Unpacking leadership-driven global scenarios towards the Paris Agreement

Report prepared for the UK Committee on Climate Change

Final Report

August 2020

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Executive Summary

In what ways can a country like the UK, with a track record of climate change policy leadership, maximise its efforts to lead and accelerate the global transition to achieve the Paris Agreement? While there is a large body of literature on the global pathways to reach the long-term temperature goal of the Paris Agreement, few studies investigate how specific groups of countries could affect the rate of global action based on a range of policies. To fill this gap the notion of 'leadership-driven' scenarios, where a coalition of countries with a higher capacity to undertake emissions reductions move first and more rapidly, has emerged.

The unique contribution of this report is to combine modelling of a 'leadership-driven' global transition consistent with expecting to keep warming well-below 2°C with an analysis of channels through which leadership countries could act unilaterally or in groups to accelerate this transition. For the UK we identify a set of specific leadership opportunities. While the UK has already demonstrated climate leadership over the last decade, through governance, diplomacy and negotiations, technology development, climate finance, and carbon markets, wider leadership is needed to drive global change. In particular, the UK's further leadership actions, along with the other leadership regions, need to be cognisant of the ways in which they can unlock the low-carbon transition in the rest of the world.

Through adopting policy-adjusted global models, expert input, and evidence review, we develop an analysis of global and UK leadership opportunities. We first establish a plausible, leadership-driven scenario that demonstrates sectoral abatement activities. This step is conducted using an energy model (TIAM-UCL) coupled with land emissions modelling to form a complete picture of economy-wide emissions. Our modelling approach combines a mix of cost-optimisation with an introduction of real-world emission drivers that include national climate targets, market and technology developments, and policy trends (Chapter 2). We then establish a framework to describe how the leadership group of countries[1] can accelerate global action towards meeting the Paris Agreement. We apply this framework against the key sectoral sources of emissions and discuss leadership opportunities in each sector (Chapter 3). Finally, following the global scenario pathway and global leadership opportunities, we review the UK's leadership potential. We reflect on the UK's relative strengths and particular opportunities to shortlist several areas of leadership focus (Chapter 4).

In the short term, the main opportunities are continued decarbonisation of the power sector (27% of 2020-2030 abatement) through accelerated uptake in renewables in the leadership countries and a shift from coal to lower-carbon fossil fuels and renewables in other countries. This is followed by increased deployment of emission reduction measures in the industry (energy efficiency, switch to low-carbon fuels and Carbon Capture and Storage (CCS) after 2030) and transport sectors (accelerated shift to electric vehicles, energy efficiency and fuel decarbonisation of shipping and aviation). Agriculture and land use emission reductions can contribute with a further 14% of the abatement through a combination of increased productivity, dietary shifts, afforestation and reforestation, restoration of degraded land, and soil sequestration.

By 2050, the leadership-driven scenario results in a global emissions reduction of 76% from 54 billion metric tonnes of CO_2 equivalent ($GtCO_2e$) emissions in 2020 (4% reduction per year) with a varied pace of reduction across the regions. The leadership group emissions reduce by 94%, consistent with these regions reducing their carbon dioxide (CO_2) emissions to net-zero and several of them achieving net-zero greenhouses gases (GHGs) emissions. Other middle- and low-income regions reduce their GHG emissions at a different pace, recognising different capabilities and opportunities. China's emissions reduce by 82% while India's emissions reduce by 48%. By 2050, the leadership group decarbonises at fastest pace across all sectors with the exception of agriculture and land use, where other developed countries reduce their emissions by 68%.

[1] Based on the input from the CCC, this group includes the UK, the USA, South Korea, Japan, the EU countries, Australia, New Zealand, and Canada.

Our analysis indicates that the six major opportunities for leadership countries are:

- Power (12% of global 2020-50 abatement): overseas capacity building (e.g. integrating high variable renewables into the grid or attracting private finance) and direct financial support can effectively accelerate uptake of already mature solutions (solar photovoltaic (PV) and onshore wind) in developing markets. Further domestic demonstration of emerging solutions (e.g. offshore wind and other higher cost renewables) will be vital in reducing deployment costs still more and generating best practice for wider global deployment.
- Industry (25% of global 2020-50 abatement): given the complexity of industrial decarbonisation, development of clusters that demonstrate the viability of low-carbon industry and associated trade measures (e.g. border carbon adjustments; embedded carbon standards, trade initiatives) will be critical levers for unlocking global mitigation efforts. Implementing trade measures in a joined-up way across the leadership regions will be particularly important in order to generate a large enough market share to drive changes in production methods elsewhere in the world. Further, leveraging private sector impact (e.g. through private sector commitments to greening their supply chains through sourcing low-carbon materials and products) can be an important channel of influence.
- Transport (18% of global 2020-50 abatement): countries can accelerate the diffusion of electric vehicles through domestic deployment, helping to reduce costs further to accelerate uptake elsewhere. Diplomatic influencing (e.g. expanding city alliances through clean air and pollution charges across the world) and leveraging the private sector's impact (e.g. businesses committing to zero emissions vehicles across their global operations) can be also effective.
- Buildings (8% of global 2020-50 abatement): leadership countries will need to accelerate demonstration of abatement solutions at scale, helping reduce the costs of relatively more expensive technologies and near-zero construction materials as well as showcasing successful energy efficiency policy and business models. The private sector's global commitments to decarbonisation can also help both realise the surge in clean energy investment required and create a broader demand for low-carbon solutions. Finally, international coordination on trade standards, knowledge transfer, and regulatory trajectories can be a powerful tool to create a global market for sustainable buildings.
- Agriculture and land use (8% and 9% of global 2020-50 abatement, respectively): shifting subsidies to supporting sustainable agriculture practices, creating market mechanisms to reward these practices, and the provision of public goods are important policy reforms that leader countries can exemplify and spread to other countries through international forums (e.g. CGIAR[2]). Diplomacy, such as a global call for action on deforestation, and sustainable supply chains can leverage substantial reductions as can financial support (mobilise global funds to tackle land use and deforestation) and trade measures (bilateral relationships and trade agreements).
- Engineered GHGs removals (6% of global 2020-50 abatement): Given the early emergence and wider governance and sustainability issues, the leadership opportunities appear in demonstrating net-zero pathways (e.g. strict sustainability standards, policy incentives), and trade measures (e.g. robust accounting and monitoring of emission standards and tradeable certifications). Overseas financial support (e.g. applying existing UN financial mechanisms) and the private sector's activity (e.g. through purchasing compliance offset credits) could stimulate global uptake in removals.

[2] Formerly the Consultative Group for International Agricultural Research.

Given the relative size of global measures, and areas where the UK appears influential over global progress, the following UK actions could be catalytic in accelerating the transition. This shortlist draws out some of the main UK opportunities, while a number of other actions could also be pursued:

1. **Evolving the Powering Past Coal Alliance (PPCA) to stimulate coal phase-out by large coal users.** Our scenario requires a rapid global shift from coal (94% reduction by 2030). Thus, expanding and broadening the membership of the Alliance with large coal users (e.g. USA, China, Russia, and India) will be necessary. As a co-founder, the UK could further lead on this expansion given its domestic coal record. One way forward could be for the UK to propose a tiered approach: first with new members agreeing to no new coal; then eliminating old and inefficient plants; and finally guaranteeing a finite lifetime for the remaining coal-powered units. Similarly, further use of public and private sector financing could be dependent on countries' coal phase-out commitments.

2. **Expanding global role of offshore wind.** As a global leader in offshore wind (36% of installed global capacity), the UK can expand the global role of this power source. With 17% of global technical potential in European waters, the UK can help in accelerating large-scale domestic deployment of offshore wind as well as further reducing the technology costs. Internationally, it can provide a targeted concessional finance and grant scheme for feasibility and Front-end engineering design (FEED) studies for offshore wind developers in low- and middle-income countries with large technical potential (e.g. Brazil, India, and Morocco). It can also explore cross-country financing programmes that have a potential in scaling up the size of projects and reducing finance costs, which could be effective in the case of capital-intensive offshore wind.

3. **Developing UK industrial CCS and hydrogen infrastructure.** The UK could further accelerate the introduction of industrial clusters, CCS, and hydrogen infrastructure. The UK has a distinct advantage in CCS potential compared to other countries due to the high availability of usable CO_2 storage sites for CCS infrastructure (70GtCO_2, equivalent to the EU's combined storage capacity) as well as having existing oil and gas expertise. With more than 60% of modelled hydrogen use outside the leadership regions by 2050, the UK has clear opportunities in developing early domestic markets, as in the offshore wind case, first through blue hydrogen infrastructure while facilitating long-term cost-reductions of green hydrogen and deployment elsewhere in the world.[3]

4. **Leading on developing a net-zero framework and pathway for aviation.** As one of the five largest CO_2 emitters from passenger flights, the UK is in a position to develop a leadership position in the aviation sector by establishing detailed binding commitments and targets, in line with the Committee on Climate Change (CCC)'s net-zero pathway, that include international aviation emissions. This means that the UK could also lead on coordinating how Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) targets can successfully interact with domestic targets and result in genuine emissions reductions that avoid double counting. Further, it can leverage the UK aviation sector's commitment to 2050 net-zero carbon emissions to increase the International Air Transport Association (IATA)'s ambition to aim for net-zero emissions by 2050. Finally, it can lead on establishing international standards for sustainable aviation fuels to ensure their genuine sustainability and then creating cross-country coalitions developing large-scale supply of cost-competitive sustainable aviation fuels (SAFs).

5. **Developing GHGs removals incentives and sustainability standards.** The UK has strong institutional capacity, CCS storage potential, and an established innovation ecosystem (e.g. £31.5m Greenhouse Gas Removal Demonstrators Fund and up to £100m of forthcoming research and development (R&D) funding for Direct Air Capture (DAC) technology). This makes it well placed to increase the number of demonstration projects of Bioenergy with Carbon Capture and Storage (BECCS), DAC, and other GHGs removals. Further, with eight million tonnes of imported biomass in 2018 and a likely future

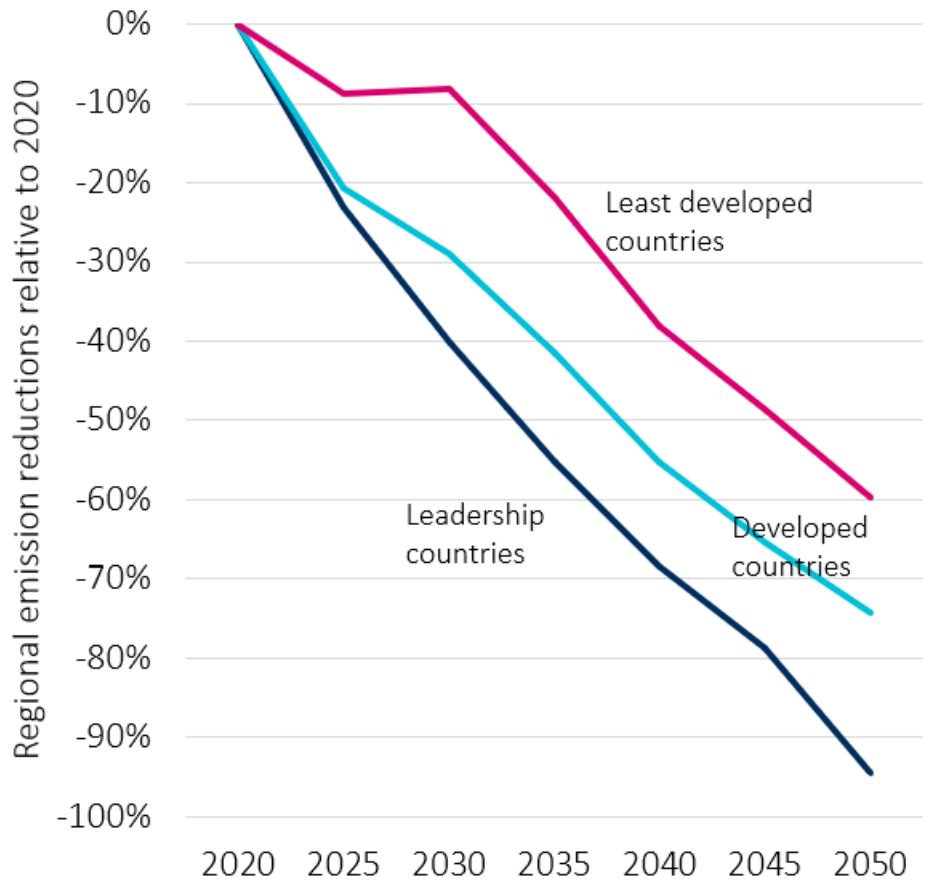
[3] Blue hydrogen is produced from natural gas after reforming to remove carbon content. Green hydrogen is produced by using power to electrolyse water.

role in BECCS, the UK could lead in the development of high sustainability standards that ensure low-carbon agricultural and sustainable land use practices elsewhere in the world. The UK is also in a strong position in leveraging the private sector's role, through its net-zero commitments, in the development of GHGs removals markets. Internationally, it has an excellent opportunity to lead cooperation on sustainability standards, introduction of effective financing mechanisms (e.g. Environmental Land Management payments), or inclusion of GHGs removals in carbon markets.

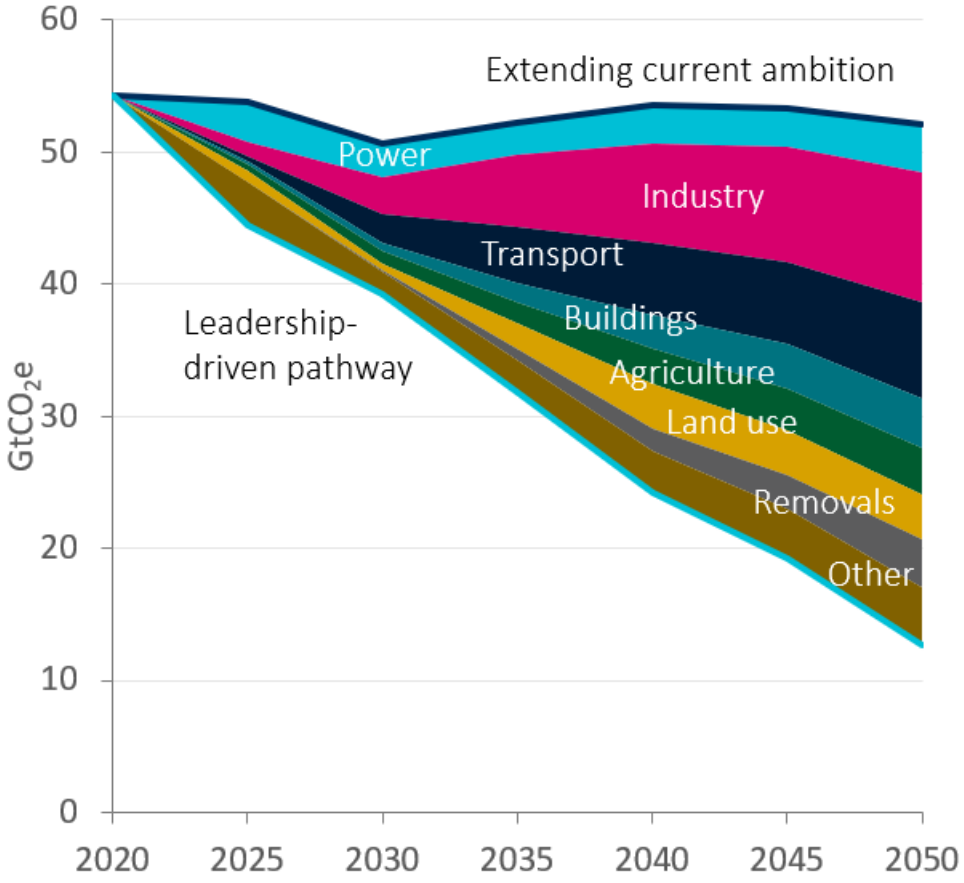
6. **Green recovery and greening the UK financial sector.** The UK could consider an introduction of innovation and commercialisation funds in areas like buildings, industry, and transport. Through its presidencies of both the Group of Seven (G7) and the United Nations Climate Change Conference (COP 26) in 2021, it could play a prominent role in forming alliances together with other key players (e.g. the EU or China) and encouraging others to commit to green recovery measures. Through international organisations, the UK could push for green conditions to be attached to any finance packages to developing countries. In the financial sector, the UK can further increase its efforts to green its domestic financial sector through accelerated transition to binding Task Force on Climate-Related Financial Disclosures (TCFD) requirements. As a world leader on cross-border lending (18% of global market share), the UK could also scale up its efforts in green cross-border capital flows by expanding the Green Finance Institute's partnerships to other markets. The UK International Climate Fund (ICF) programme could further leverage private finance commitments in critical areas (power, transport, and agriculture and land use) and regions with most cost-effective potential, leading to stronger private sector capital flows in the medium term.

The study's insights shed light on the key leadership-driven climate policy developments that may be needed to meet the Paris Agreement. In particular, its analysis could be used in steering the policy priorities at both the international and UK level that are consistent with the narrative of key group of countries leading on and enabling the global transition to the Paris Agreement target.

The leadership group accelerates decarbonisation followed by other regions



The leadership-driven pathway is largely achieved through six main areas



Source: Vivid Economics, TIAM-UCL

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Glossary and main abbreviations

Abbreviation	Detail
BECCS	Bioenergy with Carbon Capture and Storage technologies
CCS	Carbon Capture and Storage
DAC	Direct Air Capture technologies
ECA	Extending current ambition scenario. This is our reference scenario to the leadership-driven scenario
EVs	Electric Vehicles
GHGs, CO_2, NO_x, CH_4	Greenhouse Gas emissions; Carbon dioxide; Nitrogen oxides; Methane
GGRs	Greenhouse gas removals, these are either nature-based or technology-based ways of directly removing greenhouse gases from the atmosphere
$GtCO_2eq$	Billion metric tonnes of CO_2 equivalent
HHD, MLHD	High Human Development, Medium-Low Human Development, based on the Human Development Index
ICE phase out	Phase out of Internal Combustion Engine vehicles
IPCC	Intergovernmental Panel on Climate Change
NDCs	Nationally Determined Contributions to meeting the Paris Agreement target
PPCA	Powering Past Coal Initiative
SAFs	Sustainable Aviation Fuels
TCFD	Taskforce on Climate-related Financial Disclosure

1 Introduction

If met, the Paris Agreement – a global commitment to limit average temperature rise to well-below 2°C and pursue efforts to achieve only 1.5°C degrees of warming – implies changing energy, industrial system, and land use patterns throughout the world. The precise balance of energy, industry, and land use changes in the future economy depends upon the technology mix; for example, potential breakthroughs in solar power could imply major changes to the size of the market for silicon and plastics. Across all these changes, there is heightened uncertainty about the pace and scale of change, and there is a need to carefully consider the possible technology scenarios.

The field of energy-economy modelling has highlighted potential pathways that are compatible with the Paris goal. For example, over 400 pathways underpinned the Intergovernmental Panel on Climate Change (IPCC)'s Special Report on the impacts of 1.5°C, of which around 90 are consistent with the 1.5 degrees target, while a further 130 are consistent with a below 2°C target (Huppmann et al., 2018). These scenarios are of a normative nature, exploring the necessary reductions to meet global climate targets, and therefore typically back cast to show what needs to happen. They typically follow a cost-minimising framework to determine the relative level of effort between different regions of the world. Fewer of the scenarios are exploratory and contain assumptions that are consistent with historical trends regarding rates of technology diffusion, deployment, innovation, supply chain development, investor behaviour, land use change, and infrastructure development.

In terms of providing support on policy and international negotiation efforts, some gaps remain in existing modelling work that have been a focus of this research. An understanding of plausible pathways is necessary to plan policy, international engagements and to inform new investments. Further, understanding the difference between more likely pathways, given policy and market developments, and optimal pathways can provide a basis for a set of policy recommendations. However, current energy-climate models generally do not allow for this as they do not include factors that constrain what may be feasible. This research builds in a stronger alignment with the real world by considering existing targets and policies.

Previous work by the UCL Energy Institute and Vivid Economics has sought to combine considerations of international policy coordination with plausible mitigation scenarios. In UCL work for the CCC, a set of 'leadership-driven'[4] scenarios were developed in which the UK, together with a coalition of developed countries, leads global efforts of rapid emissions reductions (Pye et al., 2019). The leadership-driven scenario is more reflective of rich countries' large historical contributions to climate change and often higher capability to move ahead on the path to a net-zero world. Using the global energy system model TIAM-UCL, the study explored how the UK and similar countries can take strong and early action to meet their emissions reduction targets, which in turn could help developing countries make their low-carbon transition more plausible and less expensive.

However, the UCL analysis stopped short of developing a full analysis of the mechanisms and resulting emissions wedges that result from different aspects of leadership by a group of high-ambition developed countries. A research gap therefore is to review leadership-driven scenarios and dive deeper into the results. Doing so can identify plausible global mitigation 'wedges' that move the world from its current trajectory, consistent with present nationally determined contributions (NDCs), towards a 'leadership-driven' transition which could be stimulated by developed country leadership on technology innovation, coal phase-out, electric vehicles (EV) deployment, or many other areas. Further, an analysis of the role of the UK within a global leadership coalition can be useful to inform policy making and the allocation of overseas development assistance to support the global effort most effectively.

[4] The report described this as 'a broader coalition of countries with ambitious climate policy objectives that are in line with the 'common-but-differentiated-responsibility' principle outlined in the Paris Agreement'.

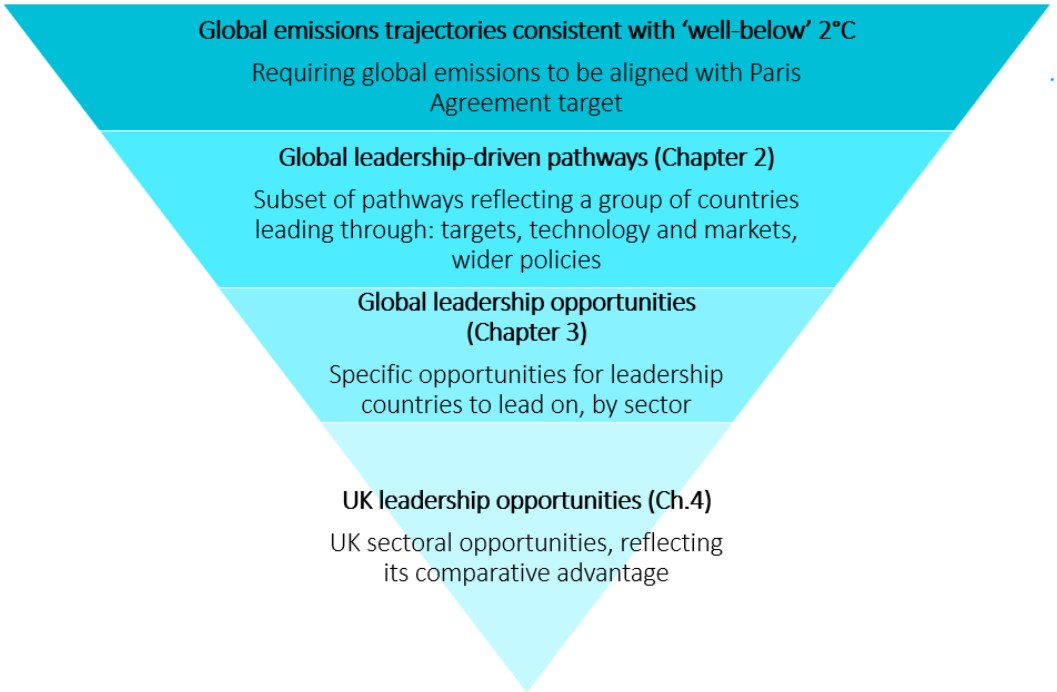
Against this backdrop the objectives of this project are:

- To identify the key 'wedges' of global mitigation that would move the world from its current trajectory towards a leadership-driven scenario compatible with achieving the Paris Agreement.
- To identify which of these the UK is best placed to support through the actions needed to achieve the domestic transition to Net Zero and wider actions that the UK takes to support decarbonisation internationally.

To meet these objectives, the report's analysis is set out in three distinct sections (Figure 1). Each of the sections first introduces our approach, presents key results, and then provides detailed analysis and discussion of relevant evidence. The three sections include:

- **Global leadership-driven pathways**: the objective of this section is to establish a plausible, leadership-driven scenario that demonstrates sectoral abatement activities. This step is conducted using an energy model (TIAM-UCL) coupled with land emissions modelling to form a complete picture of economy-wide emissions.
- **Global leadership opportunities**: the objective is to establish a framework to describe how leadership countries can accelerate global action towards meeting the Paris Agreement. We apply this framework against the key sectoral sources of emissions and discuss leadership opportunities in each sector.
- **The UK's leadership potential**: following the global scenario pathway and global leadership opportunities, we review the UK's leadership potential. We reflect on the UK's relative strengths and particular opportunities to shortlist several areas of leadership focus.

Figure 1 Overview of the report's content



Source: Vivid Economics, TIAM-UCL

2 Global leadership-driven pathways

2.1 Introduction and our approach

This chapter discusses the approach to, and results of, modelling a 'leadership-driven' scenario. This scenario reflects that the leadership countries, including the UK, are pursuing domestic emissions reductions at the highest credible rates prior to 2050. Other regions, particularly large industrial economies such as China, are still required to rapidly reduce their emissions, but do not reach net-zero emissions until after 2050. The chapter uses the modelling results to answer the following questions:

- What are the sectoral abatement measures through which the world achieves the climate mitigation targets?
- How do the sectoral measures differ regionally?

In the real world, many different drivers influence countries' carbon emissions and economic outcomes that interact in complex ways. These drivers can be summarised in three categories:

- **National climate targets**, such as net-zero emissions regulation. These are directly imposed in our model as a constraint on the emissions budget for particular regions.
- **Market and technology drivers,** such as the uptake of technologies based on cost – i.e. consumers demand EVs once they become the cheaper form of mobility relative to internal combustion engines (ICEs).
- **Policy trends**, such as carbon pricing, electricity market reforms, or ICE phase-out legislation.

As for climate targets, we introduce eight national net-zero emission targets which need to be achieved by 2050. Based on the input from the CCC, the national targets include the following group of countries: the UK, the USA, South Korea, Japan, the EU, Australia and New Zealand, and Canada. Please refer to the Appendix for details on each country's target. In many cases these targets are consistent with the current level of stated policy ambition (e.g. UK and EU) but require more ambitious commitments from others (e.g. USA).

We represent market and technology drivers through a mixed cost-optimisation approach that combines relative costs with specific sectoral technology pathways. In our modelling, the uptake in technologies is mainly determined by expected technology costs and performance, and what would be the lowest cost solution over time. However, we further reviewed global decarbonisation studies, introducing a set of technology pathways in relation to three areas. These are deemed to be significant in terms of emission potential, essential in order to meet the global temperature target, and plausible in terms of having an understanding of necessary deployment policies (see Appendix for further details):[5]

- **Buildings decarbonisation**: Proven, cost-effective policy mechanisms exist, and have been successfully adopted in both developed and emerging economies. We use the International Energy Agency (IEA)'s Sustainable Pathway to reflect the regional decarbonisation opportunities.
- **Industrial decarbonisation**: Whilst being one of the most challenging sectors to decarbonise, a number of technical solution have been explored, ranging from the deployment of energy efficiency technologies, fuel and feedstock switching to lower-carbon solutions (e.g. electricity and hydrogen), material

[5] The building and industrial emission reductions are a minimum level of emission reduction that needs to be met. Both have been surpassed by the cost-minimisation approach. The CCS storage constraint, on the other hand, is the maximum constraint. It has not been fully used up in our scenario as TIAM-UCL model selects different, more cost-effective, options, such as electrification of industrial activities.

efficiency, and other innovative technologies (IEA, 2019a). We use the IEA Sustainable Development Scenario to reflect regional decarbonisation opportunities.

- **CCS storage capacity**: to reflect of current CCS infrastructure and market developments, we introduced an IEA scenario's storage capacity constraint of up to 115 $GtCO_2e$ captured over the period of 2030-2060 (IEA, 2019b). This represents an upper capacity limit to regional CCS deployment.

Finally, we impose the major policy trends underway in our modelling. We reviewed existing evidence on major policy areas evolving globally. These are specified for each region where possible (see Appendix for further details):[6]

- **Phase-out of coal from power generation**: to reflect on the existing coal phase-out plans, as well as economic, geopolitical, and civil society pressures, we introduce country-specific restrictions in terms of expected dates of stopping building new coal power plants as well as the dates for coal phase-out from overall power generation. These should be regarded as estimates of current policy and societal trends across the regions.[7]

- **Phase-out of ICEs:** to reflect on the existing policy efforts and announcements, as well as economic, geopolitical, and civil society pressures, we introduced likely ICE sales phase-out dates for both light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs).[8]

- **Regional nuclear energy trends**: based on existing policies and announcements, the long-term deployment of nuclear energy in power generation varies significantly across the regions. To fully reflect on current real-world nuclear energy policies in our leadership pathway, we combined our existing evidence on the regional trends with IEA World Energy Outlook 2019 to establish expected shares of nuclear energy in total electricity generation.

This 'leadership-driven' framework rebalances the modelling from a global 'least-cost' scenario to one that combines specific restrictions with the global requirement of meeting the temperature goals in the Paris Agreement. These specific restrictions represent policies or drivers that we can observe in play today, where some leadership regions will be able to accelerate action sooner than others. These additional constraints are introduced to simulate the impact of different rates of policy ambition across regions of the world, with leadership countries moving much faster than others in many aspects of the transition.

We develop two main global emissions scenarios of which one applies this leadership-driven framework. The first scenario – of 'extending current ambition' provides a reference scenario against which we compare our 'leadership-driven' scenario:

- **Reference scenario – extending current ambition (ECA)**: From 2020 to 2030, all countries meet their current NDC commitments. Post-2030, countries continue to reduce emissions per unit of gross domestic product (GDP) at the decarbonisation rate observed during the 2020-30 period, but with a minimum rate set to 2%, as per Fawcett et al. (2015). This scenario does not meet the Paris Agreement, as the global average temperature increase by 2.74°C above preindustrial levels by 2100. Globally, current policies to 2030 are not yet fully consistent with the ECA scenario. Therefore, additional efforts, particularly in the power sector, above those already in place today are required to meet currently pledged commitments. These efforts are not explicitly included in our analysis of key mitigation wedges to achieve the long-term temperature goal of the Paris Agreement, but are nonetheless essential to its achievement.

[6] A previous project by Vivid Economics for the UN's Principles for Responsible Investment (PRI) determined the major policy areas evolving globally (https://www.unpri.org/inevitable-policy-response/what-is-the-inevitable-policy-response/4787.article). We have also introduced a set of sector-specific requirements to account for the existing evidence on real-world constraints and opportunities that might not be fully reflected in a cost-optimised model like the TIAM-UCL. Please refer to the Appendix for the specifics on each of these restrictions.
[7] Please refer to UN PRI (2019), slide 36 onwards, for regional details.
[8] Please refer to UN PRI (2019), slide 48 onwards, for regional details.

- **Leadership-driven scenario**: this scenario restricts global emissions by applying a global carbon budget consistent with limiting peak warming to just over 1.75°C. This is used to be consistent with a 'well-below 2°C' target (interpreted as consistent with at least a 66% probability of keeping warming to below 2°C). It is not compatible with keeping warming to below 1.5°C with ~50% probability, with additional measures required to move to a 1.5°C peak warming scenario (see Box 2). In addition, we apply the leadership-driven framework discussed above.

The core modelling framework used for the scenario analysis is the TIAM-UCL, coupled with non-energy emission pathways. This is an energy system model that we coupled with accounting for land and other emissions sources to build a complete GHG emissions pathway (Box 1).

Box 1 Global leadership-driven emissions pathway modelling framework

TIAM-UCL model

Cost-optimised model: The TIAM-UCL is a cost-optimising energy model that allows for a detailed representation of the energy system. It covers sectoral energy use demands: these include transport, industry and buildings sectors that are represented across 16 geographical regions. Further, it provides a detailed representation of energy supply: this includes electricity generation, ranging from fossil fuels to renewables, nuclear and bioenergy sources, as well as upstream activities and other energy conversion processes e.g. hydrogen.

Sectoral emissions reduction measures: the model includes emission reduction measures across the different sectors. For example, the power sector measures include renewables, nuclear, and other low-carbon technologies replacing coal and other fossil fuels in power generation. Energy end-use sectors include measures such as fuel switching to low-carbon fuels (e.g. electricity, hydrogen, biomass), use of CCS technology, sector-specific energy efficiency measures, and price-induced demand reduction.

Non-energy emissions

TIAM-UCL is an energy system model so does not capture the full range of options in the land use and forestry, and agriculture sectors, representing them simplistically. However, a large body of research considers the contribution of these sectors to emissions and mitigation, much of which was summarised in a special report by the IPCC (2019).

We supplemented the model with other emissions pathways to account for all major GHGs emissions. We used Paris target-consistent emission pathways for non-energy emissions sources from agriculture, waste, and fluorinated gases. In terms of the land use CO_2 emissions, we used a modelled scenario developed as part of Vivid Economics' Principles for Responsible Investment (PRI) project (please refer to Appendix).

Other studies indicate further emission abatement opportunities that are outside the scope of the TIAM-UCL model but can further close the gap to 1.5°C-consistent outcomes. Some of these opportunities include aspects such as wider demand side and behaviour change measures; resource efficiency and circular economy measures; further non-energy measures; and other carbon dioxide removal measures. These are further discussed in Box 2.

Box 2 Further abatement opportunities outside TIAM-UCL can close the gap to 1.5°C outcome

Other studies indicate different important emission abatement opportunities that are outside the scope of the TIAM-UCL model:

Energy service demand change

TIAM-UCL is predominantly a supply-side model that meets an exogenously determined set of energy service demand projections, which for this analysis use demand drivers based on a Shared Socioeconomic Pathway 2 (SSP2) narrative (see Appendix for further details). This includes mobility (e.g. passenger-km) or production levels in industry (e.g. Mt cement). Key options to reduce energy use through energy efficiency gains are included. With the exception of the price-induced demand response (e.g. energy service demands reduce based on higher costs of those demands), the model is constrained to meet the energy service demands. It therefore does not have broader options to reduce energy service demands, such as changes to diet, the way mobility is provided, resource efficiency (see next point), and changes to working practices. An emerging set of studies is highlighting the role that these demand-side measures can play in reducing emissions (Creutzig et al., 2018), notably two recent papers from the integrated assessment modelling community (Grubler et al., 2018; Van Vuuren et al., 2018).

Resource efficiency and circular economy measures

There are opportunities to improve production and use processes related to global materials in order to enhance their circularity and reduce waste (Stahel, 2016; Geng et al., 2019). More than half of all GHGs are related to materials management activities (OECD, 2019). Therefore, policies which aim to achieve greater resource efficiency and a circular economy may relate directly or indirectly to climate change mitigation opportunities (Ellen MacArthur Foundation, 2019; EU Commission, 2020). However, increased use of secondary materials may not necessarily lead to improved climate mitigation unless economies also increase their renewables penetration (Nechifor et al., 2020). Given the limited capacity of integrated assessment models (IAMs) to consider materials and recycling (Pauliuk et al., 2017) and a lack of economic detail in most IAMs (including TIAM-UCL), they will not capture the change in demands of the non-energy materials and resource processes which may arise from future circular economy policies.

Carbon dioxide removal measures

TIAM-UCL represents BECCS and DAC, plus it attributes a role for sequestration via the land use and forestry sector. However, there are a range of other options being discussed (Royal Society, 2018) which do not feature in TIAM-UCL, many of which are highly speculative.

2.2 Leadership-driven emissions pathway to 2050

This section investigates the regional and sectoral opportunities for emission reductions based on the modelled leadership scenario. In particular, we conclude on the following two aspects as a result of the analysis:

- **The leadership group of countries sees the quickest reduction in GHGs emissions across all sectors except agriculture and land use**. This is most pronounced in the power sector, where emissions reduce by 75% by 2030. The leadership group achieves substantial decarbonisation across most sectors by 2050. The agriculture and land use sectors are an exemption – here, the developing countries lead on the emission reduction in the short term and are followed by other industrialised countries by 2050.

- **In the short term, the main opportunities for emission reduction are continued decarbonisation of the power sector (27% of 2020-2030 abatement) through accelerated uptake in renewables in the leadership countries and shift from coal to lower-carbon fossil fuels in other countries**. This is followed by increased deployment of emission reduction measures in the industry and transport sectors (20% and 12%). Agriculture and land use emission reductions can contribute with a further 14% of the abatement. Other non-energy measures can reduce emissions still more – a rapid global shift from fluorinated gases to low-carbon refrigerants could contribute with up to 7% of the 2020-2030 abatement.[9]

By 2050, the leadership-driven scenario results in a global emissions reduction of 76% from 54 $GtCO_2e$ emissions in 2020 (or 4% reduction per year) with a varied pace of reduction seen across the regions. The leadership group emissions reduce by 94%, consistent with these regions reducing their CO_2 emissions to net-zero and several of these going further to achieve net-zero aggregated greenhouse gas emissions. Other middle- and low-income regions reduce their GHG emissions at a different pace, recognising different capabilities and opportunities given their levels of economic development. China's emissions, for example, are modelled to reduce by 82% while India's emissions reduce by 48%.

By 2100, the leadership-driven scenario is projected to result in a global average temperature increase of 1.75°C degrees. This reflects a cumulative CO_2 emissions budget of total 960 $GtCO_2$ (2018-2100), which equates to achieving a warming limit of 1.75°C at a 50% probability (Rogelj et al., 2018). We focus on the period to 2050 in the results, as this is the period that largely determines peak warming particularly as we have limited overshoot to 1.75°C, thereby constraining the role of compensatory carbon dioxide removal technologies post-2050.

This section disaggregates the difference between the reference scenario and the leadership scenario to sectoral emission reductions. We decompose the emissions reduction to energy efficiency gains, decarbonisation of energy carriers and switching to these carriers, and price-driven demand reduction measures. [10] For example, in the power sector, we allocate emission reduction drivers across the range of different technologies (renewables, nuclear, CCS) in addition to efficiency and carbon intensity gains.

The sectors described here are chosen on the basis that they represent the significant majority (87%) of the cumulative 2020-2050 emission abatement.[11] They are also sufficiently large to allow investigating the roles of the leadership group (Chapter 3) and the UK within each of them (Chapter 4).[12] Our main sectors include:

- **Power sector emissions**: this sector includes the use of fossil fuel-based power generation sources of coal, gas, and oil as well as the renewables, nuclear energy, CCS, and biomass.
- **Industry emissions**: this includes three sources and removals of industrial emissions. The first group covers the end-use emissions associated with the industrial production of chemicals, iron and steel, non-ferrous metals, non-metallic minerals, cement, pulp, and paper as well as process and non-energy emissions[13]. Second, it covers cogeneration emissions (auto-generation, combined heat and power (CHP), and heat production). Third, it includes the emissions captured by the use of CCS.
- **Transport emissions**: these include the key sources of emissions split by the type of transport activities into road transport (personal cars, road freight, buses, and other), aviation, rail, and shipping.
- **Buildings emissions**: these include direct emissions associated with energy use in residential and commercial buildings.

[9] Details on fluorinated gases emission reductions are in the Appendix.
[10] A decomposition approach based on the Logarithmic Mean Divisia Index (LMDI) is used to identify these types of abatement action. See Appendix for further details.
[11] The remaining emission reduction includes other CO_2 sources (e.g. upstream emissions) as well as other non-CO_2 sources (fluorinated gases, waste and non-CO_2 emissions associated with electricity generation).
[12] The remaining sectors, and their abatement size, are covered in the Appendix.
[13] i.e. processes in manufacturing industries and construction without fossil fuel combustion, excluding fluorinated gases.

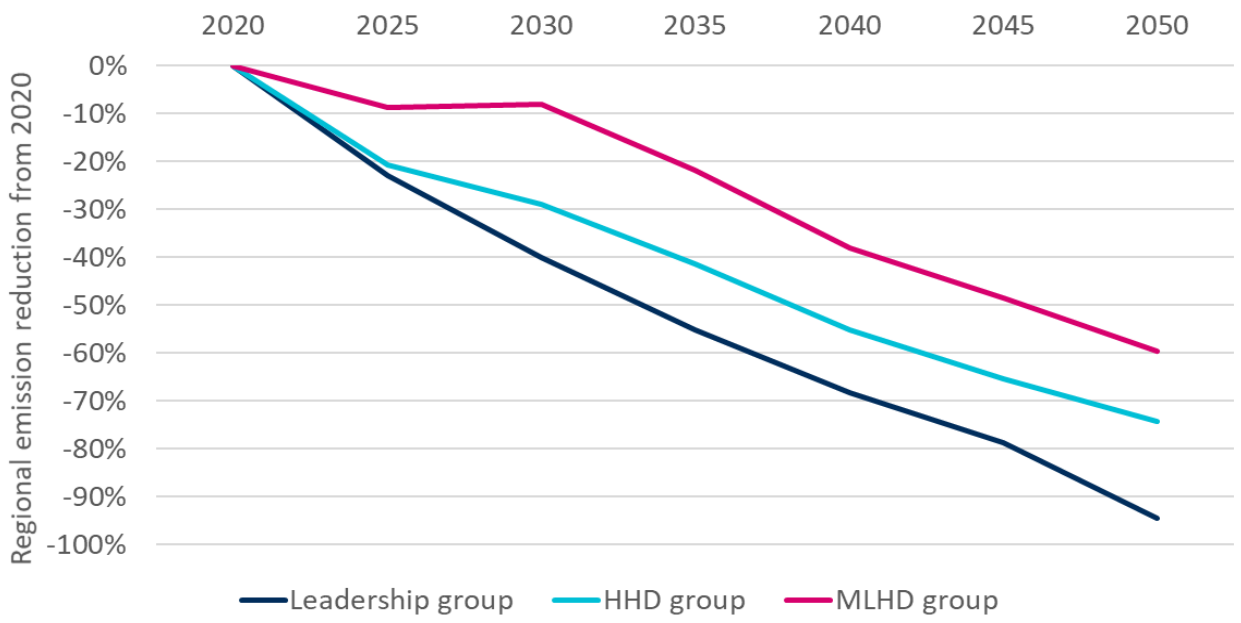
- Agriculture and land use emissions: these include the non-CO_2 GHG emissions (methane and nitrous oxide) associated with agricultural activities as well as CO_2 emissions from land use, land use change and forestry (LULUCF) activities.
- Engineered GHGs removals: the model represents two sets of engineered removals. The first include the group of technologies defined BECCS. The second group includes the set of technologies classed as DAC that TIAM-UCL represents to a limited extent.

For each sector, we discuss the regional differences and the key measures of emission reductions. In terms of the regions, we focus on results for three country groupings: the leadership group, countries with a high Human Development Index (HHD), and those with a medium-to-low Human Development Index (MLHD). Regional groupings are based on the Human Development Index scores: the HHD group exhibits a high human development index (0.7-0.8) and includes the Middle East, Mexico, South and Central America, China, and Former Soviet Union countries. The medium-to-low Human Development Index (MLHD) group, with the HDI level below 0.7, includes Africa, India, and Other Developing Asia. The leadership group typically has HDI values above 0.8.

The following figures summarise the results of the leadership-driven scenario:

- Figure 2 and Table 1 show the rate of emissions reductions across the regions and sectors, with the leadership group achieving the quickest emission reduction (7% per year) followed by the HHD (4%) and MLHD (2%) countries. Table 1 also presents the key sectoral emission reduction measures.
- Figure 3 shows the relative contribution of the main sectors to emission reduction over the period of 2020-2050 relative to the ECA case. The ECA scenario sees an overall reduction in emissions by 2030 which is almost completely due to decreasing power sector emissions. As power sector decarbonisation solutions are currently the most cost-effective, the power sector emissions drop by 48%, from 9.8 to 5.2 $GtCO_2e$, by 2030. Thus, the leadership scenario's power sector emission reduction is limited due to assumed decarbonisation efforts in the reference scenario. Under the ECA scenario, agriculture and land use sectors are expected to see a slight reduction by 5%, from 12.1 to 11.5 $GtCO_2e$, by 2030 while emissions from other sectors are either on a flat or rising path between 2020 and 2050.
- Figure 4 plots the key emission reduction milestones across sectors. These are as follows. Power: rapid power decarbonisation through coal phase-out, increased deployment of renewables and a switch to lower-carbon fossil fuels. Transport: accelerated shift to electric vehicles, first in passenger cars, followed by road freight, and then by accelerated energy efficiency and fuel decarbonisation efforts in shipping and aviation. Industry: increased energy efficiency, fuel switch and electrification efforts in the short term (e.g. iron and steel and non-metallic mineral sectors) followed by CCS uptake from 2030s onwards. Buildings: a shift from coal use to lower-carbon sources in the short term, followed by increased electrification. By 2040, gas consumption is reduced by 61% from the 2020 level. Agriculture: a combination of increased productivity, dietary shifts, afforestation and reforestation, restoration of degraded land, and soil sequestration leading to a 23% drop in emissions by 2030. Engineered GHGs removals: with delayed deployment, capturing $2GtCO_2$ by 2040.

Figure 2 Global emissions reductions – the leadership group accelerates decarbonisation followed by other regions



Note: Leadership group: the UK, the USA, South Korea, Japan, the EU, Australia and New Zealand, and Canada; HHD group: Middle East, Mexico, South and Central America, China, and Former Soviet Union countries; MLHD group: Africa, India, and Other Developing Asia

Source: Vivid Economics, TIAM-UCL

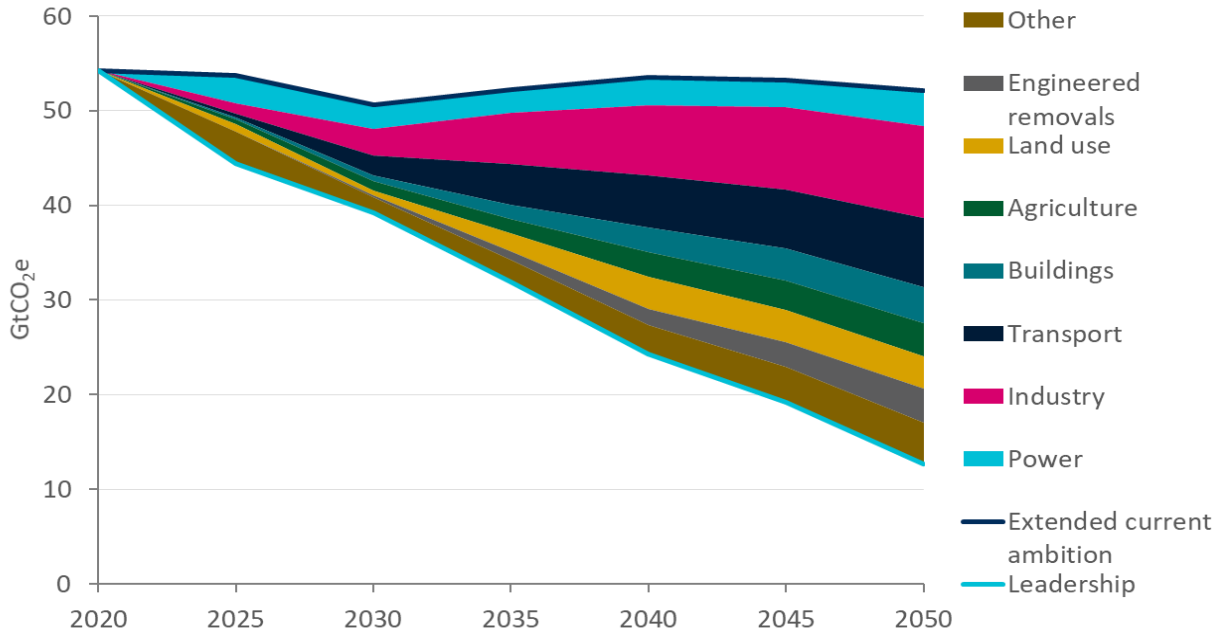
Table 1 Leadership group accelerates emission reduction in key sectors, followed by HHD and MLHD countries

Sectors	Emission reduction (2030)	Emission reduction (2050)	Emission reduction measures
Power	Leadership: -75% HHD: -67% MLHD: -57%	Leadership: -96% HHD: -92% MLHD: -92%	Solar PV, onshore and offshore wind, nuclear, other renewables; increased efficiency of fossil fuel power plants
Transport	Leadership: -34% HHD: +10% MLHD: +12%	Leadership: -84% HHD: -54% MLHD: -22%	Personal vehicles and road freight shifting to EVs; shipping and aviation to low-carbon fuels and increased energy efficiency
Industry	Leadership: -22% HHD: -20% MLHD: +4%	Leadership: -72% HHD: -72% MLHD: -30%	Switch to low-carbon fuels, energy and material efficiency; CCS infrastructure
Buildings	Leadership: -21% HHD: -18% MLHD: -6%	Leadership: -96% HHD: -77% MLHD: -81%	Energy efficiency, near-zero buildings, low-carbon heat solutions
Agriculture & land use	Leadership: -27% HHD: -34% MLHD: +12%	Leadership: -38% HHD: -68% MLHD: -65%	Agriculture productivity, dietary shifts, afforestation and reforestation, restoration of degraded land, soil sequestration
Engineered removals	Leadership: -0.4Gt	Leadership: -2.2Gt HHD: -1.1Gt MLHD: -0.5Gt	Bioenergy with CCS technologies; Direct air capture technologies

Note: Leadership group: the UK, the USA, South Korea, Japan, the EU, Australia and New Zealand, and Canada; HHD group: Middle East, Mexico, South and Central America, China, and Former Soviet Union countries; MLHD group: Africa, India, and Other Developing Asia

Source: Vivid Economics

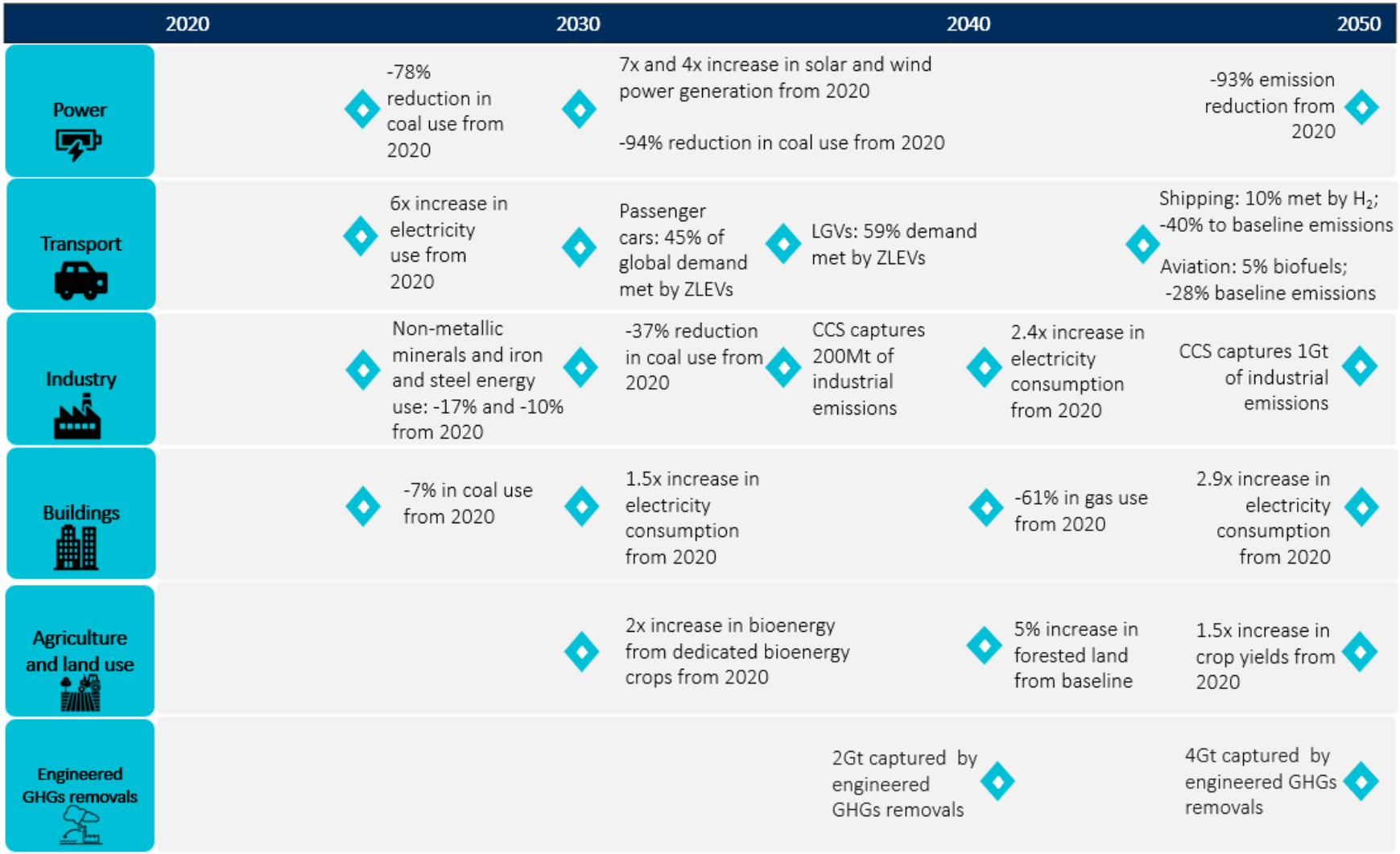
Figure 3 Leadership-driven pathway – main sectors of emissions reductions



Note: Other category includes abated emissions from other CO_2 sources (e.g. upstream emissions) as well as other non-CO_2 sources (fluorinated gases, waste and non-CO_2 emissions associated with electricity generation)

Source: Vivid Economics, TIAM-UCL

Figure 4 Key emission reduction milestones in the leadership-driven scenario



Note: The reported values are global; ZLEVs – zero level emission vehicles; LGVs – large goods vehicles
Source: Vivid Economics; agriculture and land use milestones are taken from the UN PRI (2019) developed by Vivid Economics

2.3 Sectoral leadership-driven emissions pathways

This section provides detail for the main six sectors in terms of their emission pathways. It discusses the six sources of emissions in terms of the rate of emissions reductions observed across regions and sub-sector measures applied in the TIAM-UCL modelling framework and non-energy pathways, where relevant.

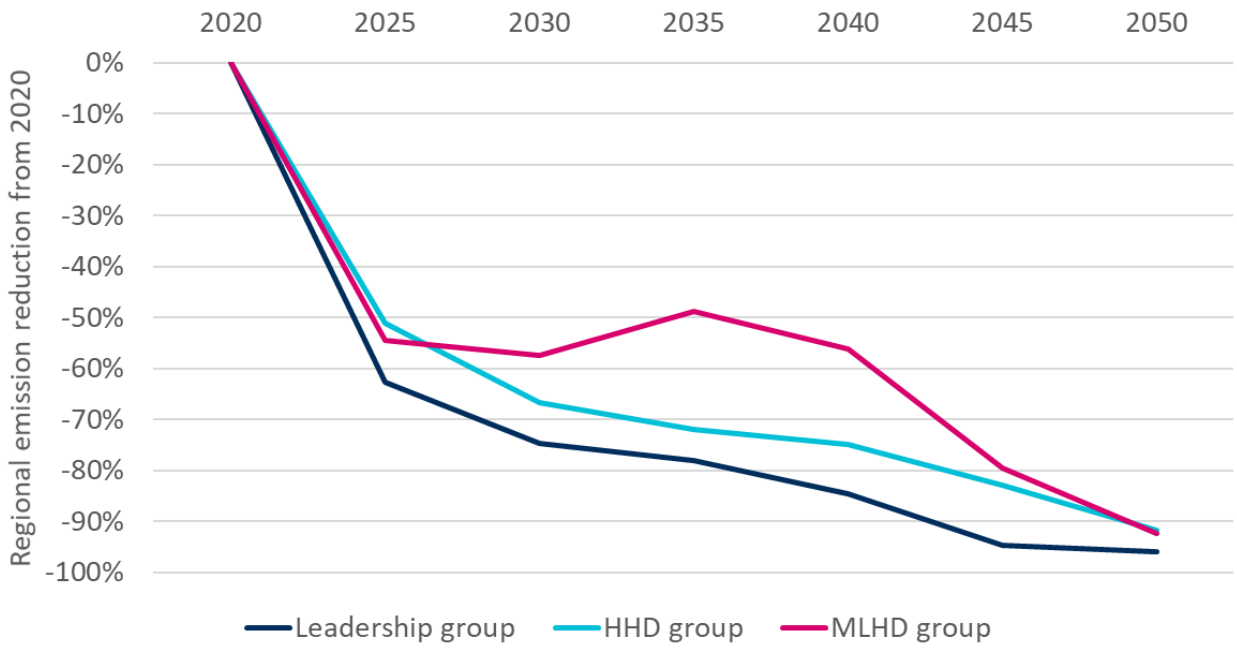
2.3.1 Power sector

Rate of emissions reductions across regions

By 2050, the leadership-driven scenario results in almost full decarbonisation of the power sector. The global power sector emissions reduce by 98% compared to 2020 through a substantial deployment of renewables and other lower-carbon solutions that replace existing fossil fuel-based power generation across the world. The largest source of emission reduction is due to the phase-out of coal from power generation (94% reduction by 2030) which represents 78% of the total 2020-2050 emissions abatement.

In terms of regional efforts, the leadership group leads on fully decarbonising the power sector but with significant contribution of other countries as they transition from coal to renewables or other lower-carbon sources. In particular, the leadership group achieves a 75% reduction in power sector emissions by 2030 and with fully decarbonised power sector by 2050, when compared to 2020. The HHD group of countries, of which China is the largest contributor, are modelled to reduce power sector emissions by 67% and more than 90% by the respective years. The MLHD group of countries, with largest reduction observed in India, achieve a reduction of power sector emissions by 58% by 2030 and more than 90% by 2050 (Figure 5). While the rate of reduction is slower for HHD and MLHD countries, all regions need near fully decarbonised power systems by 2050.

Figure 5 Power sector – rate of CO_2 emissions reductions across regions from 2020



Note: Leadership group: the UK, the USA, South Korea, Japan, the EU, Australia and New Zealand, and Canada; HHD group: Middle East, Mexico, South and Central America, China, and Former Soviet Union countries; MLHD group: Africa, India, and Other Developing Asia

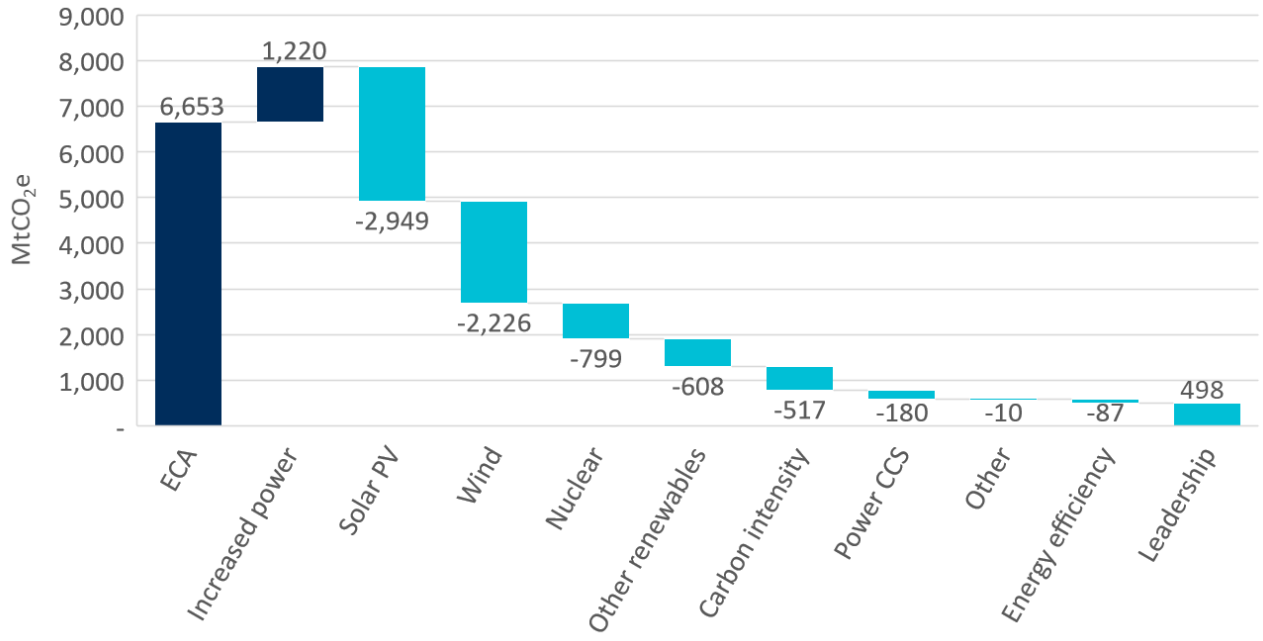
Source: Vivid Economics, TIAM-UCL

Sub-sector measures across regions

Such a degree of power sector decarbonisation will require an unprecedented increase in renewable generation installations and associated investments. Overall, this scenario implies a 21% and 18% annual growth rate in the installed capacity of solar PV and wind power respectively in the period 2020-2030. By 2050, the solar PV and wind investment costs amount to $2.5 trillion and $4.5 trillion, respectively. In China, for example, the solar PV and wind capacity (GW) is modelled to increase seven- and six-fold, respectively, by 2030 relative to 2020 values and more than 30 and 20 times by 2050. In India, the growth in solar PV and wind power is slower but still ambitious, with four- and twofold increases in respective capacities by 2030 relative to 2020 values and 19 and 13 times increases, respectively, by 2050.

The emissions displaced by wind and solar account for the largest reductions (Figure 6). Other smaller contributions include carbon intensity gains (based on some short-term coal-to-gas switching) and energy efficiency gains. On efficiency, this is much lower because it applies to fossil generation, which is in serious decline, and because strong efficiency gains have already been achieved under the ECA scenario. Figure 6 presents the abatement drivers in the power sector which include a significant deployment of solar PV and wind as well as nuclear and other lower-carbon electricity generation sources.

Figure 6 Power sector in 2050 – key emission reduction due to significant deployment of solar and wind renewables



Note: ECA – Extending Current Ambition scenario, our reference scenario
Source: Vivid Economics, TIAM-UCL

The measures' contribution to power decarbonisation vary regionally and over time, reflecting different relative costs of power sector solutions, with a continued role for lower-carbon fossil fuel generation in developing countries. For the leadership group, 62% of the 2030 abatement is due to the increased uptake in renewables (31% due to solar PV) and 22% due to nuclear energy. The renewables' share of abatement increases to 76% by 2050. On the other hand, the 2030 emissions abatement in the HHD group is mainly driven by switching to lower-carbon fossil fuels (63%)[14], e.g. switching from coal to gas, followed by increased uptake in renewables (32%). The abatement share of renewables increases to 59% by 2050. The MLHD group of countries follows a similar pattern with the exception of India that is modelled to see a large increase in renewables by 2030 already (49% of 2030 abatement) given the cost-competitiveness of solar PV.

[14] 33% of abatement due to reduced carbon intensity and 30% due to increased energy efficiency.

This suggests a potential role for lower-carbon fossil fuels in the short-to-medium term in some developing countries.

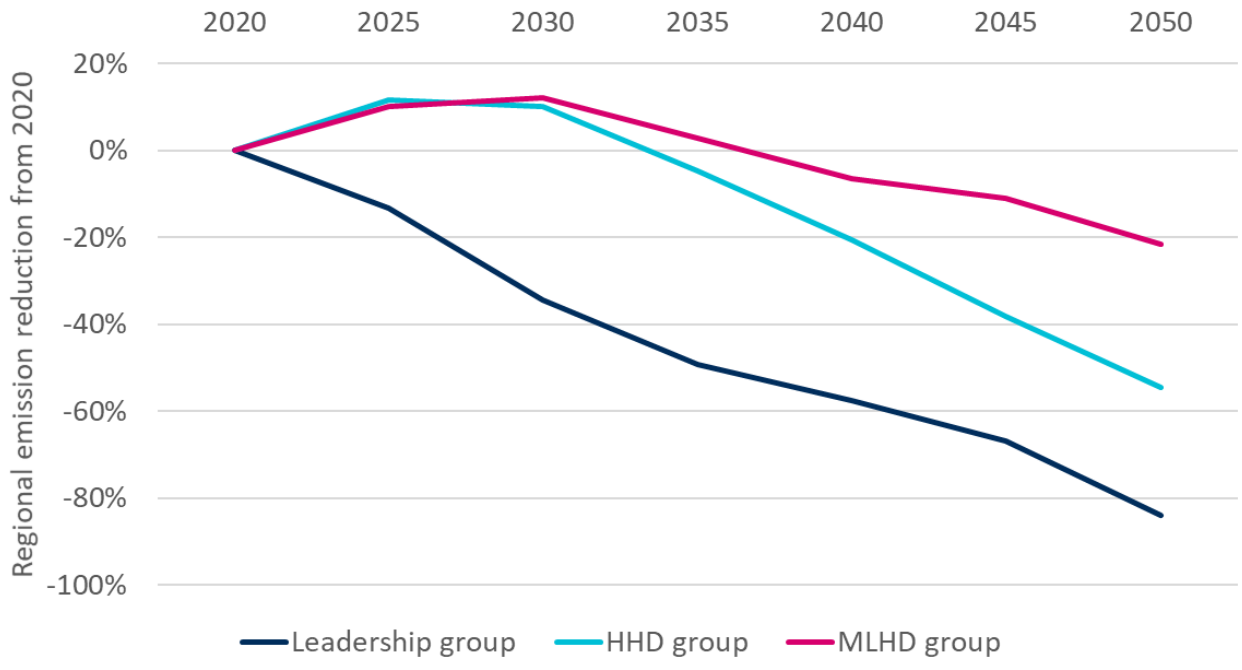
2.3.2 Transport sector

Rate of emissions reductions across regions

By 2030, the measures decarbonising the road sector account for most of the transport sector's emission reduction in the leadership group. In fact, between 2020 and 2030, reduced emissions of passenger cars and road freight account for 83% of the global abatement. This reflects the existing commitments and expected trends in phasing out ICE vehicles that we have introduced as part of the modelling framework, which are replaced by electric vehicles for passenger cars and a combination of EV and hydrogen in road freight. For instance, we assume that both Western Europe and China will phase out LDV sales by 2035 and HDVs by 2040 (see Appendix for details).

By 2050, the transport sector emissions reduce by 62% compared to 2020 as a result of expanding the transport decarbonisation efforts across all regions. Our scenario again leads to phased decarbonisation action across the regions, with significant differences between the leadership group and other countries. The leadership group emissions are projected to decrease by 35% by 2030, and then by 80% by 2050 when compared to the 2020 emissions level. In contrast, the HHD group of countries are expected to see a further increase in transport emissions by 2030 (9% increase from 2020) driven by continued growth in mobility demand, followed by a reduction of 68% over the period of 2020-2050. Similarly, the MLHD group of countries see an initial increase in emissions of 11% by 2030 but with a 62% drop in transport emissions between 2020 and 2050 (Figure 7).

Figure 7 Transport sector – rate of CO_2 emissions reductions across regions



Note: Leadership group: the UK, the USA, South Korea, Japan, the EU, Australia and New Zealand, and Canada; HHD group: Middle East, Mexico, South and Central America, China, and Former Soviet Union countries; MLHD group: Africa, India, and Other Developing Asia

Source: Vivid Economics, TIAM-UCL

Sub-*sector measures across regions*

The leadership group achieves substantial emissions reductions in the first half of the century largely through abatement of passenger cars and road freight emissions. In 2030, the switch to zero-carbon vehicles is responsible for 91% (1 $GtCO_2$) of the emissions reductions in the transport sector in leadership countries. Moving further towards 2050, abatement in the transport sector is led by emissions reductions in road freight (43%) as electrification and hydrogen solutions for heavy goods trucks are commercialised.[15] Among the leadership group countries, the USA stands out for contributions to abatement in the transport sector: in 2050, 65% of passenger car emissions reductions and 56% of road freight emissions reductions are achieved in the United States.

The HHD group follows a similar sectoral pattern to the leadership group, with China and Central and South America making the largest contributions to abatement in transport. The HHD group abates around 0.7 $GtCO_2$ from transport in 2030. Of this, 70% is abated through zero-carbon passenger cars and 30% through road freight. Abatement from road freight (0.2 $GtCO_2$) is around four times higher than in the leadership group. By 2050, the HHD contributes the most to emissions reductions in transport globally (3 $GtCO_2$ in 2050). Passenger cars and road freight are increasingly decarbonised, abating around 1 $GtCO_2$, respectively. China and Central and South America contribute to more than half of the group's abatement in transport, with 37% and 23% of emissions abated in 2050 in the two regions, respectively.

The LMHD group is slower at reducing emissions from transport, with decarbonised passenger vehicles contributing the most to abatement by 2050 and Other Developing Asia leading within the group. Emissions reductions from the transport sector in 2030 are modest (0.4 $GtCO_2$) and mostly come from the decarbonisation of passenger cars. From 2030 onwards, sectoral decarbonisation becomes more widespread: in 2050 over 2.3 $GtCO_2$ are abated in the region, with around 40% achieved through low-carbon shipping. Out of the regions that compose the country group, Other Developing Asia provides the largest contribution to sectoral abatement, with 69% of transport emissions abated in 2050.

The 2050 emission reductions are achieved through a decarbonisation effort across all transport modes. In particular, this is thanks to increased electrification, fuel efficiency measures, use of hydrogen, and price-induced changes to demand for transport across all main transport modes (Figure 8)**:**

- **Passenger cars**: these represent 48% (69 $GtCO_2$) of the total 2020-50 abatement in the transport sector. Of this, 56% are due to a switch to low-carbon electricity and thus a large increase in the deployment of EVs. Energy efficiency measures, such as an increased fuel economy of ICEs, account for 43% of the total abatement.[16]

- **Road freight:** this includes small vans and large and heavy goods trucks (HGVs). The area accounts for 28% (41$GtCO_2$) of the total 2020-50 abatement, with most of the progress made from 2040 onwards. Fuel decarbonisation accounts for 52% of the abatement (e.g. a switch to hydrogen or electricity), followed by energy efficiency measures (38%) and price-induced reduction in road freight (3%).

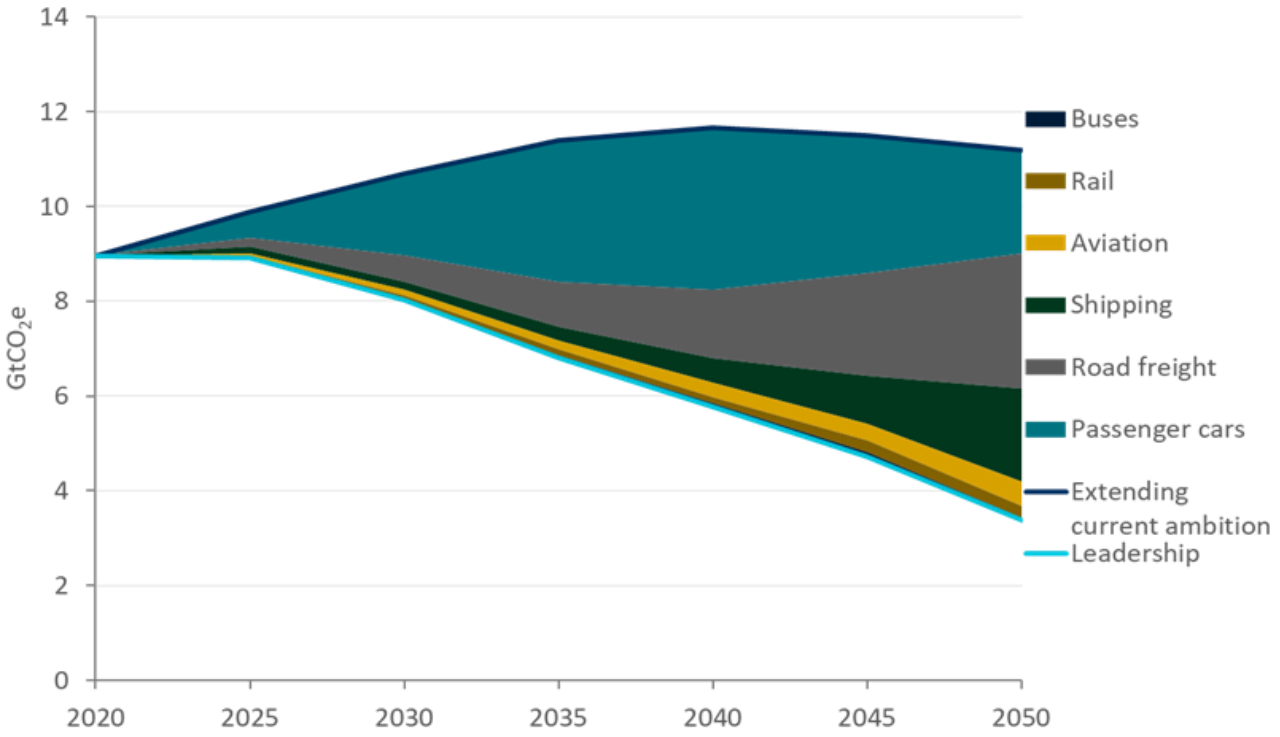
- **Shipping**: this contributes to the total abatement by 14% (21 $GtCO_2$) although its contribution is relatively limited until the last decade, 2040-2050. This is because the decarbonisation solutions are still at a state of early emergence with low-carbon solutions not yet demonstrated at scale. 47% of the total abatement are thanks to a switch to low-carbon fuels (e.g. natural gas as a lower-carbon fuel, and hydrogen in the longer term), followed by 28% of savings due to energy efficiency measures and 27% because of price-induced demand reduction.

- **Aviation**: these emissions represent 5% of total abatement (8 $GtCO_2$). While aviation emissions are expected to increase by 21% in the period of 2020 and 2050, the 2050 emissions are 28% lower than in the reference scenario. Most of the emissions reductions (43%) occurs in the leadership group, with the

[15] Abatement from passenger cars is still significant in 2050, but the baseline ECA scenario already includes such reductions.
[16] 2% are due to price-induced reduction in demand for passenger cars.

rest equally split between HHD and MLHD groups. This result is a combination of expected growth in the demand for aviation and the fact that low-carbon fuels and technologies have not yet been deployed at large scale. Consequently, emission reduction is driven largely by price-induced demand reduction (94%), followed by a switch to low-carbon (biokerosene-based) aviation fuels (6%).[17]

Figure 8 Transport sector – decarbonisation of main transport modes delivers the leadership-driven scenario



Note: The passenger car wedge starts to shrink towards 2050 due to an acceleration in the transition that is already included in the ECA scenario

Source: Vivid Economics, TIAM-UCL

2.3.3 Industry sector

Rate of emissions reductions across regions

By 2030, industrial emissions reduce by 12% when compared to 2020 levels, or slightly more than 1% emission reduction per year. This overall reduction in industrial emissions is largely driven by decreasing emissions of key industrial sub-sectors including iron and steel, non-metallic minerals (e.g. construction sector) and chemicals. These three sub-sectors represent 60% of the total 2020-2030 emissions abatement.

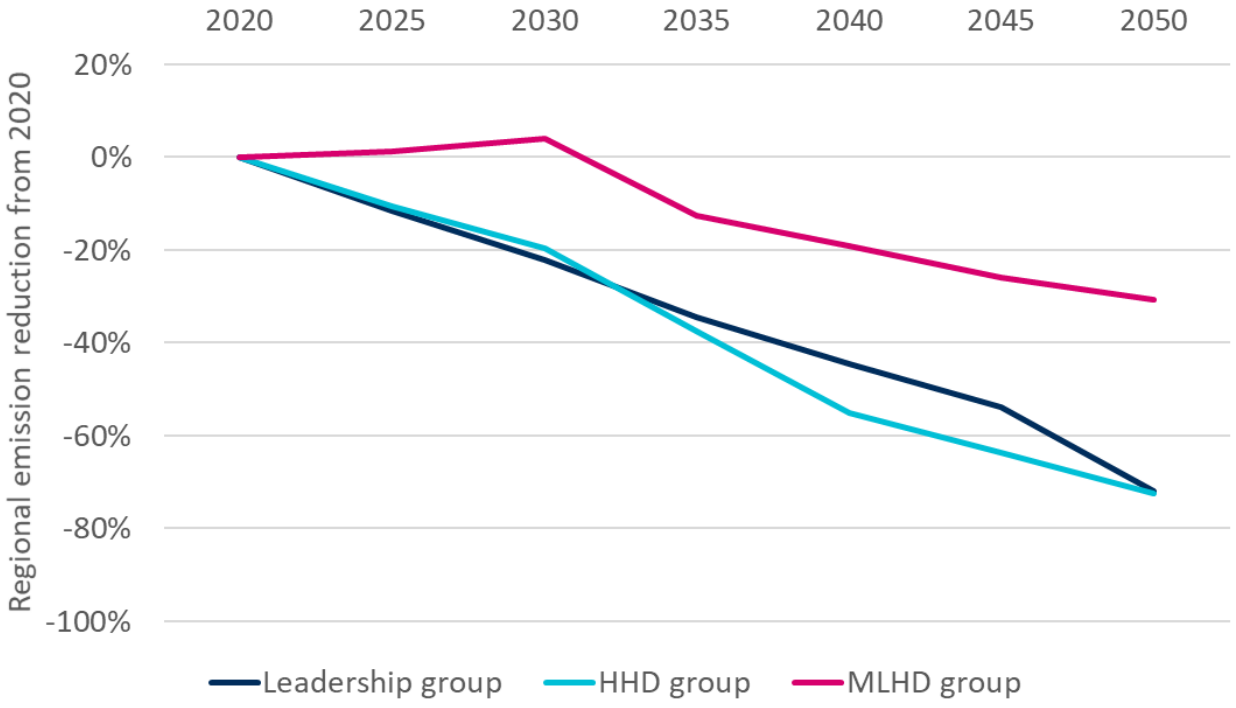
Over the period of 2020-2050, industrial emissions fall by 60%. The speed of industrial decarbonisation increases to almost 4% per year from 2030 onwards. This is a result of increased decarbonisation in key industrial sub-sectors and the increased role of CCS in capturing industrial CO_2 emissions.

Regionally, the industrial emission reduction is led by the leadership group and increased decarbonisation efforts of the HHD group of countries. The leadership group achieves a reduction in industrial emission of 31% by 2030 and 72% by 2050. The HHD group of countries achieves 25% reduction by 2030 and 72% reduction by 2050. China, for example, achieves an emission reduction of almost 80% by 2050 thanks to relatively rapid switching towards low-carbon fuels and electrification. The MLHD group's emissions drop by

[17] The scenario also considers energy efficiency measures, but these are expected to result in a slight net increase in aviation emissions (0.3%). This is likely a result of reduced unit costs leading to increased demand for aviation. Furthermore, efficiency gains are already captured under the ECA scenario.

31% over the whole 2020-2050 period. India, for instance, sees a reduction of only 8% from 2020 levels partly due to high relative abatement costs and due to limited uptake in the CCS technology (Figure 9).

Figure 9 Industry sector – rate of emissions reductions across regions



Note: Leadership group: the UK, the USA, South Korea, Japan, the EU, Australia and New Zealand, and Canada; HHD group: Middle East, Mexico, South and Central America, China, and Former Soviet Union countries; MLHD group: Africa, India, and Other Developing Asia

Source: Vivid Economics, TIAM-UCL

Sub-sector measures across regions

The decarbonisation of iron and steel, chemicals, and non-metallic minerals is responsible for most of the emissions reductions to 2050 across all country groups. The leadership group is able to abate around 0.8 $GtCO_2$ from industry in 2050, down from the 1.4 $GtCO_2$ of emissions in the ECA scenario. These emissions reductions mainly come from abatement in the chemicals (21%) and iron and steel sub-sectors (20%). The USA is responsible for about a quarter of leadership group emissions reductions from industry in 2050. Also, the HHD group sees the chemicals and iron and steel sectors providing the largest contributions to abatement (29% and 20% in 2050, respectively). Of the 5.7 $GtCO_2$ abated from the HHD group in 2050, China is responsible for around 4 $GtCO_2$ of emission reduction. In the LMHD group, the industry sector starts decarbonising from the 2030s, mainly through low-carbon iron and steel (27% of abatement in 2050) and non-metallic minerals (19% of abatement in 2050).

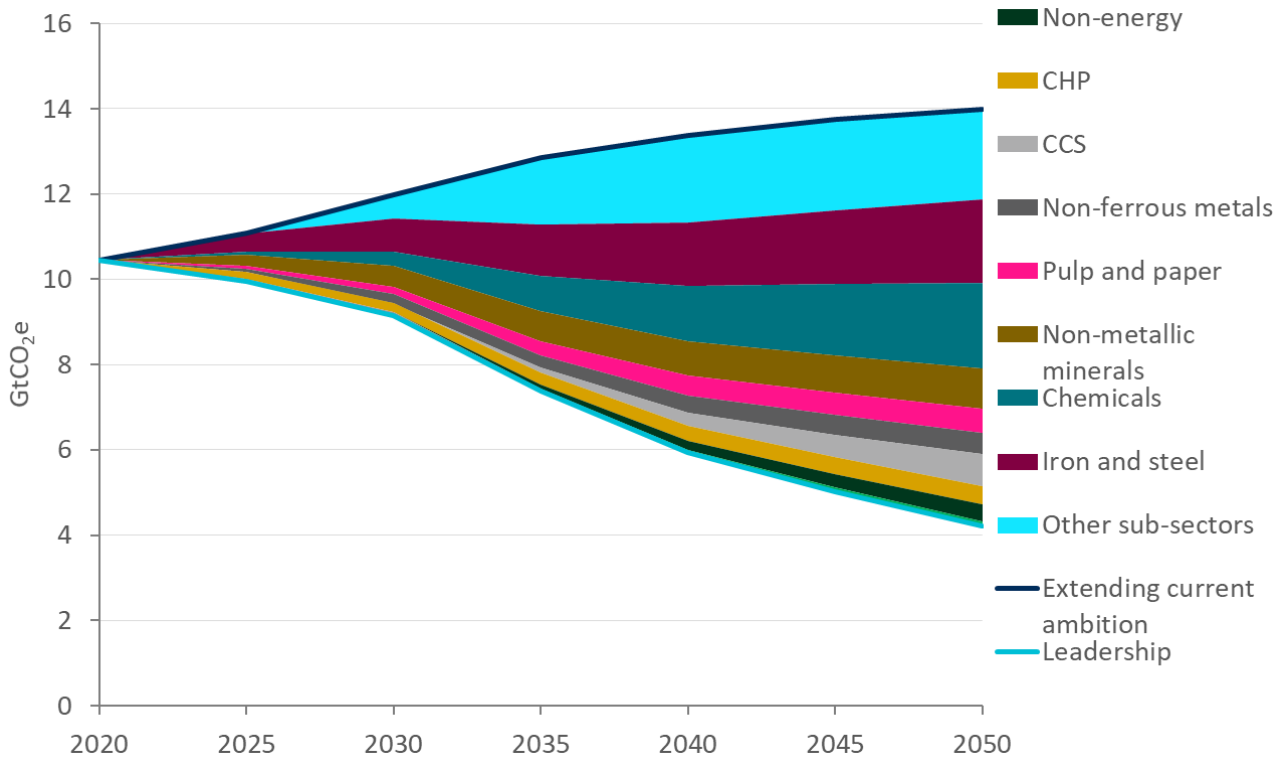
Over the period of 2020-2050, the key emission reduction measures across industrial sub-sectors include the following activities (Figure 10):

- **Iron and steel:** the emission reduction in this sector represents 22% of 2020-50 abatement, or 38 $GtCO_2$. This largely a result of fuel decarbonisation (85%), where the sector switches to low-carbon energy

sources such as electricity, followed by energy efficiency (10%) and price-induced demand reduction (5%).[18]

- **Chemicals:** emission reduction represents 18%, or 31 $GtCO_2$, of the 2020-50 abatement. Similarly, the main modelled abatement drivers are fuel decarbonisation of switching to electricity and other low-carbon fuel sources (86%), but then followed by price-induced demand reduction (11%) and energy efficiency measures (3%).[19]
- **Non-metallic minerals: this sub-**sector sees an emission reduction of 20 $GtCO_2$ or 12% of the total 2020-50 abatement. This is, again, estimated to be largely due to fuel decarbonisation (75%), followed by energy efficiency measures (16%), and price-induced demand reduction (8%).
- **Industrial CCS**: this captures around 9 $GtCO_2$ or 5% of the total 2020-50 abatement, seeing an uptake in deployment from initially low levels from 2035 onwards.

Figure 10 Industrial sector – key areas requiring an accelerated uptake in the emission reduction measures



Note: CHP – combined heat and power
Source: Vivid Economics, TIAM-UCL

2.3.4 Buildings sector

Rates of emissions reductions across regions

The leadership scenario achieves a significant reduction in buildings emissions, reducing by 86% by 2050 (Figure 12). This is in contrast to the ECA scenario, which sees a slight emissions reduction by 2030 due to

[18] Leaving aside the CCS technology, the IEA 2019a report (Figure 8) expects the key role of energy efficiency and best available technologies, followed by material efficiency and fuel and feedstock switching in iron and steel decarbonisation. Thus, we consider the full range of iron and steel decarbonisation options rather than prioritising modelled outcomes over the other options.
[19] Apart from a significant role of the CCS in the chemicals sub-sector, the IEA 2019 report (Transforming the industry through the CCUS, Figure 8) expects the key role of fuel and feedstock switching, followed by energy efficiency and best available technologies, and material.

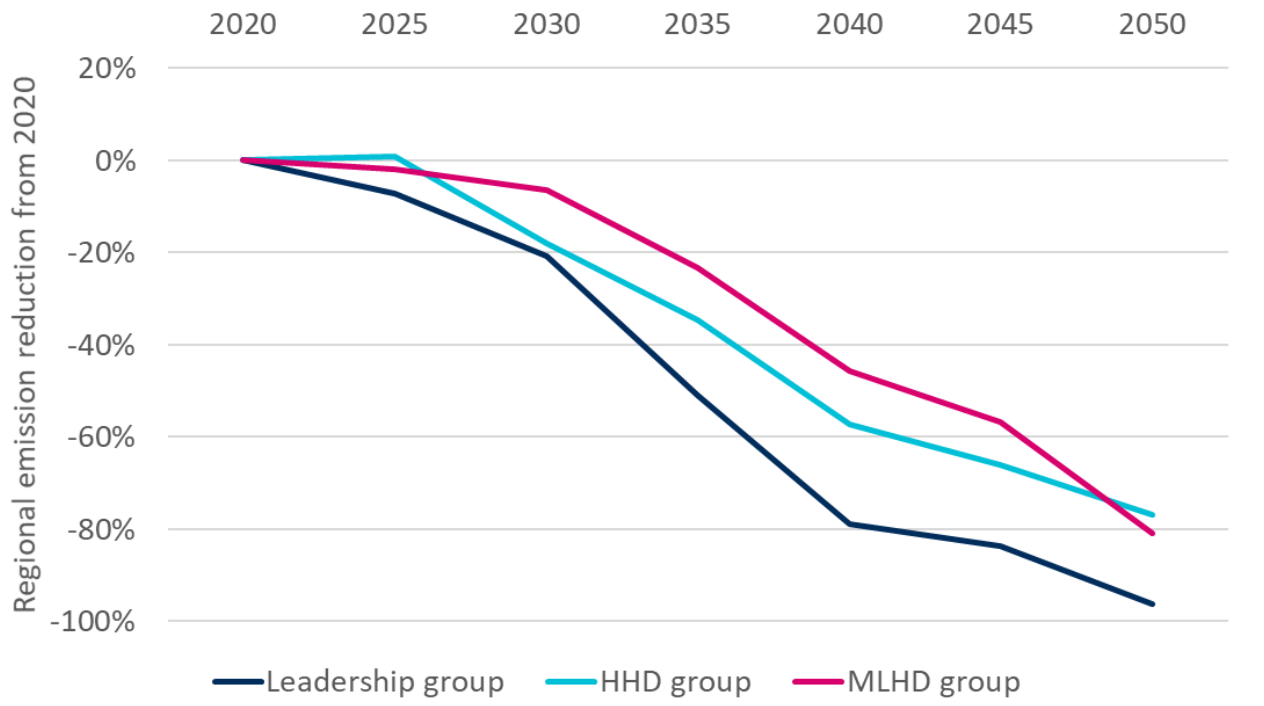
the deployment of energy efficiency measures but then an increase in emissions by 2050, with an overall increase in buildings' emissions by 22% by 2050.

The leadership group is able to almost decarbonise the buildings sector fully by 2050. In leadership countries, emissions from buildings are abated by almost one quarter in the ten years to 2030, but the largest emissions reductions are realised in the following decade to 2040. By 2050, the leadership group abates almost 98% of emissions from the buildings sector: while the leadership group produces around 1.2 Gt of emissions in 2050 under the ECA scenario, the leadership scenario sees emissions reduced to 40 Mt in that year.

The HHD group follows with a slight delay but is still able to achieve almost 80% emissions reductions by 2050. HHD countries, which include China and Latin America, are slower at picking up significant emissions reductions in the sector, with emissions increasing to 2025. Then, a ramp-up in deployment of abatement solutions helps trigger sectoral decarbonisation to 2050, when emissions are reduced by more than three quarters compared to 2020 levels: in 2050, emissions from the buildings sector in the HHD group account for 300 Mt, down from almost 1.6 Gt emitted in the same year under the ECA scenario.

The MLHD group follows the same pattern, with significant abatement starting from 2035 and more than 80% of emissions abated by 2050. Buildings' emissions from the MLHD group in 2020 are only around half those of the HHD group in the same year, thus requiring a lower decarbonisation effort. However, in the ECA scenario, emissions from the MLHD group significantly increase from 2025 and quickly reach similar levels to the HHD and leadership groups, with 1.4 Gt emitted in 2050 from the buildings sector. The leadership scenario sees this trend reversed, with emissions from MLHD countries reducing from around 600 Mt in 2020 to around 100 Mt in 2050 (Figure 11).

Figure 11 Buildings sector – regional emission reductions



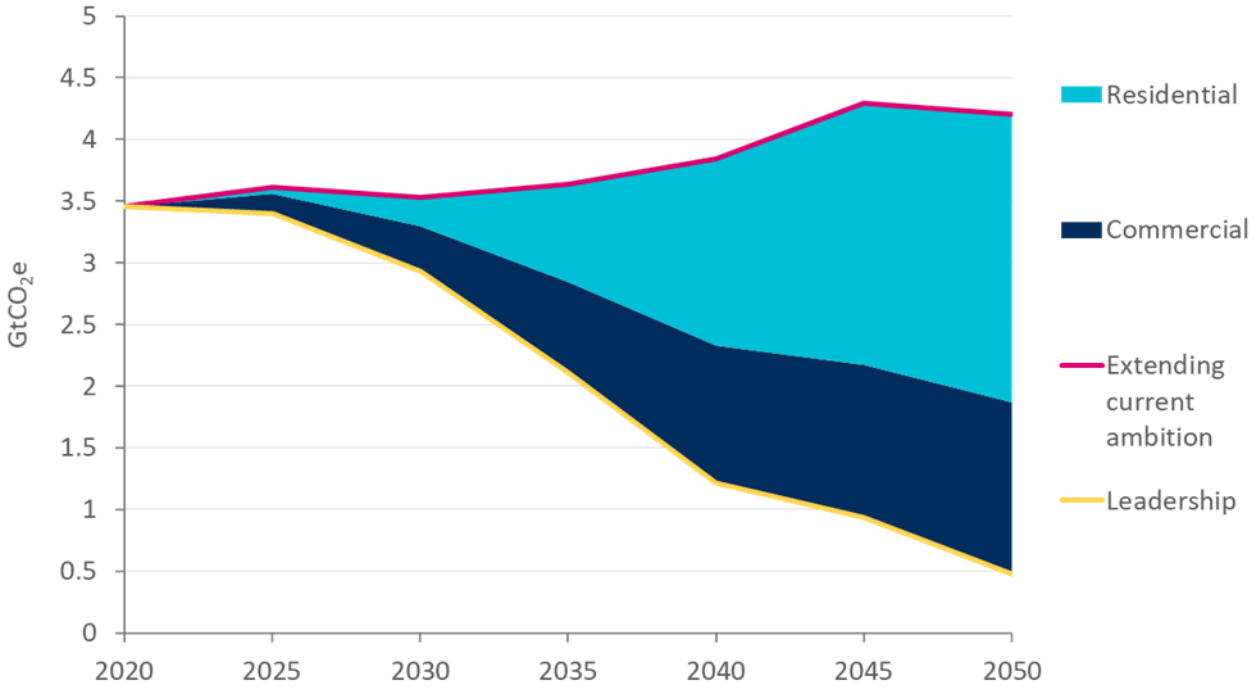
Note: Leadership group: the UK, the USA, South Korea, Japan, the EU, Australia and New Zealand, and Canada; HHD group: Middle East, Mexico, South and Central America, China, and Former Soviet Union countries; MLHD group: Africa, India, and Other Developing Asia

Source: Vivid Economics

Sub-sector measures across regions

The residential sector is the largest contributor to sectoral abatement, accounting for almost 60% of the reductions, while the rest is abated through emission savings in the commercial sector (Figure 12). Fuel decarbonisation is responsible for the vast majority of abatement, with almost 90% of emissions abated in buildings through switching to alternative fuels, such as low-carbon electricity or hydrogen, in both the new and existing building stock. Improvements in buildings' energy efficiency and reduction of energy use make up the remaining share of abated emissions. However, note that energy efficiency opportunities are largely taken already in the ECA scenario, as they are deemed to be cost-effective, and therefore are not as prominent in the leadership scenario.

Figure 12 Buildings sector – main areas that require emission reductions measures



Source: Vivid Economics, TIAM-UCL

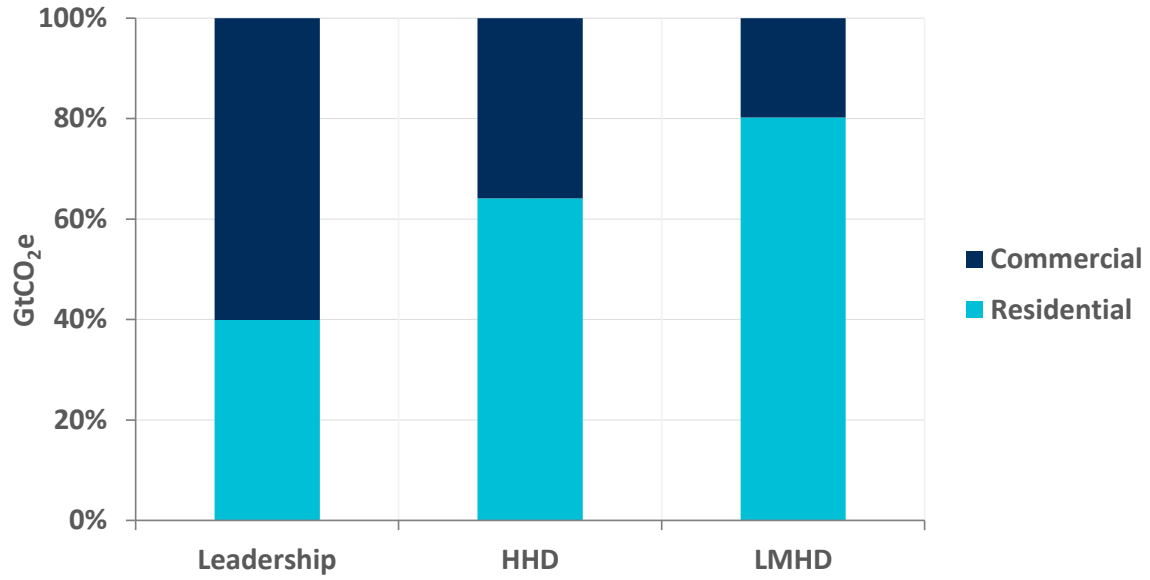
In the leadership group, the commercial sub-sector contributes to the majority of abatement. Compared to the ECA scenario, 60% of 2050 emissions reductions achieved in the leadership scenario come from the commercial sub-sector. The remaining 40% of abatement is delivered by efficiency gains in the residential sub-sector. This reflects the high importance of decarbonising commercial premises and office spaces in the developed world, as these account for a large share of emissions.

Differently from the leadership group, most of the emissions reductions achieved in the HHD group stem from efficiency gains in the residential sector. In 2050, the residential sector contributes to 64% of buildings' emissions reductions, while the remaining 36% is achieved through efficiency gains in the commercial sub-sector. This reflects the structure of the economy of the HHD group, where countries with high population density, such as China, see the residential sub-sector contributing to a large share of emissions.

In the MLHD group the residential sub-sector contributes to the lion's share of emissions reductions (Figure 13). In the years from 2020 to 2040, most of the sector's decarbonisation is driven by the commercial sub-sector. However, from 2040 onwards the residential sector contributes to the lion's share of emissions reductions, with 80% of abatement in buildings in 2050 driven by efficiency gains in residential areas. The residential sub-sector's decarbonisation is pivotal in achieving high emissions reductions in low-to-middle

income countries by 2050. This reflects the high abatement potential of residential areas with a high population density in India and Other Developing Asia.

Figure 13 Buildings sector – contributions to leadership scenario in 2050 by sub-sector



Note: Leadership group: the UK, the USA, South Korea, Japan, the EU, Australia and New Zealand, and Canada; HHD group: Middle East, Mexico, South and Central America, China, and Former Soviet Union countries; MLHD group: Africa, India, and Other Developing Asia

Source: Vivid Economics

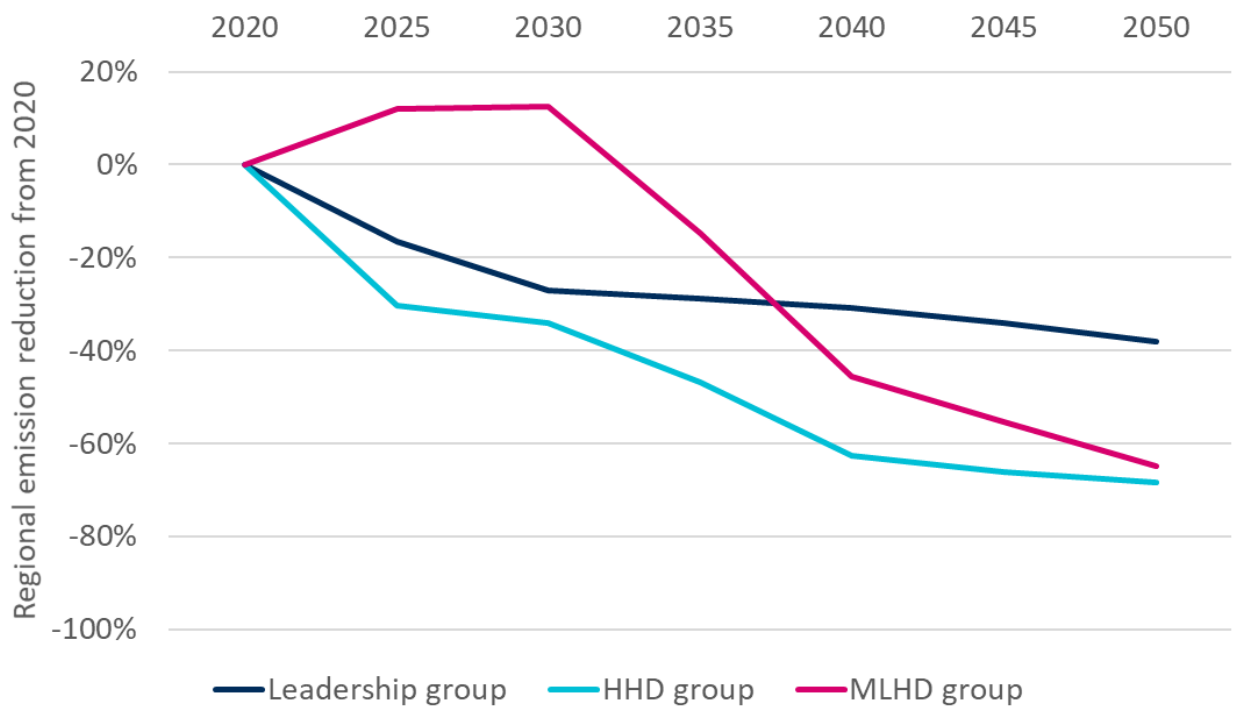
2.3.5 Agriculture and land use

Rate of emissions reductions across regions

Emissions from the agriculture and land use sector fall by 17% by 2030 and by a further 46% by 2050. Emissions in the agriculture and land use sector reduce by almost 7 $GtCO_2e$ in 2050 compared to the ECA scenario in the same year, reducing by over 60% from the 2020 level. The largest contributions to abatement efforts come from reductions in CO_2 emissions from LULUCF, followed by agricultural methane (CH_4) emissions and agricultural nitrous oxide (N_2O).

The HHD group achieves the largest levels of decarbonisation in agriculture and land use, followed by the MLHD group and the leadership group. Both the leadership and HHD groups achieve substantial levels of emissions reductions early in the century, with each of them abating more than 25% of emissions by 2030 compared to 2020 levels. The MLHD group lags behind, as it manages to achieve the first emissions reductions only by 2035. By 2050, both the HHD and the MLHD significantly scale up their decarbonisation efforts in the agriculture and land use sector, both reaching over 60% of emissions reductions compared to 2020 levels. Emissions reductions from agriculture and land use are much larger in HHD and MLHD groups, partly because abatement solutions connected to LULUCF find their largest application in these regions, such as Africa and Latin America (Figure 14).

Figure 14 Agriculture and land use sector – regional emissions reductions



Note: Leadership group: the UK, the USA, South Korea, Japan, the EU, Australia and New Zealand, and Canada; HHD group: Middle East, Mexico, South and Central America, China, and Former Soviet Union countries; MLHD group: Africa, India, and Other Developing Asia
Source: Vivid Economics, TIAM-UCL

Sub-sector measures across regions

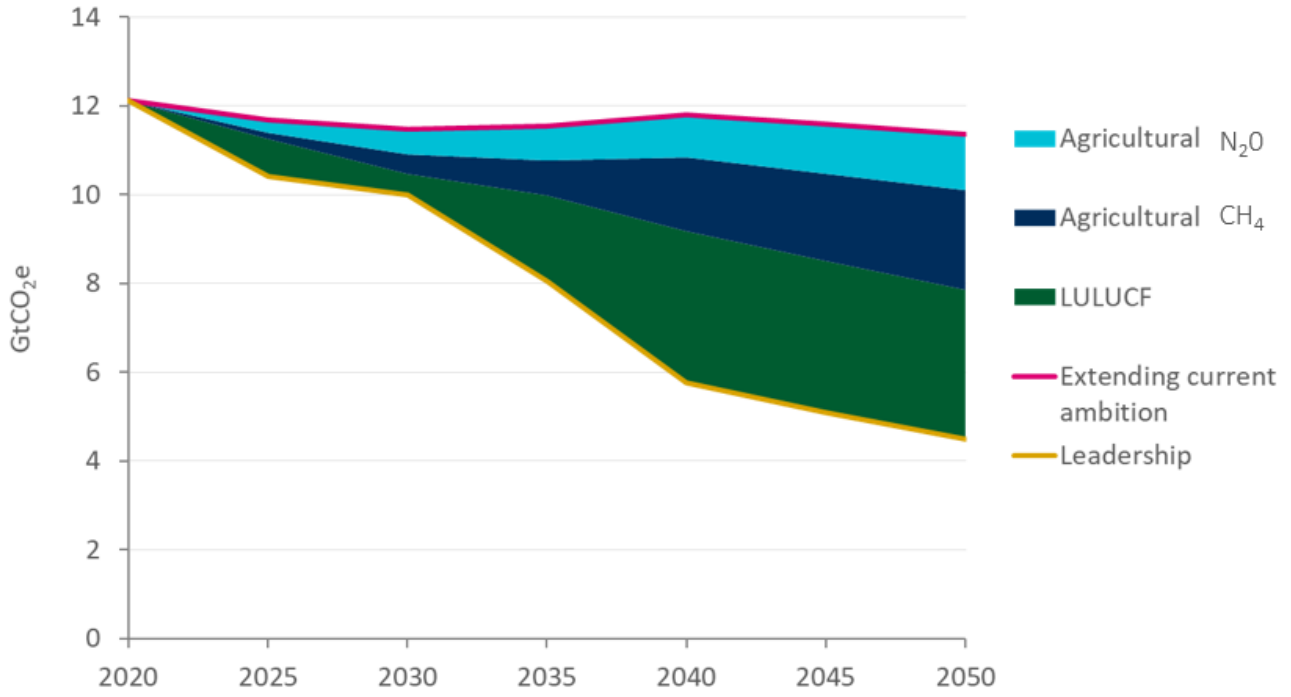
Abatement levels by 2050 are largest for LULUCF, followed by agricultural CH_4 emissions and agricultural N_2O emissions (Figure 15). Current emissions from LULUCF, CH_4, and N_2O stand at around 12 $GtCO_2e$ per year. By 2030, emissions from these sources are modelled to fall by around 17% to 10 $GtCO_2e$. Most of the abatement in 2030 stems from emissions reductions from agricultural N_2O (39%), followed by LULUCF (32%), and agricultural CH_4. By 2050, further abatement measures allow emissions to drop by an additional 46%, to 4.5 $GtCO_2e$. This achieves a 63% reduction in emissions compared to 2020 levels. In the years from 2030 to 2050, abatement from LULUCF takes the lion's share of emissions reductions, with 49% of abatement in 2050 realised through LULUCF measures compared to the ECA scenario. The remaining 51% of abatement is split across agricultural CH_4 (33%) and agricultural N_2O (19%).

In the leadership group, abatement in the agriculture and land use sector is driven by emissions reductions from agricultural CH_4. In 2050 emissions reductions in agriculture and land use achieve around 1 $GtCO_2e$ of abatement in the leadership region, down from around 2 $GtCO_2e$ of sector emissions in the same year. This is largely driven by abatement from agricultural CH_4 (59%) and from agricultural N_2O (41%). LULUCF measures do not contribute significantly to emissions reductions in the leadership regions. For example, abatement from LULUCF in Western Europe is modelled to be only around 50 Mt in 2050.

The HHD group achieves decarbonisation of the agriculture and land use sector largely through LULUCF measures. Under the ECA scenario, the HHD group still emits around 4.7 $GtCO_2e$ from agriculture and land use in 2050. In the leadership scenario, 2050 emissions fall to around 2 $GtCO_2e$. Differently from the leadership group, the largest source of abatement in the HHD regions is LULUCF: reductions in this sector pick up early in the 2020s and continue through the century; in 2050, 61% of abatement is achieved through LULUCF measures. The remaining emissions are abated through agricultural CH_4 (24%) and agricultural N_2O

(15%). LULUCF contributes to such a high share of reductions in the HHD group partly because this group includes regions with large forests and areas devoted to agriculture. For example, Central and South America achieve over 1.5 Gt of abatement in 2050 through LULUCF measures, which account for 88% of total abatement.

Figure 15 Agriculture and land use – by 2050, GHGs abatement is achieved mainly through reductions in LULUCF



Source: Vivid Economics, TIAM-UCL

Similar to the HHD group, the MLHD group achieves emissions reductions in agriculture and land use largely thanks to LULUCF measures. Significant abatement through LULUCF measures starts in the 2030s, thus lagging behind the HHD group. However, in 2050 around 53% of total emissions reductions from agriculture and land use is achieved through LULUCF measures. For example, the African continent abates over 1 $GtCO_2e$ in 2050 through LULUCF, which represents around 75% of abatement from agriculture and land use in that year.

Emissions reductions in agriculture and land use are achieved through a set of sub-sector measures. These can include:[20]

- **Afforestation and reforestation for GHGs removal**: This subset of measures includes afforestation and reforestation through direct government intervention, forest management agreements with local communities, and other policies that leverage governments' spending arm, such as grants, tax exemptions, and payments for ecosystem services. Forest cover increases by at least 5% from 2020 levels.
- **Restoration of degraded land for GHGs removal**: The dominant measure to achieve degraded land restoration is land protection, through the establishment of natural reserves, restoration programmes, and payment for ecosystem services.

[20] UN PRI (2019). Inevitable Policy Response, policy forecast.

- Soil sequestration for GHGs removal: Soil carbon sequestration involves changing land management practices to increase the absorption of CO_2 from the atmosphere. Examples include crop and nutrient management schemes, improvement of grass varieties, and the introduction of deep rooting grasses.
- Enhanced productivity in agriculture: Yield-enhancing investments and farm practices, including use of fertilisers and access to GM seeds, can significantly affect production levels. Crop yields increase by more than 50% to deliver necessary emissions reductions.
- Dietary shifts: These measures include the reduction in consumption of animal products, particularly of ruminant meats, and the development of alternative meat products and "clean meat"[21] technologies. The share of ruminant meat consumption decrease gradually to reach 75% of baseline levels in 2050.

The effectiveness of abatement solutions can vary according to the region. Solutions including afforestation, restoration of degraded land, and soil carbon sequestration can lead to more substantial abatement in the regions where LULUCF measures are forecast to have the largest impacts, i.e. the HHD and MLHD groups. Dietary shifts and enhanced agricultural productivity could be most effectively applied where groups of influence have wide appeal and large funding streams are devoted to research and development, i.e. the leadership group.

2.3.6 Engineered GHGs removals

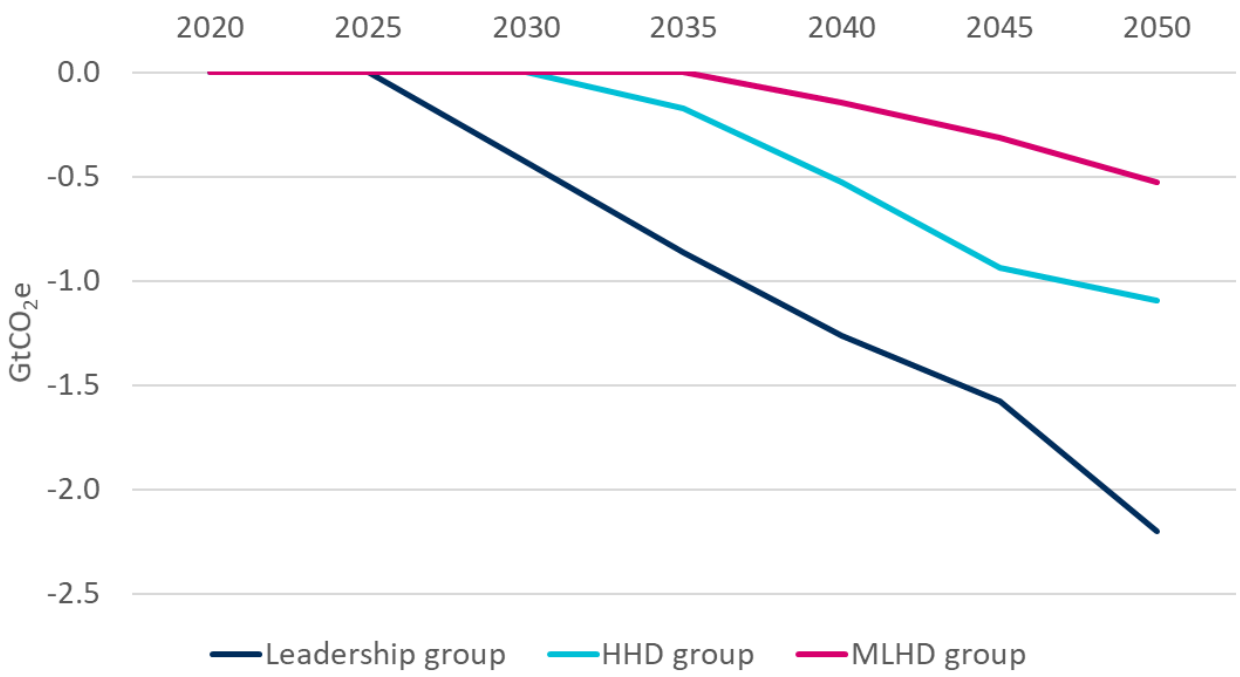
Rates of emissions reductions across regions

The engineered removals start to play an important part of the leadership scenario from 2030 onwards. Our leadership pathway allows for a role for engineered removals after 2025, with a significant increase in deployment from 2030 onwards. Overall, the engineered removals contribute to 8% of the global emission abatement over the period of 2020-2050. Of this, the majority is assumed to be delivered through the deployment of BECCS and only around 1% by the DAC technology types. DAC technologies, which are only available from 2040, become more significant after 2050, but still only account for 10% of negative emissions from 2080 onwards given relatively high costs.[22]

Regionally, the majority of engineered removals are deployed by the leadership group (Figure 16). The scenario sees 63% of removals' abatement being deployed by the leadership group, followed by 28% in the group of HHD countries, and the remaining 9% in the MLHD group of countries. In particular, the key global regions for engineered removals are expected to be the USA (28% of total 2020-2050 abatement), followed by Western Europe including the UK (19%), China (16%), Japan (6%), and Former Soviet Union countries (5%) (Figure 16). It is worth noting that due to the absence of credit purchases there is no flexibility for the leadership group to benefit from purchases of credits in other regions within this modelling scenario, but this could be a possibility in reality under functioning carbon markets.

[21] Clean meat—also known as lab-grown, in vitro, or cultured meat—is meat that is grown in cell culture, rather than in an animal's body.
[22] Given the early emergence of engineered GHGs removal technologies, these two types should be seen as an illustrative pathway rather than a prescriptive scenario.

Figure 16 Engineered removals – regional rates of deployment



Note: Leadership group: the UK, the USA, South Korea, Japan, the EU, Australia and New Zealand, and Canada; HHD group: Middle East, Mexico, South and Central America, China, and Former Soviet Union countries; MLHD group: Africa, India, and Other Developing Asia
Source: Vivid Economics, TIAM-UCL

Sub-sectoral measures across regions

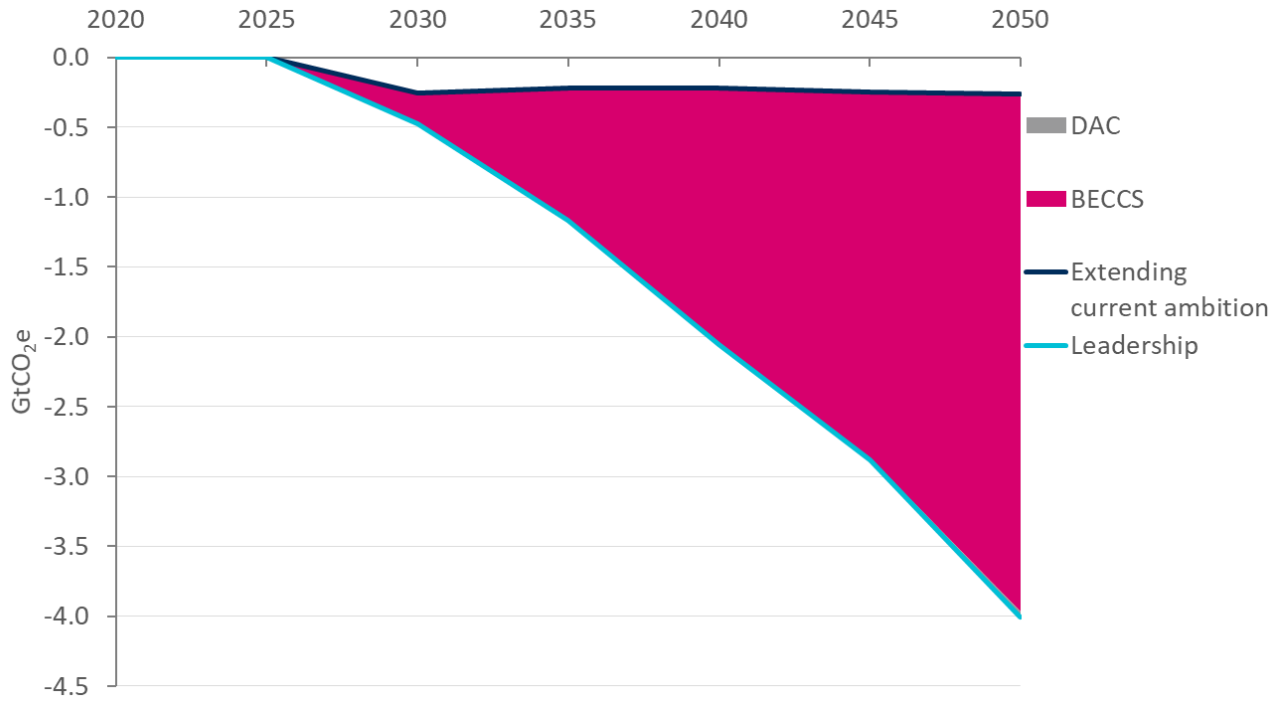
BECCS deployment starts around 2030 in the leadership group followed by the other countries, while DAC deployment becomes significant only in the second half of the century (Figure 17). The leadership group starts to significantly deploy BECCS from 2030, where more than 0.2 $GtCO_2e$ are abated in that year compared to the ECA scenario. This abatement potential grows to 1.9 $GtCO_2e$ by 2050 when the abatement solution is deployed at scale. A few advanced countries drive BECCS deployment in the leadership group, such as the USA which contributes to 42% of the abatement realised through BECCS in 2050. DAC fails to represent a significant abatement option for the first half of the century, with only 1% of emissions abatement from removals coming from DAC by 2050. Only in 2100 does this share rise to around 20%.

The HHD group follows a similar pattern, but with a five-years lag. A significant abatement from BECCS starts after 2035 and in 2050 1.2 $GtCO_2e$ are abated through BECCS. Key countries to support BECCS deployment in the HHD group include China, which is responsible for 48% of abatement though BECCS in 2050. The LMHD group sees a much lower deployment of BECCS and DAC by 2050, with only 0.5 $GtCO_2e$ abated through BECCS in 2050. This reflects the lower level of regional development compared to the other more technically advanced country groups. By 2100, DAC still has not taken off in LMHD countries as BECCS are responsible for a 92% share of the emissions reductions achieved through removals.

BECCS are often expected to be deployed at relatively low cost in the medium term as they partly rely on existing or mature technologies. However, a number of barriers has been identified to significant deployment of BECCS. So far, the two main routes of research and industrial effort include BECCS via liquid biofuel production and BECSS via biomass conversion to heat and power which are then deployed with a carbon capture and storage technology. However, a number of risks has been identified, including varying energy and carbon costs depending on the supplied biomass; BECCS technology efficiencies in terms delivering genuinely carbon-negative and energy-positive results; impacts on land use change; as well as

broader environmental challenges including water use, soil quality, and biodiversity impacts. Further, the BECCS deployment is fully dependent on the existence of CCS infrastructure at scale and the availability of genuinely sustainably produced biomass. Finally, BECCS economic feasibility is currently challenged by the difficulty in financing CCS projects and the complex value chains which are likely to be geographically dispersed, with regions with high biomass potential (e.g. South America) being different from the regions with greatest technological potential (e.g. the USA). These geographical challenges can lead to complex cross-national governance issues (Imperial College, 2019).

Figure 17 Engineered removals – key technologies delivering the leadership scenario



Note: DAC – Direct Air Capture technologies; BECCS – Bioenergy with Carbon Capture and Storage technologies
Source: Vivid Economics, TIAM-UCL

3 Global leadership opportunities

3.1 Introduction and our approach

This section aims to answer the following questions:

- What are the important leadership channels of influence that can enable decarbonisation actions to be taken across the world?
- How do these actions differ across the six key sectors?

In 2019, the International Advisory Group to the Committee on Climate Change identified the UK's historical channels of influence (CCC, 2019). These are:

- **Leadership by example**: this included aspects such as the UK's performance in reducing its emissions since 1990 by over 40%; developing the institutions to deliver this reduction (e.g. the Climate Change Act); and forward looking actions such as further policies and spending commitments to ensure meeting the fourth and fifth Carbon Budgets.
- **Diplomacy and shaping political conditions in key countries**: these included targeted diplomacy and interventions to help overcome technical barriers or to better equip key groups with analysis and arguments. These actions encouraged the introduction of carbon pricing in China; power sector reform in India; or energy planning in China, India, Latin America, and South Africa.
- **Targeted financial support**: the UK is the only developed country to have written its commitment to spend 0.7% of GDP on Official Development Assistance into domestic legislation. It has committed a proportion of that budget to climate change mitigation and adaptation activities. The UK has also been amongst the leaders in prioritising the reduction of deforestation, committing 20% of the budget.
- **Negotiating global agreements**: the UK has negotiated in the United Nations Framework Convention on Climate Change (UNFCCC) through the EU and has been very influential in shaping the positions of the EU, which has been one of the major forces in the negotiations so far. The UK has been also influential in other international institutions, such as the UN International Civil Aviation Organisation (ICAO) (aviation) and International Maritime Organization (IMO)(shipping), as well as international innovation policy (Mission Innovation).

In this report, we extend these channels to a new typology that includes (1) a wider range of possible actions and (2) new channels that may emerge in the future. The channels were expanded through an initial literature review, discussion and revision with a panel of experts, and through a project workshop (Box 3). Five of the six channels are levers primarily available to national governments, reflecting the primary interest of this study in analysing what actions national governments can take to accelerate the global transition. The final channel looks at the role of business and non-state actors.[23] The six leadership channels used in this study are covered in Table 2.

[23] Although, even under this lever, there is still a role for government in setting the obligations and frameworks for the private sector to have emission reduction impacts beyond its national borders.

Box 3 Developing the evidence on global mitigation options and leadership channels of influence

- To develop the global leadership channels of influence, we have combined a literature review with an input from selected experts, and project workshop revision.
- The literature review included some of the recent studies relevant to the global and leadership decarbonisation efforts: Project Drawdown's decarbonisation solutions; the International Advisory Group's Summary report to the Committee on Climate Change; the UN PRI's Inevitable Policy Response policy trends; the IEA's clean energy transition reports; and Brooking's report on 'Accelerating-long-carbon-transitions through international action'. Please refer to the Reference section for details.
- We have consulted on both our initial list of decarbonisation efforts and leadership channels with a panel of experts that included Peter Betts and Cameron Hepburn. Peter Betts served as a director for international climate policy at the UK Government's Department for Business, Energy, and Industrial Strategy (BEIS) for ten years, leading on the UNFCCC negotiations and several bilateral engagements. Cameron Hepburn frequently provides advice on energy and climate policy to government ministers and international institutions, including the UN and the Organisation for Economic Co-operation and Development (OECD), around the world.
- The collated leadership channels have then been discussed and reviewed through a project workshop including participants from Vivid Economics, UCL, the UK Committee on Climate Change and BEIS.

Table 2 Channels of global climate leadership for high-ambition developed countries

Channel	Description	Examples
Demonstrating a net-zero pathway	Developing and deploying mitigation solutions to achieve their domestic emissions targets, stimulating learning-by-doing and reductions in cost with benefits elsewhere.	• Bringing costs of mitigation technologies down through R&D, innovation, and large-scale deployment • Creating solutions to non-technical barriers, such as environmental land management schemes to address incentives and abatement uptake issues or creating markets to link residual emissions and removals • Creating markets for low-carbon goods/technologies with spillover benefits elsewhere in the world
Diplomatic influencing	Accelerating decarbonisation elsewhere in the world through formal and informal diplomatic channels.	• Diplomacy through coalition building around specific real-economy actions (e.g. Powering Past Coal Alliance for coal power phase-out) • Facilitating multi-lateral agreements at UNFCCC negotiations • Targeted bilateral diplomacy to accelerate low-carbon outcomes in specific national contexts • International coordination on standards and regulatory trajectories
Trade measures	Establishing trade rules in relation to carbon pricing and/or sustainability standards. In cases of large shares of global markets, this could accelerate	• Applying sustainability standards, e.g. low-carbon and sustainability product standards, limits on the allowable lifecycle GHG intensity of imported biomass, 'right to repair' rules

	decarbonisation in producer countries so that they continue to meet the low-carbon export requirements.	• Carbon border adjustments • Incorporating climate-related considerations into trade deals
Overseas capacity building	Direct technical assistance to other countries to help develop their capacity and capability in introducing climate mitigation solutions.	• Assistance in implementing effective climate governance architecture • Direct assistance in designing effective policies to overcome non-market barriers to decarbonisation. • Enabling and mobilising flows of private finance to fund mitigation with low or zero abatement costs
Overseas financial support	Financial transfers to directly fund the deployment of low and net-zero carbon technology elsewhere in the world.	• International climate finance provision • Purchase of carbon credits through international carbon markets
Leveraging private sector global impact	Leverage the global impact of the private sector through their global supply chains to create additional incentives to reduce emissions elsewhere.	• Supply chain standards and obligations • Mandating climate-related financial reporting • Creating opportunities and supporting a policy structure to enable private sector international green finance flows • Facilitating international sectoral deals between large private sector companies

Source: Vivid Economics

The relationship between the leadership channels and emissions reductions is complex. Different channels reinforce each other and could play roles across different sectors. For instance, the channels could be reinforcing each other in such a way that the private sector's action of meeting corporate targets could help in reducing costs of abatement solutions, and thus enabling a stronger role for the 'demonstrating net-zero pathway' channel, and vice versa. Further, due to the generic character of these leadership channels, they are likely to be applicable to all main emission sectors ranging from power to transport or agriculture.

In this project we make a simplification to identify the most important leadership channels in each sector based on two key dimensions. We shortlist the most important leadership channels in each sector by reviewing their role against the following criteria:

- **International connectedness:** if a given sector is highly dependent on trade and international connectedness then leadership channels affecting the trade relations are likely to be important and effective in driving change.
- **Abatement cost:** Abatement solutions are at different stages of maturity. Solutions at an earlier stage of emergence may face a prohibitively high abatement cost for developing countries to deploy them and therefore require targeted action by the leadership group to enable them to do so.

We recognise that a wider set of aspects can play an equally important role – yet these two dimensions are fit for purpose in surfacing the priority channels. A more in-depth study could look at non-cost barriers (including political and incumbent influences), to regional economic and employment opportunities, or wider co-benefits such as reduced air pollution. These are outside the scope of this project but are important considerations to identify effective implementation pathways in specific national and sectoral opportunities in the real world.

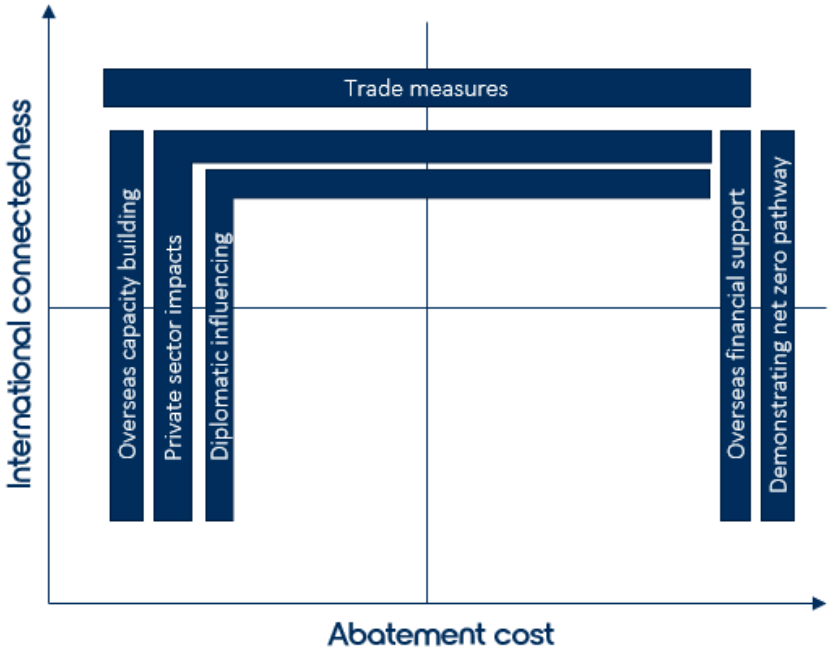
To set out this approach in a little more detail – the prioritisation of leadership channels in each sector had three sub-steps:

1. Allocate leadership channels of influence on the international connectedness/abatement cost grid.
2. Allocate sectoral abatement measures to a relevant area on the importance of connectedness/abatement cost grid.
3. Given this mapping, produce a shortlist of sector-specific candidates of leadership channels of influence that are then investigated in further detail for each sector.

As a first step, Figure 18 maps the leadership channels against our grid. The exact location of each channel is only indicative as it may vary given sectoral and local circumstances. We place the leadership channels in different quadrants of the grid based on the following:

- Demonstrating net-zero pathways: we recognise this lever to be particularly effective in areas with high abatement costs and limited global uptake so far. A domestic action of demonstrating solutions' viability can unlock these measures regardless of the international connectedness and trade intensity. Thus, the leadership action is initially inward looking.
- Trade measures: trade measures will be most effective in areas of high international connectedness and trade intensity. They may play a role in both areas where low-cost solutions exist (land use sector) as well as supporting increased uptake of more costly abatement solutions (industry sector).
- Overseas capacity building: we assume that this lever is mainly effective in areas with relatively low abatement cost but it can also be effective in both areas with relatively low international connectedness (national electricity grid management) and high international connectedness (sustainable practices in trade-exposed agriculture sectors).
- Overseas financial support: we recognise this lever to be particularly effective in areas where the deployment cost are regarded as the main barrier, and direct financial support can overcome that, regardless of the importance of trade. Thus, the leadership action is largely outward looking.
- Leveraging the private sector's global impact: private sector levers can be most effective in sectors where either abatement costs are low, so business opportunities are readily available, no matter if it is a globally tradeable sector. They can also be effective in sectors with high current abatement costs if it is a globally traded sector, such as food and agricultural products.
- Diplomatic influencing: similarly, we assume this lever to be particularly effective where abatement costs are low and abatement opportunities are readily available. It might also be effective in areas with higher abatement cost that are dependent on trade and international cooperation (e.g. aviation and shipping).

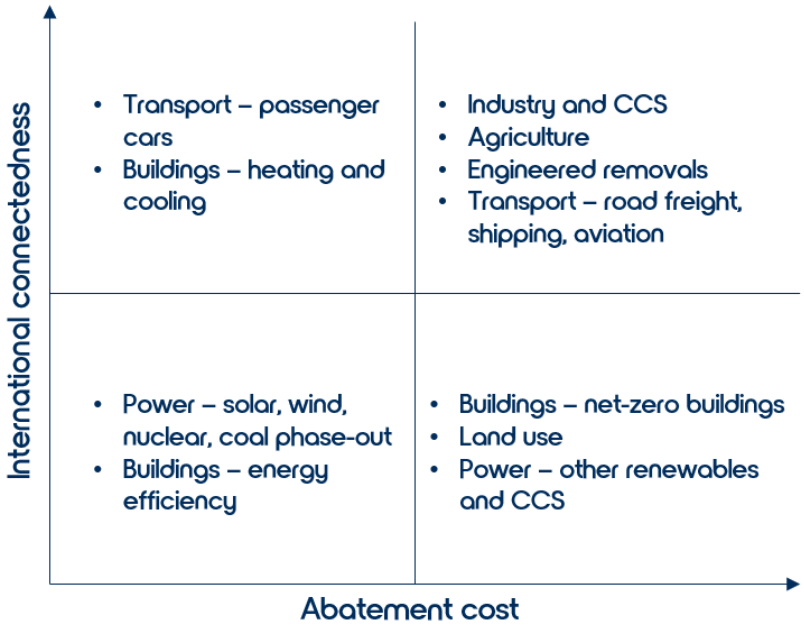
Figure 18 Mapping channels of influence against international connectedness-abatement cost grid



Note: The channels' exact position is indicative only, as it may vary given sectoral and local circumstances
Source: Vivid Economics; based on the review of evidence gathered as part of the sectoral assessments

As a second step, we mapped abatement solutions applied in our global pathway against our grid. Figure 19 summarises all of our main measures on the grid. Note that, again, the exact location of measures is likely to differ across regions and its purpose is to indicate a generic importance of the two dimensions for each measure. Relevant sectoral sections cover the exact rationale for placing the measures in different quadrants.

Figure 19 Mapping sectoral solutions against international connectedness-abatement cost grid



Note: The abatement measures' position is indicative only, as it may vary given local circumstances
Source: Vivid Economics; based on the review of evidence gathered as part of the sectoral assessments

Finally, we reviewed the shortlisted leadership channels in each sector against collated evidence on sectoral opportunities. Reflecting on the modelled results and shortlisted leadership channels of influence, we reviewed a number of existing sectoral studies and examples that point to leadership opportunities. Some of these examples are based on existing case studies or best practice, while other examples are forward looking and rather hypothetical given that some of the actions or solutions have not yet been widely deployed. As part of this, we also consider the role of the leadership group in international institutions (Box 4).

Box 4 Role of sector-focused international institutions

- Our research on leadership opportunities reviewed a wide range of evidence – of particular note was a recent Brookings (2019) report on the role of international institutions. This report argues against a single international organisation to influence global activity, as these attempts often lack focus, are highly vulnerable to obstruction by any member country that see their work as conflicting with its interests, and therefore result in weak and non-committal actions. An approach that brings together the willing and influential actors separately in each sector may be less vulnerable to obstruction, and more able to focus on the forms of cooperation that are appropriate to the stage of the transition in each sector. The report argues that a focused, sectoral approach on international level has not yet been seriously tested.
- The report suggested four strategies for deepening the role of institutional organisations across sectors. First, in sectors where no institutions for international cooperation on decarbonisation exist, find or create an institution that can play this role. Second, in institutions with levels of participation, push for deeper cooperation. Third, in institutions that are already focused on deep cooperation, expand their membership. Finally, in all sectors, strengthen government engagement in the leading institutions. Our report builds on the Brookings report by considering the role of leadership countries, and the UK in particular, in strengthening the role of international organisations across the sectors.

As a result of combining all the above steps, we produce sector-specific assessments of the global leadership opportunities. These are summarised in the next section and discussed in detail for each sector in the relevant sub-sections.

3.2 Key global leadership opportunities

Two leadership channels are expected to be important across almost all sectors. These include leadership channels that have both a domestic and an international focus:

- **Demonstrating a net-zero pathway**: across all sectors, the main leadership opportunity is for countries to demonstrate the feasibility of a net-zero carbon pathway. This can help reduce cost and non-cost barriers to other countries and, importantly, open up the role for other channels.
    - **Power:** demonstrating the feasibility of a rapid coal phase-out can strengthen the potential of diplomatic influencing (e.g. international coalitions) and increase the role of other channels, such as overseas capacity buildings and financial support in the medium term.
    - **Industry**: The current leadership countries' opportunities are in collaboratively working on developing and deploying technological solutions and then creating demand for lower-carbon industrial products. Demonstrating the feasibility of domestic industrial decarbonisation can help other countries to transition to cost-effective solutions based on the leadership example and open the role to other channels in future, such as capacity building and diplomatic influencing.

- Trade measures: in the short-to-medium term, a range of trade measure opportunities lie across most sectors. These include introduction and development of common standards as well as stronger alignment of trade policies with climate and sustainability ones.
    - Industry: A coalition of leading countries can work together in establishing trade-based instruments that enable industrial decarbonisation while reducing the competitiveness risks, such as border carbon adjustment frameworks and carbon prices.
    - Transport: the leadership countries can engage in the creation and expansion of common standards to low-carbon transport solutions across all transport modes. This includes creation of international standards for charging infrastructure or carbon fuel pricing policies.

The next most prominent leadership channels across sectors have primarily an international focus. These include the following two channels:

- Diplomatic influencing: leadership countries could accelerate global decarbonisation through the diplomatic channels in a number of sectors:
    - Power: they can further expand the role of the PPCA to large coal users by introducing a phased approach. They can also coordinate internationally in air quality standards as well as increase use of carbon pricing instruments.
    - Transport: the leadership countries can mostly utilise existing international platforms (e.g. the C40 Cities Climate Leadership Group, ICAO, and IMO in relevant sectors) in expanding the global action to transport decarbonisation.
    - Buildings: the scope of existing international platforms (e.g. World Green Building Council and the Global Alliance for Buildings and Construction) could be further extended to include targets and standards setting for signatories, as well as enforcement and monitoring of compliance.
    - Agriculture and land use: Countries can coordinate across borders to foster change in agricultural and land use practices internationally and have a broader impact. This could be done through forming alliances to coordinate R&D spending; building platforms for international cooperation and knowledge sharing; or coordinating on the functioning of international carbon and offset markets.
- Leveraging the private sector's impact: leadership countries could leverage the private sector's impact through a number of activities across the sectors:
    - Transport: Leadership governments can leverage existing private sector associations and help in creating new international initiatives. For instance, they could focus on committing businesses owning large car fleets to switching to zero emissions vehicles (ZEVs), following the example of the existing EV100 initiative that brings together companies committed to accelerating the transition to EVs. Through a coalition of countries, they could also influence the leading industrial association, IATA, towards raising its targets to a near-total decarbonisation of the sector by 2050.
    - Industry: For example, the coalition of leading countries could leverage their influence and work together with the private sector in expanding their renewable energy procurements to other products. The leading countries could also facilitate the creation of similar private sector initiatives like EV100 related to industrial decarbonisation.
    - Buildings: New private sector initiatives could help create a stronger market for zero-carbon buildings by committing to operate in high efficiency buildings and to use low-carbon materials during operations.

- ◊ **Engineered GHGs removals**: with an increased interest in corporate net-zero targets (e.g. the Corporate Leadership Group's ambition of net-zero economies), the private sector's ambition could eventually stimulate sustainable GHGs removal markets.

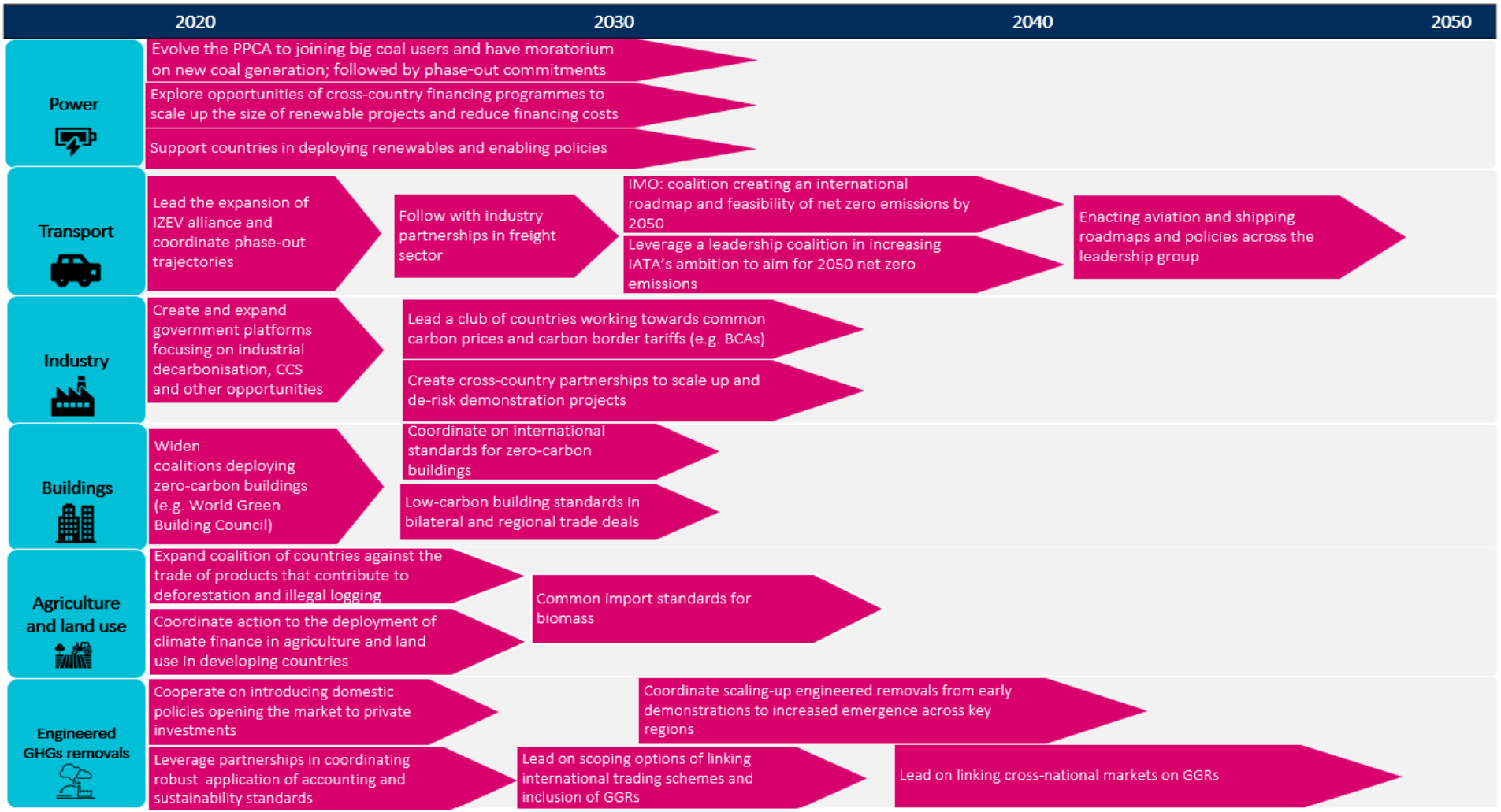
Figure 20 summarises the global leadership opportunities across the sectors and Figure 21 provides a global leadership roadmap for the actions identified in this chapter. Each aspect is discussed in detail in the following section.

Figure 20 Summary of most relevant leadership channels across sectors

Sectors	Demonstrating net-zero pathway	Diplomatic influencing	Trade measures	Overseas capacity building	Overseas financial support	Leveraging private sector's impact
Power	✓	✓		✓	✓	
Transport	✓	✓	✓			✓
Industry	✓		✓			✓
Buildings	✓	✓	✓			✓
Agriculture & land use	✓	✓	✓		✓	
Engineered GHGs removals	✓		✓		✓	✓

Source: Vivid Economics

Figure 21 Global leadership roadmap across the six sectors



Note: Dates are indicative and broadly based on the leadership-driven emission pathway results; ZEV – zero emission vehicles; IMO – International Maritime Organization; PPCA – Powering Past Coal Alliance; IATA - International Air Transport Association; BCAs – border carbon adjustments; CCS – carbon capture and storage

Source: Vivid Economics

3.3 Global leadership opportunities across sectors

This section provides a detailed global leadership assessment of each of the six sectors. For each sector, it first discusses what the most impactful leadership channels might be, given the sectoral abatement characteristics, and then provides potential leadership activities under each of the channels and sectors.

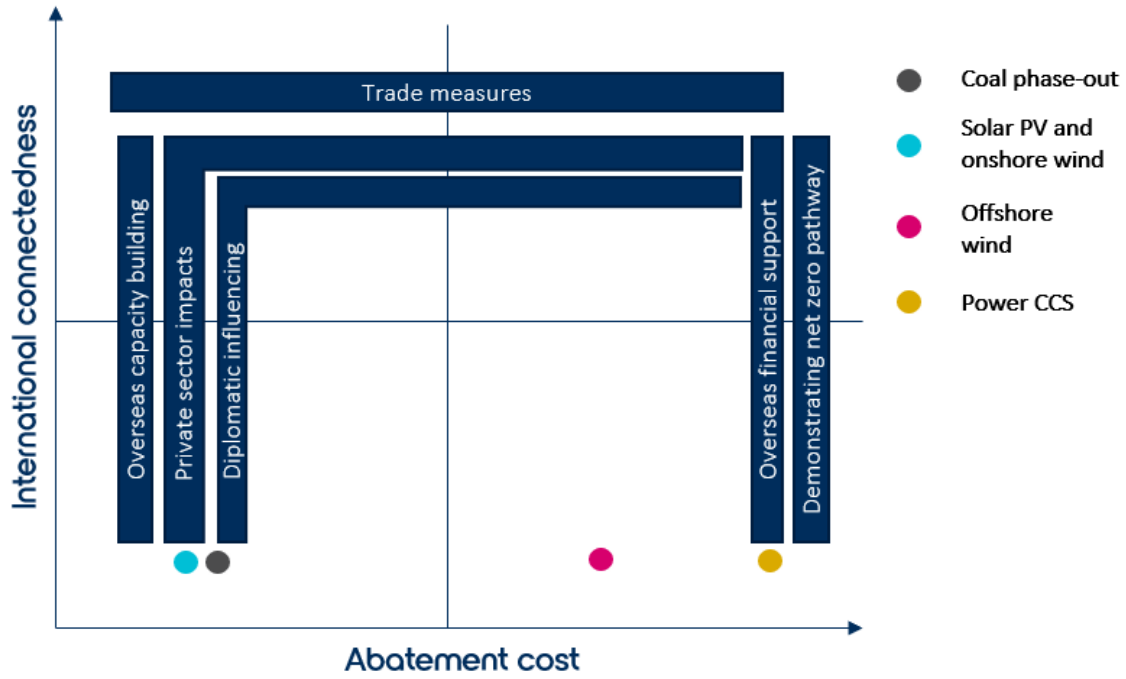
3.3.1 Power sector

The most effective leadership channels are likely to be those that can enable a significant ramping up in already mature renewables deployment alongside a fast-tracked phase-out of coal use and a demonstration of costlier decarbonisation solutions:

- **The main solutions to power sector decarbonisations are already largely cost-competitive compared to existing power generation sources**. Over 2010-2019, solar PVs showed the sharpest cost decline at 82%, followed by concentrated solar power at 47%, onshore wind at 40% and offshore wind at 29%. This means that replacing the costliest 500 GWs of coal capacity with solar and wind would cut the global annual power system's cost by up to $23 billion per year (IRENA, 2020). Power CCS, on the other hand, continues to face high deployment costs, requiring demonstrations of new business models (IEA, 2019c).
- **Trade-related measures of leadership countries are less relevant in the power sector**. National power sector generation is more driven by national market designs and policies as well as local costs.

Thus, three channels of demonstrating net-zero pathway, overseas capacity building, and financial support are likely to be effective (Figure 22). These channels can all contribute to further reduction in renewables' costs, reducing non-market barriers and increasing the level of renewables' deployment. Further, the diplomatic influencing channel is likely to be effective in accelerating the coal phase-out in other regions.

Figure 22 Key leadership channels in power sector



Note: Measures' exact location is indicative of existing global costs while it may vary due to local circumstances
Source: Vivid Economics

Leadership channels: ***demonstrating a net-zero pathway***

The leadership group should continue its members' existing efforts to decarbonise their national power sources to showcase the feasibility, cost-effectiveness, and just transition to net-zero power generation:

- **Leadership countries can act individually in developing zero carbon power market designs through relevant policies (e.g. contracts for zero emission sources, carbon pricing, or policies that address variable renewables and grid balancing) and deployment of renewable technologies**. In turn, these activities can help in creating significant markets for renewables and in reducing their deployment costs. Germany's example of significant deployment of solar PV has shown a 75% reduction in investment costs in the period of 2006-2018 thanks to technological progress, the learning curve, and economies-of-scale on both the demand and production side (Fraunhofer, 2020). Similarly, the UK has become the largest offshore wind producer in the world and is projected to see offshore wind electricity generation costs be lower than existing gas plants by 2023, or a 74% drop in the costs of electricity generation price since 2017 (BEIS, 2019).

- In turn, the power generation solutions, best practices, and successful business models can be communicated and actively showcased through existing international forums and organisations including the IEA, International Renewable Energy Agency (IRENA) and the Clean Energy Ministerial platforms.

- **In relation to power coal phase-out, it is critical to showcase that this transition can be done in a way that reduces negative impacts on the existing workforce**. Leadership countries can demonstrate a range of opportunities to re-skill coal workers into new energy sectors by providing re-training and regional redevelopment opportunities as well as infrastructural investments. A few leadership group countries have already established mechanisms in place (e.g. Canada's Just Transition Taskforce, Germany's Coal Commission). The knowledge developed in national circumstances by the leadership group should be further actively communicated and showcased at the international level to enable coordinated learning through existing and new platforms (e.g. PPCA, Just Transition Centre, and Platform for Coal Regions in Transition).

Leadership channels: ***overseas capacity building***

This channel can be particularly effective in relation to the deployment of mature renewable technologies and nuclear power, where the main barriers to increased deployment are often non-cost related. The two most effective instruments here are likely to be a combination of direct technical assistance and building countries' capabilities in mobilising private green finance. These can help overcome the challenges of creating the necessary environments to support private sector capital flows and overcome the non-cost barriers (e.g. regulatory and political economy barriers):

- **Across most world regions, solar PV and onshore wind technologies are becoming cost-competitive compared to fossil fuel generation sources thanks to continued decrease in installation and levelised costs (IRENA, 2019)**. Therefore, the most effective action for the leadership countries is to continue to offer, and expand on, direct technical assistance to less experienced countries in supporting the renewables' deployment in cost-effective ways, providing support on market reforms integrating renewables and flexible power generation into the power grid. Also, a number of existing international platforms, such as the IEA, IRENA, and Clean Energy Ministerial, could refocus from information sharing to coordinated action (Brookings, 2019).

- **Further, the leading countries' role will be critical in helping other states to mobilise private finance**. For instance, a recent analysis of China's Belt and Road Initiative, representing 126 countries involved in the scheme, has shown the urgent need for green finance to unlock trajectories to the Paris Agreement. Among other recommendations, the analysis calls for a set of actions that can help to build countries' capability in leveraging private green finance including establishing a global platform for green finance

capability building for Belt and Road Countries; boosting capacity for green procurement, and forming a coalition of international initiatives to support green financing (Vivid Economics, 2019).

Leadership channels: ***overseas financial support***

This channel has been already well established, with clean power receiving a substantial proportion of international climate finance. This can be further strengthened through a coordinated effort to shift public finance to Paris-aligned investments. Some of the leadership countries (e.g. UK, Germany, Japan) have well-functioning programmes in place that are already investing a substantial amount of public finance to renewables and other low-carbon power generation sources in developing countries. At the same time, G20 nations have supported coal projects with $28bn per year through governments' public finance institutions, such as bilateral investment banks and export credit agencies investing in coal projects, with the majority being spent abroad (ODI, 2019). Thus, there is an opportunity for the leading coalition to fully transition towards clean power financing, and potentially lower-carbon fossil fuels sources such as unabated gas[24], while ceasing unabated coal power finance. Further, a cross-country coordination between multilateral funds and bilateral donors may help in creating larger finance programmes and thus reducing finance costs and shifting to larger-scale power projects (Brookings, 2019).

Leadership channels: ***diplomatic influencing***

A range of diplomatic activities might help the transition from coal to renewables but will likely require other channels to be in place. Some of the examples include creation and expansion of global alliances, coordinated efforts on air pollution quality, or promoting the case of carbon pricing policies:

- **Coal phase-out alliances**: The Powering Past Coal Alliance has linked practical assistance with the coordinated commitments of its members to phase out unabated coal. The Alliance, together with the underpinning announcements, may have helped in shifting investors' long-term expectations about the future of coal in the power sector. However, it seems that, in the majority of cases, it is the costs of phase-out and the capacity to bear these costs that differentiate PPCA members from non-members (Jewell et al., 2019). Thus, it is likely that any coalition commitments on the large users of coal, such as China or India, will need to take account of regional circumstances. One way forward could be to agree on a set of tiered transition principles such as: agreeing to no new coal; eliminating old and inefficient plants; and guaranteeing a finite lifetime for the remaining coal-powered units (Center for Global Sustainability, 2020).

- **International coordination of efforts in air quality**: one of the indirect ways towards coal phase-out could also be through increased global efforts in improving air quality, as there have been shown to be significant co-benefits of shifting to renewables. Leading countries could strengthen their collective efforts in monitoring and enforcing these standards and expanding these to other countries by building their capabilities (Brookings, 2019).

- **Expanding the role of carbon pricing policies**: through the World Bank's Partnership for Market Readiness and Partnership for Market Implementation initiatives, the leadership coalition should focus on broadening engagement from developing countries and subnational jurisdictions at both the public and private sector levels. It should also deepen its private sector engagement so that support for carbon pricing policies is strengthened at an institutional level. It should continue to advocate for policies that are designed and communicated in a way that increase the acceptability and sustainability of carbon pricing.[25]

[24] See Section 2.3 for regional results that suggest, in developing countries, a continued role for fossil fuel-based power generation until 2030 while transitioning to renewables by 2050.
[25] https://www.carbonpricingleadership.org/

3.3.2 Transport sector

The international connectedness of the passenger cars manufacturing sector has been increasing while it is still characterised by localised production in several large regions. Thus, trade measures are likely to be less effective in the short term. For example, passenger cars are a highly traded good, implying that where they are sold can be far from where they are produced. However, the production and sales locations vary across the world (Jato, 2018):

- **Leadership countries**: in 2017, 92% of Japanese, 85% of European, and 83% of Korean car sales were of locally produced cars. Only 58% of USA cars were locally manufactured, with even lower shares observed in other leading countries - 18% for Canada and 5% for Australia.
- **HHD and MLHD countries**: almost all the cars sold in India (99%) and China (95%) were produced locally. Brazil's sales, too, are largely from domestic production (89%).

However, trade measures are likely to be important in other parts of the transport sector, such as aviation and shipping. For example, due to the international nature of much aviation and shipping, travel trade-related levers could be important in these sub-sectors where a decision by key countries and regions could determine the future trends in other countries (e.g. setting international standards on refuelling infrastructure for both aviation and shipping).

Importantly, the maturity, and therefore costs, of abatement solutions varies significantly across the transport sub-sectors. The transport sector abatement solutions are at a different stage of emergence, with electric vehicles being in the most mature position while aviation and shipping solutions are largely at an early stage of emergence:

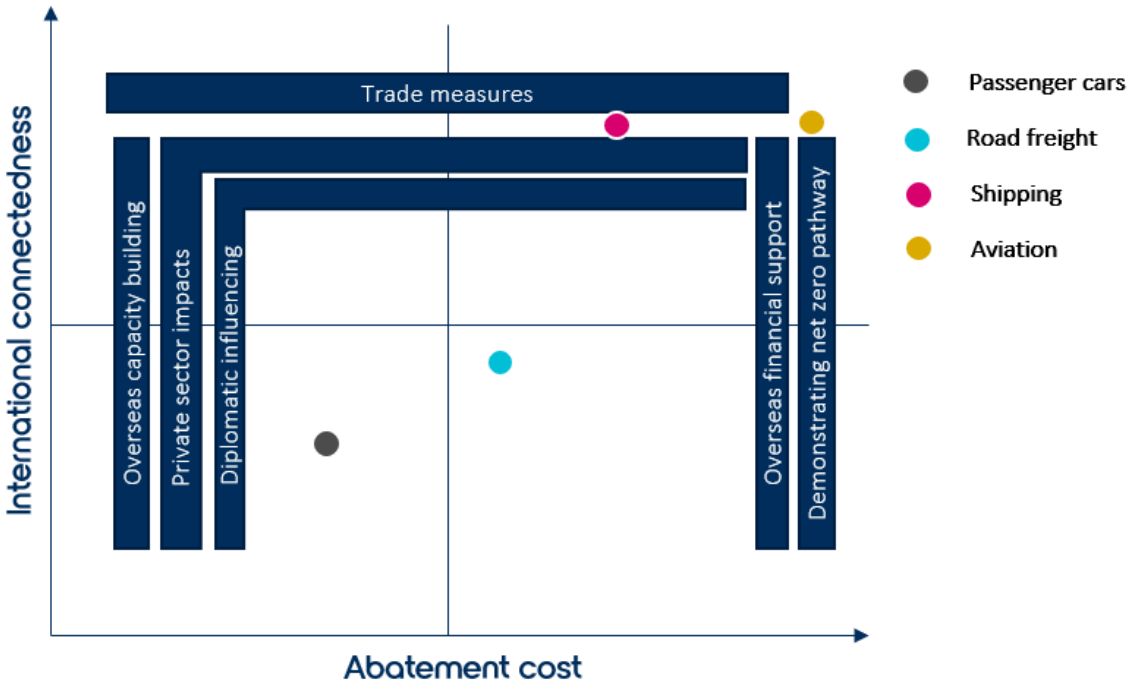
- **Passenger cars solutions**: In terms of decarbonising private car emissions, electric cars have been largely seen as the main option. Their deployment has been growing rapidly over the past five to ten years, with the global stock of passenger EVs passing 5 million in 2018, an increase of 63% from the previous year. Around 45% of EVs on the road were in China, with Europe and the USA accounting for 24% and 22% of the global feet, respectively (IEA, 2019d). The main drivers of further uptake are expected to be continued fall in battery prices, improvements in energy density, spread of charging infrastructure, and new markets. By the mid-2020s, EVs are expected to reach up-front price parity with internal combustion vehicles, but with wide variation across regions (BNEF, 2020).
- **Road freight solutions**: The transition to zero emission freight is largely in the emergence stage, with key technological solutions identified as battery EVs, in the case of smaller vans, and hydrogen fuel-cells, for larger trucks, combined with continued energy efficiency improvements or systematic improvements in logistics.[26] By 2030, battery EV trucks are expected to have a total cost of operation significantly below that of diesel or gasoline trucks (Energy Transitions Commission, 2018).
- **Shipping solutions**: zero emission solutions to shipping are also at a stage of early emergence with little market coverage. It is one of the most difficult transport sectors to decarbonise due to the high cost of low-carbon solutions (between \$150-350/tCO_2), long replacement cycles, and the fragmented nature of the industry (Energy Transitions Commission, 2018). The TIAM-UCL sees a substantial role for hydrogen by 2050.
- **Aviation solutions**: the transition to zero-carbon aviation is in the early stage of emergence with the key abatement options being fuel switching to lower-carbon alternatives (e.g. sustainable aviation fuels (SAF) and electrification), demand reduction, and increasing energy efficiency. Electrification is an option that is likely to be feasible for short-haul flights. Over 170 electrifying aviation projects are currently under development and are expected to enter the market in the early 2020s. However, the main barriers are seen as the energy density of batteries, capital costs, and lack of suitable charging infrastructure

[26] It is still uncertain what the balance will be between EVs and H_2 for HGVs and TIAM-UCL only uses H_2 for HGVs.

(Brookings, 2019). In terms of long-haul flights, a switch to SAFs is regarded as the only viable option but there are significant cost barriers, with certified SAFs being 50-100% more expensive than conventional jet fuels, and sustainability concerns over large global use of biofuels (Energy Transitions Commission, 2018).

Thus, different parts of the sector will require different leadership actions (Figure 23). Based on the review of relevant abatement opportunities, their cost profiles, and the role of trade, we have shortlisted four leadership channels that are further discussed below for each of the sub-sectors.[27]

Figure 23 Key leadership channels in transport sector



Note: Measures' exact location is indicative of existing global costs while it may vary due to local circumstances
Source: Vivid Economics

Leadership channels: ***demonstrating net-zero pathways***

Leadership countries will need to take further domestic action across all four areas with varying role of deployment and demonstration policies depending on the cost, and therefore maturity, of the solutions:

- **Passenger vehicles and road freight**: Leadership countries can individually help expand the ZEVs market by introducing effective policy measures (e.g. purchase incentives to reduce cost differential between ZEVs and other vehicles; air pollution standards; efficient charging infrastructure; and balancing additional electricity demand on the grid). Countries' cities and regional authorities can also help the first markets for zero emissions freight through public procurement of zero emission buses and waste collection trucks.
- **Shipping**: Countries should lead on organising international demonstration efforts, through organisations such as the IMO, that help scaling up the current demonstration activities in developing and testing low-carbon fuels. Once these technologies have been proved, countries can accelerate their emergence and the creation of niche markets by procuring low-carbon vessels on state-operated routes

[27] The review of leadership opportunities is largely based on international actions discussed in Brookings (2019) report and Mission Impossible sectoral focus studies.

- **Aviation**: Given the current discussion of green recovery options, countries could redirect any fiscal support to aviation and make it conditional on the aviation sector's decarbonisation efforts through R&D spend on aspects like development of SAFs for long-haul flights and electrified short-haul planes. Countries could then lead on demonstrating the solutions in domestic markets, such as how to design effective standards on biomass use in SAFs and how to scale up domestic sustainable feedstock supplies (Brookings, 2019).

Leadership channels: ***diplomatic influencing***

The leadership countries can mostly utilise existing international platforms in expanding the global action to transport decarbonisation:

- **Passenger vehicles and road freight:** Leading countries should further utilise existing international city alliances, such as the C40 Cities Climate Leadership Group, in expanding the network of cities and ambition towards ZEVs, clean air zones, and air pollution charges. Countries that have already set ICE phase-out dates (UK, Norway, France) can also work towards a coordinated action across the countries to widen and accelerate phase out of ICE vehicles elsewhere in the world. They can use established platforms such as the ZEV Alliance for passenger cars or the G20 Transport Task Group for freight.

- **Aviation**: Through international platforms such as the UN ICAO or Clean Skies for Tomorrow initiative, the leading countries could establish more practical cooperation on a number of aspects, including the mandates of SAFs between airports; sustainability standards for low-emission fuels; and development of electrified aviation technologies (Brookings, 2019).

- **Shipping**: Through their role in the IMO or as a collation of governments in other organisations (e.g. World Ports Climate Action Programme), the leading countries could develop a detailed international roadmap towards net-zero CO_2 emissions by 2050 (Energy Transitions Commission, 2018).

Leadership channels: ***leveraging the private sector's impact***

Leadership governments can leverage existing private sector associations and help in creating new international initiatives. This can help accelerate the action taken by large businesses and thus create and expand the markets for low-carbon transport solutions:

- **Passenger vehicles and road freight**: The leading countries can focus on committing businesses owning large car fleets to switching to ZEVs, following the example of the existing EV100 initiative.[28] Similarly, they could lead on forming an alliance of logistics providers that own large fleets of HDVs and on committing to procure only zero emission trucks by a certain date.

- **Aviation**: Leadership countries could create a coalition initiative across private partners (airports, airlines, and business travellers) to secure a large-scale supply of cost-competitive SAFs, and to commit to offer and travel on SAF routes. Through a coalition of countries, they could also influence the leading industrial association, IATA, towards raising its targets to a near-total decarbonisation of the sector by 2050 (Energy Transitions Commission, 2018).

- **Shipping**: A coalition of countries could leverage the high market concentration[29] in shipping to influence the key private sector actors to create a buyers' alliance. This private sector alliance would commit to switching to low-carbon fuels in a similar fashion to already existing initiatives.

[28] EV100, with 70 corporate members, is committed to using 100% ZEVs by 2030, https://www.theclimategroup.org/ev100-members

[29] For instance, container shipping is an increasingly concentrated sector in terms of operations and alliances, ship deployment, and major ports of call. Three alliances dominate the container shipping market and capacity deployed on the three major East–West trade routes (UNCTAD ,2019).

Leadership channels: ***trade measures***

The key trade-related activities that the leadership countries can engage in are the creation and expansion of common standards for low-carbon transport solutions. The actions of the coalition could involve:

- **Passenger vehicles and road freight**: The countries could lead on coordinating international standards to charging and cross-border infrastructure investments to correct for the fragmentation of national charging systems (Hall and Lutsey, 2017). In the case of freight, a similar approach could focus first on linking the main freight cross-country corridors.
- **Aviation**: A coalition of governments could work towards creating an SAF mandate imposing an increasing percentage of zero-carbon fuels.[30] They should also work together in introducing carbon fuel taxes that are applied at full rate to domestic flights and at reduced rate to international flights; finally, they should tighten biofuel sustainability standards (Energy Transitions Commission, 2018).
- **Shipping**: The countries could work together to establish a group of ports that agree on common standards, and of low-carbon fuels, and development of necessary infrastructure. Through their role in the IMO, or as a collation of governments in other organisations (e.g. World Ports Climate Action Programme), they should aim to tighten the energy efficiency design standards for new built ships and set operational efficiency standards for the existing fleet. Longer-term, they could work together towards enforcing and operationalising a carbon tax on heavy fuel oils and/or a 'green fuel' mandate (Energy Transitions Commission, 2018).

3.3.3 Industry sector

The decarbonisation of industry is highly challenging due to technical complexities and trade exposure. Five key areas include:

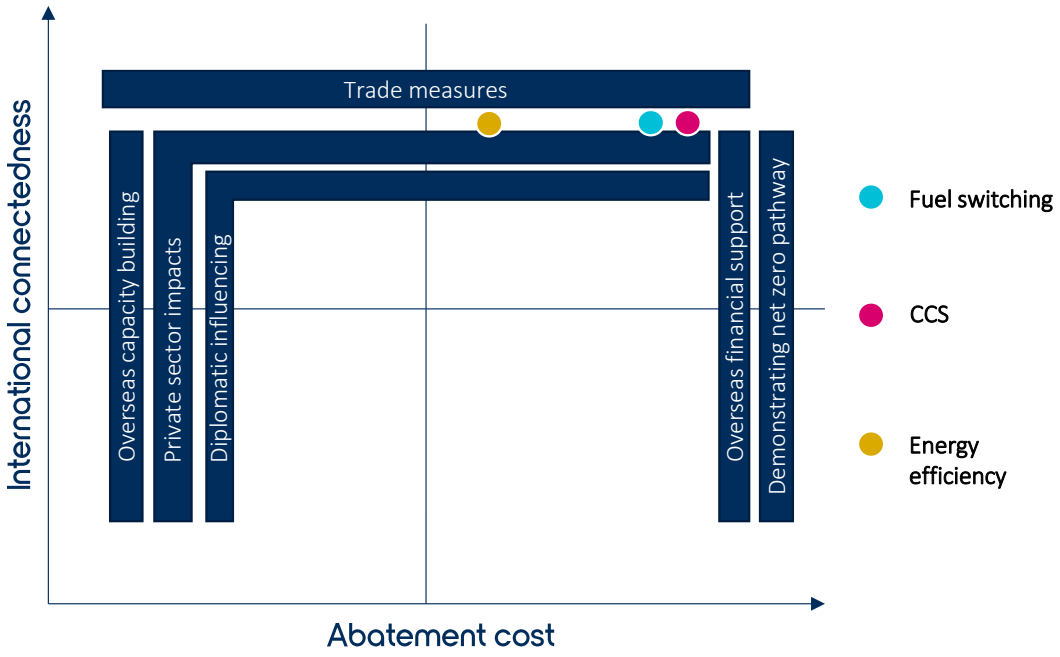
- **High-grade heat requirements**: While there are relatively low-cost options available for low- and medium-grade heat, required for uses such as food processing, around half of heat requirements are for high-grade heat[31]. These are necessary for material transformation processes, such as clinker production, and are costly to deliver with most currently available renewable energy technologies or electrification.
- **Capital-intensive, integrated production processes**: Production facilities and components have long lifespans and, where built relatively recently in developed and developing countries, still have a long life ahead of them. This means that abatement technologies must be integrated using expensive rebuilds or retrofits. Moreover, incorporating new technologies or changing to new industrial processes can be highly challenging given the integrated nature of production. For example, changing from a blast furnace to an electric arc furnace for steel production requires major capital investment and supply chain changes.
- **Process emissions**: While fuel switching is a key abatement option, a large share of emissions stems from chemical processes integral to the production of materials. For example, around half of cement emissions derives from the calcination of limestone to produce clinker.
- **Trade exposure:** Most industrial sectors trade on international markets and products – such as cement and steel – tend to be commodities. As a result, they are price takers. Producers thus are unable to pass on the technology costs of abatement without a loss of competitiveness and, in turn, a significant loss of market share.

[30] Any international commitments will need to reflect on wider potential uses of biomass and sustainability criteria. For instance, CCC (2018) advised a maximum 10% blend of biomass fuels produced without CCS for aviation fuel.
[31] High-grade heat is where the temperature is higher than 650 °C.

- **Limited technological and market readiness.** Key technologies for industrial decarbonisation, including, for example CCS and electrolysis, remain technologically and commercially immature in comparison to others, such as electric vehicles. This increases risks to investors, and slows down deployment, particularly for industries which require coordinated deployment of several immature technologies across the value chain to decarbonise.

The key areas outlined above motivate the high costs and international connectedness across industry (Figure 24). The high-grade heat requirements, high capital-intensiveness, and limited market readiness motivate the high abatement costs of industrial decarbonisation. These are high, especially for decarbonisation through fuel switching and CCS, while energy efficiency can rely on existing infrastructure to a larger extent. As industrial products are intensively traded on global markets, the sector is highly connected at an international level.

Figure 24 International connectedness and abatement costs in the industry sector



Note: Measures' exact location is indicative of existing global costs while it may vary due to local circumstances
Source: Vivid Economics

Consequently, leading countries can accelerate the industrial decarbonisation mainly through the channels of demonstrating net-zero pathways, trade measures, and leveraging the private sector's global impacts. The leadership channels are further discussed, pointing to sector-specific opportunities where possible.

Leadership channels: ***demonstrating net-zero pathway***

Given the early emergence of industrial decarbonisation solutions, the leadership countries' actions are likely to be effective in collaboratively working on developing and deploying technological solutions and then creating demand for lower-carbon industrial products. Some of the leadership actions could include:

- **Coordinated R&D and demonstration efforts**: the group of countries can act together in coordinating and developing large R&D programmes across multiple countries to finance innovation in industry. They can then work together on piloting demonstration projects backing a range of technologies and systems. Coordinating the demonstration projects at international level can ensure that all the promising options are sufficiently scoped and reflect country-specific circumstances (Brookings, 2019). Some of the main innovation opportunities are likely to include further development and piloting of CCS and hydrogen

technologies that can play a key role in the iron and steel and other industrial sub-sectors (Energy Transitions Commission, 2018).

- Coordinated demand for products: public procurement of lower-carbon products can play an important role in establishing early markets and attracting investment and innovation. The group of countries can work together in assuring demand for low-carbon industrial production through public procurement, such as publicly funded infrastructure, voluntary buyer alliances, and internationally coordinated product pricing. For example, in the case of iron and steel, leading countries could commit to 100% 'green steel' in all publicly funded infrastructure and buildings by 2040 (Energy Transitions Commission, 2018).

- Collaborative development of CCS clusters: a number of industrial clusters have been in development around the world, including the UK, Australia, and the Netherlands, as part of delivering on decarbonisation efforts and attracting industrial investments (IEA, 2019a). Through existing private sector platforms (e.g. Global CCS Institute or the CCS Association) or new inter-governmental groups, the leadership countries could coordinate the international effort in learning about and developing new CCS clusters in future.

Leadership channels: ***trade measures***

A coalition of leading countries can work together in establishing trade-based instruments that enable industrial decarbonisation while reducing the competitiveness risks. Some of the examples include:

- Border carbon adjustments (BCAs): if linked into a carbon pricing instrument, BCAs can reduce international competitiveness and carbon leakage[32] risks by ensuring that domestic industries do not face asymmetric carbon costs either domestically or externally, while also maintaining incentives for domestic abatement. While BCAs are likely to face substantial administrative and legal challenges, some regions, such as the EU, has been examining their potential as a mechanism to prevent carbon leakage while facilitating domestic industrial decarbonisation (European Commission, 2020). The leadership coalition could work together to develop and expand the BCAs to key industrial activities and, in turn, to create large markets for low-carbon industrial products.

    - Coordinated carbon taxes and embedded carbon standards: for example, a coalition of countries could work together towards a common carbon tax on steel production reaching $50-$70 per tonne of CO_2 by 2030. They could also create and progressively tighten regulations on the embedded carbon of steel-based products (Energy Transitions Commission, 2018). Similarly, the coalition could work towards setting product standards for other industrial products, such as 'green cement', and establishing ways of tracking these products through labelling practices (Brookings, 2019).

Leadership channels: ***leveraging the private sector's impacts***

The leadership countries could further leverage their influence over the private sector's global role through a number of activities:

- Private procurement: many large companies are important consumers of industrial materials such as steel, aluminium, cement, or plastics. The coalition of leading countries could leverage their influence and work together with the private sector in expanding their renewable energy procurements to other products. They could also initiate collaborative projects between producers and users to showcase the business case for lower-carbon products.[33]

- Joint ventures: the coalition can coordinate joint venture partnerships with the private sector to increase cost sharing of pilot projects. For instance, the HYBRIT joint venture has been exploring the feasibility of

[32] Carbon leakage can occur through a reduction of output in the short term, or a reduction in investment in the long term.
[33] For instance, Apple Inc. has worked with two major global aluminum companies with support from the Canadian Government to develop a process that removes CO_2 emissions from the aluminum smelting process (RioTinto, 2019).

hydrogen-based steel making in Sweden together with a number of key industrial players and has been considering in expanding the project to Finland.[34]

- Global private sector initiatives: following the example of existing initiatives, such as EV100, the leading countries could facilitate the creation of similar initiatives related to industrial decarbonisation. These could include commitments to greening their supply chains through sourcing low-carbon materials and products.

3.3.4 Buildings sector

The buildings sector is partly dependent on international connectedness, while abatement costs still substantially differ depending on the abatement option.

- Heating and cooling: At present, costs of zero-carbon heating and cooling technologies are still higher than their fossil fuel equivalents: heat pumps can be five times more expensive than an average gas boiler (Forbes, 2020), while non-GHG refrigerants still bear high costs that prevent their widespread adoption. However, many of the zero-carbon heating and cooling solutions necessary to achieve net-zero have been already developed and are being commercialised. International connectedness can help speed up commercialisation at global scale through trade.

- New zero-carbon buildings: the transition to zero-carbon buildings is still in its emergence phase (Brookings, 2019): the industry has not yet stabilised around a uniform set of standards and modern methods of construction, such as offsite construction, still need further development and research expenditure. As a consequence, costs to develop zero-carbon new buildings are still high and their share makes up less than 5% of construction in most markets today (IEA, 2019e).

- Energy efficiency: within the space of buildings' retrofit in line with energy efficiency practices, many of the necessary technologies are available and pilot programmes have proven their effectiveness (BNEF, 2020b). Abatement costs are lower, as solutions are developed already, and focused on increasing the rate and scale of refurbishment (IEA, 2019e). International connectedness plays a limited role in buildings' energy efficiency measures, as retrofit of existing buildings is done and supported at local level.

The leadership channels that are likely to be most effective in decarbonising the buildings sector are those that enable the demonstration of abatement solutions at scale and their rapid diffusion across countries (Figure 25). The combination of these channels could unlock the leadership scenario:

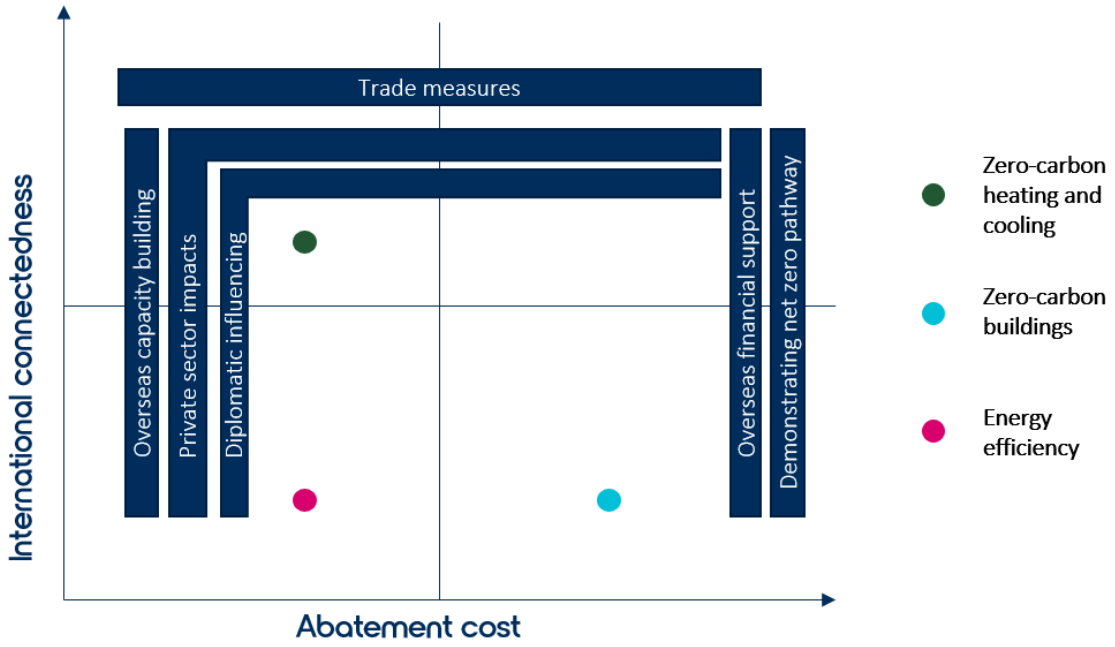
- Demonstrating net-zero pathways: here, the measures can reduce the costs of new technologies, such as heat pumps, solar thermal for carbon-free heat, and near-zero construction materials. Demonstration projects also allow the gathering of the necessary expertise and selection of the optimal business models to expand such solutions at scale. Realising sustainable buildings requires large flows of capital into the solutions developed through national pilots (IEA, 2019f).

- Leveraging the impact of the private sector can help realise the surge in clean energy investment required to decarbonise the sector and quickly create a vast market for zero-carbon buildings.

- Diplomatic and trade agreements are critical to diffuse net-zero buildings solutions, through mandatory construction policies, coordination on product standards, knowledge transfer, and sharing of best practices.

[34] HYBRIT – short for Hydrogen Breakthrough Ironmaking Technology – is a joint venture between SSAB, LKAB and Vattenfall, aiming to replace coal with hydrogen in the steelmaking process: http://www.hybritdevelopment.com/

Figure 25 International connectedness and abatement costs in the buildings sector



Note: Measures' exact location is indicative of existing global costs while it may vary due to local circumstances
Source: Vivid Economics

Leadership channels: ***demonstrating net-zero pathways***

Demonstrating net-zero pathways – governments can support innovation in the buildings sector through demonstration projects and targeted procurement:

- To achieve a fully-fledged decarbonisation of the buildings sector, many new technologies and construction processes need to be fully developed and deployed at scale: Heat pumps and solar thermal deliver carbon-free heat while achieving substantial energy savings (IEA, 2019f); innovative lighting, appliances, and refrigerants significantly cut energy demand and realise efficiency gains; smart demand-side management reduces energy use in buildings further by shifting peak electricity demand to off-peak hours; net-zero and high-performance buildings combine these innovations with the deployment of renewables onsite (Project Drawdown, 2020).
- Governments can accelerate the development of these processes and technologies in several ways:
  - ◊ Coordinated research and development can help build knowledge and best practices which can later be shared with other countries through demonstration projects and knowledge platforms. Examples of these initiatives can be witnessed in many parts of the world already: the Global Alliance for Buildings and Construction connects governments and the private sector to raise ambitions to decarbonise buildings and mobilise all actors along the value chain[35]; the Kigali Cooling Efficiency Program helps developing countries transition to net-zero-compliant cooling solutions[36]; the IEA's Technology Collaboration Programmes supports and coordinates the work of international groups of experts on a wide range of energy technologies[37].
  - ◊ Aside from financing research, development and deployment projects, governments can help redirect finance through coordinated procurement operations. The development at scale of

[35] https://globalabc.org/about/about-globalabc
[36] https://www.k-cep.org/
[37] https://www.iea.org/areas-of-work/technology-collaboration

these solutions requires capital flows to increase by an average of $270 billion a year over the next decade, on top of the $4.9 trillion already invested each year in the sector (IEA, 2019f). Coordinated procurement can have a role in creating a market for zero-carbon buildings that eventually can be self-sustained.

Leadership channels: ***diplomatic influencing***

International coordination on standards and regulatory trajectories can be a powerful tool to create a global market for sustainable buildings:

- Once solutions for zero-carbon buildings are developed, setting international standards can help achieve widespread deployment across countries. Standards can refer to energy codes for buildings and performance standards for end-use equipment. Standard setting not only helps deploy zero-carbon solutions at scale, but also channels greater financial flows to genuinely low-carbon buildings by making available opportunities more intelligible to investors (Brookings, 2018). This process can be facilitated with the creation of a global platform through which governments and the private sector can coordinate with each other on standards. The existing World Green Building Council and the Global Alliance for Buildings and Construction already include a vast set of stakeholders and commit their members to net-zero pledges, such as the Net Zero Carbon Buildings Commitment.[38]

- The scope of these platforms could be further extended to include targets and standards setting for signatories, as well as enforcement and monitoring of compliance. Coalitions can take place not only at national level, but also at the city level. Here, the smaller scale helps reduce the risk stemming from bolder policies and allows building best practices that can later be extended to other territories. A coalition of cities can agree on regulatory trajectories in fuel switching and buildings' energy efficiency and support these with financial incentives and regulations in a coordinated manner. The C40 Cities partnership already encourages sharing of best practices across a coalition of cities and is a promising starting point for a discussion on zero-carbon buildings.

Leadership channels: ***trade measures***

Trade policy can facilitate the implementation and diffusion of buildings standards across borders. Technical regulations and standards can set out specific product characteristics, including functions and performance (WTO, 1995). The inclusion of standards on emissions performance or energy efficiency for products that enter the buildings supply chain could foster the use of zero-carbon emissions products within the sector. Combined with assessment procedures ensuring conformity to the highest environmental standards, such as inspection and certification, trade policy could help foster the creation of an international market for zero-carbon products for buildings. The World Trade Organization (WTO) and other international trade forums are important platforms for enlarging the scope and breadth of environmental product standards.

Leadership channels: ***leveraging the private sector's global impact***

The private sector can help create a market for zero-carbon buildings by committing to operate in high efficiency buildings and to use low-carbon materials during operations. Businesses can help accelerate the transition to zero-carbon buildings by committing to operate in offices of the highest efficiency standards, housed in buildings equipped with zero-carbon heating and cooling technologies. Similar initiatives include RE100 and EV100, which commit participating companies to the use of renewable energies and electric vehicles, respectively. An equivalent for zero-carbon buildings could, for example, envisage coordinated procurement campaigns for heat pumps or high-efficiency air conditioners. Alternatively, businesses that operate in the construction sector can commit to buying zero-carbon materials for their operations. This can both reduce the emissions embedded in each construction work and create valuable synergies with industry, for example for the production of low-carbon steel and cement.

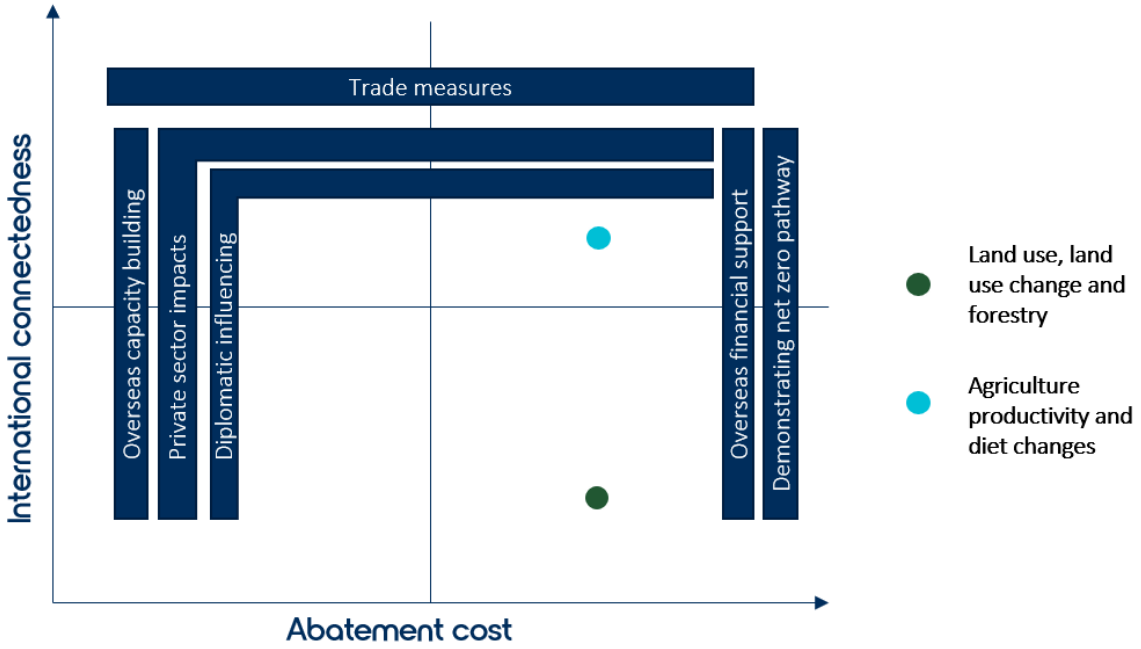
[38] https://www.worldgbc.org/thecommitment

3.3.5 Agriculture and land use

Measures around agricultural productivity and diet substitutes are under development and rely on trade for diffusion, while LULUCF measures have a more local impact and high implementation costs (Figure 26). Practices for net-zero agricultural production still lack the necessary knowledge, skills, and capabilities for diffusion across the sector and will require further expenditure in research, development, and demonstration to reduce costs. Once these practices are established, demand for agricultural products sourced sustainably can substantially increase through international connectedness. Practices of afforestation, land restoration, and land use change have high costs of implementation and uptake is often slow. The impact of land use policies is more local, and their design varies widely by region.

The choice of the most effective leadership channels to transition to net-zero will vary depending on the abatement costs and options for diffusion. Solutions that still have high abatement costs, such as increased agricultural productivity, fertiliser efficiency, and livestock emissions reductions, will initially require domestic demonstration. Once solutions become more established and their costs are reduced, they can be spread across borders through trade measures (e.g. standard setting) and diplomatic influencing (e.g. knowledge sharing). Financial assistance can help direct budget streams to sectors that require support locally.

Figure 26 International connectedness and abatement costs in the agriculture and land use sectors



Note: Measures' exact location is indicative of existing global costs while it may vary due to local circumstances
Source: Vivid Economics

Leadership channels: ***demonstrating a net-zero pathway***

Countries can act individually and collaboratively to implement policies reducing GHGs emissions from the agriculture and land use sector. Some examples of national actions that can be undertaken include:

- **Designing fiscal policies and incentives towards sustainable agriculture and land use:** National governments can reorient subsidy schemes towards sustainable agricultural practices, uses of land that increase capacity of GHG sequestration, conservation, and restoration of natural resources. They can also lead a market transition to sustainable commodities by strengthening public procurement requirements and reinforcing the mandatory due diligence obligation on businesses.

- **Incorporating the agriculture and land use sector in carbon pricing systems:** The scope of carbon pricing systems, such as emission trading schemes, can be extended to fully include the agricultural and land use sector (UN PRI, 2019). Payment for ecosystem services can also be considered within this space. Once such market mechanisms have been implemented in two or more countries, they can be linked internationally.

- **Introducing legally binding targets:** A legally binding target to end deforestation within the agricultural and forestry commodity supply chains can be introduced, no later than 2030 (Global Resource Initiative, 2020). The target should be aligned to existing commitments to end deforestation under the New York Declaration on Forests, the Amsterdam Declaration Partnership, and the UN Sustainable Development Goals (SDGs).

- **Increasing spending in R&D towards sustainable agricultural and land use practices:** Governments can support the scaling and commercialisation of innovation for more sustainable agricultural and forestry supply chains. These can include more productive agricultural practices, methane-inhibiting vaccines for livestock, and development of alternative meat products.

Leadership channels: ***diplomatic influencing***

Countries can coordinate across borders to foster change in agricultural and land use practices internationally and have a broader impact. Examples of actions that can be taken in coordination with other countries include:

- **Forming an alliance to coordinate R&D spending:** international cooperation in the development of new techniques and technologies for emissions reductions in agricultural production can help fund more substantial demonstration programmes and later develop a shared evidence base for regulatory efforts. Examples of such initiatives can already be found in the international landscape today. For instance, CGIAR is a global partnership that coordinates research on food security across borders[39].

- **Building a platform for international cooperation and knowledge sharing:** Countries can share best practices and knowledge created nationally with other international players. Examples include how to promote efficient farming, use soil carbon sequestration practices, and prevent deforestation. No widely recognised forum for international cooperation and knowledge sharing is present in this area. In the future, the Food and Agricultural Organisation could leverage the broad membership base of the United Nations to create a forum to share best practices within this space.

- **Coordinating on the functioning of international carbon and offset markets:** Carbon markets can include nature- and forest-based credits. Internationally determined standards should ensure that such credits are high-quality and address forest governance concerns, sharing benefits across society.

Leadership channels: ***trade measures***

Trade measures can help influence production and consumption patterns across countries once the best sustainable agricultural methods and land practices are identified. Trade measures in this space include:

- **Introducing and enforcing international standards**: International standards for sustainable production and certification schemes can help reduce international trade of products grown on deforested lands or following unsustainable agricultural practices. A limited subset of products is already part of similar initiatives, such as the Roundtable on Sustainable Palm Oil, the Roundtable on Responsible Soy, and the Tropical Forest Alliance (Brookings, 2019). However, a recognised government-to-government forum to discuss coordination between producer and consumer countries across a variety of products does not yet exist and could be rapidly instituted.

[39] https://www.cgiar.org/

- **Offering trade incentives on sustainable products:** Import guarantees on products grown sustainably could reduce the cost of trade for sustainable agricultural production. This in turn could reduce end-prices for consumers and increase consumption of sustainable goods, while placing an incentive for commodity producers to adopt more sustainable practices.

Leadership channels: ***overseas financial support***

Financial support can be a powerful enabler of emissions reductions in less developed countries. The modelled results detailed above show that HHD and MLHD countries can achieve substantial emissions reductions by 2050. Leadership countries can help to enable these reductions by providing overseas financial support in several ways, which include:

- **Increasing climate finance to agriculture and land use:** The coordinated action of donor countries and multilateral development banks can help channel financial flows to the agriculture and land use sector overseas. Initiatives include targeted support to producer countries for implementing sustainable production methods, investment in restoration and enhancement of areas under protection, and modernisation of agricultural systems.
- **Mobilising public-private finance collaborations:** A blended finance facility[40] could help mobilise capital at scale to support sustainable land use and agriculture through public-private collaborations (Global Resource Initiative, 2020).

3.3.6 Engineered GHGs removals

Leadership channels

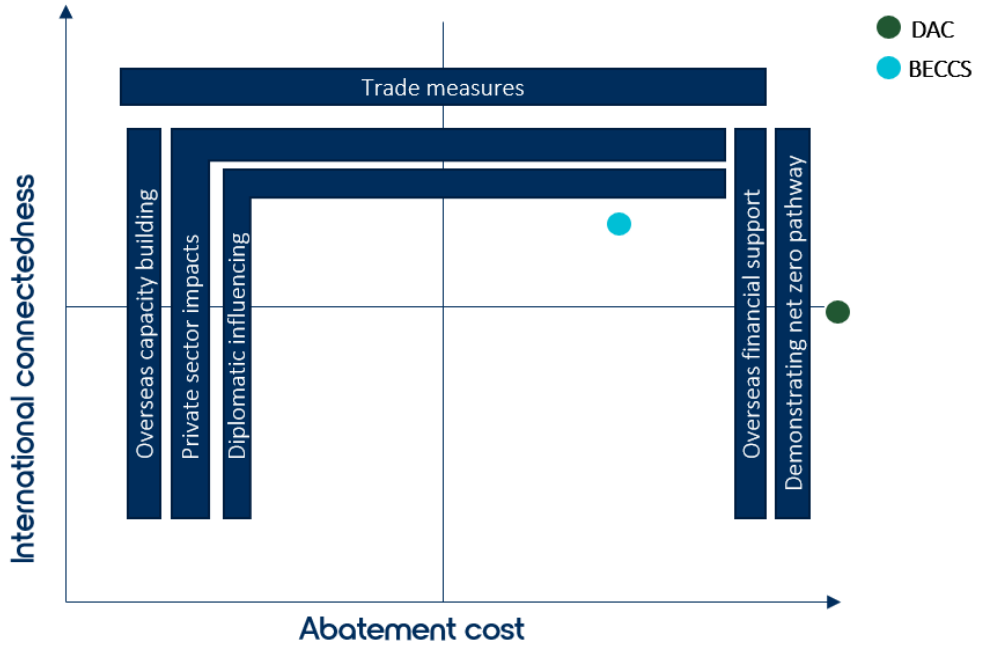
Given the early emergence of engineered removal technologies and wider governance and sustainability issues, the main leadership opportunities appear to be in the following areas (Figure 27):

- **Demonstrating net-zero pathways**: Domestically, leadership countries can support engineered greenhouse gas removal demonstration projects through: (i) directed R&D expenditure as well as through market design; (ii) market-based incentives such as contract for difference (CfDs) schemes linked to electricity prices and/or carbon market prices; (iii) tax credits per £/tCO_2e of GHG removed and any capital investment to secure private investments; (iv) introducing carbon removal obligation schemes, connected to a carbon trading scheme, where companies are required to secure negative emission certificates (Vivid Economics, 2019b). Internationally, the leading countries can work together in demonstrating the ways of linking established trading schemes to emerging GGR trading schemes.
- **Trade measures**: a coalition of countries could lead on developing the necessary policy and regulatory frameworks, such as robust international standards of accounting for negative emissions under the UNFCCC reporting or emissions certificates tradable internationally. These certificates would be issued by a certification authority to provide guarantees around certificates and monitoring of standards.
- **Overseas financial support**: in the medium term, high-ambition countries could also lead on applying existing financial mechanisms to developing BECCS and other engineered removals in developing countries. Some of the options include leveraging and revisiting existing international finance mechanisms under the UN (e.g. the Global Environment Facility or the Green Climate Fund) that are well positioned to fund BECCS projects in future. Further, governments could help in creating public-private partnership that could de-risk BECCS projects and allow them to quality for commercial loans (Global CCS Institute, 2019).

[40] The OECD defines blended finance as "the strategic use of development finance for the mobilisation of additional finance towards sustainable development in developing countries".

- **Leveraging the private sector's global impact**: with an increased interest in corporate net-zero targets (e.g. the Corporate Leadership Group's ambition of net-zero economies[41]), the private sector's ambition could eventually stimulate sustainable GHGs removals in order to reach 2050 net-zero targets. The use of compliance offset credits would need to be supplemented with sufficiently robust criteria applied to the allowable removals (linked to trade measures above).

Figure 27 Key leadership channels in engineered GHGs removals



Note: Measures' exact location is indicative of existing global costs while it may vary due to local circumstances
Source: Vivid Economics

[41] https://www.corporateleadersgroup.com/

4 The UK's leadership potential

4.1 Introduction and our approach

This aim of this chapter is to zoom in on the role of the UK leadership. This follows the context of previous analysis of leadership-driven scenarios (Chapter 2) and the assessment of actions that the leadership group can do as a whole (Chapter 3). To do so, the chapter goes through each of the six key sectors and sets out the following elements:

- A review of existing literature to establish the UK's existing strengths and activities in the identified sectoral leadership channels.
- An assessment of the scope of further potential for the UK's actions across the leadership channels.

In order to establish UK leadership actions across the sectors, we combine our sectoral leadership assessment with an assessment of UK strengths and opportunities. Our leadership framework allows us to establish the key channels of influence. We then review evidence on the UK's existing leadership activities in each of the sectors. Consequently, we establish where the UK has been actively leading the global decarbonisation efforts (e.g. public financing of low-carbon power) and where there are further UK leadership opportunities that have not yet been realised.

To be clear – where we identify a UK action, we are saying that UK activity could support accelerated global abatement, but many other actions of other nations are also required. That said, there may be examples where UK actions could be catalytic to global progress by themselves. Leadership countries can have a prominent supporting role in the short-to-medium term to accelerate the transition to a deep decarbonisation pathway. Thus, this section should be regarded as an indication of where UK actions can help in unlocking global action while recognising the critical role of other nations and international institutions. We do not seek to identify areas where UK actions could be catalytic (i.e. we do not assess the relative strength of the leadership action); however, this could be the subject of further analysis, using the evidence of this report as a starting point.

Section 4.2 summarises the key UK opportunities coming out of the assessment reviews. Section 4.26 then provides the detail on UK opportunities across the six sectors and Section 4.4 discusses cross-cutting opportunities for green recovery and green financing.

4.2 Key UK leadership opportunities

We recognise six main UK leadership opportunities. While the UK could pursue all of the opportunities discussed in the following two sections, there are several areas where (i) it is likely to be of key importance in unlocking the global decarbonisation in the short term and developing longer-term solutions; (ii) the UK seems to be in a relatively unique position in leading on these opportunities:

1. **Evolving the Powering Past Coal Alliance to stimulate coal phase-out by large coal users.** Our scenario requires a rapid global shift from coal (94% reduction by 2030). Thus, expanding and broadening the membership of the Alliance with large coal users (e.g. USA, China, Russia, and India) will be necessary. As a co-founder, the UK could further lead on this expansion given its domestic coal record. One way forward could be for the UK to propose a tiered approach: first with new members agreeing to no new coal; then eliminating old and inefficient plants; and finally guaranteeing a finite lifetime for the remaining coal-powered units. Similarly, further use of public and private sector financing could be dependent on countries' coal phase-out commitments.
2. **Expanding the global role of offshore wind.** As a global leader in offshore wind (36% of installed global capacity), the UK can expand the global role of offshore wind. With 17% of global technical

potential in European waters, the UK can help in accelerating large-scale domestic deployment of offshore wind as well as further reducing the technology costs. Internationally, it can provide a targeted concessional finance and grant scheme for feasibility and FEED studies for offshore wind developers in low- and middle-income countries with large technical potential (e.g. Brazil, India, and Morocco). It can also explore the opportunities of cross-country financing programmes that have a potential in scaling up the size of renewable projects and reducing finance costs, which could be particularly effective in the case of capital-intensive offshore wind projects.

3. **Developing UK industrial CCS and hydrogen infrastructure.** The UK could further accelerate the introduction of industrial clusters, CCS, and hydrogen infrastructure. The UK has a distinct advantage in CCS potential compared to other countries due to the high availability of usable CO_2 storage sites for CCS infrastructure (70GtCO_2, equivalent to the EU's combined storage capacity[42]) as well as having existing oil and gas expertise. With more than 60% of modelled hydrogen use outside the leadership regions by 2050, the UK has clear opportunities in developing early domestic markets, as in the offshore wind case, first through blue hydrogen infrastructure while facilitating long-term cost-reductions of green hydrogen and deployment elsewhere in the world.

4. **Leading on developing a net-zero framework and pathway for aviation.** Being among the five largest CO_2 emitters from passenger flights[43], the UK is in a position of developing a leadership position in the aviation sector by establishing detailed binding commitments and targets, in line with the CCC's net-zero pathway, that include international aviation emissions. Internationally, this means that the UK could also lead on coordinating how CORSIA can successfully interact with domestic climate targets and result in genuine emissions reductions and removals that avoid double counting under CORSIA and Paris Agreement targets (Carbon Market Watch, 2017). Further, it can leverage the UK aviation sector's commitment to 2050 net-zero carbon emissions to persuade IATA to match this ambition. Finally, it can lead on establishing international standards for sustainable aviation fuels, to ensure their genuine sustainability, and then on creating cross-country coalitions developing the large-scale supply of cost-competitive SAFs.

5. **Developing GHGs removals incentives and sustainability standards.** The UK's strong institutional capacity, a large number of CCS sinks, and established innovation ecosystem (e.g. £31.5m Greenhouse Gas Removal Demonstrators Fund[44] and up to £100m of forthcoming R&D funding for Direct Air Capture technology[45]) makes it well placed to further increase the number of active demonstration projects of BECCS, DAC, and other GHGs removals. Further, with almost eight million tonnes of imported biomass in 2018[46] and a likely future role for BECCS in meeting net-zero targets, the UK could lead in the development of high sustainability standards that ensure low-carbon agricultural practices and sustainable land use elsewhere in the world. The UK is also in a strong position in leveraging its private sector's role, through their net-zero commitments, in the development of GHGs removals markets. Internationally, it has an excellent opportunity to lead cooperation on sustainability standards, introduction of effective government financing mechanisms (e.g. Environmental Land Management payments for forestation), as well as inclusion of GHGs removals in carbon markets.

6. **Green recovery and greening the UK financial sector.** As for green recovery efforts, the UK could consider the introduction of innovation and commercialisation funds in areas like buildings, industrial, and transport decarbonisation. Through its G7 and COP 26 presidencies in 2021, it could also play a prominent role in forming alliances together with other key players (e.g. EU or China) and encouraging others to commit to green recovery measures. Through international organisations, the UK could push for green conditions to any finance packages to developing countries. In terms of the

[42] UK Parliament (2019) Carbon capture usage and storage: third time lucky?
[43] International Council on Clean Transportation (2019) Not every tonne of aviation CO_2 is created equal
[44] UKRI SPF Greenhouse Gas Removal Demonstrators
[45] UK Prime Minister Press Release (2020) A New Deal for Britain
[46] ONS (2019) A burning issue: biomass is the biggest source of renewable energy consumed in the UK

financial sector, the UK can further increase its efforts to green its domestic financial sector through accelerated transition to binding TCFD requirements. As a world leader on cross-border lending (18% of global market share in 2018[47]), the UK could also scale up its efforts in green cross-border capital flows by expanding the Green Finance Institute's existing partnerships to other markets. Internationally, the UK ICF programme could further leverage private finance commitments in critical areas (power, transport, and agriculture and land use) and regions with the most cost-effective potential, leading to stronger private sector capital flows financing these transitions in the medium-to-long term.

4.3 Potential UK opportunities across sectors to unlock the leadership-driven scenario

4.3.1 Power sector

The UK's role in enabling a global transition to a low-carbon power sector has been already substantial, with particular strengths in demonstrating net-zero pathways and overseas financial support:

- Demonstrating net-zero pathways: The UK's domestic progress in the power sector has been a clear leadership example of feasible and cost-effective decarbonisation through the combination of market design reforms incentivising renewables deployment. In particular, the UK is a global leader in offshore wind technology, with a share of 36% of the global offshore wind market, by 2017 installed capacity, and the UK has been increasingly looking for export opportunities in this market (Catapult, 2018). In March 2020, the UK Government put forward a sector deal that aims to increase offshore wind exports fivefold to £2.6 billion by 2030 (BEIS, 2020). Further, the UK has been actively engaging in international R&D collaborations in batteries (Faraday Battery Challenge) and solar PV (SUNRISE project in collaboration with India and Egypt).

- Overseas financial support: Alongside other developed countries, the UK committed to jointly mobilise $100bn per year in climate finance to developing countries from public and private sources as part of the Paris Agreement. As part of this, the UK has in place an International Climate Finance programme that has responsibility for investing £5.8bn between 2016 and 2021. Over the period of 2011 and 2018, the ICF programme has resulted in the installation of 1,600 MW of clean energy technology such as wind, solar, geothermal, and other clean energy technologies through 23 programmes, avoiding 16 $MtCO_2e$ (UK Government, 2019). The UK have also recently ended its financial support for unabated coal power generation.

- Overseas capacity building: The UK has been an active member of intergovernmental organisations such as the IRENA that, among other things, provides Renewables Readiness Assessments, conducted in partnership with governments and regional organisations, to help boost renewable energy development on a country-by-country basis. Domestically, the UK's Offshore Renewable Energy Catapult has been involved in addressing technical and engineering challenges in the Chinese market. As part of the ICF programme, the UK has also established a £60m bilateral capacity building programme PACT (Partnering for Accelerated Climate Transitions) that helps to build the capacity of high-emission, high-ambition countries to accelerate the implementation of their NDCs.

- Diplomatic influencing: the UK has jointly launched the PPCA with Canada and, more widely, has played an instrumental role in Paris Agreement negotiations as part of the EU block.

In order to fully unlock the leadership-driven pathway, the UK could explore further opportunities across these four channels through stronger coordination of international efforts. Recognising the UK's existing strengths, and reflecting our modelling results of identified leadership opportunities in the power sector, we see the UK's opportunities as follows:

[47] TheCityUK (2018)

- Demonstrating net-zero pathways: By mid-2030, the UK's domestic priority needs to be on delivering a fully decarbonised power sector at low cost in order to demonstrate to other countries its feasibility. This can be achieved through a further expansion of renewable power given the UK's large potential for a further 29-96 GW of onshore wind, 145-615 GW of solar power, and 95-245 GW of offshore wind (CCC, 2015; Vivid Economics and Imperial College, 2019). In turn, this can further help in reducing the cost of certain solutions, such as offshore wind, and thus allowing this to be a more cost-competitive option elsewhere in the world. Further, a rapid deployment and integration of variable renewables comes with systems challenges, such as intermittency, that needs to be balanced. The UK can exemplify effective solutions at the international level as these challenges will also be experienced by other countries shifting to net-zero power systems.

- Overseas financial support: Given the large amount of global renewables deployment in our scenario, the UK could target areas that still require public financial support to overcome the cost and other barriers using its ICF programme and wider programmes mobilising private finance. For example, providing a targeted concessional finance and grant scheme for feasibility and FEED studies for offshore wind developers in low- and middle-income countries is likely to be essential in the 2020s to drive down costs and make it a financially viable option. There is a significant potential for offshore wind in those countries, some 3.1 terawatts in Brazil, India, Morocco, the Philippines, South Africa, and Sri Lanka, which is about three times the installed electricity generating capacity of all EU countries (Dutton et al., 2019). Further, it could explore opportunities of cross-country financing programmes that have a potential to scale up the size of renewable projects and reduce finance costs, which could be particularly effective in the case of capital-intensive projects, such as offshore wind.

- Overseas capacity building: As discussed above, solar PV and wind are already mature technologies that are cost-competitive compared to fossil fuel-based power in most global regions. Thus, the UK could mainly focus on two aspects. First, it could target key countries by offering technical assistance on developing national strategies and implementation plans for solar PV and onshore wind deployment. Second, as shown in the case of the Belt and Road Initiative, the UK could explore leadership opportunities in establishing a global platform for green finance capability building that allows middle- and low-income countries to mobilise private finance in the solar PV and wind sub-sectors.

- Diplomatic influencing: Given the rapid shift from coal in our scenario, the UK could further lead on expanding the membership of the PPCA to include large coal users. As mentioned in Chapter 3, one way forward could be to agree on a tiered approach: first agreeing to no new coal; then eliminating old and inefficient plants; and finally guaranteeing a finite lifetime for the remaining coal-powered units (Center for Global Sustainability, 2020). Similarly, increased use of public and private sector financing could be conditional on countries' coal phase-out in bilateral agreements.

4.3.2 Transport sector

The UK government, as well as private actors, have been active in a number of policies and initiatives cross cutting the leadership channels that we have identified as important for global transport sector decarbonisation:

- Demonstrating net-zero pathways: *Road transport* - the UK Government has introduced a number of powers and packages supporting domestic development of EV infrastructure, including workplace and residential charging infrastructure funding (£200 million matched by private investors); rapid charging funding (£80m); and R&D funding (£40m) for new charging technologies (Vivid Economics, 2018). It has also set out a number of aspirations for zero emission HGVs, including the Low Emission Freight and Logistics Trial (£20m) and working with industry to develop ultra-low-emission vehicle (ULEV) standards for trucks. *Shipping* - the Clean Maritime Plan outlined the UK's pathway to zero emissions shipping, including a set of commitments to review non-tax incentives, renewable fuel obligations or potential of zero emission shipping clusters (Department for Transport, 2019). *Aviation* – the UK Government is

currently working on the Aviation Strategy for 2050 that may include aspects such as efficiency improvements; use of SAFs; or market-based measures (Department for Transport, 2020).

- **Diplomatic influencing**: The UK has been an influential member of the UN ICAO and played an instrumental role in securing the 2016 CORSIA agreement.[48] It has also been actively engaging on the Initial IMO Strategy to reducing total annual GHG from international shipping by at least 50% by 2050 compared to 2008 (IMO, 2018). Through its active role in the UN ICAO, the UK has helped in establishing CO_2 offset standards, the first worldwide scheme to address CO_2 emissions in a single sector (Department for Transport, 2020).
- **Leveraging the private sector's role**: The UK has leveraged the private sector's role mainly in terms of domestic action. This includes the private sector match funding initiatives such as the Charging Infrastructure Investment Fund, Advanced Biofuels Demonstration Competition, and Future Fuels for Flight and Freight Competition (Department for Transport, 2020).

There are a number of UK leadership opportunities to help transition the world to low-carbon transport. Depending on the state of decarbonisation solutions and existing international activities, we identify the following opportunities for the UK across different parts of the transport sector (Table 3).

Table 3 UK leadership opportunities in transport sector

Sectors	Road transport	Shipping	Aviation
Demonstrating net-zero pathway	Accelerate domestic transition to passenger EVs by reducing the total cost of ownership, expanding the charging infrastructure, zero emission zones, and providing education and communication campaigns Expand the role of zero emission zones as well as public procurement (Cambridge City Council, 2020).	Introduction of a low-carbon maritime sectoral deal given UK's comparative advantage Assess the feasibility of introducing a 2050 net-zero target	Detailed emission reduction roadmap to aviation incl. binding commitments and targets in line with the CCC's 6th carbon budget advice Following the lead of Norway and Sweden, mandate small blends of SAFs departing from UK territory
Diplomatic influencing	Expand the membership of the ZEV Alliance to other key regions; move from sharing expertise to coordinating phase-out and other regulatory trajectories	Through the IMO, lead on establishing a detailed international roadmap and feasibility assessment that shifts the leading countries from the current target of at least 50% by 2050 to reaching net-zero emissions by 2050	Lead on creating a cross-country coalition of airports to secure a large-scale supply of cost-competitive SAFs
Leveraging private sector global	Expand membership and scope of current initiatives (e.g. EV100) to leverage	Coordinate UK ports in joining the World Ports Climate Action Programme	Leverage UK aviation commitment to 2050 net-zero carbon emissions to persuade IATA to match this

[48] At present, 82 states (including the UK) have volunteered to join CORSIA from the start in 2021, representing over 75% of international aviation activity. From 2027 to 2035, the scheme will become mandatory, meaning that over the entire lifecycle of the scheme (2021 to 2035), it is estimated that approximately 2.5GtCO_2 will be offset (Department for Transport, 2020).

	private sector purchasing power Shift major logistics providers that own large HDV fleets to procure zero emission trucks by forming an alliance through existing industry partnerships (e.g. Smart Freight Centre)	following the suite of other large international ports[49]	ambition (Sustainable Aviation, 2020)
Trade measures	Coordinate on international standards for charging infrastructure Work alongside the EU in establishing a coalition of countries establishing CO_2 standards for new HDVs	Coordinate action between international ports on emission standards	Lead on establishing international standards for SAFs to ensure genuine sustainability of low-emission aviation fuels

Source: Vivid Economics

4.3.3 Industry sector

The UK has recently shown an increased activity in domestic efforts to achieve industrial decarbonisation through starting a number of initiatives and announcing several capital expenditure funds related to industrial clusters and CCS:

- **Demonstrating net-zero pathways**: the UK has recently introduced a number of decarbonisation initiatives, such as the Industrial Decarbonisation Challenge and, within that, the Industrial Clusters mission that aims to create at least one low-carbon industrial cluster by 2030 and a net-zero industrial cluster by 2040 (UK Government, 2019b). At the moment, the UK Research and Innovation (UKRI) has awarded funding to a number of studies looking to develop roadmaps to net-zero industrial clusters and to develop deployment plans for decarbonising industrial clusters (UKRI, 2020). The UK Government has also announced two decarbonisation funds for capital expenditure – the Industrial Energy Transformation Fund and the Industrial Strategy Challenge Fund. As regards industrial CCS, the UK Government awarded £26 million of innovation funding for nine projects in 2019 and, in the 2020 budget, has announced a CCS Infrastructure Fund of at least £800 million to establish CCS in at least two UK sites, one by the mid-2020s and a second by 2030 (UK Government, 2020a).

Building on the current domestic efforts, the UK has a number of opportunities for expanding the industrial decarbonisation efforts internationally. These include both domestic and international efforts across the key three channels of influence.

Demonstrating net-zero pathways: the UK can show leadership through domestic as well as international efforts:

- **It could further accelerate its industrial decarbonisation policies, including the introduction of industrial clusters, CCS, and hydrogen infrastructure**. Our leadership scenario suggests that the UK starts capturing 2MtCO_2 through industrial CCS in 2030, increasing to 5Mt and 9Mt by 2040 and 2050, respectively. The scenario reduces industry's direct emission by 21% by 2030 and by 57% by 2050 from the 2020 level, mainly through fuel switching and energy efficiency measures. The UK has a distinct advantage in CCS potential compared to other countries due to the high availability of usable CO_2 storage sites for CCS

[49] https://sustainableworldports.org/world-ports-climate-action-program/

infrastructure (70GtCO$_2$, equivalent to the EU's combined storage capacity[50]) as well as having existing oil and gas expertise. In terms of developing domestic hydrogen infrastructure, the UK has opportunities in developing early markets through blue hydrogen infrastructure while facilitating long-term cost reductions of green hydrogen infrastructure (Aurora Energy Research, 2020).

- **It can strengthen its leadership role by creating and expanding international platforms**. For instance, there are no international forums that are fully focused on coordinating government and industrial actions on steel decarbonisation and creating demand for low-carbon steel. Similarly, the UK can lead on expanding other international forums, such as the Global Concrete and Cement Association, from industry to governments. These, and other industrial sector forums, could play a direct role in coordinating international government-industry activities in technology testing and demonstration as well as coordination of market-creating policies, such as government procurement, voluntary buyer alliances, or carbon pricing. [51]

Trade measures: there are several opportunities for the UK to lead on, ranging from future trade deals to joining the EU BCAs efforts or establishing international coalitions leading on low-carbon standards and carbon pricing:

- **As an independent WTO member, the UK could make clean growth central to UK trade negotiations** by ensuring that the development of low-carbon industrial sectors is a prominent part of the future trade talks.[52] As part of multilateral discussions, the UK could join the initiative towards an Agreement on Climate Change, Trade Sustainability (ACCTS) led by New Zealand that aims for a first-of-its-kind agreement bringing together climate change, trade, and the sustainable development agenda.[53]
- **With respect to the current EU BCAs efforts, it is expected that climate, environment, and trade policy goals will be key parts of the UK-EU trade negotiations** (European Commission, 2020). The UK could be looking for opportunities in joining BCA development efforts with the EU and other ambitious countries by aligning with the EU BCA standards. Expanding the EU BCA to the UK could insulate the UK sectors from potential BCA-related costs and expand the BCA's worldwide impact on importers and other markets.
- **Alternatively, the UK could lead on coordinating a coalition of countries that work together towards a common set of carbon taxes and standards.** This could include aspects such as common industrial carbon taxes and the creation and tightening of regulations on embedded carbon in industrial products, such as low-carbon steel or green cement (Brookings, 2019).

Leveraging the private sector's global impact: as identified in the section on global leadership assessment (Section 3.3.3), there are opportunities to increase the private sector's role in industrial decarbonisation. The UK could, for example, lead on creating sectoral deals that commit to creating low-carbon supply chains, e.g. low-carbon steel used in the production of wind turbines. It can also lead on establishing and widening existing industry initiatives, similar to the EV100 initiative, in which corporate members commit to procuring low-carbon industrial products and greening their supply chains. Finally, it can follow the examples of other countries in establishing cross-country joint venture partnerships with the private sector to scale up and de-risk the initial demonstration projects.[54]

[50] UK Parliament (2019) Carbon capture usage and storage: third time lucky?
[51] "The critical actions needed today require the joint efforts of national governments and the steel supply industry, which at present have no institution for reliable coordination of purchases of low-carbon steel, and one incumbent organisation (The World Steel Association) focused on supply." (Brookings, 2019).
[52] As an immediate next step, the UK could actively support the growing number of WTO members in favour of a WTO Ministerial Statement on environmental sustainability and trade (Chatham House, 2020).
[53] The key areas include the elimination of tariffs on environmental goods and new commitments on environmental services; disciplines to eliminate fossil fuel subsidies; and development of guidelines for voluntary eco-labelling programmes and associated mechanisms to encourage their promotion and application (New Zealand Foreign Affairs and Trade, 2020).
[54] Such as the HYBRIT initiative of deploying hydrogen in steel production.

4.3.4 Buildings sector

UK action in the decarbonisation of buildings so far has been limited both domestically and internationally. Efforts have been concentrated around the development of a net-zero buildings strategy nationally, while international coordination has so far been limited.

- **Demonstrating net-zero pathways:**
    - **Deployment of energy efficiency measures in buildings and low-carbon heat has been modest so far across the UK.** For example, less than 5% of heat in buildings comes from low-carbon sources at the moment. The Renewable Heat Incentive (RHI) provides a subsidy for buildings that use renewable heat technologies and was allocated £4.5 bn of government support for 2016-2021 (BEIS, 2017), but it fails to address the upfront capital cost barrier, which has led to low deployment rates so far. Government announced the publication of an updated Heat Roadmap in 2020 (UK Government, 2020b), as no detailed plan is currently available to achieve decarbonisation of heat in the UK. Scotland is an exception in terms of advancing comprehensive trajectories for energy efficiency in buildings, with more stringent targets supported by specific steps for implementation (CCC, 2019b).
    - **The Clean Growth Strategy and recent government pledges provide a promising starting point for action on energy efficiency and low-carbon heat**, pointing towards the ambition to convert all existing homes to EPC band C standards by 2035 and advocating the phase out of all installations of fossil fuel heating systems in properties off the gas grid in the 2020s. Recent government statements give hope for new policy developments in buildings' decarbonisation: this includes the introduction of world-leading standards of energy efficiency by 2025 (UK Government, 2019c) or the £3bn Government pledge of funding to help improve energy efficiency in people's homes and public buildings, including schools and hospitals[55].
- **Diplomatic influencing:** Scotland and the City of London are signatories of the World Green Building Council, a global network bringing together government and industry leaders and promoting the transformation towards a net-zero carbon and sustainable built environment, but the rest of the UK has not confirmed its membership of the Council.
    - **Leverage private sector role:** The UK Green Building Council network is a platform that brings together over 400 organisations in the UK building industry with the aim of improving the sustainability of the built environment by influencing government and business leaders within the sector. The network is part of the World Green Building Council, which offers access to international best practices, global projects, and international events on the built environment.

The UK has many opportunities to help unlock a leadership-driven pathway in the buildings sector through both domestic actions and international commitments. Based on the UK's current efforts in decarbonising the building stock and taking part into international alliances, we have identified the following opportunities:

- **Demonstrating net-zero pathways:**
    - Domestically, the UK could aim to strengthen and extend current targets and commitments on the new and existing building stock, providing a structured roadmap of targets and policies. These include incentivising the use of low-carbon heat to move from the current 4.5% to a 90% share by 2050 (CCC, 2019c), setting a clear trajectory of standards meant to ensure that all homes built from 2025 are not connected to the gas grid and follow the highest energy efficiency standards, and providing clear guidelines on how to make all houses energy performance certificate (EPC) band C by 2035.

[55] https://www.gov.uk/government/news/rishis-plan-for-jobs-will-help-britain-bounce-back

- ◊ **Agencies across the research and innovation spectrum, such as UKRI, could continue and expand the development of demonstration projects and strengthen international partnerships.** For example, Mission Innovation, a global initiative working on clean energy innovation, is working on developing low-carbon affordable heating and cooling solutions through a project where the UK is a co-leader. Once developed, these innovative solutions can become part of international standards and deployed at scale.

- ◊ **The UK Government could support the creation of markets for zero-carbon buildings through more stringent standards for public procurement**. Associated investment could enable the upskilling of specialised personnel in charge of monitoring compliance with standards and the installation of new low-carbon technologies.

- **Diplomatic influencing: the UK could become a member country of the Global Alliance for Buildings and Construction and extend its membership to the World Green Building Council (WGBC) to the entire UK territory.** The scope of such platforms could be extended to include the development of standards (e.g. energy codes for new buildings, efficiency of heating and cooling systems) and measurements of buildings' energy performance, in line with the best available processes and technologies for zero-carbon buildings. These platforms could become a valuable forum to coordinate global effort on the decarbonisation of buildings and commit members to ambitious climate targets. For example, the Net Zero Carbon Buildings Commitment for the WGBC commits signatories to making all new buildings net-zero carbon by 2030 and retrofit existing ones by 2050.

- **Trade measures: The UK could use bilateral and regional trade deals to make clean growth central to its strategy**. BCAs could help price in emissions from carbon-intensive materials, such as cement, iron and steel, currently used in the construction sector and incentivise the use of alternative low-carbon materials, more efficient structural design, or the increased use of recycled or re-used components (Giesekam, 2018).

- **Leverage private sector impact: The UK can facilitate and incentivise the creation of voluntary coalitions within the private sector.** Companies in the building sector can commit to using low-carbon steel and cement in their operations, while businesses can commit to operating in buildings of the highest efficiency standards and to buying low-emission heating and cooling technologies for their buildings. Such coalitions would both create demand for low-carbon products and help meet zero-carbon targets in buildings. The UK Green Building Council is a promising starting point to leverage private sector impact, but a higher number of members and binding targets and commitments are necessary to bring forward change in the sector.

4.3.5 Agriculture and land use

The UK has implemented a number of reforms and undertaken initiatives aimed at reducing GHGs emissions from the agriculture and land use sector. The leadership channels where the UK's activity has been strongest so far are, among others, the demonstration of net-zero pathways and overseas financial support:

- Demonstrating net-zero pathways: The UK has developed emission reduction plans for the agriculture and land use sector, namely the Department for Environment, Food and Rural Affairs (Defra)'s Farm Emissions Reduction Plan and Scotland's Climate Change Plan. The UK has also funded numerous innovation projects within this space. For example, UKRI's Transforming Food Production Challenge made up to £90 million available to help researchers and industry transform food production and move towards net-zero emissions. The UK has also designed a number of payments for ecosystem services that are in place or set to come into force. Among these, the Environmental Land Management system (ELM) detailed in the 2018 Agriculture Bill is designed to pay public money for a range of public environmental goods. This, together with other Government schemes such as the Woodland Creation Scheme, should significantly increase the rate of tree planting across the country. However, current afforestation rates of around 13,400 ha/year still fall short of Government's stated ambitions for 20,000 ha/year (CCC, 2019b).

- Overseas financial support: The UK has been a driving force in green finance initiatives and has shown its leadership on several occasions, such as by co-chairing the G20 Green Finance Study Group and being a founding member of the Network for Greening the Financial System. Together with other developed countries, the UK has pledged to raise $100 billion annually to foster climate action in developing countries. On its part, Government has committed to spending £5.8 billion between 2016 and 2021 on climate finance activities through the ICF, jointly managed by BEIS, Defra, and the Department for International Development (DfID) (CCC, 2019c). In the space of forestry and land use, the UK has shown a longstanding support for the UN REDD+[56] initiative, focusing on emissions reductions from deforestation and forest degradation in developing countries. Together with Germany and Norway, the UK has been the largest contributor of climate finance in this area (Brookings, 2019).

The UK has several opportunities to scale up its decarbonisation efforts in agriculture and land use both domestically and internationally. Opportunities can be identified across many channels of international leadership.

- **Demonstrating net-zero pathways:** the UK can accelerate its decarbonisation efforts in the agriculture and land use sector through domestic policy initiatives and partnerships with the private sector. For example:
    - The UK could lead the domestic creation of a market mechanism (**Emissions Trading System (**ETS) or auctioned contracts) to support woodland creation (Global Resource Initiative, 2020). Forest carbon and nature-based credits would need to meet high environmental and social integrity standards, tackle forest governance concerns, and could be also linked to existing carbon markets. The ELM framework that will shortly be piloted in the UK can help identify the actions that qualify as credits. Once the mechanism is developed and well-functioning domestically, other countries can follow by creating their own market and linking it to the UK one. In this scenario, London could become the centre of a high-intensity carbon trading market by leveraging its position as a global financial centre.
    - **Through its leadership in technology and innovation on the ground, the UK is well-placed to extend this position to innovation in agriculture and land use**, by increasing support to the production of sustainable agricultural and forestry supply chains domestically. The UK could also showcase the development and deployment of the most advanced monitoring techniques (e.g. satellite imaging, soil carbon monitoring) to ensure sustainability of domestic biomass and related supply chains.
    - **The UK could expand the domestic market for sustainable products by strengthening public procurement requirements and reinforcing the mandatory due diligence obligations on business.** Being a major purchaser of food and catering services for schools, nurseries, hospitals, canteens, prisons, the military, and others, the UK Government could lead by example domestically during this process.
- **Diplomatic influencing: The UK could lead the creation of a widely recognised forum of international cooperation in the areas of agriculture and land use**. CGIAR is currently the world's largest network on agricultural innovation, coordinating R&D spending and sharing best practices across countries. Its scope could be extended to include sustainable and innovative agricultural practices and efficient farming, soil carbon sequestration practices, prevention of deforestation, and reallocation of agricultural subsidies. The UK is both one of the 20 voting members and one of the funders of CGIAR, and therefore could leverage its position to drive change.
- **Trade measures: these include measures such as the creation of trade coalitions against products grown unsustainably and the implementation of strict standards that regulate trade in agricultural goods**. With

[56] Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries

47% of food consumed in the UK being produced overseas, the UK could exert its purchasing power and influence the production methods of key importing countries.[57] For example:

- **The UK could lead a coalition of consumer countries, leveraging their purchasing power, against the trade of products that contribute to deforestation**, helping combat illegal logging and regulate the forest industry internationally. Plans to form a coalition of developing countries at COP 26 against the illegal timber trade have already been announced and will focus on strengthening the rule of law in affected developing countries, influencing international partners to increase efforts, and supporting responsible trade on the ground (*The Guardian*, 2020).

- **The implementation of import standards for biomass can be streamlined and extended to new participants through specific clauses in trade agreements**. The UK government already engages in activities that support sustainability of biomass imports, but these could be brought together in a more transparent way. A holistic and integrated approach to promote forest governance globally is provided by the EU Forest Law Enforcement, Governance and Trade (FLEGT) action plan (CCC, 2018).

- **The UK could create a sustainable commodity import guarantee scheme to incentivise increased use of sustainable agricultural practices**. By creating a cost differential for sustainably sourced commodities as compared with conventional commodities, this scheme could provide a powerful incentive for more companies to adopt sustainable practices and embed processes that verify the sustainability of their supply chain (Global Resource Initiative, 2020).

- **Overseas financial support: The UK could leverage its position as a driving force in green climate finance to lead international efforts in the provision of financial support for agriculture and land use to developing countries**. For example, the UK could lead a coordinated action to deploy climate finance through (i) targeted support to producer countries for implementing sustainable production methods, and (ii) through investment in restoration of areas under protection and modernisation of agricultural systems in developing countries. Climate finance efforts could be paired with the launch of a blended finance facility in order to mobilise capital at scale in support of sustainable land use and forests through public-private collaboration (Global Resource Initiative, 2020). London is a privileged spot to start this process as headquarter of many international financial institutions.

4.3.6 Engineered GHGs removals[58]

The UK's relative strengths in innovation and market design policies are particularly relevant to the longer-term demonstration and deployment of engineered GHG removal technologies. Domestically, the UK has strong institutional capacity and is well placed to take a lead in areas that need innovation in support mechanisms, such as CCS or removals. The UK has an established innovation system and one BECCS pilot plant built by DRAX in place. At international level, the UK has shown a leading role in establishing the Mission Innovation initiative and has recently announced that it will provide access to £1 billion of aid funding to research, develop, and demonstrate technologies and business models that enable developing countries to transition towards clean energy solutions (UK Government, 2019d). The UK also leads overseas collaborations on CCS research with other countries, such as the UK CCS centre in collaboration with South Korea, Canada, Australia, the Netherlands, China, and the USA.

In terms of domestic opportunities to demonstrate the net-zero pathway, the UK's established innovation ecosystem makes it well placed to further increase the number of active demonstration projects of BECCS and other engineered removals. These projects can be supported by R&D expenditure in partnership with other countries and/or private sector match funding, through initiatives such as Mission Innovation, and collaborations with overseas research centres aimed at sharing knowledge on CCS.

[57] Defra (2020) Food statistics in your pocket
[58] This assessment is largely based on Vivid Economics (2019b).

The UK's strong institutional capacity puts the country in a favourable position to lead on the development of frameworks to support the deployment at scale of BECCS with high sustainability standards and the establishment of GHGs removals markets. These frameworks can include:

- **Market-based mechanisms:** contract for difference schemes linked to electricity prices for BECCS in electricity generation and linked to the ETS price for industrial BECCS to reduce volatility of investment. The UK is already using CfDs contracts in the space of renewable energy and has the expertise to extend them to other technologies.
- **Tax incentives:** tax credits for £/tCO_2 of GHG removed and any capital investment in GGR to incentivise GGR deployment. The tax can be combined with a carbon levy specifically designed to fund the GGR tax credits.
- **Business obligations:** GGR obligations schemes, where companies are required to secure negative emission certificates to meet their obligations, fixed as a % of emissions associated with production. A connected trading scheme would allow entities that do not invest in sufficient GGRs to purchase certificates from entities that have surplus negative emissions certificates.

The UK is also in a strong position to leverage its private sector's global role in the development of GHGs removals markets. There has been an increased interest from UK companies in defining net-zero targets conditional on using offset options.[59] The UK private sector's ambition could eventually help stimulate sustainable GHGs removals markets but this would need to be supplemented with sufficiently robust criteria applied to the allowable removals (this is linked to trade measures discussed above).

Further, the UK has an excellent opportunity to lead on international cooperation. The UK could play a leading role in international innovation, both to develop robust accounting methods for UNFCCC reporting, and to develop the technologies themselves, leveraging its existing technical partnerships on CCUS technology development with countries such as South Korea, China, and Canada (UK Government, 2020c).

As for the trade-related actions, the UK has an opportunity to lead on developing options to link international trading schemes and inclusion of engineered GHGs removals. As its domestic trading scheme matures, it could be linked to other international GGR trading schemes. Linking with established trading schemes is also possible, although accounting challenges will likely prevent linking with large emissions trading schemes.

The UK's large-scale deployment of BECCS will require strong supply chain management practices in place so that it does not threaten wider sustainable development goals. Our leadership scenario assumes 79MtCO_2 are captured by UK BECCS plants by 2050. Thus, the UK would need to ensure that any biomass imports are sustainably sourced through work with partner countries.

4.4 UK cross-cutting leadership opportunities

The UK is also well placed to lead by example in two cross-cutting areas – green recovery and greening the UK financial sector. Pursuing these opportunities would allow greater acceleration in both domestic and international decarbonisation efforts through a combined effort of government and private sector activities.

4.4.1 Green recovery opportunities

The current pandemic crisis has led to a number of major economies introducing economic stimulus packages that, however, have largely failed to ensure that these measures lead to a more sustainable future. Across 16 major economies, announced economic stimulus packages will pump approximately $2.2 trillion directly into sectors that have a large and lasting negative impact on nature. These flows present an

[59] https://www.corporateleadersgroup.com/

opportunity to support these sectors through the current COVID-19 crisis, while also increasing their sustainability and resilience in the face of the parallel climate and biodiversity crises.[60]

An exception to this trend has been the stimulus packages in parts of Western Europe, which offer more promise. At least a portion of spending in France and the UK is likely to be nature-friendly. France and the UK benefit both from less environmentally intensive economies and their decisions to retain more stringent regulations and policies. At the same time, they have also steered some stimulus measures to drive nature-friendly outcomes.

Reflecting on our leadership channels, the UK has a further opportunity to steer the green recovery both domestically and internationally. Some of the examples include:

- **Demonstrating net-zero pathways**: Following some of the recent pledges, such as the £3 billion green investment package that could help support around 140,000 green jobs and upgrade buildings and reduce emissions[61], the UK could consider an introduction of further innovation and commercialisation funds in areas like industrial and transport decarbonisation and low-carbon heat. For example, the EU innovation fund[62] and the introduction of the Clean Hydrogen Alliance appear as promising steps in the commercialisation of green hydrogen (Euractiv, 2020).

- **Diplomatic influencing**: The UK could play a prominent role in forming alliances together with other key players (e.g. EU or China) and encouraging others to commit to green recovery measures. The UK presidencies of both COP26 and the G7 in 2021 present a clear opportunity for the UK to influence stimulus efforts in other regions towards climate mitigation measures.

- **Leveraging the private sector's and non-state actors' roles**: Through its role in international organisations, the UK could push for green conditions to any finance packages to developing countries. For example, the UK could make sure that IMF lending and grants are conditional on accelerated climate mitigation efforts and that debt relief is tied both to accelerating existing commitments to extend protected areas and to forest restoration projects (Vivid Economics, 2020).

4.4.2 Greening UK financial sector opportunities

The UK has been one of the global leaders in greening the financial sector. Some of the key recent activities across the public and private sector include:

- **International Climate Finance:** Since 2011, the ICF has mobilised £1.4 billion of private finance and £3.8 billion of public finance in key sectors including forestry and land use, industrial decarbonisation, sustainable infrastructure, and energy transitions (UK Government, 2019a).

- **Bank of England (BoE)**: The BoE carries out ongoing work to include climate change factors into macroeconomic analysis and macro financial decisions.[63] In 2020, the BoE published the first climate-related financial disclosure which defines the bank's approach towards accounting for climate change risks into its operations. The Bank regularly publishes progress reports on the impact of climate change on the banking and insurance sector. The Bank has recently included climate change risk into its stress testing frameworks. Together with the Bank of China, BoE committed to promoting the global consensus on green finance and green investment (UK Government, 2015). Its former Governor, Mark Carney, has often provided international leadership in developing national and international action on climate change through the financial system.

- **UN Principles for Responsible Investment (UN PRI):** The world's leading proponent of responsible investment, UN PRI, is headquartered in London. The PRI was established in 2006 and it now has more

[60] https://www.vivideconomics.com/casestudy/greenness-for-stimulus-index/
[61] https://www.gov.uk/government/news/rishis-plan-for-jobs-will-help-britain-bounce-back
[62] https://ec.europa.eu/clima/policies/innovation-fund_en
[63] https://www.bankofengland.co.uk/climate-change

than 3,000 signatories, for a total of over $100 trillion of assets under management. Its mission is to encourage the creation of a sustainable financial system by incorporating Environmental, Social and Governance issues into investment analysis and decision making and seeking appropriate disclosure of assets' sustainability profile.[64]

- Green Finance Initiative (GFI): Launched in 2016 by the City of London Corporation and the UK Government, GFI is a taskforce aimed at providing recommendations for delivery of the public and private investment the UK needs to meet carbon budgets and related environmental goals, and maximise the UK's share of the global green finance market (UK Government, 2019e). The focus so far has been on improving the flow of projects that generate green bonds and inform market participants about the opportunities and standards of green finance products (Green Finance Initiative, 2016).

- Green Investment Bank: (GIB) Established in 2012 by the UK Government, it was the first publicly funded bank in the world designed specifically to mobilise private finance into the green energy sector. Between 2012 and 2017, the GIB helped to finance more than £12bn of UK green infrastructure projects. After being acquired by Macquarie Group Limited, it now operates as the Green Investment Group.[65]

- London Stock Exchange Group (LSEG): Now a hub for sustainable finance globally, the LSEG totals £55 billion of market capitalisation of 74 green economy companies listed there. More than 200 Green, Sustainable, and Social bonds have been issued in London, raising more than £33 billion. The Global Green Finance Index ranks London as the top hub for green finance.[66]

However, as noted in the 2019 UK Government Green Finance Strategy, further actions need to be taken to align private sector financial flows with environmentally sustainable growth. For instance, only 10% of UK banks are taking a long-term strategic approach to managing the financial risks from climate change (Bank of England, 2018), and the total global and domestic value of outstanding green bonds is only a fraction of the financing required. Two of the Strategy's three pillars show potential to unlock both domestic and international efforts: [67]

- 'Greening finance': the UK Government expects all listed companies and large asset owners to make disclosures in line with the TCFD recommendations by 2022. It will work with industry and the British Standards Institution to develop a set of Sustainable Finance Standards and with the Financial Conduct Authority and Bank of England to tackle barriers to the growth of green finance markets.

- 'Financing green': Domestically, the UK plans to announce a package of measures to mobilise green finance for home energy efficiency and it will work with the GFI to address market barriers to greater and more rapid deployment of green capital into priority sectors. Internationally, it plans to continue its efforts through the ICF (see above) and has been working with governments such as China, Brazil, and Mexico to develop green finance markets through the UK PACT[68] programme.

Based on sectoral pathways and UK leadership opportunities, the role of the UK's green finance sector can be particularly effective through the following leadership channels and sectors:

- Overseas financial support: the UK ICF funding could further accelerate transition from coal to renewables, which will be critical in the early 2020s based on our scenario. It could also expand its role in other areas where financing is a key market barrier, such as agriculture and land use (see Section 4.3.5).

- Leveraging private sector impact: Domestically, the UK can further increase its efforts to green its domestic financial sector through, for example, accelerated transition to binding TCFD requirements. As

[64] https://www.unpri.org/
[65] https://greeninvestmentgroup.com/
[66] https://www2.lseg.com/sustainablefinance
[67] The third pillar – capturing the commercial opportunity –largely focuses on the domestic opportunities and therefore is not considered as a key pillar in driving international action (UK Government, 2019e).
[68] UK PACT (Partnering for Accelerated Climate Transitions) is a £60m flagship programme under the International Climate Finance (ICF) portfolio.

a world leader on cross-border lending (18% of global market share in 2018[69]), the UK could also scale up its efforts in green cross-border capital flows by expanding the Green Finance Institute's existing partnerships to other markets. Internationally, the UK ICF programme could further leverage private finance in key areas of our scenario. This includes financing of the power and transport sectors, as well as agriculture and land use mitigation options in the countries showing most cost-effective potential. In the longer term, it could also support financing of GHGs removals through linking its emission trading scheme with other jurisdictions and introducing GHGs removal options within the trading markets (see Section 4.3.6).

[69] TheCityUK (2018).

5 Conclusions

This study has carried out an assessment of a global leadership-driven scenario towards meeting the Paris Agreement. In partnership with UCL, we have developed the leadership-driven global emissions scenario that has been shaped by several aspects including climate targets, such as net-zero regulation; market and technology drivers, such us the uptake of technologies based on cost; and policy drivers such as the phase-out of coal from power generation or the phase-out of internal combustion engines.

Alongside this assessment, we have developed the global leadership channels of influence that can accelerate the transition to this scenario. These leadership channels cover a wide range of activities, from demonstrating a net-zero pathway, to diplomatic influencing, trade measures, overseas capability and finance support, and leveraging the private sector's influence.

Across six main sectors, we have developed a detailed assessment of regional emission pathways, emission reduction measures, and global leadership opportunities. The key findings are:

- **Sectoral emission reductions**: the leadership group of countries sees the quickest reduction in GHGs emissions across all sectors except agriculture and land use. This is most pronounced in the power sector, where emissions reduce by 75% by 2030. The leadership group achieves substantial decarbonisation across most sectors by 2050. The agriculture and land use sectors are an exception – here, the HHD group of countries leads on the emission reduction in the short term and is followed by the MLHD group of countries by 2050.
- **Emission reduction measures**: In the short term, the main opportunities for emission reduction are continued decarbonisation of power sector (27% of 2020-2030 abatement), followed by increased deployment of emission reduction measures in the industry and transport sectors (20% and 12%, respectively). Agriculture and land use emission reductions can contribute with a further 14% of the abatement. Other non-energy measures can reduce emissions further.
- **Main global leadership opportunities**: across all sectors, the leadership opportunity is for countries to demonstrate the feasibility of a net-zero carbon pathway. This is because it can help reduce cost and non-cost barriers to other countries and, importantly, open up the role for other leadership channels such as diplomatic influencing or increased roles for private and non-state actors. In the short-to-medium term, a range of trade measure opportunities lie across most sectors. These include the introduction and development of common product and sustainability standards, as well as stronger alignment of trade policies with climate and sustainability ones. Finally, diplomatic influencing actions, through cross-country sectoral cooperation, and leveraging the private sector's impact, through net-zero and sustainability commitments, can play a role across most of the six sectors.

The UK has an opportunity to accelerate the transition to a Paris-aligned pathway in several ways. Based on current strengths and activities, it could mainly help the transition through the following actions:

1. **Evolving the Powering Past Coal Alliance to stimulate a coal phase-out by large coal users.** Our scenario requires a rapid global shift from coal (94% reduction by 2030). Thus, expanding and broadening the membership of the Alliance with large coal users (e.g. USA, China, Russia, and India) will be necessary. As a co-founder, the UK could further lead on this expansion given its domestic coal record. One way forward could be for the UK to propose a tiered approach: first with new members agreeing to no new coal; then eliminating old and inefficient plants; and finally guaranteeing a finite lifetime for the remaining coal-powered units. Similarly, further use of public and private sector financing could be dependent on countries' coal phase-out commitments.
2. **Expanding the global role of offshore wind.** As a global leader in offshore wind (36% of installed global capacity), the UK can expand the global role of offshore wind. With 17% of global technical

potential in European waters, the UK can help in accelerating large-scale domestic deployment of offshore wind as well as further reducing the technology costs. Internationally, it can provide a targeted concessional finance and grant scheme for feasibility and FEED studies for offshore wind developers in low- and middle-income countries with large technical potential (e.g. Brazil, India, and Morocco). It can also explore cross-country financing programmes that have a potential in scaling up the size of projects and reducing finance costs, which could be effective in the case of offshore wind.

3. Developing UK industrial CCS and hydrogen infrastructure. The UK could further accelerate the introduction of industrial clusters, CCS, and hydrogen infrastructure. UK has a distinct advantage in CCS potential compared to other countries due to the high availability of usable CO_2 storage sites for CCS infrastructure (70GtCO_2, equivalent to the EU's combined storage capacity) as well as having existing oil and gas expertise. With more than 60% of modelled hydrogen use outside the leadership regions by 2050, the UK has clear opportunities in developing early domestic markets for hydrogen, as in the offshore wind case. This could be done through developing blue hydrogen infrastructure first while facilitating long-term cost-reductions of green hydrogen and then supporting deployment of hydrogen elsewhere in the world.

4. Leading on developing a net-zero framework and pathway for aviation. As one of the five largest CO_2 emitters from passenger flights, the UK is in a position to develop a leadership position in the aviation sector by establishing detailed binding commitments and targets, in line with the CCC's net-zero pathway, that include international aviation emissions. This means that the UK could also lead on coordinating how CORSIA targets can successfully interact with domestic targets and result in genuine emissions reductions that avoid double counting. Further, it can leverage the UK aviation sector commitment to 2050 net-zero carbon to persuade IATA to match this ambition. Finally, it can lead on establishing international standards for sustainable aviation fuels to ensure their genuine sustainability and then creating cross-country coalitions developing large-scale supply of cost-competitive SAFs.

5. Developing GHGs removals incentives and sustainability standards. The UK's strong institutional capacity, CCS storage potential, and established innovation ecosystem (e.g. £31.5m Greenhouse Gas Removal Demonstrators Fund and up to £100m of forthcoming R&D funding for Direct Air Capture technology) makes it well placed to increase the number of demonstration projects of BECCS, DAC, and other GHGs removals. Further, with eight million tonnes of imported biomass in 2018 and a likely future role of BECCS, the UK could lead in the development of high sustainability standards that ensure low-carbon agricultural and sustainable land use practices elsewhere in the world. The UK is also in a strong position to leverage the private sector's role, through the sector's net-zero commitments, in the development of GHGs removals markets. Internationally, it has an excellent opportunity to lead cooperation on sustainability standards, the introduction of effective financing mechanisms (e.g. Environmental Land Management payments), or inclusion of GHGs removals in carbon markets.

6. Green recovery and greening the UK financial sector. The UK could consider an introduction of innovation and commercialisation funds in areas like buildings, industry, and transport. Through its G7 and COP 26 presidencies in 2021, it could play a prominent role in forming alliances with other key players (e.g. EU or China) and encouraging others to commit to green recovery measures. Through international organisations, the UK could push for green conditions to any finance packages to developing countries. In terms of the financial sector, the UK can further increase its efforts to green its domestic financial sector through accelerated transition to binding TCFD requirements. As a world leader on cross-border lending (18% of global market share), the UK could also scale up its efforts in green cross-border capital flows by expanding the Green Finance Institute's existing partnerships to other markets. The UK ICF programme could further leverage private finance commitments in critical areas (power, transport, and agriculture and land use) and the regions with most cost-effective potential, leading to stronger private sector capital flows in the medium term.

Appendix

This section covers some of the technical details related to our modelling framework and scenario definition aspects of the leadership-driven pathway. It includes:

- Further details on the overall modelling framework;
- Approach to extending the current ambition scenario (our reference scenario)
- Details on the leadership-driven scenario's modelling framework

Overall modelling framework

TIAM-UCL is a global energy system model that allows for scenario exploration of energy system evolution over time, including under climate targets.

The model framework uses a least-cost approach, but one which is subject to constraints. In this study, an approach that can be characterised as hybrid optimisation-simulation has been used, where the model has had additional constraints added, to prescribe specific low-carbon options.

The model provides a whole system representation of energy services demands and supply. This means that the interconnectedness of the system can be represented, including trade-offs and linkages between sectors and regions.

Energy service demands are exogenous inputs into the model and are often representative of one of the Shared Socio-economic Pathway (SSP) narratives, used by the Integrated Assessment Modelling community to allow for scenario comparison. In TIAM-UCL, these are dynamic and can rise or fall in response to changes in the cost of providing energy services.

Sectoral representation includes upstream resources, conversion, (electricity, hydrogen, biofuels) and end-use demand sectors (buildings, industry, transport and agriculture). To ensure full GHG accounting, other sectors such as land use and forestry are also included, albeit simply.

Regional representation sees the global system split into 16 regions. Some regions are single countries (China, India, USA, UK, Japan, South Korea, Mexico, Canada, Australia) while others are grouped into regions (e.g. Western Europe that excludes the UK).

Some non-energy sector emission sources are not explicitly represented in TIAM-UCL. These include:

- **Agriculture emissions**: the exogenously defined pathway represents CH_4 and N_2O emissions from a variety of sources. For the former, these include livestock, rice paddies, soil, agricultural waste burning on fields, savannah burning, and deforestation. The latter captures N_2O emissions from agriculture, including manure. The data needed to construct this pathway is from the International Institute for Applied Systems Analysis (IIASA) Representative Concentration Pathway (RCP) database[70] and then adapted to match the TIAM-UCL regional definition.
- **Land use emissions**: Emissions from land use, land use change, and forestry are exogenously defined using the Model of Agricultural Production and its Impact on the Environment (MAgPIE) developed by the Potsdam Institute for Climate Impact Research (PIK). The model determines the least-cost means of meeting food demand, while accounting for biophysical constraints including those on land, water, and crop yields. This framework explicitly models competition between varying land uses

[70] tntcat.iiasa.ac.at/RcpDb

such as forestry, bioenergy, and food crops. The model has been calibrated with the level of ambition used in the Inevitable Policy Response (IPR) project.[71] The project envisages the adoption of forceful climate mitigation policies that are consistent with limiting global warming to a maximum of 2°C with a 66% probability.

- Fluorinated gases: The exogenously defined pathway for fluorinated gases includes sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). Data has been drawn from the IAMC 1.5°C Scenario Explorer from the International Institute for Applied Systems Analysis (IIASA)[72] and then adapted to match the TIAM-UCL regional definition.
- Other non-energy emissions: Other non-CO_2 emissions that are exogenously prescribed in TIAM-UCL include CH_4 emissions from landfills, wastewater, and non-energy incineration as well as N_2O emissions from the adipic and nitric acid industries. Once more, the data for these pathways is drawn from the IIASA RCP database and they differ between the reference and the leadership-driven scenario.

The following table provides detail on all sectors covered in our modelling framework and the size of emission reductions observed in the leadership-driven scenario. The emission savings are derived based on comparing the leadership-driven scenario's emissions against the reference scenario.

Sectoral emission reduction across all sectors in the leadership-driven scenario

Main category	Sub-category	2020-2050 abatement, $MtCO_2e$
Industry	Industry - end use	-157,974
Transport	Transport - road	-97,323
Power	Heat and power - fossil	-89,271
LULUCF	LULUCF	-67,259
Engineered removals	BECCS	-44,782
Agriculture	Methane emissions in agriculture	-36,105
Buildings	Residential	-35,134
Transport	Transport - other	-31,566
Other	F-gases	-28,223
Other	Other methane sources	-25,922
Buildings	Commercial	-25,170
Agriculture	N_2O emissions in agriculture	-24,860
Other	Upstream	-16,264
Industry	Industry - cogeneration	-10,452
Industry	Industry - CCS	-8,510
Other	Biofuel production	-5,476
Other	Other N_2O sources	-5,452
Engineered removals	DAC	-320

[71] https://www.unpri.org/inevitable-policy-response/the-inevitable-policy-response-policy-forecasts/4849.article
[72] https://data.ene.iiasa.ac.at/iamc-1.5c-explorer/

Other	Hydrogen production	-20
Power	Heat and power - CCS	2,702

Source: Vivid Economics, TIAM-UCL

Approach to extending current ambition scenario

Description of key scenario assumptions

On the energy side, the TIAM-UCL model assumes the following aspects under the current ambition scenario:

- From 2020 to 2030: All countries meet their NDC commitments, which are aggregated up to TIAM-UCL regions. Countries which have both conditional and unconditional emissions targets for 2030 are assumed to meet a midpoint of their targets. For countries which assume an emissions reduction in 2030 against an unspecified baseline, then it is assumed that the country's baseline emissions grow in line with the average of others in the TIAM-UCL region. For a more detailed description of these assumptions in TIAM-UCL see Winning et al. (2019).
- From 2030 onwards: The post-2030 continued ambition for the ECA scenario is based on the assumption used in Fawcett et al. (2015) that the emissions intensity of the economy, from 2030 to end of the century, reduces at the rate of emissions reduction as observed during the NDC period. In particular, the regional GHG emissions per unit of GDP (SSP2 scenario aligned) continues, at the rate of emissions reduction between 2020 and 2030, beyond the 2030 commitments. However, if a region's reduction rate in that NDC period is below 2% p.a., or is increasing, then the emissions per unit GDP in that region peak in 2030 and reduce at 2% per annum after 2030.

Updated NDC ambition commitments for 2030 are included for three countries: Norway, Moldova, and the Marshall Islands. A fourth country, Suriname, has also updated its NDC but does not specify a 2030 emissions target, thus its NDC is not reflected in this analysis. At the time of writing another 103 countries have stated their intention to submit an updated NDC but have not yet done so. No commitments beyond 2030, i.e. net-zero by 2050, are assumed in the current ambition scenario. The total emissions in TIAM-UCL are in line with the UNEP Emissions Gap Report (UNEP, 2019) which provides a central median estimate of 54 (51-56)[73] $GtCO_2e$ and 56 $GtCO_2e$ (54-60)[74] for the conditional and unconditional NDCs, respectively.

The selected non-energy emission pathways have been based on the following assumptions:

Some non-energy sector emission sources are not explicitly represented in TIAM-UCL. Here we describe the pathways used in the reference scenario:

- Agriculture emissions pathway: the reference scenario is based on Representative Concentration Pathway (RCP) 6 for the NDC case.
- Land use CO_2 emissions pathway: the reference scenario is based on a multi-model average RCP 6 for the NDC case based on IMAGE, MESSAGE, REMIND, and WITCH models' data.
- Fluorinated gases pathway: the reference scenario is calculated as the median of the pathways above 2°C for fluorinated gases included in the IPCC database, drawn from the IAMC 1.5°C Scenario Explorer offered by the IIASA.
- Other non-CO_2 emissions pathway: the reference scenario is based on RCP 6 for the NDC case.

[73] 10th to 90th percentile
[74] 10th to 90th percentile

Details on leadership-driven scenario modelling framework

The 'leadership-driven' requirements rebalance the modelling from the global 'least-cost' scenario to a scenario that combines specific restrictions (see below) with the global requirement to meet the temperature goals in the Paris Agreement. Some of the main characteristics are:

- Climate constraint: this is modelled based on a global carbon budget of 960 $GtCO_2$, necessary to limit global temperature rise to 1.75°C based on a 50% likelihood (Rogelj et al., 2018). The climate module ensures the temperature rise is no greater than 1.75°C in 2100, with low overshoot of no more than 1.8°C.
- Demand drivers: population and GDP growth drivers are aligned to the Shared Socio-economic Pathway (SSP) narratives, namely the 'middle of the road' SSP2 case. This sees global GDP per capita increase fourfold, and population increase from 7.8 to 9.2 billion in 2050 and remain just over 9 billion for the rest of the century.
- Resource assumptions: bioenergy resource potential is capped at 110 PJ, a level which is reached in the post-2050 timeframe. Other resources, such as fossil fuels, are modelled in detail, based on significant model development (see McGlade and Ekins, 2015, and Welsby, 2020).
- Power generation: globally the growth of solar PV and onshore/offshore wind capacity is limited to 30% and 20% (onshore and offshore combined) per year, respectively. These key renewables are modelled with the following capital cost assumptions:[75]
    - Solar PV costs are ~430 $2005/kW in 2030 and ~290 $2005/kW in 2050 based on data taken from Bloomberg New Energy Finance (BNEF) and the IRENA.
    - Onshore wind costs are 1,000 $2005/kW in 2030 and 910 $2005/kW in 2050 based on estimates from IRENA/BNEF.
    - Offshore wind costs are 2,500 $2005/kW in 2030 and 1,590 $2005/kW in 2050 based on data from the National Renewable Energy Laboratory's Annual Technology Baseline 2019[76] and BVG Associates.
- Traded commodities: while TIAM-UCL has the capability to trade GHG offsets between regions, this is switched off. All regional mitigation is therefore undertaken within each region.
- Carbon capture and storage (CCS): CCS applications are available in the following sectors – electricity and heat production, hydrogen production, biofuel production (via Fischer Tropsch (FT) processes), and industry (for combustion emissions from process heat production in iron and steel, non-metallic minerals, and other industry sub-sectors). There is also a CCS technology that captures CO_2 process emissions from the use of petrochemical feedstocks. Biomass in TIAM-UCL, which can be used in combination with CCS to generate so-called 'negative emissions' (BECCS), is assumed to be carbon neutral, and while land use is considered here, there is no competition with other uses such as food production. Cost and performance information can be found in the Global CCS Institute report (Ekins, Hughes et al., 2017). Capture rates of 50-90% are assumed, depending on technology, with power generation at the upper end of this range and FT biofuel production at the lower end. CCS capacity can grow at between 2-5% per year (industry, and power at the upper end), starting from 2030.

Under these, and other TIAM-UCL model assumptions, the model cost-optimises by selecting the lowest cost GHG emission abatement options. The model is seeking to meet energy service demands (as per the SSP2 narrative) at the lowest discounted cost (at 3.5%), subject to a range of constraints. In these scenarios, key

[75] Note that these figures represent averages across the 16 regions in TIAM-UCL for brevity - during optimisation, the model executes with regionally specific costs.
[76] https://atb.nrel.gov/

constraints are the carbon budget and regional GHG targets, which change the selection of energy sector investments, factoring in their carbon intensity.

On the energy demand and supply side, the focus of the model is on the following abatement solutions across energy sectors:

- **Fuel decarbonisation and fuel switch measures**: fuel decarbonisation includes vectors such as heat, electricity, and hydrogen that are produced without the generation of GHG emissions. Switching concerns a move to such low-carbon vectors, or other lower-carbon fuels such as bioenergy.
- **Energy efficiency measures**: this includes the efficiency improvement over time from investment in new technology, or through retrofit of existing assets e.g. industrial plants, buildings. It is important to note that in the analysis undertaken here, the wedge size for efficiency (based on the difference between the current ambition and leadership-driven scenarios) is smaller than would be expected because of the significant take-up of efficiency measures in the current ambition scenario.
- **Demand reduction measures**: this concerns the price-driven demand response associated with consumers adjusting demand for energy services based on changes in price. Exogenous demand reduction based on the use of a different SSP narrative, for example SSP1 (as in Pye et al., 2019), has not been considered in this study.

A decomposition approach known as LMDI (logarithmic mean Divisia index method) has been applied to understanding the respective contributions of the above mitigation options. With respect to the power sector, this allows a more detailed understanding of emission reduction drivers, identifying the contributions of solar PV; wind power; other renewables; nuclear power; CCS in the power sector; and reduced energy efficiency and carbon intensity of fossil fuel-generated electricity. In particular, the TIAM-UCL team used a simplified version of the Mathy et al. (2018)'s method to break down the power sector into the following aspects: i) a growing demand for electricity, ii) reductions from a switch to cleaner generation[77], iii) efficiency of the fossil fuel sector, and iv) changing carbon-intensity of the fossil fuel sector (i.e. switch from coal to gas). This is done either globally or for a given region in the same way.

The following sections defines the key aspects of the leadership-driven pathway. These include climate targets, technology and market drivers, and policy drivers. The final section covers details of non-CO_2 pathways.

National climate targets

The country-specific climate targets reflect the fact that certain countries have, or are in the process of setting, ambitious 2050 emission targets. Some countries have enacted national net-zero GHG/CO_2 targets. Some of them are key global players that have strong responsibility for past GHGs and the capability to reduce emissions, such as the USA and Australia (see table below).

National emission targets assumed in the leadership-driven scenario

Country	2050 target
Australia	At least net-zero CO_2
Canada	At least net-zero CO_2
European Union countries	Net-zero GHGs emissions
Japan	At least net-zero CO_2
South Korea	At least net-zero CO_2

[77] This is linked to the reduction in fossil share of generation and the associated emissions reduction split-out based on the share of each non-fossil source. For example, if solar PV provides 20% of non-fossil generation it is attributed 20% of emissions reduction.

United Kingdom	Net-zero GHGs emissions
USA	At least net-zero CO_2

Note: The emission targets were based on input from the CCC.
Source: Vivid Economics

Defined policy trends

Coal phase-out[78]

The share of coal in electricity generation has begun to fall in developed economies but it remains the major source for electricity generation for most G20 countries. In EU countries, the share of coal in power generation has fallen from 40% in 1990 to less than 25% today. Asian countries are now responsible for the majority of coal-fired power generation, with China accounting for 85% of new coal power capacity since 2005.

Several factors are expected to contribute to phasing out of coal. The falling costs of gas-fired and renewable energy are pricing coal out of the electricity markets. Political action to curb carbon emissions from coal is growing – as evidenced by coal phase-outs announcements in Western Europe, Canada, and Chile. Coal demand is expected to come under pressure in China from the policy priority to improve urban air quality, supported by coal-to-gas switching in the industrial and residential sectors, a push for renewables in power generation, and ongoing restructuring of the economy. More than 100 financial institutions have already blacklisted coal producers.

Coal phase-out dates for different regions

Region/country	New electricity generation	Coal phase-out date
Western Europe, incl. the UK	No new electricity generation after 2020	2030 phase-out
China	No new electricity generation after 2025	2045 phase-out
USA	No new electricity generation after 2020	2030 phase-out
Canada	No new electricity generation after 2020	2030 phase-out
Australia and New Zealand	No new electricity generation after 2020	2030 phase-out
Japan	No new electricity generation after 2020	2030 phase-out
Mexico	No new electricity generation after 2020	2030 phase-out
India	No new electricity generation after 2025	2045 phase-out
South Korea	No new electricity generation after 2025	2045 phase-out
Other Developing Asia	No new electricity generation after 2025	2045 phase-out
Eastern Europe	No new electricity generation after 2025	2045 phase-out
Central and South America	No new electricity generation after 2030	Late phase-out
Former Soviet Union	No new electricity generation after 2030	Late phase-out
Middle East	No new electricity generation after 2030	Late phase-out
Africa	No new electricity generation after 2030	Late phase-out

[78] Based on UN PRI (2019). Inevitable Policy Response, policy forecast.

Note: These represent a minimum regional restriction in TIAM-UCL. The model can choose further reduction in coal use if it finds it cost-optimal.
Source: Vivid Economics, UN PRI (2019). Inevitable Policy Response

ICE phase out[79]

Electric vehicles still only represent a fraction of the fleet, but electric mobility is accelerating. ICE sales bans have been announced by national governments in the UK and the EU, and Asia is following suit. Cities are expected to drive national-level ambition. Other drivers include expected changes in consumer behaviour, pollution and health concerns, and the strategic development of strong EV industries. Based on current policy initiatives, announcements and expected trends, we assume regional ICE phase-outs as described in the table below.

ICE phase-out dates for different regions

Region/country	Expected ICE phase-out
Western Europe, including the UK	LDV sales phase-out by 2035, HDV sales phase-out by 2040
China	LDV sales phase-out by 2035, HDV sales phase-out by 2040
USA	LDV sales phase-out by 2040, HDV sales phase-out by 2045
Canada	LDV sales phase-out by 2040, HDV sales phase-out by 2045
Australia and New Zealand	LDV sales phase-out by 2040, HDV sales phase-out by 2045
Japan	LDV sales phase-out by 2040, HDV sales phase-out by 2045
Mexico	LDV sales phase-out by 2040, HDV sales phase-out by 2045
India	LDV sales phase-out by 2040, HDV sales phase-out by 2045
South Korea	LDV sales phase-out by 2040, HDV sales phase-out by 2045
Other developing Asia	LDV sales phase-out by 2040, HDV sales phase-out by 2045
Eastern Europe	LDV sales phase-out by 2040, HDV sales phase-out by 2045
Central and South America	LDV sales phase-out by 2040, HDV sales phase-out by 2045
Former Soviet Union	LDV sales phase-out by 2045, HDV sales phase-out by 2050
Middle East	LDV sales phase-out by 2045, HDV sales phase-out by 2050
Africa	LDV sales phase-out by 2045, HDV sales phase-out by 2050

Note: These represent a minimum regional restriction in TIAM-UCL. The model can choose more accelerated phase-out of ICEs if it finds it is cost-optimal. LDV – light duty vehicles; HDV – heavy duty vehicles
Source: Vivid Economics, UN PRI (2019). Inevitable Policy Response

Nuclear energy policy trends

Nuclear power has helped the decarbonisation of the power sector in advanced economies but is now expected to fade. Nuclear power currently represents 18% of total generation in advanced economies. However, given the low level of current investments, nuclear capacity in advanced economies could decrease by two thirds by 2040.[80] Based on current policies, we expect a varied role of nuclear energy across

[79] Drawn from UN PRI (2019). Inevitable Policy Response.
[80] Based on UN PRI (2019). Inevitable Policy Response.

the world regions. The table below summarises the expected share of nuclear generation out of total electricity generation.

Expected nuclear capacity trends across regions

Country/region	Share in power generation (%, 2018)	Share in power generation (%, 2040)
United States	8.7	5.3
Central and South America	1	1.9
Brazil	1.2	2.5
Europe, including the UK	10.9	6.2
European Union	11.8	6.8
Africa	0.8	1.2
South Africa	3.5	5.5
Middle East	0.3	2.2
Eurasia	8.8	9.8
Russia	10.9	12.6
Asia Pacific	3.8	3.3
China	2.5	3.6
India	1.7	2.1
Japan	11.4	8.6
Southeast Asia	0	0.3

Note: The 2040 power generation shares are used as a binding constraint in the TIAM-UCL for each region.
Source: Vivid Economics, based on IEA (2019g)

Defined market and technology drivers

Industrial decarbonisation: Whilst being one of the most challenging sectors to decarbonise, the IEA recognises a number of non-CCS solutions to reducing industrial emissions, ranging from the deployment of energy efficiency technologies, to material efficiency, fuel and feedstock switching to lower-carbon solutions (e.g. hydrogen) and other innovative technologies (IEA, 2019a). Given both the importance and challenge of decarbonising this sector, we use the IEA Sustainable Development Scenario with developed countries reducing emissions by 34% and developing countries by 28% over the period of 2018-2040.

Required industrial decarbonisation for different regions

Country/region	Emissions reduction required by 2050
North America	-50.3%
United States	-49.6%
Central and South America	-28.7%
Brazil	-32.3%
Europe, including the UK	-65.6%

Africa	31.1%
South Africa	-58.4%
Middle East	-30.5%
Eurasia	-46.0%
Russia	-57.4%
Asia Pacific	-54.3%
China	-85.5%
India	115.6%
Japan	-63.6%
Southeast Asia	2.9%
OECD	-57.7%
Non-OECD	-48.6%

Note: This represents the minimum level of emission reduction assumed in TIAM-UCL. The model is allowed to reduce emissions further if it finds it cost-optimal
Source: Sustainable Development Scenario taken from IEA (2019g), Annex A and extended to 2050

Deployment of CCS technology: to reflect current CCS infrastructure and market developments, we introduced an IEA Clean Technology scenario's storage capacity constraint of up to 115 $GtCO_2e$ captured over the period of 2030-2060. Thus, we delay a start of CCS global storage compared to the IEA analysis to reflect prevailing CCS deployment barriers (IEA, 2019b).

Buildings decarbonisation: Proven, cost-effective policy mechanisms exist, and have been successfully adopted in both developed and emerging economies. Thus, we use the IEA's region-specific Sustainable Development Scenario, which sees 65% direct emission reduction in advanced economies and 33% in developing economies over the period of 2018-2040.

Buildings decarbonisation for different regions

Country/region	Emissions reduction required by 2050
North America	-73.1%
United States	-73.9%
Central and South America	-12.9%
Brazil	-5.6%
Europe	-81.1%
European Union	-85.4%
Africa	41.9%
South Africa	-83.2%
Middle East	0.0%
Eurasia	-46.6%
Russia	-55.5%
Asia Pacific	-66.5%

China	-81.7%
India	-29.1%
Japan	-75.3%
Southeast Asia	-8.6%
OECD	-77.9%
Non-OECD	-43.9%

Note: This represents the minimum level of emission reduction assumed in TIAM-UCL. The model is allowed to reduce emissions further if it finds it cost-optimal
Source: Sustainable Development Scenario taken from IEA (2019g), Annex A and extended to 2050

5.1.2 Defined non-energy pathways

Agriculture emissions pathway: the leadership-driven scenario uses an agriculture emissions pathway based on RCP 2.6 for the climate policy case from the IIASA RCP database. This pathway includes various mitigation options to reduce non-CO_2 emissions from agriculture which include reducing CH_4 emissions by changing livestock diets, anaerobic digestion of animal waste, and changing water management in rice paddies. The N_2O options employed include improving fertiliser use efficiency, the use of lower emissions fertilisers, and dietary changes to reduce nitrogen excretion. For full details see Lucas et al. (2007).[81]

Land use emissions pathway: the leadership-driven pathway is defined using the MAgPIE developed by the Potsdam Institute for Climate Impact Research. The model has been calibrated with the level of ambition used in the IPR project. The project envisages the adoption of forceful climate mitigation policies that are consistent with limiting global warming to a maximum of 2°C with a 66% probability.

Fluorinated gases pathway: the pathway includes SF_6, HFCs, and (PFCs). Data has been drawn from the IAMC 1.5°C Scenario Explorer from the IIASA and then adapted to match the TIAM-UCL regional definition. The leadership-driven scenario has been calculated as the median of the IPCC scenarios below 1.5°C provided in the data platform mentioned above.

Other non-CO_2 emissions pathways: as for agriculture emissions, the leadership-driven scenario uses other non-CO_2 emissions pathways based on RCP 2.6 for the climate policy case from the IIASA RCP database.

[81] https://www.sciencedirect.com/science/article/pii/S1462901106001316

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Contact us

Vivid Economics Limited
163 Eversholt Street
London NW1 1BU
United Kingdom

T: +44 (0)844 8000 254
enquiries@vivideconomics.com