climateXchange

Scotland's centre of expertise connecting climate change research and policy

ClimateXChange

Centre of Expertise on Climate Change

End of Programme Report 2016-22

Contents

List of acronyms

CAZ – Clean Air Zone
CCC – Committee on Climate Change / Climate Change Committee (name changed in 2020)
CCF – Climate Change Fund
CCP – Climate Change Plan: Third Report on Proposals and Policies 2018-2032
CCRA – Climate Change Risk Assessment
CCP – Climate Change Plan: Third Report on Proposals and Policies 2018-2032
CCPu – Update to the Climate Change Plan 2018-2032, published December 2020
CCUS – Carbon Capture Utilisation and Storage
CoEs – Centres of Expertise
COP26 - 26th UN Climate Change Conference of the Parties
CREDS – Centre for Research on Energy Demand Solutions
CXC – ClimateXChange
DACC – Direct Air Carbon Capture
DH – District Heating
ECCLRC – Environment, Climate Change and Land Reform Committee (Scottish Parliament)
EV – Electric Vehicle
FR – Forest Research
FRM – Flood Risk Management
GHG – Greenhouse Gas
IEA – International Energy Agency
IPAM - International Platform on Adaptation Metrics
IPCC – The Intergovernmental Panel on Climate Change
IUCN – International Union for the Conservation of Nature
LHEES - Local Heat and Energy Efficiency Strategies
NBS – Nature-based Solutions
NERC – Natural Research Environment Council
NET – Negative Emissions Technology
NGESCO - National Grid Electricity Service Operator
NTS – National Transmission System
NZETC – Net Zero, Energy and Transport Committee (Scottish Parliament)
OCEA – Office of the Chief Economic Advisor
PDRF – Post-Doctoral Research Fellow
PFR – Property Flood Resilience
RESAS – Scottish Government's Rural and Environment Sciences Analytical Services Division
SCCAP – Scottish Climate Change Adaptation Programme
SCCAP2 – Second Scottish Climate Change Adaptation Programme
SEEP – Scottish Energy Efficiency Programme
SEFARI – Scottish Environment, Food and Agriculture Research Institutes
SEPA – Scottish Environment Protection Agency
SRUC – Scotland's Rural College
TIMES – The Integrated MARKAL-EFOM System
UKERC – UK Energy Research Centre
UKRI – UK Research and Innovation
ULEV – Ultra Low-emission Vehicle

1 Director's Introduction

The need for urgent action on climate change has never been so stark, with the intensity and frequency of severe weather events increasing, and further warming threatening to magnify the already grave risks to food, water and energy security around the world. Effective and sustainable climate action requires a robust evidence base informed by the best research and understanding available.

This is why we are proud that ClimateXChange, at the completion of its second programme period (2016-2022) as Scotland Centre of Expertise on Climate Change, is an established and highly valued partner working right across the Scottish Government to produce such research. Our work with the wide range of policy teams in the Scottish Government reflects the breadth of areas involved in delivering a just and sustainable transition to net zero, both in Scotland and internationally. Our approach has been to embed timely academic analysis and rigour in their work, and to build what is now a very large and diverse network of leading researchers keen to engage with climate policy.

During this second programme period the number, size and range of projects undertaken by ClimateXChange and the research providers it works with has expanded rapidly to meet the fast-growing demand. Our established and trusted model has continued to meet near-term policy demands for evidence via a swathe of rapid response projects, alongside longer-term strategic policy needs. Increasingly, our work has built on the legacy of past work, connecting multiple research areas and providing the rounded evidence base required for well-integrated policy responses.

This end of programme report gives an overview of our research, knowledge brokering and expert advice over the past 6 years, and an insight into the even greater richness and diversity of the evidence it will now provide in the third programme period.

Prof. David Reay, Policy Director, ClimateXChange

2 Executive summary

ClimateXChange's remit is to provide research evidence and expert advice for policy that is timely, accessible and relevant. We support athe two-way understanding of the science needs of policy and the capabilities of research. This helps produce outputs focused on critical policy questions in the relatively short timescales required. The programme and each project is built on the principles of knowledge exchange; bringing policy and practice perspectives and experiences to the research design, and sharing academic ideas, evidence and insights in accessible, useful ways. To achieve these goals three core functions are coordinated and facilitated through the ClimateXChange Directors and Secretariat: Project management; research commissioning, and; knowledge exchange activities.

Our programme offers a flexible approach which reflects the specific requirements of each project, using full time research fellows, researchers across SEFARI, Scotland's environment, food and agriculture research institutes, or contracting researchers through open tenders in areas where we do not have the required expertise. Each project is defined by the complexity of the issue, the number of stakeholders involved, the degree of multi-disciplinarity of the research, the timelines, and the audience. Our knowledge exhange activities bring policymakers together with the research community and wider stakeholders to develop the foundations for policy and research projects.

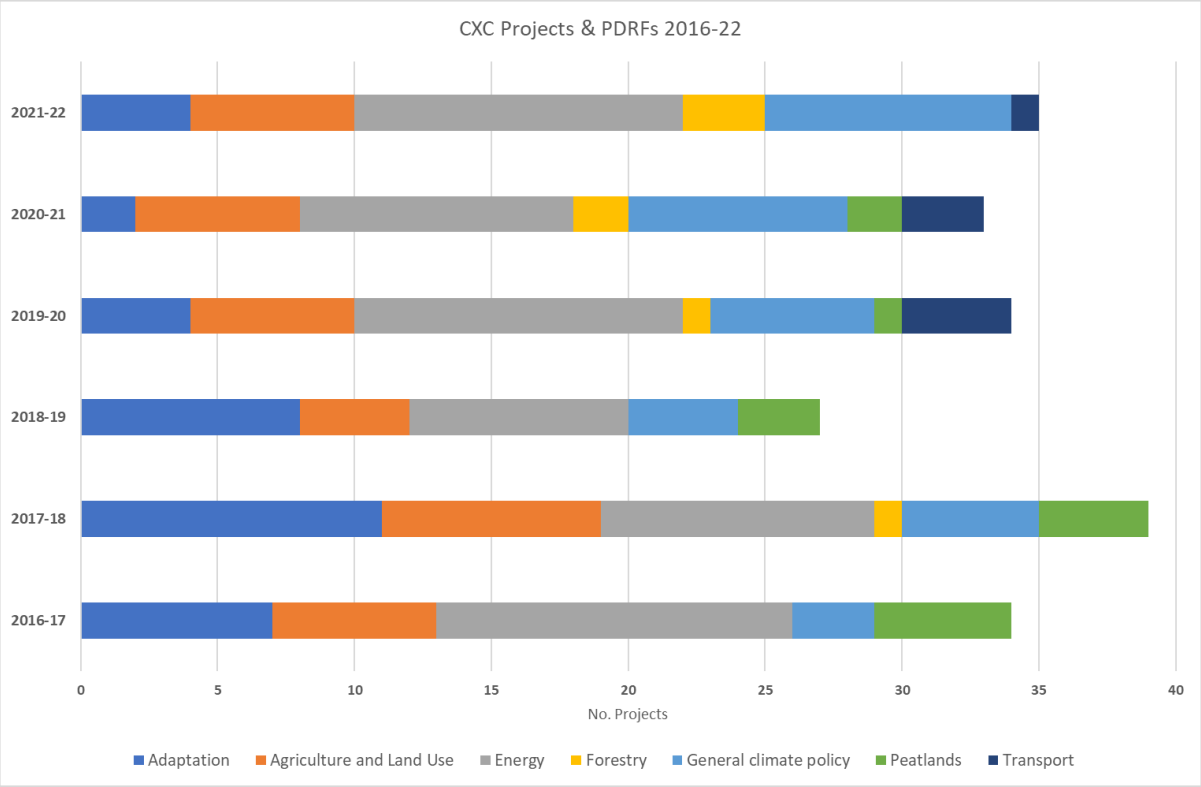
The programme period 2016-2022, the original five year period extended by a year due to the Covid pandemic, has seen climate change steadily rising up the agenda in Scotland, across the UK and internationally. The ClimateXChange programme has grown correspondingly.

Our work since 2016, with an ever increasing number of policy teams, reflects the breadth of areas involved in delivering a net zero Scotland by 2045 – five years ahead of the rest of the UK – as set out in the landmark Climate Change (Scotland) Act (2019) and reflected in the Scottish Government declaring a Climate Emergency. Throughout the programme period research support for the draft Climate Change Plan (the third Report on Proposals and Policies) has been carried forward through to preparation of the Climate Change Bill, the draft Energy strategy and the second Scottish Climate Change Adaptation Programme.

Figure 1 (below) provides an overview of the breadth of projects delivered throughout the programme period[1]. This demonstrates that, although the range of work CXC has been providing for the Scottish Government has been broadly consistent, with a similar number of projects on 'energy' and 'agriculture and land' use each year, the work programme became more diverse as the programme progressed. There has been a steady increase in projects described as 'general climate policy' and an emergence of transport-based projects in recent years. This highlights the increasing engagement with policy teams across the Scottish Government and a broader contribution to climate change policy development.

[1] Please note that: 1) The chart describes the number of projects delivered per year; projects varied significantly by value and duration and overall value has increased. 2) Many projects could be categorised across multiple themes / categories so data should be taken as indicative only

FIG 1. OVERVIEW OF NO. CXC PROJECTS THROUGHOUT THE PROGRAMME



Despite all staff across research and the Secretariat working from home as a result of the pandemic, we delivered more commissioned projects in 2021-22 than in any previous year, spending just over £700,000 on commissioned research, on top of the work done by our Post-Doctoral Research Fellows (PDRFs) and the capacity available through the SEFARI institutes. This came on top of a 50% increase in commissioned work during 2020-2021, and represents a considerable increase in project delivery. This shift towards more commissioned work towards the end of the programme (i.e. work delivered outwith the SEFARI insititutes) also reflects the broader contribution of CXC across diverse policy teams and subject areas.

This report gives examples of how we work on policy challenges from a number of angles to provide useful, accessible and actionable research and expertise.

The energy transition, central to the CCP, has been the focus for a significant number of comissioned research and fellowships. Engagement and evidence has informed the Heat in Building Strategy, the Energy Strategy, Scotland's Energy Efficiency Programme, the Heat Network Delivery Plan, and included technical modelling for Scottish TIMES and evaluating policy through work on e.g. the Local Heat and Energy Efficiency Strategy.

Forestry, agriculture and land use have been central work areas from CXC's inception in 2011. During this programme period we have worked with a range of stakeholders through commissioned work and fellowships to provide practical insights and expertise across a range of mitigation and adaptation issues. In addition to policy relevant research, we have delivered a number of briefings, practical tools and data management approaches.

Land use and nature based solutions have also been central in our work to support Scotland's approach to building climate resilience. We have worked with stakeholders

across the UK on risk assessment, impact and action indicators, and particular challenges like practical management of flood risk as a result of the changing climate.

Across climate change policy the net zero agenda has led to a focus on cross sector research, e.g. informing how the emissions impact of infrastructure investments are assessed, and working with stakeholders across business, industry and planning. We also delivered a number of projects informing public engagement approaches for net zero and contributed expertise to Scotland's Climate Assembly.

Towards the end of the programme the Covid-19 pandemic impacted both how CXC worked and the projects we delivered. This included a particular focus on learning from the Covid pandemic, and research to support a 'Green Recovery'.

3 External context

Climate change has steadily risen up the Scottish Government policy agenda during the programme, focused on a net zero Scotland by 2045 – five years ahead of the rest of the UK – as set out in the landmark Climate Change (Scotland) Act (2019) and reflected in the Scottish Government declaring a Climate Emergency.

The shift in Scottish energy policy focus, and divergence from the UK agenda on energy, became more pronounced during the programme period when the Scottish Government announced its preferred policy position to not support the development of unconventional oil and gas in Scotland. Other examples of divergence included the commitment to remove the need for new petrol and diesel cars by 2032, eight years ahead of the then UK target.

From 2019 this meant a marked step change in Scottish Government commitment to address climate change and ensure a just transition to a low-carbon economy. While the Covid-19 pandemic continued to dominate public life for much of the year, 2021-22 saw an increased focus on the climate emergency, especially in the run up to November's COP26 climate conference held in Glasgow.

Across all parts of our work, the UK policy context has been characterised by challenges and uncertainty around Brexit and its potential implications for climate policy and research. At an international level, the IPCC's finding that a 1.5C target is possible only with 'deep emissions reductions', and 'rapid, far-reaching and unprecedented changes in all aspects of society' created further urgency in both policy development and implementation. This was followed by the Climate Change Committee stating that Scotland could achieve net-zero emissions of all greenhouse gases (GHGs) by 2045, as reflected in current Scottish Government policy.

A key priority for CXC is to align research programmes and make the best use of available resources. For example, following the establishment of the National Centre for Resilience (NCR), CXC has helped develop and support its research and training agenda. We are also working closely with the Centre for Knowledge Exchange and Impact (now SEFARI-GATEWAY – Centre of Expertise on Knowledge Exchange) and the other centres of expertise (CREW, EPIC and Scotland's Plant Health Centre) to coordinate management, share learning and communicate approaches. We have also worked closely with The Climate Change Committee, a number of research groups

and networks across the UK and e.g. engaged on the UKCP18 Non-Government Users' Group,

In 2018-19 the Mid-Programme Review of the Centres of Expertise (CoEs) led to closer working with the other Centres, and greater cross-Centre learning.

Over the programme period we have worked with colleagues across the Scottish Government to develop different ways to engage more widely across the Scottish Government and over time. To ensure the best use of limited resource, an advisory group with representatives from policy and analytical teams across the Scottish Government, as well as our principal funder, RESAS, was trialled but not taken forward. At the end of the programme the Scottish Government has a well-established biannual bid process, and the CXC Secretariat work closely with the assessment panel to review bids on their relative value in developing Scotland's climate change policies.

4 Internal context

At the start of this five-year programme phase, CXC changed the membership of the CXC Directorate to better align with the programme set out in our five-year proposal. Following the changes the Directorate membership reflected the range of CXC research projects and institutions more closely, and the Directorate has been better able to provide strategic advice about the direction that CXC research needs to take.

A mid-term review in 2018/19 identified a number of areas for development. We have worked with Directors, Directorate and the other Centres of Expertise to improve our processes. This has resulted in refined processes and procedures, reflected in a comprehensive handbook used by all staff.

In 2018-19 we also trialled new methods of monitoring and evaluating our impact beyond the annual reporting cycle. The nature of CXC's knowledge exchange model means that the impacts of our work often take some time to become evident. We continuously reflect on our model, and how CXC could adapt and evolve to better report the outcomes of our work in responding to the Scottish Government's needs.

To track impact we apply a Digital Object Identifier (DOI) number to all CXC outputs which helps with standardising archiving and attribution. This is valuable to us and our research partners in tracking the impact of the research produced by CXC.

The mid-point in the programme also saw a number of staff changes. Programme Manager Ragne Low left CXC in 2018 and Dan Barlow took over the role. Following Prof Andy Kerr's departure from University of Edinburgh in 2018, the CXC Policy Director role was taken up by Dr Mark Winskel (an existing member of the CXC Directorate and Senior Lecturer in the School of Social and Political Science, University of Edinburgh). Prof Dave Reay (Chair in Carbon Management and Education, School of Geosciences, University of Edinburgh) assumed the position of Principal Investigator, and took over as Policy Director in 2019.

The secretariat has also grown with the addition of adaptation project manager capacity from 2018 and a part time communications officer from 2020. This reflects the full research budget now being managed through the Secretariat, and this requiring both capacity and expertise. All secretariat staff work with colleagues across

the Edinburgh Climate Change Institute to coordinate with other Scottish Government funded programmes and initiatives like Sustainable Scotland Network and Adaptation Scotland.

The Covid pandemic meant all staff worked from home from March 2020, and are still at programme end largely working from home. We have developed effective routines for cross-team support and staff are keen to continue a hybrid working model that will also reduce the need for project teams to travel.

The existing partnership successfully re-tendered to deliver the next research programme as the Centre of Expertise on Climate Change, this time a three-year contract from April 2022 (with an option to extend for up to two years). The partnership - University of Edinburgh, University of Aberdeen and the James Hutton Institute - expanded to include the University of Strathclyde. Prof Stuart Galloway was appointed as Director, representing Strathclyde.

5 Outputs and outcomes

5.1 Energy

5.1.1 Stakeholder engagement

a) Energy transition and security of supply

The UK power sector is undergoing profound changes as it transitions from fossil fuel generation to renewable and other low-carbon sources of energy. Engaging with energy companies, system operators, generators and other stakeholders has been an important element of designing policy and ensuring security of supply. To this end, in 2017-18, CXC participated in the 'Disruption and Continuity in UK Energy System Futures' research project, in partnership with UK Energy Research Centre (UKERC). The project involved a detailed survey of almost 130 energy researchers, policymakers and stakeholders. Subsequently, CXC appointed a research fellow to examine further the sustainable security of supply in a low-carbon electricity system in Scotland. Among other outputs, the fellow collected and reviewed the opinions of industry experts and stakeholders via an online survey in May 2021. This was followed by a round table event (under Chatham House rules) in July 2021. In a further report, the fellow examined emerging system operability concerns and the role of the British Electricity System Operator - National Grid ESO (NGESO) - in managing the power system.

5.1.2 Policy relevant outputs

a) Heat in Buildings Strategy

To support the Scottish Government's Heat in Buildings Strategy (October 2021), CXC commissioned and coordinated a substantial body of research on heat decarbonisation, one of the most challenging areas for achieving net zero. Over a two-year period, we produced more than a dozen pieces of research in this area, providing a solid evidence base for the strategy. The research was wide-ranging and accessible, highlighting CXC's ability to access a breadth of expertise as well as our skill in communicating complex issues simply. We also facilitated valuable knowledge exchange between academic researchers and policymakers. For example, we organised a Scottish and Danish Governments' workshop, over two half-days, to consider policy-relevant lessons from research on heat decarbonisation for off-gas grid residential buildings.

b) Energy efficiency fellow

CXC's PDRF on Energy Policy Effectiveness was seconded to the Scottish Government's Heat and Energy Efficiency policy team for six months between October 2018 and March 2019, and then on a part-time basis until September 2019. He subsequently produced two reports on heat decarbonisation: one reviewing policies in Europe; the other examining international lessons on technology phase-out.

5.1.3 Impact on policy

a) Energy Strategy

In 2016-17, Ragne Low, then CXC Programme Manager, undertook a six-month part-time secondment to the Scottish Government's Energy Division to help draft Scotland's first Energy Strategy (December 2017) and work on several projects related to onshore wind policy. Among other things, Ragne produced a policy statement on peatland and energy, which formed part of the Scottish Government's consultation on the draft Energy Strategy. She was also instrumental in establishing the principles for public engagement on energy enshrined in the strategy.

b) TIMES model

The Scottish TIMES energy system model is built using the TIMES platform, a modelling tool developed by the International Energy Agency (IEA), which details all Scottish energy flows and greenhouse gas (GHG) emissions. As such, it is a key tool informing Scotland's climate change policies and pathways; its reliability is therefore critical. Over the course of the programme, CXC researchers continued to help develop Scottish TIMES and its applications, and engaged stakeholders to scrutinise and improve the model. This included two reports (published in July 2017 and November 2018), led by a CXC research fellow, exploring the impacts of energy efficiency changes linked to Scotland's Energy Efficiency Programme (SEEP).

It also included a secondment from OCEA on TIMES model development and opening up the model to academic scrutiny, based within the CXC secretariat in 2017-18. The secondee gave several presentations and seminars, including on the Scottish model to the UKERC annual assembly. Many opportunities for collaboration with academics emerged during the secondment, including with CXC PDRFs working on energy economics, and energy system impacts of energy efficiency.

Finally, in 2020-21, we commissioned a technical review of the model from a leading independent expert (Prof Paul Dodds, UCL). This involved considering model inputs and performing diagnostic tests based on running the model with a test scenario. Further input on TIMES from Prof Dodds is scheduled for early in the 2022-25 programme.

5.1.4 Benefits to other stakeholders

a) District heating

In this programme, we produced three pieces of research on district heating (DH), which the Scottish Government has identified as a 'low-regret' option for heat decarbonisation. The first, published in 2018, reviews European regulatory models and their learnings for Scotland. Two further reports, published in 2020, provide an overview of more than 100 previous DH feasibility studies and also assess Scotland's waste heat potential – important information for local and national government and for industry stakeholders seeking alternative energy sources. As well as analysis, the study on previous schemes maps study locations and identifies common barriers, enhancing the Scottish Heat Map. The research on waste heat potential examines sources that could be used for DH and was cited in the Scottish Government's Heat Networks Delivery Plan of March 2022. It assesses the waste heat of 10 sectors, finding potential of almost 1,700 GWh across more than 900 sites.

c) Collaboration with UKERC and local energy stakeholders

In the Autumn 2016, CXC held two significant energy-related gatherings attended by a wide range of stakeholders: a CXC-UKERC Heat Summit and a conference on local energy systems. The summit, co-hosted with UKERC, brought together Scottish policymakers and leading UK researchers on heat transitions, identifying priority areas for research, policy and practice to support the decarbonisation of Scotland's heat. The conference, meanwhile, was attended by policymakers, community energy practitioners and other private, public and third sector stakeholders to discuss examples and exchange knowledge on the transition towards local energy systems. It produced a set of key research questions that were taken up across multiple institutions, in particular through a collaborative project between CXC and the Centre for Sustainable Energy on barriers and solutions in local energy economies.

5.1.5 Collaboration and multidisciplinary working

a) Consumers and the low-carbon energy transition

CXC undertook a wide-ranging multidisciplinary research project to support the Scottish Government in its work to promote consumer engagement and protect consumers as part of Scotland's energy transition. Working with CAG Consultants, a specialist sustainability organisation, and the Centre for Sustainable Energy, the national charity, we produced five interlinked reports, including a project summary. The research covers several disciplines, examining: changes to the energy landscape and potential impacts on Scotland's consumers; distributional impact modelling; domestic energy consumer types and existing segmentation approaches; and domestic energy consumer segmentation profiles. It draws on data associated with housing tenure, household income, rurality, and energy efficiency to create a set of eight consumer archetypes and provide a framework for exploring how the impact of energy policy changes may vary for different groups of consumers.

b) LHEES evaluation

Throughout the programme, CXC supported the SEEP by overseeing independent evaluation of Local Heat and Energy Efficiency Strategy (LHEES) pilots. This evaluation was carried out in three phases and aimed to inform Scottish Government future policy plans in relation to LHEES, as well as share lessons between local authorities and support their future work. The first phase, over 2017-19, in collaboration with the Energy Saving Trust, drew lessons from across 12 pilots. The Phase 2 pilots' evaluation, published in October 2020, focused on the organisational and social aspects, and a review of reports generated by the projects. Evaluation of the third and final phase of the pilots, published in October 2021 and involving nine local authorities, focused on areas with either high heat demand or a high proportion of off-gas-grid properties. In addition to these studies, CXC researchers fed into the second consultation on LHEES and the regulation of district and communal heating and participated in government-led stakeholder workshops on these issues.

5.2 Transport

5.2.1 Stakeholder engagement

a) Covid-19 and travel behaviour – a survey of employers

Working with Transport Scotland, in 2020, CXC moved quickly to gather information from business stakeholders across Scotland about the impact of Covid-19 on travel behaviours and future travel intentions. The research focused on employer attitudes after this group's views - as opposed to those of individuals - were identified as a key gap in the evidence base. Information was collected via an online questionnaire completed by almost 330 businesses. It included questions relating to the pre-COVID-19, lockdown and post-COVID-19 (future) periods. Ten follow-up discussions were held with questionnaire respondents, selected in part on the basis of their responses but also to represent different sizes of organisation, different sectors and examples from across Scotland.

5.2.2 Policy relevant outputs

a) ULEVs

Over the programme, CXC produced a significant body of work to support Scotland's transition to ultra low-emission vehicles (ULEVs). In 2019-20, we undertook research examining international leading practice to gather learnings relevant to Scotland. This included seven case studies to explore ULEV adoption levels and how these were achieved. A second phase of the research then matched examples of international leading practice on ULEV adoption against a range of ULEV market segments that had been identified through the 2019 CXC study, ULEV Market Segmentation in Scotland. This study segmented vehicle buyers by specific barriers and made policy recommendations to overcome these barriers and maximise economic opportunity for Scotland. Following on from this research, in 2020-21, we published a report on the economic impact of ULEV uptake. To help Transport Scotland develop interventions, the report identifies the economic impacts and the implications for policies to smooth the transition to ULEVs. The project steering group included representatives of Scottish Enterprise and Transport Scotland economists while our project manager joined the Transport Challenge Forum, established by the Energy Transition Partnership (ETP). The research was cited in the Just Transition Commission's final report.

5.2.3 Impact on policy

a) Clean air zones

A CXC research fellow (Dr Craig Morton) made a substantial contribution to the development of Scotland's Clean Air Zone (CAZ) policy. In 2016-17, he produced an influential report for Transport Scotland on the structure of Scotland's car fleet, which helped design a CAZ. Dr Morton also sat on the National Low Emission Framework Advisory Group and acted as an internal reviewer on the draft Building Scotland's Low Emission Zones strategy, working closely with Transport Scotland and SEPA. A

report on how regulation in the transport system could adversely impact certain groups was presented at the Scottish Transport Applications and Research conference, and shared with Edinburgh City Council and SESTran. Taking Edinburgh as an example, the report also assesses the level of vulnerability across south-east Scotland. Working with UKERC, the fellow also produced a Scottish Transport and Air Pollution model which was presented to the Scottish Government.

5.2.4 Benefits to other stakeholders

a) Last-mile delivery

This research provided the Scottish Government and other stakeholders with up-to-date information on a growing source of transport emissions - commercial vehicles used for home or workplace deliveries - partly because of the rise in online shopping. Our evidence review developed a profile of last-mile delivery in Scotland; produced a high-level estimate of the segment's GHG emissions; and collated commitments made by businesses operating in Scotland to reduce last-mile emissions. The report's findings were aimed at helping Transport Scotland engage with the freight and logistics industry and to identify challenges and opportunities for decarbonisation. The study also aimed to help local authorities and fleet operators, by providing a sample of information on commitments made by businesses in Scotland to improve sustainability.

5.2.5 Collaboration and multidisciplinary working

a) Future Mobility Systems

In 2019-20, CXC and Transport Scotland developed a PDRF project to understand public perceptions, user needs, and approaches to support uptake of future low-carbon mobility systems in Scotland. As with our earlier ULEV work, this involved a collaboration with the University of Leeds which hosted the fellow. Due to the Covid-19 pandemic, the project was refocused to reflect learnings from the crisis and linked to a UK-wide multidisciplinary research project, Covid-19 Transport, Travel and Social Adaption Study (TRANSAS). Other participants included the University of Oxford's Centre for Research into Energy Demand Solutions (CREDS) and the University of Stirling. Incorporating the CXC fellowship into TRANSAS enabled us to add questions regarding future mobility systems into the later waves of quantitative and qualitative fieldwork. The final report, published in late 2021, also responded to changed needs from the Scottish Government on an additional commitment, made in 2020, to reduce car kilometres by 20% by 2030. This topic was included for discussion in six two-hour focus groups conducted virtually in July and August 2021.

5.3 Forestry

5.3.1 Stakeholder engagement

a) Diversification in productive forests – stakeholder perspectives

CXC research, published in February 2020, actively sought the views of stakeholders on diversifying conifers in productive forests. Commercial forestry has become highly dependent on a small number of conifer species. Most research about diversification focuses on the biological and economic aspects. However, change in practice will only come if the people who produce, manage, harvest and buy the trees are willing and

able to work in different ways. The research is based on 55 in-depth interviews designed to capture the views and experiences of stakeholders, considering the implications of a shift in forest management.

5.3.2 Policy relevant outputs

a) Woodland adaptation and planning

CXC produced forward-looking research to understand the impact of a changing climate upon existing woodland and help develop contingency planning. In 2021, we published research identifying the current state of knowledge, and significant gaps, on drought risk in Scottish forests, including considering the policy and practice implications. The report drew on an extensive literature review complemented by interviews with Forest Research scientists involved in drought-related research. A broader 2018 study, meanwhile, looked at the role of contingency planning in climate change adaptation for the forestry sector in Scotland. Contingency plans provide economic benefits to forestry businesses, minimise the disruption to the natural environment, and support Scotland's forests in continuing to deliver the widest range of ecosystem services. The study explores which climate risks to the forest sector in Scotland may benefit from such plans.

5.3.3 Impact on policy

a) Woodland expansion

In the 2018 Climate Change Plan, the Scottish Government committed to expanding forest cover. A key challenge is identifying the land that is suitable for woodland; one task within the CCP, was to update the understanding of land suitability for woodland expansion for Scottish Forestry. The report provides a re-analysis of an earlier 2011 study. It outlines the opportunities and constraints for woodland expansion in Scotland, using a GIS spatial analysis: It increases the estimate of land area suitable in principle for woodland creation by 270,000 hectares to 2.96 million hectares. This is despite new restrictions on available land due primarily to improved mapping of the area of deep peat soils.

5.3.4 Benefits to other stakeholders

a) Afforestation and restocking on peaty soils

Our forestry work has direct benefits for Scottish Forestry and for land managers by informing practice and detailing its impact. Our 2018 report on afforestation and restocking on peaty soils, for example, examines the consequences of additional forestry activity on Scotland's high carbon content organic soils in the context of ambitions to increase woodland cover in Scotland to 25%. The report updates an earlier 2010 Forest Research report, drawing on new experimental studies, soil resurveys and model application. It was referenced in the Scottish Parliament in response to a question. We followed up on this research via an evidence discussion with Forest Research and Scottish Forestry in the form of a roundtable workshop, held in December 2021. This generated a briefing note for internal use to inform decisions on the potential for further research, including, and potentially beyond, CXC.

b) Agroforestry – potential benefits

Greater use of agroforestry in Scotland is one option that could help reach Scotland's target to increase woodland cover and help lower emissions, while also supporting

sustainable adaptation to a changing climate. A 2018 CXC report identifies the potential benefits of increased agroforestry practice in Scotland to both farmers and wider society, and aims to support wider discussion and implementation. Agroforestry is the integrated use of trees on a farm or small holding for a wide range of benefits. The study identifies the main agroforestry options applicable to Scotland. The benefits and challenges of each of the identified options are compared qualitatively, considering climate change mitigation and adaptation potential, wider benefits, monitoring metrics, market readiness and practicality of deployment in Scotland.

5.3.5 Collaboration and multidisciplinary working

a) Risk management and Scottish forestry

In 2018, CXC published a report on the lessons for Scottish forestry from risk management in the finance sector, led by a CXC Forest Research fellow. Risk management cannot eliminate risk but aims to take action to reduce the likelihood of risks occurring and to reduce the impact when they do. The study discusses several financial risk measurement and management approaches suitable to Scottish forestry, and considers the lessons of the finance sector, particularly during the recent financial crises. Many of the approaches concern reducing financial loss to ensure sector activities are preserved and supported. However, there are some lessons for wider preparatory approaches, and financial security itself will be an important factor in the resilience of the sector.

b) Woodland Carbon Code

Building on our 2018 CXC agroforestry report (see Section 4.3.4 above), CXC produced further research to assess the GHG emissions reduction potential of different forms of agroforestry suitable in Scotland. Understanding motivations for farm businesses to participate is critical - there has been growing interest in agroforestry systems as an opportunity to integrate land management objectives and contribute to meeting tree planting targets and generate GHG reductions and removals. The report therefore also examines the economic viability of adopting agroforestry practices including via carbon schemes, such as the Woodland Carbon Code (WCC) which could offer a route to financial incentives. Commissioned jointly by Scottish Forestry and the Agriculture and Climate Change team in Scottish Government, the July 2022 report finds strong evidence that agroforestry systems which are suitable for Scotland are, by themselves, generally financially viable. That is, as a land use system, they very often generate positive income for farmers.

5.4 Agriculture and land use

5.4.1 Stakeholder engagement

a) Agriculture and Climate Change Stakeholder Engagement Group

Between 2016 and 2020 CXC project manager, Dr Sarah Govan, attended the Scottish Government's Agriculture and Climate Change Stakeholder Engagement Group. This included giving a presentation in 2018 to the group on farming and adapting to a changing climate in Scotland. CXC facilitated the group's 2020

workshop exploring the science of climate change with specific reference to Scottish agriculture. The aim was to begin a conversation around the potential for systems change in Scottish agriculture, in response to a changing climate, based on the current science. The meeting brought together experts from science, farm business and government.

5.4.2 Policy relevant outputs

a) Nature-based solutions

Nature-based solutions is a term used to capture the ways in which natural processes can deliver positive outcomes. CXC research, published in June 2022, explores what is currently known about the potential to sequester carbon through active management. It assesses evidence for the GHG mitigation potential of four nature-based solutions in Scotland (agroforestry, hedgerows, un-cultivated riparian buffer zones and the restoration of species-rich grasslands) and how these can help mitigate the twin challenges of climate change and reduce biodiversity loss. It also provides a synthesis of the strength of evidence for including these as part of net-zero policy objectives and carbon codes.

5.4.3 Impact on policy

a) Marginal abatement cost curves for agriculture

To understand the different ways in which agriculture contributes to the reduction of GHG emissions, we supported SRUC in generating marginal abatement cost curves for agriculture. This involved updating estimates for agricultural mitigation and the cost-effectiveness of different options and in a format suitable for use in the Scottish TIMES model. It drew on the Smart Inventory, a large UK-wide research programme which involved a major refinement of the UK agricultural GHG inventory reporting in 2018. Our report, published in 2020, assessed 14 farm technologies and practices which can reduce GHG emissions in Scotland. This report has had considerable impact, being widely referenced both by the Scottish Government and by farmers and other stakeholders. It features in the Scottish Government's 2021 consultation on the future of agriculture in Scotland and in the 2021 Climate Change Plan Monitoring Report, as well as in the reports of farmer-led sectoral groups (arable; pig; hill, upland and crofting; and dairy).

b) Agroecological approaches

There is increasing interest in more sustainable approaches to farming. A 2021 CXC report examines five different agroecological approaches and their potential for wider use in Scotland to support policy targets relating to climate change, biodiversity, and food production. The results were presented to the Scottish Government Agriculture Reform Implementation Oversight Board in January 2022.

c) Livestock management

Over the programme, we explored extensively the potential to reduce GHG emissions by improved livestock management. Waste products – slurry and manure – are a key issue, and we first explored the potential to use anaerobic digestion as a means of generating energy from waste, in a 2017 report. We also explored the options for storing slurry on-farm and whether there might be potential for a manure and slurry

exchange system in Scotland. All three of these reports featured in Scottish Government's 2021 Climate Change Plan Monitoring Report.

5.4.4 Benefits to other stakeholders

a) Livestock and GHG emissions

Over a two-year period 2016-2018, we produced seven reports on different aspects of reducing GHG emissions from livestock production. Considerable effort was taken to present the science in these reports to a non-science audience and to make the findings accessible to farmers and other primary users. Some of the research arose out of stakeholder workshop discussions. This started a constructive dialogue and collaboration with the researcher engaging extensively with the policy team. Despite the technical nature of the analysis, the research has a crisp, plain English discussion with reference to a detailed science annex. This reflects the support provided by the CXC Secretariat on communication and writing style and ensures the research is easily accessible for a time-poor customer.

b) WWF report

Seven CXC reports were cited in a widely referenced and discussed WWF report, Delivering on Net Zero - Scottish Agriculture. The CXC research referenced included: management of methane emissions; agroforestry; forest carbon markets; and mitigation measures in the smart inventory.

5.4.5 Collaboration and multidisciplinary working

a) Natural capital approach

Taking a natural capital approach is a useful tool in tackling the combined challenge of the climate and biodiversity crises. In 2021-22, CXC undertook a project which explores how this approach might support the development of regional land use partnership (RLUP) frameworks. RLUPs are being set up to help achieve Scotland's climate change targets through land use change and the natural capital approach, which considers key natural assets and the benefits these provide to communities and regional economies. Our report examines evidence from the UK and Europe for the use of the natural capital approach in successful partnerships, including six case studies. Conducted by SRUC, the James Hutton Institute and the University of Edinburgh, the analysis was based on published literature and interviews with the case study partnerships.

5.5 Peatlands and soils

5.5.1 Stakeholder engagement

a) Peatland workshop

Scotland's National Peatland Plan highlights the importance of monitoring – to understand the baseline and to recognise change over time, especially the results of positive action for restoration. To this end, in March 2018, CXC hosted a workshop of experts and key stakeholders to explore the key issues and identify potential next research steps. Attendees included specialists and academics from the research community, senior government officials, policy colleagues, statutory agencies and landowners. We summarised the discussion in a detailed briefing note which also identified key data sets and research sources, and where they are held.

b) Soils group

The CXC project manager for climate and land use (Dr Sarah Govan) attends the Scottish Government's Soils Engagement Group. The group focuses on knowledge exchange on emerging soil science and ensures cross-sectoral collaboration on all issues relating to soil management and policy. Attendees include representatives from Scottish Government, SEPA, NatureScot, Scottish Forestry, Historic Environment Scotland, Forest Research, James Hutton Institute and Scotland's Rural College.

5.5.2 Policy relevant outputs

a) Peatland restoration

The Scottish Government is committed to restoration of Scotland's peatlands, to reduce greenhouse gas emissions, store carbon in the longer term and reverse the decline of essential biodiversity. This is underpinned by complex science that is continuously evolving. CXC has supported these policy aims and helped keep policymakers abreast of the latest science: since 2017, we have published eight substantial pieces of research on peatlands (on top of extensive work in the related field of soil). Among other things, we have evaluated previous restoration initiatives; provided advice on how practices might be improved; and examined cost-effectiveness and economic impacts. Our research has helped ensure peatland restoration – a strategic priority which has received substantial government funding - is well designed, correctly targeted and achieves results on the ground. Our work in this area demonstrates our ability to manage a wide-ranging, multi-year programme of research with diverse stakeholders – from farmers and landowners to government bodies such as NatureScot and Scottish Water. We have built strong relationships with key policy officials in the Scottish Government and NatureScot and helped access extensive knowledge and expertise while simultaneously helping researchers understand the policy context. Our extensive portfolio of work gave us the knowledge and oversight to brief the Scottish Government's expanded team in 2021-22, helping new members get up to speed quickly and set research priorities. Our track record on peatlands means we were immediately able to support delivery of the commitments in the Climate Change Plan Update (CCPu) and help government agencies target significant restoration spend effectively.

b) Soil governance

Healthy soils underpin our natural capital, economy and food security. It is important to have a clear understanding of the existing legislative and policy mechanisms that apply to soil in Scotland and where there might be overlaps or gaps. To this end, in 2018, we produced a comprehensive study examining soil governance in Scotland and the institutional architecture. The research sets out the main mechanisms for the conservation and management of soil in Scotland, and how they relate to key national institutions. We followed this in 2021-22 with an update to reflect changes in policy and legislation for the conservation and management of soil in Scotland, with extensions to consider soil carbon and biodiversity. It finds that 29 soil-related policies were updated or introduced since 2018 but that there is no single policy for soil conservation and management.

5.5.3 Impact on policy

a) Peatland ACTION evaluation

As described above (see Section 4.5.2), the Scottish Government is committed to substantial peatland restoration, establishing a multi-year programme of support. CXC has helped guide and evaluate this programme. In 2016-17, for example, we commissioned a report exploring the effectiveness of the Peatland Action Programme in order to support assessment of the feasibility of increased levels of peatland restoration. ClimateXChange researchers in the James Hutton Institute captured lessons that could be learned, information that directly informed the policies and new challenges for restoration set in the 2018 Climate Change Plan.

b) Peatland restoration and agricultural land

Work continues across government on the development of agricultural policy to reflect the post-Brexit landscape. Peat cover extends across land traditionally used for agriculture; in a 2021 report, CXC explored the potential for peatland restoration alongside other agricultural activities, outlining alternative uses that might provide an economic return.

c) Soil health

Monitoring the state of soil health is important if we are to understand the impact of a changing climate and the effectiveness of any policy initiatives. SCCAP2 identifies soil health as priority research area, following concerns over a perceived lack of data or gaps in understanding Scotland's soils. To help overcome this, CXC produced a report, in 2020, summarising previous work on Scottish soils, exploring existing datasets, and identifying metrics to support the monitoring of soil health and the vulnerability of Scottish soils to climate change. We followed this research with a short scoping study, in 2021, which provides further information on the most promising 13 indicators identified in the first report and considers their strategic relevance to monitoring soil health.

5.5.4 Benefits to other stakeholders

a) The science of peatland restoration

The Scottish Government funded three interlinked PhD research projects on the detailed science of restoring previously afforested land to a function peatland. A RESAS project from the 2016-21 Strategic Research Programme ran alongside these. CXC supported dissemination of the results of this work to a wider policy community through a plain English briefing on the purpose of the science and the emerging results. Taken together, the four projects enabled us to construct the first carbon and greenhouse gas balance following restoration of formerly afforested bog, providing insight to guide further restoration efforts. Several studies carried out by the PhD students were published in peer-reviewed journals. Alongside the academic outcomes, the projects enhanced engagement with the local community, such as collaboration with the North Sutherland Community Forest Trust sawmill at Forsinain. The RSPB was also a key partner in this research: RSPB staff were instrumental in setting up replicated plots, co-supervising early career researchers and sharing data and resources.

b) Soil tool

CXC commissioned the James Hutton Institute to develop a free, easy-to-use tool for land managers to enable them to compare the measured organic matter and carbon content of their topsoil to typical values for Scotland. The tool is based on the National Soils Map of Scotland data (as currently available on Scotland's Soils website) and provides reference/context information for the measured organic matter value at any site. The soils data is processed within the platform so that the input required by the land manager is as simple as possible and optimal data is used. The tool aims to help land managers understand quickly whether the soil in a particular area has good organic matter content, and alert them to the need for further action. The tool can be accessed on the James Hutton website at: https://om.hutton.ac.uk/

5.5.5 Collaboration and multidisciplinary working

a) Greenhouse gas removal technologies

Peatland restoration is one of several approaches that seek to remove greenhouse gases from the atmosphere. This is reflected in a wider 2019 CXC study of greenhouse gas removal technologies, drawing the subject of land use into discussions normally focused on more industrial and engineered solutions.

b) Natural environment research priorities

Following publication of the Climate Change Risk Assessment 2017 Evidence Report – Summary for Scotland (CCRA) and the independent assessment of SCCAP, CXC produced a briefing on the research priorities they identified and what CXC could contribute on the Natural Environment theme. As well as reviewing the two documents, we interviewed sector experts to produce this briefing, making detailed suggestions as to how to the research could be approached. This included experts from the James Hutton Institute, the University of Aberdeen, SRUC, Royal Botanical Gardens, Edinburgh, the University of Dundee and SAC Consulting. The briefing helped to inform the development of policy for SCCAP2 and a broader understanding of the state of knowledge at that time.

5.6 Adaptation

5.6.1 Stakeholder engagement

a) UKCP18 Non-Government Users' Group

Several CXC members sat on the UK Climate Projections 2018 (UKCP18) Non-Government Users' Group convened by the Met Office Hadley Centre. Ragne Low, (then CXC Programme Manager), Chris Ellis (then Directorate member - RBGE), Kairsty Topp (Researcher - SRUC) and Mike Rivington (Researcher - JHI) collectively represented Scottish interests on the Group, engaging with stakeholders from the wider UK Group. Ragne guided the UKCP18 consultation process towards an improved representation of Scottish stakeholders and convened a separate Scottish stakeholder group meeting, bringing the UKCP18 Project Team to Edinburgh to present and consult. That engagement generated two demonstration projects from Scotland.

b) UK Climate Change Risk Assessment 2017

CXC Programme Manager Ragne Low and CXC researcher Kairsty Topp (SRUC) were part of the author team that produced the Evidence Report for the Climate Change Risk Assessment 2017. The Risk Assessment project was managed by the Committee on Climate Change's Adaptation Sub Committee (ASC) and involved a large number of contributors and reviewers from institutions across the UK. As part of the CXC contribution, we consulted a range of Scottish stakeholders, including Adaptation Scotland, Scottish Water, and academics at the University of Dundee and RBGE. This ensured the report reflected Scottish interests, policy landscape, particular geographies and social patterns of risk, and was well aligned with Scottish stakeholder needs.

c) European Climate Change Adaptation Conference

CXC played a leading role in showcasing Scotland to the delegates at the European Climate Change Adaptation Conference (ECCA) held in Glasgow in June 2017. We offered delegates visits to several of the adaptation demonstrations our researchers were involved in. We also organised the central exhibition area 'Climate Ready Scotland', a cooperation between nine key agencies and adaptation organisations, which was opened by the Cabinet Secretary for Environment, Climate Change and Land Reform.

5.6.2 Policy relevant outputs

a) Climate change engagement and communication

To help inform the Scottish Government's climate change public engagement strategy, in 2019, we produced a report, Climate Change Behaviours: segmentation study. This research identified and evaluated different approaches to grouping or segmenting the public according to their attitudes and behaviours related to climate change. In addition, to ensure the new strategy was based on the most up-to-date evidence, the study reviewed the dominant ideas on how to change behaviour. This research, in turn, fed into two further behaviour-related CXC projects: Understanding and engaging the public on climate change, published in August 2020; and Communicating on climate change after Covid-19, published in March 21. The former - which identifies a number of ways governments can engage the public on climate change - was referenced in the public engagement strategy.

b) Monitoring and evaluation of adaptation

A CXC fellow (Dr Anna Moss, University of Dundee) worked in this field for the first four years of the programme, as well as on forestry research. She assessed indicators in relation to CCRA2, CCC ASC recommendations, and identification of key areas for indicator development. Together with another CXC fellow, she helped update 25 adaptation indicators, together with a background briefing, across the natural environment, buildings and infrastructure networks, and the society theme for the final assessment of progress by the ASC. The postholder also participated in continued dialogue with SEPA and other key stakeholders to ensure the publication of the Geddes reports and to maintain the momentum of data development.

She subsequently supported the outcomes focused framework for SCCAP2 with a particular focus on monitoring & evaluation, and adaptation governance. She delivered

reports on developing adaptation monitoring and evaluation (2017), on integrating monitoring and evaluation in SCCAP2 (2018) and on a monitoring and evaluation framework (2019). She also attended the Scottish Government adaptation team's regular SCCAP checkpoint meetings.

5.6.3 Impact on policy

a) Managed adaptive flood risk planning

Over the programme, CXC produced two substantial pieces of work on managed adaptive flood risk planning in Scotland, in the context of increasing and uncertain risks relating to climate change. The first, published in December 2019, considers whether Scottish planning follows international best practice and, drawing on Scottish case study evidence, presents recommendations for how guidance can be strengthened. As well as via a literature review, the research drew on interviews with stakeholders involved in all stages of decision making and through a workshop at Scotland's Flood Risk Management Conference 2019.

The second study, Taking a managed adaptive approach to flood risk management planning – evidence for guidance, published in June 2022, responds to the barriers identified in the first report. It aims to inform future SEPA and Scottish Government guidance for local authorities in this area by investigating how they are currently developing FRM plans, including identifying the data and expertise required, whether they are available and how any gaps might be filled. As such, it supports the Scottish Government, stakeholders and communities in delivering the Flood Risk Management (Scotland) Act 2009, SCCAP and the green recovery from Covid-19. Among other things, it demonstrates that emerging FRM practice is not yet keeping pace with policy ambitions for a more forward-looking approach.

b) Engagement with the Committee on Climate Change's Adaptation Sub Committee (ASC)

CXC researchers from the University of Dundee and the RBGE, as well as CXC Secretariat members, worked with the UK Committee on Climate Change's Adaptation Sub Committee (ASC) and the CCC Secretariat to finalise the national suite of adaptation indicators for Scotland. The indicators were actively used by the ASC in the analysis that underpinned their independent assessment of progress against Scotland's Climate Change Adaptation Programme. In addition, CXC was part of a wider collaborative process to identify 'next steps for Scotland' on climate change risk and adaptation research, as part of a UK-wide consultative process run by the ASC.

5.6.4 Benefits to other stakeholders

a) Tidal flooding on the Clyde

In 2022, CXC produced a substantial piece of work which analyses and scopes adaptation pathways to manage tidal flooding on the Clyde. The research explores the evidence base to help design and apply adaptation (investment) pathways to the tidal reach of the Clyde, drawing on international practice and UK guidance. The study is a first for Scotland providing information to help frame actions and decisions at a local,

regional and national level around future flood resilience and long-term adaptation on the Clyde; practical insights into the application of adaptation pathways practice to the Clyde; and a starting point for the co-design and development of a route map and future actions. At a national level, it supports delivery of SCCAP while at a regional and local level it supports the Clyde Mission, which is overseeing efforts to "to make the Clyde an engine of sustainable and inclusive growth". The research builds on earlier CXC reports on flood risk management investment and on managed adaptive pathways. Other expected primary users of the research include SEPA, Climate Ready Clyde and the Metropolitan Glasgow Strategic Drainage Partnership.

5.6.5 Collaboration and multidisciplinary working

a) Property Flood Resilience

CXC has played a significant role in helping formulate, and then implement, the Scottish Government's action plan for delivering property flood resilience (PFR). Anne Marte Bergseng, CXC project manager for adaptation, sits on the Property Flood Resilience Delivery Group (PFRDG), which helped develop the action plan and involved more than 20 other stakeholders. These included: the Association of British Insurers, the Scottish Flood Forum, Scottish Water, SEPA, the Royal Institute of Chartered Surveyors, BRE, local and national government, academics and several insurers. CXC then provided the research the plan recommended: firstly, a baseline study, published in June 2020, and then a follow-up study in June 2021, undertaken by Ipsos MORI, on the barriers to uptake of property flood resilience. The baseline study, which provided an up-to-date baseline assessment of the potential for PFR across Scotland, was referenced in the SCCAP 2021 progress report.

5.7 General/climate policy

5.7.1 Stakeholder engagement

a) 20-minute neighbourhoods

The Programme for Government 2020 committed the Scottish Government to working with local government and other partners to take forward ambitions for 20-minute neighbourhoods "where people can meet their needs within a 20-minute walk from their house – enabling them to live better, healthier lives and supporting our net-zero ambitions". CXC was asked to map features of Scottish neighbourhoods, rural and urban, and to work with stakeholders to define options, ambitions and actions to realise these neighbourhoods. We created a set of ambitions, including the co-benefits with tackling the climate crises, reducing health inequalities, strengthening the local economy and improving the quality of life. To cover all aspects, the project steering group encompassed a wide range of expertise and engaged with stakeholders on project scope, methodology and data gathering, and to frame the ambition and recommendations for action.

Grounding the recommendations in both physical data and the feedback from stakeholders meant the report was immediately picked up to inform debate across diverse settings and has become one of our most widely referenced pieces of research. This includes: SURF regeneration forum's 20 Minute Neighbourhood Practice Network; the Place Standard Tool website; a Nordic Council session at

COP26 looking at healthy, climate-friendly places; Transport Scotland's car travel reduction route map; committee discussions in the Scottish Parliament; and the SCCAP Progress Report 2021.

5.7.2 Policy relevant outputs

a) GHG emissions and infrastructure investment

The Climate Change (Scotland) Act 2019 included a requirement for a new methodology to improve assessment of the contribution made by infrastructure investment to Scotland's emissions. ClimateXChange research set out clearly defined options for how to take an approach forward, providing an evidence base for further discussions, with a focus on practical and applicable frameworks. It included discussion of the different options' strength and weaknesses, which the Scottish Government included in a subsequent consultation on the draft national infrastructure investment plan. The work particularly benefitted from two-way open dialogue throughout the setting of the research questions, designing the project and presenting the findings; this helped provide maximum value in the practical development of a new framework. The report was widely referenced, including in evidence presented by the Scottish Government to a parliamentary committee, in a Scottish Parliament Information Centre (SPICe) briefing and in a March 2021 budget review.

b) Industrial strategy and emissions reductions

Between 2020 and 2022, CXC produced a significant body of work on industrial decarbonisation and on developing low-carbon industries in Scotland. This included reports on incentivising low-carbon production; on developing industrial clusters; and on building up a pipeline of industrial decarbonisation projects. Fulfilling follow-up research recommended in the CCPu, we also produced studies on negative emissions technologies and on developing a Scottish CO_2 utilisation sector, two segments Scotland hopes to develop significantly under its green recovery and green jobs initiatives.

5.7.3 Impact on policy

a) Updating the Climate Change Plan

The more ambitious targets in the Climate Change (Scotland) Act 2019 necessitated a significant overhaul of policies and funding priorities to ensure Scotland achieves net-zero emissions by 2045. To help update the 2018-32 Climate Change Plan, CXC produced research evidence and expertise across the full range of net-zero challenges. The challenge was compounded by the global pandemic which led the Scottish Government to delay the update and reframe it around a "green recovery".

In early 2020, the Scottish Government formed a Climate Change Plan update (CCPu) working group. Members were drawn from the Scottish Parliament, academia, industry and environmental organisations and included CXC's Policy Director, Prof Dave Reay. CXC research was commissioned on: livestock emissions; management of storage and application of organic materials such as silage and slurry; economic opportunities

associated with electric vehicles; a new methodology to assess the emissions contribution made by infrastructure investments; how behaviours with an emissions impact changed through the pandemic; engaging the public on climate action; travel behaviours and business recovery; and communicating climate change after Covid.

Our work on whole system approaches, such as the TIMES energy model and marginal abatement cost curves (MACC), was of particular importance: the emissions envelopes set out in the CCPu are based upon TIMES modelling. To ensure the model uses the most recent data for agriculture, CXC's MACC research updated estimates of the mitigation potential and the cost-effectiveness of a selection of agricultural mitigation options.

The CCPu also made several research commitments which we helped fulfil. We have commissioned and/or completed work on: developing whole system energy scenarios for Scotland; a review of international delivery of negative emissions technologies; the potential for market benefit to incentivise lower carbon industrial production in Scotland; peatland restoration and potential emissions savings on agricultural land; the potential for leguminous crops in Scotland; methane-reducing feed additives; and realising 20-minute neighbourhoods.

5.7.4 Benefits to other stakeholders

a) Climate Challenge Fund

Established in 2008, the Climate Challenge Fund (CCF) supports community-led projects which lead to reductions in carbon emissions, and which are designed to leave a sustainable legacy of low-carbon behaviour. As of mid-2020, over 1,150 projects across all Scotland's 32 local authorities had been awarded CCF grants, with total funding exceeding £111m. CXC oversaw a three-year research project which gathered evidence of the fund's impact on the ground, its effectiveness, and how success can be monitored in future. This involved in-depth case studies of five CCF projects which the team followed for 18 months. Reflective workshops were held at three key time points and the team also used semi-structured interviews and questionnaires to collect evidence. To provide more immediate feedback to the Scottish Government, the team published three interim briefing notes over the course of the project.

Welcoming the final report at the CCF Annual Gathering 2020, Cabinet Secretary for Environment, Climate Change and Land Reform, Roseanna Cunningham MSP, said: *"*Its findings and recommendations will help to identify the specific role that community climate action can play in Scotland's transition to a net zero society and, crucially, in ensuring that we take everyone with us on that journey."

5.7.5 Collaboration and multidisciplinary working

a) Climate Conversations

The Scottish Government initiated the Climate Conversations project to encourage discussion about climate change and the transition to a low-carbon society with the Scottish public. In 2016-17, we supported development of a 'How to' climate conversations toolkit guide, producing three pieces of underpinning research. This commenced with a CXC desk review conducted by Climate Outreach and the Surefoot

Effect, which examined the existing research base used to inform the design of workshops with the public. We then produced a report on the findings from the workshops which tested and developed the draft ‘How to’ Guide. Finally, we published a framework which offers guidance on capturing and analysing data from a one-off or series of conversations. Among other things, these outputs were used in the drafting of the 2018 Climate Change Plan.

Following CXC’s involvement in providing this research, we then worked with the Surefoot Effect, Sniffer and the Scottish Government to run a seminar in March 2017. This identified key lessons from 20 real-world climate conversations across Scotland over summer and autumn 2016, drawing out conclusions for future application of the Conversations model. Our Climate Conversations work was referenced in Net Zero Nation, the Scottish Government’s public engagement strategy for climate change, published in September 2021.