Organisation for Economic Co-operation and Development

ECO/WKP(2022)43

Unclassified **English - Or. English**

20 December 2022

ECONOMICS DEPARTMENT

POLICIES TO REACH NET ZERO EMISSIONS IN THE UNITED KINGDOM

ECONOMICS DEPARTMENT WORKING PAPERS No. 1742

By Jon Pareliussen, David Crowe, Tobias Kruse and Daniela Glocker

OECD Working Papers should not be reported as representing the official views of the OECD or of its member countries. The opinions expressed and arguments employed are those of the author(s).

Authorised for publication by Isabell Koske, Acting Director, Country Studies Branch, Economics Department.

All Economics Department Working Papers are available at www.oecd.org/eco/workingpapers.

JT03510189

ABSTRACT/RÉSUMÉ

Policies to reach net zero emissions in the United Kingdom

The United Kingdom is among world leaders in reducing domestic greenhouse gas emissions, and a broad political consensus supports the target to reduce net emissions to zero by 2050. The UK's strong institutional framework is an inspiration to countries around the world, and the country is pioneering work to embed climate considerations in the financial sector. Achieving carbon neutrality will require policy to match ambition. Emission reductions so far were largely driven by electricity generation, a sector targeted by explicit pricing instruments and a cost efficient renewables auction-design subsidy scheme. Expanding pricing instruments across the economy is an essential building block to reach targets. Such measures will be more effective if complemented by well-designed sectoral regulation and subsidies, and more acceptable if implemented once energy prices have started to come down from historically high levels. Britons are conscious of the need to act. However, winning their acceptance of the needed policies may require targeting carbon revenue to compensate low-income households and investments in green infrastructure and new technologies. A mechanism defusing fears that effective policies undermine competitiveness, preferably internationally agreed, would facilitate effective policies towards emission intensive trade exposed industries.

This Working Paper relates to the 2022 Economic Survey of the United Kingdom

https://www.oecd.org/economy/united-kingdom-economic-snapshot/

Key words: Climate policy, redistribution, green investment

JEL codes: H23, H31, H32, Q52, Q58

****

Politiques pour atteindre l'objectif de zéro émissions nettes au Royaume-Uni

Le Royaume-Uni fait partie des leaders mondiaux en matière de réduction des émissions nationales de gaz à effet de serre, et l'objectif de réduire les émissions nettes à zéro d'ici 2050 bénéficie d'un large consensus politique. Le solide cadre institutionnel du Royaume-Uni est une source d'inspiration pour les pays du monde entier, et le pays est un pionnier en ce qui concerne l'intégration des considérations climatiques dans le secteur financier. Pour atteindre la neutralité carbone, la politique devra être à la hauteur de l'ambition. Jusqu'à présent, les réductions d'émissions proviennent principalement de la production d'électricité, un secteur ciblé par des instruments de tarification explicites et un système efficient d'allocation par enchères des subventions aux énergies renouvelables. Étendre les instruments de tarification à l'ensemble de l'économie est un élément essentiel pour atteindre les objectifs de réduction d'émissions. De telles mesures seront plus efficaces si elles sont accompagnées de réglementations et subventions sectorielles adéquates, et plus acceptables si elles ne sont mises en œuvre qu'une fois que les prix de l'énergie auront commencé à retomber de leur niveau historiquement élevé. Les Britanniques sont conscients de la nécessité d'agir. Cependant, pour s'assurer de leur soutien, utiliser les revenus du carbone pour compenser les ménages à faible revenu et subsidier les investissements dans les infrastructures vertes et les nouvelles technologies peut être nécessaire. Un mécanisme désamorçant les craintes pour la compétitivité, de préférence convenu au niveau international, faciliterait l'implémentation de politiques efficaces dans les industries à forte intensité d'émissions et exposées aux échanges commerciaux.

Ce document de travail concerne l'Étude économique du Royaume-Uni de 2022

https://www.oecd.org/fr/economie/royaume-uni-en-un-coup-d-oeil/

Mots clés : Politique climatique, redistribution, investissements verts

Codes JEL : H23, H31, H32, Q52, Q58

Table of contents

Tables

Figures

Boxes

Policies to reach net zero emissions in the United Kingdom

By Jon Pareliussen, David Crowe, Tobias Kruse and Daniela Glocker[1]

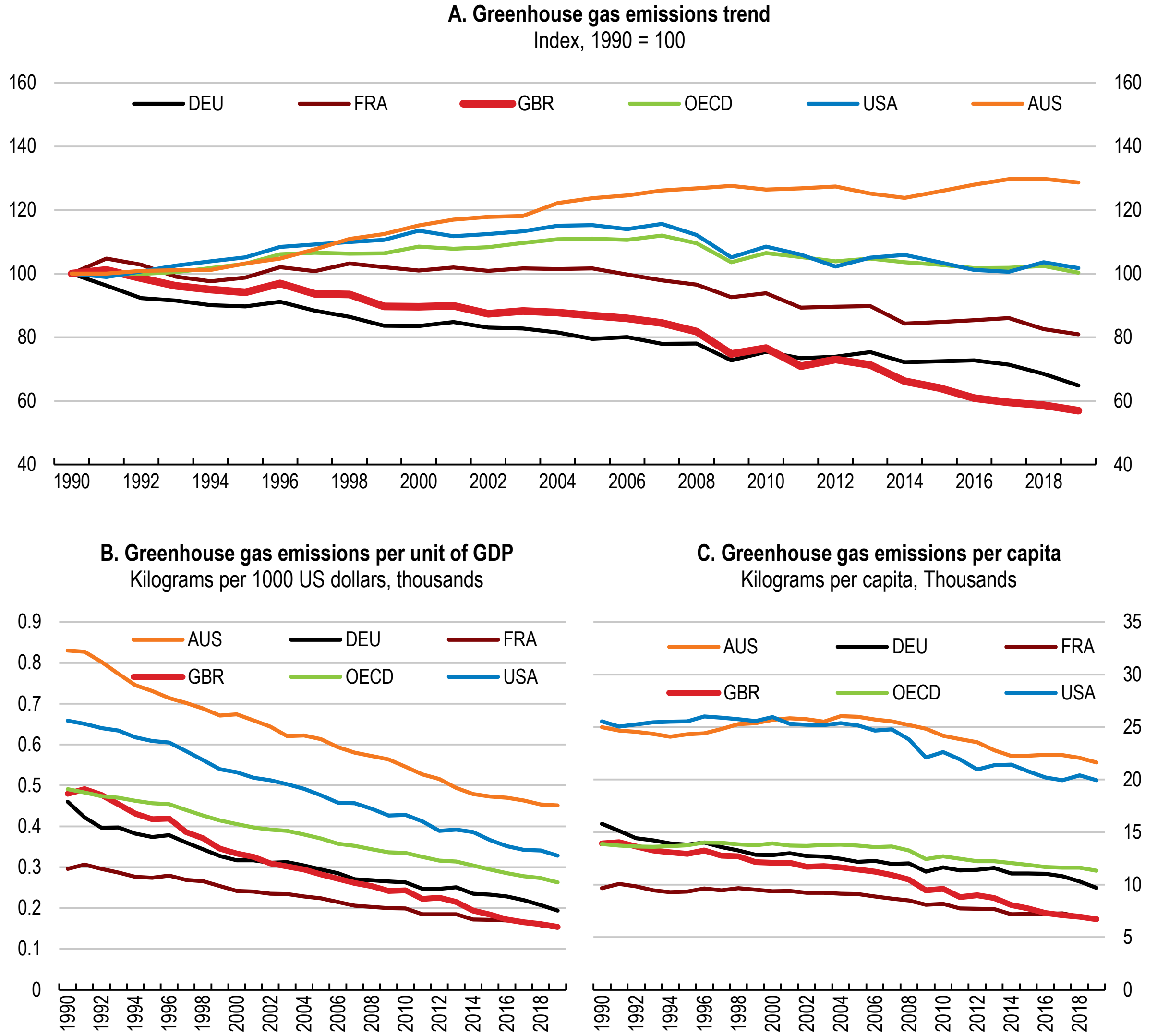
The United Kingdom is among world leaders in reducing domestic greenhouse gas emissions, and a broad political consensus supports the target to reduce net emissions to zero by 2050. The UK's strong institutional framework is an inspiration to countries around the world, and the country is pioneering work to embed climate considerations in the financial sector. Achieving carbon neutrality will require policy to match ambition. Emission reductions so far were largely driven by electricity generation, a sector targeted by explicit pricing instruments and a cost efficient renewables auction-design subsidy scheme. Expanding pricing instruments across the economy is an essential building block to reach targets. Such measures will be more effective if complemented by well-designed sectoral regulation and subsidies, and more acceptable if implemented once energy prices have started to come down from historically high levels. Britons are conscious of the need to act. However, winning their acceptance of the needed policies may require targeting carbon revenue to compensate low-income households and investments in green infrastructure and new technologies. A mechanism defusing fears that effective policies undermine competitiveness, preferably internationally agreed, would facilitate effective policies towards emission intensive trade exposed industries.

The United Kingdom reduced emissions by 40% from 1990 to 2019, among the largest reductions in the OECD (Figure.1, Panel A) and the largest among G20 countries, while GDP increased by 78%. Greenhouse gas emissions per unit of GDP were reduced almost by a factor of three since 1990 (Figure.1, Panel B), and also emissions per capita have fallen considerably (Figure.1, Panel C). In 2019, it was the first G7 country to create a legally binding target to bring net GHG emissions to zero by 2050 to deliver on the Paris Agreement. This ambition is supported by a strong institutional framework, which has inspired similar climate legislation across the world (Caselli, Ludwig and Van Der Ploeg, 2021[1]), and broad political and public support. In 2021, the UK was also the first among advanced economies to set a net zero strategy (BEIS, 2021[2]).

[1] Jon Pareliussen, David Crowe, Tobias Kruse and Daniela Glocker work in the Economics Department of the OECD. The authors would like to thank the UK Government, Filippo Maria D'Arcangelo, Aida Caldera Sanchez, Zeev Krill, Isabell Koske, and Alvaro Pereira (Economics Department), Aurelien Saussay and Josh Burke (LSE Grantham Institute), Frédérique Zegel and Enrico Botta (OECD Environment Directorate), Maria Chiara Cavalleri (OECD General Secretariat), Riccardo Boffo (Directorate for Financial and Enterprise Affairs) Peter Wyckoff and Marissa Plouin (Directorate for Employment, Labour and Social Affairs) and Dirk Pilat (Directorate for Science, Technology and Innovation) for their valuable comments and feedback at various stages of the process. Special thanks to Karimatou Diallo for editorial assistance, communication assistance by Nathalie Bienvenu and Steven Cassimon for preparing statistics and figures (Economics Department).

Figure.1. The United Kingdom has been among OECD leaders in the reduction of greenhouse gas emissions

Total greenhouse gas emissions



Note: Total greenhouse gas emissions excluding land use land-use change and forestry.
Source: OECD (2022), environment database.

The United Kingdom is experiencing widespread climate change. The average temperature is around 1.2°C warmer than in the pre-industrial period (1850-1900). The sea level has risen by 16 centimetres above pre-industrial levels, and episodes of extreme heat, intense rainfall and associated flooding have become more frequent. The United Kingdom is expected to experience warmer, wetter winters and hotter, drier summers, along with more frequent and intense extremes. The continued sea level rise will increase risks of coastal flooding and affect the functioning of coastal infrastructure (Climate Change Committee, 2021[3]; OECD, 2022[4]). While not within the scope of this paper, measures to adapt also need to be stepped up to increase resilience against inevitable climate change. Progress in adaptation has been slow, with high levels of risk from climate change in most sectors of the economy (Box 1).

Box 1. Key climate change adaptation recommendations from the Climate Change Committee

The Climate Change Committee's (CCC) progress report on adaptation (2021[3]) concludes that the UK Government's National Adaptation Programme has not improved resilience to the changing climate to the extent intended under the UK Climate Change Act. Of the 34 priority areas assessed in the 2021 progress report on adaptation, not one was demonstrating strong progress in adapting to climate risk. Policies developed without sufficient recognition of the need to adapt to climate change undermine their goals, steer behaviour in directions that lock in climate risks, and store up costs for the future. The CCC recommends a robust plan for adaptation with measurable targets to assess progress. They also gave 50 concrete recommendations, of which the following key actions were highlighted:

- Restore 100% of upland peat by 2045, including through a ban on rotational burning.
- Bring forward proposed plans to address overheating risk in homes through building regulations.
- Make the Government's next round of adaptation reporting mandatory for all infrastructure sectors.
- Build a strong emergency resilience capability for the United Kingdom against climate shocks, learning from the COVID-19 response.
- Implement a public engagement programme on climate change adaptation.

Source: Climate Change Committee (2021[3]).

Overall, the future cost to the United Kingdom from climate change has been estimated to 3%-9% of GDP by 2050 (Guo, Kubli and Saner, 2021[5]). Nonetheless, the most severe consequences of climate change will come after 2050, and are expected to be severe even if very challenging to predict. Furthermore, the extent of damage depends heavily on adaptation policies in the United Kingdom and on efforts to reduce emissions globally (HMT, 2021[6]). Key adaptation measures in the UK include improving land use and soil health; building buildings in places and with qualities, such as better insulation, that make them resilient to climate change, and retrofitting existing ones; investing in flood defences; implementing nature-based solutions; and upgrading the resilience of supply chains and infrastructure such as electricity transmission. For comparison, the cost of reaching Net Zero by 2050 is estimated at 0.6-2% of GDP by 2050, depending on sources (OBR, 2021[7]; OECD, 2022[4]).

COVID-19 and associated restrictions on mobility reduced emissions by around 13% in 2020, but very little of this reduction is set to be permanent, as structural changes to the underlying economy are expected to be relatively limited. Some changes to working and consumption patterns might persist beyond COVID-19, but their effects on emissions are uncertain and may go in both directions. For example, more teleworking reduces emissions, while a shift away from public transit towards more private car use increases them (Climate Change Committee, 2021[3]). Since March 2020, the United Kingdom has introduced successive packages of support measures equivalent to 15% of 2020 GDP, one of the largest fiscal responses to the COVID-19 crisis globally. As part of this package, green measures are estimated at 1.2% of GDP. Support for public transport services, cycling and walking is prominent (OECD, 2022[4]).

Russia's invasion of Ukraine and subsequent sanctions have led to increasing energy prices and will likely increase the use of coal in electricity generation in the short term. The cost-of-living shock is best handled by supporting low-income households, as energy price support is regressive and runs counter to climate targets. In the longer term, the combination of high fossil fuel prices and a re-assessment of the economic and political costs of energy import dependency boosts the case for domestic clean energy and energy efficiency.

Moving towards net zero is compatible with continued strong GDP growth and prudent fiscal policy, but will be challenging. For instance, climate policies will change the sectoral composition of the economy, boost investment, inflation and interest rates (Pareliussen, Saussay and Burke, 2022[8]). Some sectors are highly responsive to price signals while various market failures such as coordination failures, bounded rationality and liquidity constraints hold back action in others. Clean technologies are readily available and price competitive in some cases, unaffordable, on the testing stage, or not yet developed in others. Furthermore, the green transition will create winners and losers, and may challenge peoples' attitudes and beliefs. This difficult political economy has played an important role in limiting the coverage of effective and efficient policies in the UK. Explicitly pricing emissions assigns the cost transparently, while benefits from lower emissions, public revenues and considerable co-benefits are distributed thinly across the population. Explicit pricing is therefore often less favoured politically than other less transparent policies, such as subsidies where costs are distributed thinly across taxpayers, or regulations carrying hidden and unevenly distributed costs (D'Archangelo et al., 2022[9]).

Important challenges to take into account in the transition include:

- managing the overall economic effects of mitigation action, including concerns about productivity, unemployment, inflation and public debt,
- transforming the energy system and boosting clean energy supply at unprecedented speeds,
- managing the risk of emission-intensive, trade-exposed industries losing competitiveness if one country's action is not followed up internationally, and
- avoiding negative distributional effects and building public acceptance of efficient policies.

Against this background, this paper outlines a cost-effective, inclusive and comprehensive strategy to reach carbon neutrality by 2050, in line with the United Kingdom's ambitions. The analyses and recommendations are informed by new OECD research on the macroeconomic and distributional consequences of different policy options (Pareliussen, Saussay and Burke, 2022[8]) as well as on people's attitudes towards climate change and climate policies (Dechezleprêtre et al., 2022[10]). The paper is structured as follows: the next section gives a brief overview of UK climate targets and institutional set-up. The third section discusses policy options to reduce greenhouse gas emissions in the context of multiple market failures. The fourth section discusses how to improve political acceptability of ambitious climate policy. The fifth and last section discusses concrete climate policy options in their sector-specific context.

A brief overview of UK targets, trends and institutional set-up

The United Kingdom has a strong institutional framework emphasising evidence-based policy making, which has inspired countries around the world. The 2008 Climate Change Act was adopted based on a cross-party consensus. It defines the 2050 net zero target and defines a process to legislate 5-year carbon budgets – the cumulative volume of greenhouse gas emissions allowed at the national level for a 5 year period – 12 years ahead of time. These targets are statutory and open the Government to litigation if not met. The Act directs that these targets should be established by the Government based on advice from an independent expert body, the Climate Change Committee (CCC), which reports on progress to meet the targets to the Parliament. In addition to advising and monitoring compliance with the targets, the Climate Change Committee has become a trusted knowledge broker and has contributed to a more constructive debate on climate change issues (Caselli, Ludwig and Van Der Ploeg, 2021[1]). The Act also requires the Government to publish a climate change risk assessment every five years and to develop a National Adaptation Programme to respond to the risk assessment.

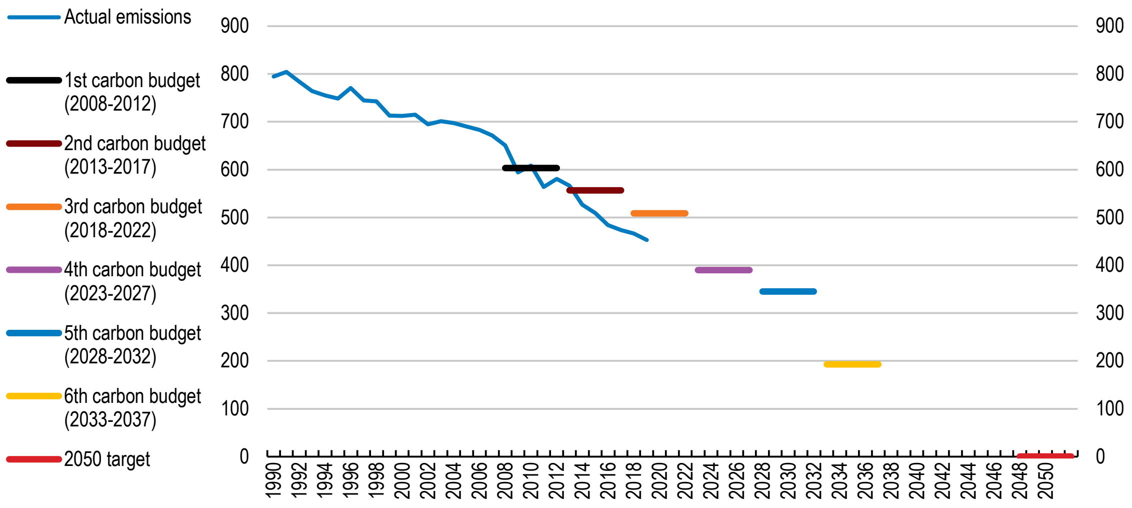
The permanent nature of the CCC has helped to ensure that the United Kingdom's overall direction of travel on climate change remains focused on the long-term target (Climate Change Committee, 2020[11]). The UK framework has inspired institutional set-ups in other countries, including Denmark, France, Germany, Mexico, New Zealand and Sweden. For example, France's 2015 Law on Energy Transition for Green Growth instituted five-year carbon budgets complemented by the creation of the High Council on Climate (HCC), a climate policy watchdog, in 2018 (OECD, 2021[12]).

Notwithstanding an overall strong institutional framework, a broad range of actors at different levels of government share responsibility for environmental outcomes and policies, broadly or in specific sectors. This may stand in the way of policy coherence. The Department of Business Energy and Industrial Strategy (BEIS) has the overall coordinating responsibility for climate change, complementary to the Climate Change Committee's role as a climate policy watchdog. The responsibility for environmental policy and regulation resides with the devolved administrations of England (served by the UK Government), Scotland, Wales and Northern Ireland. HMT is responsible for taxes, and a UK ETS authority with representatives from the UK and devolved governments is responsible for the UK ETS. Bank of England and the Financial Conduct Authority together play a leading role internationally to improve the way the financial sector can support the transition toward a sustainable economy. Line ministries are responsible for their respective sectors, coordinated by the Cabinet Committees on Climate Strategy and Climate Action (Climate Change Committee, 2021[3]). Building on existing structures to improve coordination between institutions and a shared understanding of each institution's role will be essential to achieve broad and deep emission reductions while minimising negative side effects.

Carbon budgets contribute to a stable and credible institutional framework for the government and the private sector. The United Kingdom met its first and second carbon budgets (2008-12 and 2013-17) and is on track to reduce emissions more than mandated by its third budget (2018-22) (Figure 2) (Climate Change Committee, 2021[3]). In 2021, following CCC's recommendations, the Government set the sixth carbon budget (CB6, 2033–37) to cut emissions by 78% by 2035 in order to set the United Kingdom on the path to net zero. For the first time the target also includes the United Kingdom's share of international aviation and shipping emissions.

Figure 2. Emission reduction targets have so far been met

Million tonnes of CO_2 emissions

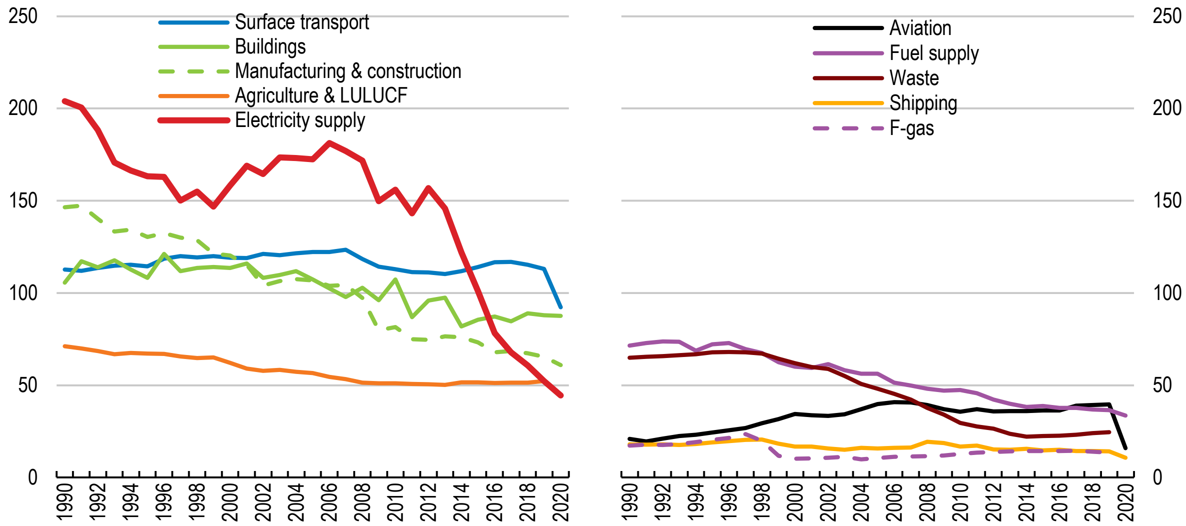


Source: OECD environment database (2021); Climate Change Committee.

Continuing this success in the future will require considerable efforts. Electricity production has so far been the largest source of emission reductions, with the shift in electricity generation from coal to gas and, in the past decade, to renewable energy. Sectoral shifts away from heavy industry towards services and higher value-added, less polluting manufacturing have also contributed (Figure 3) (Caselli, Ludwig and Van Der Ploeg, 2021[1]).

Figure 3. Emission reductions have been driven by greening electricity supply

Annual historical emissions in million tonnes of CO_2 by sector in the United Kingdom



Note: LULUCF is an abbreviation for Land use, land-use change and forestry. Fluorinated gases (F-gases) is a family of human-made gases used in a range of everyday products as well as industrial applications. The sectoral emissions for aviation and shipping include the United Kingdom's share of international aviation and shipping emissions, and are CCC estimates.
Source: (Climate Change Committee, 2021[3]); BEIS (2021) 2020 UK Greenhouse Gas Emissions, Provisional Figures.

Progress is slower in other sectors and projections show that without additional policies the UK is not yet on track to meet the fourth (2023 to 2027), the fifth (2028-2032) and the sixth budget (2033-2037), as well as the net zero target (Climate Change Committee, 2021[3]). This uneven progress reflects to a large extent the uneven coverage of effective policy instruments. In the past, it was possible to successfully concentrate policy action and emission reductions on particular sectors while shielding others. Such differentiation is no longer an option with the target of reaching net zero emissions. All sectors will need to be covered by effective policies going forward and early policy action will make the transition more gradual and less costly. Energy security concerns and surging fossil fuel prices related to Russia's invasion of Ukraine add to the urgency of the transition.

Key policy instruments for a net-zero economy

A successful transition to net zero requires a strategic, system-wide approach targeting all emitting sectors and new policy measures. Sectors including buildings, transport and agriculture will also need to accelerate their decarbonisation to meet the target (Table 1). Moreover, some sectors, such as industry, agriculture and aviation are difficult to decarbonise completely, and greenhouse gas removals (GGR), like land use and forestry and carbon capture and storage are therefore essential to compensate for the residual emissions arising from these sectors (Figure 4, Panel A).

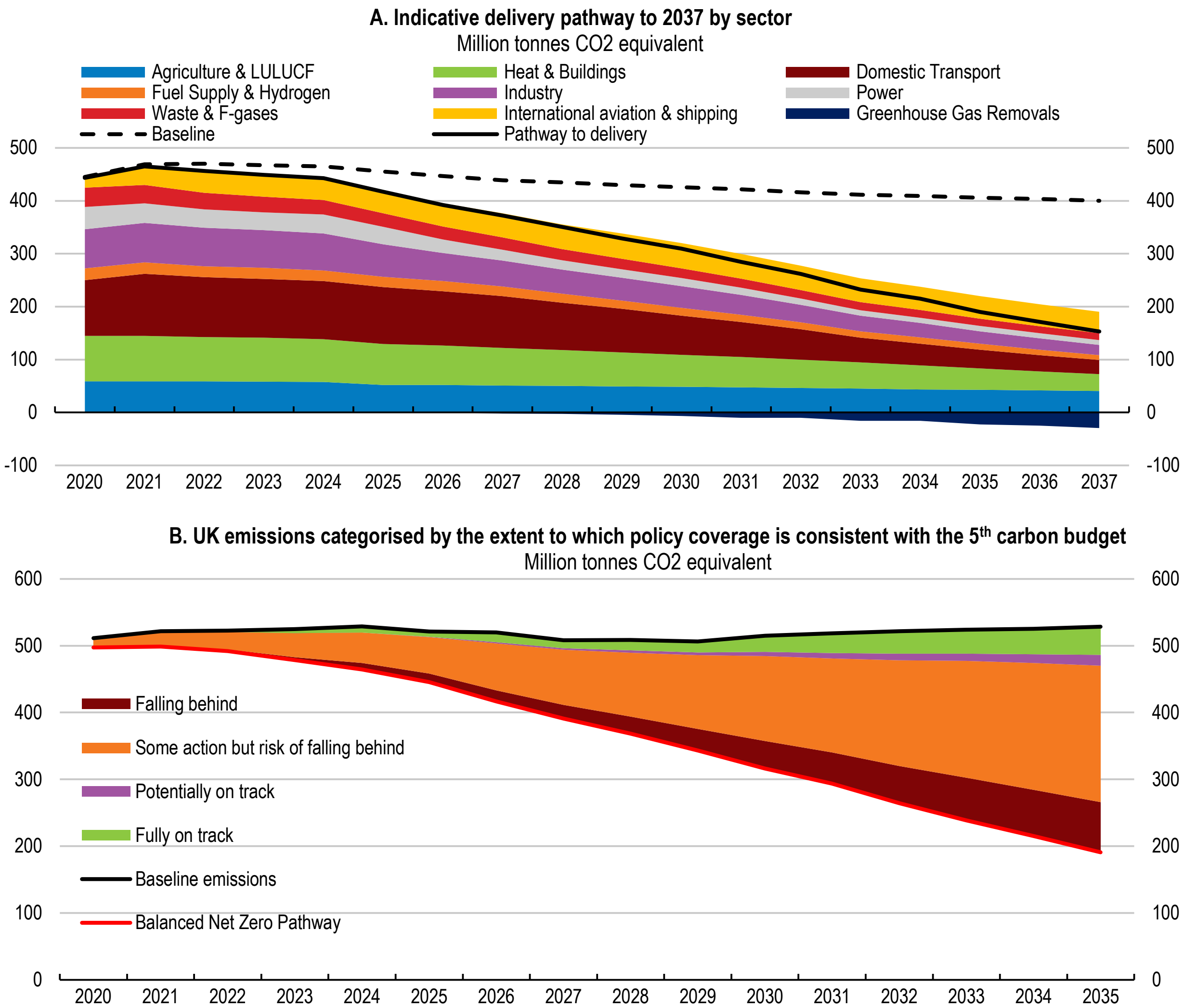
Table 1. Emission reduction policies, targets and recommendations by sector

Sector	Sector share of 2019 emissions	Reductions 1990-2019	2019-2030 reduction target	Main policies in place	Key recommendations as they apply to individual sectors
Electricity generation	11%	72%	71-76%	UK ETS, Carbon Price Support (tax), Contract for difference auctions in renewable energy, transmission network investments.	Boost public investment in transmission networks, green infrastructure, research, development and deployment, preferably through further expanding the use of competitive auction designs.
Transport	23% (in addition 4% in international aviation and shipping)	5%	35-45%	Excise duty on transport fuels, zero emission vehicle mandate planned phased in from 2024 to 2035 for cars and trucks, technology development support to manufacturers, public investment in charging infrastructure and tradable performance standards.	Include transport fuels in the UK ETS. Phase in zero-emission vehicles by regulation, as planned. Boost public investment in green infrastructure and public transit, preferably through competitive auction designs.
Heat and buildings	17%	17%	25-37%	Environmental and social charges on electricity are not matched for gas, which is the dominant heating source, building standards, various schemes to support energy efficiency and heat pumps, plan to phase out new fossil heating systems by 2035.	Include heating fuels in the UK ETS. Support investments in residential energy efficiency and clean heating systems, preferably through competitive auction designs. Increase energy efficiency requirements in building standards and introduce minimum requirements in rental housing, as planned. Accelerate the phasing-out of new fossil fuel heating systems. Boost public investment in research and development in residential energy efficiency and clean heating systems.
Agriculture, forestry and land use	12%	24%	17-30%	Support for tree planting and peat restoration, on-going agricultural support review to tilt support towards environmentally sustainable actions.	Include agricultural emissions and natural emission removals in the UK ETS. Tilt support towards competitive auctions and payments for ecosystem services. Boost public investment in research, development and deployment.
Fuel Supply	5%	61%	37-45%	UK ETS and extensive regulatory framework. Hydrogen clusters designated.	Boost public investment in research, development and deployment, preferably through competitive auction designs. Coordinate and support green infrastructure to transport hydrogen and carbon dioxide,
Manufacturing and refining	15%	53%	40-50%	UK ETS (large emitters).	Engage with the EU to avoid further trade barriers from its planned carbon border adjustment mechanism. Boost public investment in green infrastructure, research, development and deployment, preferably through competitive auction designs.
Waste and f-gases	5% (waste), 3% (f-gases)	61%	50-57%	Landfill charge, F-gas import quotas.	Include waste treatment, notably incineration, in the UK ETS.
Emission removals		N/A	1-12m tonnes per year by 2030	Support available for R&D and demonstration projects. Carbon capture and storage is in principle covered by the UK ETS if it relates to an ETS-covered emission source.	Include engineered emission removals in the UK ETS. Boost public investment in green infrastructure, research, development and deployment, preferably through competitive auction designs.

Note: The Government is consulting on the potential inclusion of emission removals and waste incineration in the UK-ETS (UK ETS Authority, 2022[13]).
Source: Net Zero Strategy; Author's compilation based on various sources.

The government's ten point plan for a green industrial revolution and the Net Zero Strategy (2021[2]) outlines a direction to reach net zero and intermediate targets, and signal a number of policy actions to come. The Net Zero Review (2021[6]) analyses key issues to take into account in policy design, and various sectoral strategies go more in-depth sector by sector, as discussed throughout this paper. These strategies are significant steps toward net zero, but urgently need to be followed up by concrete and comprehensive policies in sectors where policy coverage is inconsistent with targets, as identified by the Climate Change Committee (Figure 4, Panel B).

Figure 4. Policy needs strengthening to reach future targets



Note: Panel A: For more information on the assumptions of the baseline model see the technical appendix to the Net Zero Strategy report in the source. Panel B: For more information on the assumptions behind the baseline emissions see (Climate Change Committee, 2020[14]).
Source: UK Government (2021[2]), Net Zero Strategy: Build Back Greener; and Climate Change Committee, (2021[2]); BEIS (2021), 2020 UK Greenhouse Gas Emissions, Provisional Figures.

This section argues that emissions pricing should remain an important element of such an ambitious package of climate policy. Further improvement in financial sector regulations and more consistent use of shadow pricing in the public sector can help. Flanking measures will continue to be needed to complement carbon pricing such as regulation, standards, public investment, innovation incentives and other institutional reforms (Table 2). Education, good and easily accessible information, policy transparency and consistency can increase the efficiency and effectiveness of any of the policy options outlined below and reduce the overall cost of reaching emission targets (HMT, 2021[6]; D'Archangelo et al., 2022[9]).

Table 2. Assessment criteria for climate policies

Policy instrument	Cost efficiency	Acceptability	Implementation in the United Kingdom
Greenhouse gas taxes and emissions trading schemes.	Highly cost efficient. Dynamic incentives for continuous improvement and innovation. Revenue raising. Administrative costs depend if the tax base is already measured and other structures are in place.	Prices and impact on the cost of living are visible, which may lower acceptability. Revenue recycling can increase acceptability. Emissions trading scheme might be slightly more acceptable than a tax	The UK emissions trading scheme covers emissions in manufacturing, fuel supply, refining and air transport corresponding to around a quarter of domestic emissions. The Carbon Price Support is a carbon tax acting as a price floor in the ETS.
Taxes on polluting goods or activities.	Low to high depending on how broadly it is applied and to which extent the tax base is a close proxy to GHG emissions. Revenue raising.	Low acceptability because prices and impact on the cost of living are visible.	A landfill tax, a transport fuel excise duty and a climate change levy (not based on fuels' carbon content) exist. Charges on electricity consumption favour untaxed fossil fuels for residential heating.
Shadow prices in public procurement and cost-benefit analyses.	Potentially high, depending on implementation.	High acceptability, as it is financed by general taxation.	Carbon values are mandatory for public sector cost-benefit analyses.
Green financial policy, including updating policy to reflect systemic risks and strengthening disclosure requirements.	High to the extent that it contributes to correctly price and reduces financial risks and helps investors act on preferences for green investment.	High.	The Bank of England and the Financial Conduct Authority are at the international frontier of efforts to green financial sector regulation and supervision.
Environmental regulation	Low to high. High monitoring costs to identify most effective actions. Command and control regulations give little encouragement to innovate, but regulatory design can increase efficiency, for example with tradable performance standards.	Moderate.	Energy efficiency requirements in the building code. Input requirements in transport fuels. Tradable performance standards in car manufacturing. Hydrofluorocarbon import quotas.
Environmental subsidies	Low to high. Competitive design can boost cost-efficiency. Tends to pick winners and penalise entrants. Has a role to play to support research, development and deployment.	High.	Contract for Difference renewable energy auction scheme. GBP 26 billion of public spending on net zero planned from 2021 to 25.

Note : The table shows a subset of major policies. It is neither a complete list of policy options nor a complete list of existing UK policies.
Source: Adapted from Pisu et al. (2022[9]).

Net zero requires investment and will have economic and fiscal consequences

Effective climate policies are fully compatible with continued economic growth, but will have a number of economic consequences. Redesigning production processes or reallocating resources within firms could trigger productivity increases that are larger than those predicted by usual macroeconomic models. At the same time, some economic activities would consume more resources for the sole benefit of reducing emissions. Empirical evidence indicates that larger, more productive, low-emission and well-managed firms are better equipped to respond to more stringent policies and are thus able to raise their productivity and gain market share, while other firms can suffer negative effects (OECD, 2021[15]). Furthermore, market-based instruments minimise the social costs of reducing emissions by making it expensive to pollute while giving the polluter flexibility to reduce emissions in the least costly way (OECD, 2021[16]; Albrizio, Kozluk and Zipperer, 2017[17]).

New UK-specific integrated macro- and microeconomic modelling illustrates some of the economic and distributional consequences of an economy-wide policy package (Box 2). The most striking result of these simulations is that large emission reductions are realised regardless of the scenario considered, with higher carbon prices resulting in larger reductions, with fairly limited macroeconomic (Figure 5, Panel A) and distributional consequences.

Box 2. Net zero integrated macro- and microeconomic modelling

The OECD and LSE's Grantham Research Institute modelled UK-specific policy scenarios to move towards net zero in an integrated macro-micro framework. Results are presented as differences from a baseline of unchanged policies. Macroeconomic simulations feed into a microsimulation model to map macro-consistent distributional effects and redistribution packages.

The ThreeME model is a Computable General Equilibrium (CGE) model of neo-Keynesian inspiration with hybrid economy-energy features developed by OFCE (French Economic Observatory at Sciences Po), since 2008 with the support of the French Environmental Agency, ADEME and Netherlands Economic Observatory (ThreeME, 2022[18]). While the current study is the first time the model has been calibrated to the United Kingdom, it has earlier been used in French, Mexican, Indonesian, Tunisian and Dutch studies.

Three carbon price scenarios (low, medium and high) are modelled, converging over time towards the UK government's official shadow price trajectories ("carbon values") in their high, medium and low variants, with the following assumptions:

- Low carbon price: GBP 100 in 2030, GBP 189 in 2050.
- Medium carbon price: GBP 140 in 2030, GBP 378 in 2050.
- High carbon price: GBP 280 in 2030, GBP 568 in 2050.

The shadow price on emissions represents how much more profitable the sum of climate policies makes green production and consumption compared to polluting activities. It is modelled as a uniform carbon (equivalent) tax, but could in principle come from an emission trading scheme, regulations, subsidies or a combination of instruments. For reference, UK ETS allowances traded between GBP 68 and 88 in the first three months of 2022, but is complemented by renewable energy subsidies. One notable difference to price signals from regulations and subsidies is that the model operates with carbon tax revenues, which are redistributed to households and businesses according to different scenarios:

- "Standard" scenario: Redistribution to households and business sectors without transfers between firms and households. However, transfers can occur from carbon-intensive sectors to the rest of the economy.
- "Households" scenario: Total receipts are distributed to households.
- "Firms" scenario: Total receipts are distributed to firms.
- "Export exposure" scenario: As in the standard scenario, but the distribution of receipts among firms is adjusted to distribute more to sectors with high trade exposure (measured by the ratio of exports to output).
- "Neutral GDP" scenario: A share of revenue is withheld so that the overall GDP impact from 2040 to 2050 is zero. Remaining revenues are distributed as in the "Standard" scenario.

Residual emissions remain in all scenarios. This reflects three important features of the ThreeME model and of the scenarios considered: the model does not consider negative emissions, which will be needed to reach net zero; it is built around carbon pricing. the rigidity of demand for carbon intensive goods is governed in the model by elasticities of substitution that are calibrated on historical data – as such they may underestimate the potential for future adjustments.

Microsimulations are built on the ONS household expenditure survey (the Living Costs and Food Survey). For each revenue redistribution and carbon tax scenario in the macro model, four distribution scenarios are explored:

- Unmitigated impacts of the carbon tax.
- Uniform lump-sum redistribution of available tax receipts across all households.
- Calibrating a lump-sum redistribution to all households equal to the average carbon tax paid by households in decile 4, measured at the national level. This translates into a net gain for deciles 1-3, who pay less carbon taxes (but a larger share of their income) than higher-income households.
- Calibrating a lump-sum redistribution so that not a single decile 4 household in any region experiences a loss.

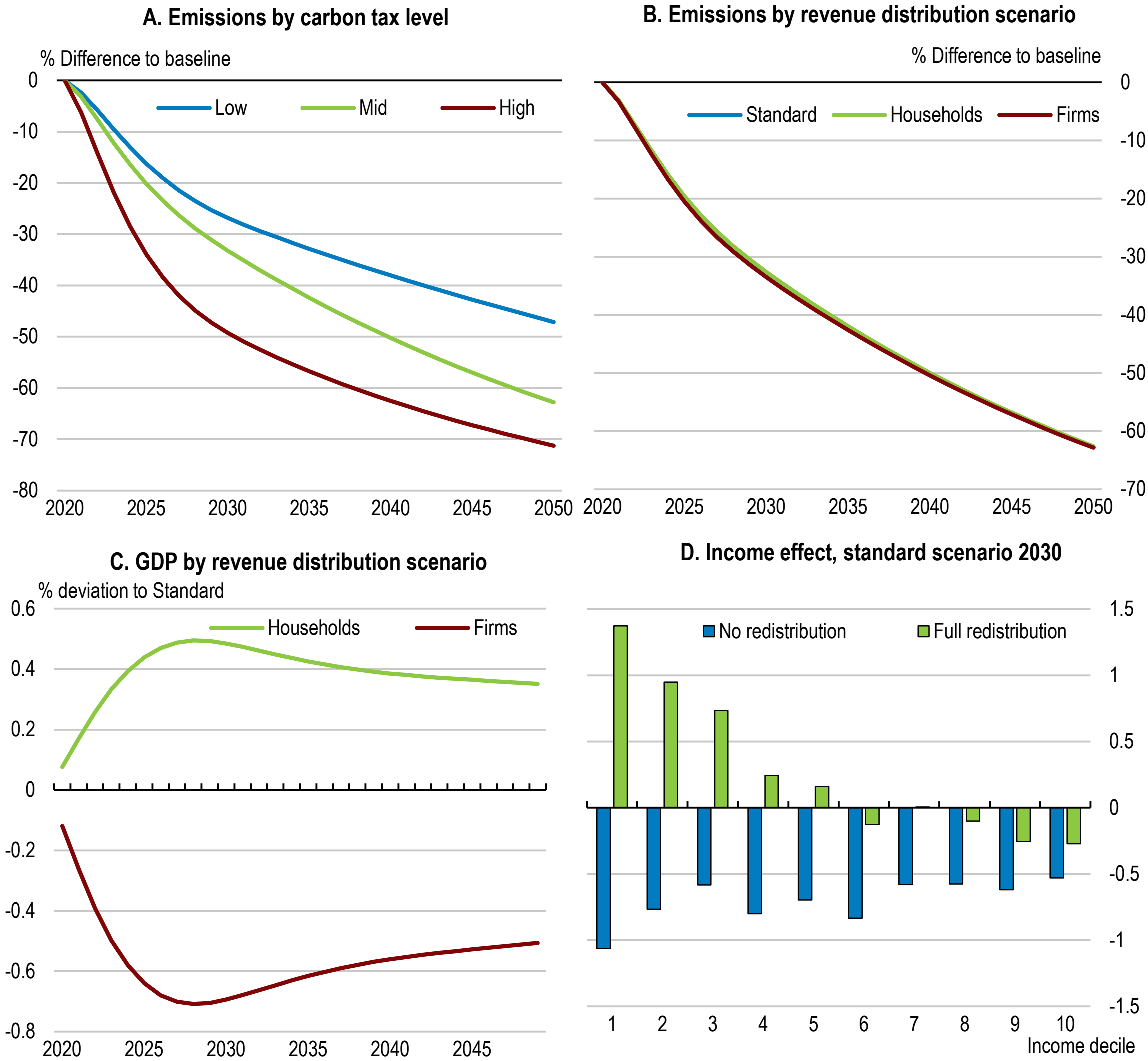
The two models are linked by disaggregating household consumption by the representative household in ThreeME using microdata from the expenditure survey, along with its corresponding carbon footprint. Macroeconomic outputs include GDP, investments, fiscal balance, inflation and labour market outcomes, as well as sectoral shares, while distributional consequences are available by income level, household type and geography.

Source: Pareliussen, Saussay and Burke (2022[8]).

A second main finding is that how proceeds are distributed have almost no effect on emissions (Figure 5, Panel B). How proceeds are handled within the broader fiscal stance and how they are distributed does play an important role in offsetting undesired macroeconomic and distributional effects. Indeed, the United Kingdom's experience in the 1980s and 90s when market reforms and rapid structural change boosted productivity and employment growth at the cost of rising unemployment (Card et al., 2004[19]) underscores the importance of sound macroeconomic policies supporting the transition.

Redistribution of carbon tax revenues affects GDP, with a higher fiscal multiplier if these revenues are distributed to households rather than firms (Figure 5, Panel C). The revenue is more than enough to offset negative income effects in the bottom half of the income distribution (Figure 5, Panel D).

Figure 5. Revenue redistribution matters little to emissions but can offset undesired effects



Note: The carbon price signal is here modelled as uniform carbon (equivalent) tax, but could in principle come from an emissions trading scheme, regulations, subsidies or a combination of instruments. The low carbon price starts at GBP 100 in 2030 and rises to GBP 189 in 2050. The medium carbon price starts at GBP 140 in 2030, rising to GBP 378 in 2050. The high carbon price starts at GBP 280 in 2030, rising to GBP 568 in 2050. Revenues are redistributed with shares equal to sector shares in output in the "Standard" scenario. All revenues are distributed to households and firms in the "Household" and "Firm" scenarios, respectively. Firms' proportional share of revenue is redistributed to firms according to their export exposure in the "Export exposure" scenario. The "Neutral GDP" scenario holds back a share of revenue (45%) to achieve average GDP growth as in the baseline from 2040 to 2050. Remaining revenues are distributed as in the "Standard" scenario. Panel D "full redistribution" implies lump-sum transfers to all households, summing up to carbon taxes paid by households.
Source: Pareliussen, Saussay and Burke (2022[8]).

Regardless of the overall GDP and distributional effects, the policies needed to reach net zero are set to trigger a large change in the industrial structure, with the transition in general benefitting those sectors and firms able to adapt and seize opportunities in the green economy. Sectors of the economy will be affected differently, as illustrated in Table 3, with notable output and employment losses in fuel supply and energy-intensive industries contrasting gains in employment and output in most other sectors. However, much of the structural change will take place within sectors. For example, construction, aviation and shipping are set to reduce emissions by 60-70% compared to the baseline while boosting output by 3-4%. This will require investments, notably in energy efficiency, zero emission energy and compatible equipment. In the GDP neutral scenario, annual investments are set to increase to 6% above baseline by 2050, not accounting for notable investments outside the scope of the model. Investments in major emitting sectors are set to increase considerably, from 10% in buildings to 39% in agriculture and land use, while the simulations do not point to a need for additional investments in the services sector, accounting for two-thirds of UK output, but less than 10% of emissions.

Table 3. Sectors of the economy will be affected differently by net zero

% difference from baseline, 2050

Sector	Emissions	Output	Investment	Employment	Wages
Agriculture and land use	-42%	-3.11%	39%	1.19%	6%
Aviation and shipping	-63%	3.28%	27%	4.68%	6%
Construction	-70%	3.74%	10%	3.96%	6%
Fuels	-60%	-35.52%	33%	-7.64%	-8%
Industry-energy intensive	-51%	-6.93%	22%	-3.63%	7%
Industry-non-energy-intensive	-65%	-1.81%	28%	-0.30%	6%
Services	-63%	-1.66%	0%	-0.33%	6%
Surface transport	-58%	0.92%	24%	1.59%	6%
Economy-wide	-63%	0.06%	6%	-0.03%	5%

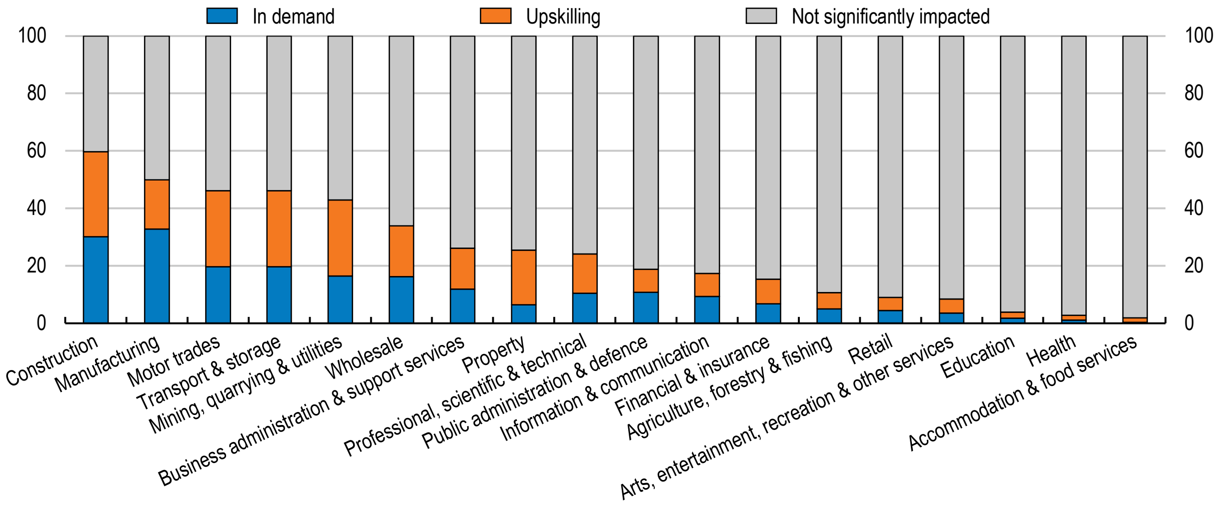
Note: The carbon price signal is here modelled as uniform carbon (equivalent) tax, but could in principle come from an emissions trading scheme, regulations, subsidies or a combination of instruments. Results based on a "Medium carbon price" starting at GBP140 in 2030, rising to GBP378 in 2050. The "Neutral GDP" scenario holds back a share of revenue (45%) to achieve average GDP growth as in the baseline from 2040 to 2050. Remaining revenues are distributed proportionately to sectors as in the "Standard" scenario.
Source: Pareliussen, Saussay and Burke (2022[8]).

The green economy will change the composition of the labour market, with falling employment and wages in some sectors offset by increases in others (Table 3) and changing skill needs also within sectors. This will only translate into a durable net employment gain to the extent labour supply meets demand in terms of both skills and location. There is a risk that unemployment increases throughout the transition if skills supply does not match demand. The United Kingdom has a resilient economy with flexible regulations in labour- and product markets that are likely to limit the pain of the transition. High-skilled people are more likely to be employed, adapt more easily to changing skill needs and have more access to training. The average level of education and skills is high in the United Kingdom, but a considerable share of the population also lacks basic literacy and numeracy skills strongly correlated with employment and the ability to learn new skills and adapt to a changing labour market.

The transition to net zero will provide new job opportunities and require new skills. Anticipating emerging skill needs and providing the up-skilling and re-skilling needed to limit labour market exclusion therefore should be an integrated part of policy measures to transit to net zero (OECD, 2021[20]). Supplying the skills needed for the green transition to ensure resilience of energy supply is all the more challenging in the context of current labour shortages and structural change following the pandemic, leaving the EU single market and on-going trends of digitalisation and automation. The UK's ability to address existing skill shortages and rapidly approaching future skill needs will depend partly on reskilling the existing workforce, but participation in continuing education and training is low (OECD, 2022[21]). As the economy transitions to net zero, some sectors will be affected disproportionally by the demand for specific skills (Figure 6). New economic activities and technology will need new skills and many existing occupations and sectors will experience a "greening" of their jobs, requiring workers to adapt (HM Government, 2021[22]). Some of the demand will rise quickly. For example, to meet the net zero target, the government aims to install 600 000 heat pumps per year by 2028 (HM Government, 2020[23]), but there were only 900 heat pump installers in the United Kingdom in 2019. It is estimated that between 7 500 and 15 000 heat pump installers need to be trained every year for the next seven years (HM Government, 2021[22]). Training opportunities should be of high quality and respond to identified skill needs, with increased use of guidance, counselling and statistical tools to target training and match it to identified skill needs (OECD, 2022[21]).

Figure 6. The transition to net zero will need substantial re- and upskilling

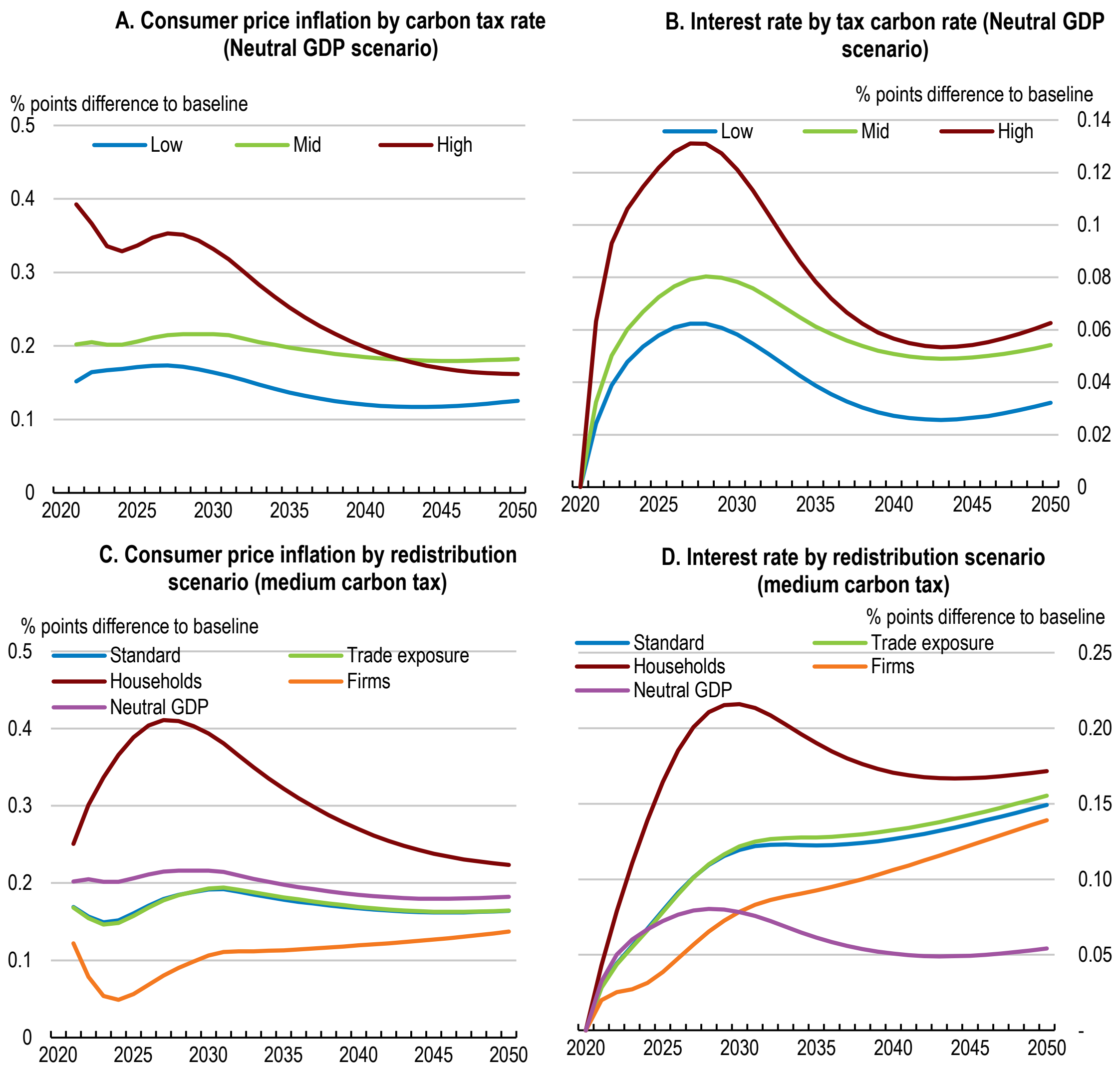
Jobs affected by net zero transition by sector, % of total jobs



Note: Jobs requiring upskilling: These are existing jobs that require significant changes in skills and knowledge. These include specialised jobs in the manufacturing and extractive sectors, such as petroleum engineers and heavy equipment operators, whose skills need to be adapted to a net-zero economy. Jobs in demand: These are existing jobs that are expected to be in high demand due to their important role in the net-zero economy. These include specialised positions in the green economy, such as wind turbine installers, but also the skills and expertise of welders, builders and engineers already working to build the infrastructure of a green economy.
Source: Place Based Climate Action Network (PCAN), Just Transition Jobs Tracker.

Structural change will drive competition for skills, and increasing investments boost the competition for capital resulting in higher wages, inflation and interest rates. Inflation and interest rates will increase with policy stringency (Figure 7, Panels A and B). Furthermore, inflation and interest rates will be sensitive to the overall macroeconomic stance and to which extent revenue is recycled to parts of the economy with high fiscal multipliers (Figure 7, Panels C and D). However, the inflationary effects of the green transition are likely to be moderate compared to recent price increases.

Figure 7. Inflation and interest rates are sensitive to policy stringency and revenue use

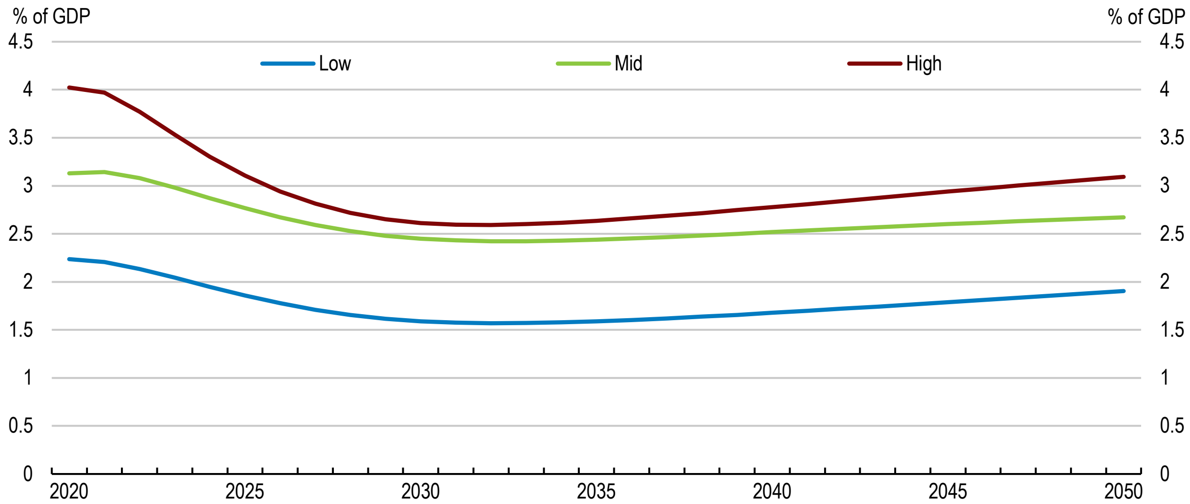


Note: The carbon price signal is here modelled as uniform carbon (equivalent) tax, but could in principle come from an emissions trading scheme, regulations, subsidies or a combination of instruments. The low carbon price starts at GBP 100 in 2030 and rises to GBP 189 in 2050. The medium carbon price starts at GBP 140 in 2030, rising to GBP 378 in 2050. The high carbon price starts at GBP 280 in 2030, rising to GBP 568 in 2050. Revenues are redistributed with shares equal to sector shares in output in the "Standard" scenario. All revenues are distributed to households and firms in the "Household" and "Firm" scenarios, respectively. Firms' proportional share of revenue is redistributed to firms according to their export exposure in the "Export exposure" scenario. The "Neutral GDP" scenario holds back a share of revenue (45%) to achieve average GDP growth as in the baseline from 2040 to 2050. Remaining revenues are distributed as in the "Standard" scenario.
Source: Pareliussen, Saussay and Burke (2022[8]).

Fiscal effects of the transition depend largely on the policy instruments used. Fiscal effects include direct expenditures, indirect effects as people and businesses adapting production and consumption change the tax base, eligibility for transfers and public services, and direct effects on tax revenue. Direct pricing instruments generate revenues, but a diminishing tax base will over time erode these as well as current revenues charged on fossil fuels. OBR (2021[7]) estimates carbon tax revenues to peak immediately at 1.5% of GDP and gradually decline towards 0.5% in 2050 (despite a steadily increasing tax rate) as the tax base shrinks. The impact of regulations also depends on how they affect tax bases. For example, the base for the fuel excise duty will erode as fossil fuel cars are phased out over the next couple of decades, with a potential revenue loss corresponding to 1.6% of GDP (OBR, 2021[7]). Findings by Pareliussen, Saussay and Burke (2022[8]) support the OBR's finding that the tax base erodes over time, but with considerable initial revenue gain (Figure 8). A temporary increase in greenhouse gas related revenues from the UK ETS or a carbon tax may coincide with the need to subsidise positive externalities and compensate those most affected by the transition (HMT, 2021[6]). However, given the current environment of historically high energy prices, implementation should be delayed until energy prices show signs of normalisation. A considerable share of benefits from investments made during the transition will fall on future generations, while adjustment costs will fall on current generations. A degree of debt financing could therefore be warranted, within an overall responsible fiscal and macroeconomic policy framework.

Figure 8. Emissions pricing can provide fiscal space to support the transition

Carbon revenues by tax rate



Note: The carbon price signal is here modelled as uniform carbon (equivalent) tax, but could in principle come from an emissions trading scheme, regulations, subsidies or a combination of instruments. The "Neutral GDP" scenario holds back a share of revenue (45%) to achieve average GDP growth as in the baseline from 2040 to 2050. Remaining revenues are redistributed with shares equal to sector shares in output. The low carbon price starts at GBP 100 in 2030 and rises to GBP 189 in 2050. The medium carbon price starts at GBP 140 in 2030, rising to GBP 378 in 2050. The high carbon price starts at GBP 280 in 2030, rising to GBP 568 in 2050.
Source: Pareliussen, Saussay and Burke (2022[8]).

Expanding the coverage of emissions pricing to reach net-zero

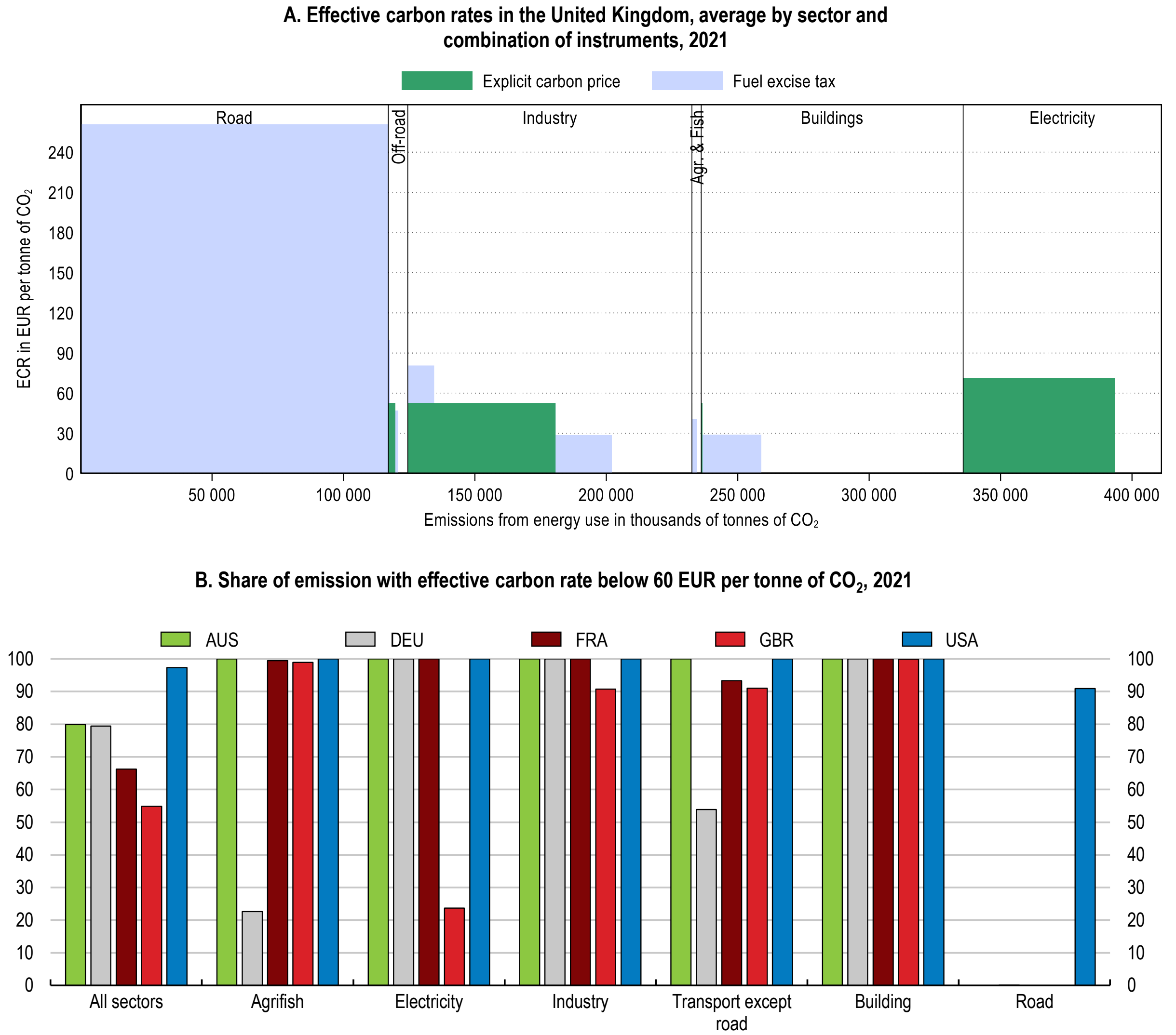
The main policy instruments available to price greenhouse gas emissions directly are taxes on greenhouse gas emissions and "cap-and trade" emissions trading schemes. The United Kingdom and other OECD countries rely on both emissions trading schemes and CO_2 (equivalent) taxes. Emission pricing has been essential for the United Kingdom to nearly eliminate coal from electricity production, as discussed below. In an emissions trading scheme, tradable emissions permits, summing up to the overall cap on emissions, are issued and sold or allocated for free to participants who can trade them freely. The cap is reduced over time to meet emission reduction targets. An emissions trading scheme sets the quantity of emissions ("the cap") and lets the market find the price, while a tax sets the price and lets the market set the quantity (D'Archangelo et al., 2022[9]). The two systems share their tax base, so systems and requirements for measuring and reporting are similar. In addition, an ETS requires market infrastructure already existing in the United Kingdom, and similar to other financial and commodity markets. The environmental effectiveness of these two instruments is largely equivalent, as the ETS cap can be adjusted over time to hit a desired price level, and a tax can be adjusted over time to hit a desired quantity. For these reasons, the policy choice between a CO_2 equivalent tax and an ETS should be a pragmatic one.

The United Kingdom set up the world's first multi-industry carbon trading system in 2002 as a pilot for the EU Emissions Trading Scheme (EU ETS). The UK Emissions Trading Scheme (UK ETS) – a spin off from the EU ETS upon departure from the EU – is the main explicit pricing instrument in the United Kingdom. The scheme covers approximately 25% of current emissions, including electricity generation, manufacturing, refineries, petroleum extraction, and domestic, UK-EEA, and UK-Gibraltar aviation. It follows similar rules to the EU ETS with a few differences, such as a slightly different cost containment mechanism and a carbon tax (the Carbon price support) acting as a price floor which is seen as instrumental in near-eliminating coal from electricity supply, as explained below. A transitional auction reserve price of GBP 22 per allowance representing one metric tonne of CO_2e might be replaced by a supply adjustment mechanism in the future. The Government has issued a call for evidence to align the ETS cap with the net zero objective by January 2024, including the level of the cap, free allocations, expanding the scope of the ETS within existing sectors and to additional sectors such as shipping, waste, and energy-from waste as well as greenhouse gas removals (UK ETS Authority, 2022[13]). Moreover, other price-based measures target other sectors. The fuel excise duty incentivises emission reductions in road transportation, the climate change levy is a tax charged on business and public sector energy use. The waste sector is subject to a landfill tax, and import quotas of F-gases create scarcity reflected in market prices.

The main problem in the United Kingdom, as in most other countries, is that a considerable amount of emissions are not covered by pricing instruments at all, or only by very weak instruments (Figure 9). Reduced VAT rates, tax reliefs and other supports subsidise amongst others fossil fuel consumption on domestic fuel and power supply, domestic passenger transport, diesel used in off-road vehicles and kerosene for heating (NAO, 2021[24]). The "Ring-fence" corporate income tax enables a 100% first year allowances for capital expenditure by the oil and gas sector. In addition, operators can fully deduct decommissioning costs from their corporate profits in the year in which they are incurred. However, contrary to some other G7 countries, the United Kingdom is not tracking support measures with potential environmentally harmful impacts. Such tracking should commence in order to quantify the extent of harmful support and adjust policy accordingly.

Compared with other European OECD countries, the price signals from the sum of tradeable emission permit prices, carbon taxes and fuel excise taxes ("effective carbon rates") are high in the road transport and electricity sectors but low in others, especially in the residential and commercial sectors (Figure 9, Panel A). In 2021, only 45% of carbon emissions from energy use were priced above EUR 60 per tonne of CO_2. The complex system of explicit (ETS, Carbon price support) and implicit (climate change levy, fuel duty and different tax treatments) carbon prices sends inconsistent signals across sectors and fuels (Figure 9, Panel B) (OECD, 2022[4]). Departments have a limited understanding of the environmental impact of their policies (NAO, 2021[24]). Moreover, renewed freezes of the fuel duty and vehicle excise duty for heavy goods vehicles, suspension of the heavy goods vehicle road user levy and reduced rates for air passenger duty for domestic flights run counter to climate objectives (OECD, 2022[4]). More recently, the fuel duty was temporary cut (until March 2023) by GBP 0.05 per litre, corresponding to GBP 22 per tonne CO_2 for petrol and GBP 19 for diesel, to respond to soaring prices in the context of Russia's invasion of Ukraine.

Figure 9. Carbon prices differ considerably across sectors



Note: Emissions-weighted average by sector and combination of instruments (explicit carbon price only, fuel excise only, both, none) in each country. The ETS price is the average ETS auction price for the first semester of 2021, with the exception of the UK where it is based on information for the period in which they were operational (UK: 19/05/2021-30/06/2021). Where applicable, ETS coverage estimates are based on the OECD's Effective Carbon Rates 2021, with ad-hoc adjustments to account for recent coverage changes. Emissions refer to energy-related CO2 only and are calculated based on energy use data for 2018 from IEA, World Energy Statistics and Balances 2020. The figure includes CO2 emissions from the combustion of biomass and other biofuels. For more information see source

Source: OECD (2021), Carbon Pricing in Times of COVID-19: What Has Changed in G20 Economies?, OECD, Paris, https://www.oecd.org/tax/tax-policy/carbon-pricing-in-times-of-covid-19-what-has-changed-in-g20-economies.htm

The United Kingdom is consulting on expanding the scope of the UK ETS in existing sectors, such as: the upstream oil and gas venting sectors, and to sectors currently not subject to an explicit carbon price, including shipping, waste, and energy-from waste. Expanding ETS coverage across domestic sectors can increase policy efficiency and reduce volatility, as factors driving emissions vary across different sectors of the economy. Such expansion should also be technically straightforward for some major emission sources not covered by the Government's proposal. Notably, fuels for transportation, machinery and heating could be included upstream in the value chain based on the carbon content of refined products, as was done in Quebec, California and the German carbon pricing system that became operational in

January 2021 (D’Archangelo et al., 2022[9]). Including upstream emissions directly in the UK-ETS would necessitate legal amendments, as ETS emissions are currently defined at the point of emissions. Other sources, such as livestock and dairy farming and land-use emissions would be more challenging to include due to technical and measurement issues, some of which could be resolved. The government does not currently propose to include agricultural emissions, but is calling for evidence on monitoring and reporting of emissions from agriculture. The New Zealand emissions trading scheme does for example include forestry, and agricultural emissions are set to be included in the ETS or in a separate pricing mechanism from 2025 (See Box 4 below).

Linking the UK ETS to the EU ETS remains an option to “give serious consideration”, as stated in the EU-UK Trade and Cooperation Agreement (European Commission, 2021[25]). Linking the UK to the EU ETS carries advantages and disadvantages, but is technically straightforward. It can be done by full participation, as is the case with EFTA countries in the EU ETS, or by formal linking through a bilateral or international agreement. In an international agreement, countries mutually accept each other’s emission certificates. A third option is indirect linking in which both schemes unilaterally accept a common asset, for example external offsets governed by the Paris agreement or allowances from a third-party ETS.

Linking emissions trading schemes in general enhances overall welfare, since it increases the price in the scheme with lower-cost abatement available (or a more generous cap) and lowers it in the system with a high marginal cost of abatement (or a tighter cap). The marginal emission reduction determining the market price in an ETS is often realised by switching electricity production from coal to gas. Since coal and gas are internationally traded, this fuel switching cost will act in the direction of convergence even in the absence of linking. This mechanism has led prices in the UK ETS and EU ETS to largely move in tandem since the UK’s departure. Industry expectations about a future link between the two systems might play a role as well. An additional advantage of linking is that it would make it easier for the UK financial sector to continue to play an important role in a growing market. However, linking can be politically difficult, since it will mean a transfer from the high-price to the low-price system where permit holders can sell their surplus for a profit until prices align. Formal linking also reduces the scope to unilaterally expand and develop the ETS or related policies like a UK specific approach to carbon leakage in line with domestic policy targets in future years.

Both the UK ETS and the EU ETS have built-in market stabilisation mechanisms to avoid extremely high or low prices. When the UK ETS Cost containment mechanism (CCM) is triggered, the UK ETS Authority, made up of HM Government, the Scottish Government, Welsh Government and Northern Ireland Executive, work together to consider what intervention, if any, HM Treasury should authorise. The ETS Authority decided not to release any additional allowances into the market when CCM was triggered for the first time in December 2021. This decision was prudent, as high prices reflected commodity market fundamentals, notably a shortage of natural gas. A release of additional allowances would not have changed this and would only have limited effects on energy bills, of which ETS compliance constitutes a small share.

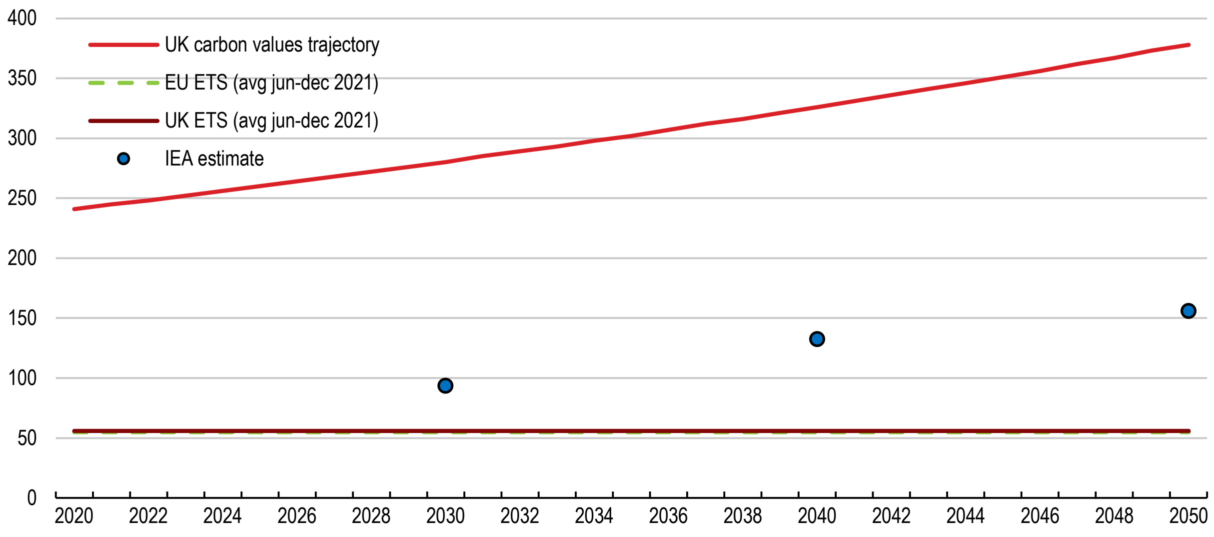
Consistent use of shadow prices in public spending can improve efficiency and policy coordination

The United Kingdom has a robust framework for monitoring and evaluating public spending programmes. The Government’s ‘green book’ describes how major public sector investment projects are assessed and helps government officials appraise the costs and benefits of policies, projects and programmes. A review of the green book in 2020, however, concluded that it had failed to support the Government’s objectives of reaching net zero (HMT, 2020[26]). The new green book requires all projects to consider their impacts on carbon emissions, whether or not they directly target the net zero objective, it provides further guidance on how emissions should be assessed and clearer objectives (OECD, 2022[4]), which is a significant step forward.

Greenhouse gas emissions values ("carbon values") are used across the government for valuing impacts on GHG emissions resulting from policy interventions. The United Kingdom first integrated carbon values in green book cost benefit policy appraisals and ex-post policy evaluations in 2002. Since 2009, a 'target consistent' approach has been used to estimate the values, where these are calculated as the marginal abatement cost of meeting domestic targets, rather than a "(global) social cost of carbon" approach. The cost trajectory published in 2021 and set to be updated every five years extrapolates IPCC estimated carbon values in 2040 (GBP 326 in 2020 prices) with a 1.5% growth rate (BEIS, 2021[27]; HMT, 2020[28]). A social cost of carbon approach to shadow pricing, the approach followed by for example the United States, is in principle better aligned with climate science and the global nature of climate change. However, the target consistent approach is appropriate in the UK context, as it aligns the official cost trajectory with national legally binding ambition and the cost of reducing emissions under national jurisdiction. The transparent methodology is also appropriate, as true carbon values are inherently uncertain and a more complex methodology would likely not improve accuracy.

Carbon values could be used more actively to coordinate and speed up policy development across government. A clear mandate and clear expectations for Departments to bring sectoral policies in line with the carbon values would help optimise investment decisions and reduce uncertainty and cost for the private sector (HMT, 2021[6]). However, carbon values are very high compared to current carbon prices in the United Kingdom and elsewhere (Figure 10). This indicates that the combined incentives facing the private sector from carbon pricing, regulation and subsidies will need to increase considerably to reach net zero. It also calls for phase-in periods in the case of explicit pricing instruments and regulations to allow people and businesses to adapt.

Figure 10. The UK carbon trajectory is considerably higher than price signals facing the private sector



Note: UK carbon values represent net zero consistent marginal abatement cost. IEA estimates for net zero consistent CO_2 prices for electricity, industry and energy production in selected advanced country regions, consider the effects of other policy measures alongside CO_2 pricing, such as coal phase-out plans, efficiency standards and renewable targets. These policies interact with carbon pricing; therefore the marginal cost of abatement can be considearbly higher than the CO_2 price shown in the figure. More information can be found in the World Energy Outlook table B.2.
Source: UK Government: Valuation of greenhouse gas emissions: for policy appraisal and evaluation; Ember Climate, Daily Carbon Prices; IEA World Energy Outlook; and OECD (2022), Economic Outlook: Statistics and Projections database.

The Climate Change Committee recommended a "net zero test" for new policy initiatives, as today's decisions on for example road building, fossil fuel production, planning and expansion of waste incineration may be incompatible with net zero and may send mixed messages to the public (Climate Change Committee, 2021[3]). Cost-benefit analyses integrating carbon values are already in principle testing whether new policy initiatives align with the net zero target. Instead of another net zero test, additional efforts should ensure cost-benefit analyses integrating carbon values are implemented consistently across government, and that the projects with the highest net benefits are pursued.

Garnering the financial sector to finance the transition to net-zero

The United Kingdom has been at the forefront of global efforts to green the financial system. The financial sector has an important role to play in financing the green transition, and the United Kingdom's role as a global financial hub extends the benefits of greening finance well beyond national borders. However, the financial sector does not work in isolation; it can only be a facilitator, delivering climate-friendly investment in response to effective policies. A clearer transition policy path would allow the financial sector to better support the green transition.

Demand for more environmentally friendly investment portfolios combined with insufficient emission reduction policies and lacking climate risk assessment and disclosure has left a vacuum in the United Kingdom and elsewhere. There is a need for the public sector to step in to channel finance to its best uses and avoid counterproductive market dynamics such as blanket portfolio exclusions of firms or sectors on simple criteria including their current emission intensity. These firms provide valuable products and services, and they can potentially play an important part in reducing emissions if spurred by conscious shareholders and policy action (BoE, 2021[29]). From April 2022, over 1 300 of the largest UK-registered companies, including traded companies, banks and insurers and private companies with over 500 employees and GBP 500 million in turnover will be mandated by law to disclose climate-related financial information. There is also scope to develop new financial products and scale up existing ones, such as "green mortgages" explicitly taking into account savings from residential energy efficiency investments (HMT, 2021[6]).

The United Kingdom is working actively to improve the UK's financial sector resilience by better assessing and disclosing risks from climate change and transition risks from a changing policy and investor landscape, and integrating these risks into the supervisory framework. Such efforts, along with a taxonomy of environmentally friendly activities will make environmentally friendly investment opportunities more attractive relative to polluting ones. In 2021, HM Treasury extended the remits of the Monetary Policy, Financial Policy and Prudential Regulations Committees of the Bank of England to also include supporting net zero and the green transition (HMT, 2021[30]; HMT, 2021[31]; HMT, 2021[32]). A similar extension was made to the recommendations for the Financial Conduct Authority (HMT, 2021[33]). The United Kingdom also issued its first green bonds in 2021, raising GBP 16 billion for clean transportation, renewable energy, energy efficiency, pollution prevention and control, living and natural resources and climate change adaptation in accordance with the Green Financial Framework (HMT, 2021[34]).

The Bank of England and the Financial Conduct Authority were the first central bank and regulator to set supervisory expectations for banks and insurers on how to manage climate-related financial risks in 2019. These expectations covered governance, risk management, scenario analysis and disclosure (BoE, 2019[35]). This was followed by a letter to regulated firms in 2020 and guidance on climate-related financial risk management by the end of 2021. A subsequent report discusses consequences for the regulatory capital framework (PRA, 2021[36])The Financial Conduct Authority and the Bank established the Climate Financial Risk Forum (CFRF) in 2019, bringing together representatives of banks, insurers and asset managers to build capacity and share best practices. In June 2020, the CFRF published its guide to help the financial industry approach and address climate-related financial risks (CFRF, 2020[37]), with more detailed guides focussing on risk management, scenario analysis, disclosure, innovation and climate data and metrics following in 2021.

Following an exploratory stress test covering insurance companies in 2019 (BoE, 2019[38]), the Bank launched the Climate Biennial Exploratory Scenario on financial risks from climate change (CBES) in 2021, with results expected in May 2022. This stress test explores the resilience of the UK financial system to the physical and transition risks associated with three scenarios (Table 4), with the aim of capturing and understanding climate related risk across the financial system and interactions between banks and insurers. It will not be used by the Bank to inform capital requirements (BoE, 2021[39]). Results from the CBES revealed notable data gaps and large variation in individual banks and insurance companies climate risk assessment capabilities. The exercise shows that climate risks are likely to create a drag on the profitability of UK banks and insurers, with the lowest cost associated with the scenario with early, well-managed action. Insufficient action will hit businesses and households vulnerable to physical risk hard. At the same time it is in the interest of the financial sector to manage climate-related financial risks in a way that supports the green transition over time (BoE, 2022[40]). The Bank is also working to climate-proof its operations by publishing its own climate-related financial disclosure annually, aligned with the Task Force on Climate-Related Financial Disclosures recommendations; by taking steps to greening their corporate bond holdings (BoE, 2021[29]; BoE, 2021[41]); and by reducing the climate footprint of its physical operations.

Table 4. The UK financial sector is exposed to climate change related risks

Summary of impacts in 2021 Climate Biennial Exploratory Scenarios

	Early action	Late action	No additional action
Transition risks	Medium, with an early and orderly transition starting in 2021 and shadow prices peaking at USD 900.	High, with a late and disorderly transition starting in 2031 and shadow prices peaking at USD 1100.	Limited, with limited transition happening and shadow prices remaining low at USD 30.
Physical risks	Limited, with mean global warming up 1.8 degrees Celsius and UK sea level rising 16 cm by 2050.	Limited, with mean global warming up 1.8 degrees Celsius and UK sea level rising 16 cm by 2050.	High, with mean global warming up 3.3 degrees Celsius and UK sea level rising 39 cm by 2050.
Impact on output	Temporarily lower, with UK growth rates averaging 1.4% year 6-10, 1.5% year 11-15 and 1.6% year 26-30.	Sudden contraction, with UK growth rates averaging 1.5% year 6-10, 0.1% year 11-15 and 1.6% year 26-30.	Permanently lower, with UK growth rates averaging 1.4% year 6-10, 1.4% year 11-15 and 1.2% year 26-30.

Note: Colour codes correspond to different levels of risk: green = limited; orange = medium; red = high. Shadow prices relate to the United Kingdom, and are expressed in 2010 USD. Scenarios run from 2021 to 2050. Early Action: the transition to a net-zero economy starts in 2021 so carbon taxes and other policies intensify relatively gradually over the scenario horizon. Late Action: The implementation of policy to drive the transition is delayed until 2031 and is then more sudden and disorderly, with material short-term macroeconomic disruption. No Additional Action: no new climate policies are introduced beyond those already implemented.
Source: Bank of England (2021[39]).

The United Kingdom engages to promote best practices to address climate risks to the financial sector and furthering understanding of the macroeconomic impacts of climate under different transition paths in various international fora including the OECD, G7, the IMF, the Basel Committee on Banking Supervision (BCBS), the Sustainable Insurance Forum (SIF) and the Financial Stability Board (FSB). The Bank of England founded the Network of Central Banks and Supervisors for greening the Financial System (NGFS) together with Banque de France and six other central banks and financial supervisory authorities in 2017. This group aims to share best practices and contribute to the development of environment and climate risk management in the financial sector. Its purpose is to define and promote best practices to be implemented within and outside of the membership of the NGFS and to conduct or commission analytical work on green finance. NGFS has since grown to 114 members and 18 observers (as of 13 April 2022), including the Financial Conduct Authority (NGFS, 2021[42]). It has issued six core recommendations covering financial stability monitoring and supervision, own-portfolio management, bridging data gaps, awareness and intellectual capacity, internationally consistent disclosure and supporting the development of a taxonomy of economic activities.

Engaging in international cooperation and market mechanisms

Potential efficiency gains from better aligning carbon prices do not stop at national borders. Engaging in international cooperation and market mechanisms can enhance welfare by reducing emissions where it is less expensive. Linking to the EU ETS is a concrete option under consideration, with advantages and disadvantages as outlined above. The Paris agreement allows offsetting residual emissions by emission reductions abroad. Any emission rights transferred will be added to the transferring country's emission cap (National determined contribution, NDC). This eliminates in principle the concerns of the Kyoto Protocol that project-based emission reductions might be inaccurately measured, and therefore indirectly increase emissions outside of the project boundaries (Box 3).

Box 3. Cooperative approaches to reach Paris Agreement emission pledges

In the Kyoto Protocol, countries with quantified commitments (Annex 1 countries) could pool their emission reduction commitments and reach them collectively, as was done by members of the European Union. Alternatively, deficit countries could buy emission quotas from countries with a surplus, or from certified emission-reducing projects abroad. Similar mechanisms to reach national targets (National determined contributions, NDCs) in cooperation, or by trading emission reductions in an international framework supervised by the Conference of the Parties (COP), exist in the Paris agreement Article 6. COP 26 in Glasgow operationalised these mechanisms with more detailed rules ("The Paris Rulebook").

A central principle to avoid double-counting is that if emission rights (Internationally Transferred Mitigation Outcomes, ITMOs) are transferred, these count tonne for tonne as emissions in the transferring country. A hypothetical example illustrates how this works: Should the United Kingdom decide to accept European Union Allowances (EUAs, the emission rights traded in the EU ETS) as valid currency in the UK ETS, and to assign zero allowances to UK ETS entities, these entities would need to buy EUAs equal to their emissions. Their emissions would in this case count towards the EU NDC, while the UK ETS sector would have achieved net zero emissions.

Source: UNFCCC (2015[43]; 2021[44]).

The United Kingdom, including its financial sector, has considerable experience in developing and participating in carbon markets, and should continue to engage constructively, evolving the international rulebook and facilitating private sector involvement. However, such trade should be handled with care to ensure that it does not contribute to higher global emissions. If trading with countries whose NDCs are inconsistent with net zero, the prospect of selling emission rights might discourage them from tightening their targets. Furthermore, such trade depends on trust that trading partners will indeed fulfil their net zero-consistent NDCs, demonstrated by clear plans and timely policy action (Climate Action Tracker, 2021[45]).

Well-designed subsidies, regulations and standards should be part of the policy mix

Regulation and subsidies can be valuable components of the policy mix where cost-effective measures are targeted. However, ill-designed and uncoordinated regulations, subsidies and pricing instruments may increase the cost of decarbonisation by complicating performance monitoring, blurring price signals and blunting economy-wide incentives. Furthermore, traditional subsidies and command and control regulations give weaker "dynamic" incentives to research, develop and go above and beyond set standards (D'Archangelo et al., 2022[9]), and they risk being less effective and more costly than assumed before implementation (HMT, 2021[6]). Ex-post performance reviews and evaluations can help, and should be an integral part of policy planning and design (OECD, 2014[46]). Given these pitfalls, regulations and subsidies need to be well-designed and selectively targeted to specific well-identified cases of market failure. These are often sector-specific and therefore discussed in their sector context below. Some considerations nonetheless apply across sectors:

Some sectors and emissions sources, like aviation, shipping, heavy goods transportation and meat production will require considerable technological development to decarbonise (IEA, 2021[47]). The necessary research and development (R&D) will be underfunded absent policies assigning a cost on greenhouse gas emissions. R&D funding suffers an additional major market failure, as the social value of R&D exceeds the private value in general (positive externality). Asymmetric information between the technology developer and potential lenders can lead to liquidity constraints. Subsidising green R&D can help overcome these market failures. There is also a role for policy to take on the risk to bring to market untested and uninsurable solutions, and steepening technology learning curves by scaling up more developed technologies. Policy support can also help overcome other market failures putting new technologies at a disadvantage, such as a bias towards status quo (inertia) and a poor understanding of the benefits from new technologies (information failures). Coordination failures may prevent network effects, which occur when the value of a service increases with the number of people using the service, form being realised (Dechezlepretre and Cervantes, 2022[48]). This can for example happen in the case of electric vehicle charging stations, hydrogen and CO_2 pipelines (HMT, 2021[6]). However, the risk of public intervention distorting competition is higher for technologies at or close to commercialisation, and these risks need to be properly understood and addressed in policy design. Subsidies to low-carbon technologies are systematically the most favoured climate policy compared to carbon pricing, bans or regulations. Similarly, support for a carbon tax is largest if its revenues are used to fund green infrastructure or to subsidise low-carbon technologies (Dechezleprêtre et al., 2022[10]).

The United Kingdom Contract for difference (CfD) auctioning scheme for renewable energy licences is a good practice example of cost efficient subsidy schemes (LCCC, 2021[49]). Reaching net zero and reducing dependence on imported fossil fuels call for accelerating CfD auctions and lifting the 5GW cap on solar and onshore wind in the coming auction round. Other prominent public support vehicles, including the new UK Infrastructure Bank and the Scottish National Investment Bank, will help mobilise green private investment and promote green finance. All in all, the 2021 Autumn Budget and Spending Review outlines the public spending contribution to Net Zero (GBP 26 billion) and other green objectives (GBP 4 billion) over 2021-25 (OECD, 2022[4]).

Regulation can be particularly useful to entice households to invest in less-polluting houses and heating systems, cars and appliances. While businesses unresponsive to explicit pricing signals will lose market share and responsive ones will grow in a competitive market, this is not the case for households. Market imperfections including information failures, liquidity constraints, inertia, split incentives and hyperbolic discounting will therefore blunt households' behavioural responses even in cases where explicit emission prices make it profitable to go green (HMT, 2020[50]). Well-designed regulations and standards can also help overcome coordination failure and realise network effects, for example by setting technical standards for electric vehicle charging stations and connectors (D'Archangelo et al., 2022[9]).

The UK building code already sets energy efficiency requirements, but these can be tightened. Minimum energy efficiency requirements have been in place for social housing for some time, and are planned implemented also for private rentals. Minimum performance standards coupled with energy labels have contributed to increasing energy efficiency in new buildings and appliances in the United Kingdom and the EU. The United Kingdom also uses fleet-wide performance standards, where car producers need to meet maximum tailpipe emissions, averaged over all cars sold in a given year, to reduce average emissions per car. Such policies have also reduced tailpipe emissions in the EU and the United States, amongst others, and are more efficient if they are tradable and tightened over time.

Mobilising political support for low-carbon policies

Even though the need to reduce greenhouse gas emissions is widely recognised and supported by a broad majority of the UK population and across the OECD (Dechezleprêtre et al., 2022[10]), concrete policies often fail to gain political traction or are hollowed out by exemptions, reduced ambition and compensatory measures blunting incentives for necessary structural change. Political economy hurdles to national policy action often revolve around industry's fear of losing competitiveness and households' fear of the increased cost of living. Local resistance can also be an issue, notably to investments in renewables.

Defusing competitiveness concerns

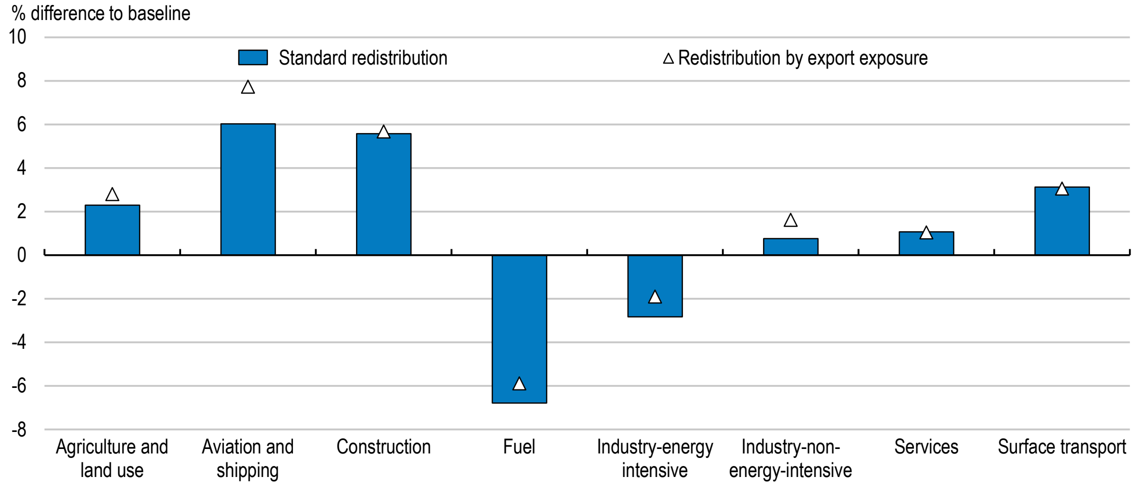
Carbon leakage is a term describing cases when climate policies in one country result in production and investment moving to other more lax jurisdictions. This will lower prices on emission-intensive products in both importing and exporting countries and spur excessive consumption, with increasing global emissions as a result (OECD, 2021[15]). Real or perceived carbon leakage and competitiveness concerns are often met, in the United Kingdom and elsewhere, by lowering policy ambition and by subsidies such as tax rebates on energy inputs or free allowances for emissions covered by emissions trading schemes.

Cross-country evidence from OECD and BRICS countries finds no evidence of losses of competitiveness from stringent environmental policies so far (OECD, 2021[15]). Companies base their decisions on where to locate production and investments on a range of factors including political stability and business climate, access to skills, input factors, infrastructure and markets. The vast majority of UK businesses produce mostly either for the home market or have low emissions compared to the value of their output, or a combination of the two. Even a sharp increase in the cost of emitting greenhouse gases in the United Kingdom carries little risk of carbon leakage for these businesses (HMT, 2021[6]). Some industrial and agricultural sub-sectors may nonetheless risk carbon leakage should the United Kingdom tighten policy considerably ahead of its main trading partners (HMT, 2021[6]).

Compensating these industries by means of subsidies, tax rebates and free allowances would benefit shareholders at the expense of the taxpayer, but would come with very limited positive effects. This point is illustrated in macro simulations where tax revenue is targeted to companies according to their export exposure. These subsidies only yield marginal improvements in output and employment in fuel supply and energy intensive industry, those industries most affected by stringent climate policies, compared to a scenario where revenues are redistributed proportionally to output (Figure 11). This is because climate policies aim to trigger structural change. A monetary incentive designed to block such structural change would imply compensating according to the carbon tax bill or a close proxy thereof, and would blunt the incentives to reduce emissions.

Figure 11. Reaching net zero requires structural change

Employment by sector under different revenue recycling scenarios (2050)



Note: The carbon price starts at GBP 140 in 2030, rising to GBP 378 in 2050. Revenues are redistributed with shares equal to sector shares in output in the “Standard” scenario. Firms’ proportional share of revenue is redistributed to firms according to their export exposure in the “Export exposure” scenario.
Source: Pareliussen, Saussay and Burke (2022[8]).

Defusing competitiveness concerns would pave the way for more ambitious and efficient domestic policies. Solid research and information dissemination might help, but the concept of leakage is intuitive and fits easily into perceptions of industrial decline, lost competitiveness and jobs. Concrete policy action addressing the root cause would therefore likely be more efficient. The best way to achieve this is through international cooperation, regulating emissions at their source in line with the internationally agreed production-based emission accounting framework. Such cooperation does not need to cover all emissions in all jurisdictions to be effective, only trade-exposed emission-intensive sectors in the largest producer countries (Nachtigall et al., 2021[51]). Sectoral deals on steel, road transport, aviation, and shipping were agreed during COP26, in an encouraging move forward. Furthermore, the idea of better measuring and harmonising direct and indirect price signals in leakage-exposed sectors is gaining traction in international organisations and fora such as the OECD, IMF and G20, with the United Kingdom’s active involvement (IMF and OECD, 2021[52]; HMT, 2021[6]).

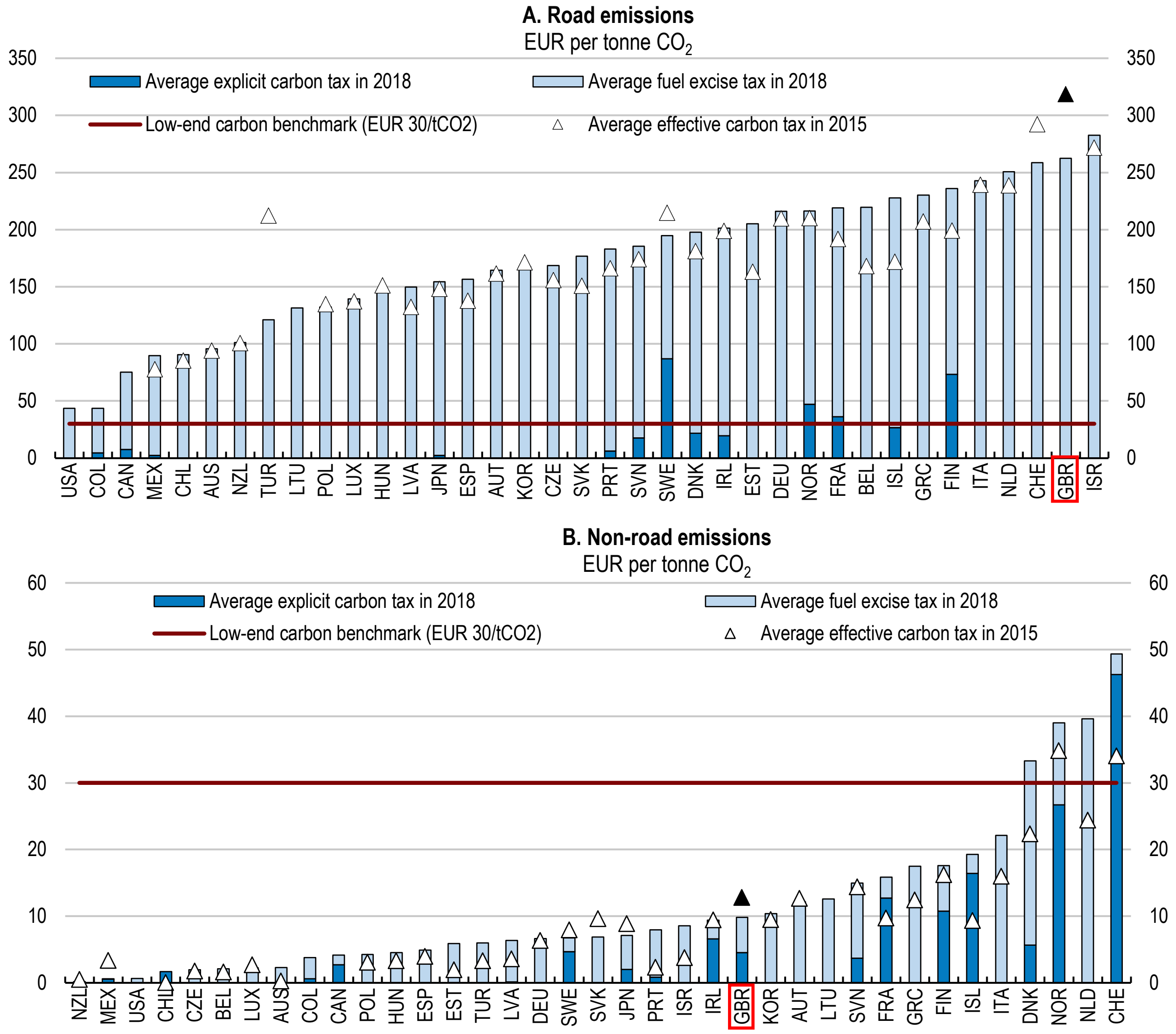
In the absence of effective international action, a Carbon Border Adjustment Mechanism (CBAM) to tax imports of a range of high-emission industrial products can in principle level competition between high-stringency and low-stringency jurisdictions. A CBAM has considerable practical and legal challenges, including that it would need to be compliant with WTO rules, it would need to consider how to account for different regulatory approaches in producing countries, and it might lead to substitution, where the most emission intensive production is simply exported elsewhere (OECD, 2020[53]; HMT, 2021[6]). Other options, like output-based carbon pricing rebates combined with a domestic excise duty on certain leakage-exposed products could also be considered (OECD, 2021[16]), but also face challenges and trade-offs.

The United Kingdom has no concrete plans to introduce a CBAM, but might be affected by EU efforts to introduce one. The EU CBAM is planned to be legislated in 2022, operational in 2023 at the earliest, and fully implemented from 2026. Under the proposal, importers of iron and steel, cement, fertiliser, aluminium and electricity would need to surrender import certificates linked to weekly EU ETS prices, with a deduction for any carbon price already paid. The free allowances currently handed out to these sectors in the EU ETS are proposed to be phased out over a ten-year period after implementation. The EU CBAM proposal is asymmetric in the sense that it does not include a refund for exports (European Commission, 2021[54]). The United Kingdom should engage with the EU to avoid additional trade barriers from the CBAM.

Addressing distributional concerns

Households directly produce greenhouse gas emissions from residential energy consumption and transport. Waste handling is also a complex task involving households and businesses, national, devolved and local authorities. Taken together, these sectors generate approximately half of UK greenhouse gas emissions. Potential emission reductions are held back by inconsistent price signals, various market failures and concerns about acceptability and distributional effects. Overcoming these hurdles and the various market failures reducing the effectiveness of pricing policies targeted at the household sector calls for a policy mix of direct pricing, subsidies and regulation, but also education and information.

Figure 12. A number of countries tax non-transport fossil fuels



Note: 2018 tax rates as applicable on 1 July 2018. The average effective carbon tax rate in 2015 is the sum of the average explicit carbon tax rate in 2015 and the average fuel excise tax rate in 2015, as reported in Taxing Energy Use 2018, converted in 2018 prices using OECD inflation data. CO2 emissions are calculated based on energy use data for 2016 from IEA (2018), World Energy Statistics and Balances. Emissions from the combustion of biofuels are included. Note that changes in average effective tax rates over time are also affected by inflation, exchange rate fluctuations, and changes in the composition of the energy mix. The comparison excludes 2015 rates for the United States and Canada as data on subnational taxes was not available for 2015. 2015 data for Colombia and Lithuania are missing because they were not yet covered in the previous vintage of TEU. For more information see the source.
Source: OECD, Taxing Energy Use 2019.

Explicit pricing instruments tend to be regressive unless compensated. Although this is not universally true, the danger of triggering cost of living shocks can be a considerable hurdle to efficient policies, as exemplified by riots in Chile and the French yellow vest movement. Such unrest is not inevitable, as OECD countries including the Netherlands, Switzerland, Norway and Denmark are taxing fossil fuels both in heating and transportation at substantial rates. A number of countries tax CO_2 emissions from these sources directly, although at low rates except in the Nordics (Figure 12).

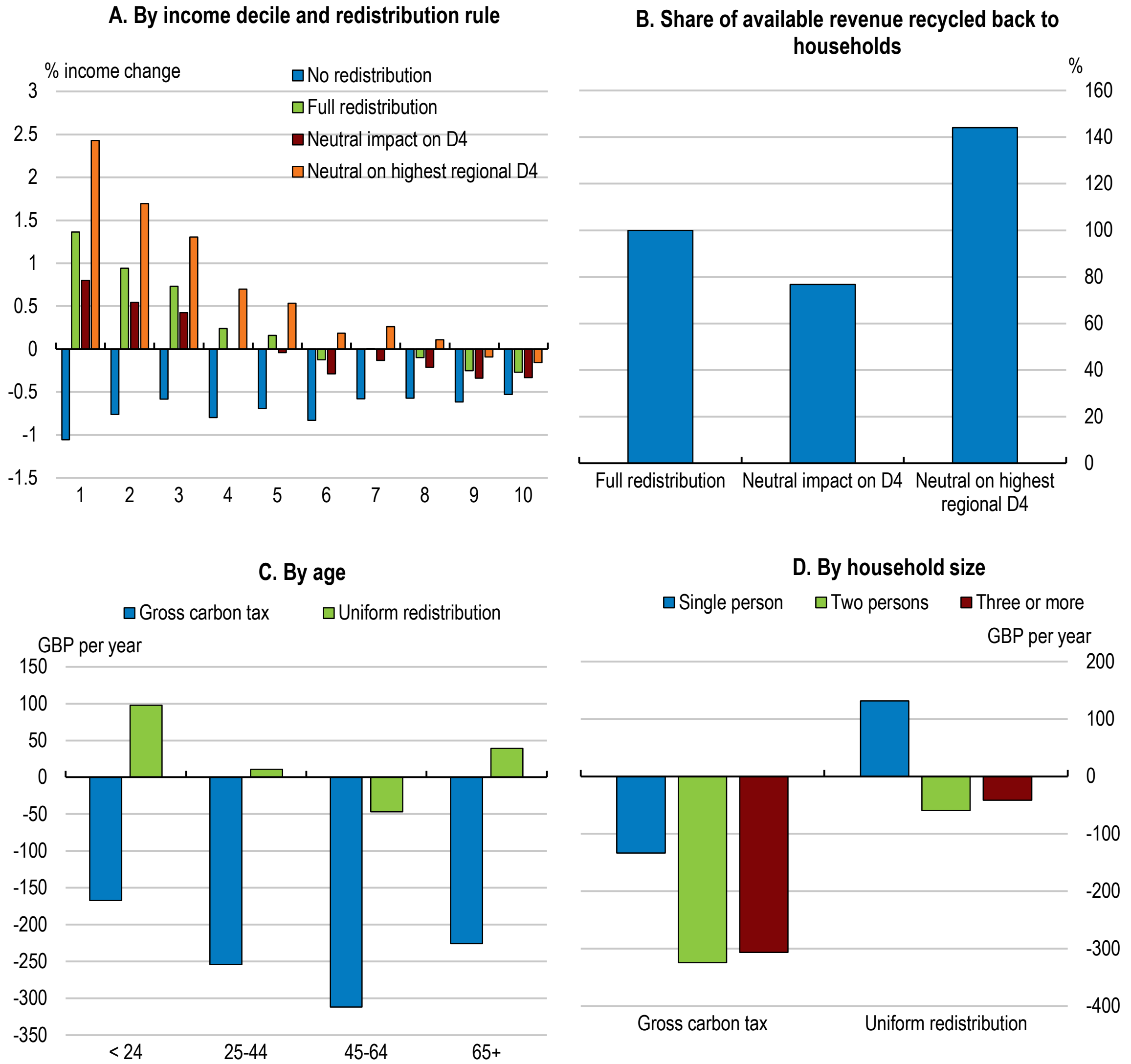
A carbon tax on transport fuels would be largely progressive in the United Kingdom, as the share of income spent on transport increases with income. Conversely, a carbon tax on heating fuels would be regressive, hitting low-income households disproportionately. The combined first-order effect of taxing emissions from household heating and transport would be regressive in aggregate (Burke et al., 2020[55]).

These first-order distributional effects do not capture that taxes and emission trading schemes also generate revenue to finance public services and transfers, which are overall progressive in the United Kingdom and across the OECD (OECD, 2022[21]). Households will be affected differently within each decile of the income distribution depending notably on their occupation, housing and transport needs, but will also have opportunities to adapt their investments and consumption to minimise costs and maximise benefits of the transition.

Explicit revenue earmarking is generally to be discouraged as it creates rigidities in spending priorities leading to inefficient allocation of resources. However, in some cases it can be a useful tool for governments to commit and clearly communicate how the additional revenues will be used in order to overcome public resistance and allow broader, more efficient and durable policies (D'Archangelo et al., 2022[9]). Burke et al (2020[55]) estimate that redistributing 19% of the revenue from a GBP 50 tax per tonne of CO_2 as a targeted cash transfer could make the tax progressive. Redistributing 70% of tax revenue as a lump-sum to all households would achieve the same end. Consistent with this, Pareliussen, Saussay and Burke (2022[8]) find that the direct effect of carbon pricing in a GDP neutral scenario with macroeconomic consequences as outlined above is regressive, with the largest income losses in deciles one, four and six. A lump-sum redistribution of the revenues available under an overall prudent fiscal stance (corresponding to 45% of total revenues) turns the policy package highly progressive, with income gains except in the two top deciles. Distributing 77% of available revenues (30% of total revenues) is sufficient to neutralise income losses in decile four and turn losses into gains in the lowest three tenths of the income distribution (Figure 13, Panels A and B).

There are also large variations within income deciles due to for example differences in housing size and transportation patterns. There is an age dimension, with a lower impact on young households who typically live in smaller houses and consume less transport fuels (Figure 13, Panel C) and household size, with larger households more affected (Figure 13, Panel D).

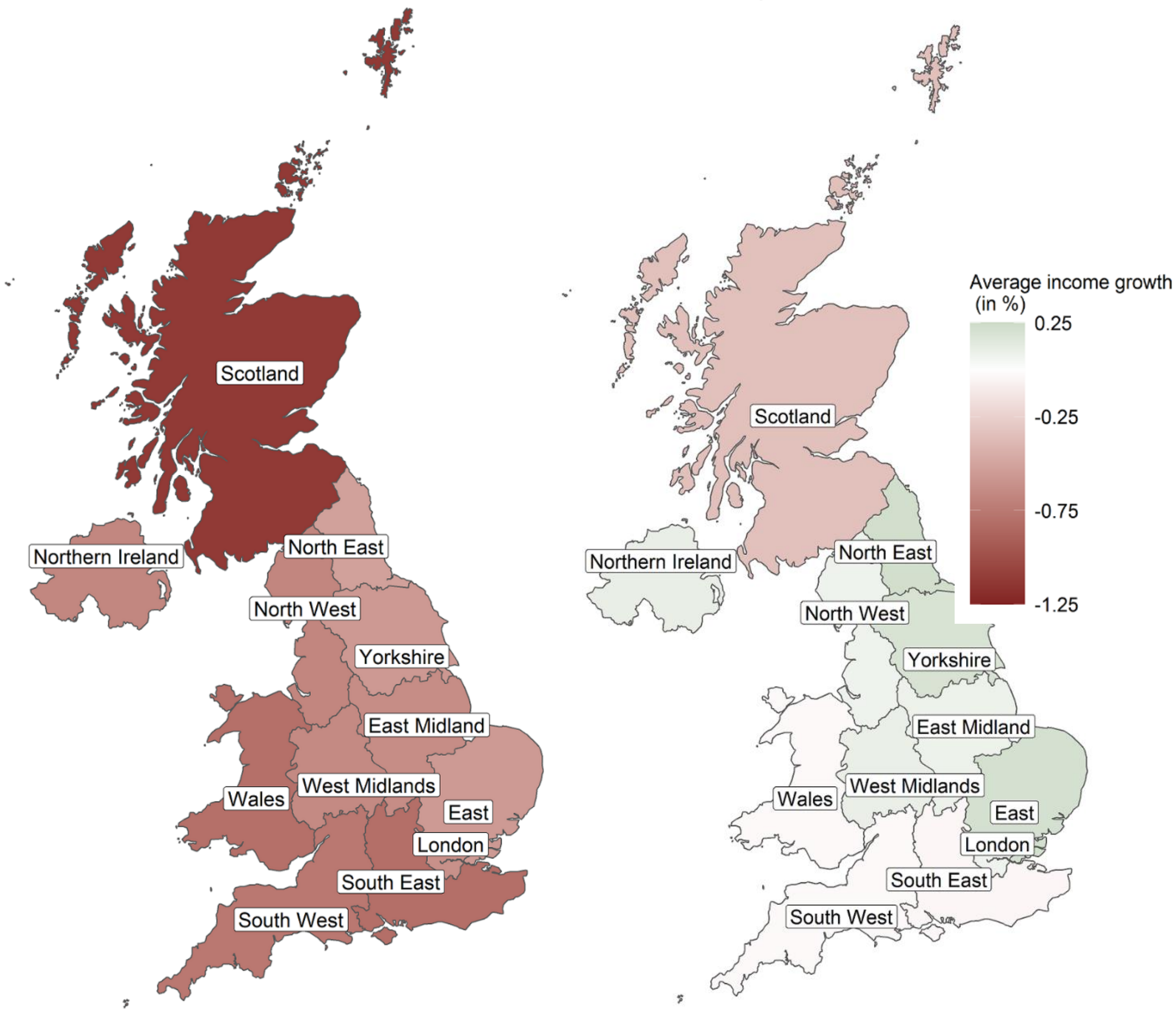
Figure 13. Revenue recycling can turn carbon taxation from regressive to progressive



Note: The carbon price signal is here modelled as uniform carbon (equivalent) tax, but could in principle come from an emissions trading scheme, regulations, subsidies or a combination of instruments. GDP neutral scenario with a medium carbon price trajectory. The "Neutral GDP" scenario holds back a share of revenue (45%) to achieve average GDP growth as in the baseline from 2040 to 2050. Remaining revenues are distributed proportionately to sector shares in output. The medium carbon price starts at GBP 140 in 2030, rising to GBP 378 in 2050. Four redistribution scenarios are explored in a microsimulation model: Unmitigated impacts of the carbon tax; Uniform lump-sum redistribution of available tax receipts across all households; Calibrating a lump-sum redistribution so that decile 4, measured at the national level, experiences no losses; Calibrating a lump-sum redistribution so that not a single decile 4 household in any region experiences a loss.
Source: Pareliussen, Saussay and Burke (2022[8]).

The effect of carbon pricing also has geographical dimensions, varying between rural and urban areas and diversified versus single-industry urban centres focussed on heavy industry. Scotland would be particularly affected because it is colder and more rural than other regions of the United Kingdom, and therefore using more heating and transport. Scotland is also home to the petroleum industry. Wales, the South East and South West would also be more affected than the national average (Figure 14, Panel A). Redistributing 30% of total tax revenue as above would ensure that a majority of the population in a majority of regions increased their disposable income, with gains notably in the lower part of the income distribution. Even so, negative income effects would remain on average in those regions most affected at the outset (Figure 14, Panel B).

Figure 14. A carbon price affects regions differently



Note: GDP neutral scenario. The redistribution scenario implies a lump-sum redistribution scaled to offset the first-order income effect from a carbon tax for the 4th income decile at the national level. This implies a redistribution of 30% of total tax revenue. Income growth is defined as % income growth within each decile, averaged over deciles.
Source: Pareliussen, Saussay and Burke (2022[8]).

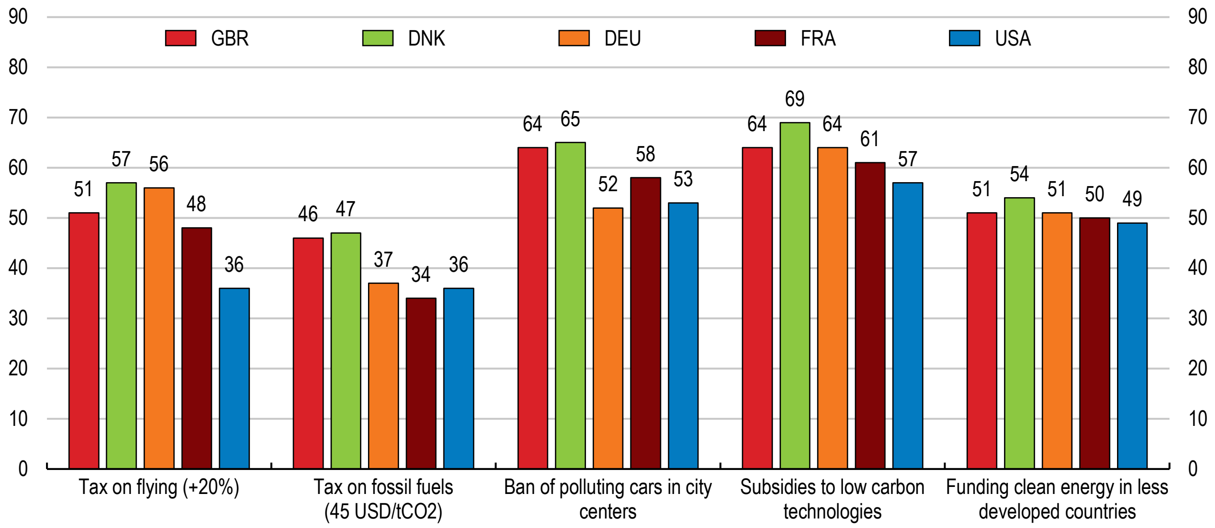
As illustrated above, recycling carbon revenues to make the overall policy package progressive means that low-income households will gain on average, but not that every low-income household will gain. Targeted capital subsidies, notably for housing energy efficiency improvements and electric vehicle charging infrastructure would on the other hand benefit the most emission-intensive households and regions disproportionately. Burke et al (2020[55]) estimate that using 33% of the revenue from a GBP 50 tax per tonne of CO_2 for housing energy efficiency measures can ensure fuel-poor households are not adversely affected. Geographically targeted support should also be considered in a transition period. However, compensating every household according to their actual exposure is not feasible without compromising the environmental effectiveness of the tax. Some will gain and some will lose, even though gains from climate action outsize losses over the longer term.

Even households set to gain, and who support the objective of mitigating climate change, might not support efficient policies. Indeed, a new OECD survey of more than 1,700 representative respondents in the United Kingdom and several other countries analyses the public acceptability of carbon pricing and other climate policies. Similar to other OECD countries, a large majority of Britons believe that climate change is real (94%), an important problem and that it is the United Kingdom's responsibility to fight it (83%). At the same time, only a minority is willing to change their lifestyle by limiting driving (40%) or reducing their beef consumption (46%) (Dechezleprêtre et al., 2022[10]).

The British are relatively supportive of climate policies like subsidies and regulations, but less supportive of a carbon tax on fossil fuels (Figure 15). At 46%, support for a tax on fossil fuels (equivalent to 45 USD/t CO_2) is nonetheless higher than in France, Germany and the United States. A majority (64%) supports non-tax policies, including banning polluting cars from city centres and subsidising low carbon technologies. A small majority (51%) supports a tax on flying that would increase ticket prices by 20% (Dechezleprêtre et al., 2022[10]).

Figure 15. A majority of Britons support climate policies, except a fossil fuel tax

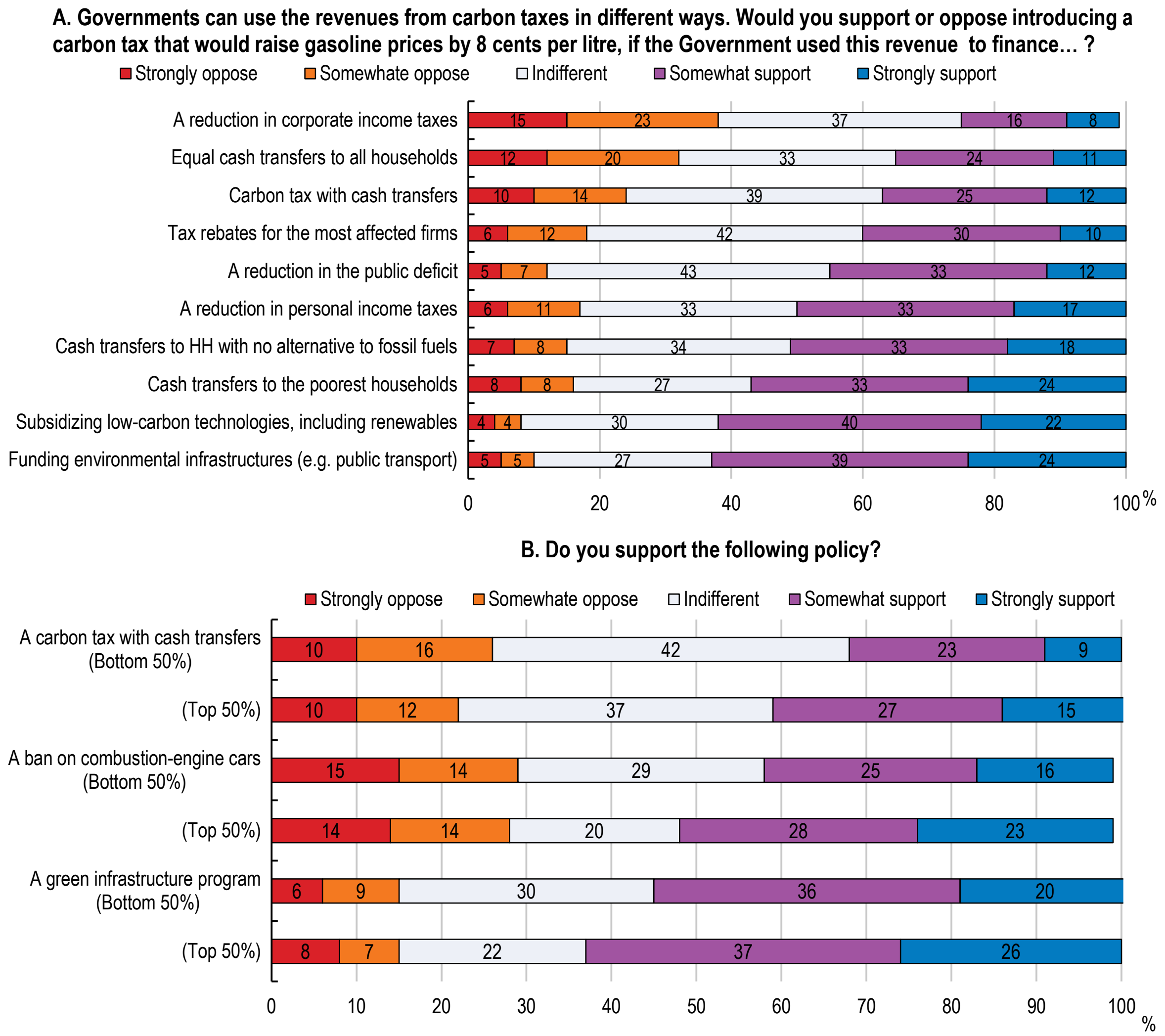
Proportion of people supporting the following measures, 2021 data



Note: The figure shows the share of people either supporting or strongly supporting the policy measures.
Source: Boone, L., Dechezleprêtre, A., Fabre, A., Kruse, T., Planterose, B., Sanchez-Chico, A., and Stantcheva, S. (forthcoming), Understanding public acceptability of climate change mitigation policies across OECD and non-OECD countries, OECD publishing, Paris

Targeted and transparent use of the revenues from carbon pricing can increase public support. A majority (58%) of respondents consider income inequality in the United Kingdom a serious issue, and 57% would support a carbon tax with revenue earmarked for transfers to the poorest households. The highest levels of support for a carbon tax (over 60%) are found when revenues finance low-carbon infrastructure and technologies (Figure 16). High-income groups are generally more supportive of climate policies. When British survey participants were given information on the expected local impacts of climate change and the effects of climate policies, they tended to be more supportive of climate policies, particularly a carbon tax with transfers (Dechezleprêtre et al., 2022[10]).

Figure 16. Stated support for climate policies



Source: Boone, L., Dechezleprêtre, A., Fabre, A., Kruse, T., Planterose, B., Sanchez-Chico, A., and Stantcheva, S. (forthcoming), Understanding public acceptability of climate change mitigation policies across OECD and non-OECD countries, OECD publishing, Paris.

Based on the above, designing a publicly acceptable integrated policy package targeting emissions from the household sector with efficient pricing policies seems within reach. Such a policy package might however be more acceptable if implemented once the currently high energy prices have started to decline. This policy package should create a clear link between revenue-generating carbon pricing and transfers to low-income households, offsetting first-order regressive effects as well as capital subsidies for housing energy efficiency improvements. A third leg of support in such an integrated package should subsidise investments in low-carbon infrastructure and technologies. It should be accompanied by accurate and easily accessible information about climate change, policy effectiveness and how revenues are distributed. These expenditures are also warranted on economic and distributional grounds.

The optimal timing of pricing emissions and associated revenue does not fully align with the optimal timing of these complementary measures. Furthermore, tax and spending decisions should each be considered on their merits rather than being pinned together, both for efficiency reasons and fiscal flexibility reasons Rather than directly earmarking revenues year by year, carbon pricing and complementary measures could be presented as a multi-year package, for example releasing funds for energy efficiency improvements, information and education up-front, before pricing is fully phased in, and releasing funds for infrastructure and technology according to needs.

Targeting policies to sectoral context

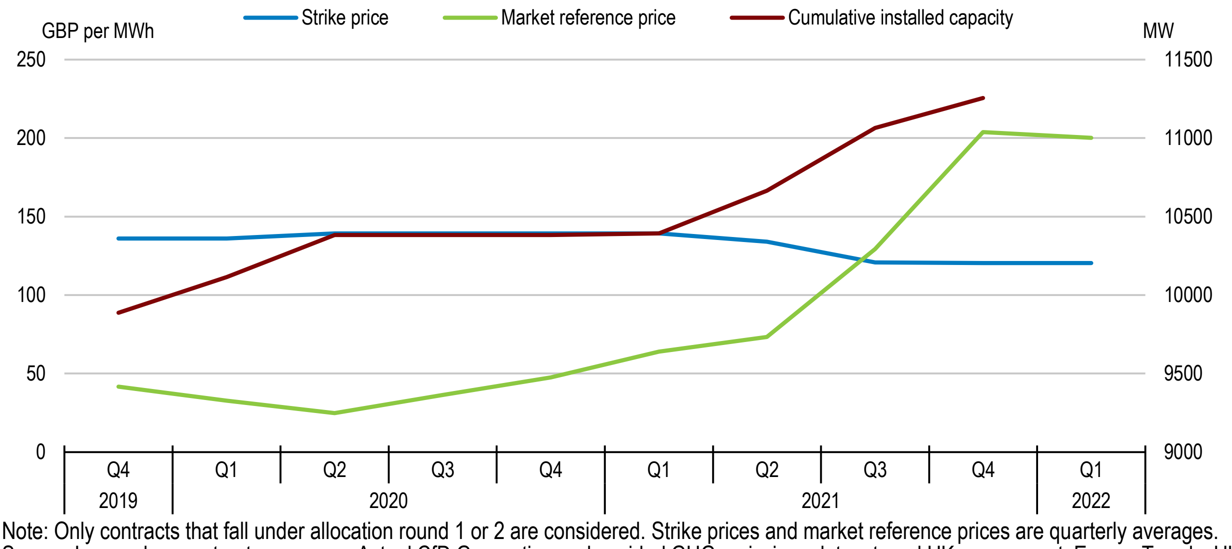
Electricity supply

Increasing clean energy supply is vital for the green transition and to increase energy security. UK Electricity demand is set to roughly double by 2050 to substitute for fossil fuels in industry, buildings and transportation and produce hydrogen as planned in the Hydrogen Strategy. Meeting increased demand while phasing out unabated greenhouse gas emissions from the generation mix will require roughly a quadrupling of renewable and nuclear electricity capacity supported by the Contract for Difference (CfD) scheme. The government has an ambition to add notably 50 GW of offshore wind and 24 GW additional nuclear capacity (HM Government, 2022[56]). Electricity generation emitted 58 Mt CO_2 equivalent emissions (CO_2e) in 2019, 11% of total greenhouse gas emissions. A spectacular 72% reduction from 1990 was driven by replacing coal generation with gas and renewables and increasingly energy-efficient appliances. This success reflects an effective mix of pricing, subsidies and regulations, and should serve as inspiration on how to reduce emissions across the economy. The UK ETS (previously the EU ETS) gives a strong carbon price and the Carbon Price Support acts as a price floor. Later it has been supplemented by a commitment to phase out coal for electricity generation entirely from 2024.

The UK ETS incentivises clean over fossil fuel electricity production. However, renewables are characterised by high capital costs and low marginal costs and price uncertainty over the lifetime of a new plant is therefore a significant barrier for investment in high capital-cost technologies (D'Archangelo et al., 2022[9]). The Contract for difference (CfD) scheme complements pricing by awarding a 15 year fixed price for new renewable electricity generation. The contract price is set in competitive auctions (Figure 17) (HMT, 2021[6]; Climate Change Committee, 2021[3]; BEIS, 2021[2]). The CfD scheme is well suited to overcome this hurdle and steepen technology learning curves for technologies at early stages of commercialisation. It is a well-designed subsidy, as it encourages competition and minimises the fiscal cost of reaching policy goals through its auction design. Indeed, in recent auctions the strike price for allocations to established technologies has been below the market-derived reference price, which means that instead of receiving a top-up, successful bidders are likely to pay the government-owned Low Carbon Contracts Company (LCCC, 2021[49]).

Figure 17. Contract for Difference auctions have made the United Kingdom a leader in offshore wind

CfD quarterly average prices under allocation round 1 and 2 and installed capacity of offshore wind



Note: Only contracts that fall under allocation round 1 or 2 are considered. Strike prices and market reference prices are quarterly averages.
Source: Low carbon contracts company, Actual CfD Generation and avoided GHG emissions dataset; and UK government, Energy Trends: UK renewables.

Separate auctions for less established technologies, as in the United Kingdom (LCCC, 2021[49]), is a way to scale up solutions for the future, and could inspire competitive subsidy designs also in other sectors, provided policy objectives are clear and outputs are measurable. Examples where an auction design could be considered include carbon capture and storage, hydrogen and charging networks, housing energy efficiency, tree planting and peatland restoration. However, sector- or technology-specific auctions face a dilemma: grouping technologies together risks crowding out technologies at a current cost disadvantage but high future potential, while more narrowly targeted auctions may waste resources by picking unviable technologies and reducing competition.

In early 2022 the Scottish government auctioned out 25 GW offshore wind development rights, including 13 GW for floating wind turbines, far outstripping the initial aim of about 10 GW. This is an important step towards target achievement, even though these projects still need to secure support through the CfD and go through planning procedures.

The transition will require considerable upgrades to the transmission network, and a considerable increase to long-term electricity storage and flexible generation capacity to match weather-dependent variations in renewable electricity supply with daily, weekly and seasonal variations in demand. The cost of this transition can be greatly reduced by using already available technologies to manage demand and increase the flexibility of the system. Home battery storage, including from electric vehicles (“Vehicle-to-grid”), combined with smart meters and smart contracts, can help households optimise their electricity consumption and even feed the grid in times of high demand, provided that barriers to flexibility on the grid are removed (BEIS, 2021[2]; BEIS, 2020[57]; BEIS and Ofgem, 2021[58]; BEIS, Ofgem and Innovate UK, 2021[59]).

The large-scale expansion of renewables, grid and nuclear capacity is set to meet resistance from affected neighbourhoods. Local resistance led to a ban on public support for on-shore wind in 2016, lifted in 2020 when on-shore wind again became eligible for CfD auctions. Local resistance to land-based infrastructure for offshore wind is also emerging as the sector expands. Planning and coordination can help alleviate the problem, as well as making sure that there are local benefits in terms of jobs, infrastructure and local tax income. The Government has launched a review to explore this issue (BEIS, 2021[2]).

The government aims to increase the share of nuclear power in electricity supply from today’s 16%, while a number of reactors are slated for closure. Concerns have been raised about the profitability of nuclear power compared to renewable alternatives when the risk of delays and cost overruns as well as life-time social costs are taken duly into account. On the other hand, nuclear is a good low-carbon complement to intermittent supply from wind and solar power. The Regulated Asset Base model is expected to help secure private financing for new nuclear by offloading some of the risks of delays and cost overruns to consumers, where this offers clear value for money. The United Kingdom is also providing considerable support through the GBP 385 million Advanced Nuclear Fund to the development of small modular reactors and advanced modular reactors (BEIS, 2020[57]). OECD countries including France and Korea are increasingly seeing nuclear power as part of a low-carbon electricity generation mix while others, notably Germany, are phasing it out. The European Commission has in its taxonomy labelled nuclear power as sustainable. The approach to nuclear energy should continue to be pragmatic, handling issues of profitability and financial risk sharing as well as nuclear safety and waste concerns responsibly and taking the full range of associated costs and benefits into account.

Fuel supply and hydrogen

Extraction, transportation and storage of fossil fuels emitted 26 Mt CO_2e in 2019, equalling 5% of UK emissions. Emissions fell 61% from 1990, driven by falling petroleum production, efficiency gains and closing of coal mines. Emissions from the petroleum sector are covered by the UK ETS and a comprehensive licensing and regulatory framework (BEIS, 2021[2]). The petroleum sector will need to reduce emissions and employ its skills and resources to help realise technological solutions such as carbon capture and storage and floating offshore wind (BEIS, 2021[2]; BEIS, 2021[60]; BEIS, 2020[57]; Climate Change Committee, 2021[3]).

Global fossil fuel energy demand will need to fall considerably in the coming decades to meet the targets of the Paris agreement, but natural gas will play a role as a transition energy source. Demand for petrochemical products including plastics, fertilisers, digital devices, medical equipment and detergents is set to continue growing for at least until 2050 (IEA, 2018[61]). Furthermore, even though the United Kingdom only imports a small share of its oil (8%, to be phased down over 2022 as part of sanctions) and natural gas (4%) from Russia, Russia's invasion of Ukraine has led to a reassessment of the economic and strategic value of domestic and diversified energy supply. Crude oil production in the United Kingdom is less emission intensive than the global average (Masnadi et al., 2018[62]). Oil and gas extraction is set to continue declining in the mature UK sector of the North Sea. Strictly limiting petroleum production in the United Kingdom would likely contribute to increasing supply elsewhere, with an uncertain net effect on global emissions. Allowing new development in the sector, in line with the Energy security strategy (2022[56]) is therefore appropriate, but should be conditional on continuous improvements in emission intensity and strict environmental policies. Furthermore, the sector should contribute to the United Kingdom's overall climate targets by advancing green technologies such as hydrogen production, carbon capture, usage and storage and floating offshore wind.

Hydrogen can potentially play an important role in reducing greenhouse gas emissions. It has potential to replace hydrocarbon inputs into industrial and chemical processes, and to feed fuel-cell electric heavy goods vehicles. Along with battery storage and further expansion of pumped hydropower storage, it is a promising solution to help match intermittent supply of wind and solar electricity with demand. Surplus electricity supply is in this case used to extract hydrogen from water by electrolysis, after which it is stored and used for electricity production when needed. Low-emission hydrogen can also be extracted from natural gas, either by conventional steam methane reforming combined with carbon capture and storage, or by emerging zero-emission solutions like methane pyrolysis (BEIS, 2021[2]; BEIS, 2021[60]; Sánchez-Bastardo, Schlögl and Ruland, 2021[63]).

The United Kingdom plans to develop up to ten gigawatts of low-carbon hydrogen production capacity by 2030 (HM Government, 2022[56]). The UK ETS already incentivises its use in electricity generation and industry, but government intervention can help realise network effects and steepen technology learning curves subject to careful cost-benefit analyses. The government has embarked on adapting the regulatory framework and it is creating a subsidy mechanism funded by a planned GBP 240 million Net zero hydrogen fund to provide capital and development subsidies to new hydrogen production facilities. Revenue support will be provided through a new Hydrogen Business Model (HBM), initially funded through the GBP 140 million Industrial Decarbonisation and Hydrogen Revenue Support scheme. From 2025, HBM contracts will be funded via a levy, similar to renewables CfDs, subject to consultation and legislation. It also sees a potential role for hydrogen replacing natural gas in residential heating, and is set to assess the value for money of blending up to 20% hydrogen into the existing gas network (BEIS, 2021[60]). Even though hydrogen may turn out to be a cost-efficient solution to some particular challenges, it is an energy carrier with considerable energy losses, first when the hydrogen is produced, then when it is transformed back into heat or electricity. This puts hydrogen at a considerable disadvantage compared to already proven and available alternatives like heat pumps for buildings and batteries for light-duty vehicles.

Manufacturing and refining

Manufacturing and refining emitted 78 Mt CO_2e in 2019, 15% of the UK total. Emissions fell 53% from 1990, mainly due to the changing structure of the UK manufacturing sector, improved energy efficiency, and a shift to low carbon fuels. The sector accounts for 8% of GDP, provides 2.5 million jobs and supports an additional 5 million jobs across the value chain (BEIS, 2021[2]). Energy intensive industry is covered by the UK ETS, and the planned tightening of allocations in accordance with net zero could raise questions around lost competitiveness and impending carbon leakage.

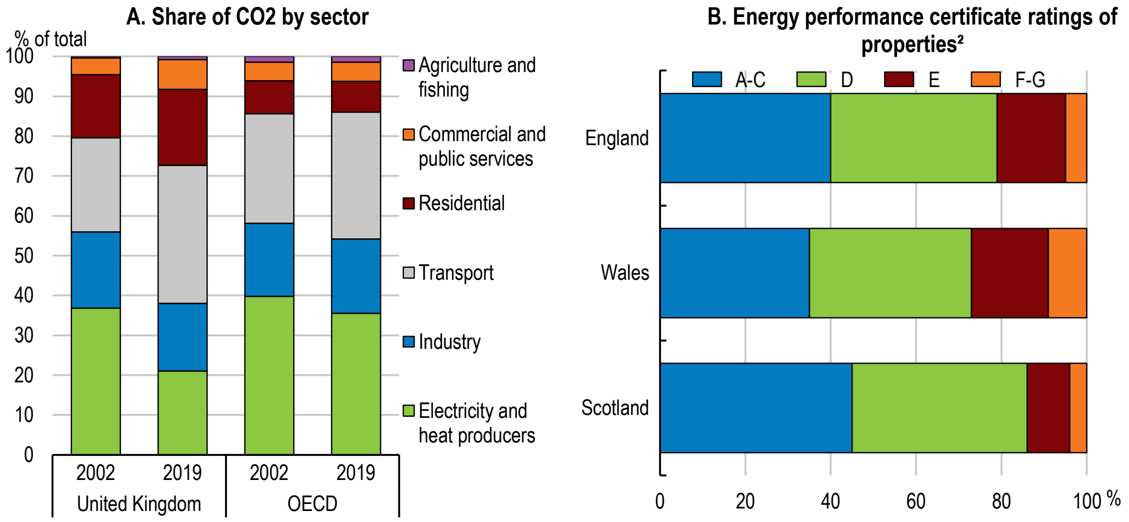
Most manufacturing sectors are little exposed to potential carbon leakage, but some industries, notably basic metals, refineries and non-metallic minerals, combine high carbon intensity with high trade openness. These could become victims of carbon leakage if the United Kingdom tightened policy considerably ahead of its main trading partners (HMT, 2021[6]).

Around half of industry emissions come from geographically concentrated industrial clusters (BEIS, 2021[2]). Stringent emission-cutting policies could affect jobs and incomes around these clusters, notably to single-industry urban centres. Diversified industrial clusters across the United Kingdom can contribute to, and benefit from, the large investments needed in the green transition. Their strong industrial base makes them well placed to expand and create new green manufacturing in areas such as batteries and electric car components, heat pumps, equipment for renewable energy and transmission networks. The Government has mobilised GBP 26 billion of government capital investment for the green industrial revolution, which will support considerable job creation. Furthermore, the designation of net zero and hydrogen clusters with associated support, notably to reduce process emissions, support CCUS and boost domestic production and R&D into heat pumps should help the transition (BEIS, 2021[2]). As discussed above, the macroeconomic effects of such structural change would be manageable, and redistribution and targeted support could help mitigate some negative side-effects. Additional support, notably to single-industry urban centres, might be needed in the future, and should focus on smoothing the transition for workers by investing in skills and supporting those who lose out.

Residential buildings

In 2019, buildings emitted 88 Mt CO_2e, 17% of total UK emissions, of which 69Mt CO_2e, 15% of the total came from residential buildings (Figure 18), the rest from commercial and public buildings. The prime source of these emissions is fossil fuel for heating, notably gas boilers, the dominant heating technology in UK homes. Since 1990, residential emissions have fallen by approximately 14%, driven by increased energy performance and improved efficiency of fossil-fuelled boilers. Phasing out emissions by 2050 in line with the net zero target and the Heat and Buildings Strategy will require heating systems with zero-emission energy carriers such as clean electricity or hydrogen in the overwhelming majority of UK homes and continuous efforts to improve energy performance (BEIS, 2021[2]; BEIS, 2021[64]).

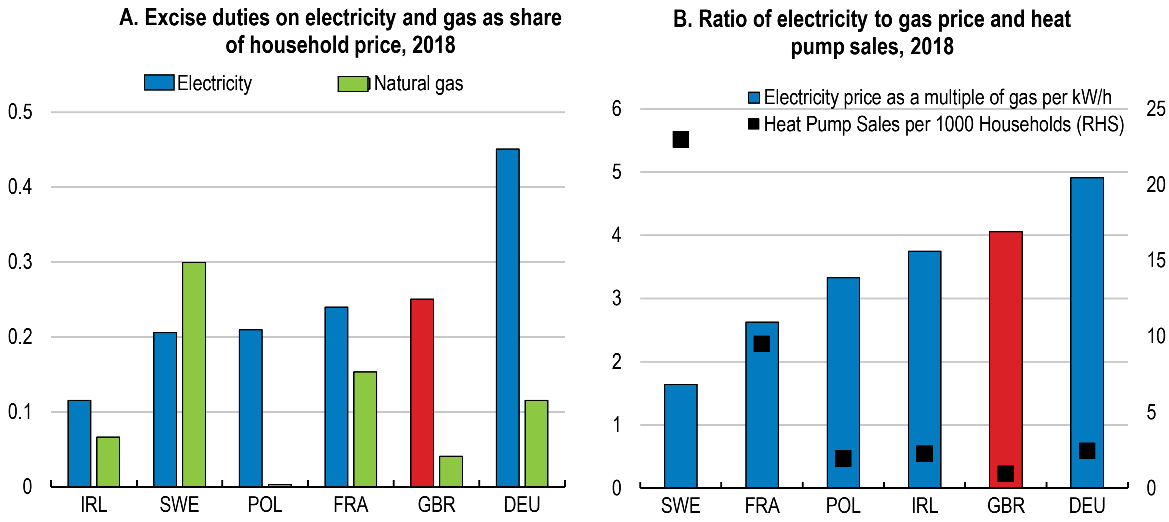
Figure 18. Carbon emission reductions from the housing sector are held back by low energy efficiency



Note: Panel A: CO2 Emissions from fuel combustion. Emissions are calculated using IEA's energy balances and the 2006 IPCC Guidelines. See http://wds.iea.org/wds/pdf/WorldCo2_Documentation.pdf for more details. Commercial and public services include final consumption not elsewhere specified. Industry includes other energy industries. Panel B: England and Wales 2021, Scotland 2019
Source: IEA CO2 emissions from fuel combustion database; and Resolution Foundation, Shrinking footprints.

Pricing of emissions in the sector is currently inconsistent, leaving gas heating less expensive than electric heat pumps (Figure 19). Taxes and charges on electricity equivalent to a price of GBP 70-80 per tonne of CO_2 are in part financing renewable electricity subsidies. In contrast, fossil fuels for heating are practically untaxed. The government has launched a call for evidence, aiming to make a decision to rebalance electricity and gas prices in 2022 (OECD, 2019[65]; HMT, 2021[6]).

Figure 19. Low charges on gas for heating hold back heat pump investments



Source: Eurostat; and European Heatpump Market (EHPA) Stats - http://www.stats.ehpa.org/hp_sales/country_cards/.

This planned rebalancing is welcome and should extend to pricing emissions explicitly by broadening the scope of the UK ETS to cover heating fuels according to their carbon content, as discussed above. However, this may not be enough to tip the cost of clean heating sources below those of dirty ones immediately and in all circumstances. The government is therefore also providing grants through the Boiler Upgrade Scheme. Even if clean sources become less expensive than dirty ones over their lifetime they require considerable up-front investments. Liquidity constraints, information failure, split incentives between landlords and tenants and consumer biases such as present bias, loss aversion, supply and skill constraints may hold back action at the scale needed (Gillingham, Newell and Palmer, 2009[66]; BEIS, 2021[64]). The government announced in its Heat and Building Strategy to give homeowners grants of GBP 5 000 to install heat pumps from April 2022 (HM Government, 2021[67]). Furthermore, the government plans to phase out the installation of new and replacement gas boilers by 2035 (2030 in Scotland). Phasing out the installation of high-carbon fossil fuel boilers in homes not connected to the gas grid by 2026 (2025 in Scotland) (BEIS, 2021[2]; BEIS, 2021[64]) is therefore complementary to this policy. It carries the co-benefit of clarifying policy direction to industry.

A second pillar to reduce residential heating emissions and manage electricity demand is to continue improving the energy efficiency of buildings. It is complementary to policies promoting heat pumps, as conventional heat pumps work more efficiently in well-insulated buildings. Energy efficiency standards for new buildings can achieve large energy savings at a limited additional investment cost. The "Future Home Standard" will ensure from 2025 that new homes produce at least 75% lower CO_2 emissions compared to those built to current standards, which is welcome (BEIS, 2021[64]).

Despite considerable improvements over the past decade, 47% of UK homes still have an Energy efficiency rating (EER) of D (Ministry of Housing Communities and Local Government, 2021[68]). The cost of insulating existing buildings depends less on household income than on a number of factors including age, size, property type (apartment vs detached/semi-detached) and building technique (HMT, 2021[6]). Social housing is for example twice as likely to be insulated as privately rented housing. Rural households will in general face larger investment costs than urban ones, as they tend to live in detached housing with relatively large surface (HMT, 2021[6]).

Incentives for landlords in the private rental market to make their homes more energy efficient are low. Energy savings benefit the renter, but the costs would fall on the property owner. Already, almost 27% of fuel poor households rent in the private rental market (HM Government, 2021[67]), and they will be particularly vulnerable to rising fuel prices as the economy transitions to Net Zero. Therefore, the Government's plan to mandate a minimum energy efficiency level also for private rentals in the future is welcome.

Energy efficiency investments are generally more profitable the lower the initial energy efficiency of a building, but the initial investment cost is higher. The housing cost burden is particularly large for low-income households. In the United Kingdom, housing-related expenditure amounts to 25% of final household consumption expenditure. Credit constraints and the consumer biases applying to investments in heating systems therefore also apply to energy efficiency investments. The average cost of upgrading the energy efficiency rating to C for owner-occupier households in the bottom fifth of the income distribution corresponds at GBP 8600 to their average annual after housing costs income, justifying support (Corlett and Marshall, 2022[69]). Support for energy efficiency improvements is also a key policy to avoid adverse distributional effects of carbon pricing, as outlined above.

A number of support schemes for energy efficiency improvements exist, including the Homes Upgrade Grant and the Social Housing Decarbonisation Scheme (HMT, 2021[6]), but current funding is mainly aimed at public buildings and social housing. Funding for energy efficiency improvements targeted notably at home-owners should be ramped up as part of a comprehensive policy package. However, a previous lack of consistency of home energy efficiency support schemes (OECD, 2022[4]) should be rectified to provide clear policy direction, for example with competitive bidding and payments based on clearly defined and measurable outputs. Such action should be supplemented by well-identified regulatory action and efforts to inform the public about the savings and co-benefits involved. Mobilising private sector providers and upskilling the construction workforce will also be a key success factor going forward, complicated by current shortages of qualified personnel in construction (OECD, 2022[21]).

Transport

Domestic transport emitted 122 Mt CO_2e in 2019, (27% of total emissions) making it the highest emitting sector in the United Kingdom. Road transport accounted for 91% of the total. Light duty vehicles such as cars and vans account for 72%, while heavy-duty road vehicles such as trucks and coaches are responsible for 18% of the sector total. Transport emissions only declined by 5% between 2019 and 1990, while total emissions fell 44%. An increase in activity and vehicle size practically cancelled out the improved energy efficiency of new vehicles. With international emissions included, transport emissions have increased by 10% since 1990, driven by a significant increase in aviation (Department for Transport, 2021[70]).

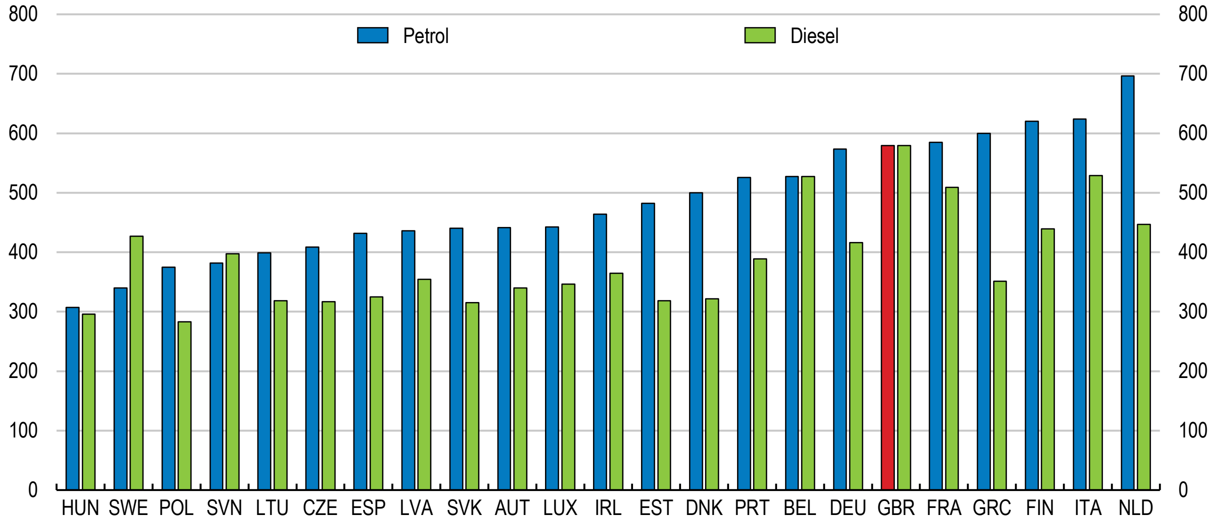
Reducing the emission footprint of road transport will mainly need to rely on reducing emissions within the current mix of transport modes for freight and passengers, as the required changes needed to the spatial distribution of the population to move a substantial proportion of freight and passenger kilometres to sustainable modes are not viable by 2050. Shifting journeys to more sustainable modes can nonetheless make a valuable contribution. The 2021 Transport Decarbonisation Plan aims to shift travel from road to rail, public transport and active transport, among other priorities (OECD, 2022[4]). Changes to spatial planning could help concentrate development within the catchment area of amenities and public transit, thus limiting urban sprawl and discouraging car dependency (OECD, 2021[71]). The National Model Design Code guides Local Authorities on how to reflect decarbonisation priorities in their own design codes.

The United Kingdom does not apply an explicit carbon tax on transport fuels. However, a fuel excise duty of 57.95 pence per litre is applied to fossil fuels. This would equate to a duty on carbon of GBP 314.80 per tonne CO_2 for petrol and GBP 268.07 per tonne CO_2 for diesel (BEIS, 2021[72]) and helps incentivise emission reductions in the sector. The tax is an important revenue stream for the Exchequer (OBR, 2021[7]), and covers other negative externalities of driving, such as local pollution, noise, road wear and the cost of accidents in addition to greenhouse gas emissions (ITF, 2018[73]). After a sustained rise between 1990 and 2009, the fuel duty has been frozen since March 2011. This policy has been acclaimed as reducing households' cost of living, but encourages high-carbon modes of transport. As the duty is a set at a nominal level, this has seen the real cost of the duty eroded. However, the duty remains high relative to EU countries (Figure 20) (Bolton, 2021[74]). More recently, the fuel duty was temporarily cut (until March 2023) by GBP 0.05 per litre for the main rates to respond to soaring prices in the context of Russia's invasion of Ukraine. This tax cut reduces the tax incentive for fuel savings by GBP 22 per tonne CO_2 for petrol and GBP 19 for diesel. Targeted support for low income households would be more effective in counteracting the soaring cost of living. A number of OECD countries have introduced such price supports, which are likely to drive market prices on fossil fuels (pre-tax) higher than what would otherwise be the case.

The vehicle excise duty (VED) has been partially based on CO_2 emissions since 2001, almost tripling the number of diesel cars. A reform introducing a criterion on NOx emissions reversed this trend from 2017. After a new car has spent a year on the road, VED is charged at a flat rate. This encourages more energy efficient vehicles entering the fleet, but reduces the incentive to choose low-polluting second-hand vehicles. The Government ran a Call for Evidence to reform the VED to reduce overall emissions from road transport in 2020 (OECD, 2022[4]).

Figure 20. The fuel excise duty remains high relative to European OECD countries

Excise duty on petrol (unleaded) and diesel (as a propellant), GBP per 1000 litres



Source: European Commission (2021), Excise duty tables: Part II Energy products and Electricity.

The Decarbonising Transport Strategy sets out the government's intention to ban the sale of non-hybrid petrol and diesel light duty vehicles from 2030 and require all light duty vehicles to have zero tail pipe emissions by 2035 (Department for Transport, 2021[75]). The long and clearly communicated lead-in time gives manufacturers time to gradually transition to zero emissions vehicles and avoid a regulatory cliff edge. Furthermore, options are being explored to gradually tighten tradable emissions standards or introducing and gradually tighten a mandatory share of zero emissions vehicles sold (Department for Transport, 2021[76]). The chosen approach will force a transition, and thereby overcome information failure and various biases that could otherwise hold back the widespread adoption of electric vehicles on a sufficient scale and timeline to meet climate targets. Experience from Norway, where electric vehicles reached a market share of 75% of new cars sold in 2020 (IEA, 2021[77]) shows that economic incentives can spur a transition towards electric vehicles, but at a high abatement cost and with benefits principally flowing to high income households (OECD, 2019[78]).

The Decarbonising Transport Strategy proposes to require all new heavy goods vehicles to have zero tailpipe emissions from 2035 (under 26 tonnes) and 2040 (all vehicles). The technological pathway towards zero-emission heavy goods vehicles is less clear, but some mix of electric vehicles, technology which would allow vehicles to draw power from the grid while in use (route electrification) and fuel cell electric vehicles are assumed to be capable of eliminating their tailpipe emissions by 2050 (Lyons, Curry and Rohr, 2021[79]). Given these uncertainties, interventions in the short term should seek to support R&D in across a range of technologies.

Electrification of the vehicle fleet will undermine the tax base for the fuel excise duty, currently equivalent to 1.7% of GDP (HMT, 2021[6]). This calls for an alternative way to tax the negative externalities of road use and replace lost revenue. The government should move towards a new system pricing road use directly as soon as possible, as it will increase charges on electric vehicle use, and is likely to meet increasing resistance as an increasing share of the population owns an electric vehicle. Such a system should continue to put a price on CO_2 emissions from fossil fuel powered cars, preferably by including fossil fuels in the UK ETS, as discussed above. Coordinating implementation with the planned rebalancing of electricity and gas charges and a wider package of carbon pricing and complementary spending as outlined above could help increase public acceptance.

The electric vehicle charging network presents consumers and suppliers with a network and coordination problem. An insufficient national charging network excludes those without a dedicated charging space from electric vehicle ownership and causes range anxiety even for those with local charging available. The low penetration of electric vehicles holds back private sector charging infrastructure investment. Government intervention to stimulate demand and supply for electric vehicle charging is therefore appropriate (Li et al., 2017[80]), focussing on coordination of networks in main travel corridors and support for charging infrastructure to complete networks in places where demand is currently insufficient.

Even though electric vehicles are projected to become cheaper than fossil fuelled ones when lower cost of use are taken into account, their higher purchase price dictate that early adopters will be high-income households. The profitability of owning an electric vehicle also differs considerably between households who have access to home charging and those confined to public charging. This differential is set to widen considerably in the future as vehicle to grid revenues become available to households with home charging (Corlett and Marshall, 2022[69]). The government currently provides a suite of incentives to support electric vehicle early adopters, boosting the case for private investment in charging infrastructure. In addition, GBP 1.3 billion will be provided to support the expansion of public and domestic charging infrastructure. Regulations are also being introduced to ensure new buildings have appropriate charging provision (Department for Transport, 2021[81]).

In addition to supporting the transition to zero carbon alternatives for private vehicles and road freight, aviation, shipping and rail will also need to transition. The United Kingdom aims to phase out diesel only trains from the network by 2040, replacing them with line electrification and hydrogen and battery trains where this is not viable (BEIS, 2021[2]). While emissions technologies enabling the full decarbonisation of aviation are not yet available, zero-emission solutions including sustainable aviation fuels and hydrogen or electric powered aircraft engines are being tested, notably for short-haul flights.

Waste and F-gases

Emissions from waste and F-gases combined amounted to 40 Mt CO_2e in 2019, or 8% of total greenhouse gas emissions. Of this, 5% of UK emissions came from waste handling, consisting of waste to landfills, waste incineration without energy recovery and wastewater treatment. Emissions fell by 71% from 1990, largely driven by reducing the methane emitted from biodegradable waste decomposing on landfills. 3% of UK emissions came from F-gases, overwhelmingly from the release of HFCs into the atmosphere. HFCs are largely used to replace ozone-depleting gases regulated by the Montreal Protocol since 1989. F-gas emissions fell by 10% from 1990 to 2019 (BEIS, 2021[2]).

In the special case of HFCs, which are used directly as product components, mainly as refrigeration gases, creating scarcity of the input itself is equivalent to explicit pricing policies. HFCs are highly potent greenhouse gases, and their phase-out is prescribed by the Kigali amendment to the Montreal Protocol. In the United Kingdom (as in the EU), imports of HFCs are restricted by a gradually tightening quota (BEIS, 2021[2]). These quotas create scarcity, and the price response incentivises substitution and research into commercially viable alternatives (European Commission, 2020[82]). Quota limits have reduced HFC consumption by 55% since 2015, putting the United Kingdom on track to meet its Montreal protocol commitment to cut consumption by 85% by 2036 (BEIS, 2021[2]).

The main policy instrument behind emission reductions in the waste sector is the landfill tax, which corresponds to approximately GBP 80 per tonne of CO_2e (HMT, 2021[6]). This tax along with increasing public awareness have greatly reduced the volumes of landfilled biodegradable waste. Municipal waste generation fell between 2005 and 2019, although both GDP and population grew over this period. Municipal waste generation per capita is below both OECD and OECD Europe averages. Previously landfilled waste is increasingly incinerated, although recycling and composting also grew. CO_2 emissions from incineration are 25 times less potent than methane emissions from landfilling, but they are emissions nonetheless. The United Kingdom, unlike many European OECD countries, does not tax emissions from incineration, but the inclusion of incineration into the UK ETS is part of the call for evidence to reform the ETS (UK ETS Authority, 2022[13]). The statutory target of recycling or composting 50% of household waste was met in Wales and Northern Ireland, but not for the United Kingdom as a whole, largely reflecting different practices among local authorities. Contaminated sites and illegal landfilling and waste exports remain challenges. The 2021 Environment Act may help, as it establishes a common approach for collection of recyclables in household waste in England and a UK-wide electronic waste tracking system to tackle waste crime, including illegal exports. Furthermore, in 2020, environment agencies and police forces across the United Kingdom formed a unit for waste crime to address the problem of organised crime groups operating in the sector (OECD, 2022[4]).

Agriculture

Agriculture, notably livestock production, emitted 46 Mt CO_2e in 2019, 10% of total UK emissions, mostly methane. Devolved Governments have the primary responsibility for agricultural policy and decarbonisation. In contrast to England, Scotland and Wales, 26% of Northern Ireland's emissions come from agriculture. Agricultural emissions fell by approximately 13% since 1990. The Net Zero Strategy estimates that emissions could be reduced to 39 Mt CO_2e by 2035, including net removals from land use and forestry. Further emission reductions are assumed from replacing 20% of meat and dairy consumption by plant based alternatives (Climate Change Committee, 2021[3]). This is in line with current trends for meat consumption (Stewart et al., 2021[83]), but not for dairy. Eliminating emissions from the agriculture sector is complicated by measurement issues, a difficult political economy and hard to abate biological processes involved in food production (BEIS, 2021[2]).

Following the exit from the EU and its Common Agricultural Policy, the government is reviewing agricultural support to increasingly tilt payments towards rewarding climate and ecosystem services and encouraging low-emitting production methods (BEIS, 2021[2]). Direct investment in research and development, financial supports for farmers and the provision of advisory services should encourage the development, scaling and application of innovative low carbon farming techniques. These supports should be structured with clear objectives, and coherence between policies, and they should be measured and evaluated against predetermined targets (OECD, 2022[84]).

Direct emission pricing belongs in a policy package to effectively and efficiently reduce emissions from agriculture, but comes with two main challenges. Quantity-based measures like the number of livestock or fertiliser use can be straightforward, but would fail to capture reduced emissions from improved agricultural practices, which are more challenging to measure at the level of individual farms (or companies). Explicit pricing policies are also politically challenging, due to their impact on food prices (Climate Assembly UK, 2020[85]), carbon leakage concerns and strong agricultural lobby groups (Arvanitopoulos, Garsous and Agnolucci, 2021[86]; D'Archangelo et al., 2022[9]). Agriculture may be at risk of carbon leakage, with high emission intensity of imports from some countries and limited scope to pass on increasing production costs to prices. However, this risk could be mitigated by comparable climate policies in the EU, the United Kingdom's main trading partner in agricultural products, substitution in agricultural production and a considerable scope to increase productivity (HMT, 2021[6]).

A hybrid system, in which quantity-based measures are subject to a carbon price, while improved practices, the provision of nature-based services and green R&D are subsidised, preferably in competitive auction designs, would likely increase policy efficiency and should be explored. If necessary to win political acceptance, such a reform could be fiscally neutral for the sector as a whole. Improved methods and data could help alleviate measurement issues in the longer term. The Government is consulting on measuring and reporting of agricultural emissions from agriculture in its call for evidence on UK ETS reform (UK ETS Authority, 2022[13]). Lessons could be learned from New Zealand, where agricultural greenhouse gas emissions have been mandatory reported since 2012, and will be included in the NZ ETS or a separate pricing system in 2025 (Box 4).

Box 4. New Zealand's approach to price forestry and agricultural emissions

The New Zealand Emissions Trading Scheme (NZ ETS) is the main tool for achieving the GHG emission targets set under the Zero Carbon Act. The NZ ETS covers all sectors of the economy except agriculture. This sector, accounting for 48% of New Zealand's 79 $MtCO_2$ equivalent gross emissions (2018), was exempt due to concerns that it would undermine competitiveness and lead to carbon leakage. Companies in the agricultural supply chain (e.g. meat processors, dairy processors, nitrogen fertiliser manufacturers and importers) are nonetheless required to monitor and report their agricultural emissions within the framework of the ETS.

The 2019 Climate Change Response (Emissions Trading Reform) Amendment Bill mandates pricing of agricultural emissions from 2025 and mandatory farm-level reporting obligations of livestock emissions as of 2024. The government and the agricultural sector are now working in He Waka Eke Noa (Primary Sector Climate Action Partnership) towards developing a system for farm-level pricing by 2025. If an alternative pricing system is not implemented by 1 January 2025, the Climate Change Response Act states that agricultural emissions will be priced under NZ ETS. In October 2022 the government opened a consultation on farm-level pricing of agricultural emissions, two options for pricing synthetic nitrogen fertiliser emissions, an interim processor-level levy as a transitional step if the farm-level levy cannot be implemented by 2025, and recognition for some types of sequestration in an adjacent contractual system from 2025, with a long-term goal of integration of new vegetation categories into the NZ ETS.

Land-use change and forestry, which are included in the ETS, increased their carbon stock equivalent to reducing gross national emissions by 30% in 2018. Under the NZ ETS, forests are defined as "post-1989 forest land" or "pre-1990 forest land". Post-1989 forests may be voluntarily registered into the ETS and are eligible to earn emissions units that represent the carbon sequestered by the forest since the start of each "mandatory emissions return period" (MERP, a five-year period defined in legislation, the current is 2018-2025), but are also liable to repay units if there is a reduction in carbon stock. As of June 2018, 50% of post-1989 forest land (approximately 325 000 hectares of 690 000 hectares) had been registered in the NZ ETS. Furthermore, the majority of landowners with exotic forest land defined as "pre-1990 forest land" (approximately 1 440 000 ha) face deforestation liabilities under the NZ ETS. There are no liabilities or entitlements for business as usual forest harvest and replanting.

A simplified accounting approach as of 2021 is expected to increase incentives for participation in the ETS. Furthermore, post-1989 forestry will be registered in the NZ ETS for 50 years, and clear-felling will be prohibited during this period. These changes are estimated to add an extra 45 $MtCO_2$ stored in New Zealand's forests.

Source: Henderson, Frezal and Flynn (2020[87]); Arvanitopoulos, Garsous and Agnolucci (2021[82]); OECD, (2022[80]); New Zealand Ministry of the Environment (2022[88]).

Land use, forestry and engineered emission removals

Some emissions are not possible to eliminate with current technologies, and in a number of cases it is not realistic to assume that technological progress will make it possible and affordable to eliminate them fully by 2050 (Climate Change Committee, 2020[14]). Yet, these activities, notably in food production, air transport, shipping, manufacturing and waste management will remain crucial to UK society and well-being. As countries in the world move towards net zero, residual emissions will increasingly need to be offset by removing greenhouse gases from the atmosphere, be it at home or abroad.

Producing negative emissions involves increasing the carbon stored naturally in forests, soil and wetlands through photosynthesis and engineered solutions to extract carbon from the air, exhaust or industrial and chemical processes and store it long-term or permanently. Solutions like bio-energy with carbon capture and storage and using charcoal produced by pyrolysis of biomass as a soil conditioner (Biochar) combine natural removal through photosynthesis with engineered storage.

Natural removals had a largely neutral effect on UK emissions in 2019. Forestry and woodland reduced emissions by 4% aided by the planting of 123 000 hectares of new woodland since 2010. This was cancelled out by 4% net emissions from peatland degraded by drainage for agricultural use, overgrazing and burning. The England Trees Action Plan (DEFRA, 2021[89]) committed to more than doubling tree planting to 30 000 hectares per year, while the England Peat Action Plan (DEFRA, 2021[90]) sets out to restore 35 000 hectares of peatland by 2025. These efforts are supported by legislative efforts and GBP 750 million funding from the Nature for Climate Fund. The government is also engaging with stakeholders to increase the use of timber for construction. Timber has a low carbon footprint relative to other building materials, and carbon is stored in buildings over their lifetime. For the purpose of domestic climate targets, forestry and land use is counted together with agriculture (BEIS, 2021[2]).

Measuring is complex with actual sequestration depending on a range of natural and local factors and considerable co-benefits if managed correctly. A regime with targeted subsidies within land use providing payments for various ecosystem services is therefore justified. The government is exploring ways to better measure emissions from the sector (BEIS, 2021[2]), strengthen the policy mix with direct pricing of measurable emissions in the future. However, natural sequestration bears the risk of extreme events like floods and fires releasing the stored CO_2 back into the atmosphere. This issue could be overcome, for example by a public or private insurance mechanism. Lessons could be learned from the New Zealand Emissions Trading Scheme, where forestry yearly removes CO_2 equivalent to 30% of national emissions (Box 4).

The United Kingdom has an ambition to sequester at least 5 Mt CO_2 per year by means of engineered greenhouse gas removals (GGR), rapidly scaling up until 2050. Prominent technologies include direct air carbon capture and storage (DACCS), bioenergy with carbon capture and storage (BECCS), Biochar, and distributing large amount of CO_2-consuming minerals on land (Enhanced weathering) or at sea (Ocean alkalinity enhancement). Variations of carbon capture and storage (CCS) technologies are technologically proven, but their cost and the lack of infrastructure to transport and permanently store the CO_2 have so far stood in the way of large-scale commercial deployment (Global CCS Institute, 2021[91]). In addition to delivering negative emissions (DACCS and BECCS), CCS has a potentially important role to play in reducing emissions from industrial and chemical processes where waste streams of greenhouse gases are not easily eliminated, from fossil fuel electricity production and in producing low-emission hydrogen from natural gas. Biochar has also been proven as a long-term, relatively low-cost means of storing carbon in soils, with considerable co-benefits in terms of soil fertility and water management, amongst others. Enhanced weathering and ocean alkalinity enhancement has a potential to remove CO_2 from the atmosphere at scale, but also entail considerable risks from the release of mineral dissolution products, calling for further research and gradually increasing the scale of trial projects (BEIS, 2021[2]; Lehmann and Joseph, 2015[92]; Bach et al., 2019[93]).

Policy efforts supporting engineered greenhouse gas removals today focus on research and innovation, as well as the designation of CCS clusters and a GBP 1 billion Carbon Capture and Storage Infrastructure Fund. This support is warranted to kick-start a sector in its infancy. Among a total 14 planned projects in the United Kingdom, two projects connected to the Humber Zero CCS cluster are at advanced stages and planned to go on line by 2028 (Global CCS Institute, 2021[91]).

Carbon capture and storage illustrates the dynamic relationship between explicit pricing and support for research, development and early technology deployment. Separating CO_2 from exhaust gases or directly from the air requires heavy capital investments. In addition comes variable costs of separation, transport, storage and monitoring. Publicly-funded R&D and demonstration projects can help bring these costs down, notably by improving technology and mapping suitable storage sites. Public coordination of the associated infrastructure or even direct investments will also help. However, most potential CCS projects do not carry any energy efficiency gains or additional revenue streams. In the absence of policy intervention, CCS therefore represents a net loss of productivity and profits. Therefore, absent an explicit or implicit price signal at least covering the variable cost, releasing CO_2 into the atmosphere will remain the better commercial decision (Box 5.

Box 5. Carbon Capture and Storage at the Sleipner West oil field (Norway) was motivated by carbon pricing

The Sleipner gas field is a natural gas field in the North Sea, about 250 kilometres west of Stavanger, Norway. Sleipner was the world's first commercial CO_2 storage project. The natural gas produced from the Sleipner West field contains up to 9% CO_2, but in order to meet export specifications and customer requirements, this has to be reduced to a maximum of 2.5%. Industry practice is to release the separated CO_2 into the atmosphere, but this would have entailed NOK 1 million per day in Norwegian CO_2 taxes. Injection costs about USD 17 per tonne CO_2.

Since 1996, the project has stored approximately one million ton of CO_2 per year into the Utsira Formation, which is a 200-250 meter thick massive sandstone capable of storing 600 billion tons of CO_2. The CO_2 is removed from the natural gas at an offshore platform before being pumped back into the ground, while the hydrocarbons are piped to land. Regular measurement and surveillance shows the storage to be safe and stable.

Source: MIT, (2016[94]).

The UK ETS already incentivises carbon capture and storage from covered entities, in which case the CO_2 counts as "not emitted" from its source. The Government recognises the need for additional incentives, and aims to launch a consultation on how to develop markets and incentives for engineered greenhouse gas removals in 2022. It has launched a call for evidence together with devolved administrations exploring the UK ETS as a potential long-term market for removals (UK ETS Authority, 2022[13]). Expanding the UK ETS as widely as technically possible across emission sources while issuing removal activities regardless of sector and technology with ETS-eligible credits under the principle that a tonne is a tonne, complemented by regulations and subsidies as discussed above, would create the necessary steering structure and incentives to reach Net Zero.

Table 5. Policy recommendations to reach net zero

Findings (main findings in bold)	Recommendations (key recommendations in bold)
Completing the institutional set-up	
Achieving carbon neutrality will require policy to match ambition. Uncertainty regarding future policy stringency holds back investments.	**Build on the Net Zero Strategy, with further concrete deadlines, policies and priorities in line with legal targets.**
Government departments are not always coordinated and policy decisions are not always in line with climate targets.	Ensure that target-consistent carbon values are consistently applied in all cost-benefit analyses across government and systematically considered in decision making.
Contrary to some other G7 countries, the United Kingdom is not tracking support measures with potential environmentally harmful impacts.	Systematically track and quantify support measures with potential environmentally harmful impacts and adjust policy accordingly.
Implementing efficient mitigation policies across the economy with support in the population	
Private incentives to reduce emissions are inconsistent across sectors and energy sources and too low in a number of sectors, including emission removals.	**Commit to gradually expanding the UK ETS to all emitting sectors and tighten the emissions cap in line with targets.**
Different biases and constraints prevent households from making climate-friendly investments in heating, energy efficiency and transportation even when they are profitable. Plans for regulatory	**Target households' energy use with concrete regulations to phase in higher energy efficiency, clean heating and zero-emission vehicles.**

back-stops exist, but they need to be translated into concrete policies spurring early action.	
Carbon pricing and regulation will in the absence of flanking policies hit low-income households, those in rural areas and those with high heating needs disproportionately at the risk of triggering public resentment.	**Allocate a portion of carbon pricing revenues to schemes compensating low-income and fuel-poor households and supporting their green investments.**
Liquidity constraints may hold back profitable investments in energy efficiency and clean housing.	**Introduce a large-scale support scheme for residential energy efficiency and clean heating systems with competitive bidding and results-based payments.**
Private incentives to research, develop and deploy new technologies are too low. Recycling revenue to support clean technologies and infrastructure increases popular support for direct pricing instruments.	**Allocate a portion of carbon pricing revenue to public investment in green infrastructure, research, development and deployment of green technologies, including carbon capture and storage.**
Support for pricing instruments increases if people receive information about their effectiveness.	Engage in education and information campaigns increasing knowledge and awareness on how explicit pricing instruments work.
Fossil fuels for heating is untaxed, while electricity charges are high.	Align charges on electricity and fossil fuel for heating to their respective greenhouse gas emissions.
Net zero will erode fossil fuels as a tax base with considerable fiscal consequences.	Replace the fuel duty with a new road pricing regime differentiating charges between fossil fuel and zero emission vehicles.
Competitive "contract for difference" auctions in renewable energy have successfully mobilised private sector investments.	Expand the use of competitive auction designs to maximise value for money of public support policies across sectors of the economy.
The low penetration of electric vehicles holds back private sector charging infrastructure investment and vice versa.	Encourage the shift towards low and zero-carbon vehicles, including with financial incentives to invest in recharging stations particularly in remote areas.
Shifting journeys away from private cars on to more sustainable modes of transport can help limit transport sector emissions.	Encourage compact development around transport nodes, and financial incentives to travel by rail, public transport shared mobility and active transport.
The net zero target and the need to strengthen energy security call for accelerated development of renewable electricity generation. The fourth allocation round of Contract for difference auctions caps allocations to the most competitive technologies.	Accelerate Contract for difference auctions for renewables by lifting caps on solar and onshore wind as well as the 5GW cap on established technologies in the fourth allocation round.
Agricultural emissions are in some cases difficult to measure, and political resistance to increasing cost burdens on food production is considerable.	Target agricultural support towards payments for emission reductions and other ecosystem services, supplementing an explicit carbon price on measurable agricultural emissions.
Skills could be in short supply, slowing transition and reallocation to green jobs. Flexible markets and active support reduce strain from structural change.	Invest in the skills needed for the green transition, notably within housing energy efficiency and clean heating.
Supporting international collaboration and increasing policy ambition in emission-intensive trade exposed industries	
Loss of competitiveness for emissions intensive trade exposed industries is a concern. The risk of carbon leakage is best addressed by international coordination to secure a level playing field.	Engage actively in international efforts to implement and measure pricing and equivalent policies targeting emission intensive trade exposed industries.
The United Kingdom is a forerunner in international efforts to green the financial system, but knowledge gaps remain, indicating scope for continuous improvement of regulation and supervision going forward.	Adapt financial sector regulation and supervision as climate-related risks and vulnerabilities are uncovered by stress-tests and related activities.
International cooperation to reduce emissions where it is least costly can increase cost efficiency and contribute to disseminating good practices, but may increase global emissions if the trade partner has low ambitions or fails to implement effective policies.	Engage in cooperative approaches established under the Paris agreement, conditional on credible commitments aligned with net zero in partner countries.

References

Albrizio, S., T. Kozluk and V. Zipperer (2017), "Environmental policies and productivity growth: Evidence across industries and firms", *Journal of Environmental Economics and Management*, Vol. 81, pp. 209-226, https://doi.org/10.1016/J.JEEM.2016.06.002. [17]

Arvanitopoulos, T., G. Garsous and P. Agnolucci (2021), "Carbon leakage and agriculture: A literature review on emissions mitigation policies", *OECD Food, Agriculture and Fisheries Papers*, No. 169, OECD Publishing, Paris, https://dx.doi.org/10.1787/9247f1e7-en. [86]

Bach, L. et al. (2019), "CO2 Removal With Enhanced Weathering and Ocean Alkalinity Enhancement: Potential Risks and Co-benefits for Marine Pelagic Ecosystems", *Frontiers in Climate*, Vol. 0, p. 7, https://doi.org/10.3389/FCLIM.2019.00007. [93]

BEIS (2021), *Government conversion factors for company reporting of greenhouse gas emissions*, Department for Business, Energy and Industrial Strategy, https://www.gov.uk (accessed on 11 January 2022). [72]

BEIS (2021), *Heat and buildings strategy*, Department for Business, Energy and Industrial Strategy, https://www.gov.uk (accessed on 11 January 2022). [64]

BEIS (2021), *Net Zero Strategy: Build Back Greener*, Department for Business, Energy & Industrial Strategy, https://www.gov.uk (accessed on 6 January 2022). [2]

BEIS (2021), *UK Hydrogen Strategy*, Department for Business, Energy & Industrial Strategy, https://www.gov.uk (accessed on 13 January 2022). [60]

BEIS (2021), *Valuing greenhouse gas emissions in policy appraisal - GOV.UK*, Department for Business, Energy & Industrial Strategy, https://www.gov.uk (accessed on 4 January 2022). [27]

BEIS (2020), *Powering our Net Zero Future. Energy White Paper*, HM Government Energy Department, https://www.gov.uk (accessed on 13 January 2022). [57]

BEIS and Ofgem (2021), *Transitioning to a net zero energy system: smart systems and flexibility plan 2021*, Department for Business, Energy and Industrial Strategy and Ofgem, https://www.gov.uk (accessed on 13 January 2022). [58]

BEIS, Ofgem and Innovate UK (2021), *Digitalising our energy system for net zero: strategy and action plan*, Department for Business, Energy and Industrial Strategy, Ofgem and Innovate UK, Policy paper, https://www.gov.uk (accessed on 13 January 2022). [59]

BoE (2022), *Results of the 2021 Climate Biennial Exploratory Scenario (CBES)*, https://www.bankofengland.co.uk/stress-testing/2022/results-of-the-2021-climate-biennial-exploratory-scenario (accessed on 24 May 2022). [40]

BoE (2021), *Greening our Corporate Bond Purchase Scheme (CBPS)*, Bank of England, https://www.bankofengland.co.uk (accessed on 5 January 2022). [41]

BoE (2021), *Key elements of the 2021 Biennial Exploratory Scenario: Financial risks from climate change*, Bank of England, https://www.bankofengland.co.uk (accessed on 4 January 2022). [39]

BoE (2021), *Options for greening the Bank of England's Corporate Bond Purchase Scheme*, Bank of England, https://www.bankofengland.co.uk (accessed on 5 January 2022). [29]

BoE (2019), *Enhancing banks' and insurers' approaches to managing the financial risks from climate change*, Bank of England, https://www.bankofengland.co.uk (accessed on 4 January 2022). [35]

BoE (2019), *Insurance Stress Test 2019*, Bank of England, https://www.bankofengland.co.uk (accessed on 4 January 2022). [38]

Bolton, P. (2021), *Petrol and diesel prices*, House of Commons Library. [74]

Burke, J. et al. (2020), *Policy brief: Distributional impacts of a carbon tax in the UK*. [55]

Card, D. et al. (2004), *Seeking a Premier Economy: The Economic Effects of British Economic Reforms, 1980-2000*, University of Chicago Press. [19]

Caselli, F., A. Ludwig and R. Van Der Ploeg (2021), *No Brainers and Low-Hanging Fruit in National Climate Policy*, http://www.janakreisl.de. [1]

CFRF (2020), "Climate Financial Risk Forum guide 2020 Summary", https://www.fca.org.uk/publication/corporate/climate-financial-risk-forum-guide-2020-summary.pdf (accessed on 4 January 2022). [37]

Climate Action Tracker (2021), *Warming Projections Global Update*, Climate Analytics and New Climate Institute. [45]

Climate Assembly UK (2020), *The Path to Net Zero*, Climate Assembly UK, https://www.climateassembly.uk/recommendations/index.html (accessed on 24 January 2022). [85]

Climate Change Committee (2021), *2021 Progress Report to Parliament*, Climate Change Committee, https://www.theccc.org.uk (accessed on 24 August 2021). [3]

Climate Change Committee (2020), *Reducing UK emissions: 2020 Progress Report to Parliament*, Climate Change Committee, London, https://www.theccc.org.uk. [11]

Climate Change Committee (2020), *The Sixth Carbon Budget*, Climate Change Committee, http://www.theccc.org.uk/publications (accessed on 14 January 2022). [14]

Corlett, A. and J. Marshall (2022), *Shrinking footprints The impacts of the net zero transition on households and consumption*. [69]

D'Archangelo, F. et al. (2022), "A framework to decarbonise the economy", *OECD Economcs Department Working Papers* 31, https://doi.org/10.1787/4e4d973d-en. [9]

Dechezleprêtre, A. et al. (2022), "Understanding public acceptability of climate change mitigation policies across OECD and non-OECD countries (forthcoming)". [10]

Dechezlepretre, A. and M. Cervantes (2022), "Driving low-carbon innovations for climate neutrality". [48]

DEFRA (2021), *England Peat Action Plan*, Department for Environment, Food and Rural Affiars, https://www.gov.uk (accessed on 18 January 2022). [90]

DEFRA (2021), *England Trees Action Plan 2021 to 2024*, Department for Environment, Food and Rural Affiars, https://www.gov.uk (accessed on 18 January 2022). [89]

Department for Transport (2021), *Green Paper on a New Road Vehicle CO 2 Emissions Regulatory Framework for the United Kingdom*, Department for Transport. [76]

Department for Transport (2021), *Greenhouse Gas Emissions by Transport Mode; United Kingdom*, Department for Transport, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/984823/env0201.ods (accessed on 18 November 2021). [70]

Department for Transport (2021), *Transitioning to zero emission cars and vans: 2035 delivery plan*, Department for Transport and Office for Zero Emission Vehicles, https://www.gov.uk (accessed on 10 January 2022). [75]

Department for Transport (2021), *Transport decarbonisation plan*, Department for Transport, https://www.gov.uk (accessed on 17 January 2022). [81]

European Commission (2021), *EU-UK Trade and Cooperation Agreement*, Publication office of the EU, https://eur-lex.europa.eu (accessed on 6 January 2022). [25]

European Commission (2021), *Proposal for a regulation of the European Parliament and of the Council establishing a carbon border adjustment mechanism*, Publication office of the EU. [54]

European Commission (2020), *Report from the Commission on the availability of hydrofluorocarbons on the Union market*, European Commission, https://ec.europa.eu (accessed on 10 January 2022). [82]

Gillingham, K., R. Newell and K. Palmer (2009), "Energy Efficiency Economics and Policy", https://doi.org/10.1146/annurev.resource.102308.124234. [66]

Global CCS Institute (2021), *Global status of CCS 2021*, https://www.globalccsinstitute.com (accessed on 19 January 2022). [91]

Guo, J., D. Kubli and P. Saner (2021), *The economics of climate change: no action not an option*, Swiss RE, Zurich. [5]

Henderson, B., C. Frezal and E. Flynn (2020), "A survey of GHG mitigation policies for the agriculture, forestry and other land use sector", *OECD Food, Agriculture and Fisheries Papers*, No. 145, OECD Publishing, Paris, https://dx.doi.org/10.1787/59ff2738-en. [87]

HM Government (2022), *British Energy Security Strategy Secure, clean and affordable British energy for the long term*. [56]

HM Government (2021), *Green Jobs Taskforce - Report to Government, Industry and the Skills sector*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1003570/gjtf-report.pdf (accessed on 7 March 2022). [22]

HM Government (2021), *Heat and Buildings Strategy*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1044598/6.7408_BEIS_Clean_Heat_Heat___Buildings_Strategy_Stage_2_v5_WEB.pdf (accessed on 20 January 2022). [67]

HM Government (2020), *The Ten Point Plan for a Green Industrial Revolution - Building back better, supporting green jobs, and accelerating our path to net zero*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf (accessed on 7 March 2022). [23]

HMT (2021), *Net Zero Review : Analysis exploring the key issues.*, HM Treasury, https://www.gov.uk (accessed on 4 January 2022). [6]

HMT (2021), *Recommendations for the Financial Conduct Authority: March 2021*, HM Treasury, https://www.gov.uk (accessed on 4 January 2022). [33]

HMT (2021), *Recommendations for the Prudential Regulation Committee*, HM Treasury, https://www.gov.uk (accessed on 4 January 2022). [32]

HMT (2021), *Remit and recommendations for the Financial Policy Committee – March 2021*, HM Treasury. [31]

HMT (2021), *Remit for the Monetary Policy Committee - March 2021*, HM Treasury. [30]

HMT (2021), *UK Government Green Financing Framework*, HM Treasury, https://www.gov.uk (accessed on 4 January 2022). [34]

HMT (2020), *Green Book Review 2020: Findings and response CP331*, http://www.gov.uk/official-documents. (accessed on 7 March 2022). [26]

HMT (2020), *Net Zero Review: Interim report*, HM Treasury. [50]

HMT (2020), *The Green Book: appraisal and evaluation in central government - GOV.UK*, HM Treasury, https://www.gov.uk (accessed on 4 January 2022). [28]

IEA (2021), *Global EV Outlook 2021*, International Energy Agency, https://www.iea.org/reports/global-ev-outlook-2021. [77]

IEA (2021), *World Energy Outlook 2021, International Energy Agency*, http://www.iea.org/weo (accessed on 10 January 2022). [47]

IEA (2018), *The Future of Petrochemicals Towards more sustainable plastics and fertilisers*, International Energy Agency, http://www.iea.org (accessed on 13 January 2022). [61]

IMF and OECD (2021), *Tax Policy and Climate Change*, OECD Publishing, http://www.oecd.org (accessed on 20 January 2022). [52]

ITF (2021), *Decarbonising Air Transport Acting Now for the Future Decarbonising Transport*, International Transport Forum, http://www.itf-oecd.org (accessed on 18 November 2021). [95]

ITF (2018), *The Social Impacts of Road Pricing*, International Transport Forum, http://www.itf-oecd.org (accessed on 18 November 2021). [73]

LCCC (2021), *Low Carbon Contracts Company (LCCC) Annual Report 2020/21*, Low Carbon Contracts Company, https://www.lowcarboncontracts.uk/index.php/publications/low-carbon-contracts-company-lccc-annual-report-202021 (accessed on 24 January 2022). [49]

Lehmann, J. and S. Joseph (2015), *Biochar for environmental management : science, technology and implementation*, Earthscan from Routledge. [92]

Li, S. et al. (2017), "The Market for Electric Vehicles: Indirect Network Effects and Policy Design", https://doi.org/10.1086/689702. [80]

Lyons, G., A. Curry and C. Rohr (2021), "Decarbonising UK Transport Final report and technology roadmaps". [79]

Masnadi, M. et al. (2018), "Global carbon intensity of crude oil production", *Science*, Vol. 361/6405, pp. 851-853, https://doi.org/10.1126/SCIENCE.AAR6859. [62]

Ministry of Housing Communities and Local Government (2021), *English Housing Survey Energy Report 2019 - 2020*. [68]

MIT (2016), *Sleipner Fact Sheet: Carbon Dioxide Capture and Storage Project*, https://sequestration.mit.edu/tools/projects/sleipner.html (accessed on 25 August 2021). [94]

Nachtigall, D. et al. (2021), "The economic and environmental benefits from international co-ordination on carbon pricing: Insights from economic modelling studies", *OECD Environment Working Papers*, No. 173, OECD Publishing, Paris, https://dx.doi.org/10.1787/d4d3e59e-en. [51]

NAO (2021), *Environmental Tax Measures*, National Audit Office, London, https://www.nao.org.uk/report/environmental-tax-measures/. [24]

New Zealand Ministry for the Environment (2022), *Pricing agricultural emissions, public consultation*, https://consult.environment.govt.nz/climate/agriculture-emissions-and-pricing/ (accessed on 14 October 2022). [88]

NGFS (2021), *NGFS Glasgow Declaration*, Network of Central Banks and Supervisors for greening the Financial System, https://www.ngfs.net (accessed on 4 January 2022). [42]

OBR (2021), *Fiscal risks report – July 2021*, Office for Budget Responsibility, https://obr.uk/frr/fiscal-risks-report-july-2021/ (accessed on 14 December 2021). [7]

OECD (2022), *Agricultural Policy Monitoring and Evaluation (forthcoming)*, OECD Publishing, Paris. [84]

OECD (2022), "OECD Economic Surveys: United Kingdom 2022", https://doi.org/10.1787/7C0F1268-EN (accessed on 22 April 2022). [21]

OECD (2022), *OECD Economic Surveys: United Kingdom 2022*, OECD Publishing, Paris, https://doi.org/10.1787/7c0f1268-en. [96]

OECD (2022), *OECD Environmental Performance Reviews: United Kingdom 2022 (forthcoming)*, OECD Publishing. [4]

OECD (2021), *Assessing the Economic Impacts of Environmental Policies: Evidence from a Decade of OECD Research*, OECD Publishing, Paris, https://dx.doi.org/10.1787/bf2fb156-en. [15]

OECD (2021), *OECD Economic Surveys Denmark 2021*, OECD Publishing, Paris. [16]

OECD (2021), *OECD Economic Surveys: France 2021*, OECD Publishing, Paris, https://dx.doi.org/10.1787/289a0a17-en. [12]

OECD (2021), *OECD Skills Outlook 2021: Learning for Life*, OECD Publishing, Paris, https://dx.doi.org/10.1787/0ae365b4-en. [20]

OECD (2021), *Transport Strategies for Net-Zero Systems by Design*, OECD Publishing, Paris, https://dx.doi.org/10.1787/0a20f779-en. [71]

OECD (2020), *Climate Policy Leadership in an Interconnected World What Role for Border Carbon Adjustments?*, OECD Publishing. [53]

OECD (2019), *OECD Economic Surveys: Norway 2019*, OECD Publishing, Paris, https://dx.doi.org/10.1787/c217a266-en. [78]

OECD (2019), *Taxing Energy Use 2019: Using Taxes for Climate Action*, OECD Publishing, Paris, https://dx.doi.org/10.1787/058ca239-en. [65]

OECD (2014), *The Governance of Regulators*, OECD Best Practice Principles for Regulatory Policy, OECD Publishing, Paris, https://dx.doi.org/10.1787/9789264209015-en. [46]

Pareliussen, J., A. Saussay and J. Burke (2022), "Macroeconomic and distributional consequences of net zero policies in the United Kingdom", *OECD Economcs Department Working Papers (forthcoming), OECD Publishing, Paris*. [8]

PRA (2021), *Climate-related financial risk management and the role of capital requirements*. [36]

Sánchez-Bastardo, N., R. Schlögl and H. Ruland (2021), "Methane Pyrolysis for Zero-Emission Hydrogen Production: A Potential Bridge Technology from Fossil Fuels to a Renewable and Sustainable Hydrogen Economy", *Industrial & Engineering Chemistry Research*, Vol. 60/32, pp. 11855-11881, https://doi.org/10.1021/ACS.IECR.1C01679. [63]

Stewart, C. et al. (2021), "Trends in UK meat consumption: analysis of data from years 1-11 (2008-09 to 2018-19) of the National Diet and Nutrition Survey rolling programme", https://doi.org/10.1016/S2542-5196(21)00228-X. [83]

ThreeME (2022), *Home* | *threeme*, https://www.threeme.org/ (accessed on 22 March 2022). [18]

UK ETS Authority (2022), "Developing the UK Emissions Trading Scheme (UK ETS) A joint consultation of the UK Government, the Scottish Government, the Welsh Government and the Department of Agriculture, Environment and Rural Affairs for Northern Ireland", http://gov.uk (accessed on 24 May 2022). [13]

UNFCCC (2021), *Cooperative Implementation*, United Nations Framework Convention on Climate Change, https://unfccc.int/process/the-paris-agreement/cooperative-implementation#eq-1 (accessed on 14 January 2022). [44]

UNFCCC (2015), *Paris Agreement text English*, United Nations Framework Convention on Climate Change. [43]