BEIS ICF Mitigation Investment Options: Synthesis Report

Final report prepared for BEIS
9 November 2020

:vivideconomics
Adam Smith International
Factor ideas for change
PBL Netherlands Environmental Assessment Agency

Contents

Acknowledgements

This research was conducted by Vivid Economics, in partnership with Adam Smith International, Factor and PBL. Vivid Economics led the project and analysis, with support from Adam Smith International and Factor who provided expert input and co-authored the Opportunity Assessment reports. PBL provided critical analysis on climate impacts, investment gaps and cost-effectiveness of mitigation measures through climate modelling using the IMAGE model.

Authors and contributing experts for the work include:

Organisation	Authors	Contributing Experts
Vivid Economics	Deven Azevedo, James Bragg, Maarten Hage, Nick Kingsmill, Aurore Mallon, Cor Marijs, Leire Sarasola, Shahbano Soomro, Bryan Vadheim, John Ward (Pengwern Associates)	Simon Dietz, Jason Eis, Sam Fankhauser, Alex Kazaglis, Penny Mealy
Adam Smith International	Andreas Beavor, Devanshi Gupta, Nicholas Haslam, Hans Verolme	Mansoor Ali, Alina Averchenkova, Ian Barrett, Adam Brown, John Cantrill, Federica Chiappe, Michael Cowing, Alekya Datta, Patrick Hardcastle, Gilberto Jannuzzi, Asier Larretxea Barja, Jon Macartney, Darius Nassiry, Katrina Pielli, Shri Prakash, Sharif Qamar, Milan Rusnak, Ian Tellam, Tali Trigg, David Shelley, Jan van den Akker, Maria Yetano
Factor	Iker Larrea, Craig Menzies, Asier Sopelana	Elena Aguirre, John Cantrill, Alexandre Fernandes, Germán García, Jiangwen Guo, Nils Hempelmann, Jules Siedenberg, Kepa Solaun, Paul Stevenson, Carolina Trimiño, Ángel Valverde, Maria Yetano
PBL		HsingHsuan Chen, Oreane Edelenbosch, Andries Hof, Nicole van den Berg, Kaj-Ivar van der Wijst, Detlef van Vuuren

The authors would like to thank the contributions of the UK BEIS steering group and all those who provided input and feedback throughout the process, guidance, the contributing experts who helped shape and steer the work, and all interviewees and workshop participants for contributing their time and expertise to this research.

Executive summary

Substantial action is needed in developing countries to achieve mitigation in line with the Paris Agreement global goals. The world is not on track to achieve Paris Agreement goals and limit global warming to well below 2 degrees Celsius, and a radical decoupling of emissions from economic growth will be needed. This calls for substantial investment in climate action – which will be costly (although more costly if deferred to the future), but which also offers unprecedented opportunities.

Building on its purpose to support transformational change, UK International Climate Finance (ICF) can continue to play a critical role in rapidly transforming markets in official development assistance (ODA)-eligible countries to catalyse public and private resources for aligning development with a 'well below 2 degree' warming goal. ICF can support climate change mitigation at the same time as stimulating growth and development through transforming markets with its portfolio of decarbonisation, private financing, forestry and land use, and partnerships and capabilities support. For ICF to support shifting the trillions that are needed, however, it will need to further realise its goal of achieving transformational change. Further realising this goal will require transformative climate finance investments that use a wide range of investment tools and supporting approaches to support enduring change and impact at scale.

This analysis provides BEIS with robust evidence to feed into the strategic approach to deploying UK ICF in support of global climate mitigation. The aim is support decision making about future UK Department for Business, Energy and Industrial Strategy (BEIS) ICF mitigation investments, with a particular focus on expanding BEIS's evidence base by focusing on areas of high importance where prior evidence or research within BEIS was (relatively) limited. For a set of 15 research priorities across the energy sector, the land use sector, transport and cross cutting technology and policy opportunities, the analysis identifies the mitigation potential, investment need, development co-benefits, cost-effectiveness, barriers that hold back autonomous action, and the UK's comparative advantage arising from its decarbonisation expertise and strengths in providing development assistance. Each opportunity area is considered using a consistent approach and against a common scoring rubric (below). The results of the assessment were validated through expert workshops and expert elicitation.

Scoring rubric for the opportunity criteria assessment

Climate impact	Development Impact	Investment gap	Cost-effectiveness	Barriers	UK Additionality
Mitigation & Transformational change potential	Number and strength of Sustainable Development Goal linkages	Current and forecast investment gaps	Relative cost to achieve equivalent levels of mitigation	Presence of barriers that limit autonomous action	Strength of UK expertise relative to other development partners
Higher potential	Stronger linkages	Larger gap	Higher effectiveness	Greater barriers	Higher additionality
Moderate potential	Moderate linkages	Moderate gap	Moderate effectiveness	Moderate barriers	Moderate additionality
Lower potential	Weaker linkages	Smaller gap	Lower effectiveness	Weaker barriers	Lower additionality

Source: Vivid Economics

Summary of criteria assessment findings

Opportunity	Climate impact	Development Impact	Investment gap	Cost-effectiveness	Barriers	UK Additionality
Variable grid renewables						
Non-variable grid renewables						
Energy storage						
Demand-side management						
Industrial decarbonisation policy						
Mass transit						
Passenger vehicles						
Forests						
Agricultural productivity						
Solid waste and wastewater						
Sustainable consumption						
Fiscal policy and Just Transition support						
Greening the financial sector						
Governance for transitions						
Climate intelligence and data						

Source: Vivid Economics

While the assessment of the 15 research priority opportunity areas identifies a diversity of opportunities with strengths in different areas, a number of common trends and themes are also apparent. The assessment provides a range of information on the relative strengths and weaknesses of different mitigation options to help inform BEIS's identification and selection of investment areas to support both mitigation and the development of future strategy. The selection of specific options sits outside the scope of this research as this will depend both on how BEIS weigh the relative value of different criteria presented here, and on additional factors including the deliverability of specific investments, the availability of suitable partners, and the presence of local political will to support investment, among other investment-specific factors considered by BEIS. Nonetheless, a holistic review of all opportunities identifies the following trends and themes that can help inform the selection, prioritisation and programming of mitigation support through the ICF.

1. Prioritising opportunities with near-term and future high mitigation potential

BEIS can support substantial climate mitigation by focusing on careful design of interventions to maximise benefits in current areas with high mitigation potential, while also laying the groundwork for mitigation from future critical sectors. Within the energy sector, there remain large near-term mitigation benefits within renewables, but it is also crucial to prepare to support broader decarbonisation through technologies including energy storage and demand-side management. Within land use opportunities, BEIS can support substantial mitigation in the near term through well-designed avoided deforestation investments, while looking towards areas with high future mitigation benefits and/or high co-benefits such as reforestation and agricultural productivity enhancements, respectively. A number of cross-cutting and policy interventions are crucial enablers of future mitigation activities, including industrial decarbonisation policy, fiscal policy, greening the financial sector and establishing governance systems. As mitigation opportunities and priorities evolve over time, BEIS will need to similarly evolve its choices about where and how to target and deliver support in order to align with emerging high mitigation opportunities.

2. Maximising synergies between opportunities while managing trade-offs

BEIS can take advantage of a number of synergies between opportunities, particularly those arising from cross-cutting opportunities, while managing potential trade-offs. BEIS has the potential to achieve multipliers on its investment by targeting areas with high synergies – notably including interventions to support climate intelligence and data, which have strong interactions with a wide range of other investment areas, and the electrification of the energy system, which emerged as a consistent theme across a range of technical opportunities. There are also a smaller number of potential trade-offs or conflicts between opportunity areas, particularly from land use implications of large-scale deployment of biomass energy with carbon capture and storage (BECCS),, which suggests a need for careful programme design and monitoring and/or geographic targeting to reduce the potential negative impacts.

3. Securing near-term quick wins and building towards future priorities in different geographies

BEIS can combine near-term mitigation in critical sectors or more investment-ready geographies, while laying the groundwork now for future mitigation priorities. Activities that target critical energy infrastructure to decarbonise the energy sector and that enable more effective action in countries with relatively more advanced markets or governance systems through financial sector reform or governance support can deliver large returns in the near term – and in the former case can also support vital COVID-19 recovery. At the same time, investments in key decarbonisation and fiscal policy opportunities and in improving capacity and expertise in government and in the financial sector in relatively less advanced countries are needed in the near term to support the realisation of emissions reductions in the longer term.

4. Strengthening and building partnerships in developing countries

The analysis confirms the benefits of support for countries where BEIS already has strong relationships – but also suggests value in broadening and deepening partnerships. Many countries where BEIS already has a clear interest and strong partnerships are likely to remain important for achieving large-scale mitigation. However, the analysis also suggests that there would be high mitigation value in broadening the reach of support to more countries while also deepening partnerships in existing countries or regions. In particular, BEIS could consider expanding energy decarbonisation and policy support across South America, continuing to expand support across Southeast Asia, and looking to support energy opportunities in East Africa and land use opportunities in West Africa.

5. Delivering mitigation through multifaceted approaches, increased bilateral programming and longer partnerships

There is particular value in using multifaceted delivery approaches that combine capital spend with technical assistance or that takes a programmatic approach – and from expanding bilateral partnerships and the duration of support. The types of interventions that are needed suggest high value in increasing the use of technical assistance (TA) within programmes – and of combining TA with capital investment. If BEIS pursues a relatively greater focus on cross-cutting interventions in the future, as suggested by the potential in these areas discussed above, there is also substantial scope to increase the use of bilateral partnerships with countries to help improve the targeting and impact of support. Across both capital and technical assistance investments, expanding the duration of support can also help increase their impact.

6. Harnessing the UK's technical decarbonisation, policy and ODA expertise

The UK expertise within its own decarbonisation pathway, its policy strengths and previous development partnerships can boost BEIS support for key mitigation opportunities, relative to other development partners. The UK's experiences in its past and planned decarbonisation pathway can support a range of energy opportunities, in particular in supporting large-scale renewables and flexibility solutions, but also current and future priorities such as demand-side management, energy storage, electric vehicle infrastructure and sustainable agriculture and reforestation. BEIS could similarly align support with UK policy and enabling environment strengths by focusing on support for governance, for greening the financial sector and for net-zero policy development. Finally, BEIS can also look to leverage previous support through development financing and partnerships, particularly in the areas of long-term planning support tools and policy development and in the broader UK government's support for forestry and agriculture.

1 Introduction

The world is not on track to achieve Paris Agreement goals and limit global warming to well below 2 degrees Celsius, and a radical decoupling of emissions from economic growth is needed to achieve global climate goals. Beyond a 1.5 degrees Celsius average warming above pre-industrial temperatures, climate change will increase the intensity and frequency of climate and weather extremes and increase baseline temperatures. The United Nations Environment Programme (UNEP) Emissions Gap Report 2019 estimates that without increased ambition to reduce emissions, the world is on track to reach 3.2 degrees warming, with devastating effect particularly in the poorest and most vulnerable regions of the world.[1] The Intergovernmental Panel on Climate Change (IPCC) SR1.5 report calls for global net zero emissions around 2050, which translates to a reduction in global emissions of 7.6% per annum in the next decade.[2] Given that the world is on a trajectory to further reduce poverty and bring larger shares of the global population into affluent middle classes, this implies a radical decoupling of emissions from economic growth. However, many ODA-eligible countries have planned rapid expansions of their emissions-intensive capital stock over the next decade.

This calls for substantial investment in climate action – which will be costly, but also offers unprecedented opportunities. Technological advances in low-carbon, climate resilient technologies and land use present a unique opportunity for leapfrogging to avoid intermediate and carbon- or energy-intensive stages of economic development and to support a Just Transition that secures workers' and communities' rights and livelihoods during the low-carbon transition.[3] ODA-eligible countries no longer have to deploy outdated emissions-intensive technologies to fuel their development, as the costs of renewable energy technologies, electric mobility, circular production processes, climate compatible land use and other solutions are coming down rapidly and are, in many cases, competitive or cheaper than those of old technologies, not only when pricing in carbon and non-carbon co-benefits. ODA-eligible countries can put the economics to their advantage and leapfrog over an emissions-intensive development phase, to a low-carbon, climate resilient economy; while at the same time establishing comparative advantages in post-carbon transition global trade and reducing the risk of creating a legacy of emissions-intensive assets at risk of stranding as and when the rest of the world ratchets up its climate policy ambitions. As IPCC SR1.5 shows, enhanced climate action in developing countries is largely consistent with, and often further contributes to, other Sustainable Development Goals (SDGs) such as the creation of decent jobs and conservation of life on land and below water.

UK ICF can play a critical role in rapidly transforming markets in ODA-eligible countries to catalyse public and private resources for aligning development with a 'well below 2 degree' warming goal. The shift from a 2 degree increase goal to aiming for a well below 2 degree warming target with efforts to further limit the increase to 1.5 degrees in the Paris Agreement implies a need for rapid scale-up of climate action across all sectors with mitigation potential globally. ICF can support climate change mitigation at the same time as stimulating growth and development through transforming markets with its portfolio of decarbonisation, private financing, forestry and land use, and partnerships and capabilities support. For ICF to support shifting the trillions that are needed, however, it will need to further realise its goal of achieving transformational change. Further realising this goal will require a focus on transformative climate finance that has the potential for lasting impact at scale.[4]

The analysis summarised in this report aims to provide BEIS with robust evidence to inform a strategic approach to deploying UK ICF in support of global climate mitigation. Through multiple phases of analysis, this research provides both broad and deep evidence to support decision making about future BEIS ICF

[1] United Nations Environment Programme. (2019). Emissions Gap Report 2019.
[2] IPCC. (2018). Global Warming of 1.5°C.
[3] Pigato et al. (2020). Technology Transfer and Innovation for Low-Carbon Development. ; Energy Transitions Commissions. (2020) Making Mission Possible: Delivering a Net-Zero Economy.
[4] Vivid Economics. (2020). Transformative Climate Finance. ; World Bank. (2020). Mobilizing Private Finance for Nature

mitigation investments, with a particular focus on expanding BEIS's evidence base by focusing on areas of high importance and/or where prior evidence or research within BEIS is (relatively) limited.

The analysis supports identification of mitigation potential, investment need and other criteria for 15 potential BEIS ICF mitigation opportunities in ODA-eligible countries. The research includes two layers of analysis: an initial broad overview analysis to identify research priorities for further consideration, complemented by deeper analysis in those research priority areas. Within each mitigation priority selected for further analysis, this work identifies further detail including where and in what types of intervention value for money is likely to be highest, drawing on evidence including mitigation potential, investment need and barriers to realising the identified mitigation potential.

Figure 1 The analysis process is designed to provide a broad and deep evidence base to support future ICF climate mitigation investment decisions and strategy

Source: Vivid Economics

2 Prioritisation Assessment of Mitigation Investment Opportunities

2.1 Prioritisation approach

An initial review identified a longlist of 36 different potential mitigation opportunities based on a broad literature review. An initial assessment identified a longlist of potential opportunity areas for ICF investment to support mitigation action, based on a broad review of general and sector-specific climate mitigation literature.[5] Following the initial identification of opportunities, the final longlist of opportunities was agreed with BEIS. This list included 36 opportunities across a range of technology or technical mitigation sectors – including land use and natural resources, the power sector, industrial decarbonisation, the buildings sector and transportation – and cross-cutting opportunities, which include interventions that may have significant mitigation potential through direct or indirect support across a range of sectors, including energy, industry, transport, buildings, and/or land use sectors, such as policy interventions, capacity building, governance improvements, and cross-cutting technologies.

The prioritisation exercise applied a consistent assessment methodology to rank opportunities, in ODA-eligible countries as a whole, against five criteria. The exercise used two evidence sources. The first was the IMAGE integrated assessment model to provide comparable analysis across a wide range of mitigation opportunities; the second was a broader literature review to validate and contextualise specific findings.[6] In this way, the prioritisation analysis applied a common yardstick using an internationally recognised modelling framework, while also drawing on a broader evidence base as needed. Table 1 below sets out the five criteria used to assess each opportunity, the evidence base applied, and how assessments of low, medium and high potential were conducted. The assessments included two rounds of quality assurance drawing on climate change, sector-specific and development experts. Following the scoring assessment, in some cases initially identified opportunities were adjusted or merged into joint opportunities in those cases where: (i) evidence from the prioritisation assessment identified meaningful differences between activities within opportunities; (ii) only certain subcomponents of interventions were considered likely to be worth pursuing, or (iii) where successful investments may require targeting multiple opportunity types jointly. Details for specific cases are included below.

[5] Including: Acemoglu et al. (2016). Transition to Clean Technology ; CDP. (2019). Major Risk or Rosy Opportunity: Are companies ready for climate change? ; Cui et al. (2010). Carbon footprint analysis of the Bus Rapid Transit (BRT) system: a case study of Xiamen City ; Fineslla (2012). Comparing Recycled to Virgin Paper ; Gallagher et al. (2017). Carbon pricing in practice: a review of existing emissions trading systems ; Ginkel et al. (2020). Climate change induced socio-economic tipping points: review and stakeholder consultation for policy relevant research ; Hoornwig et al. (2012). What a Waste: A Global Review of Solid Waste Management ; Hoornwig et al. (2015). Peak Waste: When Is It Likely to Occur? ; ICCT. (2012). Global Transportation Energy and Climate Roadmap ; IEA. (2013). Transition to Sustainable Buildings: Strategies and Opportunities to 2050 ; IEA. (2016). Energy Technology Perspectives 2016: Towards Sustainable Urban Energy Systems ; IEA. (2019). The Future of Hydrogen: Seizing today's opportunities ; Lebreton & Andrady. (2019). Future scenarios of global plastic waste generation and disposal ; Li et al. (2013). Economic transition policies in Chinese resource-based cities: an overview of government efforts ; Mason et al. (2015). A Global High Shift Cycling Scenario: The Potential for Dramatically Increasing Bicycle and E-bike Use in Cities Around the World, with Estimated Energy, CO2, and Cost Impacts ; Napp. (2017). A survey of key technological innovations for the low-carbon economy ; Narayan. (2011). Carbon footprint of bioplastics using biocarbon content analysis and life-cycle assessment. ; Nordhaus. (2015). Climate Clubs: Overcoming Free-riding in International Climate Policy ; OECD. (2012). Greenhouse gas emissions and the potential for mitigation from materials management within OECD countries ; Project Drawdown. (2020). Project Drawdown database. ; O'Neil et al. (2012). Demographic change and carbon dioxide emissions ; Roelfsema et al. (2017). Reducing global GHG emissions by replicating successful sector examples: the 'good practice policies' scenario ; UNFCCC Secretariat. (2016). Just transition of the workforce, and the creation of decent work and quality jobs ; World Bank. (2019). State and Trends of Carbon Pricing 2019 ; WRAP. (2010). Methodology for assessing the climate change impacts of packaging optimisation under the Courtauld Commitment Phase 2

[6] IMAGE is one of the prominent models in the IPCC affiliated set of Integrated Assessment Models (IAMs) as it has been applied in a large number of climate change research projects. It is characterised by a detailed technological description of the energy system, and provides a high level of technological detail and detail on land-based processes, such as water, carbon and nutrient cycles. Please see the Annex for additional detail on the value of IAMs and the use of the IMAGE model in this analysis.

In the second phase of this work, a selection of opportunities was further investigated, based on aggregate scores assessed across all five dimensions and a consensus-seeking participatory analysis. Opportunities were initially allocated to three priority levels – high, medium and low – for inclusion in further analysis based on their aggregate assessments across all five criteria. In recognition that summary assessments such as this introduce a degree of subjectivity and collapse or obscure meaningful differences between opportunities, these priority lists were used as starting points to facilitate discussion and a consensus-building assessment through a Delphi-style workshop. The Delphi- style assessment included BEIS and external expert colleagues' review of the opportunity scorings and rankings and the evidence supporting the initial recommendations, and identified a revised set of priorities through multiple rounds of discussion and voting. This was followed by a final round of assessment by BEIS to identify investment opportunities within this set where BEIS would particularly benefit from deeper analysis and those opportunities where BEIS already possesses a robust evidence base. This resulted in a final set of 15 research priorities, as shown in Table 2 below.

Table 1 Criteria considered, evidence used and scoring approach applied in the prioritisation process

Criteria	Size of opportunity	Cost effectiveness	Development impact	Market failures	Harnessing UK expertise
Content	Overall assessment of mitigation potential and investment need *	Cost-effectiveness of investments in each opportunity area	Strength of development impacts (positive and negative)	Strength of barriers to autonomous action	Degree of overlap with UK decarbonisation and/or development assistance experience
Evidence	IMAGE model, literature review & expert assessment	IMAGE model, literature review & expert assessment	Literature review & expert assessment	Literature review & expert assessment	Expert Assessment
Low	Low (e.g. <0.5 $GtCO_2$) emissions reduction &/or low investment need[1]	Bottom quartile of cost-effectiveness within the opportunity set	Negative SDG co-benefits or few, low positive benefits only	Few market failures, and no 'high' market failures	Relative contribution to UK decarbonisation plans, market development plans, public investment commitments, policy commitments and experience and relative strength providing ODA
Medium	Medium (e.g. 0.5-2 $GtCO_2$) emissions reduction &/or medium investment need	Middle quartiles of cost-effectiveness within the opportunity set	Positive SDG co-benefits with modest or mixed degree impact	One 'high' failure or multiple 'medium' failures	
High	High (e.g. >2 $GtCO_2$) emissions reduction &/or high investment need	Top quartile of cost-effectiveness within the opportunity set	Multiple positive SDG co-benefits with large impact	At least two 'high' failures, or one 'high' and multiple 'medium' failures	

Note: This table includes a narrower set of criteria to those used in the deeper analysis.
* Annual abatement potential in 2050
Source: Vivid Economics

2.2 Research prioritisation results

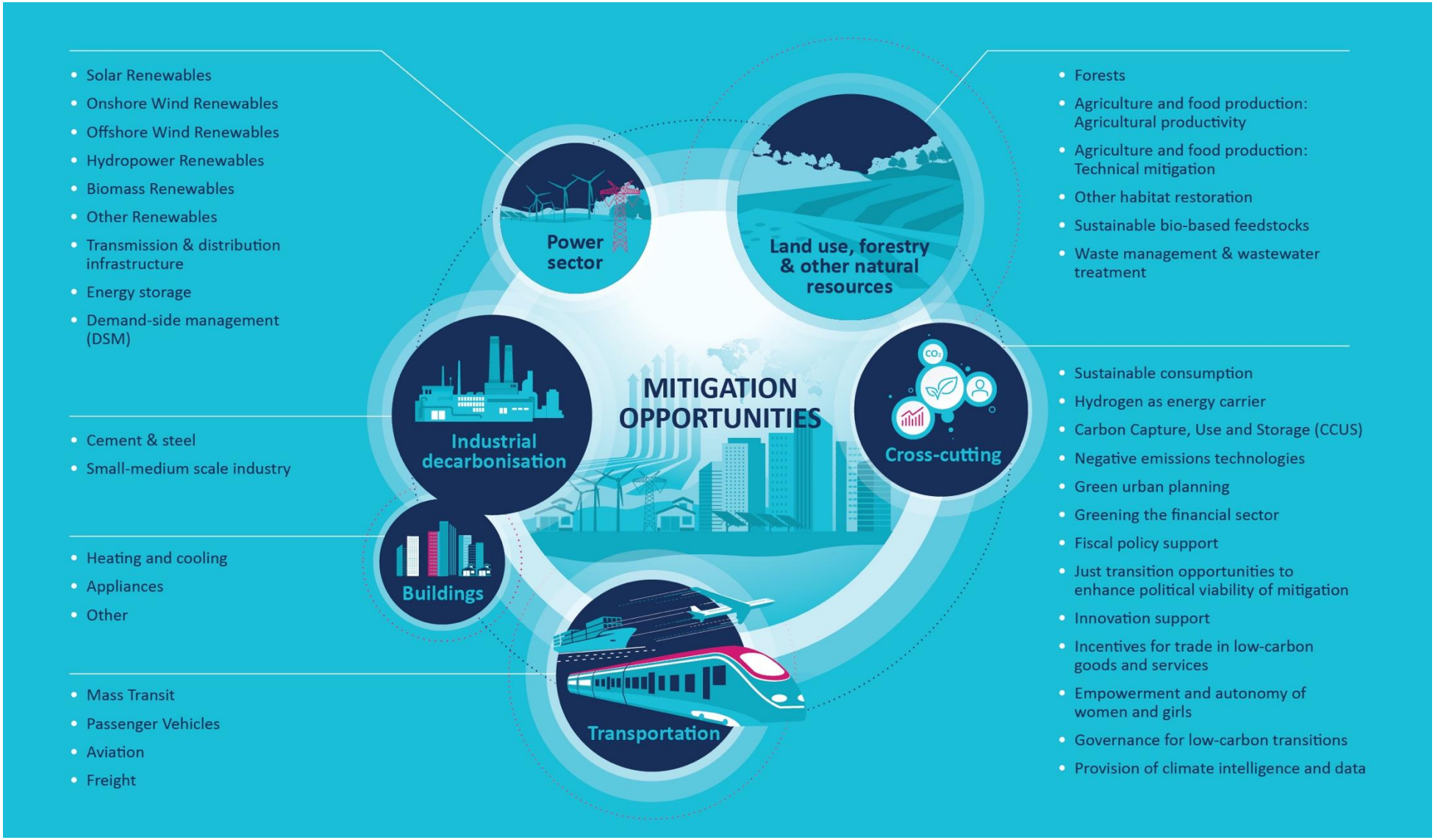


Table 2 Longlist of mitigation opportunities and research prioritisation assessment results

Sector	Opportunity	Assessment	Prioritised for further analysis?
Power sector	Solar Renewables (inc. PV, CSP, small-scale household, distributed generation)	• Utility scale PV is a large, low-cost decarbonisation opportunity • Market failures limit uptake of both utility scale PV and decentralised solar • Significant development co-benefits from decentralised solar	Yes – Within 'Variable grid renewables' (inc. grid-connected solar, and onshore and offshore wind)
	Onshore Wind Renewables	• Low cost and scalable technology with a sizeable mitigation opportunity • High certainty in the need for deployment and scale-up	
	Offshore Wind Renewables	• Offshore wind plays a similar role to onshore wind and solar, but provides lower cost-effectiveness (in GBP/tCO2 terms) • Globally, scale of deployment is expected to be approximately 1/6th of that of onshore wind, and less than that in developing countries	
	Hydropower Renewables	• Limited synergies with the UK's expertise and decarbonisation pathway • Most low cost – low impact sites already deployed • Negative societal and environmental impacts from large hydro	Yes – Within 'Non-variable grid renewables' (inc. small-to-medium hydropower, biomass and geothermal)
	Biomass Renewables	• Mitigation potential and cost effectiveness of biomass power (without CCS) is low, as finite resources are more effectively used in other sectors • CCS is covered as cross-cutting, bioenergy from residues is covered in land use	
	Other Renewables (inc. Geothermal, Tidal)	• Ocean power is likely low cost-effectiveness, while cost effectiveness of geothermal is highly context specific, scale of opportunity is relatively small • Synergies are limited as neither technology is expected to play a major role in UK decarbonisation	No – Except Geothermal (see above)
	Transmission & distribution infrastructure (including integration of renewables)	• The opportunity for T&D in ODA-eligible countries mostly reflects growing electricity demand, rather than integration of variable renewable energy • Limited additional investment need is required to support higher renewables, with approximately 65 - 80 % of investment need already met in the baseline scenario	No
	Energy storage	• Supports integration of VRE on the grid Significantly undervalued (like demand side response) and substantial further R&D benefits • Co-benefits by reducing the need for diesel generation sets and enabling off-grid energy	Yes
	Demand-side management (DSM)	• Low cost decarbonisation option and key to supporting high VRE integration • Significantly undervalued where there is no carbon pricing or reward for flexibility • Co-benefits by reducing the need for diesel generation sets etc.	Yes

Sector	Opportunity	Assessment	Prioritised for further analysis?
Industrial decarbonisation	Cement & steel	• While the ODA-eligible opportunity is large, opportunities are dominated by China SOE's (approx. 75% of global cement and steel production) and large international conglomerates. Hence, UK additionality likely minimal	Yes – Within 'Industrial decarbonisation policy'
	Small-medium scale industry	• The mitigation opportunity is sizeable, particularly in energy efficiency • Additionality of UK support and wider development impacts are likely significantly higher than cement & steel, focusing on less oligopolistic industry	
Buildings	Heating and cooling	• Low emissions amongst residential building (0.5 $GtCO_2$ in 2015) imply mitigation opportunity is limited, as most emissions occur through electricity consumption and are captured in the power opportunity • Cooling demand will substantially increase, however the main intervention to decarbonise cooling is to decarbonise power generation	No
	Appliances (inc. clean cookstoves)	• Low emissions from appliances within residential buildings (0.5 $GtCO_2$ from appliances in 2015) as most emissions occur through electricity consumption and are captured in the power opportunity • UK additionality limited to technical assistance in designing and implementing standards	No
	Other	• Low mitigation opportunity in ODA-eligible countries, as most emissions occur through electricity consumption and are captured in the power opportunity • Low cost-effectiveness associated with many interventions	No
Transportation	Mass Transit (inc. Bus, Train)	• High development co-benefits, with good opportunities to ease congestion and air pollution in urban areas • High market failures that will likely reduce uptake below the socially optimum level	Yes
	Passenger Vehicles	• Mitigation opportunity is significant given size of emissions • However, UK additionality to support fuel efficiency unclear (through investment), while battery electric vehicle support is a relatively small opportunity	Yes
	Aviation	• Opportunity is small and low cost-effectiveness compared within the transport sector • The highly international nature of the industry likely implies it is more cost effective for ODA-eligible countries to be technology takers	No
	Freight	• Mitigation opportunity is significant, especially in medium- and heavy-duty trucks, approx. 80% of abatement in 2050 • However, UK additionality limited to the design and implementation of fuel efficiency standards, with lower cost-effectiveness of other decarbonisation options	No

Sector	Opportunity	Assessment	Prioritised for further analysis?
Land use, forestry & other natural resources	Forests	• Large, widely distributed mitigation potential • Many co-benefits (biodiversity, water, jobs) • A large investment need that private finance will not fill in the near term	Yes
	Agriculture and food production: Agricultural productivity	• Large, widely distributed mitigation potential, and many co-benefits (food security, poverty alleviation, pollution reduction) • However, ready-to-scale investment need is fragmented among lots of stakeholders in underserved areas, so it is difficult for private finance to fill the gap	Yes
	Agriculture and food production: Technical mitigation	• Numerous and large co-benefits, private finance unlikely to fill gap due to many small stakeholders • However, cost-effectiveness is only high for a relatively small share of the total mitigation potential, substantial uncertainty in efficacy of many mitigation measures	No
	Other habitat restoration	• Many co-benefits, UK seen as a global leader in peatland restoration • Small size of opportunity relative to forestry and agriculture, not much geographic spread • Cost effectiveness low due to opportunity cost of peatland	No
	Sustainable bio-based feedstocks	• There are numerous negative and large development impacts, and cost-effectiveness is much lower than for other opportunities • Large energy crop plantations easier to privately finance than other opportunities	No
	Waste management & wastewater treatment	• Many co-benefits (health/well-being, reduced pollution, affordable/clean energy) and cost-effectiveness in developing countries is high • Bioenergy from waste and residues is an important contributor to BECCS potential	Yes
Cross-cutting	Sustainable consumption	• Very high mitigation potential, particularly for reducing food waste and diet change • Many positive co-benefits, especially to human health and wellbeing • Considering co-benefits, interventions are typically cost-effective and may result in net savings	Yes
	Hydrogen as energy carrier	• Moderate mitigation potential, and potentially important for carbon-intensive industries • Synergies with UK experience • However, necessity may be diminished by advances in electrification (e.g. electric vehicles vs. hydrogen fuel cell vehicles), low cost-effectiveness, and muted development impacts	No
	Carbon Capture, Use and Storage (CCUS)	• Very high mitigation potential in critical sectors such as power and industry • Low to moderate cost effectiveness, however future costs expected to decline • Optimal levels of investment in RD&D obstructed by several market failures	No
	Negative emissions technologies (inc. BECCS)	• Very high mitigation potential, may be necessary at scale in the long-term to meet Paris targets • However, potentially large adverse effects on land systems and biodiversity, concerns regarding land availability, low cost-effectiveness, high uncertainty	No

Sector	Opportunity	Assessment	Prioritised for further analysis?
	Green urban planning inc. green space, walkable design and bicycle friendly design & infrastructure)	• Low mitigation potential constrained to a few sectors • Moderate cost-effectiveness and moderate development impacts for the sustainability of cities • Large co-benefits to human health and wellbeing achieved through modal shift to active transport	No
	Greening the financial sector	• Substantial upside mitigation potential from economy-wide support for mitigation • High cost-effectiveness due to relatively low-cost policy support interventions and very high UK synergies with UK experience	Yes
	Fiscal policy support (inc. carbon pricing, subsidy reform, fiscal planning)	• Potential for deep mitigation with economy-wide coverage of emissions • Positive co-benefits impacts for human health and the environment, potential adverse effects on workers and households	Yes – Within 'Fiscal policy & Just Transition support'
	Just transition opportunities to enhance political viability of mitigation	• Substantial development co-benefits and some synergies with UK experience. On its own it is unlikely to deliver substantial mitigation benefits, but serves well to offset potential negative effects from fiscal policy while also making those policies more effective.	
	Innovation support (inc. technology and enterprise development)	• Support for broad mitigation activities, good cost-effectiveness, UK synergies and positive development impacts for clean growth, health and the environment • Mitigation is uncertain but more likely to be shallow, may require high institutional capacity and parallel bodies to implement	No
	Incentives for trade in low-carbon goods and services	• Low mitigation potential • Mixed development impacts and muted co-benefits • Low to moderate cost-effectiveness	No
	Empowerment and autonomy of women and girls	• Very large development impacts (health, poverty reduction, education and gender equality) • Very large mitigation potential (and large investment gap), cost-effective interventions leads to moderate to high cost-effectiveness • Potentially challenging to communicate and implement as interventions sit outside of typical climate investments	No
	Governance for low-carbon transitions	• Numerous co-benefits, potential for deep mitigation with wide coverage • Moderate cost-effectiveness from cheap policy support interventions, high synergies with the UK's domestic and international experience	Yes
	Provision of climate intelligence and data	• Numerous co-benefits (particularly for adaptation) • Interventions are relatively easy to implement, high cost-effectiveness, UK synergies, but potentially substantial 'distance' from mitigation	Yes

Source: Vivid Economics

3 Assessment of Research Priorities

3.1 Assessment methodology

In the detailed assessment phase, we consider each of the fifteen research priority opportunities in greater depth. This deeper analysis builds directly on the initial shortlisting analysis, adding additional analysis through a more specific geographic focus on priority geographies and through additional analytical depth.

3.1.1 Regional prioritisation

The second phase assessment identifies the five most promising regions across BEIS's investment geographies, and conducts detailed analysis for these regions. Within each opportunity assessment, the first step in the analysis includes a review of 15 ODA-eligible regions in which BEIS may invest ICF funding, and identifies the 5 most promising regions for each opportunity. The 15 potential investment regions are based on the OECD Development Assistance Committee (DAC) list of countries that are eligible to receive ODA in 2020.[7] Regional groupings, which includes both specific high-priority BEIS countries and groupings of countries within regions, have been identified based on geographic disaggregation available within the IMAGE model and in consultation with the BEIS steering group for this analysis. Table 3 sets out the geographical groupings used for the prioritisation exercise.

The top five priority regions for each opportunity were identified based on a combination of quantitative and qualitative indicators. To assess which five regions have the highest climate mitigation potential, the analysis uses outputs from the regional mitigation potential modelling from IMAGE, supplemented by additional quantitative proxy indicators for mitigation potential and expert-based assessments of regional potential. The prioritisation approaches vary slightly across different types of indicators, depending on the evidence available and the type of opportunities:

- **Energy generation and use opportunities:** The prioritisation approach is based on an opportunity's relative climate impact in a region. This is measured as the additional emissions reduction potential in a region beyond the business as usual (BAU) scenario, accounting for differences in the initial size or emissions of a region.
- **Land use opportunities**: Because climate impacts from land use interventions are complicated by land competition dynamics and natural cycles that increase uncertainty, the prioritisation approach is based on proxy variables for an opportunity's relative climate impact in a region. These proxy variables vary by intervention but are based upon quantitative evidence about physical characteristics of the intervention, such as total land area of conversion.
- **Cross-cutting opportunities**: The prioritisation approach varies across each opportunity, based on underlying conditions that support emissions reduction potential, including the national or regional policy environment(s) and commitments and national or regional market conditions.

[7] As determined by OECD's DAC list of ODA, effective for reporting on 2020 flows, available at: http://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/DAC-List-of-ODA-Recipients-for-reporting-2020-flows.pdf

Table 3 Regional prioritisation analysis considers 15 regions, including both higher emitting individual countries and regional groupings

No.	Geographic grouping	Countries
1	**South Africa**	South Africa
2	**Southern Africa** (excl. South Africa)	Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia, Zimbabwe
3	**North Africa**	Algeria, Egypt, Arab Rep., Libya, Morocco, Tunisia, Western Sahara
4	**East Africa**	Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Mauritius, Reunion, Rwanda, Seychelles, Somalia, Sudan, Uganda
5	**West Africa**	Benin, Burkina Faso, Cameroon, Cape Verde, Central African Republic, Chad, Dem. Rep. Congo, Congo, Rep., Cote d'Ivoire, Equatorial Guinea, Gabon, the Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Sao Tome and Principe, Senegal, Sierra Leone, St. Helena, Togo
6	**India**	India
7	**South Asia** (excl. India)	Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, Sri Lanka
8	**Indonesia**	East Timor, Indonesia, Papua New Guinea
9	**Southeast Asia** (excl. Indonesia)	Brunei, Cambodia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam
10	**China**	China
11	**Eastern Europe & Central Asia**	Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, Uzbekistan, Turkey, Belarus, Moldova, Ukraine
12	**Central America & the Caribbean**	Anguilla, Aruba, Bahamas, Barbados, Belize, Bermuda, Cayman Islands, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guadeloupe, Guatemala, Haiti, Honduras, Jamaica, Martinique, Montserrat, Netherlands Antilles, Nicaragua, Panama, Puerto Rico, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago, Turks and Caicos Isl., Virgin Isl. (Br.), Virgin Islands (U.S.)
13	**Mexico**	Mexico
14	**Brazil**	Brazil
15	**South America** (excl. Brazil)	Argentina, Bolivia, Chile, Colombia, Ecuador, Falklands Isl., French Guyana, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela

Source: Vivid Economics

3.1.2 Criteria assessment for prioritised regions

The criteria analysis considers each prioritised opportunity area according to six key themes for the identified top five regions to inform strategic decision-making on where and how to prioritise funding. Individual opportunity reports are structured around six critical themes for prioritisation of climate finance, agreed in consultation with key BEIS stakeholders, and building on the analysis already conducted within a number of these themes in the initial shortlisting analysis. These themes include:

- Climate impact: The relative importance of an opportunity in leading to a reduction in greenhouse gas (GHG) emissions, through the opportunity's direct impact on decarbonisation and its potential to support transformational change.
- Development impact: The degree to which an opportunity provides significant co-benefits within a region through enabling the achievement of 2030 SDGs.
- Investment need: The magnitude of investment need and the degree to which that need is likely to be unmet to 2050 by both public and private sector funding sources.
- Cost-effectiveness: The long-term effectiveness of investments in reducing greenhouse gas emissions via an opportunity, in terms of emissions per British Pound Sterling (GBP) of investment. Differences in cost-effectiveness can help to distinguish between otherwise similar opportunity-region combinations.
- Barriers to adoption: The extent to which business-as-usual support for an opportunity is likely to remain insufficient in the future by judging the strength of barriers in the political economy, the strength of market failures and the conditions in the broader enabling environment.
- UK additionality: The degree to which UK funding or support specifically is likely to be beneficial, either because of the ability to harness UK expertise or the existence of strong existing UK partnerships in an opportunity area.

In addition to the main criteria assessment, the analysis identifies and prioritises interventions to support mitigation within each opportunity area. Two final sections within each opportunity report consider:

- Intervention opportunities: The most suitable interventions for future ICF investment, based on the preceding assessment.
- Intervention case studies: Examinations of one to three previous or ongoing interventions within each opportunity area, to provide real-world context on potential interventions, and identify how interventions have addressed identified barriers and the lessons that can be taken from these investments.

The assessment considers climate impact and investment need under a 1.5-degrees Celsius scenario, several 2-degrees Celsius scenarios and a 'stated policies' business-as-usual scenario. Scenarios referred to in this work include:

- The *stated policies scenario* (also referred to as "NPI" scenario or "business-as-usual" scenario) is one in which only current implemented energy and climate policies are considered. This scenario is considered the business-as-usual scenario.
- *2-degrees scenarios.* Carbon budgets for these scenarios are set to align with "well below 2 degrees" i.e. a probability of 66% of staying below 2°C. There are various plausible pathways to reaching 2 degrees. To capture this uncertainty, we consider the following scenarios:
    - A *"Default 2 degree" scenario*. In this scenario it is assumed that national climate and energy policies were implemented until 2020, after which emission reduction measures are implemented in a cost-optimal manner across greenhouse gases, regions, and over time.

- A *"NDC 2-degrees" scenario*, in which decarbonisation actions follows current NDCs until 2030, after which decarbonisation intensifies to meet a 2°C target.
- A *"lifestyle" scenario*, in which consumers change their habits towards a lifestyle that leads to lower greenhouse gas emissions. This includes a less meat-intensive diet, less CO_2-intensive transport modes, less intensive use of heating and cooling and a reduction in the use of several domestic appliances.
- A *"renewables" scenario* (otherwise known as the "central power scenario"), with higher electrification rates in all end-use sectors, in combination with relatively ambitious assumptions on the integration of variable renewables and on costs of transmission, distribution and storage.

- *1.5-degrees scenario*. A 1.5 °C carbon budget is less than half that of the available 2°C budget, which dramatically increases the depth and rate of decarbonisation required. All mitigation options need to be deployed to (close to) their maximum potential.

Assessments across each criteria area and intervention assessments are based on quantitative evidence, literature review, and expert inputs. The methodology applied within each criteria is set out in Table 4 below, including approaches to scoring potential within each area to provide consistent assessments across all 15 opportunity assessment reports. These assessments provide rankings of how individual opportunities perform in each of the six key criteria themes – and how individual regions rank within each opportunity – through consolidation of quantitative and qualitative evidence and elicitation across experts. Note that these assessments aim to capture relative differences within and between prioritised opportunities rather than provide an absolute assessment across all potential mitigation investment areas.

Table 4 Criteria assessment themes and approach

Criteria	Theme	Content	Assessment approach
Climate impact	Mitigation potential	The direct impact of an opportunity in a 1.5^{oC} decarbonisation pathway, and the importance of the opportunity in helping to achieve decarbonisation in the near term	Percentage of total CO_2e abated by 2050, and cumulative CO2 abated in 2030 as a proportion of cumulative CO2 abated to 2050 for sector-specific opportunities. Qualitative high-medium-low assessment based on literature review and expert elicitation across regions for cross-cutting technology and policy opportunities.
	Transformational change	Potential to support activities that catalyse further change, leading to broader, faster or more ambitious climate action	Qualitative assessments based on literature review and expert elicitation across three themes: 1. Whether opportunities target *sensitive intervention points* to encourage further changes in socioeconomic/ technological/ political systems to advance climate change mitigation by improving the enabling environment. 2. Whether opportunities create *spillovers* that increase efficiency of the overall system, either nationally or globally, and so increase the speed or depth of mitigation action. 3. Whether opportunities support *innovation* in new or improved ideas/methods/products that reduce costs or increase mitigation impact within opportunity areas.
Development impact	SDG impacts	Positive and/or negative impacts on SDGs	Qualitative assessments based on literature review and expert elicitation for whether an opportunity has significant co-benefits through its positive impact on or negative consequences for achieving international development goals. Low impact indicates the opportunity has minimal effect on achieving the SDG; medium impact, it has the ability to significantly advance progress towards the SDG; high impact, it is necessary to achieve the SDG.
	Demand in target regions	Alignment with NDCs and national policies	Qualitative assessment of the degree to which opportunities align with locally agreed development needs and processes as set out in national development plans, Nationally Determined Contributions (NDCs) and other relevant national policies e.g. energy or infrastructure plans, or where opportunities align (or conflict) with local political will.
Investment need		Current and forecast investment gaps	Quantitative assessment based on, investment need (GBP) in 2020 or total public and private investment in an opportunity in 2020 (or most recent available year), and on total investment need (GBP) by 2050 for sector-specific opportunities. Qualitative high-medium-low assessment based on literature review and expert elicitation across regions for cross-cutting technology and policy opportunities.

Criteria	Theme	Content	Assessment approach
Cost-effectiveness	Cost-effectiveness of global investment	Long-term average cost-effectiveness of investing in an opportunity, in terms of the climate abatement achieved per unit of total investment	Quantitative assessment as a GBP per tonne of CO_2 abated by 2050 for sector-specific opportunities and qualitative high-medium-low assessment for cross-cutting technology and policy opportunities based on literature review and expert elicitation across regions.
	Cost-effectiveness of ICF investment	Adjusted expected cost-effectiveness for ICF specifically based on co-investment and leverage potential	Qualitative assessments for adjusted cost effectiveness based on ICF data and supporting evidence on investment mobilisation and leverage.
Barriers to adoption		Barriers to autonomous action within opportunity area due to (i) political economy barriers, (ii) market failures, (iii) enabling environment challenges	Qualitative assessment based on literature review and expert elicitation across all opportunities, including high-medium-low assessment for each region within each set of barriers. A barrier is scored low if it has minimal impact on autonomous adoption of an opportunity; medium if it slows down autonomous adoption of an opportunity; high if it prevents autonomous adoption of an opportunity. The presence of greater barriers to autonomous action suggests a greater rationale for and return on public support to enable adoption – but also greater challenges to achieving objectives. *Political economy barriers*: Degree to which the political economy or socio-economic context decreases the likelihood of policy change. *Market failures:* Degree to which common market failures – particularly unpriced greenhouse gases, RD&D spillovers, capital market imperfections, information asymmetries and network effects – inhibit uptake of an opportunity. *Enabling environment challenges:* Degree to which local factors either reduce investment in a region or reduce a region's absorptive capacity, its ability to effectively use inflows of investment in an opportunity.
UK additionality		UK additionality potential based on historical international donor activity, potential to harness UK expertise, and existing UK partnerships	Qualitative assessment based on historical flows and concentration of ODA, the UK's domestic history of opportunities within decarbonisation efforts or commitment to the opportunity within future decarbonisation plans, and on the existence of prior UK programmes and partnerships within priority regions.

Note: All high/medium/low scores for prioritised opportunities are relative assessments within the set of prioritised opportunities, rather than absolute assessments relative to all possible mitigation interventions.
Source: Vivid Economics

To mitigate against the risks of poor or inconsistent data in many of the regions examined, quantitative data is triangulated between multiple data sources wherever possible, and validated using wider literature and through expert consultation. As the quality of data varies across opportunity areas and between geographies, wherever possible multiple data sources were examined to test the accuracy of sources that are being used and triangulate between data points. Results from the analysis were additionally tested and validated through expert consultation to validate initial estimates or provide relative judgements on an opportunity's performance.

Following initial analysis, a series of expert workshops were held to test and validate key findings. Opportunity review workshops were held to convene key BEIS stakeholders and external experts to test initial results. Feedback and discussion from these workshops was integrated into the research, informing the final opportunity assessments.

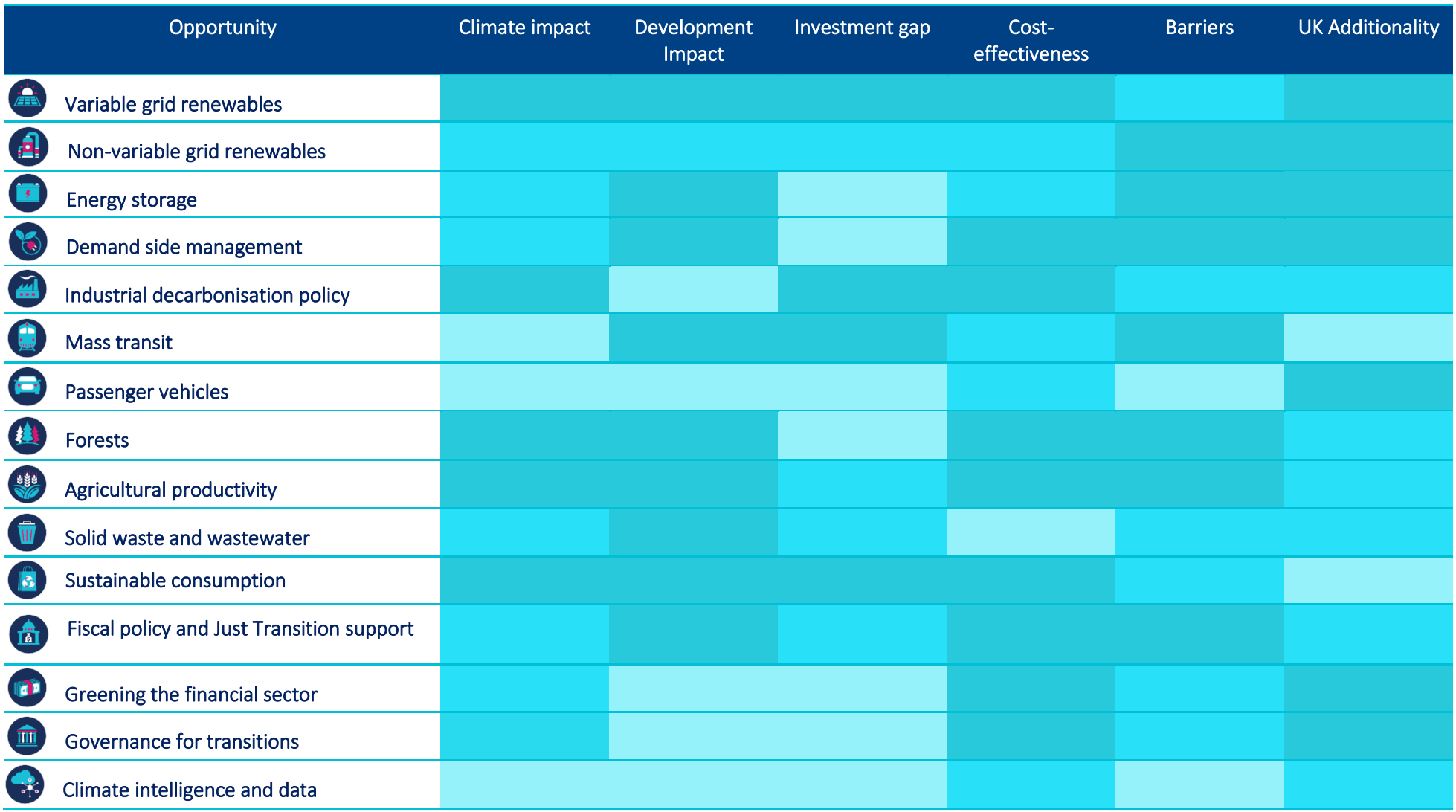
When considering summary opportunity-level scorings, it is important to bear in mind that scores are intended to convey an average across different issues. There is often high diversity of strengths and weaknesses within criteria for individual opportunities – for example, across different regions or intervention areas. A simplified scoring rubric is presented in Table 2 below.

Table 2 Scoring rubric for the opportunity criteria assessment

Climate impact	Development Impact	Investment gap	Cost-effectiveness	Barriers	UK Additionality
Mitigation & Transformational change potential	Number and strength of SDG linkages	Current and forecast investment gaps	Relative cost to achieve equivalent levels of mitigation	Presence of barriers that limit autonomous action	Strength of UK expertise relative to other development partners
Higher potential	Stronger linkages	Larger gap	Higher effectiveness	Greater barriers	Higher additionality
Moderate potential	Moderate linkages	Moderate gap	Moderate effectiveness	Moderate barriers	Moderate additionality
Lower potential	Weaker linkages	Smaller gap	Lower effectiveness	Weaker barriers	Lower additionality

Source: Vivid Economics

Figure 3 Summary of criteria assessment findings



Source: Vivid Economics

3.2 Key themes emerging from opportunity assessments

The assessment of the 15 research priority opportunity areas identifies a diversity of opportunities with strengths in different areas. The assessment provides a range of information on relative strengths and weaknesses of different mitigation options, as summarised in Figure 3, to help inform BEIS's identification and selection of investment areas to support mitigation and to support the development of future strategy. The inclusion of mitigation options within BEIS strategy or the selection of specific investment areas will depend both on how actors weigh the relative value of different criteria presented here, and on additional factors including the deliverability of specific investments, the availability of suitable partners, and the presence of local political will to support investment, among other investment-specific factors. These other factors will be judged by BEIS and are outside the scope of this research. Additionally, the summary figure provided here and the summaries for individual reports provided in Section 0 provide only an overview of the assessment – our analysis identifies substantial local context specificity in the full opportunity assessments, included in the separate report.

Nonetheless, a review of all opportunities does identify a number of trends and themes across opportunities. These commonalities and themes can help inform the selection, prioritisation and programming of mitigation support through the ICF and should be borne in mind when developing portfolios across different climate investment opportunities. As these themes emerge from the analysis of the 15 research priorities, it will be important to consider them alongside evidence on the relative benefits of other mitigation opportunities not prioritised for deeper analysis.

3.2.1 Prioritising opportunities with near-term and future high mitigation potential

BEIS can support substantial climate mitigation by focusing on the careful design of interventions to maximise benefits in current strong performing areas, while also laying the groundwork for mitigation from future critical sectors.

Within the energy sector, there remain large near-term mitigation benefits within renewables, but it is also crucial to prepare to support broader decarbonisation. While the expansion of variable renewable energy generation remains a crucial driver of emissions reductions – and an important element of immediate COVID-19 green stimulus response – to support longer-term mitigation within the energy sector it would be valuable for BEIS to increase its support for opportunities that enable and accelerate broader energy-sector decarbonisation. In particular, energy storage and DSM opportunities are critical with potentially broad reach, especially through demand reduction and efficiency measures across a range of important emitting sectors.

Within land use opportunities, BEIS can support substantial mitigation in the near term through well-designed avoided deforestation investments, while looking towards areas with high future mitigation benefits and/or high co-benefits. Large-scale mitigation opportunities are available at low cost in avoided deforestation, though careful design is needed to avoid or overcome barriers that have held back potential in previous efforts. Alongside this, there is potentially high value in investing in reforestation opportunities with a view to catalysing private investment given the currently limited framework to mobilise action at the scale needed in this sector. At the same time, agricultural productivity investments can deliver large climate benefits in themselves and can also be well aligned with broader land use mitigation (such as forest interventions) and provide high development benefits – but will require additional internal skills and capacity beyond that which BEIS has had historically.

A number of cross-cutting and policy interventions are crucial enablers of future mitigation activities. In particular, developing industrial decarbonisation policy, implementing fiscal policies that set incentives for broad decarbonisation, greening the financial sector to enable green investment at scale, and establishing the governance systems needed to drive and co-ordinate energy and climate transitions all offer high value by incentivising, enabling and accelerating future mitigation investments across economies and sectors.

3.2.2 Maximising synergies between opportunities while managing trade-offs

BEIS can take advantage of a number of synergies between opportunities, particularly those arising from cross-cutting opportunities, while managing potential trade-offs.

The opportunity assessments identify a number of synergies and linkages between different opportunity areas. Cross-cutting opportunities, in particular, offer a range of linkages to other opportunities, which is not surprising given their transversal nature. Fiscal policy interventions are likely to have strong synergies with a number of energy opportunities – particularly industrial decarbonisation policy, where effective fiscal policy can support and enable industry-specific policy support for decarbonisation and where effective just transition support may be required to deliver mitigation benefits from some aspects of industrial decarbonisation by improving their social acceptability. Similarly, fiscal policy and passenger vehicle transport opportunities activities have strong linkages, where fossil fuel subsidy reform and tax policy can be essential policy levers to support the uptake of electric vehicles (EVs).

Interventions to support climate intelligence and data have strong synergies with a wide range of other investment areas. Climate intelligence can be a crucial enabler of action across cross-cutting opportunities including sustainable consumption, where it can support behavioural and regulatory interventions, and greening the financial sector, where it can support both private and public action to increase green investment and manage climate transition risks to enable faster and more ambitious mitigation action. Climate information can also support more effective identification and targeting of mitigation investments across sector-specific opportunities, for example by informing efficient geographic location of renewables investments or effective land use decision making, can support improved monitoring of progress and understanding of (and learning from) effectiveness of investments, and can facilitate good governance and improved target setting for more intelligent action across sectors and actors.

Electrification of the energy system also emerges as a consistent theme across a range of technical opportunities. Demand-side management and energy storage play a key enabling role for large-scale variable renewable deployment, while greater uptake of electricity in transport and buildings creates a potentially greater source of flexible demand. For example, vehicle-to-grid charging is a win-win investment area across opportunities including passenger transport (as it makes EV ownership more attractive) and the power sector (as it makes it easier to integrate renewables into energy systems). This area is also a relative strength for the UK, given its national decarbonisation trajectory.

There are also a smaller number of potential trade-offs or conflicts between opportunity areas. A particular challenge is the land use implications of large-scale deployment of BECCS, which has the potential to lead to conversion of land for biomass generation, which implies a need to carefully manage the design and implementation of BECCS. Additionally, some energy sector opportunities are potential alternatives – particularly DSM and energy storage. However, in practice there are substantial investment gaps across both of these opportunities in developing countries, and investment in one opportunity is unlikely to hold back investment in the other area in the near term.

3.2.3 Securing near-term quick wins and building towards future priorities in different geographies

BEIS can combine near-term mitigation in critical sectors or more investment-ready geographies, while laying the groundwork now for future mitigation priorities.

Activities that target critical energy infrastructure and that enable more effective action in countries with relatively more advanced markets of governance systems can deliver large returns in the near term. As noted above, investments to decarbonise the power sector can deliver mitigation both in themselves, but also by enabling more widespread decarbonisation in the transport sector and (to a lesser degree) industry. Similarly, investment in avoided deforestation is a priority for rapid investment in the near term, while near-

term fiscal policy action on fossil fuel subsidy reform can help avoid investment in fossil fuel extraction that would make it highly challenging to achieve low-carbon development pathways. In countries with relatively more advanced governance systems or financial sectors, investment in climate intelligence tools and green financial sector reform can offer quick returns by enabling broad mitigation action in the near term. At the same time, near-term investments in improved capacity and expertise – through improving governance for low-carbon transitions and the uptake and use of climate intelligence and data – are in many cases crucial precursors to delivering mitigation across sector-specific opportunities, and so early investment in these opportunities may be needed to deliver large-scale mitigation.

Investments in key policy opportunities and in improving capacity and expertise in relatively less advanced countries are needed in the near term to support the realisation of longer-term emissions reductions in the longer term. Investment is needed now to lay groundwork for future emissions reductions across a number of critical energy sectors, in particular through early-stage support for developing the infrastructure needed for long-term decarbonisation, and implementing policy and regulation changes required to support, energy storage technologies, DSM technologies, electric vehicles and the deployment of CCS. Similarly, in the land use sector there is a need for exploratory support for reforestation investments and to develop opportunities for investment at scale in the medium-to-long-term. In countries with relatively less advanced governance systems or financial markets, investing in improved capacity and expertise – through improving governance for low-carbon transitions and the uptake and use of climate intelligence and data and by supporting the development of green financial systems – are crucial precursors to delivering mitigation across sector-specific opportunities. Early investment in these opportunities is needed to deliver large-scale mitigation in the future. In the financial sector in particular, as many developing countries' financial systems are still at early stages of development they will require time to reach maturity and support substantial flows of domestic green investment in line with the scale of investment needed to achieve climate ambitions.

3.2.4 Strengthening and building partnerships in developing countries

Findings from the regions explored in the analysis confirm the benefits of support for countries where BEIS already has strong relationships – but also suggest value in broadening and deepening partnerships.

The analysis confirms that many countries where BEIS already has a clear interest and strong partnerships are likely to remain important for achieving large-scale mitigation. The selection of priority regions explored in the deeper analysis was partially informed by BEIS's interest in understanding countries and regions that are already current priorities. The repeated presence of many of BEIS's current partners among the top geographic priorities should therefore be considered in light of this focus. Nonetheless, the analysis confirms that there remain substantial mitigation opportunities in many of these regions.

However, the analysis also suggests that there would be high mitigation value in broadening and deepening partnerships beyond a small set of countries. Where BEIS already has strong national or regional partnerships within particular themes, such as land use programmes and sustainable infrastructure in South America, this may include broadening the focus of partnerships into other mitigation areas, including policy support, or among other countries in the region. In other geographies, this may involve developing or strengthening national partnerships to support new opportunities, including other countries within Southeast Asia beyond current focus countries such as Indonesia and Malaysia, and expanding Sub-Saharan African partnerships beyond South Africa, for example to include supporting energy opportunities in East Africa and land use opportunities in West Africa.

3.2.5 Delivering mitigation through multifaceted approaches, increased bilateral programming and longer partnerships

There is particular value in using multifaceted delivery approaches that combine capital spend with technical assistance or that take a programmatic approach – and from expanding bilateral partnerships and the duration of support.

The types of interventions that are needed suggest high value in increasing the use of TA within programmes – and of combining TA with capital investment. Across cross-cutting interventions there is a clear need for high shares of technical assistance in ICF programming, with opportunities to build on successful bilateral and multilateral TA programmes like UK PACT and the NDC Partnership. At the same time, TA is likely to offer particular value when combined with capital investment, as this combination helps address underlying barriers to transformative change through TA while attracting sufficient interest and engagement by also providing larger volumes of capital investment. This is likely to be particularly important for energy infrastructure, which is highly capital intensive. In the land use sector, programmatic support across different sectors can improve investment outcomes and deliver better value, as land use interventions in the forestry and agriculture sector are often mutually supporting.

If BEIS pursues a relatively greater focus on cross-cutting interventions in the future, as suggested by the potential in these areas discussed above, there is also substantial scope to increase the use of bilateral partnerships. The need to provide tailored TA support to advance cross-cutting policy and enabling environment opportunities suggest greater relative value from building close ties and bilateral partnerships with supported countries. Bilateral partners can support the building of long-term trusted relationships and allow the UK to gain a better appreciation of the country context to support more effective and more contextually relevant programming and support.

Across both capital and technical assistance investments, expanding the duration of support can help increase the impact from investments. Across a range of opportunities, longer timelines for support can help secure mitigation outcomes – particularly for opportunities that require long-term capacity building, as with governance, policy development and financial sector reform.

3.2.6 Harnessing the UK's technical decarbonisation, policy and ODA expertise

The UK's expertise within its own decarbonisation pathway, its policy strengths and previous development partnerships can boost BEIS's support for key mitigation opportunities, relative to other development partners.

The UK's experiences in its past and planned decarbonisation pathway can support a range of energy and some land use opportunities. BEIS can draw on past experience in renewables, and offshore wind in particular, to support the development of large-scale renewables and flexibility solutions. At the same time, BEIS may also be able to leverage ongoing domestic activities to support DSM and storage innovation and implementation to provide international support in these areas. In addition it could design future support to make the most of synergies between domestic plans for electric vehicle charging infrastructure, low-carbon business models and expanded sustainable agriculture and reforestation to support aligned international investments. For example, the UK's leadership on the research into emerging electrochemical storage technologies, and the recycling and testing of existing lithium-ion chemistries, can be leveraged as part of wider energy storage initiatives in developing countries (such as the Energy Storage Partnership, which the UK government is a member of). Finally, the UK is well placed to harness expertise on demand-side management and electric vehicles, given ambitious domestic policies. For example, the UK is well placed to advise on the development of aggregator business models to incentivise greater DSM and the technical operation of the grid to ensure effective integration of EVs.

BEIS could similarly align support with UK policy and enabling environment strengths in governance, greening the financial sector and net-zero policy development. The UK's experience in climate governance

puts it in a leading position to support other countries in domestic governance action, drawing on both the UK's domestic action including early establishment of climate change legislation and the creation of the Committee on Climate Change (CCC) as an accountability mechanism and its international support through initiatives including the 2050 Calculator programme. The UK's leadership in international finance and sector-wide activities to advance green finance and investment also positions the UK as a prime actor in providing international support for greening of financial systems in developing countries. The UK's emerging policy frameworks to support a net-zero transition also position the UK as a strong partner on similar developing country initiatives.

BEIS can also look to leverage previous UK support through development financing channels and partnerships. In particular, the UK's strong previous support for governance, policy development and climate intelligence and data position it well as a partner for countries seeking to develop long-term planning and the relevant capacities needed in this area. Additionally, in the land use sector, previous ICF support for (mostly multilateral) forestry programmes and for agriculture (predominantly through DFID) provides the UK with a strong voice and presence in this sector – though additional efforts may be needed within BEIS to develop the capacity and networks needed to deliver this support.

4 Opportunity assessment summaries

This chapter presents summaries of the assessment findings for all fifteen research priorities. Please see the companion Opportunity Assessment Report for the full and deeper analysis of each opportunity.

4.1 Variable grid renewables

The on-grid variable renewable electricity opportunity considers a range of grid-connected variable renewable energy sources expected to provide large climate impact at high cost-effectiveness. The assessment of on-grid variable renewables includes grid-connected onshore wind, offshore wind, solar photovoltaics (PV) and concentrated solar power (CSP). As variable low-carbon power generation technologies, they deliver similar benefits, and face similar barriers to deployment, in low- and middle-income countries. Their key benefit is low-carbon, cost-effective, electricity. Variable renewable electricity is often cost-competitive with non-renewable electricity sources in many regions. There are, however, significant barriers to deployment, particularly market and institutional structures to deal with intermittency in supply, and the costs of finance.

Interventions to encourage adoption of on-grid variable renewables in focus regions include measures to de-risk investments and reform electricity market regulation. Given the largest barriers to adoption for variable renewables, example interventions include:

- Financial and technical support to de-risk investments, to address the higher costs of capital that renewable energy investments face and the unfamiliarity of local financial institutions.
- Technical assistance to reform electricity market regulation, with current regulatory systems often not allowing intermittent renewable energy to compete fairly with other generation sources.

Table 5 Variable grid renewables assessment summary

Criteria	Assessment	Notes
Climate impact 	High	• Critical to power sector decarbonisation in every region, helping to avoid around 50% of power sector CO2 emissions (7.3 gigatonnes of carbon dioxide [$GtCO_2$]) in 2050 beyond business-as-usual (BAU).[8,9] • Large positive spillovers on all other sectors through the provision of low-cost and low-carbon electricity, particularly via onshore wind and solar PV which can be cost competitive with non-renewable electricity today.
Development impact 	High	• Substantial and long-lasting positive development impact. Variable renewables are critical to achieving Sustainable Development Goal (SDG) 7, access to low-carbon reliable energy, as well as improving progress towards SDG 3, good health and wellbeing, and SDG 8, decent work and economic growth.
Investment gap 	High	• Total investment gap in the opportunity is high, USD 9 trillion by 2050, given the capital intensity of renewables and scale of deployment required. • Investment will need to double relative to BAU. • Over 70% of investment required is in solar PV and onshore wind.
Cost-effectiveness 	High	• PV and onshore wind are a highly cost-effective mitigation opportunity across all regions, often able to deliver CO2 emissions for GBP at no additional cost. • Regional cost-effectiveness impacted by the emissions intensity of the current power generation mix, natural endowments, local supply chain, and financing costs and cost of renewable integration for the local grid.
Barriers to adoption 	Medium	• Despite increasing cost-competitiveness, several moderate political economy, market failure, and enabling environment barriers slow down the adoption of variable renewables. Most significant barriers include presence of fossil fuel subsidies, weak or non-existent power transmission infrastructure, and the poor financial capacity of local utilities and governments to enter into power purchasing agreements.
UK additionality 	High	• The UK has leading expertise in feasibility assessments and financing of variable renewable energy domestically and internationally. Compared to other international donors, UK additionality is greatest in offshore wind energies.

[8] This figure reflects emissions reductions in the IMAGE renewables decarbonisation scenario vs the BAU scenario. The percentage reduction in emissions is calculated relative to 2050 BAU emissions from the power sector.
[9] All figures in this report will reflect mitigation potential beyond BAU – the BAU is taken to be IMAGE's new policies scenario.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through variable renewables:

- South Asia (including India), Indonesia, and South Africa are likely to deliver the largest mitigation opportunity, due to their high grid emissions intensity and availability of low-cost solar and wind.
- Despite declining technology costs, significant barriers continue to reduce the profitability of variable renewables for investors, including the risks of a public electricity off-taker not being able to pay for the power it purchases over the lifetime of the generation asset
- Government intervention can most cost-effectively crowd-in private sector investment by:
  - ◊ Taking on market risks, through credit or power purchase guarantees.
  - ◊ Reducing market risks over the longer term, by assisting utilities on tracking and improving their financial sustainability.
  - ◊ Or lowering financing costs, through concessional finance.[10]
- Amongst regions with the largest mitigation potential, the UK can leverage its strong Official Development Assistance (ODA) ties with South Asia and Southern Africa.

[10] World Bank. (2019). "The role of the public sector in mobilising commercial finance for grid-connected solar". https://openknowledge.worldbank.org/bitstream/handle/10986/32185/The-Role-of-the-Public-Sector-in-Mobilizing-Commercial-Finance-for-Grid-Connected-Solar-Projects-Lessons-Learned-and-Case-Studies.pdf?sequence=1&isAllowed=y

4.2 Non-variable grid renewables

The non-variable renewable electricity opportunity considers a range of non-variable renewable energy sources, which could provide large climate impact, but are subject to high levels of uncertainty. The assessment of non-variable renewable electricity includes grid-connected small- to medium-scale hydropower, geothermal generation, and biomass-fired power (with and without carbon capture and storage (CCS)). As firm low-carbon power generation technologies, a common benefit within each region is low-carbon, reliable, electricity – competing with alternative forms of firm generation, demand-side response, and nuclear. Biomass energy with CCS (BECCS) also provides a further benefit: negative emissions. As a result, BECCS could be key to driving higher climate impact from the opportunity. However, uncertainty over the technical and economic potential of BECCS contribute to uncertainty in the opportunity as whole. Additional barriers to the opportunity include a lack of data on the economically exploitable geothermal and small- to medium-scale hydropower potential.

Interventions to encourage adoption of on-grid non-variable renewable electricity in focus regions include provision of better data on resource potential and policy support on electricity market design. Given the largest barriers to adoption, example interventions include:

- Policy support for the design of electricity market regulation that recognises the value of firm and dispatchable[11] low-carbon energy, to address the lack of clear revenue streams for power system flexibility or baseload generation.
- Technical assistance in resourcing mapping and feasibility assessments, with a lack of spatially fine data inhibiting investment by the private sector and impairing the capacity of local policy makers to make effective policy roadmaps.

Table 6 Non-variable grid renewables assessment summary

Criteria	Assessment	Notes
Climate impact 	Medium	• Importance to power sector decarbonisation is highly variable, helping to avoid between 3% to 40% of power sector CO_2 emissions in 2050 beyond business-as-usual (BAU), depending on the mitigation scenario.[12,13] • Increasing BECCS deployment by 2050 is both the main source of CO_2 emission abatement, as well as the driver of high uncertainty. Upper bound estimates of emissions reduction should be treated with caution – explaining the medium climate impact assessment.
Development impact 	Medium	• Significant positive contribution to achieving Sustainable Development Goal (SDG) 7, access to low-carbon, reliable energy, SDG 3, good health and wellbeing and SDG 8, decent work and economic growth. However, impact is more variable across regions and less certain than in the case of variable renewables. • Potential negative impacts on SDG 15, life on land, where use of land for geothermal energy, hydropower, and biomass crops displaces local communities and existing industries.
Investment gap 	Medium	• Cumulative investment gap ranges between USD 1.7 – 5.7 trillion by 2050, as investment need is 1.5x – 3x the investment expected under business-as-usual. • Uncertainty in the levels of BECCS deployment and declining availability of cost-competitive hydropower are key sources of uncertainty.
Cost-effectiveness 	Medium	• Small-scale hydro and geothermal power can be highly cost-effective, but costs are highly variable by region. • BECCS, as an immature technology, is likely to see cost reductions which make it an increasingly effective mitigation method by 2050.

[11] Defined as: "Of or relating to a source of electric energy production whose output can be switched off or on or otherwise moderated according to demand". Source: https://www.thefreedictionary.com/dispatchable

[12] This figure reflects emissions reductions in the IMAGE renewables decarbonisation scenario vs the BAU scenario. The percentage reduction in emissions is calculated relative to 2050 BAU emissions from the power sector.

[13] All figures in this report will reflect mitigation potential beyond BAU – the BAU is taken to be IMAGE's new policies scenario

Criteria	Assessment	Notes
Barriers to adoption 	High	• Moderate political economy barriers to uptake include fossil fuel subsidies and community opposition to geothermal drilling or use of land for bioenergy crops. • Significant market failures relating to lack of information on resource potential, capital mismatch between high capital costs and delayed returns, and a missing market for firm or dispatchable power. • Enabling environment barriers include the poor financial capacity of local utilities to enter into power purchase agreements (PPAs).
UK additionality 	Medium	• Strong expertise in developing regulatory frameworks to incentivise non-variable low-carbon power and financing of renewables domestically and internationally. • Amongst the non-variable renewable energies, the UK's relative expertise lies in BECCS deployment.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through non-variable renewables:

- To realise the potentially large climate impact from non-variable renewables will require:
  - ◊ Better data on resource potential for small to medium scale hydropower and geothermal.
  - ◊ Regulatory frameworks that recognise the value of firm or dispatchable power.
- The cost-effectiveness of an intervention ought to consider the relative costs of deploying variable renewables within a region, accounting for the system integration costs of each type of energy. In many regions, increasing solar and wind generation could deliver emissions reductions at a lower GBP/ton of carbon dioxide (tCO_2.)
- China, India, and Brazil are expected to deliver the largest absolute mitigation potential due to their economically exploitable hydropower endowments and large power sectors today – notably, more information is required to understand the split in small- to medium-scale hydropower in each region.
- UK government official development assistance (ODA) can support the potential climate impact of BECCS by providing technical assistance towards the development of a local, sustainable biomass feedstock supply chain. Meanwhile, domestic BECCS deployment can help to decrease international technology costs.

4.3 Energy storage

Energy storage considers a range of interventions to encourage the adoption of electrochemical (battery) and non-electrochemical storage, to support an increase in renewable integration and demand side response. The assessment of energy storage considers the utilisation of stationary storage by industrial, commercial and household users with connection to a grid network.[14] It focuses on how storage can support grid flexibility and renewable integration, including 'smart grid' demand side response opportunities.

Interventions to encourage adoption of energy storage in focus geographies include financial incentives, pilot projects and reform of electricity market regulation. Given the largest barriers to adoption for storage technologies, example interventions include:

- Financial support to pilot storage technologies, to demonstrate viability of relatively new storage technologies in the local context and build a local supply chain of skilled technicians; and,
- Technical assistance to support electricity market regulation, with current systems often not incentivising storage's value as a provider of flexibility services to the grid, due to the lack of an ancillary service market, time of use electricity prices, or net metering legislation.

Table 7 Energy storage assessment summary

Criteria	Assessment	Notes
Climate impact 	Medium	• Sizeable indirect impact on power sector emissions by enabling integration of variable renewables (which could help to reduce around 50% of power sector emissions by 2050), reducing dependence of polluting forms of back-up power, and increasing opportunities for demand side flexibility
Development impact 	High	• Critical impact on SDG 7 by enabling greater access to reliable, clean energy, as well as subsequent additional positive impacts on health and well being and economic growth. Potential negative impact on local environment due to poor end-of-life management practices, and the extraction of raw minerals for electrochemical storage technologies.
Investment gap 	Low	• Investment gap of USD 0.45 trillion is low compared to other opportunities, due to lower overall investment need of USD 1.1 trillion. • Largest forecast investment gap in India, approximately USD 70 billion.
Cost effectiveness 	Medium	• Increasingly cost effective in markets which integrate storage as part of a 'smart grid' and allow storage to provide multiple flexibility services to the grid. • Relative cost effectiveness will depend on local availability of alternative firm low carbon power and centralised demand side response (to provide flexibility)
Barriers to adoption 	High	• Multiple barriers to adoption, including lack of trust and understanding amongst policymakers (and industry) on the use of storage; high costs of investment; and, minimal financial incentives for the services that storage can provide (such as demand flexibility necessary for renewable integration or grid ancillary services for reliable grid power)
UK additionality 	High	• UK is active and influential in the international donor landscape, with strong expertise in research of emerging electrochemical storage technologies and the recycling of lithium-ion batteries. Further expertise in the integration of energy storage and smart grid design, including 'energy as a service' business models can be harnessed in interventions.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through energy storage:

[14] The assessment does not consider storage for mobility e.g. electric vehicle storage (which is considered in the passenger vehicle report) or off-grid storage (which was considered out of scope following Phase 1 of the analysis)

- Behind the meter storage has the potential to provide the largest and most immediate climate impact opportunity, particularly in countries with an unreliable grid network or a high reliance on back-up generators (BUGs).
- India, West Africa and South Africa are likely to have the largest mitigation opportunity due to weak grid capacity, reliance on BUGs and high grid emissions intensity today.
- Adoption of storage will only increase if two fundamental barriers are overcome:
    - ◊ policymakers and local industries are aware of the value that storage can provide and the relative costs of storage technologies versus alternatives, such as diesel generators; and,
    - ◊ the payback period for storage technologies is minimised, either through RD&D to reduce technology costs, business models which allows storage to stack revenue streams or financing which reduces consumer borrowing constraints.
- Technical constraints of storage technologies, particularly lithium-ion batteries, must also be overcome to ensure faster and more sustainable adoption of energy storage. Key concerns are the recyclability and safe disposal of lithium-ion batteries, and their degradation under high temperatures (relative to lead acid or non-electrochemical storage).
- The UK is well placed to harness its expertise in academic research and testing surrounding storage technologies, and knowledge on business models to monetise the benefits of storage.

4.4 Demand side management

The demand side management opportunity is defined as measures to increase power system flexibility and encourage power demand reduction, using both price and non-price signals. In this assessment, demand-side management focuses on the power sector. It includes measures to influence the consumer use of electricity (households, commercial users and industry), either in the time pattern of use or magnitude of demand (e.g. energy efficiency and energy conservation). It also includes measures to improve the operation of grid assets, to improve system flexibility and increase efficiency of generation. There are numerous strategies to achieve the outlined types of DSM considered in this report, including electricity market design, customer self-generation, behavioural change policies, and use of digital, smart technologies by consumers and network operators within a smart grid.

Interventions to encourage adoption of demand side management include technical assistance to local utilities and policymakers, advisory support to businesses and financing of smart grid infrastructure. Given the largest barriers to adoption of demand side management, example interventions include:

- Technical assistance in the development of electricity market regulation and design of effective behavioural change policies; and,
- Financing of capital and software, including data management systems and remote smart metering systems throughout a grid network.

Table 8 Demand side management assessment summary

Criteria	Assessment	Notes
Climate impact 	Medium	• Large indirect impact on power sector emissions by enabling integration of variable renewables (which could help to reduce around 50% of power sector emissions by 2050), reducing dependence on polluting forms of back-up power and reducing overall energy demand • Transformational impact on all sectors in the long-term through increased efficiency of energy consumption across transport, buildings, industry etc
Development impact 	High	• Substantial positive impact on SDG 7, access to low carbon, reliable power, and SDG 3, good health and wellbeing, by supporting renewables integration. Further positive impacts on economic growth and industry can be achieved through system wide impact of DSM
Investment gap 	Low	• Investment need, and therefore gap is low (around USD 2 trillion) compared to other opportunities, reflecting lower levels of infrastructure required for centralised DSM • Costs are not negligible, however, and can be high in the case of payments to industrial users to reduce demand, or deployment of metering units and smart end-use appliances in the transition to a smart grid
Cost effectiveness 	High	• DSM is in principle a low-cost measure but there are costs associated with overcoming barriers to delivery, and this is poorly understood. • Cost effectiveness is greatest where behavioural inertia can be overcome, through behavioural change policies, or circumvented, through automation and use of AI
Barriers to adoption 	High	• Substantial barriers to greater DSM include policy inertia, resulting from poor understanding of the ability of DSM to achieve energy access and climate goals; the missing market associated with the provision of 'flexible power' to integrate renewables; and, the lack of technical capacity to implement DSM measures e.g. a poor digital ecosystem.
UK additionality 	High	• Extensive domestic experience in implementing DSM measures, both through effective regulatory design and private sector business models, such as aggregators.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through demand side management:

- The nature of the local electricity demand will influence the ease of rolling out DSM. In countries with large industrial demand, such as South Africa, incentives-based mechanisms targeted at industrial users could provide a large degree of the flexibility needed.
- DSM policies can increase their climate impact through measures to:
    - ◊ Increase the price responsiveness of consumers, through behavioural change policies, or
    - ◊ Increase the participation rate of consumers by automating decision-making, through use of artificial intelligence and smart appliances.
- To increase local support for a DSM strategy, policies should seek to leverage the tangible monetary benefits from DSM, such as the potential to increase revenues of electricity operators through AI.
- India and South Africa both have significant regional demand for DSM and can deliver large climate mitigation potential.

4.5 Industrial decarbonisation policy

Industrial decarbonisation policy includes policies that incentivise energy intensive industries to decarbonise, through supply side incentives as well as through boosting demand for low carbon products, and that help ensure industrial decarbonisation does not hinder competitiveness. Given the heterogeneity of potential mitigation measures across industrial sectors, this opportunity does not attempt to prioritise the merits of supporting specific technical interventions (e.g. hydrogen use in cement production over hydrogen use in steelmaking). Instead, cross sectoral interventions are considered. The opportunity will focus on energy and emission intensive industries.

Policies to enable industrial decarbonisation in focus geographies include:

- Regulatory standards for industries such as emission standards or requirements on recycled content in products;
- Carbon pricing for industries such as carbon taxes or emissions trading schemes; and,
- Policy to support low carbon industrial business models.

Table 9 Industrial decarbonisation policy assessment summary

Criteria	Assessment	Notes
Climate impact 	High	• Helps to avoid around 28% of direct industry sector CO2 emissions (3.4 Gt CO2) in 2050 beyond business as usual • Though improvements in energy efficiency will be the key mitigation opportunity to 2030, CCS will become the dominant industrial mitigation opportunity across all regions by 2050
Development impact 	Low	• Development impact is greatest in supporting SDG 9, by improving innovation in industry, and SDG 12, by helping increase demand for and supply of low-carbon production. • Potential negative impacts on gender equality (SDG 5) could result from automation and digitalisation.
Investment gap 	High	• Investment need of USD 39 trillion by 2050, which will vary substantially between regions depending on scale of industrial sector and relative split in efficiency improvements versus more capital-intensive interventions • An investment gap of around USD 5 - 6 trillion by 2050 is expected, relative to BAU investment levels, which implies an average annual investment of USD 180 billion.
Cost effectiveness 	High	• There are substantial industrial abatement opportunities which are cost effective on a marginal £/tCO2 basis. • CC(U)S is relatively cost effective, within the range of 30-60 £/tCO2
Barriers to adoption 	Medium	• Political economy barriers range from entrenched (fossil fuel) subsidy systems, to entrenched vested interests, and limited transparency. • Market failures include unpriced GHG emissions and investment cycles. • Enabling environment issues include policy (dis)continuity, workforce and skillsets availability, and inadequate knowledge sharing networks.
UK additionality 	Medium	• Moderate-to-high synergies with the UK's approach to industrial decarbonisation policy, including: designing and negotiating minimum carbon pricing systems, voluntary standards and agreements; assessing policy and financial mechanisms to address cross-border competitiveness issues; developing climate finance accelerators.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through industrial decarbonisation policy:

- There is a substantial gap between average industrial energy productivity in low and middle -income regions relative to the EU and US - India and Eurasia's industrial energy productivity is 75% lower

than European energy productivity (measured in USD/GJ). [1516] A substantial amount of total mitigation potential can be achieved by closing this gap.

- The largest absolute mitigation opportunities are in India and China, due to their large industrial base.
- Which measures are more or less cost effective in regions will heavily depend on the availability of CCS, particularly the availability of low-cost storage, and local energy prices.
- The UK has a large opportunity to harness expertise from domestic industrial policy, particularly around the deployment of CC(U)S in industry and the design of policy and financial mechanisms to address cross-border competitiveness issues.

[15] IEA (2020). "Tracking Industry 2020". https://www.iea.org/reports/tracking-industry-2020
[16] Eurasia includes Russian Federation, Kazakhstan, Uzbekistan, Turkmenistan, Azerbaijan, Georgia, Kyrgyzstan, Tajikistan

4.6 Mass transit

The mass transit opportunity considers all interventions related to the movement of individuals using group travel, primarily buses and trains, and is expected to be a cost-effective pathway to decarbonising transport in densely populated urban areas. The mass transit assessment will consider the role of group travel in reducing passenger transport emissions, either by increasing mass transit's share of passenger transport activity or reducing the emissions intensity of transit by buses and trains. It will focus on buses and trains, as they are the most prevalent forms of group travel. The rationale for mass transit relates to its potential to deliver emissions reductions at a lower cost than other transport interventions (e.g electrification of passenger vehicles) and provide additional development benefits, such as congestion relief. Uptake and climate impact are therefore dependent on the local context, and will be highest in densely populated urban areas where a high utilisation rate is more likely.

Interventions to encourage adoption of low-carbon mass transit in the focus regions include financial support to subsidise large upfront infrastructure costs and technical assisstance to ensure more effective, integrated mass transit solutions. Examples of such interventions include:

- Financial support towards mass transit infrastructure, such as in the purchase of low-carbon bus fleets, installation of charging infrastructure and, in fewer cases, financing of rail infrastructure.
- Technical assistance to improve the planning and design of mass transit systems, with the current quality of service delivery often inhibited by ineffective urban planning, non-integrated transport solutions, and a limited use of digital technologies to maximise efficiency.

Table 10 Mass transit assessment summary

Criteria	Assessment	Notes
Climate impact 	Low	• Mass transit can help avoid around 11% of passenger transport CO2 emissions (0.7 gigatonnes of carbon dioxide [CO2]) by 2050, beyond business as usual (BAU), with impact potentially greater under more ambitious mode-switching assumptions. • Climate impact is highest in regions with densely populated urban areas, where mass transit is particularly cost-effective at meeting increasing mobility demand, while reducing emissions and delivering additional co-benefits e.g. time savings.
Development impact 	High	• Significant potential for mass transit to help achieve several Sustainable Development Goals (SDGs), including the ability to create sustainable cities, which improve levels of gender equality, economic growth, and help ensure improved health outcomes through reductions in local air pollution.
Investment need 	High	• Investment need of USD 63 trillion by 2050 is amongst the largest across the opportunities considered, driven by the capital intensity of infrastructure provision. • An investment gap of around USD 39 trillion by 2050 is expected, relative to BAU investment levels, which will vary substantially across regions depending on their required infrastructure provision.
Cost-effectiveness 	Medium	• Mass transit can be a highly cost-effective opportunity, due to the value of the transport service obtained, together with the efficiency in its provision. • The largest driver of cost-effectiveness will be the subsequent utilisation rate and the extent of mode-shifting away from other more polluting forms of transport.
Barriers to adoption 	High	• Adoption is slowed by many political economy, market failure, and enabling environment barriers, including: lack of public sector capacity to budget and plans for mass transport investment, non-existent urban planning frameworks which reduce viability of mass transit projects, and capital mismatch from the delayed returns to significant, upfront capital costs.
UK additionality 	Low	• Despite relatively lower potential to harness existing UK expertise, UK Official Development Assistance (ODA) has been effectively used for building capacity related to urban planning. The UK can also readily deploy relevant expertise in bus rapid transit (BRT) infrastructure and smart ticketing systems.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through mass transit:

- Mass transit will deliver the largest climate impact in regions with large, densely populated urban agglomerations, due to their ability to achieve higher utilisation rates and deliver co-benefits of reduced congestion and air pollution.
- West Africa and India are regions where climate impact ($GtCO_2$ abated) is likely to be largest.
- In nearly all regions, except India (where train travel is more prevalent), interventions ought to focus on decarbonising bus travel, which is the most widely adopted mass transit mode. To enable this transition, a large share of investment need is expected in enabling infrastructure for electric buses, where the private sector is likely to continue to underinvest.
- The full benefits of mass transit interventions are only achieved in a holistic transport and urban development strategy, which ensures that pricing and system-wide operational efficiency are optimised to encourage mode-shifting.

4.7 Passenger vehicles

The passenger vehicles opportunity considers all low emissions passenger vehicles except those used for mass transit and is expected to provide a low climate impact given the scale of electric vehicle (EV) deployment already expected under the business-as-usual (BAU) scenario. Broadly, we consider two vehicle categories: cars and two-wheelers. Cars includes fuel cell and battery electric vehicles (FCEV/BEVs), and fuel efficiency internal combustion engine vehicles (ICEVs). Both two- and three- wheelers are considered, as they represent a significant share of passenger kilometres (km) in ODA-eligible countries- often over 60%. This includes all motorised two wheelers, ranging from low power e-bikes and mopeds to motorcycles and rickshaws. Notably, large emissions reductions are forecast from this opportunity in the BAU scenario due to fuel efficiency improvements and increasing uptake of EVs, both cars and two-wheelers.

Interventions to encourage adoption of low-carbon passenger vehicles in focus regions include financial support to install charging stations and technical assisstance to support EV-friendly urban planning. Examples of such interventions include:

- Financial support towards enabling infrastructure, specifically the provision of electric vehicle charging stations, which is often underinvested in by the private sector until the market is mature.
- Technical assistance to improve urban planning and help integrate EVs into the smart grid, with poor urban planning and concerns over EV charging's impact on the grid network often leading to lower levels of uptake or public sector interest.

Table 11 Passenger vehicles assessment summary

Criteria	Assessment	Notes
Climate impact 	Low	• Additional investment in passenger vehicles decarbonisation can help avoid around 20% of total passenger transport sector emissions by 2050, beyond the BAU. The relatively low climate impact is due to already high emissions reductions expected under a BAU scenario, due to energy efficiency improvements and adoption of electric vehicles. • In regions with large two-wheeler markets, most notably India, the transition to EVs (and the climate impact) could be faster compared to markets with mostly four-wheelers.
Development impact 	Low	• Largest development impact results from reductions in local air pollution and the consequent positive impact on Sustainable Development Goal (SDG) 3, good health and wellbeing. • Potential negative impact on SDG 12, sustainable consumption and production, if end-of-life management practices for electric vehicle batteries are not in place.
Investment gap 	Low	• Investment gap is negative, around USD 19 trillion less is required relative to BAU due to the considerable investment forecast to occur under BAU and the declining costs of EVs, which are expected to become cheaper than ICEVs. • The key additional investment to support low-carbon vehicles is enabling infrastructure e.g. charging stations.
Cost-effectiveness 	Medium	• Cost-effectiveness of EVs improves over time, as they are expected to reach cost parity with ICEVs by the mid-2020s; they will soon deliver CO2 abatement at GBP no additional cost.[17] • Electric two-wheelers are already cost-effective for certain vehicle classes.
Barriers to adoption 	Low	• Coordination challenges and network effects associated with the provision of enabling infrastructure (e.g. charging stations) for low-carbon vehicles continues to be the most significant barrier. • Though low-carbon vehicles have historically faced barriers related to the unpriced carbon externality and policy bias towards incumbent automotive and oil distribution sectors, these barriers are reducing in many regions (e.g. India) due to EV cost declines and planned ICE phase-outs

[17] Jürg et al. (2019). E-Mobility Options for ADB Developing Member Countries. https://www.adb.org/sites/default/files/publication/494566/sdwp-060-e-mobility-options-adb-dmcs.pdf; BNEF (2020) Electric Vehicle Outlook 2020 https://about.bnef.com/electric-vehicle-outlook/

Criteria	Assessment	Notes
UK additionality 	High	• The UK has substantial experience in increasing uptake of low emissions vehicles and implementing demand management measures to both reduce personal vehicle use and integrate vehicles into the grid network. • There is substantial international influence that can be leveraged within ongoing activities, including work by BEIS's COP26 team on overcoming barriers to transition to EVs across an extensive network of countries.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through decarbonising passenger vehicles:

- Electric vehicles are expected to be an increasingly cost-effective mitigation opportunity, forecast to reach cost parity with internal combustion vehicles in the 2020s. EV deployment could therefore be significantly faster than climate modelling suggests. However, to realise the full benefit of cost declines will require EV adoption to be paired with rapid renewable deployment by 2030.
- India and South America deliver a particularly large mitigation opportunity, due to their large and fast-growing passenger vehicle fleets. In India, the mitigation opportunity will be delivered through the decarbonisation of the large two-wheeler market, more so than in South America (excluding Brazil).
- Public sector intervention will be most cost-effective when:
  - ◊ Targeting the provision of enabling infrastructure, such as EV charging stations.
  - ◊ Supporting low emission vehicle (LEV)-friendly urban planning.
  - ◊ Ensuring the efficient integration of LEVs into the grid network.
- The UK has a substantial opportunity to harness its expertise in the design and implementation of demand management mechanisms, and installation and integration of charging infrastructure.

4.8 Forests

The forests opportunity considers all interventions that affect rates of deforestation, forest degradation, reforestation, restoration of degraded woodlands, and afforestation as well as the use of improved forest management techniques. The mitigation potential from this opportunity is very large and primarily in avoided deforestation and reforestation interventions. The high cost-effectiveness of the opportunity leads to a modest investment need relative to other opportunities considered in this series of reports. However, global investment in forest mitigation must still increase substantially under a 2-degree compliant scenario. Development impacts are large, driven by the preservation of biodiversity and ecosystem services that come with avoided deforestation and the potential to generate these benefits through re/afforestation. Barriers to adoption are significant, largely due to difficulties in monitoring interventions and weak property rights in many regions experiencing deforestation, and have proven difficult to overcome for a variety of past development aid interventions. Some of the many existing programmes in this opportunity space have overcome these barriers to have substantial impact, reinforcing the importance of careful, long-term intervention design should BEIS choose to pursue investment in this area.

The interventions considered here to increase forest mitigation activity in focus regions include:

- Transform the political narrative, ensure complementarity rather than competitiveness between forests and other land uses and infrastructure, support the enhancement of forests policy and ambition, and strengthen the enforcement of the law at national, state, and local levels.
- Support large-scale re/afforestation in regions with sizeable amounts of secondary forest and degraded land as well as sustainable forest management via the deployment of bilateral public finances to incentivise private investment, and establish comprehensive payment for ecosystem services (PES) models and initiatives including all forest goods and services.
- Enact improvements to reduced deforestation and forest degradation 'plus' (REDD+) in all regions, in partnership with other donors, including progression towards jurisdictional and national initiatives, coordination with other forestry initiatives, measurement, reporting, and verification (MRV), REDD+ readiness, and adaptation to dry forest countries.
- Secure and clarify land tenure and land rights between government, business, smallholders, and forest and indigenous communities, offer long-term training and capacity development within national, state, and local governments, and strengthen decentralised and participatory forest management.
- Where high political economy issues are apparent, channel support to state and local government, international and domestic business, civil society, and indigenous and forest communities.
- Support countries, states, and municipalities to form sustainable partnerships with international business interests to strengthen deforestation-free commodity supply chains and improve domestic forest carbon policies and standards to establish offset markets and increase private investment.

Table 12 Forests assessment summary

Criteria	Assessment	Notes
Climate impact	High	• According to IMAGE modelling results, forests may support up to 4 gigatonnes CO2 equivalent per year (Gt CO2e/year) of land use emissions mitigation in low- and middle-income countries by 2050. • Recent literature suggests the mitigation potential of forests could be even higher.

Criteria	Assessment	Notes
Development impact 	High	• Impact on Sustainable Development Goals (SDGs) is high, including SDGs 1, 2, 3, 6, 8, 12, 13 and 15, focused on the non-monetised goods and services that forests provide including no poverty, zero hunger, health and air quality, the quality and supply of water, jobs and employment, responsible consumption and production, and land-based biodiversity. • If interventions are implemented insensitively there are potential negative SDG impacts as well, including loss of livelihoods, food shortages and higher food prices, particularly for women and indigenous groups, water availability, and biodiversity via monocrop plantations.
Investment gap 	Low	• Global investment in the opportunity will need to scale up to, on average, USD 58 billion per year between now and 2050, an order of magnitude above today's levels. • While the cumulative investment gap of USD 1.7 trillion by 2050 appears large, this is a comparatively smaller investment gap than many other opportunities, such as variable renewables at USD 9 trillion.
Cost-effectiveness 	High	• Forests are one of the most cost-effective mitigation opportunities. • The cost of reforestation and afforestation is significantly smaller than the present-day cost of bio-energy with carbon capture and storage (BECCS), the only other negative emissions technology with a currently clear potential pathway to at-scale deployment.
Barriers to adoption 	High	• In all regions, high political economy barriers, moderate to high market failures, and high enabling environment barriers exist • Barriers include political commitment, entrenched interests, fiscal support, funding shortfalls, carbon accounting, lack of carbon price and recognition of forest goods and services, REDD+ MRV and transaction costs, REDD+ suitability to dry forests, weak and competitive policy, unclear and insecure land tenure, judicial systems and law enforcement, technical capacity, horizontal and vertical coordination, fragility of benefits to indigenous and forest communities, and REDD+ influence on governance. • Moreover, competition for land use from agriculture, infrastructure growth, mining, and food consumption is a major barriers.
UK additionality 	Moderate	• Domestic value is moderate to high resulting from good technical expertise in re/afforestation, sustainable forest management (SFM), support to forest governance, markets and private sector engagement, REDD+, and opportunities arising from the UK's hosting of the 26th UN Climate Change Conference (COP26). • The UK has good ties in Indonesia and Southern and West Africa and moderate ties in Brazil and South America with recent support focused on REDD+.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through investment in forests include:

- Combining REDD+, re/afforestation and SFM, forests represent one of the single largest mitigation opportunities explored in this series of reports. While the literature presents a wide range of values for the exact scale, location, and type of land that needs to be protected or reconverted into forested area, scenarios universally agree that much more land area, hundreds of millions of hectares, needs to be forested than is the case today. Sources generally also agree that, in principle, forests represent some of the cheapest mitigation opportunities available, and that natural forested habitats offer a variety of development co-benefits, including biodiversity, disaster resilience and water and climatic systems, the scale of which can hardly be overstated.

- Forest investments and development programmes are not new and seem to have had mixed success over their long history due primarily to the scale of barriers faced. Despite the numerous goods and services that forests bring, the barriers to improvement are substantial, relating to issues of political will, technical capacity, availability of funding, law enforcement, land tenure and the economic incentive to keep or restore forests – as well as wider concerns about political and the influence of agriculture, transport and energy systems on forests.

- In response interventions must be well designed and substantially funded, have political buy-in, and incorporate a long-term plan. Mitigation efforts in the forests sector take time to mature and yield benefits, and one common feature of past interventions with sub-optimal outcomes has been donor planning horizons that are too short for the long-lived nature of forest interventions. Experts interviewed over the course of this work have suggested that donors must be prepared to make long-term commitments of 20 years or more, respecting the long timeframe for forest interventions to generate impact.
- The UK has decades of bilateral ODA experience in forested countries and continued presence in all priority regions via historic support to forest governance, law enforcement, markets, and indigenous and forest communities. Interventions to address barriers should consist of a combination of technical assistance and exchange of expertise and of sizeable results-based payments for forests mitigation. Programmes should also be aware of technical and financial absorptive capacity issues in forest countries, especially in Southern and West Africa. The funding channels for interventions will vary – a combination of bilateral and multilateral channels will be necessary based on UK additionality and the strengths of existing multilateral mechanisms. Donor and programme coordination need to improve.
- The time profile of the intervention need favours avoided deforestation efforts in the short term, transitioning to large-scale re/afforestation efforts in the medium term of 2030 and beyond. In order for re/afforestation interventions to be ready at the scale required, intervention design should be considered and tested early where possible.

4.9 Agricultural productivity

The agricultural productivity opportunity – encompassing agriculture and food production productivity enhancements – considers all mitigation measures in agriculture which have a demonstrable impact on productivity. The mitigation potential of this opportunity is large, being highest in regions with low agricultural productivity and/or high current rates of deforestation. Investment need is large in absolute terms, but moderately sized relative to energy opportunities assessed in the other companion opportunity reports. The cost-effectiveness and positive development impacts of the productivity-enhancing interventions considered in this analysis are generally high, due to measures often being cost-saving or income-boosting, leading to increased income security and reduced hunger. Barriers to adoption are significant, largely due to difficulties disseminating information amongst many small landholders, agricultural lobbies wielding significant political influence in many of the focus regions, and inadequate infrastructure existing in most of the focus regions. UK additionality is moderate due to the UK having strong historical support of agricultural development, but the agriculture development space already being crowded.

Interventions to encourage adoption of agricultural productivity enhancements in focus regions include:

- Technical assistance and capacity building for the construction of new infrastructure, application of natural solutions, and use of climate-smart agriculture practices.
- Collection and distribution of data for improved farm management decisions.
- Developing effective dissemination strategies that resonate with target farmers.

Table 13 Agricultural productivity assessment summary

Criteria	Assessment	Notes
Climate impact 	High	• The mitigation potential of agricultural productivity enhancements is large by 2050 at well over a few gigatonne carbon dioxide per year (Gt CO2/year). • Precise estimates of the mitigation potential of productivity enhancements are not prevalent in the literature as they are difficult to quantify and depend heavily on uncertain projections over how crop yields will evolve in a baseline scenario.
Development impact 	High	• Significant potential to achieve immediate and lasting impacts on most Sustainable Development Goals (SDGs), and particularly in addressing hunger and malnutrition; reducing poverty and promoting sustainable and equitable livelihoods; as well as building climate resilience, and promoting the sustainable use of water resources, soils, and the environment.
Investment gap 	Medium	• The absolute magnitude of the cumulative investment need is substantial at over USD 4 trillion to 2050, however, this figure is only moderately sized relative to the investment need assessed in the companion energy opportunity reports.
Cost-effectiveness 	High	• Many agriculture productivity enhancement measures are cost-saving, leading to negative or close-to-zero marginal abatement costs. Measures that are necessary to couple with productivity enhancement measures, such as forest protection, are also relatively cheap in the regions assessed, at under 10 USD/t CO2.
Barriers to adoption 	High	• Significant market failure-related barriers exist, including poor information dissemination networks, key knowledge gaps, and unpriced greenhouse gases (GHG) emissions. • Key political economy barriers exist, including powerful agricultural lobbies; these can stymie progress, as can productivity enhancement interventions that are overly simplistic and focus on technocratic or managerial solutions. • Significant enabling environment barriers include inadequate (food storage and distribution) infrastructure and limited agricultural data collection systems.

Criteria	Assessment	Notes
UK additionality 	Medium	• Strong ongoing ties and historical track record in supporting agriculture sector development, especially within various target regions. • Leadership roles and collaboration building within multilateral programmes; albeit that the agriculture sector is a very crowded development space. • Significant donor funding provider, and solid track record in both Research, Design and Development (RD&D) and leveraging private sector participation.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through improving agricultural productivity:

- The development impacts associated with agricultural productivity enhancements are likely the, or one of the, highest among the 15 mitigation opportunities assessed. This is because these interventions can directly lead to both positive outcomes for farmers, through larger and more secure incomes and food sources, as well as for the surrounding environment, through reduced fertiliser use and the expansion and protection of forests.
- The full benefits of agricultural productivity increases will only be realised if productivity enhancing interventions focus on promoting climate-smart agriculture over conventional agriculture, and if forest protection policies are implemented to prevent productivity enhancements from leading to increased deforestation.
- Agriculture is a crowded development space and so interventions must be carefully selected to ensure that they have value in addition to programmes already in place.
- West and East Africa likely have the largest mitigation opportunities due to rapidly growing populations and low current productivity.

4.10 Solid waste and wastewater

The solid waste and wastewater opportunity considers the construction and enhancement of waste management and wastewater treatment facilities. Importantly, this includes the use of waste and biomass residues for energy**.** The mitigation potential from solid waste and wastewater is moderate relative to other opportunities at around 1 – 2 gigatonnes carbon dioxide equivalent per year (Gt CO_2e/year) by 2050. Despite the opportunity's medium-sized mitigation potential, the investment need is large and urgent at USD 140 billion/year by 2030. This is because investments in waste management improvements generally have very high non-carbon benefits, in particular, public health impacts. Similarly, measured in dollars per tonne CO_2e abated, the cost-effectiveness of investments into the solid waste and wastewater sector is not high, but considering the many co-benefits associated with landfill and wastewater improvements, mitigation investments into this sector become more attractive in terms of total impact per dollar. In all regions assessed there are relatively high political and enabling environment/absorptive capacity barriers to action, often linked to corruption in many countries' waste sectors. The UK's additional value in this sector is moderate, resulting from moderate to high domestic expertise and relatively low levels of donor investment in the regions assessed.

The interventions considered here in order to increase solid waste and wastewater mitigation activity in focus regions include:

- Institutional capacity building for national, state, and municipal governments on policy, consistency of implementation, and technologies.
- Capacity building to help government to improve the regulatory environment for the private sector and increase participation.
- Formal and complementary informal platforms and mechanisms for dialogue between national and sub-national governments, private sector, non-governmental organisations (NGOs), and universities.
- Public awareness initiatives to better communicate with and engage citizens about the benefits of solid waste and wastewater management.
- Research, design and development (RD&D) support in partnership with stakeholders for low-carbon technologies.
- Concessional financing and associated advice, for example assisting public-private partnerships and offering debt and guarantees, and demonstrating pilot projects in in more advanced technologies.

Table 14 Solid waste and wastewater assessment summary

Criteria	Assessment	Notes
Climate impact 	Moderate	• Mitigation potential by 2050 is 2.2 Gt CO2e/year in the 1.5-degree scenario. • 80% of this mitigation potential comes from the use of agriculture and forest residues used in bioenergy carbon capture and storage (BECCS).
Development impact 	High	• Impacts on Sustainable Development Goals (SDGs) are high, focused on SDGs 3, 6, 7, 13, 14, and 15 and impact on public health, clean water and sanitation, air pollution, clean and affordable energy generation, and improving conditions for life on land and in water. • If interventions are implemented insensitively, there will be negative SDG impacts, particularly amongst low-income populations that rely on work in the informal waste sector.
Investment gap 	Moderate	• In the 1.5-degree scenario, the cumulative investment gap for the solid waste and wastewater sector across all Official Development Assistance (ODA)-eligible regions is large at about USD 3.4 trillion • This is double the investment gap of forests, but less than half the investment gap of variable renewables.

Criteria	Assessment	Notes
Cost-effectiveness 	Low	• The cost-effectiveness of landfill mitigation is above USD 50/ t CO2 and the cost-effectiveness for wastewater treatment abatement is in the hundreds of dollars per tonne abated. • Interventions that increase the use of BECCS residues are likely cost-effective; however, assessments that quantify their abatement cost are not yet available in the literature.
Barriers to adoption 	Moderate	• In all regions, moderate to high political economy barriers, moderate market failures, and moderate to high enabling environment barriers exist, which have prevented the deployment of proven infrastructure and technologies. • Barriers include lack of political will, entrenched interests, high informal employment, corruption, lack of trust between government and stakeholders, financing shortfalls, lack of carbon price, low land availability, RD&D shortfalls, data shortages, government clarity and consistency, policy implementation, private sector participation, institutional coordination, use of technical capacity, government HR and budgets, and public awareness.
UK additionality 	Moderate	• The UK's additional value is moderate, resulting from moderate to high domestic expertise and low levels of donor investment and attention. • In priority regions the UK has typically had low to moderate ODA ties in waste management with most assistance focusing on sustainable urban growth.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through investment in solid waste and wastewater treatment include:

- The investment case for many waste and wastewater treatment interventions hinges mainly on development impacts other than mitigation, such as reductions in air and water pollution and improvements in health that accompany better sanitation. This may imply interventions are best managed by UK government bodies, such as the Foreign, Commonwealth and Development Office (FCDO), with experience outside the context of ICF.
- Waste and wastewater treatment opportunities remain firmly in the realm of public investment in most localities, particular in lower and middle-income urban settings and rural areas. The variety of existing barriers to action mean that countries generally cannot rely on the private sector to fill the existing substantial funding gaps resulting from historic underinvestment in waste and wastewater facilities, networks, and infrastructure.
- There is currently low donor presence and interest in the solid waste and wastewater sector, particularly in the bilateral arena, which raises the potential to address immediate barriers. In all regions, the imperative in the next five to ten years should be to lay the foundations of decent basic solid waste and wastewater infrastructure and technology while the enabling environment improves, including factors such as institutional capacity development, private sector participation, awareness raising, and cost recovery. Thereafter, investment might turn to more advanced mitigation technologies such as engineered landfills, waste incineration, methane capture and use, and waste-to-energy. China, and to an extent Brazil, may be readier for new technologies sooner than other regions.
- Bioenergy generation from agricultural waste streams, representing a large portion of this opportunity's mitigation potential, is currently still in early pilot stage and limited to industrialised country contexts. Early investments in this area could help support scale-up and development over time. Interventions, however, should take care to ensure the sustainability of agricultural residue streams, which, depending on location and land management practices, can have larger carbon mitigation potential if put toward building soil carbon.

4.11 Sustainable consumption

The sustainable consumption opportunity considers interventions to reduce the consumption of carbon-intensive goods and decrease emissions from avoidable landfilling of solid waste. This assessment includes interventions to reduce food waste through behavioural change among consumers and preventing losses along the supply chain, increasing household rates of recycling and reuse by changing consumer habits and improving institutions and/or facilities for the disposal and treatment of waste, and reducing consumption of fast-moving consumer goods (FMCGs) and plastics.

Interventions to support sustainable consumption include:

- Financing, technical assistance, and capacity building to reduce the consumption of FMCGs, to support consumers broadly with recycling, to promote behavioural change, and to prevent food loss throughout the cold chain.
- Combined technical assistance and financing to promote business-to-business partnerships, to encourage public-private partnerships, and to support the development of Bioeconomy Strategies and the design and implementation of regulation and fiscal policy.
- Direct investment in the improvement of general infrastructure, the improvement and expansion of cold chains, improved storage and transport of agricultural food commodities, and replacement of old equipment.

Table 15 Sustainable consumption assessment summary

Criteria	Assessment	Notes
Climate impact 	High	• High aggregate mitigation potential, particularly in regions with large gaps between waste production and current recycling rates and high producers of food waste – notably China and Brazil. • High potential across a range of interventions, including technical recycling investments but especially among behavioural interventions to reduce food waste and material consumption.
Development impact 	High	• Significant potential to achieve immediate and lasting impacts on most Sustainable Development Goals (SDGs), and particularly in addressing hunger, promoting good health and well-being, contributing to sustainable cities and communities, and advancing responsible consumption and production.
Investment gap 	High	• Investment need is high to meet sustainable consumption aspirations, though investment spend is considerably less for interventions to change consumer behaviour than for capital spending or infrastructure investments. • New facilities for the treatment and recycling of waste likely to require high levels of additional investment.
Cost-effectiveness 	High	• Infrastructure investments and technological investments to support increased recycling, reduced food waste, and improved cold chains are frequently cost-effective, but may require high upfront costs that inhibit investment. • Regulatory and behavioural interventions offer greater cost-effectiveness, though the associated emissions reductions may also be lower than with technical interventions unless large-scale behavioural change is created
Barriers to adoption 	Medium	• Moderate political economy barriers, such as unsuitable regulations on food safety and packaging, moderate market failures, such as information asymmetries, and high enabling environment barriers, such as social impact of emissions not reflected in prices in all the focus regions.
UK additionality 	Low	• The UK has relevant experience in the design and roll out of awareness raising campaigns collaborations; RD&D in systems and solutions that reduce food loss and waste; and design and roll out of key waste management infrastructure. Therefore, the UK can build on previous experience in the focus areas.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through sustainable consumption:

- Brazil and China are likely to provide particularly large mitigation opportunities within this opportunity. There is likely to be significant development impact potential across all regions though demand may be highest in China and Indonesia given considering policy factors.
- The range of interventions within the opportunity offer good cost-effectiveness, especially for behavioural and regulatory interventions.
- The UK can build on its significant strengths and experience in the focus areas to overcome moderate to high barriers. Design and roll out technical assistance, capacity building, and financing interventions. To be successful, interventions should engage with companies and non-governmental institutions, as the private sector is often better positioned to generate innovative solutions to prevent food loss and waste.

4.12 Fiscal policy and Just Transition support

The Fiscal policy and just transition support opportunity considers the reformation of fiscal policies to reflect Paris Agreement targets and incentivise sustainable development, and just transition initiatives that aim to facilitate fiscal policy changes. This assessment of fiscal policy actions includes fossil fuel subsidy reform (FFSR), carbon pricing, clean energy support schemes, and revenue recycling for green investment. These measures are most effective when combined with *just transition support*, which encompasses participatory approaches to provide representation of vulnerable groups' interests within decision-making both during and after transitions, and policies that address the potentially negative impacts of policy changes and economic transitions for these groups, to ensure that they benefit from new economic opportunities. Taken together, the objective of fiscal policy and just transition support is to create a sustainable economy that provides decent work (SDG 8) and contributes to the eradication of poverty (SDG 1).[18]

Interventions to support mitigation fiscal policies and just transition include:

- Providing technical assistance and capacity building in FFSR to support uptake.
- Providing technical assistance and capacity building through key carbon pricing initiatives to similarly support the uptake of, and ambition within, policy reforms and measures.
- Providing technical assistance to support the just transition, by supporting domestic policy making in target regions, potentially supported by programmatic spending to support social or industrial just transition investments.

Table 16 Fiscal policy & just transition assessment summary

Criteria	Assessment	Notes
Climate impact 	Medium	• Fiscal policy support offers potentially large levels of abatement that can be ratcheted up with increased ambition over time, while just transition efforts can support and enable fiscal policy reform. • A price on carbon at socially optimal levels could offer substantial mitigation throughout lower- and middle-income countries, on the order of 1 gigatonne (Gt) carbon dioxide equivalent (CO2e) per year in the developing world.
Development impact 	High	• Potential to achieve immediate and lasting impacts on some Sustainable Development Goals (SDGs). The opportunity will reduce local pollution and promote good health and well-being, generate green jobs, and contribute to sustainable cities and communities.
Investment gap 	Medium	• Investment need for fiscal policy and just transition support are low to moderate in aggregate terms relative to other mitigation interventions as it involves regulatory and policy-based measures, and may deliver new revenues or cost savings. • Just transition support likely to be particularly costly in countries with high carbon-intensity sectors and high exposure to transition risk.
Cost-effectiveness 	High	• High cost-effectiveness given moderate costs for policy development and implementation and potentially substantial cost savings from reduced government expenditures on subsidies, potentially leading to negative cost emissions reductions. • Cost-effectiveness of just transition support and green diversification depend on the extent of transition risk, and the likelihood that the region can compete in the green economy.
Barriers to adoption 	High	• Strong political economy barriers and inertia towards fossil fuels in all the regions covered; less relevant market failures; varying enabling environment barriers depending on institutional and bureaucratic capacity.

[18] International Labour Organisation (ILO). (2015). Guidelines for a just transition towards environmentally sustainable economies and societies for all.

Criteria	Assessment	Notes
UK additionality 	Medium	• The UK has experience in diversifying away from coal through a combination of policy instruments including carbon markets, is already one of the largest funders of fiscal policy interventions, and has supported interventions in the focus regions.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through fiscal policy action and just transition support:

- China and India are likely to provide particularly high levels of abatement
- Medium development impact potential, with highest relative demand in South Africa and China.
- The opportunity faces strong political economy barriers, with focus regions betting heavily on coal-based power to satisfy their energy needs.
- The UK can build on its successful experience in diversifying away from coal through a combination of policies and can provide the required technical assistance and capacity building, though may face questions from partners based on the UK's domestic just transition experiences.
- To be successful, FFSR and carbon pricing interventions need to be coherent with the wider policy context, be built on strong analytical content, address distributional issues through revenue recycling and just transition considerations, and be based on effective communication strategies.

4.13 Greening the financial sector

The greening the financial *sector* opportunity considers interventions to embed the management of climate risks across the financial sector and to accelerate the pace of green investment in ICF-supported countries. This assessment of greening the financial sector includes interventions to support the deeper integration of low-carbon approaches in investment through reporting and management of climate risks, regulatory incentives for green investment among financial institutions, green asset and green investment promotion by establishing systems and processes to enable new investment classes, and financing incentives for green assets.

Interventions to support greening the financial sector include:

- Awareness raising and capacity building for central banks, financial regulators, and ministries of finance and supporting the establishment of climate risk reporting approaches in countries with more sophisticated financial sectors.
- Providing financing to promote and accelerate green investment and new green assets and savings tools in countries with weaker financial systems, including support for development and uptake of new tools, such as green bonds.
- Providing technical assistance, capacity building, and co-ordination support across the financial sector, including global advocacy and network formation, development of green financing strategies and taxonomies, pipeline development, financial institution awareness and uptake of green financing, advancing green banking approaches, and policy and regulatory improvements.

Table 17 Greening the financial sector assessment summary

Criteria	Assessment	Notes
Climate impact 	Medium	• Moderate aggregate mitigation potential across developing countries, in particular in relatively more developed and larger financial markets, especially China and India. • High potential for actions to support and enable mitigation across many key sectors of the economy, but connections between financial sector greening initiatives and large-scale mitigation action are as of yet unproven due to relative novelty of action, even in mature financial markets.
Development impact 	Moderate	• Impact on Sustainable Development Goals (SDGs) 1, 7, 8, 9, 11, 13, and 15 is moderate, with emphasis on clean energy, industry, infrastructure, and cities, recognising that greening finance will influence sectors with direct impact on SDGs in the future. All regions have more advanced financial sectors so SDG impact may be swifter. Negative impact could emerge from insufficient attention to a just transition.
Investment gap 	Low	• While overall flows of investment needed to achieve mitigation goals are high, levels of investment needed to support greening of the financial sector are lower given the focus on policy and regulatory action. • Regions with relatively less well developed financial markets are likely to face larger investment gaps, while some markets (e.g. China) with high mitigation potential face relatively lower gaps.
Cost-effectiveness 	High	• Policy, regulatory, and capacity building measures will be lower cost than technical and capital investments in other opportunities, while still offering substantial transformative impact if well-targeted and designed to support uptake from financial institutions. • However, limited quantitative evidence exists on the cost-effectiveness of policy interventions to support the greening of financial sectors, even in mature financial systems.
Barriers to adoption 	Medium	• In all regions, moderate to high political economy barriers, moderate market failures, and moderate enabling environment barriers exist ranging from lack of political commitment, state capture, poor recognition of climate risks, limited availability of capital, suitable financial instruments, lack of policy and regulation, and lack of capacity. A majority of barriers apply to all the countries under analysis.

Criteria	Assessment	Notes
UK additionality 	High	• High additional value lies in the skills, resources and networks of UK based banks, non-bank financial institutions (NBFIs), and advisory bodies, UK leadership of initiatives such as the Green Investment Bank and Task Force on Climate-related Disclosures (TCFD), and COP26. The UK has moderate to strong ODA ties with all regions, focused on policy and regulatory reform and incentives for green investment.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through greening the financial sector:

- The strategies and mechanisms for greening the financial sector sufficiently to meet the objectives of the Paris Agreement have not yet been found or deployed. This suggests a large potential arena for support and associated large mitigation benefits associated with action.
- There is substantial need for development of financial sectors across developing country markets, and a wide range of graduated support approaches given the novelty of actions to support greening of financial sectors even in developed markets. BEIS will need to support the range of financial sector actors from commercial banks, corporates, and institutional investors to ministries of finance, central banks, and regulators.
- BEIS support is likely to have most immediate effectiveness in more mature financial markets, but it should also not overlook the potential to support faster development and leapfrogging opportunities in earlier-stage markets. Assistance should be planned over a five- to ten-year period.
- Cost-effectiveness of policy and regulatory measures is still not well understood, and targeted support could play an important role in developing knowledge about public goods here to help improve effectiveness of action on a broader scale.

4.14 Governance for transitions

The governance for transitions opportunity considers the development of policies, institutions and systems to guide and enable low-carbon transitions. The assessment includes interventions to help develop co-ordinated sectoral and cross-sectoral policies (including developing overarching national climate legislation and specific policies for transitions within sectors), establishing climate change co-ordination and/or expert institutions to oversee, enable or advise on transitions, developing climate monitoring and evaluation systems to enable effective tracking of transitions, and mainstreaming climate change within policies, regulations and implementation.

Interventions to support governance for low-carbon transitions include:

- Supporting institutional co-ordination and the establishment or strengthening of climate institutions, including the revision and strengthening of existing institutional frameworks, structures and mandates across national and sub-national government and establishing expert institutions to deliver technical, policy, regulatory and scientific expertise.
- Supporting the development of strategies, policies and other frameworks to enable co-ordination and better governance, including establishing or strengthening climate finance strategies for channelling public finances to climate action and supporting development of coordinated climate change policies, strategies and laws, credible and long-term sector policies and regulations, and Nationally Determined Contributions (NDCs).
- Supporting improved co-ordination and engagement in governance, including strengthening the platforms for engaging stakeholders in business, finance and civil society engagement nationally and at state and municipal level, advising and supporting sub-national actors to play greater roles in climate governance and action, and supporting the forging of shared political narratives and raising awareness of climate change within national and sub-national government and communicate climate planning and policy amongst stakeholders.

Table 18 Governance for low-carbon transitions assessment summary

Criteria	Assessment	Notes
Climate impact 	Medium	• Moderate aggregate mitigation potential across developing countries, due to widespread support for and enabling of broad mitigation action. • However, potential impact from supporting governance for transitions will depend to a very substantial degree on the ambition and success of subsequent policy action, and as intermediate steps between governance interventions and resulting mitigation outcomes may include many intermediary steps, these could delay or dilute the impact of governance activities.
Development impact 	Low	• Governance underpins the success of sectors that have direct development impact. As such impact on sustainable development goals (SDGs) is moderate with emphasis on affordable and clean energy, economic growth and work, industry, innovation and infrastructure, reduced inequalities, cities and communities, life on land, strong institutions, and partnerships for the goals.
Investment gap 	Low	• While aggregate demand for governance support is high, the total scale of investment needed for related activities is likely to be moderate in absolute terms, and low relative to other prioritised mitigation opportunities due to the focus on policy and technical assistance interventions.
Cost-effectiveness 	High	• Policy support and capacity building measures will be lower cost than technical and capital investments in other opportunities, while still offering substantial transformative impact if well-targeted and designed. • However, there may be substantial lags and intermediate steps between governance interventions and emissions reductions, and previous experience with programmes aimed at building governance capacity suggests programmes often face barriers. • Nonetheless, relative benefits and costs suggests high cost-effectiveness relative to other mitigation opportunities considered.

Criteria	Assessment	Notes
Barriers to adoption 	Moderate	• In all regions moderate to high political economy barriers, mild market failures, and moderate enabling environment barriers exist. • Common barriers are lack of political commitment to climate action – especially in Covid-19 response packages; entrenched interests; domestic and international policy coherence; institutional frameworks, structures and mandates; accountability mechanisms; vertical coordination; stakeholder coordination; public finances; climate information and data; and technical capacity shortages.
UK additionality 	High	• The UK's additional value is high resulting from the effectiveness and ambition of its climate policy and institutional framework and its political influence. • In priority regions BEIS and FCDO, formerly DFID, maintain moderate ties via ODA-funding and support by the UK parliament.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through governance for low-carbon transitions:

- There is broad demand and need for governance support to overcome political economy constraints, improve and mainstream climate change within policy and institutional frameworks, and strengthen coordination between national and sub-national government and between government, business and civil society. Salient barriers revolve around political leadership, absence of comprehensive climate laws and sector plans, lack of effective institutional frameworks, poor sub-national government coordination, and disjointed engagement with important stakeholders in finance, business associations, and civil society. This suggests a wide range of opportunities for BEIS to contribute to, and good opportunities to play to UK strengths and additionality.
- The relatively lower cost of governance-supporting interventions compared to technical interventions, coupled with large benefits through support for system-wide mitigation suggests overall high relative cost-effectiveness – but this is contingent on the success of governance interventions, which can fail to achieve their aims.
- Governance has notable development benefits insofar as it underpins the success of sectors with direct development impact and enhances mitigation and adaptation simultaneously. Negative impacts may arise where low-carbon governance has the potential to increase unemployment and inequality in some sectors. This requires interventions to encompass a just transition for workers and communities and participatory approaches to the representation of vulnerable groups.
- There is a need for careful identification of demand and design of interventions, and attention to barriers, especially political economy and capacity, that could limit success. The UK should offer lasting support, over a five- to ten-year horizon, that a) will achieve durable reform rather than quick fixes, b) has the backing of government and stakeholders, c) enhances networks and communities of change, and d) transfers expertise to country institutions.
- Effectiveness in supporting governance is linked to international recognition of the UK's domestic ambition and effective policy and institutional action, including climate legislation and the Committee on Climate Change (CCC). Continued ambition, for example net-zero policies and via COP26, may open up further opportunities to support mitigation through governance interventions.

4.15 Climate intelligence and data

The climate intelligence and data opportunity considers interventions to provide the information and tools needed to inform and plan climate mitigation. Climate data and intelligence are crucial enablers of climate action – they are needed to inform public and private mitigation outcomes and can support transformative climate mitigation. This assessment of climate intelligence and data includes mitigation-supporting activities including actions to support the developing or improving of emissions inventories and models to identify priority areas, set targets, and create policy and technology pathways. It does so to help in identifying new opportunities and transition risks for targeted investment, through an economic and environmental profile that highlights risks and opportunities arising from a changing climate and the transition to a sustainable economy, and to disseminate new information regarding institutional and technological innovations and developments.

Interventions to support the uptake and use of climate intelligence and data include:

- Technical assistance to identify and address data gaps and assess current methodological approaches, including the improvement and/or update of sectoral activity data and emission factors, development of, or guidance in, the selection of existing models and tools, and development of methodologies and user-friendly, dynamic tools to perform cost-benefit analyses of mitigation options.
- Capacity building support for the uptake and use of climate intelligence and data, including promoting the implementation of climate services information systems, supporting the identification of required monitoring, reporting and verification (MRV) systems, and developing capacity building programmes to create permanent, autonomous, well-functioning, and articulated institutions.

Table 19 Climate intelligence & data assessment summary

Criteria	Assessment	Notes
Climate impact 	Low	• Moderate mitigation potential in absolute terms, but lower relative to other opportunities considered in this assessment. • Support in this area is not sufficient to deliver mitigation on its own, but can enable it across a very wide range of regions and sectors, and is a crucial enabler of action for many other mitigation opportunities.
Development impact 	Low	• Climate intelligence and data would be conducive to achieving numerous SDGs – including Decent work and economic growth, Industry, innovation and infrastructure, Sustainable Cities and Communities, 1Climate Action, and Partnership for the goals – through the provision of critical information for local actors to make informed, forward-looking decisions.
Investment gap 	Low	• Individual interventions can be relatively high cost for world-class intelligence and data, but aggregate investment needs across developing countries is low relative to other mitigation opportunities as limited infrastructure and capital spend is required. • Investment likely to vary substantially across regions due to high variability in current capacity, technical expertise, and needs.
Cost-effectiveness 	Moderate	• Relatively lower mitigation outcomes but also relatively lower costs for individual interventions suggest overall moderate cost-effectiveness of intelligence and data interventions. • There are likely to be lags and intermediate steps between climate intelligence interventions and ultimate emissions reductions for some interventions, particularly for those informing government action, reducing the relative cost-effectiveness of these actions.
Barriers to adoption 	Low	• Key political economy barriers include poor governance and limited commitment to climate intelligence generation. This is a widespread issue in target regions, which hinders the adoption of planning and assessment instruments. • Significant enabling environment barriers include insufficient public funds, lack of institutional capacities and data, infrequent monitoring, downstream infrastructure constraints, and lack of a climate change legal framework.

Criteria	Assessment	Notes
UK additionality 	Moderate	• The UK has strengths and experience useful for certain areas of intelligence and data, especially developing robust and verified greenhouse gas (GHG) emissions inventories, and models for emissions projections and transition risk scenarios, using high-quality meteorological data and owned tools such as the UK 2050 Calculator and the UK carbon budgets MRV system. • Provision of support to, and strong partnerships with, world-leading institutions, economists, and climate scientists, such as the Met Office, the Network of Central Banks and Supervisors for Greening the Financial System (NGFS), the Nationally Determined Contribution (NDC) partnership, etc.; and through a number of high-profile climate intelligence and data programmes. The latter include the Sentinel Programme, Transition Pathways and Risk Analysis for Climate Change Mitigation and Adaptation Strategies (TRANSrisk), and INNOPATH, among others.

Source: Vivid Economics, Adam Smith International & Factor

Key lessons for supporting mitigation through climate intelligence and data:

- Climate intelligence and data includes a wide range of potential interventions and can support activity across a variety of sectors, and indeed can be critical for effective action in many cases. A standalone assessment of mitigation impact therefore underestimates the wider and transformative impact from this opportunity area.
- The UK's comparative advantage is likely to be most clear in supporting generation of high-quality technical inputs, such as emissions data and inventories and developing models for GHG emissions projections and transition risks pathways.
- Previous interventions suggest that to be successful, interventions should engage a consolidated team of local actors within relevant government ministries and involve national academic institutions, to ensure the transfer of information from the beginning of the process.

5 Conclusions

UK ICF can play a critical role in rapidly transforming markets in ODA-eligible countries to catalyse public and private resources for aligning development with a below 2 degree global warming goal. The world is not on track to achieve Paris Agreement goals and limit global warming to 1.5 degrees Celsius, and a radical decoupling of emissions from economic growth is needed to achieve global climate goals. This calls for substantial investment in climate action – which will be costly, but also offers unprecedented opportunities.

The analysis summarised in this report provides BEIS with robust evidence to help inform a strategic approach to deploying UK ICF in support of global climate mitigation. The analysis supports identification of mitigation potential, investment need and other determinants of investment for 15 BEIS ICF mitigation investment priorities in ODA-eligible countries. In conjunction with broader considerations including specific country contexts, the deliverability of individual programmes and local political will, these opportunity assessments can help inform BEIS's decision making for future strategic priorities for investment.

Taken as a whole, the opportunity assessments also suggest a number of recommendations for how BEIS might position its international finance through the ICF to support effective and ambitious mitigation action in the immediate and longer term.

1. Seek opportunities with near-term potential to take advantage of quick wins and to help support a green recovery from COVID19, such as continued decarbonisation of the energy system, but take note of and start laying the foundations for supporting future high-impact opportunities. This may require building new skills to support areas where BEIS has less of a track record, notably in the land use sector.

2. Continue to deepen partnerships with countries where BEIS has strong ties to take advantage of continued mitigation opportunities – but also plan for and start building towards future partnerships as the current partners' need for support diminishes.

3. Expand the use of bilateral approaches for delivering mitigation support to ensure programmes are closely aligned with national priorities and build on UK diplomatic strengths, and consider expanding the duration of support to help ensure sustainability of impacts.

4. Harness UK expertise in areas of traditional and current strength – including renewables development and deployment, governance frameworks and greening the financial systems – and plan for future synergies between the UK's continued decarbonisation efforts and international support, for example through demand-side management innovation, reforestation experience and net-zero policy development.

References

Acemoglu et al. (2016). Transition to Clean Technology.

CDP. (2019). MAJOR RISK OR ROSY OPPORTUNITY: Are companies ready for climate change?

Cui et al. (2010). Carbon footprint analysis of the Bus Rapid Transit (BRT) system: a case study of Xiamen City.

Energy Transitions Commissions. (2020) Making Mission Possible: Delivering a Net-Zero Economy.

Fineslla (2012). Comparing Recycled to Virgin Paper.

Gallagher et al. (2017). Carbon pricing in practice: a review of existing emissions trading systems.

Ginkel et al. (2020). Climate change induced socio-economic tipping points: review and stakeholder consultation for policy relevant research.

Hoornwig et al. (2012). What a Waste: A Global Review of Solid Waste Management.

Hoornwig et al. (2015). Peak Waste: When Is It Likely to Occur?

ICCT. (2012). Global Transportation Energy and Climate Roadmap.

IEA. (2013). Transition to Sustainable Buildings: Strategies and Opportunities to 2050.

IEA. (2016). Energy Technology Perspectives 2016: Towards Sustainable Urban Energy Systems.

IEA. (2019). The Future of Hydrogen: Seizing today's opportunities.

IPCC. (2018). Global Warming of 1.5°C.An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

Lebreton & Andrady. (2019). Future scenarios of global plastic waste generation and disposal.

Li et al. (2013). Economic transition policies in Chinese resource-based cities: an overview of government efforts.

Mason et al. (2015). A Global High Shift Cycling Scenario: The Potential for Dramatically Increasing Bicycle and E-bike Use in Cities Around the World, with Estimated Energy, CO2, and Cost Impacts.

Napp. (2017). A survey of key technological innovations for the low-carbon economy.

Narayan. (2011). Carbon footprint of bioplastics using biocarbon content analysis and life-cycle assessment.

Nordhaus. (2015). Climate Clubs: Overcoming Free-riding in International Climate Policy.

OECD. (2012). Greenhouse gas emissions and the potential for mitigation from materials management within OECD countries.

Pigato et al. (2020). Technology Transfer and Innovation for Low-Carbon Development.

Project Drawdown. (2020). Project Drawdown database.

O'Neil et al. (2012). Demographic change and carbon dioxide emissions.

Roelfsema et al. (2017). Reducing global GHG emissions by replicating successful sector examples: the 'good practice policies' scenario.

United Nations Environment Programme. (2019). Emissions Gap Report 2019.

UNFCCC Secretariat. (2016). Just transition of the workforce, and the creation of decent work and quality jobs.

Vivid Economics. (2020). Transformative Climate Finance.

World Bank. (2019). State and Trends of Carbon Pricing 2019.

World Bank. (2020). Mobilizing Private Finance for Nature.

WRAP. (2010). Methodology for assessing the climate change impacts of packaging optimisation under the Courtauld Commitment Phase 2.

Annex

Integrated Assessment Modelling in the context of the BEIS ICF mitigation opportunities assessment

Introduction

This note briefly sets out what integrated assessment models (IAMs) in general can and cannot tell us, how we plan to use an IAM in this project, and how our wider project methodology addresses known weaknesses of IAM modelling. IAMs model the relationship between emissions of greenhouse gasses (GHGs), the effect of GHGs on the climate, and the physical, environmental and societal impacts of climate change. IAMs provide a valuable tool for understanding possible mitigation pathways. However, their outputs require careful interpretation. While IAMs (and energy system models) form the bedrock of the scientific literature on decarbonisation pathways, their outputs have also been widely criticised for their sometimes unrealistic outputs. For example, many IAMs rely heavily on negative emissions (through bioenergy with CCS) to reach certain temperature goals, which has often been criticised as unrealistic by observers due to real world limitations such as land availability. As set out in Box 1, the level of BECCS in IAMs should not be viewed as a forecast but requires a more nuanced interpretation. As discussed in this note, the case of interpreting IAM's BECCS illustrates how all IAM results need to be carefully interpreted, and complemented with additional analysis.

IAMs attempt to model plausible long-term future scenarios, recognising that the future is deeply uncertain and unknowable. While IAMs provide a wealth of detailed outputs, this does not mean they predict the future. Instead, the outputs of IAMs can be interpreted as internally consistent worlds, which *could* become reality. Model results out to 2050 (and beyond) are inherently deeply uncertain. A key reason for this is technological uncertainty, which is notoriously hard to predict. To illustrate, in 1990 few would have predicted ubiquitous smartphones and all the markets (such as ride sharing services) these unlock. Similarly, in 1990, a manned mission to Mars would have seemed likely by 2020, but this has not materialised.

This note argues that policy decisions, including UK International Climate Finance support, can be informed by IAM results but these need to be complemented with additional analysis. Within an IAM, modellers are required to make judgements on likely technological development and availability, some of which will certainly be wrong. Furthermore, modelling by necessity abstracts away from important policy considerations, such as societal acceptability. Policymakers must keep this in mind when using IAM outputs to inform decisions. Box 1 further highlights this, using BECCS as an example.

Box 1 A typical critique of IAMs: their reliance on bioenergy with CCS (BECCS)

- By combusting biomass and capturing the emissions from this process, BECCS can provide negative emissions. However, it remains an unproven technology. It is currently not deployed at scale anywhere globally. Furthermore, there are genuine questions around the ability of the global land use system to provide large-scale sustainable feedstock.
- Despite this, most IAMs deploy BECCS at scale in the long term. This is based on *current best estimates* of BECCS cost and availability, which suggest BECCS would be cheaper than, for example, deploying fuel cell electric vehicles (FCEV) in freight transport, and provide a cost optimal way to remain within a carbon budget (note for 1.5 °C, negative emissions provided by BECCS are crucial to remain with the carbon budget).
- IAM's use of BECCS in the latter half of the century should be interpreted in this light: BECCS potentially plays a valuable role in the system if it becomes available. The IAM result does not *forecast* BECCS will become available at scale.
- An additional layer of analysis is required on whether society can risk reliance on such a technology, or whether this represents an unacceptable risk. If the risk is acceptable and the technology can be part of a sustainable development pathway, policymakers may wish to prioritise early demonstration of BECCS (including sustainable sourcing of inputs) to demonstrate that it can be available at scale. If the risk is unacceptable, this may warrant a more significant emphasis on other technologies that can realise the mitigation potential instead.

Advantages, limitations and strategies to overcoming them

Advantages of IAMs

The key benefit of IAMs is their ability to provide quantitative and internally consistent outputs of what a decarbonised world might look like.[19] Provided input assumptions are properly updated, IAMs allow modellers to present a worldview based on the best available scientific understanding of the climate, emissions and their impact on global warming, technological advances, the economy, the land use system, etc. Put differently, IAMs provide views on how the world *could* be designed to address the global warming problem. Specifically, IAMs are useful to identify:

- *The role of different technologies in the system*. IAMs consistently highlight, for example, the prominent role renewables are expected to play. Modelled build out rates can be compared against the real world, to understand whether the world is on track to reach climate goals.
- *The need for policy.* IAMs can be used to model a reference or business as usual scenario, and compared against the rate of decarbonisation required. This allows for the identification of policy gaps. Furthermore, it has implications for investors who can determine, for example, whether investment in a new coal fired power plant can be reconciled with a climate scenario.
- *Policy trade-offs.* For example, nuclear technologies, carbon capture and storage (CCS) and several land use options come with considerable risks. IAMs can quantify what the additional cost might be of decarbonising without these technologies.

Furthermore, IAMs can be used to run 'experiments', for example, testing the impact of bans on certain emitting technologies (e.g. ICE sales bans) on the decarbonisation pathway.[20] Building on Box 1 and the

[19] See the IPCC's supplementary material for a fuller discussion of the advantages of IAMs: https://report.ipcc.ch/sr15/pdf/sr15_chapter2_supplementary_materials.pdf

[20] An extensive discussion of using scenarios and 'experiments' in IAMs is available in the scientific literature. See for example: https://www.sciencedirect.com/science/article/abs/pii/S2542435119303605

BECCS example, several IAM runs could be done with different constraints on the maximum amount of bioenergy that can be sustainably produced in the world. This would illustrate

- *Technology role:* The role BECCS can play in reaching 1.5C, and the £ cost savings to the global economy if large scale BECCS is available.
- *Policy need:* The large cost savings BECCS provides to the energy system, can provide an argument for the need to develop strong international policy frameworks to support sustainable bioenergy production.
- *Policy trade*-offs: Large scale bioenergy production will have implications on global land use, and (amongst other effects) reduce space for agriculture and likely increase food prices. IAMs highlight these trade-offs, to inform policy decisions.

Limitations of IAMs

IAMs necessarily make simplifying assumptions, which create several key limitations. Table 1 provides a comprehensive list based on a recent academic literature review, although it should be noted that many of these criticisms aren't limited to IAMs but extend to any existing scenario forecast. Two key criticisms are:

- *Policy and economic responses* are often not modelled in detail. For example, IAM's typically use a carbon price as a proxy for climate policy and assume that all decisions are made based on what is cost optimal, or, in other words, an implicit carbon price. In reality, a large proportion of climate policy will not be implemented through a carbon price. Furthermore, other factors beyond cost will determine the mitigation options that are selected. This needs to be taken into consideration by policymakers – the modelled IAM implicit carbon price should not directly inform e.g. the level of carbon taxes, nor should a high marginal carbon price in an IAM necessarily be seen as a sign of implausibility of a modelled scenario. Targeting decarbonisation policies (e.g. standards or targeted subsidies) to unlock the most expensive decarbonisation technologies means that in reality the average carbon price across the economy is likely to be significantly lower than the modelled implicit carbon price in an IAM. Furthermore, the co-benefits of many decarbonisation options, including from reducing air pollution and spurring innovation, mean that society may be willing to bear some of the cost.
- *A heavy reliance on modeller inputs, particularly cost assumptions.* Technology costs are difficult to forecast, as seen for example in the unexpectedly rapid reduction in solar PV cost over the past decade. IAM model runs from ~5 years ago have been significantly updated to account for recent trends, including much reduced solar costs, which has impacted IAM results. Rather than a limitation of IAMs per se, it reflects a far more general point, applicable to all models, that the outputs of a model can be critically sensitive to the input assumptions used. This is particularly challenging given the inability to accurately forecast innovation advances, which, by its nature, is inherently uncertain. Robust analysis can still be done, but needs to be transparent about assumptions, and recognise uncertainties, especially where technology is immature.

Table 20 Literature review of common criticisms of IAMs

Criticism/Limitation Category	Example of Specific Criticism	IAM Community Response
Lack of transparency	Difficult to see what drives results, both within and between models, owing to lack of availability of underlying assumptions and model structure details.	Much greater availability of data and details on models and inter-model diagnostic tests.
Inappropriate input assumptions	Low share of solar PV in relatively recent mitigation modelling exercises	Implementation of lower costs has led to a much larger share of total PV deployment.
Lack of clarity on model inputs versus outputs	Degree to which (radical) demand reductions are a result of reactions to price increases, or input constrains set by modeller	Different future scenarios of socioeconomic development (SSPs) have explicit analysis of degree of energy efficiency in baselines
Reliance of mitigation costs on baseline assumptions	Significant differences in baselines can result in significant differences in costs of achieving mitigation against these baselines. For example, continuing current trends in emissions or assuming current or stated policies are implemented would lead to a significantly different baseline forecast to which intervention scenarios are compared.	Different future scenarios of the shared socioeconomic pathways (SSPs)[21] have explicit analysis of emissions and fuels in baselines
Inadequate representation of innovation processes	Inadequate representation of innovation in low-carbon technologies, in particular spill overs from one technology's innovation to others.	IAM's are increasingly representing latest analyses of whole sector innovation rates (e.g. multi-cluster technology learning in transport where drive train improvements in BEVs can be translated into FCEVs). Nevertheless, endogenous representation of innovation is not mainstream.
Lack of representation of behavioural and economic systems that have mitigation potential	Behaviour changes such as transport modal shifts are, in general, not endogenously represented but instead defined by modeller inputs.	Some studies have explored specific modal shifts in an IAM framework. The representation, by the nature of a high level model, is high level.
Lack of assessment of real world feasibility	Limited discussion of feasibility of pathways given full consideration of social, political, economic, technical barriers and drivers.	Explicit acknowledgement of the focus on technical and economic feasibility
Lack of interaction with other policy goals	Lack of consideration of mitigation pathways in light of other policy goals such as energy security, SDGs	Growing number of studies specifically exploring these interactions and trade-offs

[21] See https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change for an explanation of the shared socioeconomic pathways.

Criticism/Limitation Category	Example of Specific Criticism	IAM Community Response
Lack of representation of fine temporal or geographical scale	Lack of representation of operation of electricity systems considering geographical dispersion of wind, solar resources, and systems balancing with high penetrations of renewables, as occurs in more detailed national electricity sector models.	Incorporation of finer time-slicing (e.g. at hourly level) to represent operation of storage and intermittent renewables in electricity systems

Source: Reproduced from Gambhir et al. (2019),). A Review of Criticisms of Integrated Assessment Models and Proposed Approaches to Address These through the Lens of BECCS. Available from https://www.mdpi.com/1996-1073/12/9/1747/pdf-vor

The limitations of IAMs have implications for any analysis which uses their outputs. The following section details how IMAGE is used in this project, and how the wider analysis within the project addresses limitations of IAM results.

How we use IAMs in this work

In this project, IAMs are used to identify cost-effective response strategies to climate change through a range of different plausible scenarios. To address the range of criticisms and limitations explored above, the results of IAMs will be complemented with substantial additional analysis across this project. We first briefly discuss the advantages of IMAGE and the selected scenarios, before discussing how we interpret IMAGE results, and how we ensure our interpretation is robust to IAM limitations.

The advantages of the IMAGE model

IMAGE is one of the prominent models in the IPCC-affiliated set of IAMs as it has been applied in a large number of climate change research projects. Among others, it has been used to develop the 2 degree (RCP2.6) marker scenario. IMAGE also has provided input to several IPCC assessment reports (e.g. AR4, AR5, and the 1.5 degree special report) and the UNEP emission gap reports. IMAGE will also contribute to the IPCC's forthcoming 6th Assessment Report by developing newly updated 2 and 1.5 degree scenarios.

IMAGE is characterised by a detailed technological description of the energy system, but has less detail on economics and policy instruments than economic models. Several types of IAMs have been developed, evolving from different classes of models with a specific disciplinary focus and point of entry. The common feature of all IAM models is that they describe a combination of the human and earth systems to gain a better understanding of global environmental problems. A key trade-off in IAMs is detail versus simplicity (required to allow modellers to set out trade-offs between scenarios). IMAGE provides high level of technological detail and detail on land-based processes, such as water, carbon and nutrient cycles. Compared to other IAM's its treatment of policy and economic processes is simpler.

A key advantage of IMAGE for this project is that no new model runs are needed, and recently developed and reviewed scenarios can be used. As set out in the proposal, we will use a recently developed set of scenarios. The key dimensions defining a scenario are set out in Figure 4. These scenarios contain i) the latest evidence on policy ambitions and the IPCC's carbon budgets, ii) most of the sectors of interest listed in the ITT, including detailed descriptions of the land use and food sector, iii) a relatively high disaggregation of geographies, distinguishing 26 regions of which 16 are ODA-eligible regions; these include 5 African regions, Central America, Brazil and 9 Asian non-OECD regions.

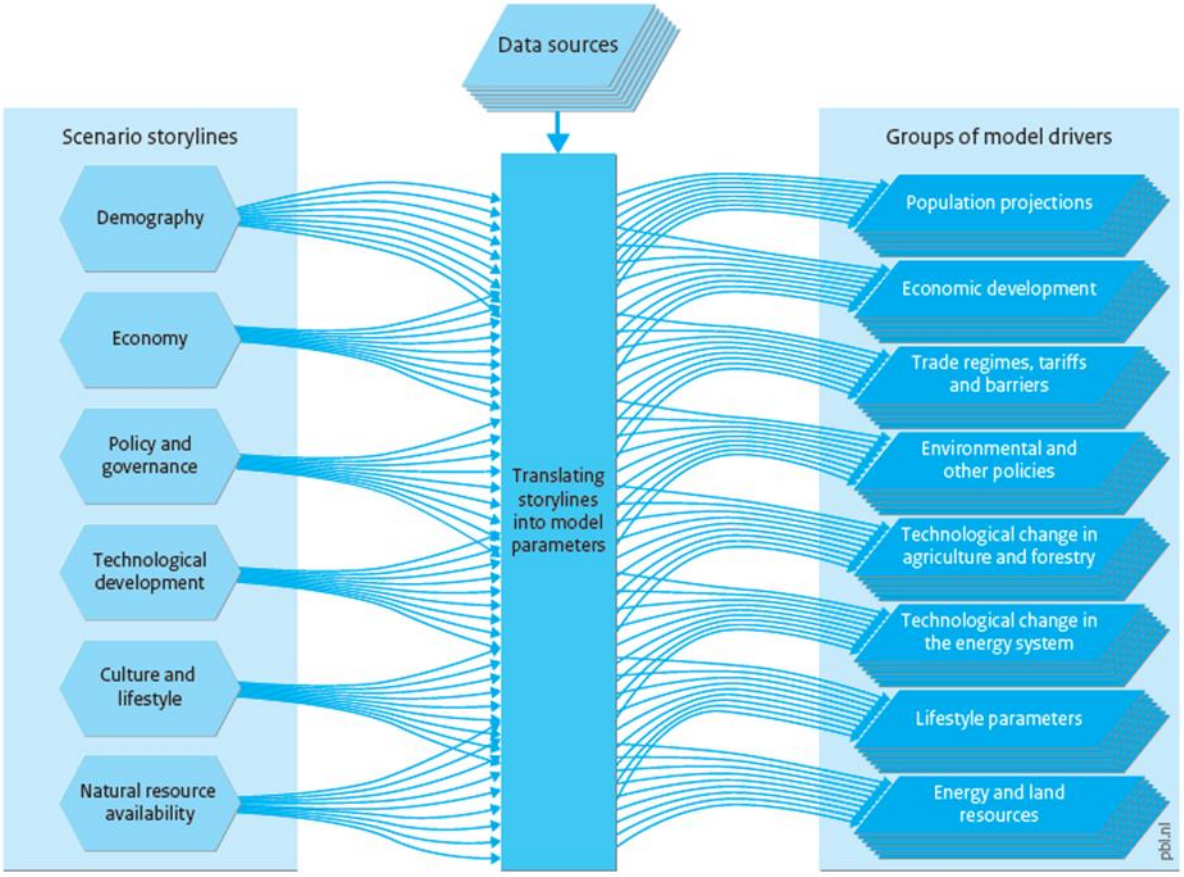
There is extensive further documentation available on the IMAGE model. Box 2 provides a set of relevant sources.

Box 2 Further documentation on the IMAGE model

- **Model description:** Stehfest et al. 2014 publication and https://models.pbl.nl/image/index.php/IMAGE_framework
- **Input assumptions:** https://models.pbl.nl/image/index.php/Variable_overview#External_parameters

  The external variable of interest is "Initial production costs" and "Initial technology costs". These are continuously updated based on the latest research and come from many different sources, with over >100 different initial cost inputs. Some key cost assumptions are provided below for solar PV as an example.
- **Previous publications:**
  - Van Vuuren D P, Stehfest E, Gernaat D E H J, Van Den Berg M, Bijl D L, De Boer H S, Daioglou V, Doelman J C, Edelenbosch O Y, Harmsen M, Hof A F and Van Sluisveld M A E 2018 Alternative pathways to the 1.5 °C target reduce the need for negative emission technologies *Nature Clim Change* **8** 391-7
  - Doelman J C, Stehfest E, Tabeau A, van Meijl H, Lassaletta L, Gernaat D E H J, Hermans K, Harmsen M, Daioglou V, Biemans H, van der Sluis S and van Vuuren D P 2018 Exploring SSP land use dynamics using the IMAGE model: Regional and gridded scenarios of land use change and land-based climate change mitigation *Glob Environ Change* **48** 119-35
  - Van Vuuren D P, Stehfest E, Gernaat D, Doelman J C, Van den Berg M, Harmsen M, De Boer H-S, Bouwman A, Daioglou V, Edelenbosch O, Girod B, Kram T, Lassaletta L, Lucas P L, Van Meijl H, Muller C, Van Ruijven B, Van der Sluis S and Tabeau A 2017 Energy, land use and greenhouse gas emissions trajectories under a green growth paradigm *Glob Environ Change* **42** 237–50
  - van Soest H L, de Boer H S, Roelfsema M, den Elzen M G J, Admiraal A, van Vuuren D P, Hof A F, van den Berg M, Harmsen M J H M, Gernaat D E H J and Forsell N 2017 Early action on Paris Agreement allows for more time to change energy systems *Clim Change* **144** 165-79
  - van Sluisveld M A E, Martínez S H, Daioglou V and van Vuuren D P 2016 Exploring the implications of lifestyle change in 2°C mitigation scenarios using the IMAGE integrated assessment model *Technological Forecasting and Soc. Change* **102** 309-19
  - Roelfsema, M. *et al.* Reducing global GHG emissions by replicating successful sector examples: the 'good practice policies' scenario. *Clim. Policy* **18**, 1103–1113 (2018).

Figure 4 Scenario definition in IMAGE



Source: PBL

Scenario selection

The scenarios used for this project were developed in the European project CD-LINKS (https://www.cd-links.org/), supplemented by selected scenarios of Van Vuuren et al, 2018. The advantage of using the CD-LINKS scenarios is that other models have run similar scenarios (using the same model protocol), so that our results can be put in context and compared to those results, but at the more aggregate level of non-OECD economies rather than the 16 non-OECD regions represented in IMAGE. All these scenarios are based on the Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs) framework. The SSP-RCP scenario framework is commonly used in scenario analysis, as it provides a common framework that considers uncertainties in socio-economic developments with differing challenges for mitigation and adaptation.

- *The SSPs* describe plausible alternative trends in the evolution of society and natural systems over the 21st century at the level of the world and large world regions (Kriegler et al. 2012). SSPs consist of two elements: a narrative storyline and a set of quantified measures of development.
- *The RCPs* represent trajectories for the development of greenhouse gas emissions and concentrations. These pathways may be affected, to a greater or lesser extent, by the introduction of mitigation policies.

This work will consider a 1.5-degrees Celsius scenario, several 2-degrees Celsius scenarios and a stated policies scenario, otherwise referred to as the business-as-usual.

- The stated policies scenario (also referred to as "NPI" scenario or "business-as-usual" scenario) is one in which only current implemented energy and climate policies are considered. That is, there is no specific carbon budget in this scenario. This scenario is considered the business-as-usual scenario and is helpful to contrast with more ambitious climate mitigation scenario to understand the climate action gap

- 2-degrees scenarios. Carbon budgets for these scenarios are set to align with "well below 2 degrees" i.e. a probability of 66% of staying below 2 °C. There are various plausible pathways to reaching 2 degrees. To capture this uncertainty, and identify where mitigation potential is heavily influenced by changes in scenarios (e.g. behavioural change, or rapid renewable cost declines), we will consider the range of mitigation potential across the following scenarios:

  - A "Default 2 degree" scenario. In this scenario it is assumed that national climate and energy policies were implemented until 2020, after which emission reduction measures are implemented in a cost-optimal manner across greenhouse gases, regions, and over time.

  - A "NDC 2-degrees" scenario, in which decarbonisation actions follows current NDCs until 2030, after which decarbonisation intensifies to meet a 2 °C target. Note, this is effectively a "delayed action" scenario, given in an 'optimal' pathway, significantly more action (beyond the NDCs) would be taken earlier.

  - A "lifestyle" scenario, in which consumers change their habits towards a lifestyle that leads to lower greenhouse gas emissions. This includes a less meat-intensive diet, less CO_2-intensive transport modes, less intensive use of heating and cooling and a reduction in the use of several domestic appliances. This scenario will allow us to highlight the reduced mitigation potential and investment need in "hard to treat" sectors where more action is taken by consumers.

  - A "renewables" scenario (otherwise known as the "central power scenario", with higher electrification rates in all end-use sectors, in combination with relatively ambitious assumptions on the integration of variable renewables and on costs of transmission, distribution and storage. We choose to use IMAGE's renewables scenario as our "central power scenario", due to uncertainty over the high rates of BECCS deployment and the relatively small role of renewable variable renewables in IMAGE's 1.5-degrees scenario.

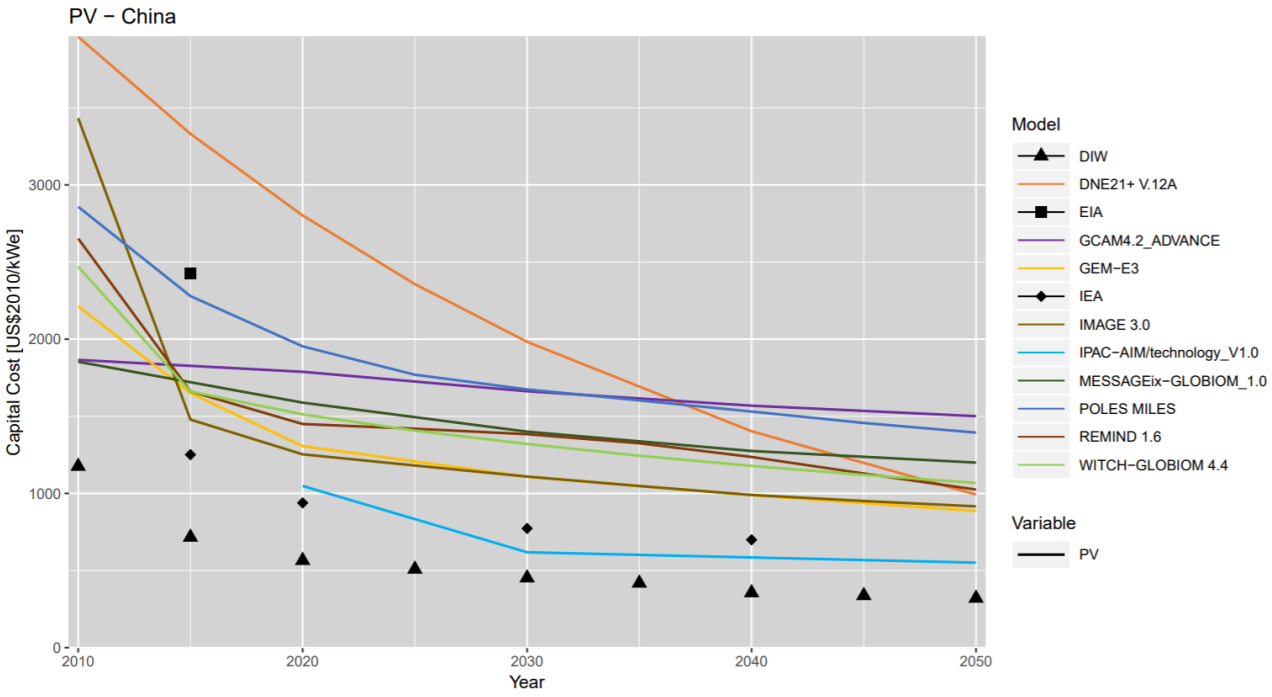
- 1.5-degrees scenario. A key factor influencing mitigation potential and investment need is the level of climate ambition. A 1.5 °C carbon budget is less than half that of the available 2°C budget, which dramatically increases the depth and rate of decarbonisation required. Whereas 2°C scenarios have some plausible headroom in their carbon budget, the carbon budget for 1.5°C is very tight, which leaves little room for flexibility, and hence the variation between possible 1.5°C scenarios is far smaller than that between 2°C scenarios. Put differently, all mitigation options need to be deployed to (close to) their maximum potential. BECCS, for example, will play a large role in the 1.5 degrees scenario. As discussed further in the Non-Variable Renewables Opportunity Report, deployment of BECCS ought to be treated with caution.

With regard to socio-economic assumptions, we have assumed middle-of-the-road developments (SSP2) for all the scenarios. While differing socioeconomic developments will influence total investment needs, the relative importance of different mitigation measures depends much more on the mitigation pathway strategy itself than on socioeconomic developments. We therefore decided to focus on different mitigation strategies rather than on different socioeconomic developments.

As further explained in Box 3 below, it is challenging to present a like-for-like comparison of technology cost input assumptions across different models, as these model assumptions represent different types of costs and feed into different types of modelling frameworks. IAMs internally use different cost assumptions in

different scenarios, across different regions, and over time. Krey et al (2019) provide a comprehensive comparison of technology costs across IAMs. Figure 5 presents, as an example, solar PV capital costs in China for a set of IAMs, as documented by the study. As can be seen, in the case of solar PV in China, many IAMs use costs assumptions significantly above costs that are currently observed in the market by the IEA. In response to the Krey et al findings, the IMAGE team have adjusted their solar PV costs to reach $600-700/kW by 2040 in some regions. IMAGE costs for other technologies covered in the Krey et al study appear more closely aligned with IEA projections, but notably, as discussed elsewhere in this note, these are likely to be wrong (either too high or too low) and will need to be adjusted over time.

Figure 5 Solar PV capital costs in China across different IAMs



Source: Krey et al (2019)

How we calculate mitigation and investment need

For the purposes of this project, we identify the contribution to decarbonisation of different mitigation options in the selected IMAGE scenarios. We will focus on the emissions reduced (mitigation impact) and investment need of different mitigation options (e.g. solar PV). To distinguish between short-term and long-term effects of different mitigation options, we will present results for 2020-2030 and 2020-2050.

- *Total required investment per option* is calculated by forcing the model to adhere to a certain carbon budget. This is done by applying a price on carbon, which changes the relative costs of fuels and stimulates energy efficiency improvements. The carbon price trajectory is determined in such a way so that the target is achieved. For more stringent targets, the carbon price will therefore increase more sharply and to higher levels to make the required investments in low-carbon technologies profitable. The investment required into different mitigation opportunities is then represented as the cumulative capital expenditure on the total mitigation that needs to be achieved, as determined by the model's optimisation, which can be split out by sectors, regions, and time periods as needed.
- *Mitigation impact of opportunity:* Standard model output includes total primary and final energy use, CO_2 emissions by sector, energy mix by sector, and total energy investments. Contrasting the reference scenario with a range of mitigation scenarios provides insight in the required change in the

energy mix and land use. We apply a decomposition analysis, specifically developed for this project, to determine the impact of individual mitigation options on the change in emissions.

Ensuring conclusions drawn from IMAGE are robust

The project will take three complementary approaches to ensure conclusions informed by IMAGE results are robust. As explained above, the future is uncertain, and hence quantitative modelling results should be interpreted as guides on the plausible importance of opportunities, rather than forecasts. The project will endeavour to highlight where IMAGE results are robust to differences in scenarios, model inputs, and other analyses. For example, we will highlight that there is relative certainty about the mitigation potential and investment need in variable renewables as a group, and less certainty about whether solar or wind will be the dominant variable renewable technology. We will test the robustness of conclusions with three criteria:

1. *Robustness of conclusions against variation driven by scenario design in IMAGE:* To mitigate the risk that conclusions are biased by modeller decisions on IMAGE inputs, we consider the specified range of IMAGE scenarios, quantifying how they cause mitigation potential and investment need to vary, and will identify drivers of differences between scenarios.

2. *Robustness of conclusions against variation between IMAGE and other IAMs:* The project contextualises IMAGE results against other IAM results generated as part of the CD-LINKS project, involving a set of prominent scenarios that were part of IPCC SR1.5 and updated thereafter, to capture where differences in modelling frameworks (and different input assumptions) drive significant output differences. Where possible, ranges are quantified. This is discussed further in Box 3.

3. *Robustness of the limitations of IAMs as a modelling class:* The broader limitations of IAMs are addressed through supplementary literature review, which addresses issues associated with sustainable development, market failures, innovation potential and political economy constraints. Where studies outside of the IAM community might give quantified results of mitigation potential and investment need, these are also reported.

Phase 1 contextualises IMAGE results at a high level, whereas Phase 2 undertakes a more through contextualisation. Given the additional analysis required to fully contextualise IMAGE results is labour intensive, most of this effort will be focussed on shortlisted opportunities.

- **In Phase 1,** IMAGE outputs are used to shortlist opportunities for in depth analysis. To do this, we need to be confident of the order of magnitude of IMAGE outputs, but do not require high accuracy. To ensure we understand the robustness of the IMAGE outputs, we will do the following:

  - *Quantitatively show ranges of mitigation potential and investment need across IMAGE scenarios.* Where these are large for an opportunity, we will highlight what drives this. For example, CCS mitigation potential is significantly lower in the IMAGE electrification scenario, highlighting that more optimistic assumptions on renewable costs drive down CCS mitigation potential. Where other comparable IAM results are available from the CD-LINKS set of models covered in the IPCC SR1.5 report, we will highlight the wider IAM modelling range (note, this may not always be possible quantitatively).

  - *Qualitatively highlight disagreements across the literature and other modelling suites.* Other IAM scenarios and studies such as the IEA World Energy Outlook, Shell Sky Scenario, etc. provide scenarios with significantly different roles for opportunities such as hydrogen. Based on a brief review of the sources listed in the inception report, discrepancies with established sources (e.g. Project Drawdown) on mitigation potential and investment need will be highlighted.

- **In Phase 2,** a more thorough understanding of uncertainty is required. To this end, a comprehensive review of alternative assessments of mitigation potential and investment need will be carried out, as well as substantially more detailed additional analysis. This analysis will consider barriers which may mean IMAGE results of mitigation potential are implausible.
    - ◊ *Reasons for overestimating mitigation potential and investment need:* Political factors, economic market barriers, system barriers (e.g. insufficient transmission infrastructure), environmental barriers, etc.
    - ◊ *Reasons for underestimating mitigation potential and investment need:* Innovation potential, cross-sectoral spill-over benefits, wider development impacts.

Box 3 Comparing IMAGE inputs and outputs to other IAMs and literature

- **Previous work has shown IMAGE results are comparable, and yield similar conclusions, to other long term modelling efforts**. The CD-LINKS IAM intercomparison project contributed scenario outputs to the IPCC SR1.5 analysis and was subsequently updated. CD-LINKS consisted of scenarios from IMAGE, AIM/CGE, MESSAGEix-GLOBIOM, POLES, REMIND-MAgPIE, and WITCH-GLOBIOM. Building on this analysis, McCollum (2018)[22] shows that for the NDC and default 2 °C scenario, global-average annual energy investments in the period 2016-2050 as calculated by IMAGE strongly resembles those by the IEA and IRENA, although other IAMs generally show somewhat higher investments.
- **The techno-economic assumptions across IAMs vary considerably.** As set out in a review by Krey et al (2019),[23] input assumptions and technological representation of key decarbonisation technologies vary significantly across models. As noted in the paper, this range in techno-economic inputs reflects large ranges in the literature on technology cost expectations. The paper notes the importance of the techno-economic representation in modelling frameworks as well as cost inputs themselves. This means comparing IMAGE input assumptions to other sources directly is not necessarily meaningful without a full analysis of how the technology is represented in the model.
- **Given this, we intend to focus our robustness analysis on comparison of IAM outputs from the CD-LINKS project, highlighting where this may be driven by relatively "optimistic" or "pessimistic" views on technology costs, where relevant and meaningful.**

[22] McCollum D L, Zhou W, Bertram C, De Boer H S, Bosetti V, Busch S, Després J, Drouet L, Emmerling J, Fay M, Fricko O, Fujimori S, Gidden M, Harmsen M, Huppmann D, Iyer G, Krey V, Kriegler E, Nicolas C, Pachauri S, Parkinson S, Poblete-Cazenave M, Rafaj P, Rao N, Rozenberg J, Schmitz A, Schoepp W, Van Vuuren D and Riahi K 2018 Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals Nature Energy 3 589-99

[23] Available from https://www.sciencedirect.com/science/article/pii/S0360544218325039?via%3Dihub

Table 21 summarises how our approach maps onto commonly referenced IAM criticisms.

Table 21 Approach to interpreting IMAGE results robustly

Criticism/Limitation Category	Approach to ensure robustness of conclusions
Lack of transparency	Fully documented IMAGE inputs and model setup
Inappropriate input assumptions	Modelling outcomes will be compared against other IAM results to test robustness of conclusions
Lack of clarity on model inputs versus outputs	Fully documented IMAGE inputs and model setup
Reliance of mitigation costs on baseline assumptions	Contextualise by referring to *current* state of the world as well as baseline scenario. E.g. additional solar deployment in 2 degree scenario in 2030 will be related to reference scenario deployment in 2030, as well as to current deployment levels. This will provide additional context on the scale of growth required from today.
Inadequate representation of innovation processes	Innovation processes are represented using assumptions on cost reductions. We can test these by comparing outputs to other IAM model runs. In addition, innovation potential and sectoral spill overs are separately assessed in phase 2 to highlight the dynamic benefits of investment in a particular opportunity which supports innovation (e.g. lowers costs).
Lack of representation of behavioural and economic systems	In phase 2, we will conduct additional analysis around: • *Political and governance barriers* will be assessed per geography, to test the realism of suggested IMAGE investments • *Local system characteristics,* and availability of inputs to highlight local feasibility • *Financial absorption* capacity will be assessed as part of feasibility of proposed investments
Lack of assessment of real world feasibility	
Lack of interaction with other policy goals	
Lack of representation of fine temporal or geographical scale	Additional analysis will highlight country specific barriers to investment levels produced by IMAGE.

Source: Vivid Economics

Company profile

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

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

Contact us

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

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