Technical Annex: Delivering Net Zero UK – A Stocktake

May 2024

Oxford Smith School of Enterprise and the Environment

The Smith School of Enterprise and the Environment (SSEE) was established with a benefaction by the Smith family in 2008 to tackle major environmental challenges by bringing public and private enterprise together with the University of Oxford's world-leading teaching and research.

Research at the Smith School shapes business practices, government policy and strategies to achieve net-zero emissions and sustainable development. We offer innovative evidence-based solutions to the environmental challenges facing humanity over the coming decades. We apply expertise in economics, finance, business and law to tackle environmental and social challenges in six areas: water, climate, energy, biodiversity, food and the circular economy.

SSEE has several significant external research partnerships and Business Fellows, bringing experts from industry, consulting firms, and related enterprises who seek to address major environmental challenges to the University of Oxford. We offer a variety of open enrolment and custom Executive Education programmes that cater to participants from all over the world. We also provide independent research and advice on environmental strategy, corporate governance, public policy and long-term innovation.

For more information on SSEE please visit: www.smithschool.ox.ac.uk

This Technical Annex contains analysis cited in the Report ("*Delivering Net Zero UK: A Stocktake")* and Policy Brief ("*Getting a Good Deal on UK Net Zero")*. The Smith School team involved in the preparation of this Report were Harry Lightfoot Brown, Anupama Sen 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.

Contents

About this document

This Technical Annex should be read in conjunction with *Delivering Net Zero UK: A Stocktake* (Smith School 2024). It provides further detail on the assumptions, data, models and analysis that underpin that study. The two documents, in turn, are synthesised in a policy brief for decision makers, *Getting a Good Deal on Net Zero* (Sen et al., 2024), which takes stock of the economic and fiscal impacts, and the opportunities, of reaching net zero emissions in the UK.

Delivering Net Zero UK creates a set of technology deployment pathways for the UK aligned with the Climate Change Committee's (CCC) Sixth Carbon Budget Current Policies and Net Zero scenarios, for a high cost and low cost world. It breaks down the investment requirements by economic actors and analyses the cost impact on different types of households, as well as jobs across the UK. The study has been designed to reflect the most up-to-date costs and learning rates projections across both green technologies and their conventional alternatives, which allows a direct comparison of the Total Cost of Ownership (TCO) under realistic investment decision-making conditions.

This Technical Annex details the analytical approach taken in each of those steps. The full list of data sources are provided in Appendix 1.

1. Methodology

1.1 Overview

To conduct our analysis, we have developed four scenarios that cover a range of deployment and cost trajectories to conduct our analysis.

- **Current Policies – high cost:** Consists of low net zero technology deployment and is associated with high costs.
- **Current Policies – low cost:** Consists of low net zero technology deployment and is associated with low costs.
- **Net Zero – high cost:** Consists of net zero technology deployment inspired by the CCC's Sixth Carbon Budget Balanced Net Zero pathway and is associated with high technology costs.
- **Net Zero – low cost:** Consists of net zero technology deployment inspired by the CCC's Sixth Carbon Budget Balanced Net Zero Pathway and is associated with low technology costs.

Both the Current Policies scenarios and Net Zero scenarios were informed by **CCC Sixth Carbon Budget analysis**. Further information on how the scenarios have been constructed can be found in Section 2. Once the baselines and key input assumptions have been established, the following **three modules** of analysis were implemented, for all scenarios, out to 2030.

MODULE 1: HOW WILL THE NET ZERO TRANSITION BE FINANCED?

Module 1 explores the financial aspects of shifting towards net zero, focusing on the allocation of capital expenditures (CAPEX) across various actors, namely households, the government, and businesses in the investment scenario. Additionally, it evaluates the unit costs of key technologies including electric vehicles (EVs), home retrofits and heat pumps to calculate the TCO, applying actor-specific discount rates for a more accurate analysis. The module further details the distribution of CAPEX by actors, instruments, years and technologies, highlighting the (dis)inflationary effects and the 'green premium' or cost savings associated with adopting green technologies.

MODULE 2: WHAT ARE THE FIRST-ORDER IMPACTS OF NET ZERO ON HOUSEHOLD EXPENDITURE?

Module 2 examines the direct impact of pursuing net zero emissions on household finances, moving from the assessment of CAPEX and operational expenditures (OPEX) to the TCO. This shift is crucial as it affects retail energy prices, which in turn influence household decisions related to adopting green home technologies and EVs. The module provides a detailed analysis of costs by household archetype, modelling their expenditure over time. It aims to estimate the financial costs and benefits households will experience through the transition, offering insights into how different types of households will be affected.

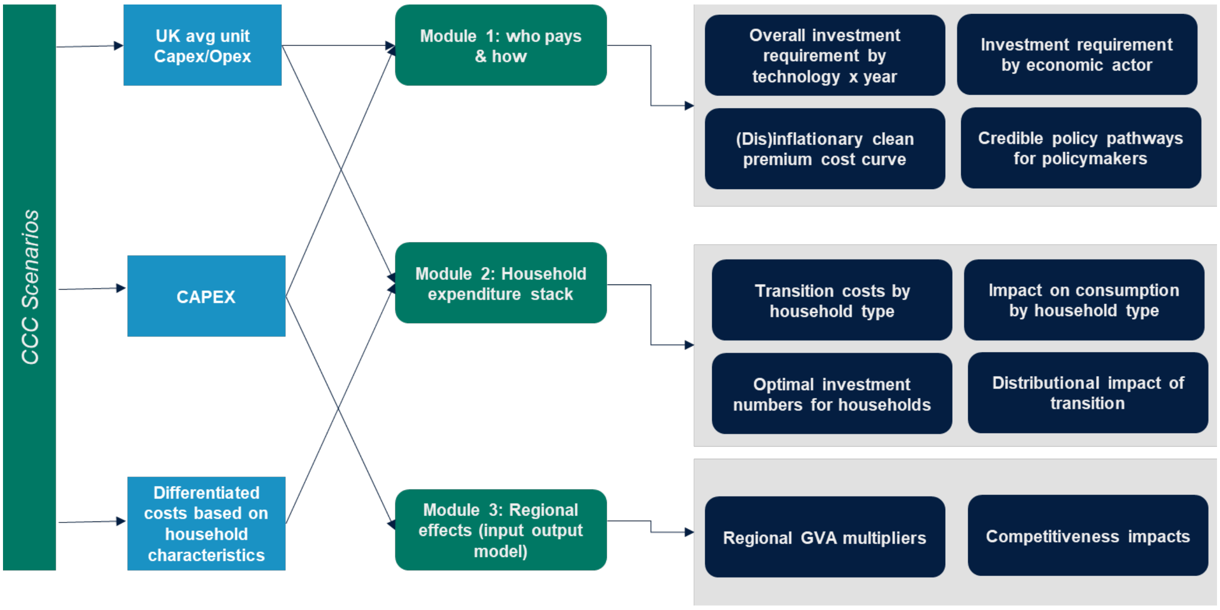
MODULE 3: HOW DOES THE TRANSITION DRIVE UK JOBS AND GROWTH?

Module 3 studies the wider economic effects of the transition towards a greener economy in the UK, using input-output modelling alongside an investment scenario. This analysis focuses on how such investments will drive regional development, create jobs, enhance Gross Value Added (GVA) and boost overall competitiveness. The module specifically investigates the regional impacts by applying capital expenditures (CAPEX) through input-output tables, providing insights into the implications for GVA, skills development and competitiveness.

1.2 Model schematic

Figure 1 summarises how the three model components interact. The model schematic shows how outputs from modules feed into other modules of analysis and produce key outputs.

Figure 1: High-level model schematic



Source: Team research.

2 Baseline and scenarios

2.1 Scenario overview

To conduct the analysis, **four scenarios aligned to the CCC Sixth Carbon Budget have been produced**:

1. Current Policies (high cost)
2. Current Policies (low cost)
3. Net Zero (high cost)
4. Net Zero (low cost)

These aim to cover the variety in potential outcomes due to variations in policy and economic conditions. They produce the (unit) CAPEX/OPEX and deployment data needed for our three modules. By using the same scenarios, we ensure that each modules is linked and aligned.

2.2 Current Policies scenario

The baseline for this report is the Current Policies scenario, in general constructed using the baseline policy scenario from the CCC's Sixth Carbon Budget.[1] Where possible, figures have been updated to reflect realised deployment. The Power sector Current Policies scenario is not based off the Sixth Carbon Budget; instead, it is from the Department for Energy Security and Net Zero (DESNZ) 2023 Energy and Emissions Projections. The baseline represents a

[1] See Chapter 1 in the CCC Sixth Carbon Budget Methodology Report.

Current Policies scenario consistent with existing climate policy. The Current Policies scenario is run for both a **high cost** and **low cost** world.

2.3 Net Zero scenario

To construct a net zero world in which sufficient policies to reach net zero are implemented, this report utilises the CCC's Sixth Carbon Budget Balanced Net Zero Pathway.[2] The CCC Net Zero scenario provides the deployment figures for different technologies in the economy that will be used in our analysis, as well as the infrastructure build-out requirements needed to enable the use of green technologies (grid upgrades, EV charging infrastructure). This scenario is run for the **high cost** and **low cost** world.

2.4 Constructing the high cost world

To account for varying potential states of the world due to economic and political volatility, a low cost and a high cost scenario have been constructed based on the following set of assumptions.

In a high cost world, the disruptions from COVID19 and the war in Ukraine continue and the distortions they bring to the market remain unresolved. Inflation is prolonged at the current level in this period. This has three consequences for our modelling:

1. Real marginal costs are higher due to supply disruptions. Accordingly, this is modelled by lower learning rates going out into the future.
2. As a response to inflation, central banks keep interest rates high, leading to a higher Weighted Average Cost of Capital (WACC)[3] and hurdle rates.[4]
3. Prices are higher in this world as fossil fuel prices are higher, which makes the conventional technology more expensive.

Consequently, unit CAPEX and OPEX will be **higher**, alongside TCOs. Overall there is a **less favourable environment** for households to switch to green technologies.

2.5 Constructing the low cost world

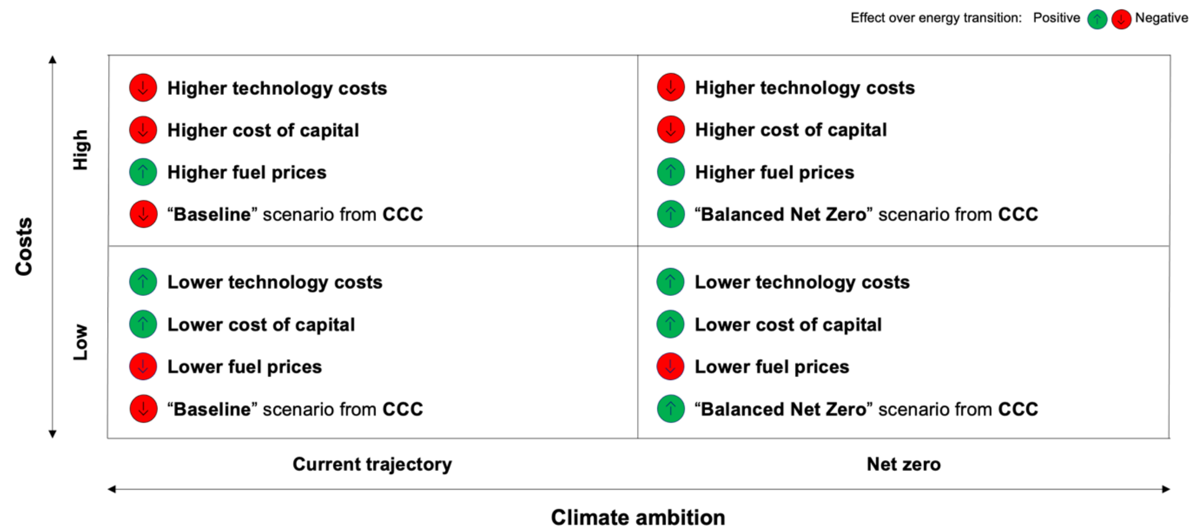
In a low cost world it is assumed that geopolitical instability subsides and supply chain constraints are reduced. Secondly, inflation is assumed to fall, leading to lower interest rates (see Appendix). This has the inverse consequences for modelling:

1. Real marginal costs are lower. Subsequently, this is modelled by higher learning rates.
2. With lower inflation, central banks reduce interest rates. As a result, WACC and hurdle rates are lower.
3. Prices are lower in this world, including fossil fuel prices.

[2] See Chapter 1 and relevant sector chapters in the CCC Sixth Carbon Budget Methodology Report.
[3] The Weighted Average Cost of Capital (WACC) is a financial metric used to calculate the average cost of capital, including both equity and debt.
[4] A hurdle rate is the minimum rate of return on an investment that is required by investors. It represents the lowest return on an investment that would make it acceptable to proceed with the project or investment.

Consequently, unit CAPEX and OPEX will be **lower** alongside TCOs. Overall, there is a **more favourable environment** for households to switch to green technologies. The detailed drivers for all scenarios are broken down in **Figure 2.**

Figure 2: Cost scenarios overview



Source: Team research.

3. Inputs and assumptions

3.1 Overarching assumptions

In this section we outline key inputs and assumptions.[5] A further breakdown of the costs used in this study can be found in Appendix 1.

Time horizon: This study looks at the period 2020-50, with a significant focus on the first decade to **2030.**

Sectoral scope: The primary focus of this analysis was on deployment of low carbon units in three key sectors.

- **Power:** Renewable generation and infrastructure development
- **Buildings:** Retrofits and heat pump installation
- **Transport:** Primarily electric vehicles and charging infrastructure, with small investments in rail and freight
- The report also had a light-touch focus on **Industry** (see Section 7.2)

[5] As outlined in Section 2, sector deployment has been informed by CCC Sixth Carbon Budget analysis. For details, see Chapter 1 and relevant sector chapters in the CCC Sixth Carbon Budget Methodology Report.

3.2 Overarching technology cost assumptions

In order to assess the cost for the transition, several assumptions have been made on the CAPEX, OPEX and learning rates for the technologies considered. The assumptions have been informed by desk-based research. A full breakdown of the cost assumptions has been provided in an Appendix 1 to the Technical Annex.

COST TRAJECTORY AND LEARNING RATES

1) **Establish base year (2020) costs:** We use DESNZ figures for power technology costs; a range of studies broken down by cost driver to estimate low and high heat pump costs; and recent market studies for battery costs. For more information on the costs used please see **Appendix 1**.

2) **Estimate future costs.** We A) apply learning rates to base year costs, based on forecasts of B) international deployment, which drive cost reduction for the technology overall.

   A. **Learning rates:** The learning rates for each technology determine how quickly the price falls for a given technology. In our analysis, a learning rate says that the cost will decline by a certain percentage for a given doubling in global deployment. Our learning rates are applied to the global deployment figures from the IEA, as outlined above. To determine learning rates in the low and high cost scenarios, we exclude the minimum and maximum outlier values from the range and use the remaining upper and lower bound estimates
   B. **International deployment:** IEA STEPS and NZE[6] broadly align with the 'Baseline' and 'Net Zero' deployment scenarios, accordingly. Therefore, IEA STEPS and NZE are used as a proxy for global capacities across power technologies, heat pumps, and batteries.

See Appendix 2 for for further details of the learning rates; and for a more detailed discussion also see Section 7 – Uncertainties and limitations.

FOSSIL FUEL PRICES

The fossil fuel prices used to inform the analysis are from the Department for Energy Security and Net Zero (DESNZ) and International Energy Agency (IEA). See Appendix 1.

[6] The International Energy Agency has produced global energy demand scenarios, STEPS and NZE. The Stated Policies Scenario (STEPS) aims to offer insight into the likely trajectory of energy system evolution, drawing upon an in-depth analysis of existing policy. The Net Zero Emissions by 2050 Scenario (NZE Scenario) outlines a prescriptive path for the worldwide energy sector to reach net zero CO_2 emissions by 2050. It assumes that developed economies achieve net zero emissions before other regions.

ELECTRICITY PRICES
The electricity prices used to inform the analysis are taken from the the Department for Energy Security and Net Zero (DESNZ). See Appendix 1.

CARBON PRICE
The carbon Price used has been informed by the Department for Energy Security and Net Zero (DESNZ) – see Appendix 1. We assume that the UK ETS will approach a value of £107/tCO_2 over time.

3.3 Household cost of capital assumptions

Assumptions have been made for the costs of capital faced by different households based on their income classification. The assumptions are detailed in Table 1 and have been informed by a number of papers. The literature shows a wide range of estimates on the implicit discount rate. The premium faced by different households has been derived from estimates in Newell et al. (2015).[7] Broadly, studies show discount rates are negatively correlated with income and education.

The cost of capital is calculated by comparing the range of financing options available to households today. The rate for personal loans compared to the Bank of England base rate is estimated using Bank of England data. The top decile of UK households by income and wealth keep 28% of financial assets in savings (Advani et al., 2020).[8] This enables households in this bracket to adopt net zero solutions using their own capital, with a relatively low opportunity cost. In contrast, lower-income households are constrained in the financial terms available to them.[9] UK credit scores (an indicator of financing costs) 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).[10]

[7] Evidence suggests that cost of capital and discount rate are also correlated with wealth, education and age. The focus on income enables assessment of the variation in uptake, while recognising that more nuances are embedded in the decision to invest. Newell, R. G., & Siikamäki, J. (2015). Individual Time Preferences and Energy Efficiency. American Economic Review, 105(5), 196–200. https://doi.org/10.1257/aer.p20151010
[8] Advani, A., Bangham, G., & Leslie, J. (2021). The UK's wealth distribution and characteristics of high-wealth households. Fiscal Studies, 42(3–4), 397–430. https://doi.org/10.1111/1475-5890.12286
[9] Derived from 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.
[10] Financial Conduct Authority. (2022). Credit Information Market Study Interim Report and Discussion Paper. https://www.fca.org.uk/publication/market-studies/ms-19-1-2.pdf

Table 1: Discount rates and cost of capital

Household income	Cost of capital		Implicit discount rate premium	Notes
	Housing retrofit	Electric vehicle		
'High' > £80,000	Base rate	Base rate	+ 6%	Can utilise savings or extend mortgage for housing investments. Risk aversion and other factors in implicit discount rate are lower for high-income households.
'Medium'	Base rate + 5%	Base rate + 3%	+ 8%	For housing investments, can utilise unsecured personal loan. Securitisation against vehicle asset allows for lower rates for purchases of electric vehicles.
'Low' < £15,000	Base rate + 20 %	Base rate + 10%	+ 10%	Unsecured personal loan likely deemed unaffordable, or with higher interest rates to compensate increased credit risk. Alternative is overdraft or credit card. Risk aversion and other factors in implicit discount rate are higher for low-income households.
On-bill financing	Base rate + 3-10%	N/A	+ 10%	Underwriting modified to consider billpayers past payment history, reducing credit costs for middle- and low-income households and resultant rates.

Source: Team research. Note: Estimates based on review of literature, adapted for our analysis. The implicit discount rate premium refers to a notional higher discount rate that different tiers of households may use in investment decisions.

4. Module 1: Investment requirements

4.1 Module 1 overview

For this analysis we used a model which allocates capital expenditures to deploy technologies associated with the low cost and high cost scenarios among key economic agents such as households and governments, considering various financial mechanisms such as debt, equity and loans.

Additionally, the module assesses the unit costs of green technologies to determine their TCO, applying tailored discount rates for each actor. It details the distribution of CAPEX and explores the economic implications. After the model estimates the public finance need without policy, a number of policies are introduced to reduce the amount of government spending in the transition.

4.2 Model specifications

The model is designed to optimally allocate investments by aligning investment characteristics with investor preferences, drawing on the historical involvement of various capital sources in green finance. It adjusts for changes in the risk/return profile of investment opportunities within specific climate scenarios.

The model operates under the assumption that both individuals and companies are perfectly rational, making investment decisions based on their TCO, which compares the costs of low-emission and high-emission technologies. Additionally, it assumes that carbon tax commitments by governments are taken as credible by investors.

The model presupposes an unlimited capacity to meet the investment demands of the transition towards net zero, implying no constraints on the supply of capital, its geographical distribution or government budgets. This approach enables the analysis of how investment allocations might shift under various scenarios.

Our modelling does not consider the specific investment requirements to achieve climate goals – these are treated as exogenous inputs. However, these inputs have been constructed by us, as outlined in sections 2 and 3. It also does not consider how agents might adjust their spending in response to different price levels; such decisions are predetermined within the investment inputs to the model.

4.3 Factors that influence spending

TOTAL COST OF OWNERSHIP

The modelling utilises a **TCO** approach to determine the public finance need. To calculate a TCO, this study computes the Net Present Value of costs for technologies at different points in time. 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.

A clean technology is cost-competitive when it is cheaper on a TCO basis than its conventional equivalent. In other words, if the (discounted) OPEX savings associated with switching to a green technology are greater than the increase in upfront cost, compared to a conventional technology, then the clean technology 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.

Weighted average cost of capital

A component of the TCO calculation is the cost of capital faced by agents. For consumers, we assume that they face relevant market borrowing rates for technologies based on their income level, as detailed in the assumptions section. For commercial spending, a **weighted average cost of capital (WACC)** approach is taken. To calculate the WACC, we calculate the weighted average cost of debt and cost of equity.

This study takes technology-specific costs of capital, adjusted using a risk-free rate that corresponds to the cost world realised (see below). The technology-specific cost of capital is the sum of the risk-free rate, country risks, sector-wide risks and technology risks. The final values are -1% (risk-free rate in the low cost world) to 3.5 % (risk-free rate in the high cost world). See Appendix 1 for details.

4.4 Modelling layers: how is spending split in the economy?

The modelling has layers that split how investment is allocated across agents in the economy for the Current Policies and Net Zero scenarios. Table 2 details the split between commercial vs. consumer spending, consumer loans versus consumer cash, balance sheet versus project finance, and public finance. Following the split in funding outlined by the layers, the model allocates finance across instruments and actors, to determine who pays for the transition and how much is invested.

Table 2: Model layers

<table>
<tr><th>Actor</th><th>Instrument</th><th>Methodology</th></tr>
<tr><td rowspan="2">Households</td><td>Consumer loans</td><td rowspan="2">• Commercial spending is split from consumer spending using historical spending patterns for the technology. Consumers are assumed as unlikely to invest in large technologies such as nuclear power plants.
• Within consumer finance, modelling splits it into consumer loans and consumer cash, based on the share of loans and cash on households' balance sheets as in the OECD's national financial accounts.</td></tr>
<tr><td>Consumer cash</td></tr>
<tr><td rowspan="2">Businesses</td><td>Balance sheet</td><td rowspan="2">• Within commercial finance, there is a split between project and balance sheet finance using historical data from the Climate Policy Initiative.
• Only 'large' technologies, as measured by installation size, receive project finance. Renewable energy projects are the primary users of project finance vehicles.</td></tr>
<tr><td>Project finance</td></tr>
</table>

Government	CAPEX subsidies	• The government finances technologies to ensure they are cost-competitive. Where a clean technology is more expensive than its conventional equivalent, the government would step in to equalise its costs.

Source: Team research.

After calculating the allocation of consumer and commercial spending for both scenarios, we can calculate **the public finance needed** to enable the necessary deployment.

The necessary deployment of technology for each scenario is considered an exogenous input. Spending occurs at the individual agent level using a TCO approach, as outlined above. Where the TCO for green technology is less than that of traditional technology, it is assumed that the green unit is adopted.

In cases where green technology is more expensive from a TCO perspective, it is presumed that the government covers the TCO gap to fulfil the exogenous deployment required to meet the scenario targets. For example, consider the illustrative public subsidy required for a heat pump. Assume a heat pump costs £2,000 per year on a total cost basis, including both upfront purchase costs and ongoing electricity costs, and that a gas boiler costs only £1,000 on a total cost basis. Then, the government would need to provide a £1,000 subsidy to ensure that the heat pump is cost-competitive. Thus, the additional investment required from the government is equal to the TCO gap resulting from the deployment of all green technologies that are more expensive than their conventional counterparts. This example assumes no policy. The next section details how different policy mechanisms can be used to reduce the public investment requirement.

4.5 Policy levers to reduce public investment gap

When green technology costs exceed those of their conventional (dirty) counterparts from a TCO perspective, policy intervention is necessary to bridge the price difference. We calculate the TCO gap by computing the present value of cost flows for pairs of technologies. Over time, as technology advances, green technologies get cheaper and more cost-competitive, reducing the public support requirement.

To reduce the amount of public spending needed, a range of policy levers could be deployed to drive increased private sector investment and reduce the need for public sector investment, creating the 'balanced policy mix'.[11] The balanced policy mix used in this report reflects the government's stated policy mix, scaled up to achieve net zero. Table 3 describes the policies.

[11] See Table 2 of main report.

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.

Table 3: 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 public-private 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. The 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).[12] The involvement of the UK Infrastructure Bank sets the CAPEX subsidy.[13]	All

[12] Jennings, T., Tipper, H. A., Daglish, J., Grubb, M., & Drummond, P. (2020). Policy, innovation and cost reduction in UK offshore wind. UCL's Bartlett School of Energy, Environment and Resources.

[13] A concessional loan has two effects. Firstly, it delivers a subsidy (this is the sub-market rate or the longer tenor); secondly, it de-risks the opportunity for private investors because the presence of government funds is a signal to private investors. To model the subsidy, we take an estimate of the UKIB financing capacity (~£570m p.a.). To model the effects of de-risking, we apply a 30% reduction to the cost of capital estimated across all

OPEX subsidies	The government deploys OPEX subsidies for utility-scale power. It de-risks the technology by providing revenue certainty.	Utility-scale Power

Source: This study uses the relevant net zero strategy for each sector to plot the credible policy pathway for each sector 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).

5. Module 2: Distributional Analysis and Household Archetypes

5.1 Module 2 overview

After establishing the transition costs, we look into the distributional impacts of the investments required. These impacts are scrutinised through the lens of strategically selected archetypes, for heating and transportation. For each archetype and technology, a TCO analysis is conducted, demonstrating how different household archetypes are impacted by the transition.

5.2 Distributional impacts: Home heating specification

To dissect how costs are distributed among societal members, archetypes emerge for home heating. Each is characterised by the following critical dimensions:

1. **Tenure:** Does the household finance the capital expenditure?
2. **Efficiency:** Is additional insulation necessary?
3. **Income**: Does income influence the cost of capital?

These dimensions are important for this study because they are the dimensions along which the cost for decarbonising a home will vary the most. Subsequently, households are classified into these archetypes, enabling a nuanced analysis of costs. The classification covers households across the UK and enables us to assess how different income groups may be affected.

An **Inefficient** home is defined as one that requires retrofits and heat pump installation, whereas an **Efficient** home is defined as one that only needs heat pump installation. Efficiency thresholds have been obtained from the CCC's Sixth Carbon Budget analysis.

commercial investments. This is roughly the cost of capital reduction offshore wind saw over the past 10 years. The sum of these effects creates the blended finance lever. (Refer to Figure 6.2 in Report).

Table 4: Household archetypes

Efficient Fuel Poor	Owner-occupied	High efficiency, fuel poor	2%
Inefficient not fuel poor	Owner-occupied	Low efficiency, not fuel poor	20%
Efficient not Fuel Poor	Owner-occupied	High efficiency, not fuel poor	35%
Inefficient Landlord	Rented	Split into landlord/ renter perspective	17%
Efficient Landlord	Rented	Split into landlord/ renter perspective	23%

Note: The 'distribution' adds up to 97%, not 100%. The missing 3% is the 'Inefficient FP' archetype, beyond the scope of this study.

CALCULATING THE COST OF HEATING DECARBONISATION

Costs are assigned to each archetype within two scenarios: low cost and high cost. Considerations include:

Fuel poverty: A direct correlation between fuel poverty and elevated capital costs is assumed, due to disproportionate interest rates affecting those with lower incomes.

Efficiency: The initial energy efficiency determines the extent of investment required for adequate insulation and the transition to low-carbon heating. Low energy efficiency homes need retrofitting before they can have heat pump installation.

Landlord: Landlords bear the financial responsibility for capital expenditures.

Each archetype's home decarbonisation cost is then assessed from a TCO perspective, factoring in CAPEX and OPEX, calculated on an annualised basis.

5.3 Distributional impacts: Transport specification

For Transport, the economic implications of decarbonising transportation are assessed on the acquisition of **new electric vehicles.** EVs purchased on the second-hand market are not accounted for in this study. To calculate the TCO and distributional impacts of transport decarbonisation for households, households are split into five key archetypes based on two dimensions:

1. **Car ownership:** The number of cars owned by a household
2. **Income:** The level of income affects the cost of capital faced by households

This generates the following five groups:

Archetype	Car ownership	Description	Distribution
Group 1	1	Low income	8%
Group 2	1	High income	35%
Group 3	2	Low income	1%
Group 4	2	High income	26%
Group 5	0	All	23%

Source: Authors, CCC (2020). Note: The distribution adds up to 93%, not 100%. The missing 7% are households that buy more than two cars, who are typically high income.

Group 5, with 0 car ownership, groups low income and high income together as neither is expected to purchase a new car. The cost of transport decarbonisation for this group can be seen in changes to public transport.

CALCULATING THE COST OF TRANSPORT DECARBONISATION:

In the same way as for home decarbonisation, costs are assigned to each archetype within two scenarios: low cost and high cost. For Transport, considerations include:

- **Purchase price:** Taken from up-to-date market data and detailed in Appendix 1, as outlined in the input and assumptions section.
- **OPEX costs:** Fluctuate with DESNZ's high and low fuel price forecasts, as detailed in the input and assumptions sections.
- **Cost of capital**: Low-income households face capital access barriers due to credit constraints, thus relying on higher-cost traditional loans. See Assumptions section for full details.

Each archetype's transport decarbonisation cost is then assessed from a TCO perspective, factoring in CAPEX and OPEX, calculated on an annualised basis.

6. Module 3: How does the transition drive jobs and growth?

6.1 Module overview

In this section we utilise a third proprietary model to quantify economic and social impacts of investments required to deliver the net zero transition. Social impacts are estimated using an **input-output (IO) model**[14] that can be adjusted to work with any input-output data source. For an example of this method see O'Callaghan, Bird and Murdock (2021).[15]

The analysis utilises the investment requirements obtained from our scenarios in **Module 1,** to be fed into the input-output table. The result is both the direct impacts on the sectors of investment, including jobs in those sectors, and indirect impacts up the value chain. An increase in spending in a certain part of the economy results in increased spending elsewhere, as goods and services are necessary to provide for the increased demand. These effects are combined, demonstrating the broader economic impacts. This approach allows us to model impacts by **sector** and **region.**

6.2 Model specification

The model specification includes the following steps.

1. **Determine economic data:** In the report we use country-specific input-output tables from EORA,[16] an emissions-augmented input-output table available for a broad set of countries globally. EORA provides the product interactions between 26 sectors for the UK, and the rest of the world. EORA enables international comparisons.
2. **Input investment portfolio from Module 1:** Based on the scope of UK net zero transition investments obtained in Module 1, we build a sectoral profile of expenditures both in the construction (CAPEX) and operational phases (OPEX). These profiles are built from a library of global investment examples, which combine detailed costing data to understand the components of delivery.
3. **Estimating the employment impacts:** The modelling approach uses input-output table from EORA to determine effects of CAPEX/OPEX on employment and GVA. The output of the model is split among direct and indirect impacts. The direct impact is derived from the activities of the investment itself. Indirect impact is the result of spending within the supply chain, excluding those felt outside the UK through trade impacts.

[14] Input-output modelling is an analytical method used in economics to represent the interrelationships between different sectors of an economy. It employs matrices to illustrate how the output from one sector becomes the input for another, showcasing the flow of goods and services through the economy, and therefore enabling the estimation of impacts cascading up and down the value chain.
[15] '[A prosperous green recovery for South Africa](#)', Oxford University Economic Recovery Project, Smith School of Enterprise and the Environment.
[16] https://worldmrio.com/eora26/

Spending on intermediate goods at each step in the supply chain is converted into GVA, intermediate good expenditures and imports sequentially. Imports are considered economic leakages because this creates economic activity outside of the local economy.

The methodology incorporates **Social Accounting Matrices (SAMs)** to facilitate the computation of economic multipliers. SAMs are input-output tables that quantify flows of all economic transactions within and out from an economy.

6.3 Regional impacts

Based on the model output, the job impacts are disaggregated by region using a four-step approach:

1. Assume the additional investments were spread proportionally across the UK according to existing economic activity. The actual investments are likely to differ from this, however the location of changes are not specified in the scenarios and therefore this assumption is used to show the general impacts across the UK. The effects could be targeted into specific regions, leading to more concentrated job gains.
2. Map our modelled changes in jobs (in the form of Eora 26 sectors) to ONS's standard industrial/sectoral classification.[17]
3. For ONS sectors, understand what share each region of the UK has of total jobs within each sector based on labour market statistics.
4. Based on the model output, allocate changes in employment to regions according to these shares.

6.4 Model assumptions

There are four key assumptions in the proprietary model that are consequential to results:

- **Constant returns to scale as production is increased.** In other words, the empirical technology observed in the IO table is assumed to be the same at any level of production.
- **Slack capacity.** There is enough underused capacity in the economy to scale up production without requiring additional investment. This is considered reasonably valid in the context of an economic downturn.
- **Fixed prices.** The model does not allow for price adjustments. This assumption is critical, as the model does not consider substitution effects between inputs, but rather assumes they will always be used in the same proportions. In the short run, this is a reasonable assumption, but in the longer run, prices will reflect the increase in demand through an upward movement.
- **No induced impacts.** The model excludes the mechanism by which increased household wealth prompts greater consumer spending.

[17] ONS Standard Industrial classification can be found here: https://www.ons.gov.uk/filters/f097989b-1467-4478-b3ca-a34ed5763776/dimensions/unofficialstandardindustrialclassification

ECONOMIC IMPACT TYPE DEFINITIONS

Direct: Impacts generated directly from the asset through activities such as planning, construction, and operations and maintenance.

Example: The building of a hotel asset will require the hiring of a construction company, leading to a positive direct economic impact in the construction sector through higher employment and capital consumption.

Indirect: Impacts generated by upstream industries that supply inputs for the asset; supply chain companies may supply raw materials, intermediary goods and components, or provide financial and other professional services.

Example: The development of the hotel requires the construction company to purchase materials from their suppliers, e.g. steel. Therefore, the investment in the development of a hotel has a positive indirect economic impact on the steel production sector.

7. Uncertainties and limitations

In constructing our scenarios and analyses, we relied on a series of assumptions to outline the potential outcomes in both high cost and low cost worlds. Our ambition was to leverage the most current and comprehensive data available. Nevertheless, it is critical to recognise that our analysis is subject to uncertainties and limitations. This section provides an overview of these areas.

Beyond the uncertainties delineated within the pathways we have set out, we acknowledge a broader spectrum of uncertainty that encompasses our analysis. The potential sources of uncertainty are manifold, encompassing the historical calibration of capital for the actors involved, price forecasts, and the alignment of scope between different scenarios, among others.

Given this level of wider uncertainty, we present two carefully developed scenarios, underpinned by numerous assumptions, and offer them as they are. This approach doesn't downplay the complexities and uncertainties inherent in our projections; rather, it openly acknowledges them. The results should be considered within the context of these limitations.

By detailing these uncertainties and limitations, we aim not only to outline the boundaries of our analysis but also to foster informed discussions around achieving net zero in the UK. Acknowledging the inherent complexities and adopting adaptable strategies will be crucial.

For the two scenarios we have developed, we outline the following uncertainties in more detail:

- **Scenario relevance**
- **Sectoral scope**
- **Costs and learning rates**

7.1 Scenario relevance:

Baseline uncertainty:

Our analysis utilises deployment pathways aligned with the CCC's Sixth Carbon Budget for both the Current Policies scenario and the Net Zero scenario. It is important to note that the context for these deployment rates has evolved since the time of the Sixth Carbon Budget, in December 2020. Additionally, government policies have undergone significant updates since the initial analysis, impacting the relevance of our foundational scenarios.

The Current Policies scenario, based on the CCC's Sixth Carbon Budget, might now reflect outdated parameter values (e.g. GDP). Adjustments have been made to these initial deployment numbers to make the scenarios more realistic; these include Power and Transport.

However, these adjustments will never fully represent the real world 'current policy', in its complexity. Despite these potential discrepancies, we believe this represents a relevant update to the analysis, before the Seventh Carbon Budget takes primacy.

We acknowledge that some parameters, especially costs, are not publicly disclosed in the CCC's scenarios. Our approach relies on a combination of CCC deployment numbers and updated costs from public sources to construct a baseline scenario reflective of low-carbon technology deployment under current policies.

7.2 Sectoral scope and sector impact:

The sectors of focus: Our analysis focuses on the Power, Transport, Buildings and Industry sectors, intentionally excluding Agriculture and Land Use due to their specialised dynamics and policy frameworks. 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.

Relatively low Industrial sector impact: We recognise the industrial sector's minimal immediate investment requirement, due to the anticipated timeline for substantial technology deployment and its shift towards lower-carbon energy sources in this sector, primarily taking place after 2030. We justify the relatively low CAPEX required for industrial decarbonisation within this timeframe.

Distributional impacts: The objective of the distributional analysis in this study is to demonstrate how the public investment need for households could be limited through a mix of policy instruments, across household archetypes. It is assumed the government is able to efficiently target residual households with capex subsidies to trigger the 'switch'.[18] Our aggregated analysis is useful for deriving key stylised facts, but further analysis would be needed for a more complete disaggregated distribution of costs and benefits, or for instance of a limited deployment of the technology between households.

7.3 Costs and learning rates:

Predicting the future costs of technology is inherently uncertain. The assumptions we have made are detailed in Section 2 of this document. However, here we make a number of clarifications on the cost projections we have used.

Exclusion of outlier values represents a conservative assessment: Historically, cost projections for green technology have been conservative, with real-world costs outperforming forecast costs for technologies such as wind and solar (Way et al., 2022).[19] Therefore, by excluding outliers,[20] this could represent a conservative assessment. Real-world performance for green technologies may well outperform our projections. Consequently, this would reduce the overall investment needs to get on track to net zero.

The use of declining learning rates: Literature on learning curves estimate a single and constant learning rate on historical deployment and cost data. We make a more conservative assumption with learning rates decreasing over time. It aims to encapsulate two arguments: i) decreasing marginal gains of efficiency and technology improvement, and ii) the existence of a floor price beyond which prices cannot drop. As we emphasise below, this assumption does not impact the forecasted investment costs. We apply declining learning rates in our models for two main reasons:

1. **Observation of plateaus in cost reduction:** Initially, technology costs decrease significantly as improvements are made in various aspects, like efficiency or manufacturing processes. Over time, each of these aspects may reach a point where further cost reductions become harder to achieve. This has been observed in

[18] We do not model for the impacts of imperfect information.
[19] Way, R., Ives, M. C., Mealy, P., & Farmer, J. D. (2022). Empirically grounded technology forecasts and the energy transition. *Joule*, *6*(9), 2057-2082. https://doi.org/10.1016/j.joule.2022.08.009
[20] The minimum and maximum outlier values from the range.

technologies such as solar PV, where different factors contributed to cost reductions at different times, but the rate of reduction slowed down as those factors matured. [21]

2. **Challenges with floor costs:** Instead of setting a minimum possible cost (floor cost) beyond which prices cannot drop, we use declining learning rates. This approach is chosen because determining a realistic floor cost is difficult and often leads to a wide range of uncertain values. Thus, for the purposes of this study, we believe that declining learning rates provide a more analytically suitable method without relying on uncertain floor costs.

It is important to note that switching from a constant to a declining learning rate model **does not drastically change our forecasts, or, therefore the results of this study**. This is due to the following reasons:

- The most significant cost reductions occur early on, when the technology is less mature and has more room for improvement.

- We apply declining learning rates starting from 2028, and since our forecasts only extend to 2030, the impact of reduced learning rates on cost predictions is minimal. For instance, using a constant rate would only slightly decrease the projected costs for solar and wind technologies to 2030, by about 2% for solar and 1% for wind.

Therefore, for the purposes of this study, we believe that while the choice of declining learning rates is analytically preferable for accuracy and avoids the pitfalls of defining floor costs, its impact on short-term forecasts up to 2030 is limited.

Accounting for 'random shocks' in our projections: Our scenarios are deterministic, that is, based on assuming known learning rates that do not account for unforeseeable 'random shocks' that historically introduce 'noise' into deployment and cost forecasts.

In our analysis, we use 'high' and 'low' scenarios to estimate the potential outcomes as set out in Section 2 above. These scenarios are based on varying key parameters, such as learning rates and costs, to understand potential futures. This method helps us quantify uncertainty to some extent – specifically, the uncertainty that stems from our partial knowledge of the real learning rates.

However, this approach mainly captures uncertainties due to uncertainties in the learning rate. It does not fully account for unpredictable events or 'random shocks' – unexpected occurrences that can significantly affect outcomes. Examples of such shocks could include sudden technological breakthroughs, economic crises or changes in policy that we didn't foresee.

[21] Kavlak, G., McNerney, J. and Trancik, J.E. (2018). Evaluating the causes of cost reduction on photovoltaic modules, *Energy Polocy*, Vol. 123, December 2018, pp. 700-710. https://doi.org/10.1016/j.enpol.2018.08.015

In mathematical terms, we fit a predictive line through historical data points to project future trends. While this line captures the general direction of the data, it doesn't perfectly pass through every point – there are deviations, or noise, around the line. This noise represents the random fluctuations or shocks in the past, suggesting that future projections should also consider similar variability, but for the purposes of this study we do not take into account this source of uncertainty.

For a fuller discussion of methods that deal with this uncertainty, please see Farmer & Lafond (2016),[22] Lafond et al (2018),[23] Way et al (2022).[24]

[22] Farmer, J. D., & Lafond, F. (2016). How predictable is technological progress? *Research Policy*, *45*(3), 647-665. https://doi.org/https://doi.org/10.1016/j.respol.2015.11.001

[23] Lafond, F., Bailey, A. G., Bakker, J. D., Rebois, D., Zadourian, R., McSharry, P., & Farmer, J. D. (2018). How well do experience curves predict technological progress? A method for making distributional forecasts. *Technological Forecasting and Social Change*, *128*, 104-117. https://doi.org/https://doi.org/10.1016/j.techfore.2017.11.001

[24] Way, R., Ives, M. C., Mealy, P., & Farmer, J. D. (2022). Empirically grounded technology forecasts and the energy transition. *Joule*, *6*(9), 2057-2082. https://doi.org/10.1016/j.joule.2022.08.009

Appendix 1: Key cost assumptions

Data in 2030	Cost environment		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; the high cost world reflects the upper end of market participant forecasts (e.g. JP Morgan).
Oil price	$64/bbl	$85/bbl	The fossil fuel prices used follow an assessment of existing estimates, e.g. DESNZ and IEA forecasts.
Gas price	$9/MBtu	$12/MBtu	See above.
Electricity price	$106/MWh	$119/MWh	Follows DESNZ 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 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 the main report). 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[1]	£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 and BNEF for the base year cost (GBP 110/MWh), learning rates from review studies.
Combustion engine car upfront cost	£28,500	£28,500	Similar to EVs with a bottom-up approach, but benchmarking different studies (e.g. UC Davis) for the costs of ICE-specific components like the engine, transmission, exhaust and engine control unit.

Air-to-water heat pump upfront cost[1]	£5,700	£7,600	Learning rate approach with base year costs coming from benchmarking eight different studies, normalising to a 7.4 kW size to be aligned with CCC. Learning rate range coming from, for example, UKERC.
Gas boiler upfront cost	£2,600	£2,600	Mainly from Element Energy and normalised to a 24 kW size. Costs include a regional installer, labour, controls, fittings and heat distribution system.
Offshore wind upfront cost[1]	£1,900/kW	£2,500/kW	Base year cost (including pre-development costs) is from DESNZ. Future cost range comes from the use of a learning rate approach. Learning rate range is from review (e.g. review) (10-14% today).
Solar PV upfront cost[1]	£300/kW	£570/kW	Base year cost from IRENA with pre-development costs from DESNZ. Future cost range comes from the use of a learning rate approach. Learning rate range is from review, e.g. review (20-30% today).
Natural gas upfront cost	£538/kW	£579/kW	Taken from CCGT H Class of DESNZ and kept constant over time.

1. Global deployment numbers for the learning rate calculations come from IEA NZE and STEPS scenarios.