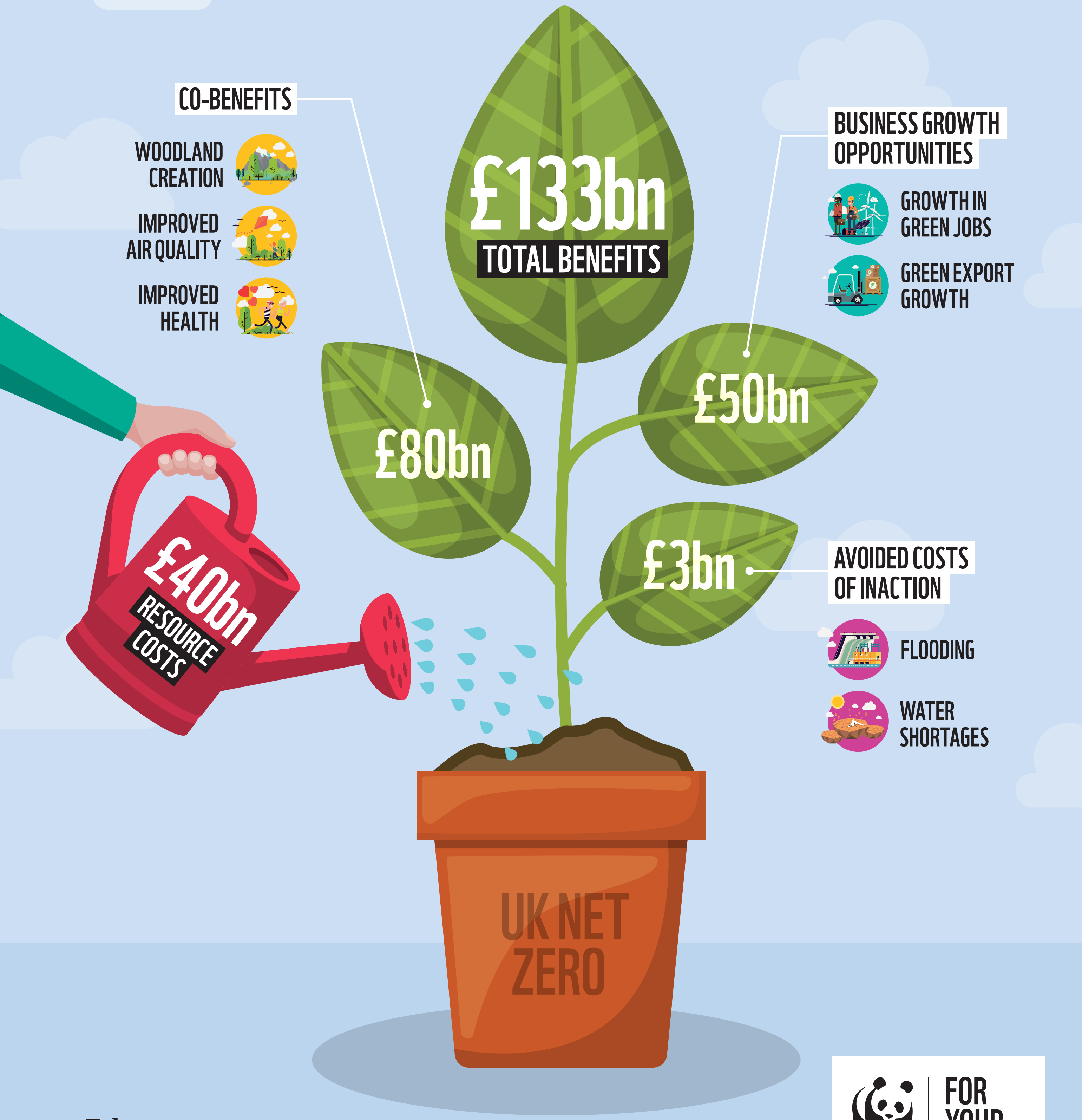
KEEPING US COMPETITIVE:

A UK INVESTMENT STRATEGY FOR NET ZERO



February 2020

Vivid Economics Report prepared for WWF UK

WWF FOR YOUR WORLD

This report was written for WWF UK by Vivid Economics. WWF UK will use the findings to shape their net-zero policy, building on a previous report by Vivid Economics commissioned by WWF - 'Keeping it Cool' -published in 2019.

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COMPANY PROFILE

Vivid Economics is a leading strategic economics consultancy with global reach. We strive to create lasting value for our clients, both in government and the private sector, and for society at large.

We are a premier consultant in the policy-commerce interface and resource- and environment-intensive sectors, where we advise on the most critical and complex policy and commercial questions facing clients around the world. The success we bring to our clients reflects a strong partnership culture, solid foundation of skills and analytical assets, and close cooperation with a large network of contacts across key organisations.

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WWF FOREWORD

BY ISABELLA O'DOWD

When the UN Climate Conference (COP26) is held in November, all eyes will be on the UK to step up and lead the world to address the climate and nature emergency. With such a key role hosting the most important UN climate conference since the Paris Agreement in 2015, we must continue to lead by example to ensure the summit is a success. Credibility will be key to the UK Government's position and their ability to bring other countries on board with increasing their ambition on their commitments to action.

The UK has seized the opportunity in adopting a legally binding net zero greenhouse gas emissions target by 2050 and has committed to leave the environment in a better state for the next generation. While this is a positive first step, the only way for this target to be credible – at home, and to other countries - is if the government brings forward the policies and financial commitments to ensure that it can be delivered.

Transitioning the UK to a net-zero emission economy will require substantive and assertive action from the UK public and private sectors. In order to match the scale of the challenge to achieve net-zero, significant investment is required, not least in the short term, regardless of the preferred net-zero date or pathway.

The forthcoming Comprehensive Spending Review this year is the perfect opportunity for the Government to show its spending commitment and credibility with regards to the net-zero target. Last year, WWF, along with other environmental organisations, published *'Government Investment for a Greener and Fairer Economy'*. The findings complement this report and highlight that, in order to put the UK on track for net-zero, the Government must commit to increased spending on climate and nature. WWF believes that we need to double investment for climate action and restoring nature, with Government spending and measures to leverage private investment to the equivalent of 2% GDP per year – in line with the advice of the UK's own advisers, the Committee on Climate Change. This would bring total spending on climate and nature to around £40 billion a year, which is an additional £25 billion on top of the £17 billion a year already spent.

Last year WWF commissioned Vivid Economics to produce *Keeping it Cool* which sets out two feasible pathways towards net-zero – including 2045 and 2050. This report builds on that analysis and looks at the scale of the investment required, and the co-benefits of these investments, before detailing the implications for how this transition is funded.

The report shows that the additional immediate spending is far outweighed by the co-benefits, the growth opportunities and, indeed, the costs of inaction. The net-zero transition could yield over £133 bn of annual benefits to the UK. This is the result of wider improvements to human health and the natural environment alongside unlocking substantial business opportunities for the UK. These benefits need to be considered alongside the upfront costs as they will have a quantifiable impact on the economy. Moreover, these co-benefits may also lead to direct savings for the exchequer on key spending priorities, such as the National Health Service or public infrastructure projects. One obvious example is in buildings: eliminating cold homes with energy efficiency upgrades would not only decrease emissions but could also improve the ability of UK homes to provide adequate heat and cooling, having the potential to save the NHS billions of pounds annually.

This report argues budgeting decisions supporting carbon emission reductions and removal should not be motivated by the traditional carbon externality rationale alone. Instead, there is a clear case for rationales traditionally used for funding industrial and innovation priorities, social housing, and public health, to help meet the investment needs arising from decarbonisation and nature restoration in the next decade.

The decisions we make this year, and in this decade, will have consequences for generations to come. Annual required investment will double if we delay ramping up investment in decarbonisation and nature to 2030. As such, successfully navigating the transition to a sustainable economy is just as much about protecting the livelihoods and wellbeing of future generations as it is about protecting those around today.

EXECUTIVE SUMMARY

UK ACTION IS NECESSARY TO RESPOND TO THE SCIENTIFIC EVIDENCE ON MAN-MADE GLOBAL WARMING

The evidence is now clear that achieving the UK net-zero target is necessary, feasible, and cost effective. The Committee on Climate Change's (CCC) *Net Zero* report highlights the necessity of UK action to respond to the scientific evidence on man-made global warming and provides an evidence base on the necessary technological and behavioural changes. Vivid Economics' 2018 *Keeping it Cool* report sets out two feasible pathways towards net-zero – including one earlier than 2050.

In 2020, HM Treasury's (HMT) Net Zero Review[1] will consider how the transition to net zero will be funded and assess options for where the costs will fall. The way which funds are raised and dispersed must support a net-zero pathway in a manner that maximises co-benefits, unlocks associated business opportunities, and ensures a Just Transition. By quantifying the co-benefits of emissions reductions and considering policy implications of these benefits, the report moves beyond considering emission reductions in the traditional economic frame – as a market failure (negative externality) which needs to be fixed.

This report argues budgeting decisions supporting carbon emission reductions should not be motivated by the traditional carbon externality rationale alone. Instead, there is a clear case for rationales traditionally used for funding industrial and innovation, social housing, and public health, to help meet the investment needs arising from decarbonisation in the next decade.

In preparation for the Treasury review, the contribution of this report is to:

1. Summarise the evidence on costs and benefits of net zero in the medium term (by 2050 at the latest).
2. Estimate the level of low-carbon investment required for a net-zero pathway in the short term (2020s).
3. Provide recommendations for raising revenue whilst achieving a Just Transition.

1 https://www.gov.uk/government/publications/net-zero-review-terms-of-reference

COSTS AND BENEFITS

The net-zero transition could yield over £90 bn of annual benefits to the UK. The net-zero transition can bring substantial net benefits to the UK, many of which are not directly captured in macro-economic modelling. Crucially, a policy approach which recognises the wider co-benefits is needed to ensure that these are indeed captured. This report synthesises estimates of 4 types of costs and benefits.

- *The avoided yearly costs of global inaction provide over £3 bn of benefits to the UK.* UK climate leadership, and (assumed) global action, must be deployed in parallel to avoid significant climate damages in the UK. Monetary estimates of key climate impacts on the UK, such as increased flooding and heat stress, are limited, but where monetised, exceed £3 bn. This is a significant underestimate of the total cost of inaction since it ignores the likely larger indirect impacts of climate change on the UK (disruption to global supply chains, potential global political instability, etc.). Rapid UK action is instrumental to avoid facing these costs.

- *Business opportunities that may be unlocked by a net zero transition exceed £50 bn per year.* A net zero transition, supported with targeted supply side (industrial strategy) policies, can unlock substantial business opportunities for the UK in, for example, exporting offshore wind goods and services. We set out bottom-up estimates of the Gross Value Added (GVA) and jobs associated with selected opportunities, which total over £50 bn. Although these opportunities are unlikely to all be additional (that is, the UK would capture some of the opportunity without a net-zero transition), they do represent some of the potential indirect benefits of investment in the net zero transition.

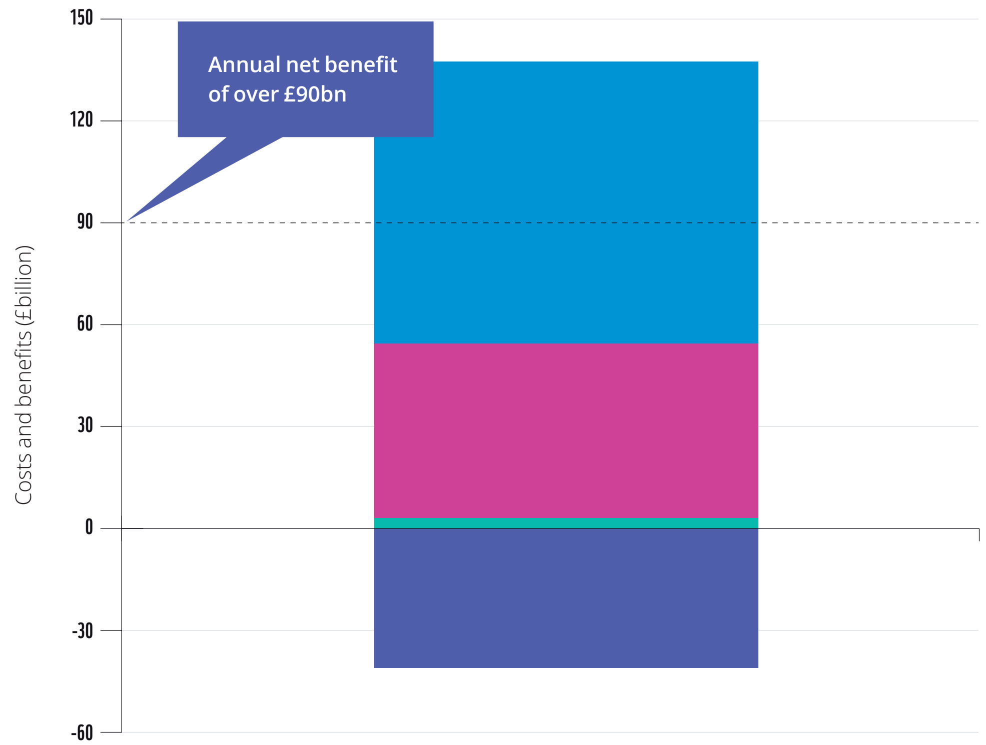
- *Over £80 bn of annual co-benefits can be captured.* The co-benefits of decarbonisation are large. These include health benefits from more active travel, and more and higher quality green spaces. The most valuable co-benefit, however, is expected to be improved air quality, which has large health benefits. Note, while some co-benefits will be captured regardless of how net zero is achieve (e.g. use of internal-combustion engine (ICE) vehicles will need to be virtually eliminated), careful policy design will be necessary to maximise the co-benefits of e.g. additional quality green spaces.

- *Yearly resource costs are expected to total around £40 bn.* There are costs to the economy of achieving a net zero economy compared to business-as-usual (BAU). For example, heating a home using a heat pump is often more expensive than a gas boiler (taken into account both higher upfront costs and lower running costs). Across the economy, the Committee on Climate Change estimates resource costs are relatively small compared to gross domestic product (GDP) (1-2%). Indeed, the benefits set out above significantly outweigh the costs.

+£80bn

OF ANNUAL CO-BENEFITS CAN BE CAPTURED

FIGURE 1:
ANNUAL NET COSTS AND BENEFITS OF ACHIEVING NET ZERO (2050)



Note: The estimates of annual costs and benefits are based on bottom-up literature of costs and benefits. They are hence incomplete due to the scope of previous studies. For example, estimates of the business opportunities only consider business opportunities associated directly with selected low-carbon technologies.
Source: Vivid Economics

SHORT-TERM (2020s) INVESTMENT REQUIREMENTS

To achieve net zero, we have identified additional annual investment needs (combined public and private) of approximtely £30 bn during the 2020s (£300 bn over the decade).[2] As a point of comparison, this is roughly equivalent to 15% of the Department for Work and Pensions' (DWP) annual spend, or 1% of UK GDP. Many of these investments will yield a positive private return in the long run and provide wider social co-benefits. Nevertheless, the investment levels required in the 2020s are unlikely to be met without significant government support. For key sectors, this involves rapid and large increases in investment, and hence a need for urgent policy intervention. For example, the investment levels required in building retrofits imply a 30% increase in total spending on home repairs and upgrades, and an approximate 10 fold increase in installation rates of e.g. loft insulation. The levels of public support to achieve this are likely to be similar to the succesful support to scale up offshore wind in the UK.

2 The required investment levels are uncertain and investment levels provided in this report are intended to be illustrative to inform the discussion of the relative scale of investment. Where there is available evidence, we refer to more detailed analyses on sector-specific investment requirements. A lack of complete data on existing decarbonisation investments means that it is not possible to fully account for existing decarbonisation spending investment levels and hence determine the exact degree to which the identified investment needs are additional.

To incentivise the required investment, substantial policy change is needed in the early 2020s. A combination of carbon taxes (through e.g. an emissions trading scheme (ETS)), sector-specific carbon prices and levies, government subsidies, standards and regulation will be necessary. An economy-wide carbon price provides an underlying incentive and can help ensure decarbonisation efforts are efficiently shared across the economy. However, carbon prices are likely to be too low and unpredictable (from an investor point of view) to support the required levels of investment across most sectors. Additional policies will be critical to unlock the investment levels required.

RECOMMENDATIONS FOR RAISING FUNDS AND ACHIEVING A JUST TRANSITION

We identify 5 areas of policy where increases in action are urgent to incentivise the level of investment required.

Strengthening of traditional decarbonisation policy:

1. *Economy-wide carbon prices (tax) need to increase* to over £40/tCO2 in all sectors in the early 2020s to provide a baseline incentive. A UK ETS with a reserve price of over £30/tCO2 could help support this and provide some necessary certainty around minimum prices.
2. *Sector-specific taxes, levies, and regulation will continue to play a central role and need to be strengthened.* Sector-specific decarbonisation policy is essential to tackle sector-specific market barriers, can be targeted to avoid regressive impacts, and can be pragmatically adjusted to ensure a required rate of ramp up of decarbonisation options. Across the economy, these will continue to play a central role, and a higher economy-wide carbon price should be seen as a complement to rather than a substitute for sector-specific policy
3. *Substantial increases in public subsidy are required in key sectors,* which needs to be recognised in departmental budget allocation. Particularly in the buildings sector, public support needs are expected to be high. Relevant departmental budgets to e.g. the Ministry for Housing, Communities and Local Government should be allocated in recognition of the high share of public support required.

Broadening of decarbonisation policy:

4. *Large health and economic co-benefits merit additional public funding* and require a coordinated approach across government departments. Innovation and industrial strategy support should be at the heart of decarbonisation efforts, and the low carbon business opportunities available across the economy justify public investment to help maximise UK competitiveness in growing green markets. Similarly, air quality improvements are a highly valuable benefit of decarbonisation, and public support should be proportional to this public benefit.
5. *Existing government funding should be increasingly conditional on decarbonisation action.* For example, annual grants provided to public transport operators can be made conditional on investment in low-carbon transport options.

£20bn

ESTIMATED ANNUAL CARBON TAX REVENUES BY 2030

Treasury can recycle carbon tax revenue, and use innovative public investment mechanisms to facilitate the net zero transition.

- *Carbon taxes[3] can raise a substantial portion of annual investment needs.* The London School of Economics (LSE) estimates carbon tax revenues could be around £20 bn by 2030. This is of a similar scale to the necessary investment levels during the 2020s, and can provide budgetary room for government to subsidise decarbonisation where this provides wider public benefits (e.g. innovation), or distributional concerns justify transfers (e.g. in buildings or agriculture). To avoid regressive distributional impacts, taxes within each sector should be redesigned to ensure decarbonisation incentives are provided without increasing the overall tax burden on vulnerable groups. For example, increases in tax on gas use for households can be offset by decreases in tax on electricity.
- *A publicly owned (green) infrastructure investment company* can provide a key vehicle for the required investment by providing contractual certainty around e.g. the future carbon price, to crowd in private investment. This could be achieved by expanding the remit of the low-carbon contracts company (LCCC) to provide a range of contracts to support business models across greenhouse gas removal (GGR), hydrogen production, low-carbon electricity production, buildings retrofits etc. As is the case for current contracts for difference (CfDs) in the power sector, this company could raise funds through levies, but could also be directly supported through general taxation.

A Just Transition is a necessary part of a successful pathway to net zero and will require broader policy beyond progressive carbon taxes.

- *Fairly taxing emissions and subsidising decarbonisation* actions is a key aspect of a Just Transition. Carbon taxes are inherently regressive, and lower income households should be compensated to avoid this through, for example, additional support for energy efficiency retrofits. More broadly, sector specific carbon taxes could be means tested, or the tax burden for low-income households could be reduced elsewhere.
- *Minimise the impacts of job losses* in sunset industries such as oil and gas, or engine manufacturing. Localised impacts of losing a major employer can be significant, and locally or regionally targeted retraining programmes will need to be provided so workers can transition into other sectors. More broadly, government will need to ensure that retraining and certification of e.g. gas boiler installers towards heat pumps installers is readily available.
- *Fairly distribute the benefits of a Just Transition.* This includes ensuring low-carbon job opportunities can be accessed by those negatively impacted by the transition but will also require, for example, ensuring available decarbonisation subsidies are taken up by low income households in at least equal proportion to middle- and high-income households. Lastly, a Just Transition will need to fairly distribute the benefits and costs of the net zero transition across generations.

3 See section 3.1.1 for a definition of carbon pricing and taxes used in this report

INTRODUCTION

Achieving net-zero requires several decades of transformative change across the economy, and will require a large increase in decarbonisation action during the 2020s. Current rates of decarbonisation will not suffice to meet net-zero. The CCC's 2019 climate progress report shows the UK is not on track to meet its 4th and 5th carbon budgets (set with a target of 80% reduction by 2050 in mind). Out of the 24 indicators of progress the CCC monitors, the UK is currently only on track to meet 7. Hence, achieving net-zero requires a step change in action.

A step change in action will require a step change in investment; HM Treasury's Net-zero Review[4] will provide a key contribution to how the necessary decarbonisation investments can be raised. While there is now an evidence base on the feasbility of a net-zero target, substantial work is still required to determine how best to fund the transition to net-zero. Crucially, detailed thinking is required around the way in which funds are raised and dispersed in order to support a net-zero pathway in a manner that maximises co-benefits, unlocks associated business opportunties, and ensures a just transition.

This report sets out the scale of the investment levels required, and the (co)-benefits of these investments, before detailing the implications for how this transition is funded. We argue that both the scale of the investment required in the 2020s, and the size of the co-benefits of the transition, justify substantial changes to both the scale of government funding, and its motivation. Achieving the net-zero transition require transformative change across all economic sectors, and departmental budgets need to reflect that all departments will need to take action. The report is set out as follows:

PART 1:

In the first part of the report, we provide evidence on the costs and benefits of a net-zero transition.

- Section 1.1 briefly describes the high-level channels through which a net-zero transition will create societal costs and benefits, and how these can be compared.
- Section 1.2 sets out evidence on the long-term costs of decarbonisation. The section considers the cost of installing and operating the necessary technology to fully decarbonise.
- Section 1.3 quantifies the costs of inaction. UK inaction would contribute to global climate change, which will negatively impact the UK. Furthermore, one of the key benefits to the UK of a net-zero transition is its likely impact as a climate leader on increasing global mitigation efforts. This section briefly considers the negative impacts on climate change of BAU.
- Section 1.4 considers selected co-benefits of a net-zero transition (beyond avoided climate damages). We consider both economic business opportuntiies and wider co-benefits such as reduced air pollution.

4 https://www.gov.uk/government/publications/net-zero-review-terms-of-reference

PART 2:

This part of the report focusses on the investment needs that arise from a net-zero pathway in the 2020s.

PART 3:

The final part of the report considers policy needs to achieve a just transition towards net-zero.

- Section 3.1 highlights policy considerations for a just transition given the scale of required investment.
- Section 3.2 focusses on particularly vulnerable groups, and highlights key distributional considerations.

OUT OF THE 24 INDICATORS OF PROGRESS THE CCC MONITORS, THE UK IS CURRENTLY ONLY ON TRACK TO MEET 7. HENCE, ACHIEVING NET-ZERO REQUIRES A STEP CHANGE IN ACTION

1. THE COSTS AND BENEFITS OF A NET-ZERO TRANSITION

The following provides a summary of existing evidence on the net costs and benefits to society of achieving net-zero to inform subsequent discussion of the likely investment needs (both public and private) during the 2020s, and implications for policy. As highlighted by the CCC, there are many reasons for transitioning towards net-zero, many of which go beyond a simple assessment of the potential damages caused by climate change to the UK. This synthesis is intended to highlight the relative importance of co-benefits of net-zero to the UK. As set out in more detail in Section 3, their magnitude has implications for how the transition is funded, and merits consideration within HMT's net-zero review.

1.1 COMPARING THE COSTS AND BENEFITS OF A NET-ZERO TRANSITION

This study compares bottom-up estimates of costs and benefits, focussing on benefits typically not considered in economic modelling. There are many channels through which climate change and a net-zero transition will impact the UK economy. Macro-economic modelling of the net-zero transition focusses on the impacts of the required capital expenditure and the differences in operating costs of certain technologies; or put differently, the impact of the resource costs of a net-zero transition on the economy. With this focus, models conclude the net-zero transition is likely to have a relatively small economic impact (see Box 1). However, macro-economic models have difficulty capturing co-benefits of net-zero, or the potential for the transition (combined with strong policy) to drive UK green competitiveness and business. This report focusses on these co-benefits to fill the analytical gap and considers implications for decarbonisation policy.

The (co)-benefits to the UK of a net-zero transition are likely to significantly outweigh the costs.[5] As summarised in Figure 2, the annual resource costs of net-zero (as estimated by the CCC) are significantly lower than the benefits summarised in this report. The benefits of air quality improvements alone could outweigh the resource cost of net-zero (note, the estimate presented in this report is not based on full meteorological and dispersion modelling). Furthermore, our estimate of some of the business opportunities unlocked by net-zero are of a similar order as the resource costs.

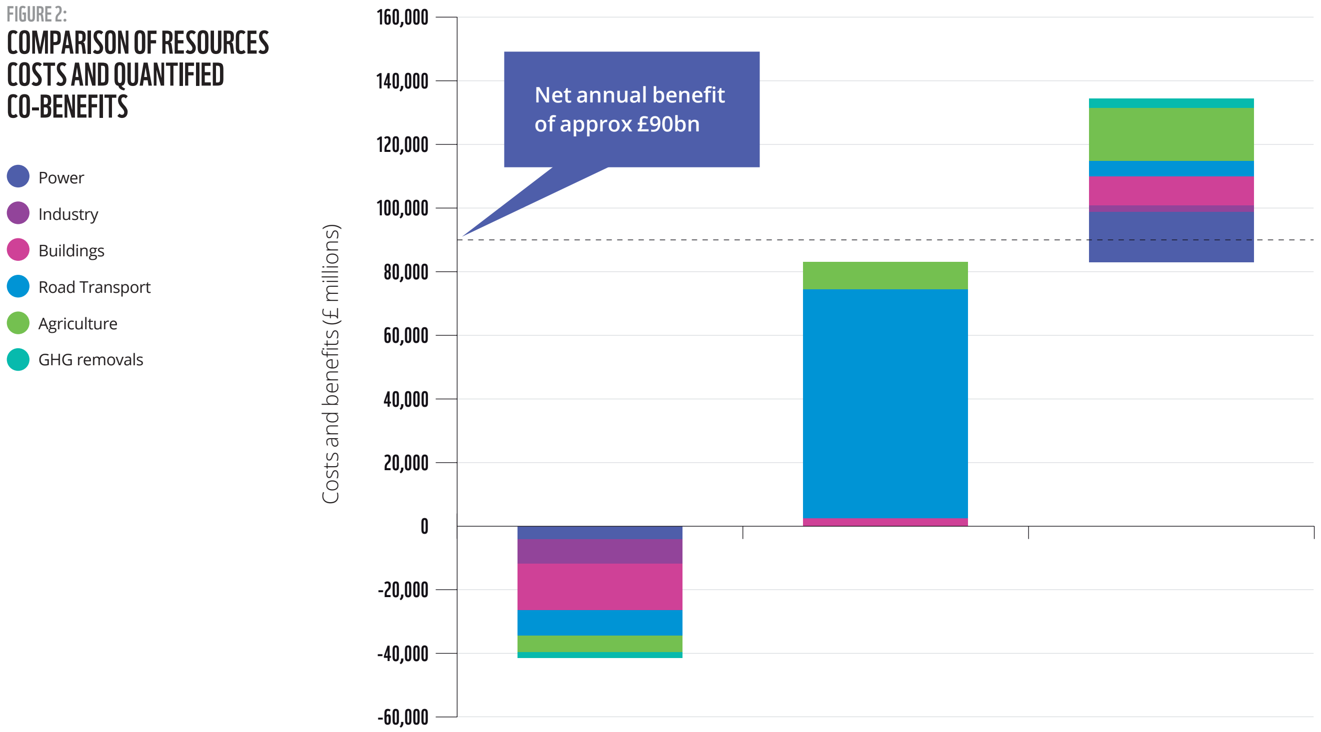
5 As noted above, this study has not attempted to macro-economically model general equilibrium impacts. However, given previous attempts all project small net GDP impacts (Box1), the conclusion that co-benefits of net-zero are likely to outweigh the costs is likely to be valid even if wider economic impacts are considered.

The presented costs and benefits of net-zero are, by their nature, uncertain and incomplete. Estimates should be interpreted as indicative and are intended to provide a sense of scale of investment required for a net zero pathway.

- *Uncertainties:* Both the costs and benefits of net-zero are uncertain, and (amongst other things) will depend on wider economic conditions, implementation strategies, climate change impacts, and technological development.
  - *Policy design* will affect the efficiency with which decarbonisation measures are implemented, and the effectiveness of industrial strategy. However, many policies are yet to be designed and hence create uncertainty around future costs and benefits.
  - *Innovation* is likely to drive costs down for many technologies. Resource cost estimates include estimates of future cost reductions, but innovation by its nature involves new discovery and hence cannot be fully anticipated or predicted. Historically, estimates by e.g. the International Energy Agency (IEA) and CCC have underestimated future cost reductions and overestimated resource cost. Hence, resource costs may be lower than currently expected.
  - *Macro-economic conditions* will affect the UK's ability to capture low-carbon business opportunities, and the degree to which these are additional. If the UK economy is near full employment, low-carbon opportunities partly displace economic activity in other sectors, since capital and labour resource are limited. In this case the net benefit green business opportunities will be smaller than our estimate. Conversely, during a recession, well-targeted public investment in green business is likely to have further indirect economic benefits beyond the GVA benefits presented in this report. Box 1 summarises insights from macro-economic modelling of the net-zero transition and its net-economic impact.
- *Incomplete estimates:* The net-zero transition will impact almost all aspects of the economy directly or indirectly. Comprehensively anticipating and quantifying all the channels of (indirect) impact is beyond the scope of this study. Instead, this study focusses on co-benefits with an established evidence base. Our intention is to provide high-level estimates of the co-benefits, highlighting their magnitude compared to the costs of net-zero, and argue for the need to use net-zero co-benefits to inform government spending. While the estimates provided in this report provide a fair reflection of the current evidence base, there is a need for significant detailed work to estimate co-benefits more accurately and completely. The sum of the co-benefits presented in this study should hence *not* be seen as a complete estimate of the total co-benefits from net-zero.

FIGURE 2:

COMPARISON OF RESOURCES COSTS AND QUANTIFIED CO-BENEFITS



Note: Estimates of resource costs are based on CCC evidence summarised in Section 1.1.1. Estimates of the co-benefits and gross value added from business opportunities are set out in Sections 1.3.1 and 1.3.2.

Source: Vivid Economics

BOX 1:

MODELLING THE NET ECONOMIC IMPACT OF A NET-ZERO TRANSITION

Different economic modelling approaches suggest different conclusions on the net economic impact of a net-zero transition. Conceptually, there are 2 broad approaches which each have different strengths and weaknesses:

- *Computational general equilibrium (CGE) approaches* typically assume markets operate efficiently and economic resources (labour, capital, etc.) are fully utilised. Hence, the resources required to achieve net-zero have to be drawn from other productive uses. Because of the opportunity cost this implies, CGE models tend to conclude the net-zero transition is a net cost to the economy.
- *Crucially, macro-econometric simulation approaches* do not assume the economy always operates efficiently. This allows for the investment associated with the net-zero transition to have multiplier effects. These positive effects can be large enough to offset the initial costs of the investment and hence econometric approaches can conclude the net-zero transition has a net positive impact (Cambridge Econometrics, 2014).

Despite their different approaches, both macro-economic modelling efforts suggest the overall impact on GDP is likely to be modest. To illustrate, CGE modelling of the economic impact of decarbonisation on the EU predicts a net impact of -0.5% of GDP and econometric modelling predicts a 2% increase in GDP compared to a baseline. To put this into perspective, both modelling approaches predict economic growth between 2020-2050 of around 50-60% (although this does not consider the potential damages of climate change).

1.2 COSTS OF ACHIEVING NET-ZERO

Despite being a narrow measure, **it is informative to consider resource costs as an initial estimate of the net cost/benefit of a decarbonisation measure.** Resource costs capture the net cost difference (both capital and operation costs) of a low-carbon vs. a high-carbon technology delivering broadly the same service. This is an incomplete measure since, for example, the resource costs of electric vehicles (EVs) take into account higher upfront costs, and lower fuel costs, but do not consider the benefits of lower air pollution. Resource costs are typically lower than the investment required because they are partly offset by savings in operational costs. For example, the upfront cost of energy efficiency retrofits for an average house are around £12,000 (CCC, 2019a). However, a large proportion of this initial cost is offset by savings in energy bills. Hence, the overall resource cost of the measure is significantly lower.

When the economy reaches net-zero, the annual resource cost is expected to be 1-2% of GDP, with the bulk of costs (0.4%) associated with decarbonising buildings (CCC, 2019c).(CCC, 2019c). This economy-wide estimate captures the additional capital and operational expenditure associated with low carbon technologies compared to supplying the same goods and services with BAU technologies. For example, the additional lifetime costs of heat pumps over heating using traditional gas boilers are a key component of the resource costs in the buildings sector. Across the economy, the net cost is expected to be low as a share of GDP, a key reason for transitioning to net-zero.

While resource costs are significant, in a net-zero economy they are likely to be outweighed by the co-benefits. At 1-2% of GDP, resource costs of net-zero are £40-80 bn per year compared to a BAU scenario. That is, the costs of delivering the same energy system services will be £40-£80 bn higher compared to a high-carbon BAU scenario. However, the business opportunities, and co-benefits such as air quality are expected to be more valuable than the resource costs.

1.3 THE COSTS OF INACTION

1.3.1 GLOBAL IMPACTS OF INACTION

£551bn

POTENTIAL GLOBAL ECONOMIC DAMAGES FROM BUSINESS AS USUAL

The direct monetary impacts of continued UK emissions are around £0.5 trillion compared to a net-zero pathway. The UK emitted 503 MtCO2e in 2017; 1.3% of global emissions. In a BAU[6] emissions trajectory the UK would emit over 7,000 Megatons (Mt) of additional CO2e by 2050 compared to a net-zero pathway. Assuming a long-run average social cost of carbon between £62 and £77/tCO2 (Pindyck, 2016), this equates to an additional £441 billion to £551 billion in global economic damages.

However, the key cost of UK inaction is likely to be global inaction. UK domestic climate policy could impact global efforts through two channels. Firstly, UK progress to Net-zero sends a clear signal to all countries that the UK is committed to making meaningful contributions to curb global warming. As a large historical emitter and developed country, the UK achieving net-zero aligns with the principle of 'common but differentiated responsibilities'. Clear UK progress towards net-zero could facilitate greater cooperation and more ambitious commitments from the international community. Conversely, fragmented and divided efforts make limiting global warming more costly, and less feasible (Blanford et al., 2014). The second channel through which the UK's domestic efforts could impact mitigation outside of its borders is through the development and transfer of low-carbon technologies, leveraging for example its expertise in fuel cells or CCS.

6 BAU in this report assumes that annual CO2e emissions remain at 2017 levels, 503 Mt, until 2050.

5-20%

OF GLOBAL GDP THE COST TO THE GLOBAL ECONOMY IF ALL COUNTRIES REMAIN ON THEIR CURRENT EMISSIONS TRAJECTORIES

The costs to the global economy if all countries remain on their current emissions trajectories could reach 5 to 20% of global GDP, and even an increase from 1.5 to 2 °C warming is likely to have a 2.3-3.5% impact on global GDP (IPCC, 2018b; Stern, 2007). Recent evidence shows that even incremental warming will have significant impact. Moving from 1.5 to 2 °C warming would cause an additional $15-38.5 trillion annual damages in 2100, equivalent to 2.3-3.5 % of global GDP (IPCC, 2018a). Climate damages from BAU emissions would vastly exceed this, reaching up to 20% of GDP.[7] Without full global cooperation, beginning with ambitious reductions among developed nations such as the UK, damages are more likely to reach these high levels (Blanford et al., 2014). Furthermore, although useful, estimates of climate change damages do not include the non-negligible risk of catastrophe, nor do they speak to the value of natural life and human experience that will be affected in the future (see Box 2).

BOX 2:

DIFFICULTIES IN QUANTIFYING CLIMATE DAMAGES

- **Estimates from integrated assessment models (IAMs) are uncertain and do not capture the risk of potential catastrophic outcomes.** The climate system is complex, and how it will respond to further emissions cannot be fully modelled. For example, there is some evidence that points to the existence of a 'tipping point' in the climate system, which cannot be captured in a continuous model (King, Schrag, Dadi, Ye, & Ghosh, 2015). Similarly, IAMs typically assume society effectively adapts to climate change where possible, which may not be the case, increasing the climate damages.

- **Some of the current effects of global warming, such as premature fatalities from extreme weather events or biodiversity loss, are not easily expressed in economic terms.** For example, preserving biodiversity is valuable for more reasons than simply the provision of food and water, but this value is not captured in GDP. The preservation of human life is similarly valuable beyond an individual's contribution to the economy.

- **Future climate impacts will be even harder to represent in economic accounts.** Permanent loss of biodiversity will indirectly affect markets for food, fresh water, and wood products. However, the effects of environmental degradation such as decreased biodiversity will also manifest outside of these markets, such as through the deterioration of air and water quality, as well as the loss of cultural services like recreation, ecotourism, and aesthetic value. With species extinction at rates 100 to 1,000 times higher than background rates, further population growth, land use change, and increasing resource extraction will accelerate this trend unless drastic action is taken (Mace et al., 2018).

7 Based on the Stern Review, which assumes that annual emissions increase to 84 Gt CO2e by 2050, a 125% increase from current levels.

- **Difficulties expressing environmental impacts in economic terms affects policy appraisal.** The conventional approach to project (or policy) appraisal in the UK, cost-benefit analysis (CBA), inadvertently disadvantages those for which the environment and its corresponding services are at stake. Specifically, this method requires the tallying of all negative and positive changes that come as a direct result of the project, and evaluating the relative merit of the project in terms of its benefit-to-cost ratio i.e. its return to society. Even when there are adverse consequences for the environment that are well known, difficulties expressing these changes in monetary terms can result in their omission. Moreover, it is unlikely that the valuation evidence will develop to the degree necessary to have robust, generalisable values for ecosystem goods and services by 2030—at least not to the degree needed to make their inclusion in CBA commonplace.

1.3.2 DOMESTIC IMPACTS OF INACTION

Many of the domestic impacts of climate change are difficult to fully anticipate and quantify; however, key risks include flooding, heat extremes, and water shortages.

£900m

POTENTIAL ANNUAL COST OF FLOOD RISK MANAGEMENT BY 2040

- *Flooding* - By 2050, the number of people and total value of physical assets vulnerable to flooding risk will increase substantially as warming occurs (CCC, 2016).
- *Heat extremes* - Increased temperature anomalies and heatwaves will increase the number of premature deaths and decrease productivity. For example, the 2003 heatwave is estimated to have reduced UK output by £400-500 million (CCC, 2016).
- *Water shortages* - A changing climate will likely result in water shortages affecting public water supply, agricultural production, and industrial cooling requirements. Shortages could mean 25% of water extraction is ecologically damaging in the UK (CCC, 2016).

Beyond risks that lend themselves to quantification, climate change will have many highly uncertain but severe impacts on the UK. The most recent climate change risk assessment (CCRA) highlights potentially severe climate impacts that increase exponentially with the degree of warming. For example, in a 4 degree scenario there will not be an 'economic case' to invest in the level of coastal defences that would be required to prevent permanent abandonment of some coastal communities (Sayers et al., 2015). Furthermore, there are likely to be numerous knock-on impacts on the wider economy. For example, a 4 degree scenario would place an additional 1.5 million households at significant risk of flooding.[8] Preliminary estimates suggest this could reduce the value of affected properties by £1.1 bn (Sayers et al., 2015). This figure could increase significantly if flood risk becomes a more salient consideration for buyers.

Inaction on the mitigation of climate change will also increase the costs of required action for climate adaptation. The investment needs for adaptation to climate change are significant. For example, the Environment Agency's analysis of flood and coastal risk management suggests that the optimal level of investment into flood risk management is £850 to £900 million a year by the 2040s (Environment Agency, 2014). Moreover, adaptation to changing weather patterns, such as through increased use of air conditioning, will require additional investment in the electricity system (Auffhammer, 2018). The required levels of adaptation investment will increase substantially if global warming exceeds 1.5˚C. Current nationally determined contributions (NDCs) are expected to limit global warming to 2.9˚C (Climate Action Tracker, 2019). It is therefore prudent to plan for scenarios significantly beyond 2˚C warming, yet current levels of adaptation in the UK are insufficient for a 2 ˚C scenario[9] and there are no thoroughly evidenced estimates of adaptation costs for higher levels of warming.

BOX 3:

FLOODING IN UK COASTAL COMMUNITIES

- Given the costs involved, the economic case for investing in community scale defences in low-lying flood plains in England is limited (Environment Agency, 2014). It would likely be cheaper to abandon thousands of properties in coastal communities such as Great Yarmouth, which are already experiencing the effects of coastal erosion, than to construct the required coastal defences. Even if this were not the case, building defences would likely have consequences for the cultural significance of these landscapes and the quality of life for those living behind them. This is particularly relevant for regions with coastal populations like Kent, Essex, Norfolk, and Suffolk.

- Coastal flooding in regions such as Kent and South London will see an 80% to 100% increase in annual economic damages by 2050 under a BAU emissions pathway. The baseline exposure to flooding in the region is £33 million in annual damages and 86,000 properties at risk (Sayers et al., 2015). Under a BAU scenario, this is set to increase by £27 million - £33 million and put an additional 69,000 to 86,000 properties at risk of flooding in 2050—further increasing to £100 million and 270 thousand properties at risk by 2080 (Sayers et al., 2015).

£2.5bn

ANNUAL COST TO THE ECONOMY FROM HIGHER TEMPERATURES IN THE UK

The direct climate impacts of key risks to the UK are likely to exceed multiple billions of pounds per year. One approach to estimating the total climate damages from inaction is to use Integrated Assessment Models (IAMs) at the country level, which simulate how changes in the earth's physical systems, i.e. climate, affect its social and economic systems. Using this localised, top-down method suggests higher temperatures in the UK will have an annualized cost of approximately £2.5 billion from 2019 to 2050. However, taking stock of bottom-up estimates of climate impacts on the UK suggests this is a significant underestimate. Bottom-up monetary estimates of the damages from flooding and higher temperatures alone suggest annual damages closer to £3 bn until 2050. However, even this figure is misleading since it excludes impacts such as water shortages and loss of natural capital, where less work has been conducted to express the impact in monetary terms.

The direct economic impacts of climate change on the UK will be significant, and indirect impacts could be more severe. As a net-importing country which relies on global growth for its own economic prosperity (Bank of England, 2019), the UK will be affected by climate impacts occurring elsewhere. Increased frequency of extreme weather events such as droughts could impact prices of imported agricultural commodities and food security (CCC, 2016). Similarly, disruptions of global supply chains may send ripple effects throughout other sectors such as manufacturing, aviation, and shipping.

8 A 1 in 75 chance of being flooded in a given year (Sayers et al., 2015).

9 For example, if current levels of investment are maintained, at best 30-50% of expected annual damages from flooding would be prevented, implying roughly £400 m in additional flooding damages by 2050 (Sayers et al., 2015).

Climate Change Impact	UK Baseline (current climate)	UK 2050 on BAU emissions pathway	Notes
Flooding and Coastal Erosion	• £1.2 bn in EAD	• £2 bn in EAD	Includes damages from coastal, fluvial, and surface water flooding.
Increased frequency of hot days and heatwaves	• 2,000 annual heat-related deaths	• Over 5,000 annual heat-related deaths • £200-£250 m in annual productivity losses in labour-intensive sectors	Estimates assume current levels of adaptation. Productivity losses based on previous manufacturing losses during UK heat waves, which are expected to occur every other year by 2050 (House of Commons Environmental Audit Committee, 2018).
Water shortages and increased water stress	• 2,000 megalitre surplus of water for the UK • Water deficits in some regions	• Daily water deficits between 800 to 3,000 megalitres for the UK • Damage from water extraction up to 25% of the time in some catchments	Water shortages will be exacerbated by deployment of low-carbon technologies such as carbon capture and storage (CCS) that require freshwater for cooling.
Loss of natural capital and associated ecosystem goods and services	• 38% of agricultural land in England and Wales classified as 'best and most versatile'	• 62% decrease of agricultural land in England and Wales classified as 'best and most versatile'	Best and most versatile land refers to land grades 1,2 and 3a, i.e. the most productive arable land in the UK. The nonmarket value of species and habitat loss not included.

TABLE 1:
HEADLINE CLIMATE IMPACTS AND ECONOMIC/ENVIRONMENTAL COSTS

Note: Estimates of resource costs are based on CCC evidence summarised in Section 1.1.1. Estimates of the co-benefits and gross value added from business opportunities are set out in Sections 1.3.1 and 1.3.2.

Source: Vivid Economics

1.4 BENEFITS AND OPPORTUNITIES ASSOCIATED WITH A NET-ZERO TRANSITION

Large-scale emission reductions in the UK provide wider benefits beyond climate change mitigation. We consider two broad impacts:

1. *Co-benefits of the net-zero transition,* which the Intergovernmental Panel on Climate Change (IPCC) defines as "the positive effects that a policy or measure aimed at one objective might have on other objectives." (IPCC, 2014). This includes, for example, the reduction in air pollution and its associated health benefits as a consequence of transitioning a locale to zero-emission vehicles. Co-benefits are often not directly valued in private markets, however their societal value can be large, as set out in Section 4.1.
2. *The UK business opportunities* that can be unlocked by a net-zero transition. These benefits, discussed in Section 4.2, focus on how rapid decarbonisation can help the UK develop a comparative advantage in low-carbon sectors. This is necessarily a partial lens, but highlights the potential scale of some of the indirect economic benefits that could be unlocked.

1.4.1 CO-BENEFITS OF THE NET-ZERO TRANSITION

Many co-benefits from reaching net-zero by 2050 are the result of wider improvements to human health and the natural environment. For example, a modal shift away from motor vehicles towards green public transport, cycling, and walking will reduce traffic congestion, road accidents, and air pollution, and increase physical activity. Other notable co-benefits include healthier diets, higher visitation of greenspace such as woodlands, and improved indoor living conditions. These changes in turn will have a quantifiable impact on the economy by boosting worker productivity as well as increasing the longevity of the population, which can be expressed in monetary terms (see Box 4). Moreover, these co-benefits may lead to direct savings for the exchequer on key spending priorities, such as the National Health Service (NHS) or public infrastructure projects (as discussed in Section 3.1.3). For example, eliminating cold homes with energy efficiency upgrades would not only decrease emissions but could also save the NHS billions of pounds annually (Jennings et al., 2019b).

BOX 4:
CO-BENEFIT OF AIR QUALITY IMPROVEMENTS

Improvements to health from better air quality will create annual benefits equivalent to 1.07% of GDP in 2050. We used the UK's air pollution inventory and the Department for Food and Rural Affairs' (DEFRA) (2019) air quality damage cost guidance to quantify the annual damages avoided from achieving a net-zero target by 2050. These benefits amount to a present value of £338 billion from 2019 to 2050, analogous to an annualised benefit of £18 billion in avoided damages over this time period. Expressed as a percentage of GDP, the co-benefit of 1.07% of GDP in 2050 is quite similar to those previously estimated by the CCC when it considered the benefits of reducing both air and noise pollution (CCC, 2013).

1.07%

OF GDP (EQUIVALENT) CREATED IN ANNUAL BENEFITS BY 2050 THROUGH IMPROVEMENTS TO HEALTH FROM BETTER AIR QUALITY

Overall, the co-benefits of a net-zero transition alone could fully recoup the resource costs of rapid decarbonisation in the UK. Although only high-level estimates are possible (and more precise estimates would require significantly more modelling), the total economic co-benefits from improvements to health and the environment surpass the resource costs of net-zero by 2050, currently priced at 1-2% of GDP. Table 2 below summarises further potential co-benefits of the net-zero transition, with quantification of the potential benefits included where possible. In conjunction, these estimates are indicative that net benefits are possible for the UK if the transition leads to a wider, systemic change in behaviours and lifestyles among the general population.

Co-benefit	Benefits	Annual co-benefit in 2030	Annual co-benefit in 2050	Notes	Key studies
Air quality	Improved physical health, reduced financial burden on NHS, protection of buildings, decreased ecosystem acidification.	• £14 billion	• £52 billion (1.3% of GDP)	Estimate excludes damages accruing outside of the UK, as well as ozone damage.	(World Health Organization, 2016), (CCC, 2013), (CCC, 2019c)(CCC, 2019c)
Noise	Reduced financial burden on NHS, increased productivity and educational outcomes.	• £0.5 billion		Achieved through insulation and glazing in buildings.	(CCC, 2013)
Diet	Improved physical health, reduced financial burden on NHS	• £8 billion	• £8 billion (0.2% of GDP)	Based on a 50% reduction of red meat consumption.	(CCC, 2013), (CCC, 2019c) (CCC, 2019c)
Active Transport	Improved physical health, reduced financial burden on NHS	• £2 billion	• £20 billion (0.5% of GDP)	Modal shift towards walking, running, cycling, and public transport.	(CCC, 2013), (CCC, 2019c) (CCC, 2019c)
Congestion and Road Accidents	Time savings, increased productivity, reduced financial burden on NHS	• £8.2 billion		Includes NHS costs, lost income, and nonmarket value of a prevented fatality.	(CCC, 2013), (CCC, 2019c) (CCC, 2019c)
Improved indoor living conditions	Energy poverty alleviation, improved physical health, reduced absenteeism for adults and school children, reduced burden on NHS	• Up to £2.5 billion	• Up to £2.5 billion	Based on costs of cold homes-related illnesses; does not include costs of sick days or benefits of reduced indoor pollutants.	(CCC, 2019e; Jennings et al., 2019; Nicol, Roys, Garrett, & Building Research Establishment, 2010)
Woodland creation	Air filtration, recreation value, improved physical health, flood management	• £10 million	• £0.5 billion (< 0.01% of GDP)	Estimate is based on ongoing research at Vivid Economics; does not include value of carbon sequestration to avoid double counting.	In-house calculation

TABLE 2:
MONETISABLE CO-BENEFITS OF A NET-ZERO TRANSITION
Source: Vivid Economics

1.4.2 BUSINESS OPPORTUNITIES OF THE NET-ZERO TRANSITION

Sustainable growth in the UK is feasible if supported by structural changes across the economy. The UK has already demonstrated a capacity for low-carbon growth. By decreasing GHG inventory emissions by 43% since 1990 while growing its economy by 70 % over the same period, the UK has disproven the conventional depiction of climate action and economic growth as conflicting objectives (Jennings et al., 2019). Indeed, many improvements in efficiency are likely to provide net economic benefits by improving productivity through energy or material efficiency. As set out in Box 1, economic modelling suggests achieving net zero is fully compatible with continued growth, and could provide a net economic benefit compared to BAU. This will partly depend on whether the UK, supported by policy, is able to capture new low carbon business opportunities.

Low-carbon sectors are more productive and innovative than their traditional counterparts and can help support higher economic growth. In general, continued UK growth will depend on its ability to increase productivity; in other words, its ability, to direct resources to high-growth, high-productivity sectors. Investment in materials and energy efficiency, as well as in low-carbon sectors specifically can help support this. Low-carbon sectors tend to be more productive than their carbon-intensive equivalents (Doda, 2016). Furthermore, innovation in low-carbon technologies results in more knowledge spillovers than innovation in carbon-intensive technologies (Dechezleprêtre et al., 2016). This suggests that sectors central to the net-zero transition can be important drivers of future economic growth.

Given existing UK competitiveness in key low-carbon technologies, investment into these areas could unlock sizeable business opportunities (Vivid Economics, 2019b). Vivid Economics' analysis for BEIS identified large business opportunities associated directly with low-carbon technologies. As shown in Figure 3, an effective UK green industrial strategy could help unlock:

- *Green exports (turnover) could grow from around £5 billion today to £80 billion per annum by 2050.* An early net-zero transition in the UK helps to support the UK building competitive supply chains in, for example, CCS.
- *GVA from the unlocked business opportunities in both the domestic and international market would exceed £40 billion,* over 1% of UK GDP and comparable in scale to 2050 annual resource costs of net-zero (set out in Section 1.1).
- Growth in these sectors is expected to support around *200,000 export-oriented jobs* by 2050, with a further *270,000 jobs supported by domestic low-carbon opportunities.*

+£40bn

GVA ANNUALLY FROM THE UNLOCKED BUSINESS OPPORTUNITIES

Seizing green business opportunities will help ensure continued competitiveness of existing industries (such as automotive) and build out new industries (such as hydrogen or smart technologies).

- *Protecting existing jobs*: The single largest business opportunity is associated with low-carbon transport, particularly EVs. The UK's automotive sector is a major UK export industry and supports over 180,000 jobs. Coherent government support ensuring UK EV demand and supply side capabilities, will be important to help ensure the UK automotive industry transitions to EV manufacturing, and continues to support large numbers of jobs and GVA (Vivid Economics, 2018a). As discussed in Section 3.2.1, ensuring the UK captures these business opportunities can also play a key role in the Just Transition, by maintaining employment opportunities requiring similar skills and (likely to be) located in similar regions.

- *Creating new jobs:* Low-carbon opportunities such as carbon capture utilisation and storage (CCUS), hydrogen production, and smart systems also provide new sizeable (export) opportunities (Vivid Economics, 2019b). Early investment in these industries could help the UK develop its existing expertise in these currently small global markets into large future market shares in, what are expected to be, sizeable global export markets.

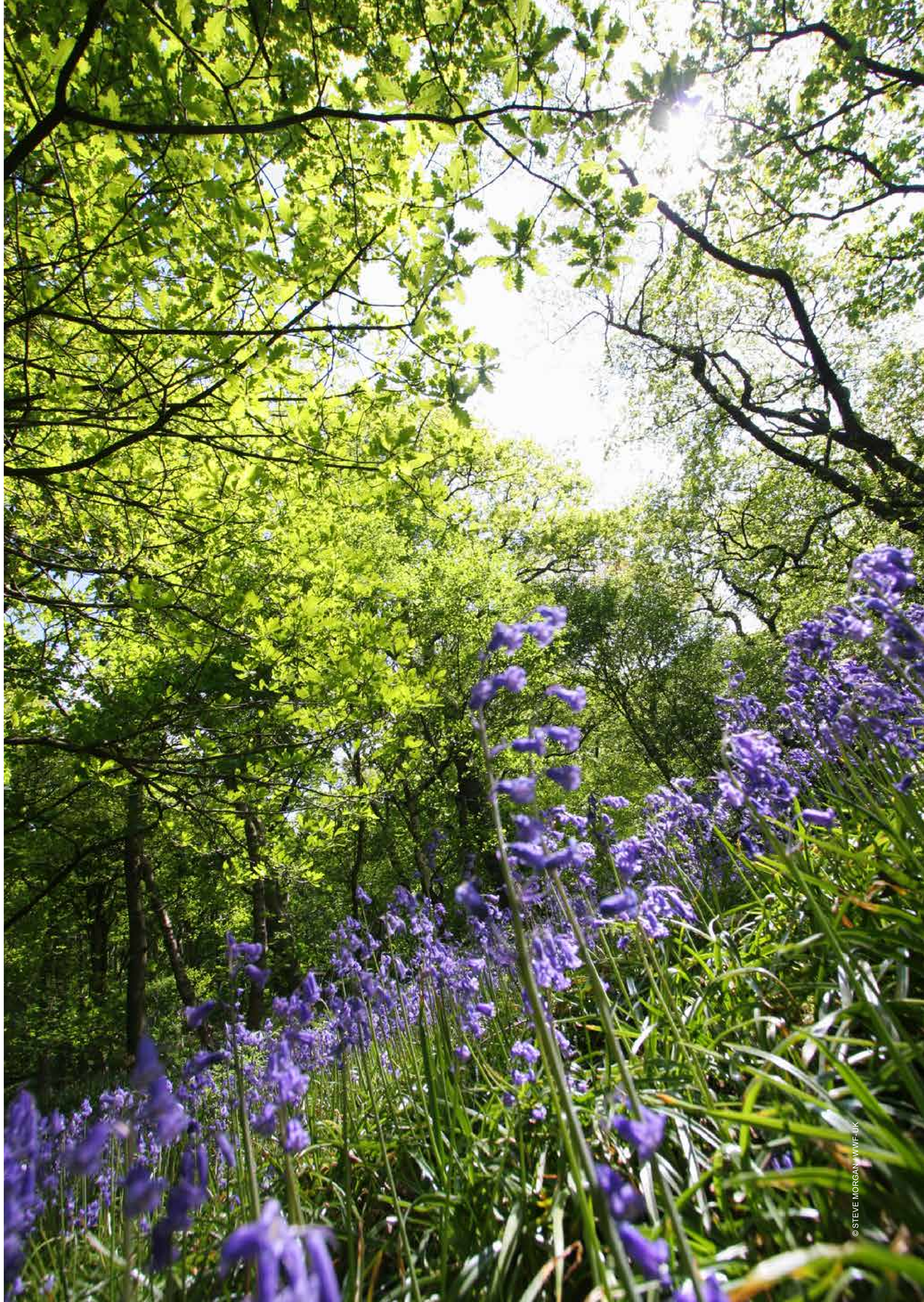
A coordinated policy, aligning incentives from decarbonisation policy and industrial strategy, will be necessary for the UK to capture available business opportunities. To capture the identified business opportunities, the UK will need to combine both supply and demand side policies. For example, capturing business opportunities associated with hydrogen production will require both domestic UK demand to support economies of scale in the UK production of low carbon hydrogen technologies (e.g. electrolysers) and strong innovation support to encourage knowledge spillovers and supply chain development. Sections 3.1.2 and 3.1.3, provides more detail on how a mission-oriented approach can support cross-department coordination to support both demand and supply of new energy technologies and increased levels of funding.

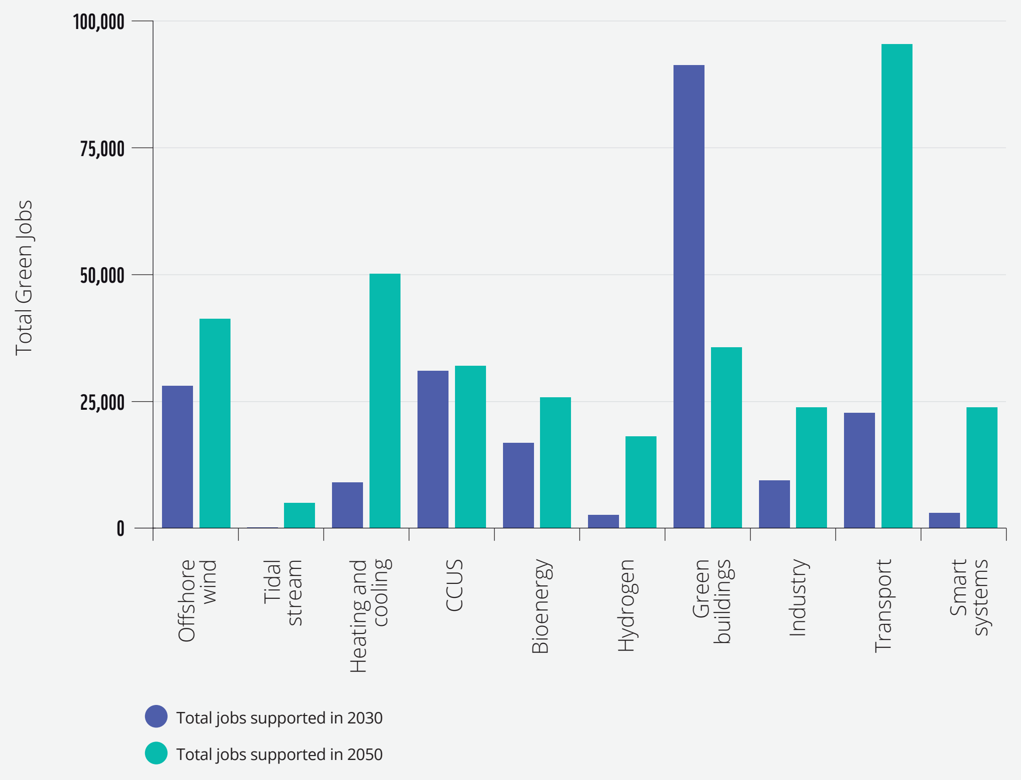
BOX 5:

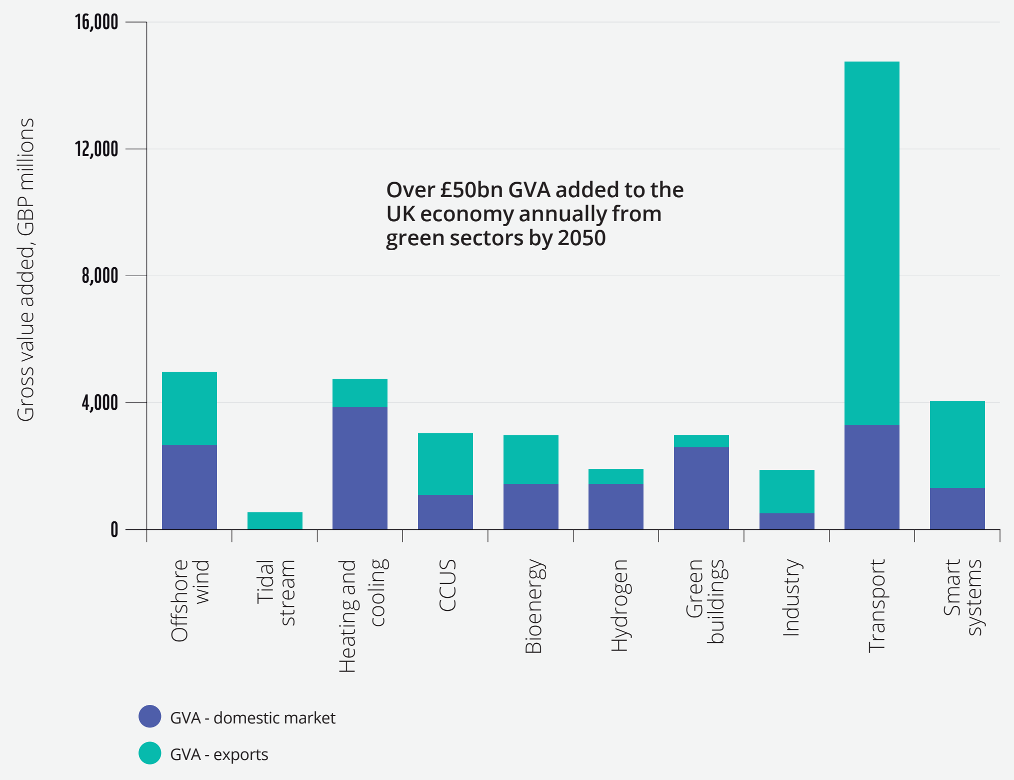
ESTIMATING GREEN BUSINESS OPPORTUNITIES

- The presented business opportunities represent an assessment of the plausible GVA directly associated with the provision of selected green goods and services.
- The business opportunities are estimated based on:
  - An estimate of the future market size of green technologies (e.g. offshore wind) based on deployment scenarios from the IEA (global) and Energy System Catapult (UK) and technology costs.
  - A judgement of plausible future UK market shares, based on current market shares and an optimistic assessment of the future market share the UK could capture.
  - Further detail on the business opportunities summarised here is available in the Energy Innovation Needs Assessments overview report and technology-specific sub-theme reports.[10]

10 vailable from: https://www.gov.uk/government/publications/energy-innovation-needs-assessments







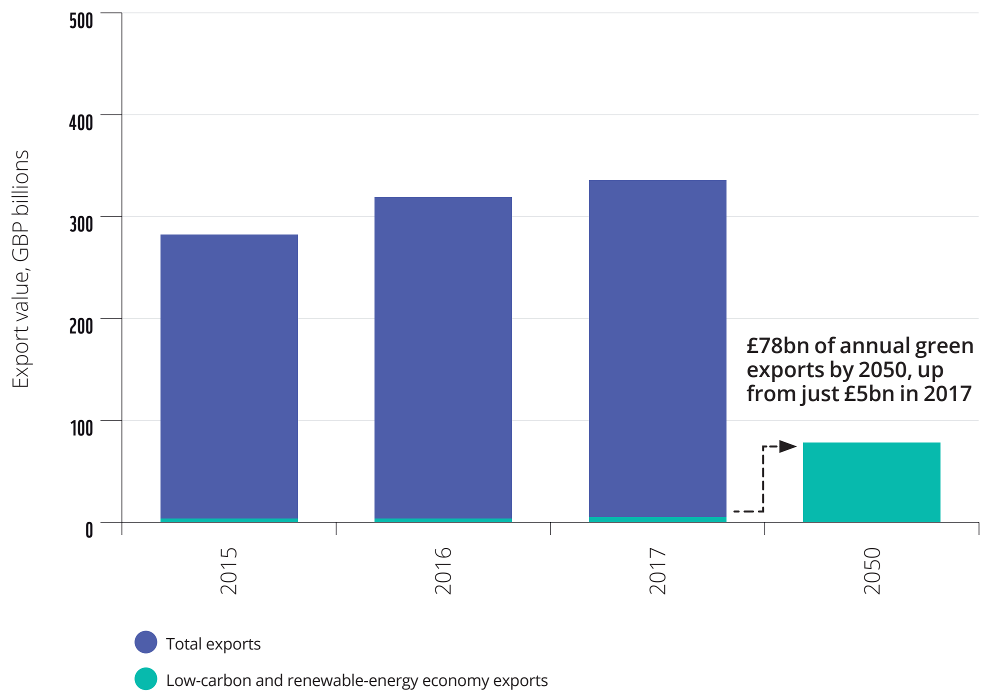


FIGURE 3:

POTENTIAL JOBS SUPPORTED IN SELECTED LOW-CARBON INDUSTRIES

Note: *The methodology for the quantitative analysis to support the above estimates is set out in detail in the Energy Innovation Needs Assessments (Vivid Economics, 2019b)*

Source: *Vivid Economics*

2. SHORT TERM INVESTMENT NEEDS FOR A NET-ZERO PATHWAY

2.1 INVESTMENTS REQUIRED TO ACHIEVE NET-ZERO

A net-zero pathway will require significant investment in the short term, regardless of the preferred net-zero date or pathway. In the long term, there is some optionality in how the UK achieves net-zero. For example, significant reductions in UK meat consumption would free up space in the UK's carbon budget, which could be used to reduce deployment of negative emissions options such as bioenergy with CCS (BECCS).[11] Nevertheless, achieving net-zero in the UK before or at 2050 requires virtually all mature mitigation technologies to be deployed, and all immature technologies to be developed, rapidly during the 2020s.

Precise investment requirements are uncertain and will depend on policy choices; the estimated investment needs in this report are based on high-level required rates of deployment and are intended to be indicative rather than prescriptive. This report provides indicative estimates across sectors, based on existing evidence. The investment needs set out below are in line with Vivid Economics' previous work for WWF on net zero pathways (Vivid Economics, 2018c). The aim is to highlight the scale of investment required, implied by the need for deployment of essential decarbonisation technologies in the 2020s. This approach implies several key factors determining total investment needs are not considered:

- *This report does not provide investment needs directly associated with areas where there are clear policy choices* that need to be made to reach net-zero. To illustrate, we provide investment estimates associated with charging infrastructure for EVs – which will be necessary with high certainty – but do not provide investment requirements for a large-scale expansion of UK rail infrastructure. Mode switching from ICE vehicles to rail can play an important role in achieving net-zero; however, there are several possible investments to help decarbonise transport, and decisions around e.g. highspeed rail are driven by many wider considerations beyond decarbonisation.
- *Furthermore, this report does not quantify how investments should be split between the public and private sectors.* Per sector, we provide qualitative indications of the likely split between public and private investment. However, significant further work is required to formulate detailed decarbonisation policy per sector, assess the need for and value for money of potential public investment, and provide associated detailed costings. As a point of comparison, a recent joint report by 8 NGOs includes policy judgements this report does not make, with associated recommended public spending levels (CAFOD et al., 2019a).

Additional annual low-carbon investment (public and private) needs during the 2020s exceed £30 bn. A net-zero pathway requires significant additional investment, beyond a BAU scenario, particularly for the sectors where large-scale deployment of low-carbon technologies is required during the 2020s. As set out in Box 6, assessing additionality is non-trivial. Nevertheless, it is clear the largest investment requirements are expected in power (approx. £10 bn per year), buildings (over £10 bn per year), and transport (over £5 bn per year). The power sector needs to deploy low-carbon technologies rapidly now, to provide a supply of low-carbon electricity to other sectors later. In transport and buildings, limits to feasible build rates and stock turnover imply the need for large-scale action now, to ensure a realistic pathway to net-zero in 2050.

11 See Vivid Economics (2018c) for more detail on the potential emission savings from a reduction in meat consumption.

BOX 6:
ESTIMATING THE ADDITIONALITY OF LOW-CARBON INVESTMENT NEEDS

- **Assessing additionality requires a definition of baseline investment levels**. Defining this baseline is not trivial. For example, a renewables investment baseline could plausibly be defined as current investment levels, investment levels based on the announced intention to hold biannual CfD auctions to deliver 2GW per year, or high levels assuming optimistic cost decreases.
- **Low-carbon investment levels are only partially tracked in the UK.** Disentangling BAU and current low-carbon investment levels, and their dependence on policy, is challenging. Forecasting future evolution even more so.
- **This report makes simple judgements on additionality per sector.** These are set out clearly in the discussion of each sector. To provide an alternative point of comparison, Figure 8 in the Appendix highlights how estimated investment needs compare to more aggregated sectoral investment data from the Office for National Statistics (ONS).

The investment levels required are a large share of the current sectoral investment levels, particularly for buildings. To provide a sense of the degree of change that is required within a sector, we compare our estimates of low-carbon investment needs to existing sectoral capital expenditure. As shown in the Appendix, high-level estimates of the investment levels required for decarbonisation during the 2020s are a large proportion of current investment (capital expenditure) across sectors, particularly in buildings, GHG removal, agriculture and power. This suggests that unlocking the necessary additional investment will require substantial policy change, discussed in more detail in Section 3.

POWER

The power sector will require large-scale investment in low-carbon generation technologies, a more decentralised transmission and distribution system, and storage capacity to address intermittency.[12] The annualised system cost[13] of the power system is estimated to increase by approximately £10 bn between 2020 and 2030, primarily driven by large capital investment needs (Vivid Economics & Imperial College, 2019). Recent work to estimate the costs associated with rapid power sector decarbonisation, compatible with large-scale EV and heat pump deployment, highlights 3 key investment needs totalling nearly £14 bn, set out below. As a rough approximation, we estimate around £10 bn of the £14 bn of annual investment needs set out below to be additional, based on a comparison of current and required annual power sector investment levels.

- *Approximately 5 GW of renewable capacity needs to be added yearly, requiring roughly £10 bn in capital expenditure.* The rate of deployment required is a significant increase from current commitments (2 GW per year committed to in the offshore wind sector deal) and would be cheapest to deliver through a combination of offshore wind, onshore wind, and solar. The required investment levels are around £10 bn per year.[14] Given recent price reductions, much of this investment could be delivered on a 'merchant' basis (or with only minimal net government subsidy through contracts for difference (CfDs)). Note, any public support to help deliver this additional capacity would be in addition to already contracted public subsidy through CfDs.
- *Average annual investment out to 2035 for the networks are around £3 bn, roughly double current levels* (Vivid Economics & UCL, 2019). Transmission and distribution investment must expand to support a larger and more distributed power system. The price control framework is likely to continue to be the basis for supporting the required investment (and passing costs on to consumers), although changes may be necessary to support the expected step change in investment required.
- *Storage capacity increases require an approximate annual investment of £0.8 bn per year.*[15] Storage capacity will need to increase by around 2 GW per year during the 2020s, starting from low current installation rates. As with low-carbon generation, investment could primarily be delivered by the market, but would require significant change in how flexibility is rewarded.

£0.8bn

ANNUAL INVESTMENT REQUIRED IN STORAGE CAPACITY

INDUSTRY

Ongoing energy efficiency investment, the development of CCS infrastructure, and innovation support for hydrogen, are the primary investment needs in the 2020s. Annual investment needs in the 2020s are relatively modest compared to other sectors. This is partly because the more costly investments in industry, such as those required to switch to hydrogen fuel, will primarily occur after 2030, given that these technologies are at the early stages of development. Nevertheless significant investment is required in three categories: energy efficiency, CCS, and fuel switching (electrification, biofuels and hydrogen). Without significant policy change to encourage these investments, and further direct government support (beyond e.g. the approx. £60 mn per year from the Industry Energy Transformation Fund[16]) these investments are unlikely to occur, and hence they can be considered as additional.

- *The capital cost of energy efficiency improvements beyond normal equipment replacement cycles are modest, and can often be recouped through savings on fuel costs.* This investment should be provided by the private sector since natural incentives for energy savings are in place. However, the public sector still has a role to play to help (particularly small) businesess make these investments, through subsidy or loans. Furthermore, energy efficiency regulation and standards can play an important role in incentivising private investment.
- *The investment costs during the 2020s for industrial carbon capture are substantial, with around £300 mn per year required on capex in industrial capture units.* A net-zero pathway includes approximate 3 $MtCO_2$ of industrial CO_2 captured, which would require approximately £3 bn of capital investment in retrofits to achieve, or £300 mn a year during the 2020s (Wood, 2018). CCS business models are currently under development by BEIS, but regardless of the precise business model design, will likely need to involve substantial public support, particularly for trade-exposed industry.[17]

12 The specific investment needs heavily depend on the future evolution of the sector. For example, greater investment in storage could negate some of the need for investment in transmission and distribution networks.

13 This is defined as the total cost of maintaining, operating, and investing in the power system. It includes fuel costs, maintenance costs, annualised investment costs, etc. For a full explanation of how this is calculated, see Appendix A here: https://www.e3g.org/docs/Whole-system_cost_of_variable_renewables_in_future_GB_electricity_system.pdf

14 Based on an average cost of £2,000/kW for installed renewable capacity in line with cost estimates available from (IRENA, 2019).

15 Assuming an average cost of £400/kW for battery storage (BNEF, 2019a).

16 This fund includes over £300 mn of public funding spread over 5 years. For more information, see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/838309/ietf-finalising-design-consultation.pdf

17 BEIS recently closed a consultation on CCS business models. More detail is available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/819648/ccus-business-models-consultation.pdf

- *Around £100 mn per year of further investment is required for CO2 transmission and storage infrastructure.* Capital investment required for an initial infrastructure backbone will vary depending on the locations chosen. However, based on cost estimates for transmission infrastructure in Scotland, requiring around £400m in total investment, annual investment required for the UK is likely to be less than £100mn in the 2020s (Vivid Economics, 2019a). As with the business models for capture plants, how CO2 transmission and storage is funded is currently being considered by government, but will likely include a substantial public element.
- *Fuel switching costs, particularly for an initial clean hydrogen project, require substantial investment.* The 2020s will primarily be used to demonstrate a first-of-its-kind, large-scale, hydrogen project – including hydrogen production and commercial use for industrial heat. The large-scale investments associated with a wider roll-out are primarily required in the 2030s and 2040s. Nevertheless, several £100 mn pounds will likely be required throughout the 2020s to support commercial-scale demonstration[18], analogous to an annualised investment requirements of less than £100 mn each year, a large share of which will likely be in the form of public grants.

1-4%

INCREASE IN THE COST OF CONSTRUCTING NEW RESIDENTIAL BUILDINGS TO LOW-CARBON

BUILDINGS

Decarbonising new and existing building stocks will require large upfront investment, particularly to retrofit existing buildings. This report does not attempt to identify the optimal strategy to decarbonise the UK's building stock, and its associated investment. Significant policy choices will be required in this sector, on both the overall strategy for building decarbonisation, the relative roles of the private and public sectors, and the relative burden across incomes levels and generations. Nevertheless, it is clear that compared to the current trends, the cost-effective path to decarbonising buildings incudes a switch to building net-zero (or very low-carbon) buildings as soon as possible, and significantly increasing the pace of retrofits of existing building stocks (both commercial and residential). The following sets out indicative investment levels associated with deployment rates compatible with net-zero.

- *Constructing new residential buildings to be low-carbon increases build costs by £1,000-7,000, 1-4% of building costs* (CCC, 2019e). Ensuring new buildings are (nearly) net-zero is cost-effective from 2021 if carbon prices are taken into account (Currie & Brown and AECOM, 2019). A plausible route to delivering the required investment is through tightened building standards, which distribute the costs across landowners, builders, and buyers. The CCC recommends such standards are implemented from 2025 at the latest.
- *Annual investment costs to decarbonise existing residential buildings during the 2020s will likely exceed £12 bn, and are the single largest investment need.* The average energy efficiency retrofit package for existing buildings requires around £12,000 of upfront investment, with a further £10,000 required to install low-carbon heating (CCC, 2019e).[19] The costs will be partly offset by reduced energy bills over time; however, the upfront cost is large. Government can use standards to incentivise some decarbonisation of existing buildings, particularly by wealthy households. However, given the large upfront cost, substantial government subsidy is likely to be required to incentivise deployement, and avoid regressive impacts on households less able to pay.
    - *Energy efficiency retrofit deployment rates need to increase rapidly.* 24 million energy efficiency packages need to be delivered in 20 years (CCC, 2019a). Although retrofits in the next 10 years do not necessarily need to bring homes to near net-zero standards, significant retrofits are still required to bring energy efficiency of buildings up to at least energy performance certificate (EPC) band C. The required installation rates are similar to peak rates under previous regulated schemes in the UK, but significantly exceed current deployment under the Energy Company Obligation (ECO). For example, loft insulation rates will need to increase approximately tenfold, and solid wall insulation deployment rates 4-5fold (CCC, 2019a). A conservative estimate suggests over £10 bn of annual investment is necessary to achieve energy efficiency deployment rates of the order required.
    - *Off-gas[20] low-carbon heat alone will require around £2 bn of annual investment.* Low-carbon heating installation can cost effectively focus on the off-gas building segment during the 2020s (CCC, 2019c). Average annual installation rates would need to be 200,000 (compared to 20,000 heat pumps per year currently), which corresponds to an approximate annual investment of £2 bn.

ROAD TRANSPORT

Rapid cost reductions are likely to enable significant increases in sales; however, current sales of low-carbon vehicles are behind target. For both light- and heavy-duty vehicles (LDVs and HDVs), the total cost of ownership of low-carbon vehicles is expected to fall below that of ICE equivalents (BNEF, 2019b). For LDVs this is expected to occur during the 2020s, whereas for HDVs it is likely to occur after 2030 (for most use cases). Consequently, most of the investment in decarbonisation in the next 10 years is focussed on the LDV fleet. The CCC recommends a full ICE phase-out by 2030-2035 at the latest, and highlights the benefits of a phase-out by 2030, as also set out in our recent report for WWF (Vivid Economics, 2018a). Furthermore, low-emission alternatives should also reach substantial sales shared for HDVs by 2030 (50% of busses, 45% for small rigid HDVs and 10% for large articulated HDVs) and to ensure a realistic pathway towards net-zero.

- *EV sales need to increase for LDVs which will require continued public investment in the short term.* 2.5% of light duty vehicle sales were electric in 2018, below the 3.4% target set by the CCC to meet the current carbon budget (CCC, 2019d). EV sales penetration will need to increase significantly and reach 100% well before the current 2035 phase out date. To ensure the EV market (including the aftermarket) scales up sufficiently quickly in the UK for a 2030 ICE sales phase-out, sales penetration will need to increase substantially year on year during the 2020s. This suggests that despite cost decreases, grants will need to remain available in the short term, and only be phased out

18 This estimate is highly indicative, based on existing grant sizes for sizeable hydrogen demonstration projects and the likely need to support several sites across the UK. A list of current hydrogen projects across Europe is available from: https://hydrogeneurope.eu/index.php/projects

19 This includes a "medium" energy efficiency package, the most common package by 2050 in a net-zero scenario. The low-carbon heating costs includes all costs associated with retrofitting a house which was heated using a gas boiler.

20 Buildings not currently connected to the gas grid.

as EV showroom costs approach parity with ICEs.[21] Given the uncertainty around relative EV and ICE costs, we have not quantified the additional investment required, but given around 3 million vehicles are sold annually in the UK, and EV/ICE price differences are currently several thousand pounds, additional investment needs will be several billion in the early 2020s.

- *Charging and refuelling infrastructure will require over £1 bn of investment per year during the 2020s* (Vivid Economics, 2018b) (CCC, 2019c). Most of this will be private charging stations, for example at the home or workplace, and is additional to current investment levels. In the short term this cost could be supported by existing grant schemes to help incentivise EV take-up; however, as EVs reach cost parity public support could be removed. A fast roll out of rapid public chargers will likely require government support, although the annual investment need is modest.
- *HDV (excluding public transport) investment is primarily focussed on preparing for rapid deployment beyond 2030 and in the order of several £100 million per year by the end of the 2020s.* This includes investment in initial procurement of low-emission HDVs and associated charging and fuelling stations, and given negligable current investment levels is considered fully additional (Ricardo Energy and Environment, 2019).
- *Investment in low-carbon public busses will require around £0.5 bn annually.* To achieve at least 50% of annual bus sales being low-carbon by 2030, sales will need to ramp up significantly. Given their high utilisation, low-carbon busses will likely reach cost parity with ICE busess early in the decade (Mckinsey, 2017). Most of this investment hence falls within natural replacement of England's 34,000-strong bus fleet[22]. To encourage this, government can make its substantial contribution to bus operators (£2 bn out of total revenue of £5.5 billion) conditional on procurement of low-carbon busses.[23]

£1bn

OF INVESTMENT PER YEAR REQUIRED FOR CHARGING AND REFUELLING INFRASTRUCTURE

AGRICULTURE, LAND USE CHANGE, AND NATURE-BASED GREENHOUSE GAS REMOVAL (GGR)

From a purely climate mitigation point of view, annual investment required in agriculture and nature-based solutions is at least £1.2 bn. UK-wide funding for afforesation (the primary nature-based GGR) is currently below £100 mn per annum, and hence the vast majority of investment need for nature absed solutions is additional. Furthermore, this estimate only includes investment needs for nature based measures within the CCC's further ambition net-zero scenario (30,000 ha/a afforestation).[24] More ambitious rates can be considered, and other nature-based solutions (providing wider ecosystem services) are not included in this estimate. Cumulatively, it will cost around £39 bn[25] from now until 2050 to implement low-carbon farming practices and restore or create new carbon sinks in the UK. Ongoing work at Vivid calculates that this process will cost roughly £1.2 bn in 2030, increasing to £2.1 bn by 2050.[26] As with most net-zero investments, the societal benefits of this process will surpass the annual investment required by about 2040, bringing economic benefits of £4 bn a year by 2050.

£4bn

A YEAR OF ECONOMIC BENEFITS BY 2050

- *Increased carbon sequestration from new woodland planting will require £520m annual investment by 2030, ramping up to £1.1bn in 2050.* This assumes that by 2030 planting rates for new coniferous and broadleaved woodland will reach over 30 kilohectares (kha) a year to reach sequestration rates of 12.5 Mt of CO_2 per year in 2050. Although planting rates remain constant from 2030 to 2050, annual costs increase as the cumulative hectares of trees increase, and thus the resources needed for maintenance grow.[27] Note, higher planting rates on the order of 50 kha/year are plausible and would require annual investment levels to increase to £0.9 bn and £1.7 bn by 2030 and 2050, respectively.
- *Average annual peatland restoration costs are likely around £65 mn per year from now to 2050.* Rather than rapidly ramping up over time, the most cost-effective delivery of peatland restoration is likely a relatively steady rate of restoration year on year, implying similar costs in the 2020s as in 2050. Most of this spending will likely need to be delivered by government.

Decarbonising the agricultural and land use sector will require new economic incentives for UK farmers to introduce low-carbon agricultural practices, such as silvoarable agroforestry. The environmental land management schemes (ELMS) can play a key role providing here required incentives. It is worth noting that there are significant synergies between land use investment to reduce emissions, and investment to improve other forms of natural capital. The estimates presented here are narrowly focussed on decarbonisation. Estimates of investment needs to improve natural capital more broadly are provided in the a recent joint NGO report on *Government investment for a greener and fairer economy* (CAFOD et al., 2019a).

ENGINEERED AND OTHER SPECULATIVE GGR

GGR costs are relatively modest for the next decade, as the focus is on demonstration rather than large-scale deployment. Many GGR techniques, such as enhanced weathering, are currently immature. UK-based pilots are required, although preferably at significant scale; investment levels for these trials are of a different order (several £10s of millions) compared to investment for widespread deployment. There are, however, several exceptions where investment in deployment is required during the next decade. In particular, investment in a first-of-a-kind BECCS plant could exceed £1 bn. Given the potential scale of BECCS required, a first-of-a-kind plant by 2030 is on the cost-effective pathway. In total, this could require over £1 bn of investment (Wood, 2018) and hence around £100 million of average annual spending. There are established risks around the sustainability of biomass supply to large-scale BECCS and it is possible to achieve net zero with significantly less BECCS than suggested by the CCC (Vivid Economics, 2018c). Early independent investment is needed to ensure proof of concept and viability from both carbon and sustainability perspectives – and which should be considered priority to open up investment in a plant at scale.

21 Showroom costs, rather than total cost of ownership costs, are the primary price factor affecting decisions.

22 The average age of England's busses is approximately 8 years. This suggests the majority of England's busses will be replaced by 2030.

23 Public support for bus operators and annual revenues are provided by the Department for Transport (DfT), available from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/852652/annual-bus-statistics-2019.pdf

24 Lower than the potentially 40,000 ha/a proposed in our Keeping it Cool report, and 50,000 ha/a of afforestation included in the CCC's speculative scenario.

25 These estimates include public and private investment. They are presented as gross costs. Costs are £39.2 bn from 2019 to 2050, and private benefits around £17 bn.

26 Costs are £1.4 bn in 2030 and increase to £3b bn by 2050.

27 Calculations rely on lifetime costs of £20,800 and £22,400 per hectare of new coniferous and broadleaved woodland planted, respectively.

OTHER SECTORS AND INVESTMENTS FOR DECARBONISATION

The estimated £30 bn of annual investment is an indicative, but incomplete, estimate. We focus on the largest investment needs clearly additional to BAU, which raise questions around how costs should be distributed. This is not a complete list and hence is an underestimate of the total investment needed to decarbonise in the 2020s. Further investment needs not explicitly considered include:

- *The need to invest in transport infrastructure,* particularly rail and infrastructure to encourage active travel (e.g. cycle lanes). The investment need heavily depends on decisions on how infrastructure is expanded (e.g. decisions on whether tramlines are reintroduced in city centres) and are difficult to disentangle from investment levels required for a BAU scenario (e.g. investment in high speed rail). These investments are typically publicly funded and sizeable. For example, bringing spending to support active travel to Dutch levels (around £26 per capita) would require approximately £2 bn per year (CAFOD et al., 2019b).

- *Investment to decarbonise waste, F-gases, aviation, and shipping.* Investment needs in waste and f-gases are low and can be relatively easily achieved through clear standards.[28] Aviation and shipping will require significant investment in the long term to decarbonise, but UK efforts in 2020 primarily focus on innovation rather than deployment of low-carbon airplanes or ships (and the supporting infrastructure). Box 7 provides some further detail on decarbonisation of aviation and shipping.

£2bn

INVESTMENT REQUIRED FOR PUBLIC TRANSPORT INFRASTRUCTURE

28 Required investment for reductions in waste and F-gases are minimal and oftentimes cost-savings. The 2014 EU F-gas regulation puts the UK on track to reduce F-gas emissions by 12.5 Mt CO_2e by 2050, and the residual 3.5 Mt can be mitigated through other negative or low cost measures, such as more efficient air conditioning technologies and metered dosed inhalers (Ricardo Energy and Environment, 2019). Emissions reductions in waste are also possible through low cost measures such as increased recycling rates and reductions in avoidable food waste (CCC, 2019b).

BOX 7:

INVESTMENT TO DECARBONISE AVIATION AND SHIPPING

- *Fuel switching may bring international shipping to net-zero emissions by 2050 and requires innovation and demonstration spending now.* Deep emissions reductions will depend on the uptake of hydrogen-based liquid fuels such as ammonia to power the fleet in the future (CCC, 2019b). The current role of hydrogen fuels in shipping is restricted to demonstration projects, and the current costs of hydrogen-based liquid fuels are too high to compete with conventional oil-based fuels (IEA, 2019). New investment in R&D will be needed to drive down the abatement costs of these technologies, currently at £135 per tonne of CO_2, to incentivise widespread deployment (IEA, 2019). Shipping is a highly international sector, and the UK only has a limited shipbuilding industry. Hence, generally the UK's most effective role in pushing innovation in the decarbonisation of shipping is likely through international collaboration. There are, however, exceptions for specialised domestic vessels, such as ferries (Vivid Economics, 2019a) . Given the long lifetime of ships, government can cost-effectively support the replacement of aging existing ships (at the end of their economic life) with low-carbon alternatives.

- *Similarly, to realistically achieve net-zero flights, significant R&D spending is required now.* The use of synthetic fuels for aviation is feasible but thermodynamically and economically challenging; likewise, it is questionable whether the use of scarce biomass resources to replace jet fuel is appropriate to decarbonise the sector (CCC, 2019b). However, synthetic fuel technology and battery-powered flight are still in the early stages of development and have so far been limited to small demonstration projects and feasibility studies (IEA, 2019). Moreover, the marginal abatement cost for hydrogen-based liquid fuels is currently high, at around £300 per tonne of CO_2. Significant investment in R&D in hydrogen fuel is likely necessary before these technologies are economically viable. Demand reductions can also play a significant role in reducing emissions from aviation, but do not necessarily require increases in investment.

- *During the 2020s, decarbonisation for aviation and maritime shipping will primarily be driven through fuel efficiency improvements, which requires limited investment beyond BAU.* Fuel costs are a large percentage of costs for aviation and shipping, and hence market incentives for fuel efficiency improvements in these sectors are already substantial. Previous studies project fuel efficiency improvement to aviation between 0.5 and 0.6% annually over the coming decades, resulting in in a cumulative improvement of about 10% by 2030 (Department for Transport (UK), 2017; IPCC, 1999; Peeters et al., 2005). Similarly, the Energy Efficiency Design Index (EEDI) implemented by the International Maritime Organization mandates a minimum energy efficiency level per capacity mile, which will be tightened every five years to reduce fuel consumption in maritime shipping.

3. CREATING A JUST TRANSITION

To ensure a just transition, new policy is required to: a) generate the levels of investment needed to achieve net-zero emissions in the UK, and b) to ensure both the cost and benefits of net-zero are fairly distributed. As highlighted in Section 2, substantial new investment is required to achieve sweeping GHG reductions across the UK economy.

These investment levels will not be reached through market forces alone. A comprehensive policy pathway to net-zero must include, among other things, new (and enhanced) private market incentives, standards and regulation, as well as greater direct public investment. Inevitably, the necessary structural changes to capital flows to achieve a net-zero economy will create winners and losers. Careful policy design will be required to minimise the impacts on vulnerable groups. With the right policies in place, net-zero is attainable and can improve the standards of living for today's and future generations. This section sets out key principles to achieve this.

3.1 FUNDING NET-ZERO: POLICIES TO FACILITATE PRIVATE AND PUBLIC INVESTMENT

A combination of taxes, subsidies, and regulation will be required to drive the necessary investment in low-carbon investment during the 2020s. Market and behavioural failures are at the heart of the investment gap in decarbonisation measures. These failures necessitate a more active role from the public sector, to both crowd in private investment, as well as providing public funding directly. Furthermore, as shown in Section 1, decarbonisation also brings large co-benefits. Given this, this section explores how funding to provide public co-benefits (such as air quality improvements) can help reduce the decarbonisation investment gap.

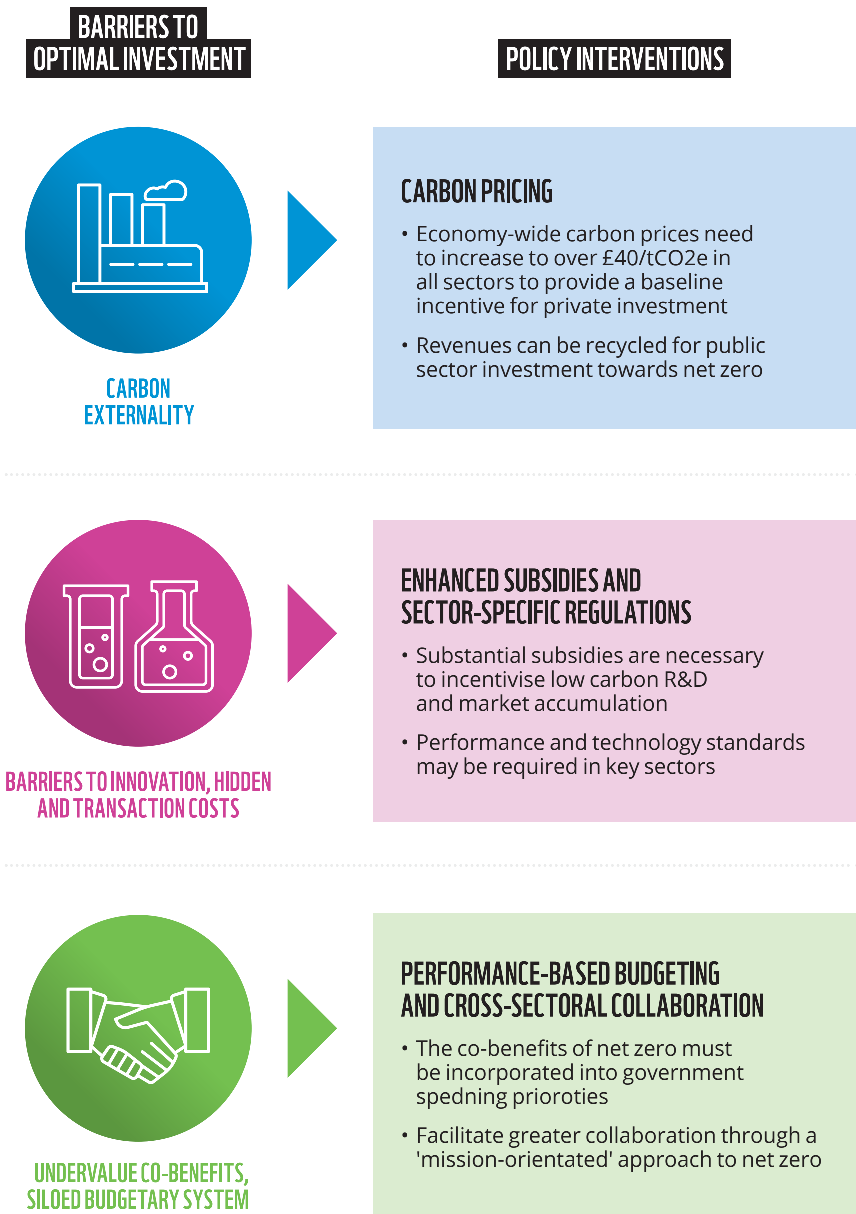
The section is structured around three key messages:

- **3.1.1.** *Carbon prices, through both an ETS and sector-specific carbon taxes need to increase.* Carbon pricing helps direct resources to the most efficient decarbonisation methods, and a minimum carbon price across sectors helps ensure a common level of effort across the economy. Carbon prices will need to rise significantly from their current levels, around 24 Euros[29], to incentivise the required levels of investment. Recent work by LSE suggests the carbon prices in all sectors should be £40-£50 in 2020 and rise over time (Burke et al., 2019).
- **3.1.2.** *Carbon pricing alone will not suffice; large public investment and targeted regulation will also be required.* Barriers beyond the carbon externality hold back investment and further policy is required to unlock the required levels. Regulation and standards can play a large part in ensuring private investment in low-carbon technologies, particularly in markets where consumers and producers are relatively unresponsive to price signals. Furthermore, a significant increase in the scale of public subsidy will be required in key sectors.

29 Based on the December 2020 futures price from (European Energy Exchange, 2020).

- **3.1.3**. *The co-benefits of net-zero justify substantial increases in public subsidy which needs to be recognised in the UK's departmental budget allocation.* The UK Government's siloed budgetary system does not effectively allocate spending on decarbonisation measures with large co-benefits. The cross-departmental mission-oriented approach described in this section can help address this. For example, budgeting for public health should involve not just the Department for Health and Social Care (DHSC), but also those government institutions that indirectly improve health outcomes through programmes, for example, that increase low-carbon transport or encourage active travel.

FIGURE 4:
KEY BARRIERS TO INVESTMENT AND POLICY SOLUTIONS
Source: *Vivid Economics*



3.1.1 CARBON PRICING

Clear carbon price signals across the economy provide an economy-wide incentive, and helps ensure decarbonisation investment is allocated cost-effectively. A carbon price (see Box 8), ideally implemented through an EU-linked ETS, raises the prices for carbon-intensive goods and services. Ensuring a carbon price of £40-50/tCO2 (Joshua Burke et al., 2019) will help to :

- Increase the competitiveness of low-carbon alternatives and drive private investment towards these technologies.
- Ensure that producers and consumers of carbon-intensive products internalise (some of) the societal cost this imposes
- Ensure a minimum level of decarbonisation effort across the economy.

BOX 8:
CARBON PRICING TAXONOMY

- Carbon prices discussed in this report refer to explicit carbon prices implemented through various market-based instruments. These can take several forms:
  - *Emissions trading scheme.* An ETS sets a cap on total emissions through the issuance of permits i.e. allowances which can be freely traded amongst polluting firms. A UK ETS could take one of two forms: a UK ETS linked to the EU ETS, or, a standalone UK ETS. The difference between the two options is that the former allows permits to be traded across borders, whereas the latter would involve only domestically issued emissions permits which would be traded solely between UK firms. Although either model has its benefits, previous work at Vivid Economics has found an EU-linked ETS to be the most viable approach for its climate targets (Vivid Economics, 2019c).
  - *Economy-wide carbon taxes.* While an ETS creates a carbon price through restricting supply, a general carbon tax is explicitly levied on every tonne of CO2 emitted. Ideally, the carbon tax should be equal to the social cost of carbon, which is likely to fall in the range of £40-£100 in 2020 before increasing to £60-£140 in 2030 (Burke et al., 2019). In a scenario where an EU-linked ETS is postponed, an interim carbon tax, such as the proposed UK Carbon Emissions Tax (CET), could be implemented to maintain confidence and crowd-in low carbon investments from the private sector (BEIS, 2019c; Vivid Economics, 2019c)
  - *Sector-specific carbon taxes.* A carbon price can also be targeted to the most emissions-intensive sectors of the economy. These taxes are typically applied in sectors such as transport or energy, the UK fuel duty on petrol and diesel consumption being one example. More broadly, sector-specific carbon taxes can also prove useful when the abatement costs of low-carbon technologies are known. For example, a carbon price of £120/t CO2 in the power sector by 2050 would be sufficient to make carbon capture and storage technologies competitive (Josh Burke et al., 2019). The carbon price could be higher or lower, dependent on the low-carbon technologies needed to decarbonise that specific sector, and at what price these technologies would become economically viable.
- Economists often also consider implicit carbon prices e.g. through bans on carbon-intensive technologies. Technology standards, such as a ban on coal-burning power plants, implicitly raise the price of electricity and this price increase can be viewed as a carbon price. For clarity, this report treats such policies separately.

Continuing with a (UK-based) ETS can maintain a cross-sectoral price on carbon, and avoids short-term disruptions to investment incentives. A trading scheme brings efficiency benefits, and past experience in the UK and internationally has shown ETS schemes to be an effective tool in setting carbon prices and incentivising decarbonisation (Vivid Economics, 2019c). A UK ETS, preferably linked to the EU ETS, would allow the UK to utilise governance structures already in place. By maintaining existing ETS frameworks, and introducing a sufficiently high auction reserve price, power, industry, and aviation can be provided with a strong decarbonisation incentive by 2021 (Vivid Economics, 2019c). The ability to implement the scheme quickly is valuable – implementing a new form of economy-wide carbon pricing would be complex and risks leaving implementation until the mid-2020s. This would delay climate investment flows, at a time when they should be ramping up. Furthermore, maintaining a scheme linked to the EU ETS lowers the administrative costs to the UK Government.

THE ABILITY TO IMPLEMENT THE SCHEME QUICKLY IS VALUABLE

A The UK ETS needs to be substantially strengthened to support required levels of decarbonisation investment towards the net-zero target. While the EU ETS has successfully created cross-sectoral decarbonisation incentives, the current carbon prices fall short of what is required for a pathway towards net-zero. The UK ETS design will need to draw lessons from the EU ETS process to be effective. Crucially, the carbon price will need to be increased significantly, and provide greater price certainty. An auction-based system with a built-in reserve price could help achieve this. The required price level will depend on design detail, but is likely to be at least £30/tCO2 (Vivid Economics, 2019c). Higher, more certain prices will provide the right signals to crowd in private sector investment from consumers and producers.

Sector-specific carbon taxes also play an important role. Existing sector specific policy provide levers to adjust the carbon price within specific sectors, for example, the transport sector. Although transport sector taxes are also motivated by the need to fund public road infrastructure, fuel duty and differentiated vehicle taxes (by g/km emissions) are already substantial components of the effective carbon taxes paid by motorists.[30] Vehicles taxes, in particular, could be used to ensure showroom costs (known to be the primary focus for buyers) for EVs are lower than for ICE vehicles to support a smooth sales trajectory towards a full ICE sales ban. More broadly, sector-specific taxes can be used to:

- Flexibly adjust decarbonisation incentives to ensure sectoral decarbonisation rates and take-up of e.g. heat pumps (by changes to relative tax rates on gas and electricity, as recommended by the CCC 2019c) are in line with a net-zero pathway.
- Provide a level of certainty on the minimum carbon price in markets beyond the fluctuating carbon price associated with an ETS, as is currently provided by the carbon price floor (CPF) in the power sector.
- Provide potential exemptions or rebates to vulnerable groups.

30 In the long term, sector-specific taxation may need to change substantially to offset the loss of substantial carbon tax revenues. For example, revenues from fuel duty will be substantially reduced by the 2030s. EV use will likely need to be increasingly taxed to raise revenue for the public provision of road infrastructure.

3.1.2 MARKET FAILURES BEYOND THE CARBON EXTERNALITY

Policy to address market failures beyond the carbon externality is equally important to achieving net-zero. We consider three broad categories of further market failures:

- *Positive externalities from innovation* (knowledge spillovers), which imply private funding for innovation is typically too low. This is particularly acute in low-carbon technologies, where knowledge spillovers are 40% greater compared to their brown counterparts (Rydge et al., 2018).
- *Financial market failures,* which limit low-carbon investment even when there are positive returns. The need to create wholly new supply chains around e.g. hydrogen production and use, with relatively immature technologies and policy/regulatory uncertainty implies private investors will often require large returns, significantly above social discount rates. Government can reduce this by providing contractual certainty.
- S*ector-specific market failures* are often crucial barriers to low-carbon investment. For example, a key barrier to energy efficiency improvements to rental homes is that the benefits and costs are distributed across renters and landlords (landlords pay for improvements, but also benefit from property value increases; renters benefit from lower energy bills, but also face the hassle of building work).

Achieving net-zero will require substantial public support for innovation – government will have to create new markets as well as address market failures. Policy recommendations for climate change have typically focussed on correcting the carbon externality – a market failure. However, there is a growing consensus that a decarbonisation strategy which relies solely on a carbon price—no matter how high—is not optimal, and has significant adverse consequences on welfare (Acemoglu et al., 2016). Transitioning to a sustainable economy will require subsidies or other forms of government support to spur innovation and accelerate market penetration. Policy must both correct and create markets to achieve net-zero, supporting both the demand for low-carbon technologies as well as the supply.

Increased government intervention in the form of publicly funded R&D, subsidies, and deployment support is required to increase the pace of low carbon innovation. Given the substantial knowledge spillovers from green innovation, public subsidies for research, development, and demonstration can be efficient. This is especially true for decarbonisation technologies which are likely to play a role across a low-carbon energy system, such as batteries, smart EV charging, hydrogen fuel cells, and CCS (Dietz et al., 2018a; Vivid Economics, 2019b). Once the technology has been sufficiently developed, various policy instruments can be utilised to support commercialisation, market accumulation, and diffusion of low-carbon technologies.

Aside from early stage innovation support, government plays a key role in addressing financial market barriers to commercialising technologies. Put differently, government will need to support private investment flows into early stage low-carbon technologies. Decarbonisation technologies such as CCS, hydrogen use in industry, or hydrogen busses require significant up-front capital investment to adopt. This is risky for private investors, given the rate of return is dependent on relatively untested technologies with uncertain costs, the long-term evolution of carbon prices, and (often) the successful scale-up of counterparties (e.g. investing in a hydrogen bus fleet requires confidence in the supply of hydrogen at a stable price). The relatively high risk-level will often deter investors, or require high returns (beyond what would be socially optimal). In the mould of offshore wind contracts for difference, government can step in and take on risks associated with technology and policy uncertainty. Particularly in the short term, contracts can be auctioned for the operation of e.g. industrial hydrogen use, providing the necessary investor certainty and acting as an anchor for a wider hydrogen supply chain.

Sector-specific barriers will often prevent the necessary levels of low-carbon investment and require sector-specific policy. There are technologies available today that could be implemented at a negative cost i.e. generate net savings, notably in markets for energy efficiency upgrades, yet not adopted. Hassle costs and transaction costs, such as the time it takes to find information and the inconvenience of home upgrades, can prevent the uptake of technologies even when they economically viable. Barriers such as these limit the effectiveness of (carbon) price incentives and even the effectiveness of targeted schemes, such as the domestic renewable heat incentive (RHI). Further sector-specific policy will be needed, both in the form of standards and substantial public subsidy.

Regulation and standards can play a key role in addressing sector-specific market failures, but large public investment is nevertheless needed. EU-wide regulation is currently a key driver for the European automotive sector to invest in EVs. Similarly, tightening building standards will be central to ensuring improved energy efficiency in buildings. Rosenow et al. (2018) found that 25-50% of energy consumption in UK residential homes could be achieved by 2035 through energy efficiency upgrades, resulting in average household savings of £270 annually. However, as with carbon pricing, standards will often have regressive impacts. Where this is the case, substantial public funding is required to ensure a just transition. Box 9 highlights several key areas of public investment.

£270

IN AVERAGE ANNUAL HOUSEHOLD SAVINGS COULD BE ACHIEVED BY 2035

Sector-specific policy is best designed by relevant departments, but will have implications for overall government budgeting as well. Decarbonisation policy needs to be carefully integrated into wider sectoral policy frameworks, and complement other policy objectives. Given this, HMT's net-zero review does not consider sector specific policy. While sector-specific policy should be left to the relevant departments, it is worth highlighting the need for close collaboration, particularly when sector-specific barriers limit deployment of technologies which have cross-sectoral impacts. For example, certain GGR technologies will face barriers specific to the agricultural sector, but help to offset other sectors' emissions. Similarly, electrification of heat faces barriers specific to the housing market, but significantly affects the power sector. This suggest the need for cross-departmental decarbonisation budgets in certain areas. There are already examples of departmental collaboration to support international decarbonisation. For instance, the Department for International Development (DFID), Department for Business, Energy and Industrial Strategy (BEIS) and the Department for Food and Rural Affairs (Defra) share responsibility for supporting mitigation efforts abroad through the UK International Climate Finance (ICF) budget (£5.8 bn over 2016-2021).[31] Considerations of shared responsibilities and a more collaborative budgetary system for domestic decarbonisation are set out in detail in Section 3.1.3.

31 See https://www.gov.uk/guidance/international-climate-finance for further detail.

BOX 9:

AREAS WHERE SUBSTANTIAL PUBLIC INVESTMENT IS LIKELY TO BE REQUIRED

- **Buildings:** A significant proportion of the £12bn in new annual investment will need to be publicly funded. In Scotland alone, public funding required to support a net zero-compatible rate of roll out is around £0.9 bn for low-carbon heat and energy efficiency retrofits (Vivid Economics, 2019a). Even a narrow focus on subsiding low income households (a sub-section of the required policy) would require several billion of annual public funding alone (see Section 2.1.1).
- **Agriculture and land use:** Recognising the trade-offs between climate action, food production and biodiversity, afforestation and reforestation are a crucial component of future GGR. About £14 bn will be spent over the next 30 years to maintain planting rates required for high levels of natural carbon sequestration.[32] Annual public financial support to landowners of around £440 mn above current levels will likely be necessary.[33] Furthermore, ongoing work at Vivid Economics estimates that public support for bioenergy land use options will require an additional £360 mn of investment every year (to produce bioenergy levels in line with Vivid's pathways in the Keeping it Cool report Vivid Economics. (2018c)).
- **Innovation and demonstration:** CCS, BECCS, direct air capture (DAC) and hydrogen technologies are all essential components of the UK's net-zero plan, but do not currently have a natural market. A price on carbon is one step to making these technologies competitive with conventional fossil fuels, but is not sufficient in isolation. Carbon pricing must be supplemented with other forms of public sector support, such as government investment in R&D, transport infrastructure, or direct subsidies in order to push these technologies beyond demonstration and into the commercial stages of development. In effect, government will have to act as a market maker, rather than only addressing market failures. New investment in these areas will require at least £1 bn annually (see Section 1.1.2).

BOX 10:

REINVESTING CARBON REVENUES INTO THE TRANSITION

- **Increasing carbon pricing could raise £20 bn a year of public revenue until the 2030s.** In addition to strengthening private incentives for low-carbon investment in the private sector, increasing carbon prices pragmatically would raise significant revenue, particularly during the 2020s when emissions are still substantial. The revenue raised will depend on the policy package implemented, but the LSE's estimates that its proposed set of carbon pricing measures would raise approximately £20 bn per year (Burke et al., 2019).
- **Revenue raised from carbon pricing can be reinvested to support decarbonisation.** Acemoglu et al. (2016) show that optimal climate policy involves the public sector funding 80-90% of R&D in low-carbon technologies over the short-medium term (Dechezleprêtre et al., 2016). Similarly, the IEA (2010) estimate that a 50% reduction in global GHG emissions from 2007 levels by 2050, a considerably less ambitious target than net-zero, would still need a 2-5fold increase in public spending on R&D (Dechezleprêtre et al., 2016). Having spent just over a billion USD[34] on low-carbon R&D in 2018 (IEA, n.d.), a portion of carbon revenues could be devoted to increase public R&D or subsidies for private R&D in low carbon technologies. Moreover, there would still likely be abundant revenues leftover to put towards other policy interventions, including deployment subsidies or government contracts.

32 To address concerns of food security and offshoring of agricultural carbon emissions, all net-zero land use measures, including woodland planting, bioenergy crops, agroforestry, and peatland restoration, are modelled based on the assumption that per capita food production remains constant (CEH, 2018). Moreover, the Net-zero scenario assumes that only 17% of bioenergy for BECCS is imported (CCC, 2019)

33 Based on Vivid Economics analysis for forthcoming Vivid Economics report commissioned by the CCC.

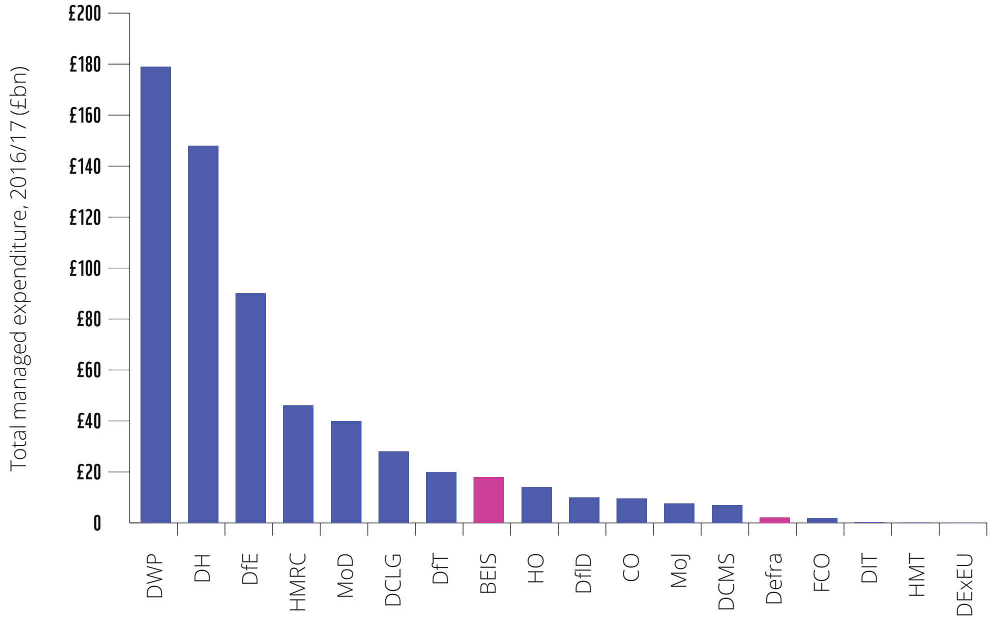
34 Purchasing Power Parity in 2018 USD.

3.1.3 BUDGET ALLOCATION AND MEETING NET-ZERO INVESTMENT REQUIREMENTS

Achieving net-zero will require cross-departmental changes in public spending. Historically, key departments supporting decarbonisation programmes are BEIS and Defra.[35] Considering their limited departmental budgets, compared to, for example, the Department of Health and Social Care, the importance of leveraging cross-departmental spending power is clear. Large annual public subsidy requirements to, for example, support low-carbon buildings which will require public funding of the order of £12 bn, would either require large increases for e.g. BEIS, or partly leverage budgets from e.g. the Ministry of Housing. As set out below, this could be justified by the co-benefits decarbonisation investment provide

FIGURE 5:

MANAGED EXPENDITURE BY DEPARTMENT (2016/2017)



Source: Adapted from Institute for Government, 2017)

The co-benefits of net-zero investment justify substantial further decarbonisation investment. The net-zero co-benefits (£83 bn) and business opportunities (£51 bn) detailed in this report sum to £134 bn by 2050. Currently, investment in supporting active travel in the UK is £220m per year (CAFOD et al., 2019b), substantially lower on a per capita basis than countries such as the Netherlands. This, combined with the substantial health co-benefits of active travel (£20 bn, see Section 1.4.1), suggests there is significant space to increase spending while providing value for money delivering both carbon reductions and health benefits.

35 For example, the Countryside Stewardship grants for woodland creation or hedgerows and boundaries are both funded by Defra.

Prioritising public funding for public services according to where value for money is greatest is a recognised challenge under the current budgetary system. The National Audit Office (NAO) found that while HM Treasury's budgetary system is effective at limiting spending, it "does not require consistent assessment of the value from proposed spending, or promote cross-departmental comparisons" (NAO, 2012, p. 6). A key reason for this issue—and one that is especially relevant to the creation of a sustainable economy—is that government spending often creates outputs that are not measured in monetary terms (Barber, 2017; see Box 11). Accordingly, straightforward value-for-money assessments are not possible. Although complete value-for-money comparability between departments is unattainable, more action is needed to demonstrate that the benefits of spending towards net-zero are equally or more valuable compared to other spending priorities. Moreover, this information should be used to inform the upcoming comprehensive spending review expected this year.

BOX 11:

PROCESS OF DEPARTMENTAL BUDGET ALLOCATION

- **Public resources are allocated across UK Government departments during periodic comprehensive spending reviews (CSRs), which typically occur in 3-5 year cycles.** CSRs are conducted by HM Treasury, who set departmental spending with the objective of maximising value for money, within the spending limits and priorities set by the UK Government (NAO, 2018). The most recent CSR was conducted in 2015. In the interim of the next CSR, expected this year, a spending report has been published by HM Treasury which has specified health, education, crime, and Brexit as top priorities for the next spending cycle (HM Treasury, 2019). Departments are also required to submit an annual single departmental plan (SDP), which specifies how it will implement objectives, and the Government's priorities, through the provision of public services.

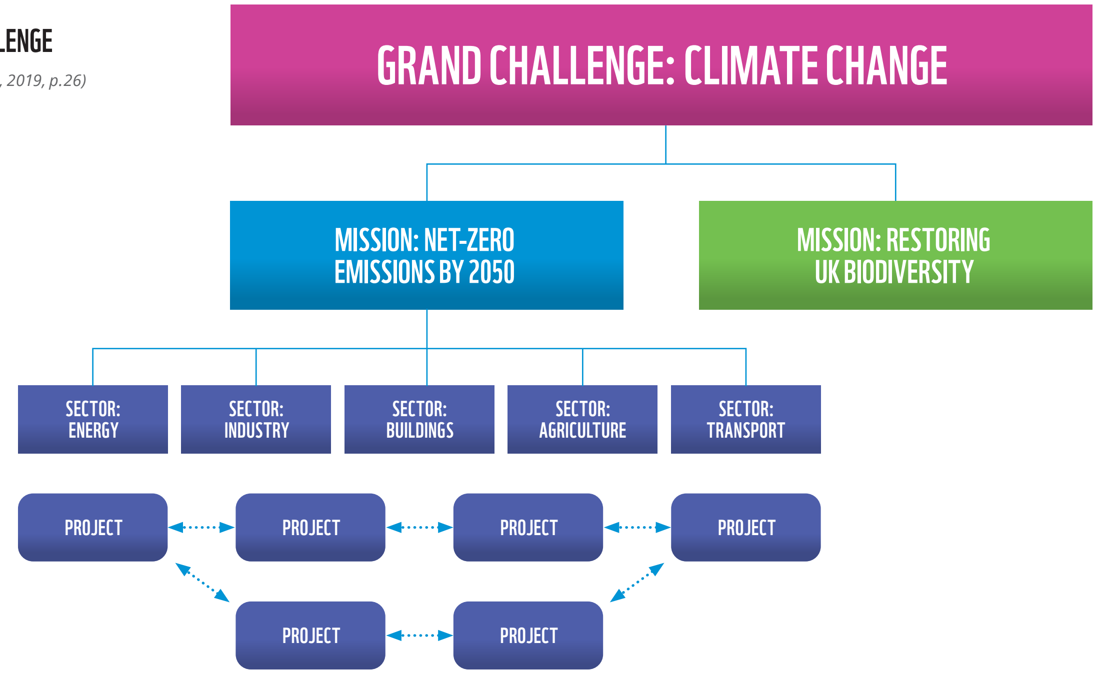
- **The NAO has acknowledged challenges limiting the allocative efficiency of current departmental budgets.** Whereas the value created by a public utility can be directly observed through revenues from water or energy tariffs, the performance of this utility cannot be easily compared to the performance of a publicly funded ecosystem restoration programme, or publicly funded museum, which create less tangible cultural outputs. Accordingly, the budgetary system does not mandate assessment of the value that will be created from departmental spending (NAO, 2012). This disadvantages net-zero investment, for which spending is known to generate considerable value.

A 'mission-oriented' approach to net-zero can help ensure public decarbonisation investment sits within a coherent cross-departmental programme. Climate change is a cross-cutting issue which does not neatly fall under the purview of a single government department. However, the current budgetary system constrains opportunities for cross-sectoral and inter-departmental collaboration and often reduces climate investment to a set of non-overlapping projects. The NAO concludes that the compartmentalisation of government budgeting "can undermine overall value for money, and negatively affect local services, because multiple central government departments take separate, narrow views." (NAO, 2018, p. 11) Work done by the UCL Commission for Mission-Oriented Innovation and Industrial Strategy (MOIIS) has put forward a more inclusive approach to grand challenges such as climate change, which calls for greater collaboration—between government departments and economic sectors, public servants and private agents—to foster investment and innovation (MOIIS, 2019). This includes the establishment of a dedicated and autonomous 'grand challenge team', which brings together various departments that coordinate through a series of interrelated projects, operating under the umbrella of an overarching mission (see Figure 6).

FIGURE 6:

NET-ZERO GRAND CHALLENGE

Source: Adapted from MOIIS, 2019, p.26)



The co-benefits of net-zero suggest clear candidates for projects within departmental remits which contribute to the net-zero grand challenge. Take for example the DHSC and the NHS, which receive the second highest level of funding from the UK Government out of any department, and have been listed as a key priority in HM Treasury's 2019 spending round report (HM Treasury, 2019). While cost-effective treatment and prevention of respiratory and cardiovascular disease coincides with the objectives of the DHSC, investments in EV deployment made by the Department for Transport could achieve similar health outcomes through the promotion of reduced concentrations of motor-vehicle emissions (see Box 12). Similarly, energy efficiency upgrades in residential homes could mitigate the financial burden on the NHS by £0.42 for every £1 spent in fuel-poor homes, and up to £2.5 bn annually across the UK (BEIS Committee, 2019). Accordingly, reframing these investments as cost-effective public health interventions, or as opportunities for re-educating or up-skilling the workforce, is one way to emphasise that climate spending contributes to some of the UK Government's other biggest priorities.

Greater decarbonisation and better performance on other policy objectives (e.g. health) can be achieved if decarbonisation co-benefits are fully taken into account. Creating the infrastructure for active travel, increasing the deployment of EVs, providing energy efficiency retrofits, and encouraging the switch to plant-based diets are all interventions which simultaneously contribute to the objectives of the NHS and put the UK on the pathway to net-zero. Indeed, better decarbonisation and health outcomes could be achieved for less money if decarbonisation co-benefits are fully considered (see Box 12).

BOX 12:

CONSIDERING VALUE FOR MONEY SPENDING IN THE NHS

- **The NHS uses Quality-adjusted life years (QALYs) to measure changes in health outcomes, and spends £18,000 on average for every QALY delivered.** NICE define a QALY as "measure of a person's length of life weighted by a valuation of their health-related quality of life." (NICE, 2013a) More precisely, a QALY corresponds to a year of perfect health. To ensure value for money spent, a cost-per-QALY threshold of £20,000 has been established to compare different health interventions by cost-effectiveness (NICE, 2013b). Healthcare interventions which provide QALYs at a cost less than £20,000 are deemed cost-effective, and the mean cost to the NHS per QALY gained is £18,000 in the UK (Claxton et al., 2015).

- **The UK would gain 1.9 m QALYs if the equivalent of the NHS's projected budget increase was allocated to investments in off-road cycle paths and low-emissions zones (LEZs) for motor vehicles.** The projected increased in NHS spending, as specified in the interim 2019 spending round report, is £6.2 bn, meaning that 338 thousand QALYs could be gained if the NHS maintains its current mean spend (£18,000) to achieve a QALY. A recent report published by NICE (Ballinger et al., 2016) conducted an economic analysis of the cost-effectiveness for different policy interventions in the UK. The authors' analysis found that every £ spent on off road cycle paths generated nearly £14 in health benefits, analogous to a cost per QALY of £5,075. Similarly, every £ in costs from the establishment of LEZs led to £27 in health benefits—a cost per QALY of £2,465. Based on these estimates, if the £6.2 bn in new NHS funding were split evenly between investments in cycle paths and LEZs, this would result in 1.5 m more QALYs gained. Put differently, investing in cycle paths and LEZs could achieve the same amount of QALYs for £4.9 bn less than the NHS based on average performance.

GOVERNMENT WILL NEED TO CAREFULLY CONSIDER HOW TO SUPPORT LOW-INCOME HOUSEHOLDS AND OTHER VULNERABLE GROUPS THROUGH THIS TRANSITION

3.2 MANAGING THE DISTRIBUTIONAL CONSEQUENCES OF NET-ZERO

A just transition requires more than simple avoidance of the regressive impacts of climate policy. Economists have typically focussed on the distributional considerations of policy designed to incentivise low-carbon investment. As highlighted throughout this report, policy will need to include large public subsidies, incentivise change in private investment flows, and impact prices of carbon intensive products and services. Government will need to carefully consider how to support low-income households and other vulnerable groups through this transition. For example, government can target its investment, disproportionately targeting subsidies for energy efficiency retrofits to poorer areas. However, policy design for a just transition will need to include broader considerations, including:

- *The distribution of the (co-) benefits* of a net-zero transition. This includes, for example, considering the regional distribution of green business opportunities across the country. Government will play a key role in unlocking these through its industrial strategy, and can thus help shape the geographical location of, for example, hydrogen production infrastructure.
- *The distribution of the costs of climate change.* Damages caused by climate change will inevitably be felt more heavily by certain groups. For example, coastal communities will disproportionately feel the impact of rising sea levels and farmers will disproportionately be affected by extreme weather events. Government policy should be mindful of the distributions of these impacts, and allocate sufficient resources to affected communities to offset the impacts of climate change. This could be (partly) achieved by disproportionality targeting public subsidies for decarbonisation to communities likely to be worst affected by climate change.

This report considers three cross-cutting just transition considerations relevant for the HMT Net-zero review. Many just transition policy considerations will fall within sector-specific departmental policy. Nevertheless, there are several just transition considerations which create macro-economic shifts in wealth and opportunity. We hence set out:

- *Employment impacts.* Structural shifts in the economy will create large changes to which skills are in demand. This transition needs to be carefully managed to avoid regional decline similar to that experienced as a result of the transition away from coal extraction.
- *The impact of decarbonising buildings.* Investment needs in this sector are particularly large, and the cost distribution (if not addressed by policy) fundamentally regressive.[36] Although regressive impacts can be avoided through careful policy design targeted at building decarbonisation policy, this may be administratively complex to achieve. An alternative may be to offset regressive impacts by progressive changes to e.g. income tax.
- *Intergenerational impacts.* Climate change is fundamentally an intergenerational issue. Delaying investment shifts the burden of climate change to later generations. This report briefly highlights consequences of further delay in required investments.

36 The costs of e.g. heat pump installation or energy efficiency retrofits, while cheaper in smaller homes, do not scale proportionally to the incomes of homeowners. Hence , low income households will need to pay a significantly larger of their income for these measures.

3.2.1 EMPLOYMENT AND REGIONAL IMPACTS

At an aggregate level, the economic opportunities associated with low-carbon technologies are likely to offset those associated with current carbon-intensive industries. The relatively small macro-economic impacts of the low-carbon transition imply that at an aggregate level, the number of jobs supported by the economy are not materially affected. Furthermore, as set out in Section 1.4.2, a substantial number of low-carbon jobs are likely to be created.

A number of existing jobs in large sectors will become obsolete in the green economy. The net-zero transition will affect jobs in four distinct ways (UNFCC, 2016):

- *Job elimination:* when jobs are lost, and skills are not transferrable to other vocations (e.g. oil and gas industry jobs, or reduced employment needs in primary sectors owing to energy efficiency improvements);
- *Job substitution:* when jobs are lost, but skills are directly transferable to a less carbon-intensive industry (e.g. a switch from petrol/diesel vehicle to electric vehicle assembly (Vivid Economics. 2018b));
- *Job transformation:* when jobs are not lost, but require up-skilling to accommodate more changes in consumer demand for less carbon-intensive services or products (e.g. maintenance and installation of gas boilers in the brown economy to heat pumps or heat networks in the green economy; or farmers undertaking forestry or silviculture in addition to current crops or livestock).
- *Job creation:* when new jobs in new sectors are created. New jobs will be created requiring new skills. The UK will need to consider whether its educational system (academic as well as vocational) appropriately prepares future job seekers for the demands of the future labour market.

INVESTMENT INTO RESKILLING PROGRAMMES ARE LIKELY TO BE THE MOST COST-EFFECTIVE WAY TO MITIGATE THE IMPACTS OF JOB LOSSES

Policy action can ensure that significant structural employment shifts from eliminated or transformed jobs are managed appropriately. Investment into reskilling programmes, such as *vocational training programmes*, are likely to be the most efficient and cost-effective way to mitigate the impacts of job losses during the net-zero transition. A study by LSE's Grantham Institute estimates that over one-fifth of existing UK jobs are 'exposed', or at risk, to the green transition; of these, about half (10% total) will require reskilling (Robins, Gouldson, Irwin, & Sundmant, 2019). At the moment, investment in upskilling for green jobs is not a priority for the UK Government, and responsibility for green skills training is largely left to private employers (Cedefop, 2019). Public training programmes and other subsidies/incentives for private vocational training should target *green* skill development specifically, especially for disrupted workers, such as France's *"Pole Emploi"* programme, which uses data to monitor needs for green skills and directly helps clients into green job opportunities (Cedefop, 2019).

Jobs exposed to potential elimination are not distributed evenly throughout the UK, and targeted regional support will be required. The East Midlands (23.1%), West Midlands (22.5%), and Yorkshire and the Humber (22.2%) have the highest proportion of 'exposed' jobs. Reskilling must therefore target these regions accordingly (Robins, Gouldson, Irwin, & Sundmant, 2019). Industrial strategy and sector deals can be used to help bring new low-carbon jobs to areas disproportionately affected. For example, Siemens signed a Memorandum of Understanding with the UK Government in 2010 to establish an £80 million offshore wind turbine factory at Alexandra Dock in Hull, a major manufacturing site in Yorkshire and the Humber, which to date has created over 1,000 new green manufacturing jobs (University of Hull Logistics Institute, 2017).

BOX 13:
THE IMPORTANCE OF MANAGING THE DECLINE OF CARBON-INTENSIVE SECTORS: PAST EXPERIENCE WITH THE COAL SECTOR

- **The impact of unmanaged decline of carbon-intensive sectors can be significant and have long-lasting regional impacts.** For example, the closure of UK coal mines en masse in the 1980s led to upwards of 250,000 direct job losses, the effects of which are still felt today – 43% of all coalfield neighbourhoods are among the most deprived in Britain (Emden & Murphy, 2019). Furthermore, even when displaced workers find new jobs, they can often be of lower quality, reducing quality of life. An assessment of the Welsh Development Agency's initiative to offset job losses in the mining industry found that new jobs were of lower pay and skill relative to previous mining jobs (Robins et al., 2019). These realities underscore the need for proactive policy to ensure those affected by structural employment shifts do not become economically marginalised.(Robins et al., 2019).
- In addition to reskilling programmes, **the government can seek to implement social protection programmes** and **early retirement schemes** to assist disrupted workers and protect livelihoods. These measures served to protect livelihoods in the Ruhr Valley in Germany as the region famously underwent drastic economic restructuring, shifting away from coal mining and steel toward the service sector. As mentioned above, social protection programmes can be funded by the progressive use of revenue from carbon pricing.

Other industries will face job substitution or transformation; while workers in these sectors will experience disruption, their skills are broadly aligned with the green transition and employer led retraining can play a primary role. For example, an employee in the freight industry whose job is substituted from a high-carbon means of freight (e.g. road transport) to a lower-carbon alternative (e.g. rail) will possess skills and experience necessary to transition into a new role *within their industry*. This is not to say that no additional on-job/skills training will be required; rather, that employees changing jobs within an industry (substitution) or roles within a job (transformation) already possess substantial relevant experience , and thus have skills that are 'aligned' with the green transition (Robins et al., 2019). Any retraining required can typically be provided at relatively low cost by employers.

2.5m

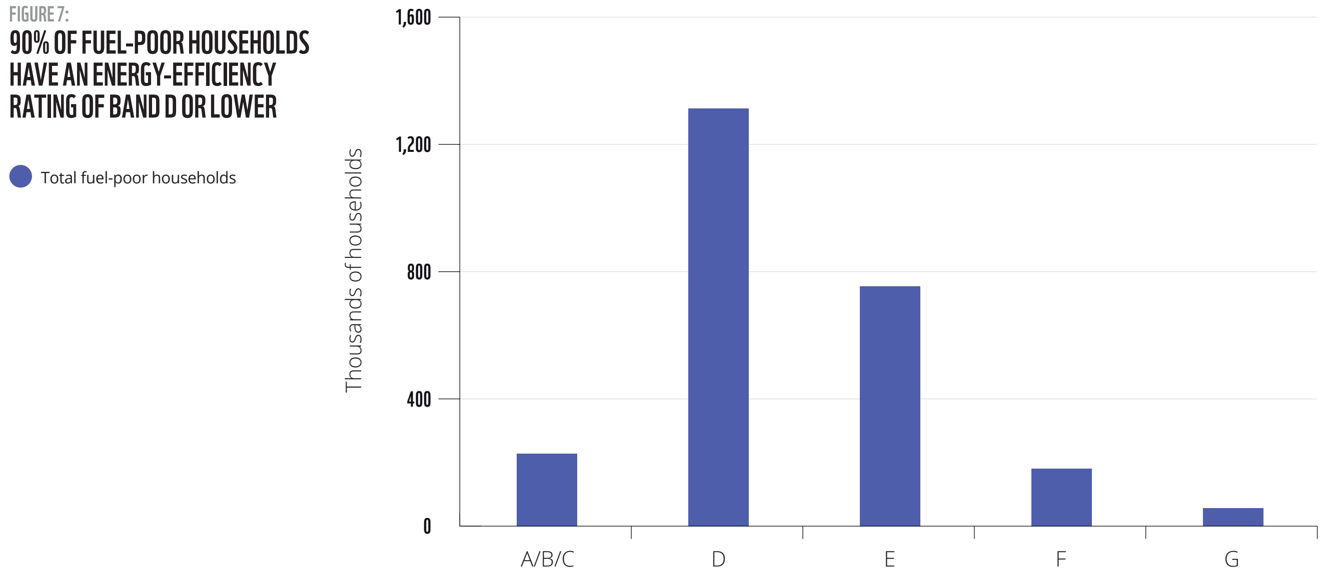
HOUSEHOLDS IN ENGLAND AFFECTED BY FUEL POVERTY IN 2017

3.2.2 FOCUS ON THE BUILDINGS SECTOR

If the costs of decarbonisation are reflected in fuel prices, hundreds of thousands of households will be at greater risk of fuel poverty without support for energy efficiency improvements. Fuel poverty, or the inability to afford to keep one's home adequately heated, affected 2.5 million households in 2017 in England alone (BEIS, 2019b). Poor thermal efficiency of housing stock is a primary driver of fuel poverty – as shown in Figure 7, 90% of English households in fuel poverty live in in properties with an energy efficiency (EPC)[37] rating of D or below. The green transition could increase household energy bills by an average of 7-9% by 2030, and as fuel prices rise in conjunction with the UK's net-zero push, an additional 200,000 families could be living in fuel poverty in the absence of energy-efficiency improvements (Committee on Climate Change (UK), 2017).

37 Energy Performance Certificate Ratings, with bands A (best) through G (worst).

FIGURE 7:
90% OF FUEL-POOR HOUSEHOLDS HAVE AN ENERGY-EFFICIENCY RATING OF BAND D OR LOWER



Source: *Vivid Economics, based on data from BEIS.*

Policy support to increase the thermal efficiency of buildings for low-income households can mitigate regressive impacts of a net-zero transition. Insulation in buildings can lift as many as 74% of fuel-poor households out of fuel poverty (Committee on Climate Change (UK), 2017). However, energy-efficiency retrofits have high capital and hassle costs, and existing financial incentives such as the Energy Company Obligation (ECO) do not go far enough to assist fuel-poor households. Mandates for building efficiency standards are necessary to overcome misaligned incentives (e.g. the "landlord-tenant dilemma"[38]) and improve energy efficiency in buildings for the 20% of UK households that live in renter-occupied dwellings.

Renewable and low-carbon heat technologies can also lift households out of fuel poverty. Renewable heat technologies such as heat pumps can help save on energy bills owing to lower operating costs, but are likely to be unaffordable for many fuel-poor families due to high upfront capital requirements. Increasing subsidies for consumers switching from gas boilers to heat pumps, along with increasing the RHI's feed-in tariff for renewable heat to offset increased electricity costs, can help fuel-poor households access financial support to switch to low-carbon heating systems.

Tackling fuel poverty through energy-efficiency retrofits and low-carbon heat uptake has a synergistic relationship with reaching net-zero goals. To meet decarbonisation goals, emissions from residential housing stock must fall by 24% by 2030 relative to 1990 levels; however, energy use in residential buildings, which accounted for 18% of all UK carbon emissions in 2018, *rose* by 2.8% from 2017-18 to 65.9 MtCO2 (CCC, 2019e) (BEIS, 2019a). Government policy to support energy efficiency in buildings therefore provides a *win-win*, as reduced energy consumption both lowers utility bills for vulnerable groups and reduces emissions. By one estimate, a combination of various

38 The "landlord-tenant dilemma" occurs when the building owner is responsible for investment into energy-efficiency improvements or renewable heating systems, but only the tenants receive the benefits from lower energy bills.

efficiency measures in buildings – wall insulation, glazing, heat controls, water tank insulation and flow reduction, demand response measures, and electrical efficiency – could save up to 6 $MtCO_2$ per annum by 2030 from reduced energy consumption, an over 9% reduction from current levels (CCC, 2019e). When these policies are implemented in conjunction with the uptake of low-carbon heat systems (heat pumps, heat networks), these reductions will be even greater.

However, policies to tackle energy poverty (and in turn reduce emissions) require extensive public expenditure. Given that energy-poor households, by definition, are pushed over the poverty line[39] by energy bills, retrofitting for households in energy poverty may need to be entirely through public subsidies. If the 2.3 million fuel-poor English households living in residences with an efficiency band of 'D' or lower are to move up to at least band 'C' by 2030, assuming an average energy performance improvement package cost of £12,000 (with significant variation based on the building type and current band), the UK government would likely need to spend around £27 billion, or £2.7 billion per annum through to 2030. Subsidies to install low-carbon heating systems or replace energy-inefficient appliances would add to this significantly – although costs will vary depending on the decarbonisation approach, even a conservative estimate of just £5,000 per heating system would add over £12 billion total.

3.2.3 INTERGENERATIONAL IMPACTS

£64bn

PER YEAR INCREASE IN INVESTMENT WOULD BE REQUIRED IF ACTION IS DELAYED UNTIL 2030

The principle of intergenerational equity is key to the Just Transition: today's generation passes on a natural environment that is in a condition at least as good as they received it. Climate change is fundamentally an intergenerational issue. The decisions we do (or do not) make today will have consequences for generations to come. As such, successfully navigating the transition to a sustainable economy is just as much about protecting the livelihoods of workers and households of the future as it about protecting those around us today. The just transition therefore implies that the current generation's effect on the environment, especially its extraction and consumption of natural resources, does not take place at the expense of future generations.

Even a 10 year delay in ramping up decarbonisation investment would double annual required investment for the next generation. As set out above, additional annual investment of at least £30bn will be necessary throughout the 2020s to achieve net-zero by 2050, assuming these costs will be distributed evenly over time i.e. that the burden is shared across generations. Postponing this investment to a later date (e.g. 2030) implies that inaction today would need to be compensated by more rapid decarbonisation in future decades. For example, looking at the agricultural and land use sector, a 10-year lag in action would increase annual costs from £1.3 bn to £2.8 bn—a 115% increase. More broadly, delaying action to 2030 would translate into an increase in required investment to at least £64bn a year beginning in 2030. This is likely to be an underestimate, given delayed action would require more rapid supply chain ramp ups, likely lead to stranded assets, and other disruption likely to increase costs.

39 Fuel poverty in England is measured using the Low Income High Costs (LIHC) indicator. Under the LIHC indicator, a household is considered to be fuel-poor if they have required fuel costs that are above average (the national median level) and, were they to spend that amount, they would be left with a residual income below the official poverty line. The UK poverty line is defined as below 60% of median income. Different fuel poverty definitions are used in Northern Ireland, Wales, and Scotland.

In addition to shifting the burden onto future generations, slower progress decreases the economic and technical feasibility of 2050 goals. In order to limit warming to 2 degrees Celsius, annual GHG emissions would need to be reduced at twice the speed if decarbonisation is delayed to 2030 (Gambhir et al., 2017). More precisely, this translates to a 7-14% decrease in CO_2 emissions every year (2017). By comparison, the fastest decrease in CO_2 emissions ever witnessed took place in Sweden from 1974 to 1984 at a rate of only 3% a year (Dietz et al., 2018). Accordingly, achieving reductions on this scale would be unprecedented and dependent on the success of underdeveloped and costly technologies such as DAC. In terms of costs, achieving 2 degrees warming after a 10-year delay would require the price on carbon to immediately increase to \$1,400/tCO_2 in 2030. By 2100, the price on carbon would need to be \$7,000/tCO_2, increasing more than \$1,000 every decade (Gambhir et al., 2017). In terms of costs as a percentage of GDP, IAMs show resource costs increasing by about 30% if decarbonisation begins in 2030 (2017).

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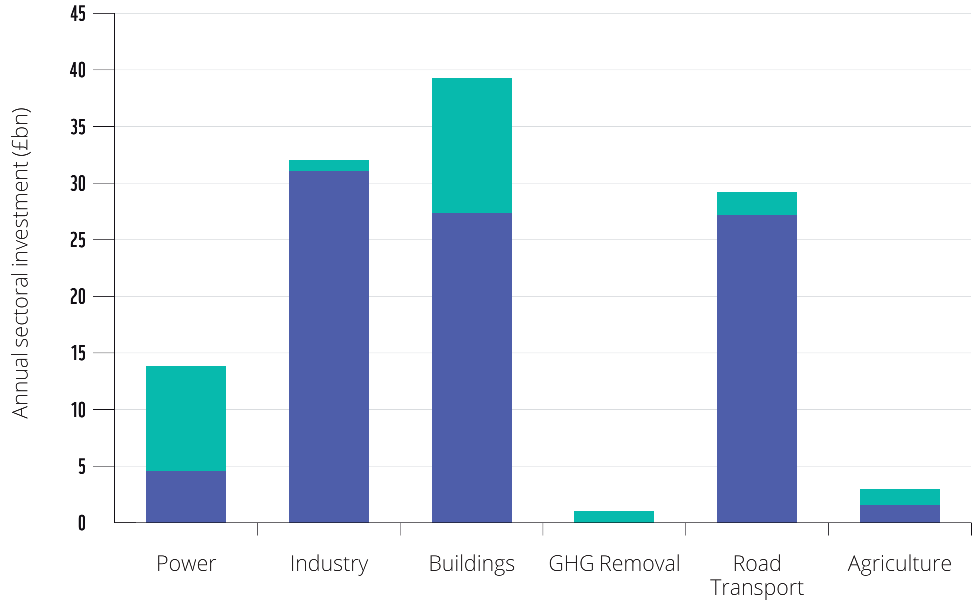
APPENDIX

FIGURE 8:
COMPARISON OF TOTAL INVESTMENT NEEDS PER SECTOR AGAINST CURRENT SECTORAL CAPITAL EXPENDITURE

Current investment
Required additional investment



Note: *1. Estimates of additionality are set out in more detail in sector discussions below.*
2. Estimates of current investment levels are indicative. Power sector is likely an over-estimate as it includes water utilities. Buildings includes total investment in housing repair and maintenance, and excludes new builds. Investment in road transport includes all transportation and storage, and is therefore likely an overestimate. Similarly, investment in agriculture is likely overstated due to the inclusion of the fishing industry.

Source: *Vivid Economics based on ONS business investment by asset and ONS data on construction output*[1]

1 Available from: https://www.ons.gov.uk/businessindustryandtrade/constructionindustry/bulletins/constructionoutputingreatbritain/november2019

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