximates the trade-offs faced by real-world investment decision makers and, therefore, the public spend that may be required to reach net zero. Investment decisions can be modelled based on the lifetime cost, or total cost of ownership (TCO), to buyers of a conventional technology versus a clean technology, based on estimates of future relative unit costs, carbon prices, fossil fuel prices and financing costs (see Box 1 for detail). For example, a private sector utility faced with a decision to build an offshore wind farm or a combined cycle gas turbine (CCGT) plant might make that decision based on the relative return on investment for each option on a TCO basis, discounting the relative savings on operating expenditure (OPEX) of the wind asset versus the CCGT asset at a technology-specific cost of capital. Similarly, a household considering purchasing an electric vehicle (EV) instead of an internal combustion engine vehicle (ICEV), or investing in insulation and a heat pump instead of running a gas boiler, might discount any future cost savings at a discount rate that reflects their cost of capital and a range of other barriers to action, such as the transaction costs involved in switching to the green technologies. In some cases, the clean technology may carry a TCO premium compared to the fossil fuel-based option, but this may change if government interventions scale up to compensate for it. This study considers a range of support levers: a carbon price, mandates, behavioural and credit de-risking measures, OPEX subsidies, CAPEX subsidies, and blended finance.

This study finds that achieving the 2030 carbon target requires ~25% more investment than current policies will deliver across Power, Transport, Buildings and Industry. In a Current Policies scenario, reflecting existing spending patterns, investment in the energy system averages £124bn per year to 2030, or £128bn in a high cost world. This includes all high-carbon and low-carbon investment into Transport, Buildings, Industry and Power and represents the natural turnover of assets – i.e., buying new cars as old cars retire. With a push to net zero, the additional investment is around £30bn in a low cost and £40bn in a high cost scenario (~20% of total).[1] The £30bn-£40bn range presents the values in a low cost and a high cost scenario, as specified for this study, not the full range of uncertainty in outcomes under different combinations of future prices. Of the total investment, households could account for around two thirds, while businesses could account for around one third. Households account for a larger share because net zero requires electrifying personal transport and greening

[1] The £30bn-£40bn could be offset by billions of pounds in annual operating cost savings to 2030 (Section 4).

homes with heat pumps and insulation across the country. Over time, the share of investment associated with businesses could rise as decarbonising Industry becomes more feasible with maturing technologies in the 2030s onwards.

Figure 2: Additional investment to get to net zero
Average annual investment need, 2024-30, £bn[1,3]



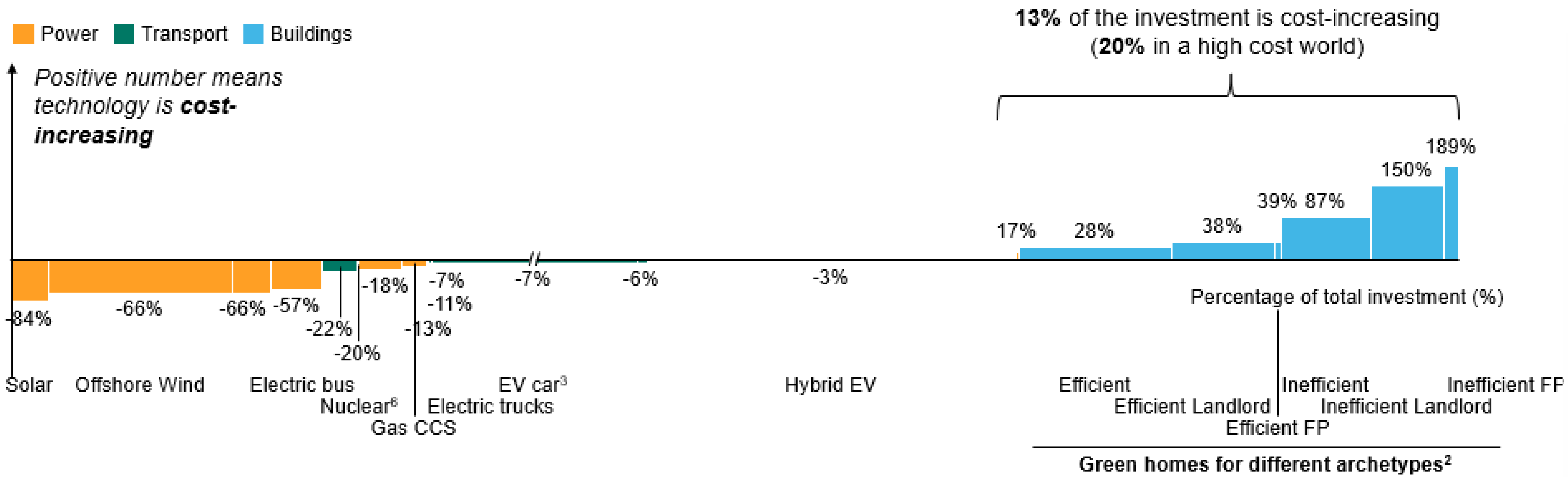
1. The additional investment is calculated by subtracting estimates of the investment under a Current Policies scenario from estimates of investment required under a Net Zero scenario. This is focused on purely the CAPEX involved, ignoring any OPEX savings.
2. Current policies refers to the investments that would be made into the energy system anyway, without a push to Net Zero. Current policies investments involve less clean technology by proportion.
3. Numbers may not add up due to rounding.

Source: Team research based on investment estimates, aligned with CCC deployment and updated cost information, as described in Approach.

The vast majority (80-87%) of low-carbon investments in a Net Zero scenario will reduce lifetime costs to households and businesses over investment lifetimes, relative to continued reliance on fossil technologies. The cost implications are calculated by comparing the TCO of the clean technology and the carbon-intensive technology it replaces. By 2030, ~87% of the investment is estimated to be cost-decreasing (i.e., reduce total spending on capital and operating costs) in a low cost world (Figure 3) and this figure is around 80% in a high cost world. The cost-increasing investment, in both scenarios, is largely concentrated in one area: household investment in heat pumps and retrofits in the buildings sector. Household energy investment decisions are partly driven by cost, but also by a range of non-economic factors such as perceptions of social status or lack of information on the long-term viability of a product. Evidence suggests households may require a relatively higher return on domestic energy investments, estimated at 6-10 percentage points higher than their borrowing costs, which implies that additional public spend would be required for households to switch to clean technologies.

Figure 3: Low-cost world green premium curve for non-infrastructure spending[4,5]

Green premium[1] curve in Net Zero low cost scenario, 2030, green premium against investment

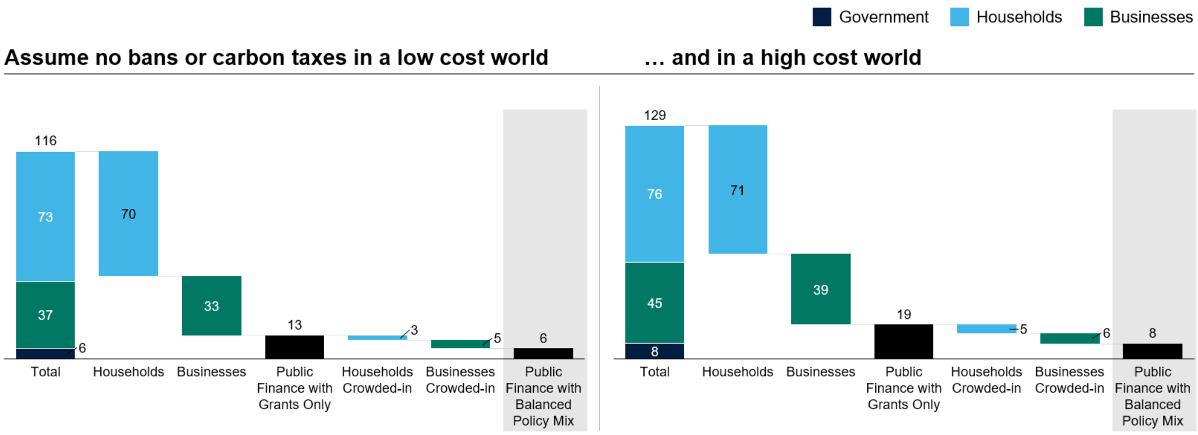


1. Green premium means how much more expensive, in percentage terms, the low-emissions technology is than the high-emissions technology.
2. 'Inefficient FP' means an owner-occupied household that is fuel poor investing in a heat pump + retrofit;
   'Efficient FP' means an owner-occupied household that is fuel poor investing in a heat pump;
   'Inefficient' means an owner-occupied household that is not fuel poor investing in a heat pump + retrofit;
   'Efficient' means an owner-occupied household that is not fuel poor investing in a heat pump;
   'Landlord' means a rented home investing in heat pump and/or retrofit.
3. EV cars are ~50% of the investment so there is a break in the x-axis to ensure the other technologies are visible.
4. This green premium curve cannot consider infrastructure technologies (e.g. transmission and distribution) because there are no carbon-intensive technologies to compare them against. The rest of the report does consider these technologies.
5. This graph assumes government has used policy to reduce green premia, including carbon pricing. Forecasts of the fossil fuel prices, electricity costs and carbon prices used are from DESNZ's central scenario, detailed in the Technical Annex.
6. The greatest cost uncertainty is for nuclear, which can be subject to cost overruns and delays.

Source: Team research based on investment estimates, aligned with CCC deployment and updated cost information.

Our analysis suggests that a 'balanced policy mix', mirroring that in place today but scaled up to reach net zero, could achieve the 2030 goals at a reasonable impact on public finances. A balanced policy mix[2] combining carbon pricing, mandates, behavioural measures and blended finance could support investment decisions in these low-carbon assets, while reducing the scale of public spending that may be needed. A balanced policy mix aligns economic incentives to achieve efficiency gains and distributes the cost of the TCO premium between economic actors. For example, behavioural measures can reduce perceived risk of switching to clean technologies and blended finance can reduce the cost of capital and de-risk investment to crowd in private capital. Taken together, the policy package could reduce the total level of public sector investment in the form of CAPEX subsidies needed from £13bn to £19bn per year, in a hypothetical policy environment with grants only, to £6-8bn to 2030, in a more realistic environment with a balanced policy mix (Figure 4).

Figure 4: Effect of policy levers given a balanced policy mix
Average annual low-carbon investment need[1,2,3], 2024-30, £bn



1. The required subsidy is calculated using a TCO approach. Where a clean technology is more expensive than its carbon-intensive equivalent on a whole-lifetime basis, subsidies or other policies are necessary to cover the gap and ensure that the clean technology is cost-competitive. Over time, as technology advances, green technologies get cheaper and more affordable, reducing the public spend requirement.
2. The modelled 'balanced policy mix' is based on policies which are in place already (albeit not at the level of ambition needed to achieve the Net Zero scenario) or are under consideration by policymakers. For example, the government has indicated that it wants to use mandates to decarbonise cars. Under this, a given proportion of the cars that manufacturers sell must be EVs. The modelling consequently assumes that transport decarbonises using mandates, but that the EV sales mandate is high enough to achieve Net Zero.
3. Numbers may not add up due to rounding.

Source: Team research based on cost modelling, as detailed in Approach

[2] See Table 2 for a detailed description of the balanced policy mix.

This study further investigates how the costs and benefits of the net zero pathway might vary across different household archetypes, depending on the policy environment. The impact of technology investment decisions on household budgets varies with several factors, including energy efficiency of the home, income, household size and tenure (i.e. whether the home is owned or rented – for example, in case of the latter, the landlord may bear the cost of upfront investments, but tenants may see the benefits). Depending on these factors, the cost of decarbonising home heating during the transition could range from a hypothetical maximum of £400 to £3,100 per annum per household in a low cost world (Figure 5).[3] The costs vary by different households: 78% of households would not require a deep retrofit and would therefore pay less. However, policy levers such as manufacturer mandates for heat pumps can substantially alleviate costs and reduce the annual household cost of a net zero home to ~£120 to £180 per year (Figure 5). In contrast, the shift to electric cars could deliver a cost saving of ~£275 to £500 per year per household with one car. This implies that a well-coordinated systems transition could in some cases secure net savings for households.[4]

Although a balanced policy mix could reduce the cost to households, lower-income and vulnerable households need to be supported through the transition to a net zero world. The annual household cost of a net zero home of ~£120 per year under a balanced policy mix could rise to ~£170 per year in a high cost world,[5] potentially requiring additional measures to ensure this cost does not fall disproportionately on lower-income households.

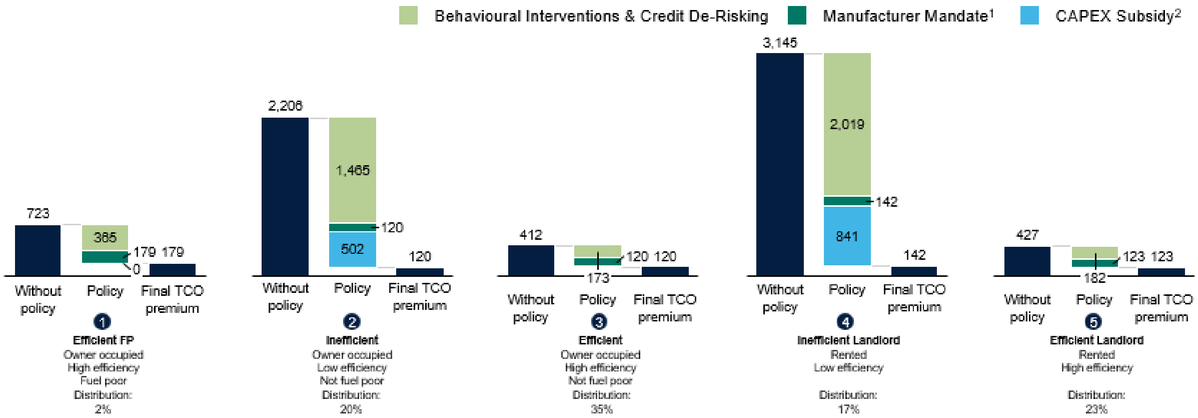
[3] The £400 to £3,100 range comes from taking the least-expensive archetype, 'Efficient' in a low cost world, and comparing against the most-expensive archetype, 'Inefficient FP' in a high cost world.

[4] The distribution of operating savings across different household types over time (for example, when property is bought and sold) could vary, contingent on the efficiency of the housing market. Behavioural measures within the balanced policy mix – for instance, information campaigns – could play a key role in delivering efficient outcomes.

[5] Based on the 'Efficient' archetype.

Figure 5: Theoretical cost of home conversion faced by different household archetypes given subsidy and mandates

Average annual TCO premium of different households[3,4,5] in 2030, low cost world, £

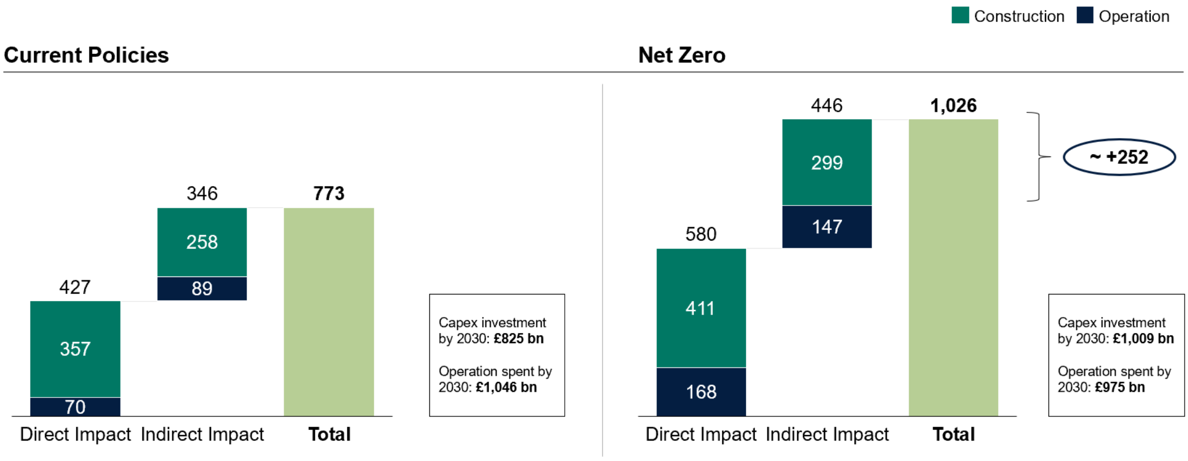


1. Assuming 50% of the TCO gap between heat pump and gas/oil boiler are covered by manufacturer mandates.
2. Assuming 50% of the TCO gap between heat pump and gas/oil boiler are covered by CAPEX subsidies, 100% of the TCO gap for retrofits are covered by CAPEX subsidies.
3. 'Inefficient FP' means an owner-occupied household that is fuel poor investing in a heat pump + retrofit; 'Efficient FP' means an owner-occupied household that is fuel poor investing in a heat pump; 'Inefficient' means an owner-occupied household that is not fuel poor investing in a heat pump + retrofit; 'Efficient' means an owner-occupied household that is not fuel poor investing in a heat pump; 'Landlord' means a rented home investing in heat pump and/or retrofit.
4. 'Without policy' reflects behavioural discount rates that result in a significantly higher perceived cost to the household.
5. The 'distribution' adds up to 97%, not 100%. The missing 3% is the 'Inefficient FP' archetype beyond the scope of this study.

Source: Household model, based on cost modelling, as detailed in Approach.

Delivering net zero could support the creation of ~250,000 new jobs across the economy by 2030. These full-time equivalent jobs are above those in the Current Policies scenario (Figure 6) and are the result of the construction and installation of new technologies, alongside operational jobs that continue throughout the lifecycle of the investments and beyond 2030. They include 'direct jobs' (i.e. ~150,000) as well as 'indirect' jobs (i.e. 100,000). Additional jobs are mainly related to investment in EVs, Carbon Capture and Storage, and heat pumps, and would be concentrated in specific sectors: Maintenance & Repair, Financial intermediation, Transport equipment (the manufacture and repair of vehicles) and Transportation services.

Figure 6: Full-time equivalent jobs created, thousands



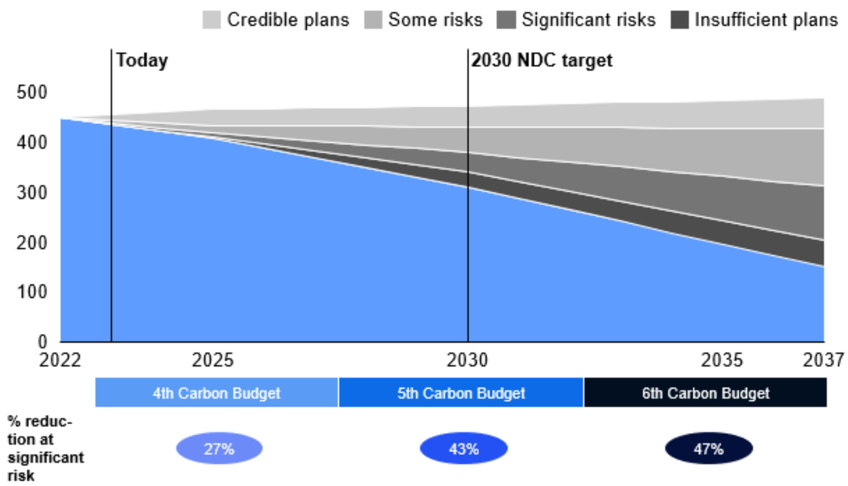
Source: Input-output modelling, based on EORA input-output matrices. See Technical Annex for details.

1. Context

The UK has two key climate targets: a legally binding net zero emissions target for 2050, and a 68% emissions reduction Nationally Determined Contribution for 2030 (CCC, 2020).[6] To drive progress towards achieving these targets, the government has set a range of objectives for low-carbon technology deployment, including plans to fully decarbonise the power sector by 2035 (UK Government, 2023a). The government currently plans that all new heating appliances in homes and workplaces will be low-carbon from 2035 onwards (DESNZ, 2023b). All new cars sold in the UK from 2035 will have to be electric.

While there has been some progress achieving the 2030 target, CCC analysis indicates that greater action will be needed. The rate of emissions reduction will need to substantially increase for the UK to meet the 2030 target; outside the Power sector it needs to nearly quadruple, from annual reductions of 1.2% to 4.7% (CCC, 2023a). According to the CCC, only 25% of the emissions reductions required by 2030 are associated with credible plans, while around 40% of the required emissions reductions have plans that are either inadequate or have 'significant risks' attached to them (Figure 1.1).

Figure 1.1: Net zero pathway emissions reductions mapped by credibility of existing plans
MtCO2e, 2022-37



Source: Climate Change Committee 2023 Progress Report to Parliament (CCC, 2023a).

A series of shocks have profoundly reshaped the economic environment since the publication of the CCC's most recent advice on the pathway to net zero. The Sixth Carbon Budget advice was published in December 2020, after which inflation soared due to supply

[6] The 68% reductions target is against a 1990 baseline.

chain disruption during Covid-19 and energy price rises following the Russian invasion of Ukraine. The Bank of England raised interest rates to combat inflation, which increased the cost of capital for green investments, with uncertainty over future rates. In summary, the UK (and the rest of the world) are in a different place to when the Sixth Carbon Budget was conceived.

In light of this uncertainty, there is a need to better understand the distribution of the costs and benefits of achieving UK net zero across economic actors, in different scenarios that describe the two possible futures. This report updates the cost assumptions of the CCC and explores the distribution of costs across households with different socioeconomic and other characteristics; across regions, with implications for incomes and employment; and across industry sectors, with implications for industrial competitiveness.

2. Approach

This study incorporates five strands of analysis.

First, it quantifies the investment needs and economic costs for different levels of climate ambition and different cost environments. The Current Policies scenario considers the deployment of technology aligned with existing policies, while the Net Zero climate scenario aligns with the "Balanced Pathway" in the Sixth Carbon Budget (CCC, 2020). Cost estimates across both high- and low-cost environments build on the latest publicly available techno-economic data[7] alongside research literature on innovation, learning, and cost reduction. The high cost world has relatively higher inflation, real interest rates and higher technology costs, for example due to continued supply chain disruption.[8] Table 1 shows how the key assumptions compare in a high and low cost world. Combining the deployment numbers from CCC and the updated cost information yields the overall investment numbers. Figure 2.1 shows a schematic of the four scenarios under consideration.

Second, it estimates the cost implications of net zero and characterises the cost of the transition deriving from the current and potential future cost premia of some specific low-carbon technologies. Clean technologies are cost-competitive when their TCO is lower than that of a conventional technology that serves the same purpose (see Box 1, below, for more detail). If a technology is not cost-competitive, then it is cost-increasing for the investor, resulting in cost premia for delivering the transition. Note that this study does not focus on the considerable benefits associated with net zero. Analysis by the Grantham Research Institute at LSE (GRI, 2022) finds that the total climate change damages to the UK will rise from 1.1% of GDP in 2022 to 3.3% by 2050 and 7.4% by 2100, under current policies. The cost estimates presented in this report pale in comparison to the benefits of avoiding these climate damages.

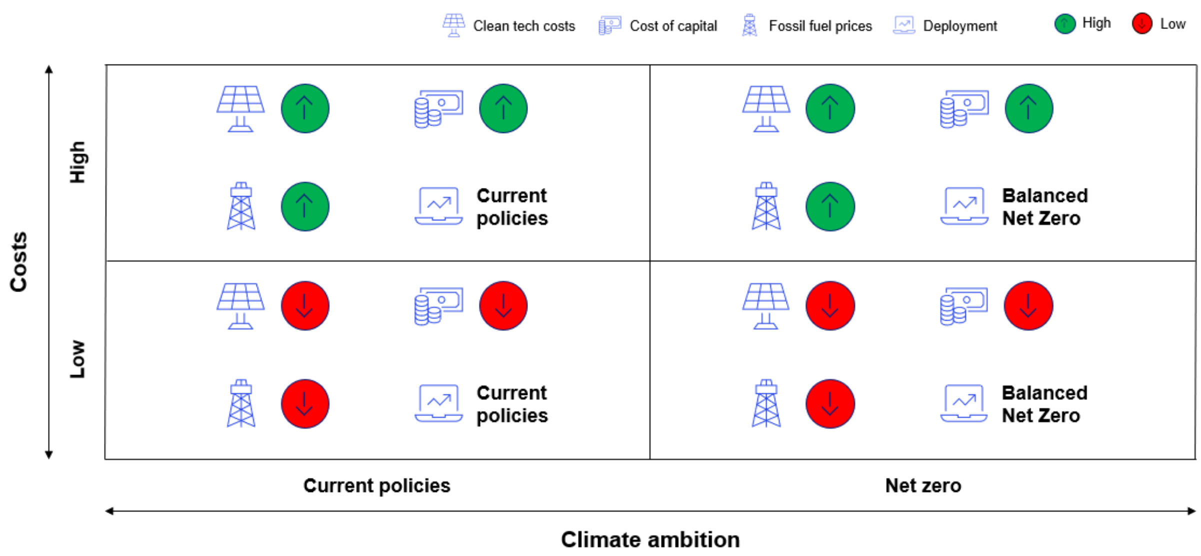
Third, it identifies how a package of policy levers (or a balanced policy mix) could incentivise greater private sector investment, reducing the level of public sector investment needed. Where clean technologies are not cost-competitive, the model estimates the potential public finance requirement to fill the cost-competitiveness gap. The hypothetical benchmark is that, without a balanced policy mix, the government would provide direct capital subsidy support to fill the public finance gap. With a balanced policy mix, the government can use supplementary measures including carbon pricing, mandates, behavioural measures and blended finance to reduce the public sector cost and to encourage private investment decisions. Box 2 (below) provides more detail on the approach to modelling the policy pathway.

[7] See Technical Annex
[8] For instance see ETC (2024).

Fourth, it estimates how the economic impact of the net zero transition varies across different household groups. This results in estimates of the additional costs for different types of households that would need to retrofit homes and decarbonise their modes of transport. The analysis highlights where support may needed for vulnerable households during the transition, including support to overcome non-monetary barriers. These include the effort, information and time required to switch to a clean technology (Steg, 2023). Values and beliefs may hold back a household from making a clean investment, e.g. the Value-Belief-Norm (VBN) theory of environmentalism. Stern (2000) demonstrates how values affect perceptions of climate change and then behaviours and actions. Steg (2023) provides a base of empirical evidence and additional references.

Finally, it analyses how the transition and associated investments can also create additional jobs and their potential location across the UK. Estimates of the scale of net job creation, and the sectors of impact, allow consideration of where these effects are most likely to be felt, and the implied regional skills needs. This study employs input-output modelling to estimate the impact investments have on the UK economy, considering the sectoral employment effects that take hold and their potential regional distribution. This study's central estimate of around 250,000 jobs is within the CCC's (2023b) estimate that net zero could create between 135,000 and 725,000 net new jobs by 2030.

Figure 2.1: Quadrant representing the four modelled scenarios[9]



9 For a more detailed explanation of the methodology please refer to the accompanying Technical Annex.

Table 1: Key assumptions

Data in 2030	Cost environment[1]		Comment
	Low cost world	**High cost world**	
Real risk-free rate	-1%	3.5%	The real risk-free rate is usually estimated from 10-year bond yields. The low cost world assumes the risk-free rate returns to the 2010-20 average using Bank of England data (2024); the high cost world reflects the upper end of market participant forecasts, e.g. JP Morgan (2024).
Oil price	$64/bbl	$85/bbl	The fossil fuel prices used follow an assessment of existing estimates – e.g. DESNZ (2023a) and IEA (2023) forecasts.
Gas price	$9/MBtu	$12/MBtu	See above.
Electricity price	$106/MWh	$119/MWh	Follows DESNZ (2023a) central and high projections of electricity long-run variable costs. The electricity price was uplifted by a factor of 1.5x for heat pumps, to reflect that heat pump demand will require new generation capacity, backup capacity and network investment.
Carbon prices	£107/tCO2e for Power sector	£107/tCO2e for Power sector	Taking DESNZ (2023a) forecasts for traded carbon prices in the Power and Industry sectors. The carbon price is an exogenous component of the balanced policy mix (see Table 2). In a high cost world, the government spends more in non-carbon pricing parts of the balanced policy mix, rather than letting carbon prices rise.
EV car upfront cost[2]	£30,400	£32,100	Bottom-up cost considering the cost of individual items like the inverter, the electric drive and thermal management. Battery cost was done with a learning rate approach, using IEA (2023) and BNEF (2022) for the base year cost (GBP 110/MWh), learning rates from review studies, e.g. Louwen and Junginger (2021).
Combustion engine car upfront cost	£28,500	£28,500	Similar to EVs with a bottom-up approach, but benchmarking different studies, e.g. Fries et al. (2017), for the costs of ICE-specific components like the engine, transmission, exhaust and engine control unit.

Air-to-water heat pump upfront cost[2]	£5,700	£7,600	Learning rate approach with base year costs coming from benchmarking 8 different studies, normalising to a 7.4 kW size to be aligned with CCC. Learning rate range coming from, e.g. Heptonstall and Winskel (2023).
Gas boiler upfront cost	£2,600	£2,600	Mainly from Element Energy (2020) and normalised to a 24 kW size. Costs include a regional installer, labour, controls, fittings and heat distribution system.
Offshore wind upfront cost[2]	£1,900/kW	£2,500/kW	Base year cost (including pre-development costs) is from DESNZ (2023). Future cost range comes from the use of a learning rate approach. Learning rate range is from review, e.g. Samadi (2018) (10-14% today).
Solar PV upfront cost[2]	£300/kW	£570/kW	Base year cost from IRENA (2023) with pre-development costs from DESNZ (2023a). Future cost range comes from the use of a learning rate approach. Learning rate range is from review, e.g. Samadi (2018) (20-30% today).
Natural gas upfront cost	£538/kW	£579/kW	Taken from CCGT H Class of DESNZ (2023a) and kept constant over time.
Nuclear upfront cost	£5100/kW	£6600/kW	Based off IEA (2023) in NZE scenario, with high cost determined by no cost increases. Note that nuclear costs are the most uncertain due to the prevalence of delays and cost overruns in some nuclear projects.

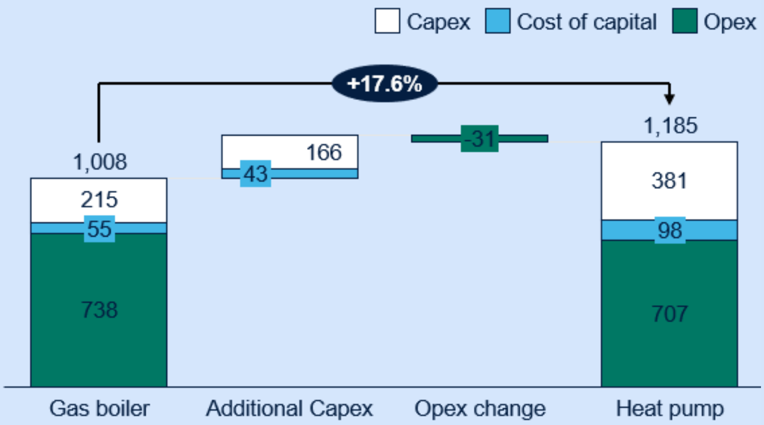
1. Global deployment numbers for the learning rate calculations come from IEA (2023) NZE and STEPS scenarios.
2. Note that the high and low cost worlds do not reflect the full range of possible cost outcomes. The cost worlds reflect different assumptions around interest rates (above) and learning rates. These costs reflect this study's central expectation of costs under those scenarios.

Find more detailed information about sources and methodology in the attached Technical Annex.

Box 1: Total Cost of Ownership logic

A clean technology is cost-competitive from the point of view of an investor/buyer when it is cheaper on a Total Cost of Ownership (TCO) basis than its conventional equivalent. Figure 2.2 gives an illustrative example of comparing a heat pump against a gas boiler. The heat pump is not cost-competitive because the TCO is lower for the conventional technology (the gas boiler) than the clean technology (the heat pump).

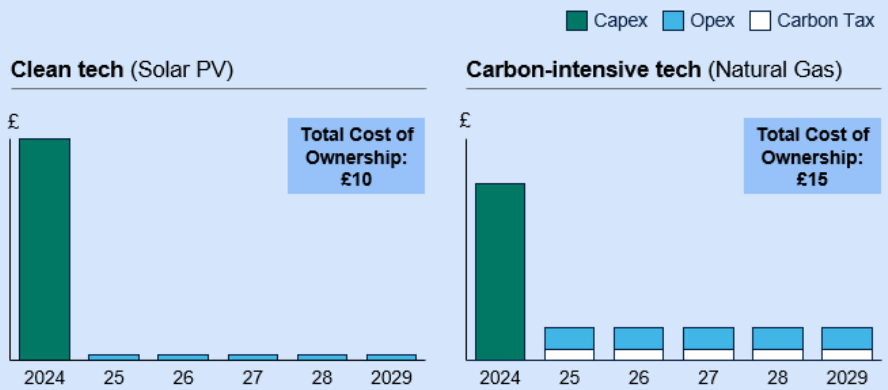
Figure 2.2: Example TCO for a heat pump as well as a gas boiler
Illustrative £/heat pump-year



Source: Household model, based on cost modelling, as detailed in Approach.

To calculate a TCO, this study computes the Net Present Value of costs for technologies at different points in time. Taking an investor/buyer perspective, this means taking the costs (CAPEX, OPEX and carbon taxes) for a given technology and discounting all future costs using a technology-specific cost of capital. Figure 2.3 illustrates the (hypothetical) cost flows of a natural gas generator as well as Solar PV. Solar PV is associated with high upfront costs and low operational costs, while gas has an opposite cost profile. If the (discounted) OPEX savings associated with switching to solar are greater than the increase in upfront cost, then solar is cost-competitive. In a Net Zero scenario, the TCO of clean technologies will tend to decrease over time as innovative technologies reach maturity. The TCO of carbon-intensive technologies will tend to increase due to higher carbon taxes.

Figure 2.3: Example TCO for Solar PV as well as natural gas



Source: Household model, based on cost modelling, as detailed in Approach.

Box 2: Policy approach

The policy modelling estimates who would pay for the transition both under a scenario in which government grants are used to bridge the gap in financing, and with a 'balanced policy mix'. The modelled 'balanced policy mix' is based on policies which are in place already (albeit not at the level of ambition needed to achieve the Net Zero scenario), or are under consideration by policymakers. Table 2 sets out the policy levers modelled in this study and explains how they drive uptake of low-carbon investment.

To ensure sufficient uptake of technologies and a given policy mix, public spend through subsidies or other levers may be necessary. The required support is calculated using a TCO approach. Where a clean technology is more expensive than its carbon-intensive equivalent on a TCO basis, subsidies or other policies are necessary to cover the gap and ensure that the clean technology is cost-competitive. Over time, as technology advances, green technologies get cheaper and more affordable, reducing the public spend requirement.

Consider the hypothetical public subsidy required for a heat pump in Figure 2.4. Assume a heat pump costs £2,000 per year on a total cost basis, including both upfront purchase costs as well as ongoing electricity costs, and that a gas boiler costs only £1,000 on a total cost basis. Then, a £1,000 subsidy may be required to ensure that the heat pump is cost-competitive. Of total heat pump investment, 50% would potentially require a public subsidy based on this estimate. This example assumes no policy. By contrast, given a mandate forcing all heating systems bought to be heat pumps, no public subsidy would be required and the private sector would bear the cost of the transition.

Figure 2.4: Illustrative Total Cost of Ownership for heating systems

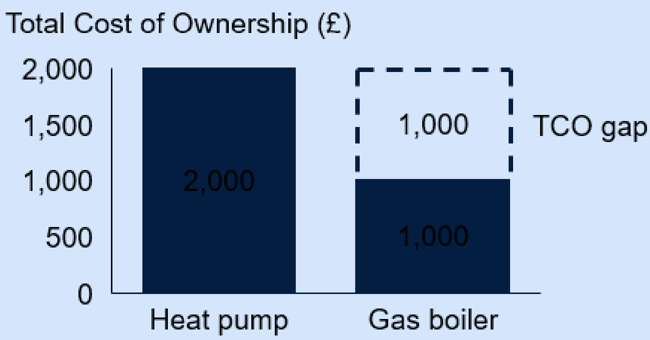


Table 2: Modelled policy levers in the balanced policy mix

Policy lever	Description	Sector
Carbon price	The balanced mix assumes the government will use carbon pricing to decarbonise the Power and Industrial sectors. Carbon prices are derived from DESNZ forecasts. Carbon prices close TCO gaps by making carbon-intensive technology relatively more expensive.	Power, Industry
Mandates	The balanced mix applies manufacturer mandates for heat pumps, cars and vans. The government is assumed to use mandates and CAPEX subsidies in a 50/50 blend where mandates exist.	Transport, Buildings
Behavioural measures and credit de-risking	Behavioural measures reduce household barriers to uptake of low-carbon technologies. These can be deployed as private-public partnerships, including information campaigns, support for 'one stop shop' solutions and marketing of low-cost financing options. Behavioural measures are combined with credit de-risking, which are financing solutions that minimise credit and default risk. An example is on-bill financing of energy efficiency and low-carbon heating solutions. These policies reduce myopia and reduce the discount rate households use to make investment decisions. Specifically, in the model, the measures reduce household discount rates to the cost of capital faced by households.	All
Blended finance	Blended finance is the strategic use of public funds to crowd in private investment. This study considers concessional loans, leaving aside guarantees and other instruments. A concessional loan has two effects: first, it delivers a subsidy since the loan is at sub-market rates; second, it de-risks the investment for private investors, further reducing the cost of capital. This study assumes that blended finance could deliver a 30% reduction in the cost of capital that businesses face. This is in line with a UCL study on offshore wind with the introduction of Contracts for Difference (Jennings et al., 2020). The involvement of the UK Infrastructure Bank sets the CAPEX subsidy.[10]	All
OPEX subsidies	The government deploys OPEX subsidies for utility-scale power. They de-risk the technology by providing revenue certainty.	Utility-scale Power
CAPEX subsidies	CAPEX subsidies are the last resort. CAPEX subsidies will cover the remaining TCO gaps. That is, the government directly pays for the portion of the asset that is not cost-competitive.	All

Source: This study uses the relevant Net Zero strategy for each sector to plot its credible policy pathway using the policy preferences revealed. For power, 'Powering Up Britain' (UK Government, 2023a); for transport, 'Decarbonising Transport' (UK Government, 2023b); for buildings 'Heat and Buildings Strategy' (DESNZ, 2023c); for industry 'Industrial Decarbonisation Strategy' (UK Government, 2021).

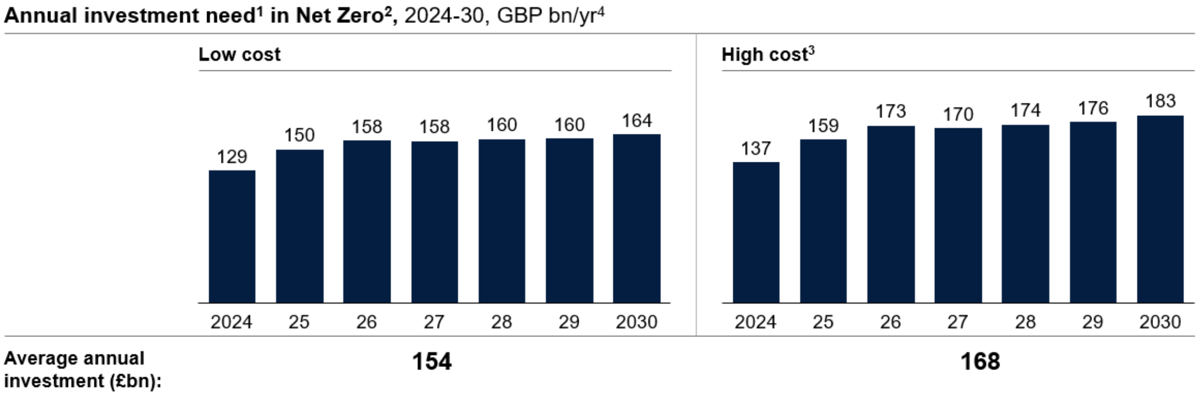
[10] See Technical Annex for detail.

3. Investment needed to deliver net zero

Delivering net zero poses two implications for the UK. First, the level of investment across the whole energy system that is necessary to reach net zero is roughly 25% above spending in the Current Policies scenario, with average annual investments from now to 2030 across both low-carbon and carbon-intensive technologies of between £154bn in a low cost world and £168bn in a high cost world. Under current policy, that level ranges from £124bn to £128bn annually. As a result, the gap in investment currently sits at around £30bn-£40bn annually. The Current Policies scenario represents investments that would be made anyway into the energy system, even without a push to net zero. Second, the composition of investment in the UK 's energy system would need to substantially change to increase the share of clean technology investment. Households and businesses would have to replace unabated fossil technologies with low-carbon technologies across the Power, Transport, Buildings and Industry sectors. This chapter sheds light on both challenges and breaks down the investment required across the relevant technologies, actors and sectors.

A Net Zero scenario to deliver a mix of high- and low-carbon technologies requires an average annual investment of £154bn per year to 2030, or £168bn in a high cost environment; this is around 25% higher (in both cost environments) than the investments that would have taken place anyway, even without a push for net zero). The investment increases over time in a low (high) cost world, rising from £129bn (£137bn) during 2024 to £164bn (£183bn) in 2030 (Figure 3.1). As time goes by, clean technologies become more affordable and supply chains become more developed. Consequently, deployment of clean technologies increases. This is reflected in more overall investment as the decade passes, even in the context of rapidly falling unit costs for a given clean technology which pushes the investment per unit delivered down.

Figure 3.1: Capital investment required for net zero

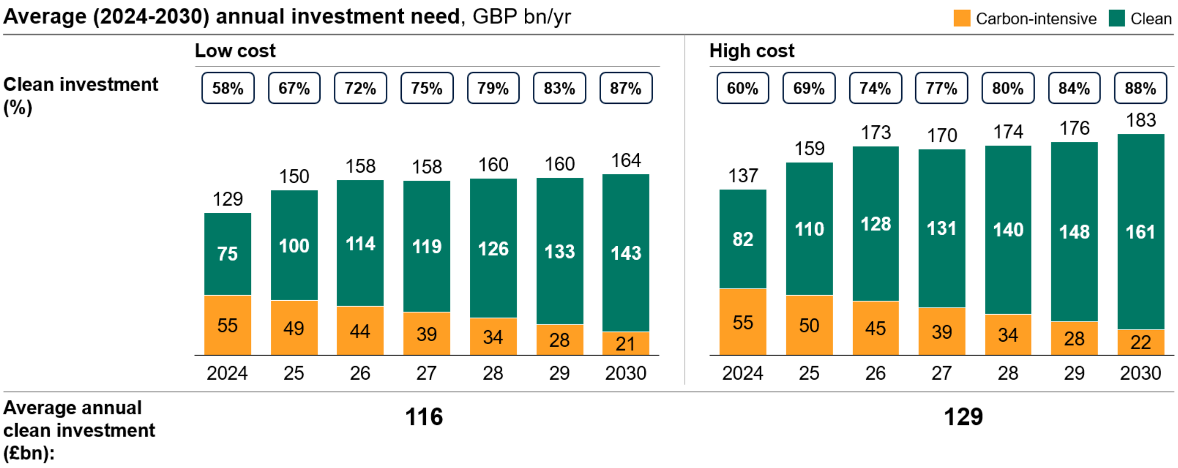


1. Investment includes energy system capital expenditures (power, buildings, transport and industry), including consumer durables (e.g. cars and heat pumps). Operating expenses are excluded.
2. The net zero deployment numbers (e.g. how many EVs we assume on the roads) come from the CCC's Balanced Net Zero pathway. The cost numbers come from our own updates, based on updated techno-economic data.
3. A high cost world is one where the current supply chain disruptions and higher real interest rates prevail and a low cost world is a return of the benign macroeconomic conditions of the 2010s. Specifically, a low cost world means steep learning rates for clean technologies, low fossil fuel prices, and low real risk-free rates (-1%). A high cost world is the opposite: it means shallow learning rates for clean technologies, higher fossil fuel prices and high risk-free rates (3.5%).
4. GBP is in real 2022 terms.

Source: Team research based on investment estimates aligned with CCC deployment and updated cost information, described in Approach.

Of this investment, on average £116bn-£129bn (75%) goes towards clean technologies, while 25% goes towards conventional carbon-intensive technologies. Figure 3.2 shows that, to achieve Net Zero, the share of clean technology investment within the energy system could rise rapidly from around 60% to 90% by the end of the decade. This assumes that government will incentivise households to buy EV cars and housing developers to use heat pumps in new homes.

Figure 3.2: Clean and carbon-intensive investment[1]

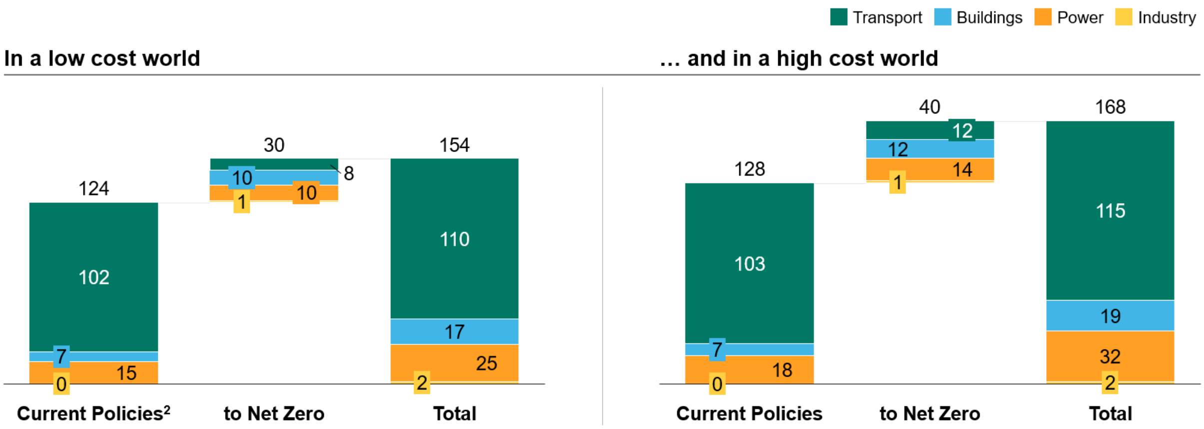


1. Numbers may not add up due to rounding.

Source: Team research based on investment estimates aligned with CCC deployment and updated cost information, as described in Approach.

To deliver net zero, decarbonising Britain's energy system requires between £30bn and £40bn additional investment. Relative to current policies, the additional annual investment is ~20% of total spending. In Figure 3.3, the additional investment is the column 'to Net Zero'. The additional investment is roughly evenly split between Power, Transport, and Buildings. Even though Transport is the largest sector and cars the largest technology, the additional investment is not proportionally as large because households are expected to replace cars regardless over this period, whether with EVs or traditional petrol vehicles. The additional investment necessary in Transport largely reflects the increase in upfront cost of electric cars against combustion engine cars. In contrast, for Power, net zero requires massive electrification because of more electric cars on the road as well as heat pumps drawing from the grid. The CCC estimates that, to reach net zero, generation will rise by 20% from 2024 to 2030 (CCC, 2020). The UK would also need to invest in upgrading the transmission and distribution network. The model estimates grid upgrades require ~£4bn of additional investment alone each year to 2030.

Figure 3.3: Additional investment to get to net zero
Average annual investment need, 2024-30, £bn[1]

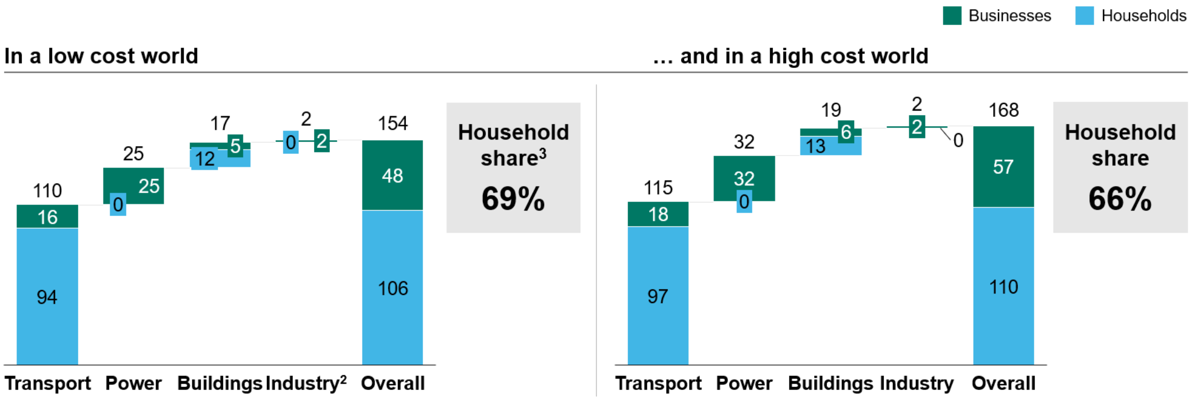


1. The additional investment is calculated by subtracting estimates of the investment under a Current Policies scenario from estimates of investment required under a Net Zero scenario. This is focused on purely the CAPEX involved, ignoring any OPEX savings.
2. Current policies refers to the investments that would be made into the energy system anyway, without a push to net zero. Current policies investments involve less clean technology by proportion.
3. Numbers may not add up due to rounding.

Source: Team research based on investment estimates aligned with CCC deployment and updated cost information, as described in Approach.

Household technologies, primarily EV cars and heat pumps, have the largest net zero investment envelopes, accounting for around two thirds of the total investment need. Two thirds of the investment needed (£106bn-£110bn) could be made in household sector decarbonisation, while one third could be made by businesses (£48-£57bn) (Figure 3.4). Households make most of their investments in the Transport and Buildings sectors, while Businesses make most investments in the Power sector. The Transport sector is mostly EV cars, plug-in hybrid EVs (PHEVs) and electric buses. The Buildings sector comprises heat pumps and insulation, and the Power sector is mostly large utility-scale generation or investments for the grid and flexibility such as interconnectors and batteries.

Figure 3.4: Households and business investment
Average annual investment need, 2024-30, £bn

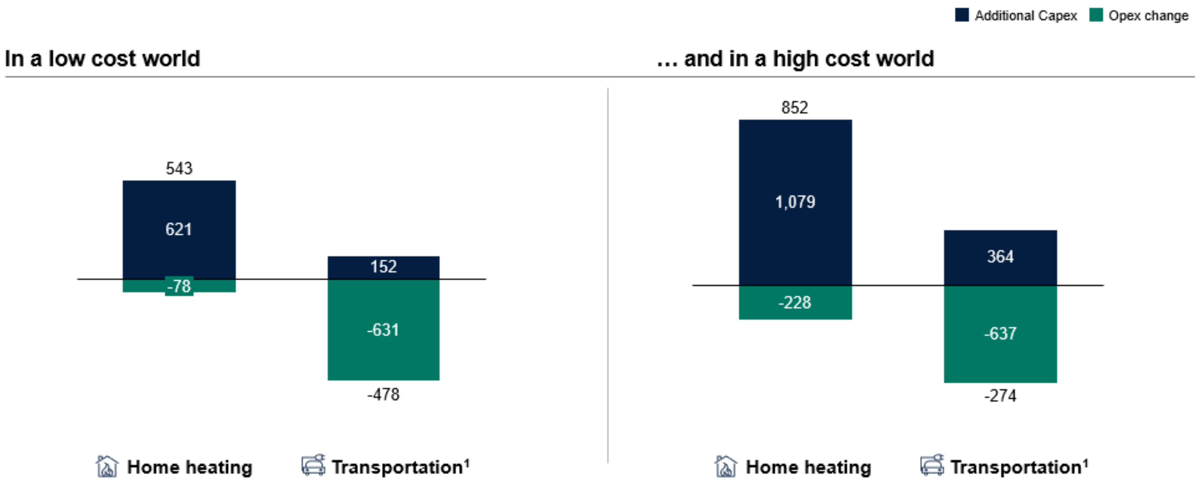


1. Team research makes the split between households and businesses using historical spending patterns for our green technologies. For example, the model assumes that 90% of cars are owned by households, while 10% are owned by businesses. And that households make 70% of heat pump investment. Most power technologies, except solar PV for rooftops, and all industry technologies have no household finance whatsoever.
2. Industry represents such a small envelope of investment because there is limited investment in decarbonisation in industry in the 2020s.
3. What is meant by the investments made by households is that the asset is ultimately owned by a household. The household could still be going to a (commercial) lender for the financing of a new car, but if that household ultimately owns the car, it would be considered a 'household' investment on this page.

Source: Team research based on investment estimates aligned with CCC deployment and updated cost information, as described in Approach.

For an average individual household, this investment premium could range from £550 to £850 for home heating and a cost saving of ~£275-£500 for transportation. Taking these large investment numbers to a household's perspective, the premium for each household could be between £550 and £850 per year to install a heat pump and insulation, while it would be around £275-500 per year less for transport (Figure 3.5). Transportation could therefore become cheaper for the average household, as the upfront cost of an EV car falls significantly by 2030, on top of running cost savings.[11] This would be supported by rapid cost declines in battery technology (CCC, 2020). By contrast, the age of the UK buildings stock presents a continuing challenge to decarbonising Buildings (DESNZ, 2023b).

Figure 3.5: Green premium for the average household for greening their home and transport[2]
Average annual TCO premium of individual household in 2030, £



1. Transportation assumes a one car household.
2. Numbers may not add up due to rounding.

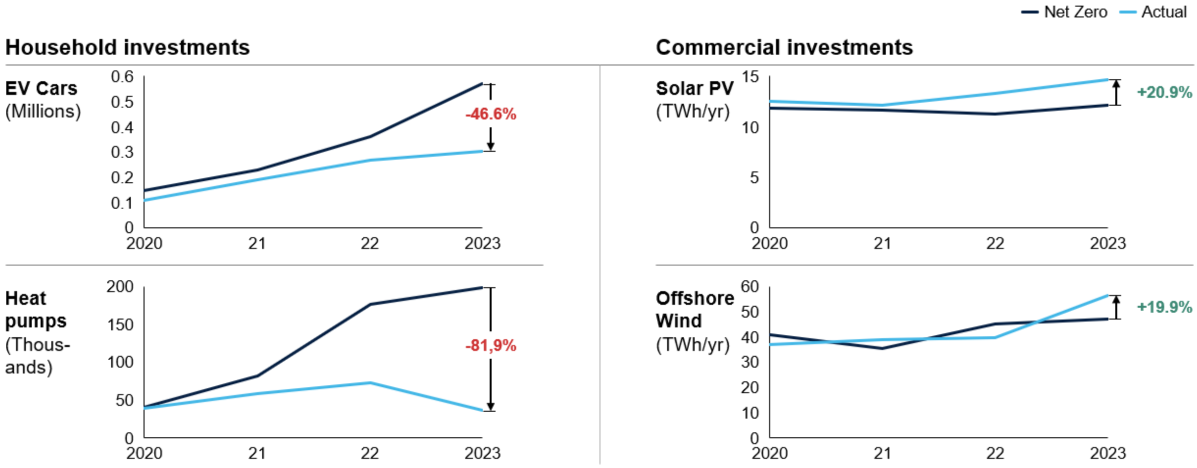
Source: Team research based on investment estimates aligned with CCC deployment and updated cost information, as described in Approach.

To date, business investment has been in line with the Net Zero scenario, while large investments have yet to be made in the household sector. From Figure 3.6, solar and offshore wind have generated more electricity than the CCC Net Zero trajectory predicted was necessary in 2020. The key household technologies, by contrast, have fallen behind the CCC scenario. Annual heat pump deployment is ~80% below net zero and EV car sales are ~50% below net zero. This result reflects a mature policy environment within the Power sector and

[11] Note this study assumes no changes to the tax paid by EV cars.

evolving policy environments for Transport and Buildings. In Power, there are a plethora of effective policies that have helped make renewables cost-competitive: Contracts for Difference, the Renewables Obligation and the Regulated Asset Base model. For Buildings and Transport, the policy landscape is less developed. The CCC, in its annual report to Parliament, gave the Transport and Buildings sector plans a rating of 'significant risks', compared with power's rating of 'some risks' (CCC, 2023a). The modelled Net Zero scenario requires this policy gap to be filled.[12]

Figure 3.6: Actual deployment of selected clean technologies
Actual deployment against CCC Net Zero trajectory, 2020-23



Source: CCC Balanced Net Zero Pathway for Net Zero numbers. For actual deployment: EHPA (2023); ONS (2023); DESNZ (2023b).

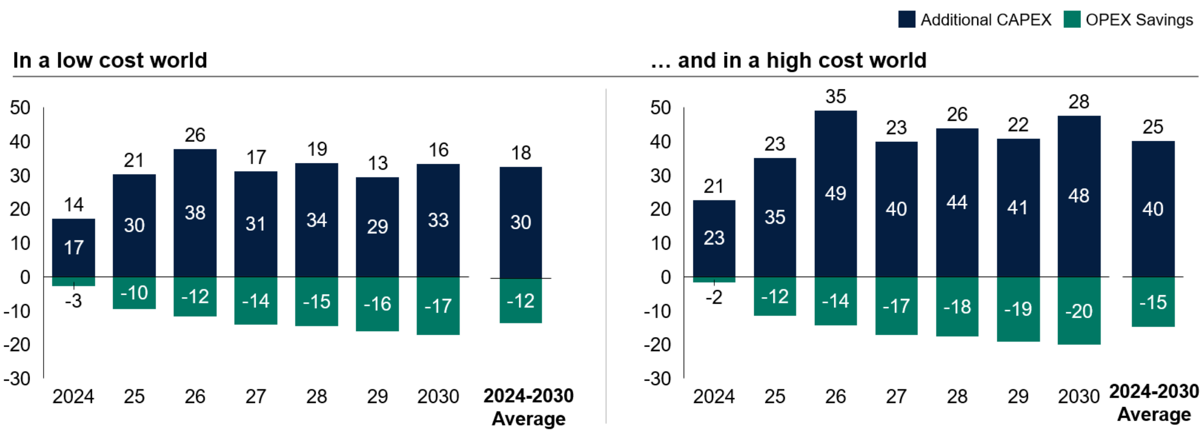
Investment in energy systems could rise by 20% on average to 2030 and the composition of that investment could shift to be ~90% clean by 2030. This would require rapid uptake of EVs and heat pumps and retrofitting of homes. As the next chapter will explore, the higher investment numbers here do not incorporate the operating cost savings that come with net zero (e.g. the savings on buying petrol when switching to an EV). With these savings factored in, the investment need for the transition is significantly lower.

[12] The scope of this analysis includes the following CCC sectors: Buildings, Manufacturing and Construction, Electricity Generation, and Surface Transport sectors. Other CCC sectors, for example, Aviation, Shipping, and Agriculture do not feature. The sectors covered are collectively the energy system and represent 92% of all the investment required to decarbonise the UK over this time period (2024-30), according to the CCC. (See Technical Annex).

4. Net spend for the 2030 target

The £30bn-£40bn additional annual investment to hit net zero is partly offset by ~£12bn-£15bn in operating cost savings. The net spend is £18bn-£25bn. As Figure 4.1 shows, the transition could require additional investment, but this could be partially offset by operating cost savings (OPEX savings), leaving a net spend that is lower. The extensive OPEX savings associated with the transition occur because clean technology is typically CAPEX intensive. This means the upfront cost of the clean technology is greater than the carbon-intensive technology it replaces, but it costs less to run on an ongoing basis than the carbon-intensive technology. This is true in the Power sector, for example, in that solar farms have minimal operating costs, in Transport because EVs are cheaper to charge than to fill a combustion engine car with petrol, and in Buildings because heat pumps are cheaper to operate than gas boilers.

Figure 4.1: Net spend in net zero[1]
Additional CAPEX and OPEX savings[2] in a net zero world[3]
versus a current policies world, 2024-30

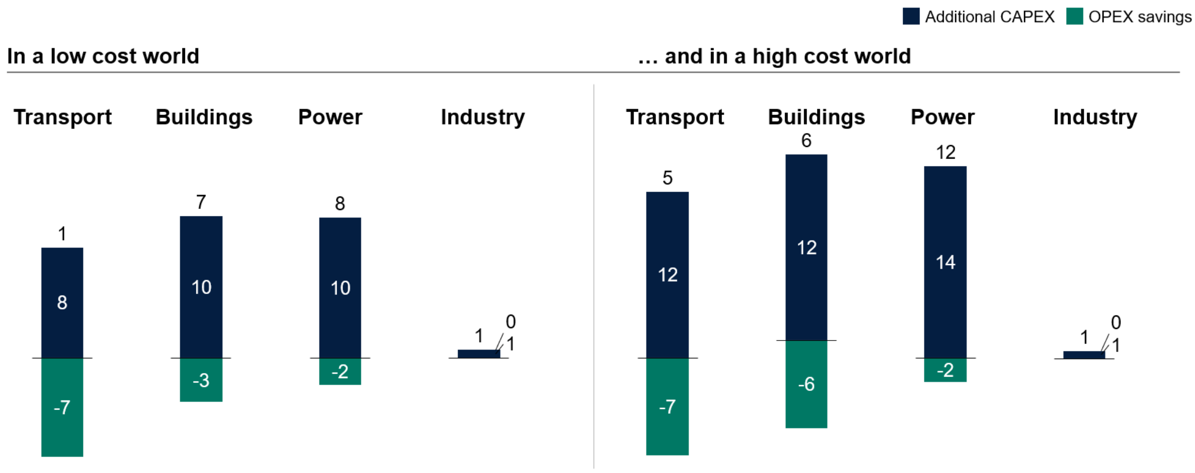


1. Numbers may not add up due to rounding.
2. The additional CAPEX is the capital expenditure in a Net Zero scenario minus the capital expenditure in a Current Policies scenario for a given year. The OPEX savings are the operational expenditures in a Net Zero scenario minus the operational expenditures in a Current Policies scenario.
3. The Climate Change Committee's sixth carbon budget performs a similar analysis. It arrives at a larger net spend in the transition, estimating an average net spend of ~£30bn across our sectors (2024-30). The difference is that the baseline the CCC considers is a more conservative one with little "significant additional uptake of low-carbon technologies from today", while this study considers a Current Policies scenario.

Source: Team research based on investment estimates aligned with CCC deployment and updated cost information, as described in Approach.

Breaking out the net spend across sectors, the OPEX savings associated with net zero are largest in Transport. In the Transport sector, by 2030, an EV car is 60% cheaper to run each year than a combustion engine car.[13] This contributes to an average £7bn p.a. OPEX saving in a net zero world (Figure 4.2). Buildings and Power are both associated with OPEX savings in a low cost world, but they are smaller. In a high cost world, however, the OPEX savings associated with Buildings are much greater because a high cost world has higher gas prices, which makes heating a home using a gas boiler more expensive. However, large OPEX savings do not fully offset the CAPEX increases associated with net zero, which need to be managed through policy (as we discuss later).

Figure 4.2: Net Spend in net zero by sector
Average additional CAPEX and OPEX savings in a
net zero world versus a current policies world, 2024-30



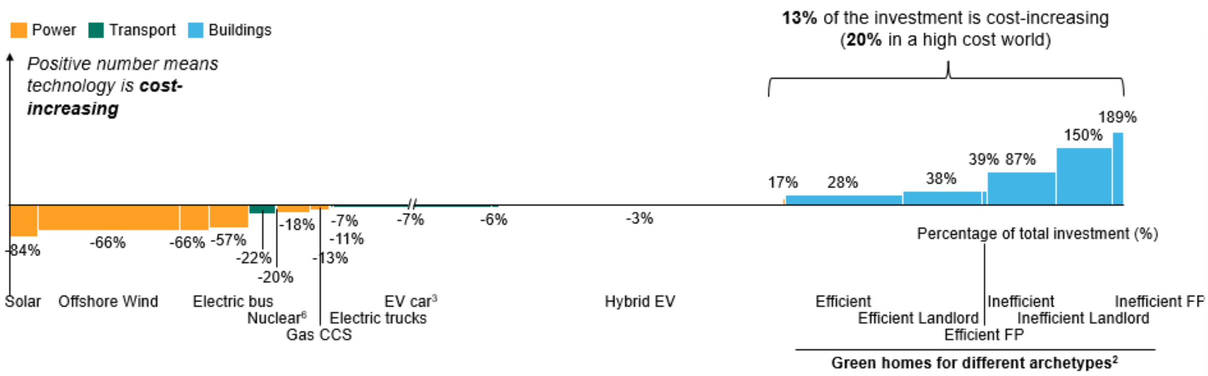
Source: Team research based on investment estimates aligned with CCC deployment and updated cost information, as described in Approach.

Of the investment in 2030, ~13% is cost-increasing, while ~87% is cost-decreasing in a low-cost world. Building on the above, a cost-decreasing clean technology is one that is cheaper than its carbon-intensive equivalent on a TCO basis. That means the OPEX savings, when discounted to today, are greater than the additional CAPEX required. Using this logic, the model calculates a green premium: the extra spend in percentage terms associated with the clean technology (Figure 4.3). The Power sector is the main source of cost decreases. For example, offshore wind is 66% cheaper on a TCO basis than natural gas. In contrast, the

[13] This analysis does not consider potential reforms to the tax regime such as road user charging; however, such reforms would not erode the benefit of low-carbon vs fossil technologies.

Buildings sector is the source of major cost increases. Greening a home could save money on monthly bills, but not enough to fully offset its upfront cost.

Figure 4.3: Low cost world green premium curve for non-infrastructure spending[4,5]
Green premium[1] curve in Net Zero low cost scenario, 2030, green premium against investment



1. Green premium is how much more expensive, in percentage terms, the low-emissions technology is than the high-emissions technology.
2. 'Inefficient FP' means an owner-occupied household that is fuel poor investing in a heat pump + retrofit; 'Efficient FP' means an owner-occupied household that is fuel poor investing in a heat pump; 'Inefficient' means an owner-occupied household that is not fuel poor investing in a heat pump + retrofit; 'Efficient' means an owner-occupied household that is not fuel poor investing in a heat pump; 'Landlord' means a rented home investing in heat pump and/or retrofit.
3. BEVs are ~50% of the investment so there is a break in the x-axis to ensure the other technologies are visible.
4. This green premium curve cannot consider infrastructure technologies, e.g. transmission and distribution, because there are no carbon-intensive technologies to compare them against. The rest of the report does consider these technologies.
5. This graph assumes government has used policy to reduce green premia, including carbon pricing. Forecasts of the fossil fuel prices, electricity costs and carbon prices used are from DESNZ's central scenario, detailed in the Technical Annex.
6. The greatest cost uncertainty is for nuclear, which can be subject to cost-overruns and delays.

Source: Team research based on investment estimates aligned with CCC deployment and updated cost information.

The transition, therefore, involves a significant increase in investment, but 80-87% of that investment could be cheaper than the conventional alternative by 2030. The Buildings sector remains difficult to decarbonise, as emphasised by how behind the UK is on its heat pump targets (Figure 3.6). In a low cost world, ~87% of the investment is cost-decreasing. In a high cost world, this figure falls to 80%, but the message remains the same: big cost decreases in clean technologies ensure that most of the transition is cost-competitive. It can be funded by the private sector, so long as there is also public spend, such as through carbon pricing. Climate finance and access to capital, especially for households, will be extremely important when achieving net zero.

5. Household investment decisions

Households do not necessarily invest in energy efficient technologies; this observed effect is often referred to as the energy efficiency paradox. Multiple explanations lie behind the slow household uptake of new technologies (Schleich, et al., 2013). The relative importance of each for different household groups should shape any desirable policy measures to increase uptake.

There are five well-documented reasons why households may 'underinvest' in new green technology, the evidence over which has recently been summarised by Schleich et al. (2023). First, in considering the trade-offs between the typically upfront costs of investments and the benefits which occur spread out through the future, households place a greater weight on their current consumption. This private timing discount rate will vary by household, depending on the degree of patience, but is recognised across all types of household consumption decision making. The delayed benefits of investments mean households may heavily discount the value of benefits in their decisions. Second, risk aversion occurs when households are averse to the uncertainty over future cost savings, technology and risks from holding debt. Beyond this, households may place a greater weight on the risk of losses, increasing the level of aversion to uncertainty and acting to disincentivise uptake. Households may also have an aversion to holding debt. Finally, social norms and pro-environmental attitudes can alter rates of uptake, both of which can develop over time.

Beyond these factors, however, if the costs of action are perceived to be high, people are less likely to act on their values. Costs can be non-monetary and include effort, information and time. When the costs of action are larger, underlying values are less related to uptake, as people prioritise reducing costs (Steg, 2023).

As a result, households require returns that are well above market interest rates to be willing to invest. For energy modelling, the returns required are combined into an implicit discount rate that varies by household type. Average subjective discount rates are well above market interest rates in a wide range of studies, with variation in rates both within and across studies. While rates do not appear to be substantially different across countries in Europe and North America, a recent meta-analysis over 34 studies showed the median implicit rate to be 25%, however also suggested challenges resulting from publication bias (Matousek et al., 2022). In a study focused on a green household investment (the purchase of a water heater), median, mean and standard deviation of the discount rate were 11.0%, 19.3% and 22.8% respectively in the US – figures that are used as a basis in this report (Newell & Siikamäki, 2015).

Households' discount rates are negatively correlated with income and education across a broad range of studies. The evidence of correlation with other variables, including gender and age, is mixed (see for example Newell & Siikamäki, 2015, Bruderer Enzler et al., 2014).

Once the implicit discount rate for the decision to invest is accounted for, households face an actual cost of capital which alters their costs to pay back a purchase. Evidence suggests cost of capital are also correlated with wealth, education and age. The focus on income in this study enables the assessment of the variation in uptake, while recognising that more nuances are embedded in the decision to invest.

High-income and wealthy households can utilise savings or extend mortgages for housing investments, leading to relatively low costs of capital. The top decile of UK's households by wealth keep 28% of financial assets in savings (Advani et al., 2020). Risk aversion and other factors in implicit discount rate are lower for high-income households.

Middle-income households can utilise personal loans or finance to invest, which Bank of England data suggests track around 2.5% to 5% above base rates (Bank of England 2023). Unsecured personal loans are typically the optimal choice for housing investments, unless sufficient equity exists in housing. Securitisation against vehicle asset allows for lower rates for purchases of EVs.

Low-income households can use unsecured personal loans, but these are likely deemed unaffordable, or with higher interest rates to compensate increased credit risk. In the UK, credit scores exhibit a strong correlation with the Index of Multiple Deprivation, a measure which captures local area levels of deprivation and can be indicative of poverty levels (Financial Conduct Authority, 2022), leading to banks charging higher rates to borrowers, or denying loans. The alternative is overdraft or credit card. Risk aversion and other factors in implicit discount rate are higher for low-income households.

On-bill finance uses underwriting modified to consider billpayers' past payment history, reducing credit costs for middle- and low-income households and resultant rates. The closest example the UK has to such a scheme is the now-discontinued Green Deal,[14] which reported equivalent interest rates of 8-10%. Some private providers are continuing with similar finance mechanisms, but these higher rates remain.

[14] https://ukgbc.org/resources/green-deal-finance/

Table 3: Discount rates and cost of capital

Household income	Cost of capital		Implicit discount rate premium[1]
	Housing retrofit	Electric vehicle	
High >£80,000	Base Rate	Base Rate	+ 6%
Medium	Base Rate + 5%	Base Rate + 3%	+ 8%
Low <£15,000	Base Rate + 20%	Base Rate +10%	+ 10%
On-bill financing	Base Rate + 3 -10%	NA	As above

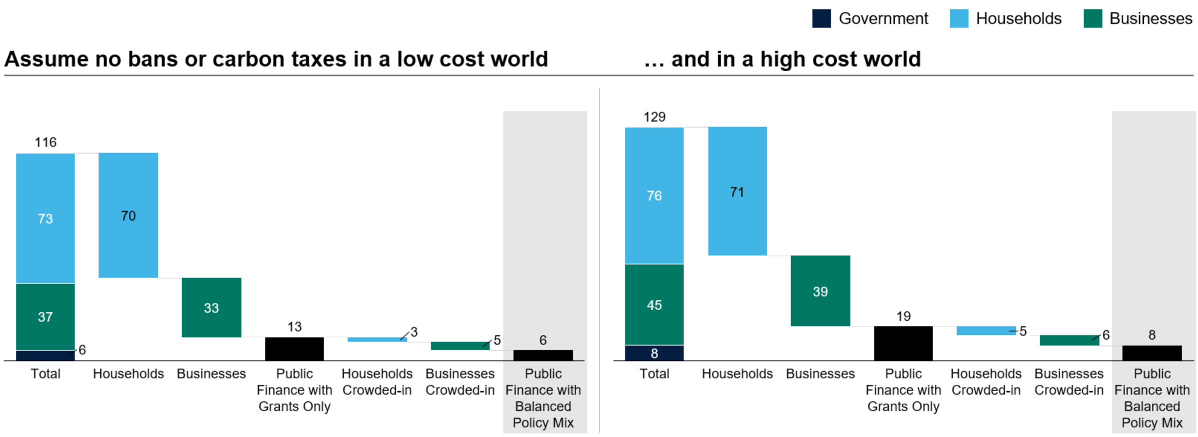
Adapted from evidence in Newell, R. G. & Siikamäki, J. (2015). Individual Time Preferences and Energy Efficiency. American Economic Review, 105(5), 196-200 and UK household income data and interest rates.

6. Implications for policy

This chapter considers the impact of a package of policy levers on the level of public sector investment needed to deliver a Net Zero scenario. The preceding chapters presented a costed net zero path that assumes governments compensate for the extra costs that economic actors face when investing in clean instead of conventional technologies through grants. In reality, the government works with a mix of policy instruments including carbon taxes, mandates, blended finance and behavioural interventions that could together reduce the fiscal burden to the government. This chapter first describes a net zero pathway using grants as the only policy instrument, without climate policies, and then considers it with a balanced policy mix.

In the hypothetical case that the government only uses grants, net zero could require an additional £13bn-£19bn public sector investment annually to 2030. Using only grants, Figure 6.1. shows that government could be accountable for 11-15% of the transition directly, paid for using direct capital subsidies. In a low cost world, the public finance share is 11%. In a high cost world, clean technology is less cost-competitive, so the government would face a greater public finance need, increasing the public finance requirement by ~30%, to reach 15% of the high cost investment envelope.

Figure 6.1: Public finance need given a balanced policy mix
Average annual low-carbon investment need,[1,2] 2024-30, £bn



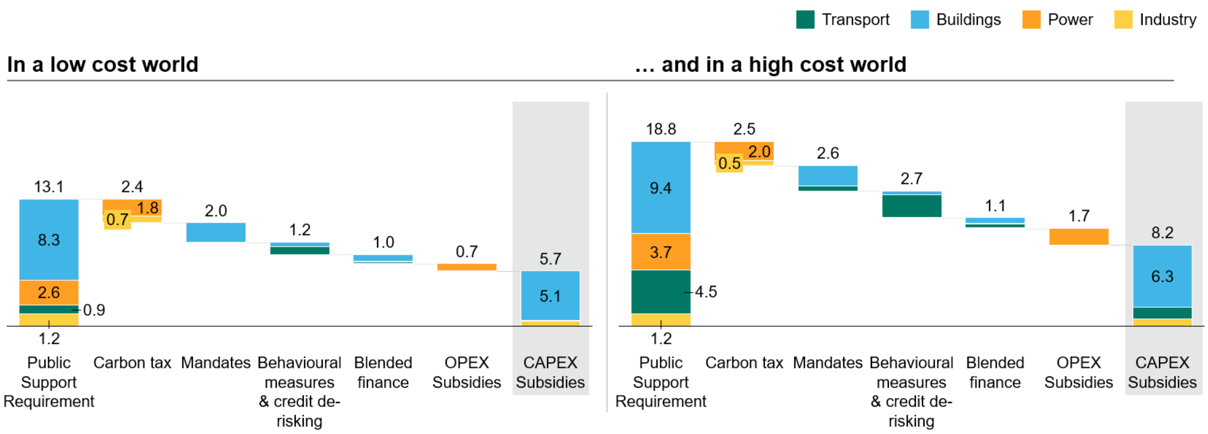
1. The required subsidy is calculated using a TCO approach. Where a clean technology is more expensive than its carbon-intensive equivalent on a whole-lifetime basis, subsidies or other policies are necessary to cover the gap and ensure that the clean technology is cost-competitive. Over time, as technology advances, green technologies get cheaper and more affordable, reducing the public spend requirement.
2. Numbers may not add up due to rounding.

Source: Team research based on cost modelling, as detailed in Approach.

A range of policy levers could drive increased private sector investment and reduce the need for public sector investment. A policy design combining carbon pricing, regulation, behavioural interventions and blended finance could support investment decisions while reducing the scale of subsidies needed. The 'balanced policy mix' used in this report reflects the government's stated policy mix to achieve a net zero ambition. Table 2, in the Approach chapter, lists the policies modelled and applies them to each sector. Overall, the balanced policy mix assumes Power and Industry decarbonise using carbon pricing, while Transport decarbonises using mandates. All sectors use blended finance and behavioural measures to decarbonise.

With a mix of policy levers, delivering the low-carbon technologies required to achieve net zero could require only £6bn-£8bn public sector investment. The furthest-right column in Figure 6.1 shows the allocation of investment across the main economic actors and the instruments they use given the assumptions in the balanced policy mix. Compared to the grant-only option, a balanced mix reduces public investment by 50-60% and the CAPEX subsidies provided by government have fallen significantly. As a result, the government's share of the investment has fallen from between 11% and 15% to between 5% and 6%. This crowds in £3bn-£5bn of household investment and £5bn-£6bn of business investment.

Figure 6.2: Effect of policy levers given a balanced policy mix
Average annual low-carbon investment need[1,2], 2024-30, £bn



1. The modelled 'balanced policy mix' is based on policies already in place (albeit not at the level of ambition needed to achieve the Net Zero scenario) or under consideration by policymakers. For example, the government has indicated it wants to use mandates to decarbonise cars. That is, manufacturers would need to ensure a given proportion of the cars they sell are EVs. The modelling consequently assumes that transport decarbonises using mandates, but that the EV mandate is high enough to achieve Net Zero.
2. In the balanced policy mix, the government uses carbon pricing for power and industry; mandates for cars and heat pumps; behavioural measures to de-risk household technologies; blended finance to de-risk commercial technologies using concessional loans; OPEX subsidies for commercial power; and CAPEX subsidies for the remaining investment .

Source: Team research based on cost modelling, as detailed in Approach.

Quantifying the balanced policy mix, together the policies could reduce the level of public sector investment needed by around 50-60% from 2024-2030. Figure 6.2 quantifies how the policy levers in the balanced policy mix could reduce the level of public sector investment, in both low cost and high cost environments.

In a low cost environment, the policy levers reduce the public spend requirement from £13.1bn using only grants to £5.7bn with a balanced policy mix. In contrast, in a high cost environment, the policy levers reduce the public spend requirement from £18.8bn using only grants to £8.2bn with a balanced policy mix. Mandates deliver between 25% and 27% of the reduction in public spend in the Buildings sector, which increases private sector investment in heat pumps. Carbon taxes deliver a further 25-30%, which primarily increases private sector investment in the Power sector. Behavioural measures and blended finance deliver between 30% and 35%, which primarily increases private sector investment in the Buildings and Transport sectors. OPEX subsidies cover the rest of the gap to make Power sector technologies cost-competitive.

The balanced policy mix presented is only one of many policy combinations that are possible. It assumes that the policy mix of the recent past is scaled up, but future UK governments have other options to achieve net zero: the weights on different policies in the mix could change. For example, the government could put a higher emphasis on carbon prices, increasing the scope of carbon pricing to more sectors. There may also be scope to extend the remit of public financial institutions to de-risk clean technology investments using instruments such as guarantees and to reform financial sector regulation to relax risk-related capital constraints on clean assets. Further emphasis on such measures may be particularly effective if a higher cost scenario materialises with higher financing costs, because these instruments operate to reduce those financing costs.

7. Distributional impacts

The TCO premium will vary by household, based on factors such as building efficiency, cost of capital and car ownership. The cost of net zero homes and EVs are modelled for different types of households. The cost of net zero home conversion is modelled separately for six types of households in line with the composition of the CCC Net Zero scenario. Households that undergo an energy efficiency retrofit in the CCC scenario are categorised as 'inefficient', while households that do not are categorised as 'efficient'. As inefficient homes require a retrofit, they incur a higher cost. Households are also categorised as fuel poor ('FP') or not fuel poor. Fuel poor homes typically face a higher cost of capital, and therefore incur a higher cost. Together the combination of efficient/inefficient and fuel poor/not fuel poor homes combines into four household types. One of these, 'inefficient FP', makes up 3% of the distribution, but as these households require interventions beyond the scope of this work to adopt energy efficient interventions, they are not focused on here. Finally, households in privately rented accommodation are categorised separately to reflect that landlords – who make investment decision in rented homes – may not experience the benefit of any cost savings arising from energy efficiency retrofits and heat pumps. The cost of EVs is modelled for three types of household: those with no car, one car or two cars. As EVs are cost saving in the modelled scenario, the degree of saving depends on the number of cars in the household.[15]

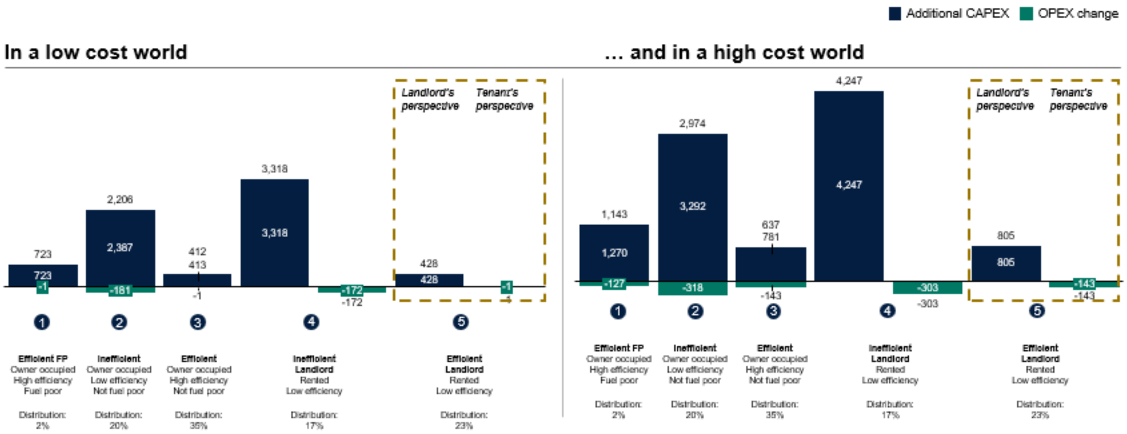
Depending on these factors, the cost of home conversion in the low cost scenario could range from £400 to £3,100 per year, requiring new policy to deliver an equitable transition. Overall, the cost of a net zero home conversion is lower for 'efficient' households which do not require investment in a retrofit. The additional cost for these households is £400 to £700 per year (Figure 7.1). Similarly, the cost is lower for households that are not fuel poor and are able to finance their investments at a lower cost of capital. The premium for these households is £400 to £2,200 per year. The additional costs for tenants are the lowest as they do not pay the upfront cost of a heat pump or a retrofit, but benefit from lower heating bills in a low cost world. In principle, this could mean the rent would go up to partially recover the landlord's investment. The landlord and renter would share the benefit of the investment; rent payments are not modelled in this analysis.

A high cost world could increase the TCO premium of a net zero home by ~50%, without policy support. In a high cost world, the CAPEX of a retrofit, and the capex premium of a heat pump relative to a gas boiler, are higher than in a low cost world. As a result, the TCO premium of a net zero home rises from between ~£400 and ~£3,000 in a low cost world to between

[15] For a full breakdown of archetypes, see the Technical Annex.

£600 and £4,000 in a high cost world. For some households, the increase in TCO premium is particularly large: for efficient fuel poor households (group 1), the TCO premium would rise from ~£700 to ~£1,150, a ~60% increase. This group, however, only represents 2% of households.

Figure 7.1: Theoretical cost of home conversion for different household archetypes
Average annual TCO premium for different households[1,2] in 2030, £



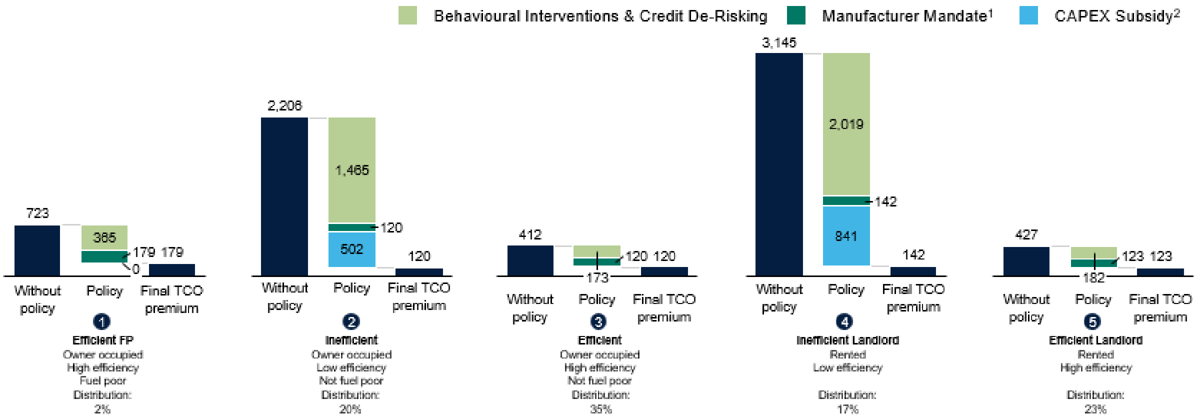
1. 'Inefficient FP' means an owner-occupied household that is fuel poor investing in a heat pump + retrofit;
   'Efficient FP' means an owner-occupied household that is fuel poor investing in a heat pump;
   'Inefficient' means an owner-occupied household that is not fuel poor investing in a heat pump + retrofit;
   'Efficient' means an owner-occupied household that is not fuel poor investing in a heat pump;
   'Landlord' means a rented home investing in heat pump and/or retrofit.
2. The 'distribution' adds up to 97%, not 100%. The missing 3% is the 'Inefficient FP' archetype beyond the scope of this study.

Source: Household model, based on cost modelling, as detailed in Approach.

A combination of manufacturer mandates and capex subsidies could reduce the annual cost of home conversion paid by the household to £120-£180. A balanced policy mix such as that outlined in Table 2 could reduce the high TCO premia facing some households (Figure 7.1). In the modelled policy mix, there are behavioural measures and measures such as on-bill financing that reduce the myopia associated with energy efficiency investments (see 'Household investment decisions' section), so that the discount rate households use is equal to the cost of capital. On top of this, the government reduces the TCO premia of retrofits through CAPEX subsidies (i.e. government would subsidise the installation of specific insulation measures such as cavity wall insulation until they are cost-competitive). Further, in the modelled policy mix, a combination of CAPEX subsidies and manufacturer mandates apply to heat pumps, each reducing the TCO premia in equal measure (Figure 7.2). To reduce any overpayment of subsidy, government could offer a different level of subsidy depending on factors that affect the retrofit cost, such as EPC rating, age of home or size of home.

Figure 7.2: Theoretical cost of home conversion faced by different household archetypes given subsidy and mandates

Average annual TCO premium of different households[3,4,5] in 2030, low cost world, £

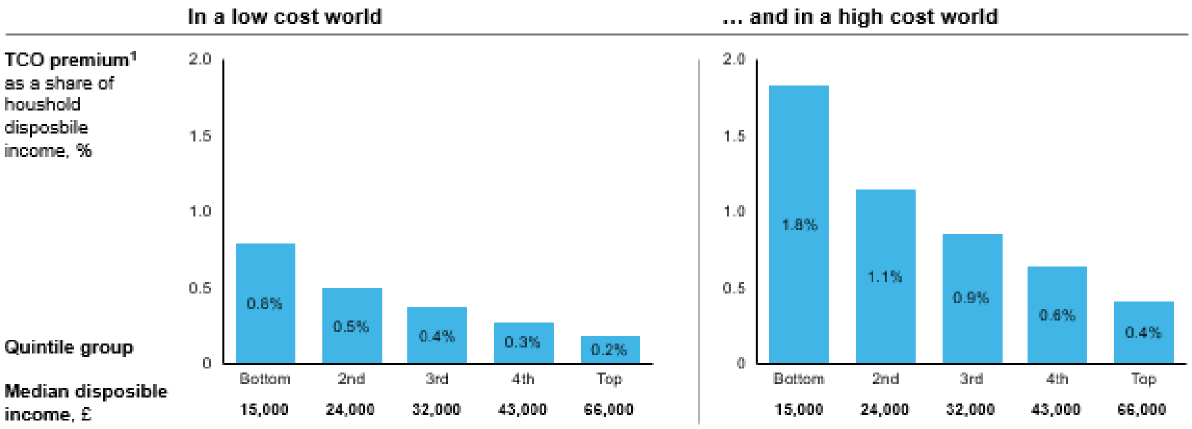


1. Assuming 50% of the TCO gap between heat pump and gas/oil boiler are covered by manufacturer mandates
2. Assuming 50% of the TCO gap between heat pump and gas/oil boiler are covered by capex subsidies, 100% of the TCO gap for retrofits are covered by capex subsidies
3. 'Inefficient FP' means an owner-occupied household that's fuel poor investing in a heat pump + retrofit; 'Efficient FP' means an owner-occupied household that's fuel poor investing in a heat pump; 'Inefficient' means an owner-occupied household that's not fuel poor investing in a heat pump + retrofit; 'Efficient' means an owner-occupied household that's not fuel poor investing in a heat pump; 'Landlord' means a rented home investing in heat pump and/or retrofit.
4. Without policy reflects behavioural discount rates that result in a significantly higher perceived cost to the household
5. The 'distribution' adds up to 97%, not 100%. The missing 3% is the 'Inefficient FP' archetype beyond the scope of this study.

Source: Household model, based on cost modelling, as detailed in Approach.

Despite this cost reduction to households, there remains a need to ensure this cost does not impose a disproportionate burden on lower-income groups. Figure 7.3 shows that the same TCO premium will take up a decreasing proportion of a household's income as that household's disposable income goes up. The bottom quintile of households (with less than £15,000 per year disposable income) could spend 0.8-1.8% of their income per year on net zero home conversion. For fuel poor households in the bottom quintile of households, the range could be ~50% higher. For the top quintile, however, this would drop to 0.2-0.4% of their income. The cost of net zero home conversion as a share of household income is therefore higher for lower-income households. Some form of support may therefore be needed to mitigate the impact of this cost and ensure that lower-income households transition to a net zero world.

Figure 7.3: Cost of home conversion for different households
Average annual TCO premium of different households in 2030, £

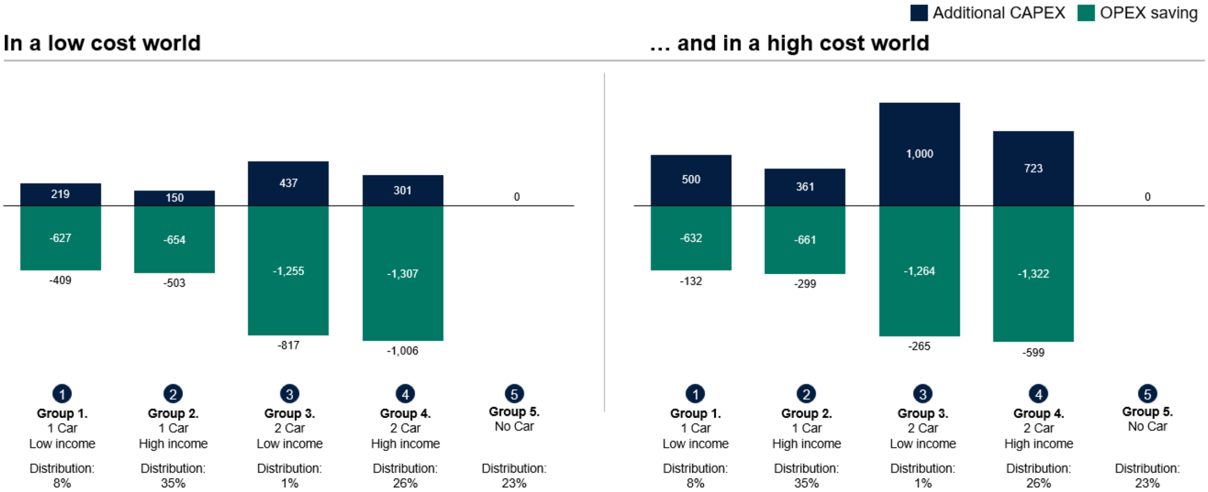


1. Using TCO premium for 'Inefficient' as illustration: £120 – low cost, £288 – high cost.

Source: Household model, based on cost modelling, as detailed in Approach.

In contrast, the shift to electric cars could deliver a cost saving of ~£275-£500 per annum per household with a car. Figure 7.4 shows the difference in CAPEX and OPEX between EV and combustion engine cars for different household types in 2030. EV cars have a CAPEX premium due to the higher purchase price than their combustion engine equivalents, but OPEX savings due to the lower cost of electricity when compared to fuel. High-income households face a lower cost of capital, hence there is a slightly different CAPEX premium associated with the archetype. Overall, and in contrast to investing in home conversion, the OPEX savings outweigh the CAPEX premium by 2030.

Figure 7.4: Cost of shift to electric cars for different household archetypes
Average annual TCO premium of different households[1] in 2030, £



1. The 'distribution' adds up to 93%, not 100%. The missing 6% are households that buy more than two cars, who are typically high income.

Source: Household model, based on cost modelling, as detailed in Approach.

Converting existing homes to net zero could involve a cost of £120-£180 annually in a low cost world with a balanced policy mix, while shifting to EVs could *save* households ~£275-£500. For 'Efficient' households (which do not require deep retrofits) the balanced policy mix reduces costs to ~120-£170 annually in a low cost to a high cost world.[16] Some households investing in both home conversion and EVs could therefore see a net benefit from the energy transition. Other households which invest in home conversion only – either because they do not have a car or continue to purchase internal combustion engine vehicles – would not save money. Some form of support may therefore be needed to protect lower-income households that fall into this category.

The distributional impacts associated with the transition require further exploration. The distribution of operating savings across different household types over time (for example, when property is bought and sold) could vary, contingent on the efficiency of the housing market. As demonstrated in the modelling, opex savings do not necessarily accrue to the actor making the investment. Behavioural measures within the balanced policy mix – for instance, information campaigns – are likely to play a key role in delivering efficient outcomes.

[16] Modelling result; not shown in figures.

8. Jobs and competitiveness

Analyses of economic impacts of the net zero transition often tend to focus on numbers of jobs. While this is a relatable metric, the evidence on labour market impacts of the transition is complex and continuously evolving. The net zero economy will feature a mix of new, different and conventional jobs, with some skills (e.g. electricians) in higher demand.

The net zero transition will change the composition of jobs: there will be downscaling or removal of fossil fuel energy generation with an associated displacement of workers, but also a demand for new workers to build and manage new clean energy infrastructure. This necessitates the need to plan ahead for potential skill shortages and unfilled vacancies (Bücker et al., 2023). The literature also highlights the issue of transience or permanence of jobs: classification of occupations as 'green' or 'brown' overlooks the fact that some roles may be crucial for only part of the transition (Bücker et al., 2023). A review of evidence in the UK suggests that net zero-aligned investments – in clean automotive, hydrogen and carbon capture, utilisation and Storage, renewable energy, and housing energy efficiency – can create tens of thousands of jobs in the short term, typically in construction and installation (Valero et al., 2021). In the medium- to longer-run, job creation opportunities are related to R&D and production of new technologies (Valero et al., 2021).

Delivering net zero will therefore not only have direct environmental effects, it will also impact and support the economy. There is not yet a universally agreed definition of what a 'green' job is. Jobs have been classified as 'directly green' when they involve the emergence of new occupations, or alter the skills and knowledge requirement of existing occupations towards 'green tasks', and 'indirectly green' when they support green activity but do not involve any 'green tasks' (Valero et al., 2021). Recent research has shown the potential for green investments to support more jobs (O'Callaghan et al., 2021) and that green jobs tend to be higher quality and provide higher wages than non-green jobs (Valero et al., 2021). Implementing net zero has the potential to bolster economic opportunities for a large number of people in the UK.

Both private and public sector investment in the green economy are anticipated to lead to job creation. Delivering on the financing and construction of the projects through capital investments creates jobs at the time of implementation, which, as investments will continue through to 2030 and beyond, can be considered in terms of full-time equivalent employment opportunities. Once the projects are in use, the continued maintenance and repair of any investments over their lifecycle supports further jobs, for example, mechanics maintaining EVs.

Additional jobs are also created indirectly up the supply chain, as inputs into production themselves require sourcing; while some of these may be delivered internationally, evidence suggests that a large proportion will be generated within the UK. Finally, further impacts are likely to occur through second-order effects, including induced spending and the facilitation of sectors through the broader presence of new green technologies (O'Callaghan et al., 2021).

Input-output modelling is used to estimate these direct and indirect job impacts, while recognising that further job effects through co-benefits may also occur. This approach reflects recent research on the potential for a green COVID-19 recovery (O'Callaghan et al., 2021). This analysis showed that investments provide an initial short-term jobs boost during the capital investment stage and these impacts are typically larger for a given green investment than for non-green investment. However, the impacts are also long lived, providing more green jobs in the longer term. Approximately 20% of current jobs in the UK and Europe are green, when defined through an occupation-level definition of greenness (Valero et al., 2021). Workers in green jobs tend to be more highly educated and on good-quality permanent contracts, however the evidence suggests that green jobs typically provide higher wages and better-quality jobs for those at all education levels, and that these jobs are more resilient to concerns regarding automation.

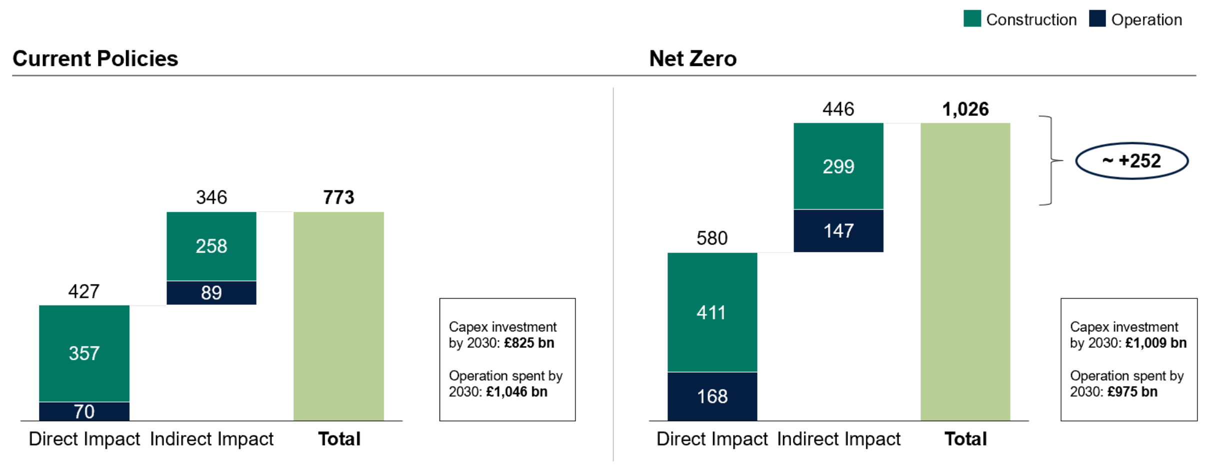
Delivering net zero requires workers that have the skills to meet this new demand. Broader research, beyond the direct scope of this study, demonstrates the need for educational and workforce programmes to support this, for example, through the reskilling of gas engineers to install and maintain heat pumps. There is also evidence that, currently, green jobs are more likely to be carried out by men and older workers, necessitating training and access for a more diverse population to deliver equitable access to new jobs, and to ensure a resilient economy (Valero et al., 2021).

There is an early leader's advantage in securing gains from the global transition to net zero (Andres et al., 2021). Countries who have invested early are developing greater footholds in the green technology markets, which then enable them to secure further growth opportunities through international sales and greater competitiveness in the global economy in the long term. While the position of different countries in terms of their current ability to deliver complex green products and services is diverse, the patterns are not static. International capital markets and variations in public support for investment is rapidly altering the global picture – for example, through the emergence of China as the leading solar panel manufacturer, or the recent growth in wind-generation capabilities in Spain.

Delivering net zero in the UK would therefore help support the UK's green competitiveness and its potential future growth opportunities. It would support the development of supply chains, placing the UK in a stronger position to gain market shares and comparative advantages in sectors internationally. While some areas of green technology production are already well developed globally, the UK has comparative strengths in the services sector, particularly finance, and governments, companies and sectors that invest earlier in the green transition have a lot to gain.

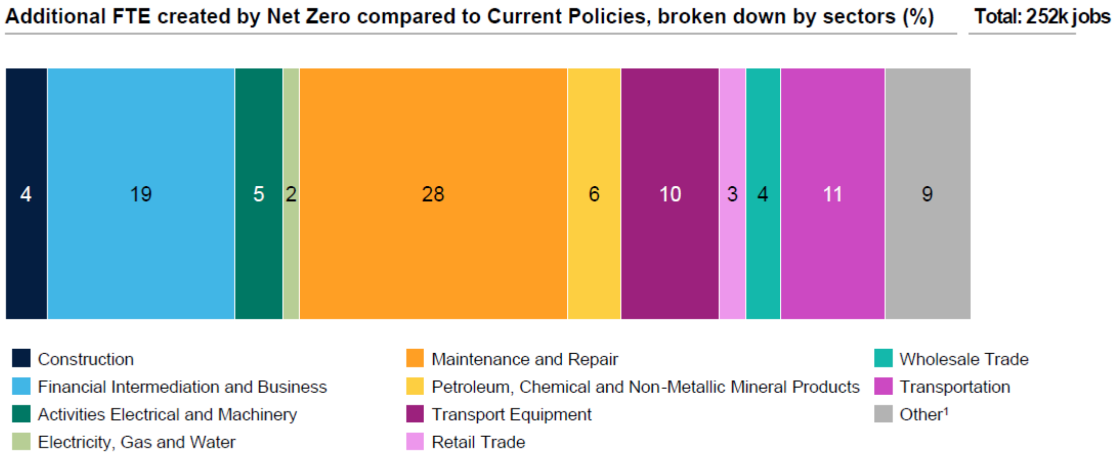
In terms of direct and indirect job creation, by 2030 the investments to deliver net zero could create 252,000 full-time equivalent jobs above those in the Current Policies scenario. These jobs are the result of the construction and installation of new technologies, which occur in the year of delivery, alongside operational jobs that continue throughout the lifecycle of the investments and beyond 2030. Figure 8.1 shows the scale of job creation in each scenario. Delivering net zero directly creates over 100,000 additional operational jobs, and 56,000 extra construction jobs in any given year. The scale of impact increases with the addition of indirect jobs in the UK supply chain, supporting over 100,000 extra full-time equivalent jobs.

Figure 8.1: Full-time equivalent jobs created in addition to the baseline, thousands



The additional jobs are concentrated in the Maintenance & Repair, Financial intermediation, Transport equipment and Transportation sectors, reflecting the operational need of new technologies which will by necessity be delivered domestically, and the UK's comparative advantage in the financial sector. An extra 71,000 jobs are created in Maintenance and Repair, part of the broader construction sector, under net zero, driven by the need to install, maintain and operate new equipment. An additional 25,000 jobs in Transport equipment, which includes the construction and repair of all types of vehicle, and 27,000 jobs in Transportation, which includes transport service delivery, are delivered under the Net Zero scenario. This scenario also delivers 48,000 additional jobs in financial intermediation, strengthening a sector in which the UK has an existing comparative advantage and which may therefore lead to greater international gains.[17]

Figure 8.2: Percentage of additional FTE jobs created by Net Zero, by sector, compared to a Current Policies scenario



1. Agriculture, fishing, mining and quarrying, food and beverages, textiles and wearing apparel, wood and paper, metal products, other manufacturing, recycling, hotels and restaurants, post and telecommunications, public administration, education health and other services, private households.

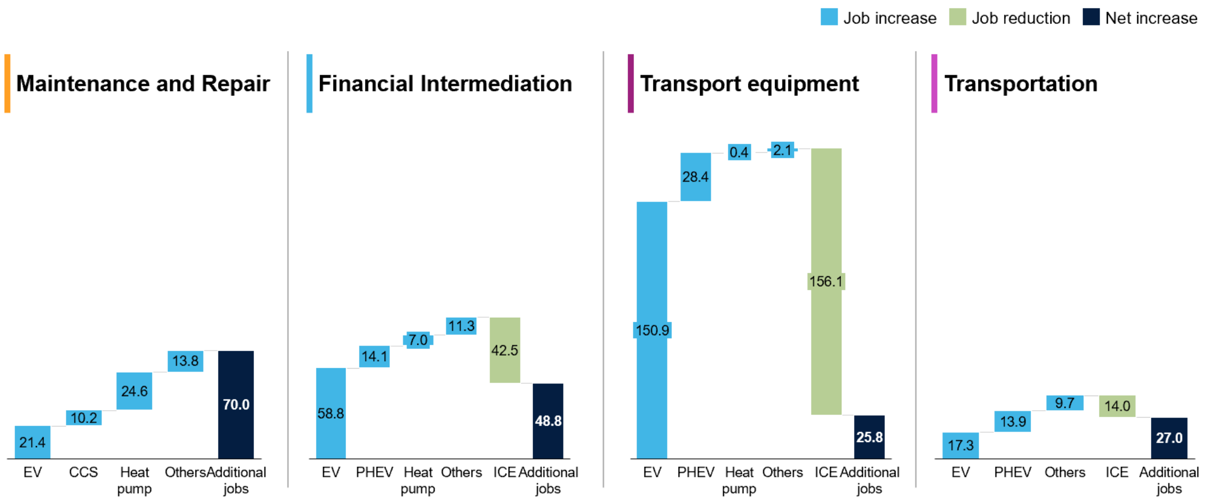
Over time, the UK could succeed in developing more additional jobs higher up supply chains, including in electrical and machinery, transport equipment, and other manufacturing. The modelling takes the current structure of the economy, including the share of production inputs that are sourced domestically and internationally for each sector. In reality, the shares can change. Facilitating policy and business environments could encourage greater domestic manufacturing or innovation to support the green transition. This could enhance UK

[17] The modelling uses input-output tables from the present day, whereas in reality over the medium term, the investments in the green economy will also alter the input shares of future production. This simplification enables a more transparent modelling process that focuses on the direct and indirect impacts. However, as a result, when production technologies alter toward greener energy sources, some of the jobs created which are currently attributed to petroleum, chemical and non-metallic mineral products are likely to shift into greener energy and product sectors. These potential second-order effects are not captured.

competitiveness internationally, leading to further positive impacts on employment through increase domestic sourcing and a greater scope to export green products.

Additional jobs are mainly driven by investment in CCS and heat pumps. Figure 8.3 sets out the split in additional jobs by their source. While EVs support new jobs in maintenance and repair, financial intermediation and transport, many of these are at the expense of equivalent jobs from ICE vehicles which will no longer be required; the net effect is substantially lower as both green and non-green investments would support similar numbers of jobs, albeit with different specialised skills. Heat pumps and CCS both create new jobs in addition to those from the baseline scenario, particularly in maintenance and repair and financial intermediation. This reflects both the UK's existing areas of comparative advantage and the requirements to maintain new technologies once they are operational. Any skills development programmes would need to respond accordingly.

Figure 8.3: Sources of additional jobs, FTE, thousands



The location of these jobs will vary according to the regional focus of investment; an initial assessment considers the distribution of employment effects assuming that the additional investments are spread equally across the UK's existing areas of economic activity.[18] This analysis allows the distributional impact to be considered, while recognising that the actual impacts will vary according to the location of final investments. For investments in housing, these assumptions are likely close to the reality of delivery, as retrofitting will take

[18] Investments are mapped to areas of existing employment within given sectors.

place across the UK roughly according to the distribution of households. However, for some sectors, such as Carbon Capture and Storage, investments will likely be more localised, driving job creation in particular areas of the UK. It is not possible to forecast the location of all jobs created without pre-determining the location of such investments. However, by looking at the existing distribution of economic activity, the likely location of job creation can be revealed. Figure 8.4 shows the split across the UK according to the sector in which a job lies and Figure 8.5 shows how the additional jobs could vary across the UK, without additional targeting.

Job creation as a share of existing employment is greatest outside of London, supporting the delivery of new jobs throughout the UK. Noting that these are conservative estimates, with secondary benefits excluded from the analysis, every region outside of London gains at least seven new jobs for every 1,000 existing jobs. If capital investments were targeted to specific regions, these impacts could be greater. The facilitation of new sectors and opportunities beyond this analysis would also likely bring these numbers up.

Jobs in maintenance and repair are spread throughout the UK, creating over a quarter of additional jobs in all regions outside of London. This corresponds to the need to maintain investments throughout the country. However, some existing sectors are already highly clustered, with financial intermediation in particular heavily focused in London. As a result, approximately 40% of all new jobs in London are in this sector.

Figure 8.4: Job impacts by region of the UK, thousands

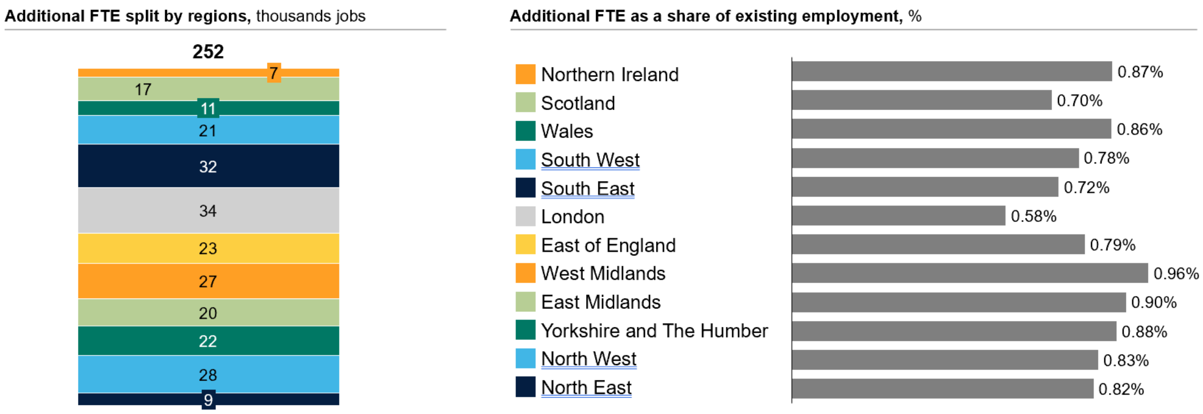


Figure 8.5: Sectoral FTE jobs created as a share of additional jobs by region

Glossary

Table 4: Glossary

Term	Definition
Spend	The cost associated with a technology, including both upfront and running costs
Net spend	The investment an actor makes net of running costs
Lifetime cost	The cost of a technology on a total cost of ownership basis
Total cost of ownership (TCO)	The spend associated with that technology, both upfront and running costs, discounted to the present day
EV	Electric Vehicle – e.g. an electric car
CCS	Carbon capture and storage – e.g. a natural gas power plant that captures all the CO2 released and stores it in subterranean caverns
Public spend	The government outlay on subsidies to support the use of green technologies, in particular CAPEX subsidies on the upfront cost associated with a technology
Household archetypes	The cost of net zero home conversion varies. This study explores six different 'archetypes' – types of household. Inefficient, i.e. poorly insulated, homes and fuel poor households face higher expenses to green their home, while privately rented households might benefit from energy efficiency improvements that they did not pay for
Balanced policy mix	See Table 2. The balanced policy mix mirrors the policy mix in place today, but scaled up to reach net zero goals
Green premium	The extra spend in percentage terms associated with the clean technology, compared to the conventional technology

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