Extreme Climate Change Scenarios for Scotland
Workshop Report

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Overview

Six scenarios of the impacts of extreme climate change in Scotland were explored by breakout groups at the James Hutton Institute.

The aim was to identify future research priority areas that could arise as a result of these scenarios. Funding for the workshops was provided by SEFARI Gateway and the Hutton Institute's Science Challenge Leader programme.

Main Findings

Findings included the identification of potential research topics across a range of subjects relevant to the organisations represented. In particular, the following topics were emphasised:

- **Improvements to academic/policy interactions and communications**
- **Optimal design of agricultural payments systems to accomplish specific goals**
- **Breeding and genetic modification of crops, livestock and marine organisms**
- **Identification of crops suitable for marginal land**
- **Identification of influencing mechanisms (e.g. taxation, education, social media, community empowerment) for influencing individual and community behaviour**
- **Preventing and mitigating social unrest caused by climate change-related factors, and protecting democratic institutions**
- **Understanding impacts of policy options to enable resilient social and community planning and social innovation**
- **Limiting future damage to the environment (particularly soil and water conservation)**
- **Preventing, monitoring and dealing with the spread of new pathogens**
- **Transitions in agricultural productivity to increase arable cropping for human consumption and decrease livestock/ feedstock production**

Introduction

Two workshops were held at the James Hutton Institute's Aberdeen and Dundee sites on the 29th of January and 5th of February 2019. These were intended to drive discussion about possible future research challenges in relation to climate change, and to identify ways in which the organisations represented might tackle these challenges. Over 50 people attended, with groups discussing different scenarios of extreme climate change in Scotland.

The six scenarios were written as one-page narratives by the workshop organisers, each telling a different 'future history' about the effects of extreme climate change in Scotland. They were set between 2030 and 2080 and covered a wide range of potential impacts. For each, efforts were made to make them both interesting and realistic, and to provide a story that would engage the attendees and make them think.

Briefly, they included:

- A simultaneous collapse in the North Sea marine ecosystem and Scotland's agricultural crop yield, driven by extreme weather and changing ocean circulation.
- A radical shift in government towards a 'war economy' as an attempt to mitigate and adapt to the severe impacts of climate change on food production, social unrest and economic output.
- Disease outbreaks affecting human health, crop and livestock production and heathland, driven by warmer weather and water shortages, and damaging Scotland's economy.
- Attempts by the Scottish Government to enact social justice-related reforms following severe social unrest caused by food and water shortages and amplified by tabloid news and social media.
- Large-scale climate change refugee movements driven by rapid sea level rise, with issues of housing, community integration and economic reform.
- Implementation of government legislation towards a significantly greener economy, driven by political changes, and their effects on societal and individual actions.

The style of the scenarios was derived from the text of existing climate change scenarios and the 'Shared Socioeconomic Pathways' developed to explore a wide range of possible futures under different CO_2 emissions pathways. The scenarios presented were shorter and less extensive in their coverage than these SSPs, to allow for rapid reading and focus on specific questions.

Format

Attendees were split into six discussion groups, with each group examining two of the six scenarios. Each group had one note-taker/rapporteur who provided feedback from the group. The morning was used for examination of the scenarios, and afternoon was used for general discussion, feedback and coverage of topics raised during the morning. Notes were transcribed by group rapporteurs and Matt Aitkenhead. Draft reporting was circulated to all attendees for comment before publishing.

SSP discussion

Dr Mike Rivington and Dr Alessandro Gimona presented additional information during the workshops, to provide context explore the possibility of developing a sixth SSP (Shared Socioeconomic Pathway) for extreme climate change in Scotland. Existing SSPs were felt by the workshop organisers to be extremely useful, but lacking in two key areas: firstly, they do not provide adequate consideration of extreme climate change under a high CO_2-emission pathway resulting in mean temperatures above 4.5°C of baseline; secondly, they do not sufficiently consider the effects of climate change-driven events and impacts around the world on Scotland. Alessandro Gimona presented the possibility for attendees to contribute to the development of a 'high emissions / extreme climate change' SSP for Scotland, which is ongoing.

Attendees

While most workshop attendees were from the Hutton Institute, other organisations were also represented. These included:
- SRUC
- SEPA
- SNH
- Edinburgh University
- Aberdeenshire Council
- EAUC – the Alliance for Sustainability Leadership in Education
- James Hutton Limited
- Scottish Green Party
- Keep Scotland Beautiful

Scenarios

In the following section, each of the scenarios is given as presented to the workshop participants. The text at the bottom of each describes the discussion topic(s) to be covered. Below that is an interpreted summary of the information provided from the two groups that discussed each scenario. In addition to the scenario texts, each scenario was accompanied by several screenshots and headlines from news organisations that were relevant to that scenario and from the last six months. This was done to provide a sense of context and realism to the participants and to encourage them to engage with the scenarios more fully.

Scenario One – 2040 (So long and thanks for all the fish)

Warming of the North Sea has decreased the numbers and health of cold-water species such as cod, and increased presence of other species. In the North Atlantic, the circulation of warm and cold waters slows significantly in one year as large quantities of meltwater from Greenland and the Arctic disrupt the existing circulatory patterns. This reduces the influx of marine invertebrates and other species at the lowest levels of the marine food chain.

Severe storms during the Spring result in a massive pulse of soil erosion along the east coast of the UK and the coasts of Holland, Denmark, Germany and Sweden. The timing of this produces a large flux of nitrogen and phosphorus runoff into the North Sea and the Baltic Sea, resulting in severe eutrophication.

As a result, the food web of the marine ecosystem in the North Sea, Baltic Sea and eastern North Atlantic effectively collapses, with large 'dead zones' developing over the course of a single year. Fishing intakes from the UK and the EU falls significantly. In Scotland, the consolidation of the fishing industry to a small fleet of large vessels causes financial losses to a relatively small number of people, but they are nevertheless extremely vocal and have disproportionate political leverage.

The effects of ongoing severe weather during the summer cause significant crop failures, particularly in cereal crops. This strongly affects the animal feed production capacity of Scotland. The effects of this and the fishing industry collapse mean that Scotland suddenly becomes a significant net importer across all food categories. This raises strong concerns in the Scottish Government about food prices and food security.

They want answers to the following questions:
- How can we greatly increase (i.e. double) cereal crop production over a five-year period in a manner that is resilient to extreme weather events?
- What can be done to restore and recover the marine food web in the North Sea?
- What alternative food products could be developed and produced in Scotland that we are not currently taking advantage of?

Summary of responses to Scenario One

In the marine environment, measures to increase water oxygenation and preserve marine biodiversity would need to be researched. This could include measures to create a marine DNA bank like those developed for terrestrial plants and animals. Exploring alternative marine food products was identified as a key approach to reducing disproportionate impacts on a small number of species.

Understanding the processes and risk factors associated with soil erosion is necessary, to avoid land management that increases erosion risk. This would include the ability to identify and promote management options that reduce soil erosion, such as novel crops. Specific approaches for investigation included mapping the suitability of land for specific crops, rather than the general 'land capability for agriculture' approach. Increases in legume growth and use in the food system was argued as important from perspectives of both soil health and protein production for human food.

Active intervention in terrestrial biodiversity would require advances in crop breeding and genetic manipulation, along with targeted introduction of new species. It would also require an increase in acceptance for genetically modified crops, and ways of reducing cultural barriers in farming systems to the adoption of new environmentally sensitive land management options and technologies.

Research into novel approaches in agriculture was seen as important across many areas. Alternative protein sources such as legumes as mentioned above, but also insects, fungi etc. were discussed. Innovations in farming location (vertical farming, aquaculture, rooftop gardens) need to be explored. The identification and development of crops that could be grown on marginal land was recognised by several people.

A key area for development identified was the reduction in livestock and crop growth for animal feed, and an associated increase in cropping for direct human consumption. This would also involve developing novel products from crops such as potato and barley, and adoption of agricultural systems that mixed forestry and cropping more effectively.

Within rural areas, a closer integration of alternative energy production and farming systems was seen as a key area of research, linking strongly to associated circular economy and workforce education priorities. Achievement of this was recognised as needing advances in aspects of governance and subsidies, particularly to promote local produce and environmentally sensitive food producers. Legislation in this area was identified as a potential two-way channel of development between Scotland and the rest of the world.

Scenario Two – 2050 (The drums of war)

The effects of climate change have increased, with severe weather events commonplace and food production unreliable and high-risk. Oil production has dipped, and energy prices are high. The UN is making strong efforts to provide a global response, but some countries (particularly developed, democratic ones) are struggling with a backlash from voters against efforts to curb carbon emissions.

Individual countries are suffering consequences of this global breakdown, with some governments making more efforts than others and adopting a range of different strategies. The general trend is towards nationalism and authoritarian control.

The Scottish Government declares a state of emergency after multiple crop failures and extreme weather events. Under pressure from the public and several international organisations (UN, World Bank, EU) to adapt policies in order to receive emergency aid, a government of national unity is formed.

Restructuring of the government creates the following Ministries with expanded powers:

- Food Security
- Energy
- Manufacturing and Production
- Transport

Under these Ministries, several industrial and commercial sectors are nationalised, including agriculture, the rail network, finance and energy production. The roles of national security and policing are kept separate from one another, but the Scottish Home Office is given expanded powers to curb civil unrest. Rationing is not introduced but production and provision of certain goods and services is severely curtailed, such as whisky production.

The enaction and implementation of the relevant legislation and the restructuring of the Scottish economy into a 'War Economy' resulted in some civil unrest and protests. However, the results of these changes were a greatly strengthened national food security and resilience against later climate-change induced shocks to the global economy and environment. By 2080, many other countries had enacted similar restructurings and Scotland was hailed as a perfect example of 'how to do it right'.

It was acknowledged that a significant part of this success was due to strong efforts made by SEFARI and other environmental and regulatory organisations, informing and advising the development of key policy areas, and identifying challenges in advance in order that they could be dealt with effectively. The integrated and transdisciplinary efforts of a dozen key organisations was identified as having prevented great suffering and loss of life and having provided answers that gave Scotland's population and environment a stronger and more secure future in the struggle to come. Describe how you think this was accomplished.

Summary of responses to Scenario Two

Dealing with shortages was a common theme throughout the responses to this scenario. Water supply, food security and how these could be addressed were identified as important research areas. For farmland specifically, crop growth on marginal land with low inputs, and low-impact agricultural management to reduce erosion were key topics.

Transitions from current farming systems to more resilient agricultural production aimed directly at food for human consumption, and reduced livestock production, was again important. Linked to this was a perceived need to find new ways to shift consumption and dietary patterns towards more grains, vegetables and fruit, and less meat and dairy. On the marine side, suggestions were made that we should be looking for ways to cut fishing quotas, resolve issues relating to 'by-catch' and provide alternative economic support to rural, coastal regions.

This centrally-planned economic model for agriculture and fisheries was heavily explored and drove participants to identify several priority areas of socioeconomic research. The question of exactly which economic sectors would need to be nationalised to achieve the stated aims, and which could remain privatised, would require significant theoretical advances in social and economic modelling.

Models of 'social justice' that allow these changes to be made to the agricultural landscape while providing support to rural communities are needed. These include topics relating to rural regeneration, the knowledge economy, teleworking and promoting engagement in the decision-making process by the communities most affected by these changes.

In order to develop an atmosphere of consensual politics and governance, public education was seen as vital. Some of the radical changes could be seen as an erosion of democratically distributed power, and a perception of authoritarianism. Finding better methods to ensure engagement and trust in government at the same time as market freedoms are reduced is a significant challenge, and one that requires interdisciplinary research. Retention of democratic voting rights while encouraging people to vote for policies with long-term benefits and short-term costs is not an easy problem to solve.

Scenario Three – 2030 (A pox on both your houses)

A summer heatwave throughout the UK depletes water supplies to the point where tankers are used to provide water. Sewage systems struggle to cope. In late summer, a series of tropical storms sweep north across Europe, with massive rainfall for two weeks. Crops that were already struggling are wiped out, and severe soil erosion takes place. Urban drainage systems become overwhelmed. A pulse of raw sewage mixed with nutrient-rich soil floods through urban areas.

In the following two months there is another hot dry spell, with no water for sanitation. A cholera epidemic breaks outs in the Central Belt, with tens of thousands of cases overwhelming the health services. In rural areas, private water supplies are also contaminated, and thousands of people are forced to move temporarily to the north-west of Scotland where relatively clean water is available. Tourism and agricultural industries are effectively abandoned during the late summer and autumn.

In agricultural areas, the lack of monitoring and treatment of pathogens results in an outbreak of diseases amongst cattle, sheep and pigs. Farmers are forced to slaughter and burn approximately half of all livestock. Crops are affected by diseases that had previously been unable to gain a foothold, with the lack of farm labour preventing effective treatment and allowing them to spread.

A strain of heather root rot thrives in the warmer, drier conditions and spreads rapidly, killing off large swathes of moorland. Several tree species also start causing severe problems for native tree species, and there are several bog and forest fire outbreaks that cause significant damage before they can be brought under control.

In the aftermath, Scotland's health, agricultural and tourism sectors are left struggling to recover. The Scottish economy is estimated to have lost 10% of GDP over a single year (over £20 billion). The Scottish Government wants to ensure that this series of events never occurs again, and approaches research and environmental organisations with the following questions:

- What research questions need to be answered to inform the development of a more resilient water supply and sanitation system?
- How can farmers prevent the future spread of disease amongst livestock and crops in reduced workforce situations?
- What do we need to know about measures that could be introduced to restrict the spread of plant pathogens through the Scottish environment?

Summary of responses to Scenario Three

Advances in technology for monitoring the transmission and spread of disease was a strong topic of discussion here. Various mechanisms, including the use of novel sensing technology, modelling and automated monitoring systems were proposed. Challenges to the development of 'plant passports' and more effective monitoring of livestock movements (within as well as between businesses) were discussed. At an individual animal level, monitoring of behaviour could also lead to identification of symptomatic behaviour if understood better.

Water supply and sewage treatment/processing research covered a wider range of discussions, from social and cultural adaptations to technological solutions. Introduction of water metering and enhanced recycling of wastewater are both areas that present research obstacles in terms of social acceptance and uptake. The use of nature-based solutions for increased catchment water retention, wastewater treatment and improved agricultural irrigation efficiency was identified as a priority research area.

Technology for diagnosing and treating water contamination, and for treating sewage at a household level was discussed as another research topic. Linking to the monitoring and management of water supply and demand, smarter systems are needed for reacting rapidly to changing patterns of usage and identifying and isolating potential outbreaks of disease linked to the water supply.

An improved understanding of water-borne pathogens is needed, including how these organisms interact with the environment, how they can be avoided and what Integrated Pest Management strategies and tools could be developed for their control. Enhancing the resilience of cropping systems to disease outbreaks was also identified, through approaches ranging from breeding to in-built genetic variation within crops, and increased diversity of cropping systems (i.e. more or different varieties and crop types). It was also noted that animal disease outbreaks could be reduced if alternative protein sources to meat were investigated and promoted.

In order to achieve some or all of the above, reforms to land ownership and management would be needed. The social impacts of these reforms would need to be better understood and researched, including methods of conflict resolution and compensation for economic losses, modelling of farm structure/arrangement and subsidy systems, and the socioeconomic impacts of an enhanced circular economy.

Scenario Four – 2040 (Chaos is a ladder)

Effects of climate change have increased over the last 20 years. There have been no major 'trigger' events, just an elevated background of worsening conditions. Coastal and river engineering has mitigated the worst of flooding and coastal erosion, with no areas abandoned but a difficult financial environment created. A lack of flood insurance coverage and stagnating housing market has effectively trapped people in coastal areas and prevented them from buying or selling property.

During summer, there have been water shortages. A focus on maintaining water supplies to urban areas has resulted in crop failures from lack of irrigation, with some shortages and price spikes. Multiple news stories have resulted in shelf clearances at supermarkets, with some rioting. There has also been widespread crop damage and some coastal erosion during storms, with tree collapse preventing the emergency services accessing the sick and injured.

Despite lobbying, the Scottish Government has resisted onshore hydrocarbon extraction even as offshore extraction has declined. Increased onshore and offshore wind and wave energy production has maintained electrical supplies, but there have been occasional power outages.

Significant increases in taxation have occurred to raise income for environmental restoration and climate change mitigation. Some of these tax increases have been on hydrocarbon fuels, leading to less affordable travel (particularly flights). Subsidies for landowners have become strongly biased towards sustainable management practices, leading to claims of increased food costs.

The tabloid press runs a strong daily feature on the inability of the government of the day to look after the Scottish population, blaming corruption and careerism and questioning the usefulness of environmental protection measures. These same news outlets highlight the apparent successes of authoritarian regimes in maintaining stable societies around the world.

Combined, these factors have resulted in greatly increased social unrest. There have been several situations where opposing groups of protestors have fought violently, and a lot of people have been encouraged by extremist political parties to provoke rioting. The Scottish Government is concerned that they are losing control of the situation, and wants answers to the following questions:
- How to develop a more inclusive society that improves the lives of the large disenfranchised minority, without causing significant environmental damage?
- How to regulate food production to prevent price spikes, hoarding and black-market profiteering?
- How to reduce the impact of extremist authoritarian language, coming from both Scottish and international sources, on the attitudes and behaviour of protestors and voters?

Summary of responses to Scenario Four

Maintaining food, energy and water supplies under the conditions suggested by this scenario was recognised as a significant challenge. Improvements to automated monitoring and control systems for production, storage, distribution and consumption is a broad but important area for research. The modelling of price controls on supply, demand and distribution should be investigated as well.

Controls on production to meet necessary minimum requirements were discussed, particularly in relation to agricultural production. As with Scenario Three, restrictions on free-market behaviour would need not only mechanisms for achieving this physically but also methods of achieving democratic consent for these restrictions. Improved education and development of methods to avoid and limit authoritarianism and extremism would be vital. Methods to protect and restore democratic institutions and frameworks would be needed.

Developing of educational and outreach tools was important. Social media research, communication of the relevant science in 'plain language' and finding ways to encourage people to engage with the decision-making process were all discussed. Methods to avoid and deal with civil unrest and to allow people to recognise and be resilient against extremist language are important in this.

Education about local food production, food sourcing and preparation and legislation to deal with food supply situations to protect vulnerable members of society were encouraged as research topics. Alongside these, there was interest in determining incentives or initiatives that would motivate community cohesion and long-term planning/policy development amongst community leaders and policy developers.

Scenario Five – 2080 (The Great Wave)

Monitoring of the West Antarctic Ice Shelf warns that rapid ice loss is beginning. It is estimated that the volume of ice loss will result in sea level rise of one metre over a period of 20 years. Accelerated ice melting in Greenland and the East Antarctic increases the background rate of sea level rise to an additional 30 mm/year. This will rapidly make large areas of the world's coasts uninhabitable.

The UN begins a large refugee movement program to relocate an estimated 500 million people worldwide, with the backing of most countries of the world. This program is organised to ensure that communities are relocated to single locations, rather than being scattered and separated.

The Scottish Government decides to take in a large number of refugees. This fulfils two objectives of (i) reversing population and economic decline and (ii) providing a counter to several nationalist governments in the rest of Europe who resist taking in refugees. The Government agrees to resettle 100,000 people a year for the next ten years from South East Asia. The people to be moved are largely from rural, coastal, subsistence agriculture communities with low socioeconomic indicators.

Currently, the population of Scotland is six million. The economy is flat, with moderately successful renewable energy economy and high-tech manufacturing industries. Past efforts to boost the circular economy has been successful, and there have been significant changes to land ownership and land management legislation in recent years. Tree planting in upland areas has replaced moorland, and both the economic and natural environment are considered relatively resilient.

The refugees are to be housed in new, low-cost housing on brownfield sites, and in some cases in poor urban areas that have seen population declines. The Scottish Government has stated an intention to integrate them into Scottish society and to ensure that they are granted UK citizenship. The Westminster government is struggling with sea level increases and inundations in both rural and urban areas and agrees to this on the provision that the communities are settled in Scotland.

What social changes would be required to adapt to this influx of refugees, to ensure that:

- The incoming communities were properly integrated into Scottish culture and life?
- Resistance from racist elements of the Scottish population was minimised and mitigated?
- Economic benefits to the Scottish economy were realised?

Summary of responses to Scenario Five

Research areas driven by this scenario covered a range of physical, social and planning/legislative areas. These largely covered the challenges of (i) providing places for refugees to live, (ii) integration into Scottish society, and (iii) realising long-term benefits. In terms of shelter, electricity, food and water, a strong priority identified was in finding how to put infrastructure in place in advance of large numbers of climate change refugees. It was accepted that this is an issue that is only going to become greater, and also that there are challenges in rationalising investment in infrastructure development before it is urgently needed.

Research into nature-based solutions linking natural spaces, waste management and ecosystem services was identified as an approach that could provide an environment sufficiently resilient to deal with the impact of large numbers of refugees while infrastructure was constructed. There would also need to be relevant research into urban planning and rural community development using appropriate socioeconomic modelling tools.

Establishing cultural links early on with countries that are likely to have mass dislocation of people was also identified as an approach that would 'prepare the ground' for this kind of scenario. Forming research links on related topics between Scotland and these countries was suggested to achieve this familiarity and help tackle the research questions at the same time. Specific areas of agricultural research, including exploring the integration of agricultural practices from different countries without own, was one suggestion.

In addition to identifying the countries in question, it is important to identify which demographics are most likely to move and what levels of relevant education and skills they would bring. This would improve preparations and allow appropriate educational courses to be developed to integrate the refugees into Scotland's workforce.

For cultural integration, a strategy would need to be developed and tested in advance. This would need to include methods for positive messaging and encourage recognition of the benefits to both native and new Scots. It would also need to develop an understanding of perturbations to the existing system, potential challenges and opportunities and overall, a well-understood (well-modelled?) anticipation of what was needed to deal with any problems at a local or national level.

Returning to the concept of forward planning and infrastructure, it would be necessary to prepare the two populations in advance of the scenario outlined here. Concepts of environmental stewardship, long-term planning for a resilient social safety net, and shared responsibility for the future of Scotland would need to become a key component of education and the national story before this scenario happened, not during or after. Finding ways to do this should become a priority sooner rather than later.

Scenario Six – 2030 (The Party's over)

Increasing evidence of climate change and its impacts is seen through the previous decade, with a gradual ramping-up of severity. The percentage of the Scottish population voting for parties with 'green' credentials increases. However, a combination of pressure from industry representatives and a fear of electoral wipe-out mean that the main political parties remain resistant to adopting wide-scale policies that would be economically damaging.

Following national elections, a coalition is formed in which a newly organised, militantly environmental political party has a small number of ministers as part of a 'confidence and supply' arrangement with a minority government. This party forces the government to agree to a broad policy of reducing Scotland's carbon emissions by 50% over ten years, regardless of economic impact. The government aims to achieve this through reductions across a number of industrial sectors including agriculture, energy production and manufacturing.

Potential goals that have been identified include, but are not limited to:
- Significantly increased taxation on red meat
- Adjusting subsidies to discourage farmers from keeping livestock
- Limiting the number of flights allowed to one per person per year
- Encouraging people to have fewer children
- Restrictions on extraction of oil and gas in Scottish waters to match existing onshore restrictions

It is accepted by the government that making these changes will result in stronger and clearer changes to individual lifestyles than before, and that some of these changes will not be voluntary. The government is willing to risk enacting these policies on the belief that any political backlash will be aimed at the environmental party instead of their own.

The Government's priority therefore is to enact these changes without causing social unrest and without disproportionately disadvantaging any demographic group, but nobody knows how to accomplish this. An additional concern is that policy changes enacted must be economically 'neutral' as far as possible and avoid increasing the wealth gap between rich and poor. What research would be needed to accomplish this?

Summary of responses to Scenario Six

This scenario presents a range of significant changes to behaviour, at scales from the individual, through the local and up to the national government. As such, it raised discussion about how these changes could be implemented through a wide range of options including incentivisation, legislation and social engineering. It also raised a fundamental research question as to what might be the different social, economic, political and ecological impacts of these different options working in concert, in order to understand the risk of potential unintended consequences and how to mitigate that risk. How might liberal democracy be affected by radical social engineering?

Also identified were several key areas of research into the 'physical' landscape. These included renewable energy research, carbon capture and storage, energy grid efficiency and the development of better metrics to quantify the environmental costs of production. Discussion also touched upon research into the economics of resource management, i.e. determining which resources or economic sectors could be nationalised to reduce their environmental impact, and how this would be achieved.

All of this work would need to be supported by research into alternatives forms of measuring national wealth and production, that might complement or replace GDP, leading to metrics that would better guide policy-making in the above areas towards outcomes that favour societal sustainability in the face of extreme climate change.

In relation to agriculture, research into the development and increased use of high protein crops (e.g. pulses) and the development of crops to provide plant-based plastics was highlighted. There was also an emphasis on research into the development of low-carbon agricultural management and improvements to local production systems to reduce carbon emissions from transport, and on low-emission transport solutions.

Research into the various 'levers' that might be available for changing behaviours was identified as vital to the goals necessary in this scenario. Providing information to inform individuals about their own choices was one challenge identified, with more investigation needed into how to communicate this information effectively. Using the James Hutton Institute and other organisations to provide an example for environmentally beneficial practices was one approach that several participants raised.

Incentivising change was another research area identified. Identifying the incentives that most effectively change individual behaviour in a desired manner is important, as is identifying the most reasonable and acceptable steps that individuals could take to reduce their environmental impact. Exploring the differences between examples that have worked (e.g. plastic bag charges, sugar tax) and those that have been less effective or poorly implemented (e.g. fuel tax increases).

Research into how to accomplish specific objectives was also highlighted as important, for example how to support a reduction in red meat consumption (perhaps by carrying out further research on health impacts of red meat consumption), as well as in private car ownership and flights (perhaps by research and development of faster communication channels that did not rely on cars and planes). A credit exchange programme to constrain flying was mentioned as a specific measure to seek to design and evaluate. Research would also be needed to further assess the sustainability impacts of adopting red meat and milk alternatives from an integrated, systemic and life-cycle perspective. However, it was also mentioned the need to investigate more systemic, transformative processes that could lead to the type of behavioural change that was being suggested.

Some relatively radical solutions were put forward as worthy of exploration, such as allocation of individual 'tax credits', changes to financial support for families with children and placing restrictions on the numbers of houses owned for renting purposes. The social acceptance of new policies and the economic and environmental consequences of their implementation will need additional investigation. Research into diversification of agricultural systems and other economic sectors to reduce emissions and maintain economic growth was also seen as important.

Discussion and Conclusions

Levels of engagement were high at the workshops, with animated discussion and a free flow of ideas. Several of the participants stated an enthusiasm for following up on the workshops, either through contribution to forward planning for research or participating in the development of a new Shared Socioeconomic Pathway. Feedback was also largely positive and highly constructive. Some comments were given on how the workshop format could be improved if it were to be repeated.

The provenance of the scenarios (i.e. developed beforehand and presented to the participants), and their wording will have impacted upon the identification of research areas and how the participants engaged with the scenarios. This needs to be considered in terms of the outcomes of the day and any potential bias in the findings. There was also some feedback to the effect that the event had been slightly upsetting for some people, due to the extreme nature of some of the scenarios presented. While the organisers had not actively attempted to upset participants, it was insightful to observe individual reactions to the scenarios and their implications, and to consider how the 'real thing' might elicit a significantly stronger response.

Research areas identified as priorities during the workshops covered a very wide range of disciplines. This is partly due to the range of expertise covered by the participants, but also because of the different questions and challenges identified. Mathematical and computational research areas included modelling of farm-scale land management, behavioural shifts and subsidy/taxation systems. Several modelling approaches exist of relevance, most notable agent-based modelling.

Physical research topics covered a range of potential engineering and manufacturing solutions to specific challenges, rather than attempts to find 'one big solution' to the climate change problem. Infrastructure development in the form of urban planning research was important, as was exploration of technological solutions to the design of production and distribution systems (e.g. raw materials, food, water supply, energy).

Research into biological solutions formed a large part of discussions. Crop breeding for increased productivity and resilience featured heavily, ranging from new varieties to large-scale genetic modification and introduction of GM organisms into the terrestrial and marine environment. Disease and pathogen research also linked back to physical and mathematical research priorities featuring monitoring and modelling technologies.

Agricultural research covered a wide range of scientific topics but could be seen as an important interdisciplinary area in its own right. One major theme was research into crops that could be grown on marginal land with low inputs. Others were: exploration of approaches to land management that reduced soil erosion; increased environmental resilience (e.g. nature-based solutions, increased cropping diversity, circular economy); increased production of specific crop types (legumes, food for direct human consumption); finding ways to reduce livestock and dairy production.

Social science research runs parallel with many of the biophysical topics identified. Sometimes this is because the adoption or acceptance of new biotechnologies may require changes in attitudes or perceptions (GM crops/animals, novel monitoring technologies). However, fundamental social science research e.g. into education, behavioural changes and cultural shifts is also needed, implying work that spans the individual to institutional level.

Economically and politically, many of the scenarios implied a need to better understand the interactions between different societal sectors, especially society and government. This may include understanding the relationships and social contracts needed for individuals to support or accept policies that place new restrictions or requirements on certain behaviours. Social science research also has an important role to play in understanding the risks (both from sustainability and social justice viewpoints) of implementing the different policy and technology options.

Several common themes arose when discussing future research priorities. These included:
- Agriculture
  - Crops on marginal land
  - Alternative crop types
  - Reduced livestock production
  - Erosion reduction measures
  - Crop diversity
  - GM crops/animals

- Environment
  - Nature-based solutions
  - Monitoring
  - Modelling

- Resource distribution
  - Water
  - Food
  - Energy
  - Raw materials
  - Local economy
  - Circular economy
  - Infrastructure and planning

- Governance challenges and Economic transitions
  - Nationalisation of specific sectors
  - Limitations on free market systems
  - Subsidy and taxation levers for 'social engineering'
  - Societal engagement in policy and its development
  - Conditions for socio-cultural change and transitions

- Individual behaviours
  - Education and awareness
  - Dietary changes
  - Carbon budget assessment / taxation

- Systemic societal transformations towards sustainability?
  - Systemic analysis of policy impacts and risk distributions across sectors
  - New methods of measuring wealth and production
  - Community development and empowerment as a driver of change
  - Planning for a resilient social safety net and to protect the vulnerable in times of climate change crises
  - Maintenance of democratic institutions in times of climate change crises

- The James Hutton Institute (and other relevant organisations) setting an example of environmental sustainability

There was a pattern of activities across all the groups and scenarios throughout the two workshops. Various technological solutions were proposed as topics for research where this was appropriate, but there was no clear prioritisation or preference for individual technologies. However, most of the discussions revolved around how to achieve greater public engagement and willingness to change and finding ways to achieve this without appearing (or acting) in an authoritative manner.

Opposite but not necessarily opposing themes of decentralisation of production and centralisation of control were commonly suggested throughout all scenarios. The decentralisation of production was strongly linked to increased individual engagement with, and control over, the adoption of policies. It is therefore possible that rather than 'centralisation' of control, what was being suggested was looking for ways to achieve 'commonality' of control over how individuals and society behaved. This had strong links to the themes of social justice and equality that were also heavily debated throughout; research into these areas seems to be a vital component of achieving any of the societal and cultural shifts needed to deal with extreme climate change.

To a certain extent, the workshop participants behaved and discussed in a manner that represented the response of society as a whole to climate change; they were willing to discuss and suggest areas of research that would have an impact on others, but when presented with options that would require changes to their own behaviour, the discussion became more contentious and occasionally dismissive. Certainly, some participants struggled to imagine themselves in the situations described and instead stated a preference for looking for activities, policies and measures that would allow these scenarios to be avoided.

A possible further reason for this was also mentioned during the workshop, in that there was confusion about the time period for which participants were supposed to be making the research suggestions (i.e. trying to avoid these scenarios vs. finding solutions to them if they happened). For any repeat of this workshop, clarification of this would need to be given at the start. There is a significant difference between crisis risk reduction research (what researchers are largely trying to do now) and crisis management research (what we would have to be doing should these scenarios happen).

A major element throughout the workshops that was raised but not resolved was the need to find ways for the general public to accept the need for this kind of research and its implied findings. Attendance at the workshops was largely an exercise in self-selection; people who wanted to attend were those interested in the subject and keen to find solutions. They were therefore not truly representative of broader society and may not have been able to visualise the mindsets and obstacles to implementation of some of the suggested research priorities. Achieving funding allocated to these research topics and disseminating the results is likely to be a challenge in itself, above and beyond those of the broader research landscape. Convincing taxpayer-funded bodies to support this kind of research is therefore a question in its own right.

Another challenge is a lack of contextualisation of the responses obtained. It is not possible to simply state 'X should be a priority area of research' without giving context about what other conditions would need to be met for that research to be possible. Some of these conditions may also require research to be carried out, or for specific socioeconomic conditions to be possible. Identifying those specific conditions would be also a research priority. Discussion is therefore required regarding the context of research priorities, before they are tackled.

The aim of this report is to inform development of future research priorities and proposals relating to climate change in the Scottish environmental research community. Some existing current research areas already align with the research priorities identified here, while others may require further development or improved interdisciplinary integration. This report will also be disseminated to policymakers and the wider scientific community in the hope that it is useful for informing future decision-making.

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