Infrastructure Commission for Scotland

Low Carbon Infrastructure

Literature Review

Nathan Goode

January 2020

Aventia
CONSULTING

Infrastructure Commission for Scotland

Low Carbon Infrastructure

Literature Review

"It is not enough to will the ends: the means have to be provided to achieve them"

Natural Capital Committee

Nathan Goode

January 2020

Aventia CONSULTING

Contents

1. Introduction 8

2. Scope of review 9

3. Review parameters 11

4. Synopsis 13

4.1 Setting the Context 13
4.2 Framing the Challenge 13
4.3 Linkages between Infrastructure & Carbon Emissions - Overview 14
4.4 Transport 15
4.5 Energy 16
4.6 Housing 17
4.7 Other Sectors 18
4.8 Approaches to Investment 19
4.9 Approaches to Evaluation 20
4.10 The role of government and Scottish Government programmes 20
4.11 Decision-Making Hierarchies 22
4.12 Spatial Considerations and Green Infrastructure 22
4.13 End of life assets 23
4.14 New Technologies 24
4.15 Conclusions and recommendations 24

5. Setting the Context 27

5.1 Introduction 27
5.2 Defining infrastructure 29
5.3 Defining carbon 30
5.4 Sustainable development 31
5.5 Mitigation and adaptation 34
5.6 Pricing infrastructure use 35
5.7 Building carbon into infrastructure pricing 36
5.8 The effect of market uncertainties 36
5.9 Inclusive growth and low carbon 39
5.10 A Paradigm Shift? 41

6. Framing the Challenge 42

6.1 Scope 42
6.2 Policy Context 43

6.3 The effects of global warming (across the UK) 44
6.4 Decarbonisation (mitigation) in Scotland 46
6.5 Adaptation in Scotland 50

7. Linkages between Infrastructure and Carbon Emissions - Overview 55

7.1 Infrastructure for the long-term 55
7.2 Carbon in the asset lifecycle 57
7.3 Present and future infrastructure 61
7.4 Resilience shift? 64
7.5 The fragmentation of infrastructure management 66

8. Transport 67

8.1 Introduction 67
8.2 Going backwards? 71
8.3 The Future of Travel 72
8.4 Electric or hydrogen? 75
8.5 A Business Perspective 76
8.6 Scotland's Transport Strategy 78
8.7 Conclusions 78

9. Energy 79

9.1 Introduction 79
9.2 Overview 80
9.3 Scotland's Energy Strategy 2017 80
9.4 Electricity Market Reform 86
9.5 The effect of geography 89
9.6 The Energy Quadrilemma 90
9.7 Heat 92
9.8 The Renewable Heat Incentive 95
9.9 Public Engagement 97

10. Housing 98

10.1 Introduction 98
10.2 The Future of Housing 99
10.3 Balancing Multiple Outcomes 103
10.4 The Green Deal and ECO 105

11. IT, digital, communications 107

11.1 Mitigation 107
11.2 Adaptation 108

12. Water supply and flood prevention 111

12.1 Water 111
12.2 Flood Prevention 111

13. Approaches to Infrastructure Investment 114

13.1 Introduction 114
13.2 The Green Investment Challenge 115
13.3 Equity 115
13.4 Project and Asset Finance 116
13.5 Competing with tech 120
13.6 Finance - Scotland 122
13.7 UK Plans 124
13.8 Sovereign Green Bonds 126
13.9 Other Finance Initiatives 128
13.10 Project pipelines 129
13.11 Pipeline – Energy efficiency in Germany 131
13.12 Pipeline – UK Offshore Wind 132

14. Approaches to Evaluation 133

14.1 The infrastructure “hierarchy” 133
14.2 Defining “net zero” 134
14.3 Carbon Pricing 135
14.4 Non-carbon criteria 136
14.5 Green Book 136
14.6 Magenta Book 139
14.7 Horizon Scanning 140
14.8 Transport Guidance 141
14.9 Models and standards for sustainability 143
14.10 Disclosure and reporting 146
14.11 Multi-criteria analysis 149
14.12 Concluding remarks 151

15. The role of government and Scottish Government programmes 152

15.1 Introduction 152
15.2 Programme for Government 152
15.3 Scotland’s Energy Efficiency Programme 155
15.4 Low Carbon Transition Infrastructure Programme (LCITP) 160
15.5 Renewable Energy Investment Fund (REIF) 160
15.6 Community energy 161
15.7 Role of local government 162
15.8 Procurement 164
15.9 Water and Flood Management 167

16. Decision-Making Hierarchies 170

16.1 Introduction 170
16.2 What do we mean by a hierarchy? 170
16.3 Process hierarchies 170
16.4 System hierarchies 173

17. Spatial Considerations and Green Infrastructure 176

17.1 Introduction 176
17.2 Scotland's geography 177
17.3 Planning and Place 179
17.4 Cities 180
17.5 Greenspace 184
17.6 Green and Blue Infrastructure 186
17.7 Wellbeing 189
17.8 Peatland Restoration / Bio-carbon capture 190
17.9 Accounting for Green Infrastructure 191
17.10 The case for Green and Blue Infrastructure 193
17.11 Scottish Policy Initiatives 194

18. End of life assets 195

18.1 Nuclear 195
18.2 Oil & Gas Decommissioning 196
18.3 Reuse / Circular Economy for end of life O&G assets 198
18.4 Offshore Wind 200

19. New Technologies 202

19.1 Introduction 202
19.2 Energy system innovation 205
19.3 Wave & Tidal Power 209
19.4 Hydrogen 211
19.5 Low Carbon Freight Transport 213
19.6 Carbon Capture & Storage 215
19.7 Circular Economy 217
19.8 Negative emissions technologies 218

20. Conclusions and Recommendations 223

Appendix A – 20 Big Questions 228

Appendix B - Climate Ready Scotland SEA: relationship between draft programme and other plans 231

Appendix C – Procurement Reform Act 236

Appendix C – Blue-green infrastructure "win-wins" 237

Appendix D - Bibliography 239

Endnotes 263

1. Introduction

Credibility and trust are important elements for delivering a net zero carbon society. They are the building blocks for leadership. We should recognise that if the programmes and initiatives that are the manifestations of policy go awry, there is a risk that these elements will be corroded, making the task much more difficult. For this reason, while much of this report is concerned with physical outputs and tangible outcomes, governance and engagement are strong underlying themes.

Climate change is a global challenge and infrastructure is a universal foundation for modern civilisation. While this report specifically aims to support the Scotland's progression towards low carbon infrastructure by undertaking a review of relevant literature, I have therefore adopted a broad interpretation of what should be considered relevant. It is important to step out of national or regional "bubbles" and draw on ideas, experiences, successes and failures from across the globe. The opportunity to take short cuts by learning from countries facing different scales and types of comparable challenges is too good to pass up.

The decarbonisation of infrastructure is conceptually complex, and some simplification of terminology was needed to develop a narrative framework for this review. I have used the acronym NZCI ("Net Zero Carbon Infrastructure") to describe the overarching conceptual framework or objective. This covers both existing and potential infrastructure that supports this objective. The relationship between infrastructure and carbon emissions concerns mitigation (= reducing carbon) and adaptation (= responding to the effects of climate change) and the acronym covers both aspects.

Notwithstanding the broad scope of "infrastructure" as a concept, this literature review is heavily influenced by the relationship between energy and infrastructure. This is because most of the greenhouse gases we emit connected to infrastructure relate in some way to energy use. So even when considering infrastructure segments other than power, energy is still a primary driver in terms of emissions.

Finally, it should be noted that this is a rapidly evolving sector. Every week sees relevant announcements and developments. "Literature" as a generally or publicly available written synthesis of ideas and developments in the sector is a significant but not comprehensive source of information on the linkages between infrastructure and carbon, both because there is a time lag between action and publication and because not everything that matters in this sector can be found in structured, written form. So this review can only be one element of a multi-faceted and continuing process of research and no more than a snapshot in time.

2. Scope of review

The Infrastructure Commission for Scotland has commissioned a review of existing research and related analysis to determine the relationship between infrastructure, as defined by the Scottish Government, and carbon emissions, both embodied and lifecycle/operational carbon.

The intention is to set a clear direction of travel which will influence the approach and prioritisation of infrastructure investment. For each component the review aims to cover, as a minimum, a reflection on carbon emissions across the full lifecycle of infrastructure assets, taking into account the current plans to reduce carbon emissions, that have been made to address carbon emissions within Scotland and how these plans may change the future balance of priorities.

Infrastructure for the purposes of this review is defined as:

"The physical and technical facilities, and fundamental systems necessary for the economy to function and to enable, sustain or enhance societal living conditions. These include the networks, connections and storage relating to enabling infrastructure of transport, energy, water, telecoms, digital and internet, to permit the ready movement of people, goods and services. They include the built environment of housing; public infrastructure such as education, health, justice and cultural facilities; safety enhancement such as waste management or flood prevention; and public services such as emergency services and resilience."

The key lines of enquiry are as follows:
The robustness and relevance to the Scottish context of available research on the carbon impacts of infrastructure, including an assessment of the gaps in the evidence-base;
Carbon impacts by infrastructure sector (SG definition which includes social and economic infrastructure) and for infrastructure overall;
The relative impact of each sector within the Scottish context i.e. the relative scale of both the particular infrastructure sector and its carbon emissions;
A high-level critique of types of infrastructure investments and evaluation approaches that operate as a barrier to the transition to a net zero carbon economy, and those that accelerate the transition;
Any relevant analysis of the role and ability of Local Government, Scottish government and its agencies to influence infrastructure carbon emissions to support its net-zero-carbon ambitions. The analysis should include consideration of infrastructure-related procurement procedures;
Any spatial considerations i.e. urban/rural/other spatial categorisation as appropriate;
What evidence is available to support use of a hierarchy of principles to guide infrastructure investment to achieve a net-zero carbon future;

The evidence on carbon impacts of adapting/upgrading/maintaining existing infrastructure assets;

A consideration of the role of green infrastructure i.e. trees; other carbon sinks and negative emissions tech such as peatland restoration/bio-energy carbon capture, use and storage;

Consideration of any role of 'new tech'/earlier stage negative emissions technologies which are significant factors in the UK CCC Net Zero analysis related to recommendations for Scottish Gov net zero 2045;

Consideration of Scottish Government programmes such as the LHEES/EES and related whole area planning to integrate energy efficiency upgrades and low carbon heat transition in building stock.

The relevant lines of enquiry are highlighted at the beginning of the corresponding chapter. The synopsis in the next chapter summarises the key points from each chapter of the full report.

3. Review parameters

A literature review should provide a foundation-stone for an evidence-based approach to policy development and implementation. This review aims to be broad in its investigative scope, but is bound in principle to provide an incomplete picture both because of the extent of the literature available and because there is a time lag between development and research and an information gap in terms of what key actors are willing to disclose publicly. Much decarbonisation-related activity is relatively new, so, as one would expect, the quantitative evidence base in terms of outcomes as opposed to policy and ideas is correspondingly limited. That said, there are numerous useful case studies in different sectors, and some of these are referenced in the report.

Since a key aspect of this brief was to examine “the robustness and relevance” to the Scottish context of available research, it should be highlighted that we found Scotland-specific analysis relatively hard to come by, notwithstanding the fact that a number of Climate Change Committee reports in particular make a concerted effort to tell a distinctive story about the all countries within the UK and about Scotland in particular.

While literature that is not specific to Scotland can still be relevant, there are various reasons why a shortage of studies for Scotland creates material gaps in the analysis (by not explicitly factoring in Scotland’s demographic, economic and geospatial characteristics, for instance).

These gaps may be exacerbated by the fact that where reports are commissioned at a UK-level (with supposedly a UK-wide remit), Scotland’s distinctive challenges and opportunities don’t particularly stand out; English characteristics dominate simply as a function of relative scale.

Isolating literature that is exclusively about low carbon to the exclusion of everything else, other than narrowly technical literature, is also very difficult. Carbon, or more precisely carbon dioxide, merges with other substances, themes or policies at various levels, such that it is not feasible or helpful to apply too strict a definition. We explore this in more detail in the contextual chapter (Chapter 5).

Much of the literature reviewed can be categorised as:

- *Statements of intent in policy terms*
- *“Calls to arms” in order to underline the urgent need for action; or*
- *Generalised advice which, while it may be well reasoned, is short on specifics and therefore not directly actionable.*

These types of literature are all important and relevant in their own way and the volume of such literature is to be expected given the growing sense of crisis about climate change. However, these types of literature have been used selectively in this report to avoid duplication and to keep the broad thematic areas as clear as possible.

On the other hand, while in certain sectors qualitative case studies are in reasonably good supply, extensive and consistent publicly available data on infrastructure performance is not. Whatever other steps are taken by the IC in support of Scottish Government’s net zero carbon strategy, putting the necessary steps in place to build the evidence base should be a priority.

All documents reviewed have been listed in the bibliography but not necessarily cited in the text.

If the IC wishes to build on this literature review, it would seem sensible to turn to more primary research, where engagement with key participants and stakeholders enable ideas and propositions outlined in this “desktop” exercise to be challenged, refined and updated.

Review Structure

The remainder of this review is organised as follows:

Chapter 4 provides a synopsis of the whole report.

Chapters 5 to 7 examine the linkages between decarbonisation and infrastructure treating infrastructure as a broad “asset class”.

Chapters 8 to 12 examine specific sectors within infrastructure, with individual chapters on transport, energy and housing, IT & digital and flood prevention.

Chapters 13 and 14 consider tools and processes - both those that are specific to carbon and decarbonisation and those that function for infrastructure more generally.

Chapter 15 examines the role of government in general and the role of the Scottish Government in particular, while Chapter 16 considers decision-making hierarchies.

Chapter 17 looks at the role of “place” through spatial considerations and blue and green infrastructure.

Chapters 18 and 19 consider end of life assets and new technologies respectively.

Chapter 20 concludes the report and offers 10 recommendations for future policy development in this area.

4. Synopsis

4.1 Setting the Context

Infrastructure is a series of interconnected systems, embedded in still larger physical, economic and societal systems and all of this within the biggest system of all – our planet.

Scotland has committed itself to becoming a net-zero carbon society by 2045 – five years before the rest of the UK. Achieving this objective is critically dependent on its infrastructure.

Social inequality and responses to climate change are closely linked, through the question of how decarbonisation strategies in infrastructure are paid for and by whom.

Market-based approaches to policy support for low carbon infrastructure have encountered significant challenges without resolving the apparent short-term/long-term conflict between affordability and sustainability.

The electricity sector shows that policy based on the status quo can create obstacles as well as pathways. The link between fossil fuel prices and electricity generation is weakening and electricity is also transitioning from a unit-based commodity to an availability-based service as a result of low or zero marginal cost renewable energy generation.

Thinking on climate change is also shifting, with the need to adapt to climate change becoming an increasingly important policy driver. The concepts of decarbonisation and low (or zero) carbon have become nested in a broader environmental and sustainability agenda.

In infrastructure, mitigation and adaptation strategies may not always be aligned. Adaptation responses create extensive connections across and within systems and therefore need broad sets of indicators to demonstrate success.

A shift in emphasis can be seen away from single purpose carbon reduction strategies towards tackling a broader connected front of environmental challenges. However, actions to deliver these strategies remain piecemeal and lacking in scale. NZCI policy-making must now learn from the limitations of previous low carbon policy and align capital planning instruments with Scotland's carbon budgets and net zero targets.

4.2 Framing the Challenge

This review examines both the effects of infrastructure on carbon and the effects of carbon on infrastructure. Infrastructure plays a critical role in the delivery of a net zero carbon society. The literature has identified serious policy deficits in infrastructure at the UK level – notably for transport, heat, carbon capture and storage, housing, buildings and industry and afforestation. Delivering NZCI also requires shared infrastructure, combining electricity, hydrogen and CO_2 technologies.

Scotland has made relatively good progress to date in reducing carbon emissions. This is largely due to decarbonisation of electricity supply. Little progress, however, has been made in transport, agriculture and heat for non-residential buildings. Domestic transport is essentially as carbon intensive as it was in 1990. There is some identified progress in the residential sector, but not at the scale required.

Low public engagement is a key barrier, as well as the more technological and socio-economic requirements for supporting infrastructure.

The UK is not considered to be on course to meet its carbon budgets, Scotland has been seen to be performing relatively well in this context.

There is a mixed picture on the uptake of "low-regret" actions to adapt to climate change. For example, there is a reportedly high deployment of sustainable drainage systems in new development but a low uptake of property-level flood protection measures in existing buildings.

"Climate Ready Scotland", a consultation draft for Scotland's Climate Adaptation Programme paints an optimistic public picture that doesn't necessarily align with the challenges raised in the expert literature.

Scotland is considered to be making good progress in raising awareness of adaptation, building capacity and incorporating consideration of climate change into long-term decision-making, but the latest Committee for Climate Change (CCC) report on Scotland[1]makes it clear that a step-change in policy-making and implementation is now needed, which includes placing decarbonisation at the heart of decision-making and improving the level of public engagement. "Now, the report says, [the Scottish Government] must start delivering emissions reductions in the real world"[2]

4.3 Linkages between Infrastructure & Carbon Emissions - Overview

Infrastructure is currently estimated to account for 53% of total UK emissions. It largely comprises long-term, "intergenerational" assets. The need to protect existing assets from climate change and make them more resilient is recognised, but it is not clear what mechanisms exist for making the right choices about existing and future infrastructure, based on long-term decarbonisation objectives.

The Committee for Climate Change (CCC) identified the following key areas where new infrastructure is needed for decarbonisation:

- *electricity generation,*
- *heat,*
- *CO_2 ;*
- *transport networks.*

Interactions between sectors and across the economy as a whole system (including supply chains) need to be reflected in decision-making to avoid "locking-in" high-carbon infrastructure or behaviours.

"Capital" or "embodied" carbon are expected progressively to become more important than operational phase carbon, but this relies on ongoing decarbonisation of the electricity supply, decarbonisation of space heating and continuously improving building energy performance.

A combination of factors is likely to increase resilience risks for infrastructure in the future. These include:

- *Worsening / more extreme weather conditions*
- *Increased societal dependence on infrastructure*

- *More complex infrastructure*
- *Greater interdependence between infrastructure elements*

Thinking on resilience is changing, with greater emphasis on the importance of learning from disruptions and adapting to change - not just 'bouncing back' but 'bouncing forward'. Critical infrastructure systems need to transition from a 'fail-safe' managerial approach, towards a *'safe-to-fail'* approach.

4.4 Transport

Transport represents a major policy challenge. Not only is the sector's historical carbon performance poor but predicting the future of transport is difficult.

Car traffic is still increasing in Scotland. Vehicle kilometres on Scotland's roads have risen by 37% since 1993. 62% of people drove to their place of work in 2017, compared with just under 10% who took the bus and 5% who travelled by train. Transport is the highest carbon-emitting sector in Scotland[1].

By 2050, there is scope for near-full decarbonisation of "surface transport", making use of electric and hydrogen fuel cell vehicles powered by low-carbon electricity and hydrogen. Use of these vehicles will require significant infrastructure investment.

There are certain accelerating technological trends and behavioural shifts, such as electrification, automation and shared mobility. Transport needs to place carbon more explicitly at the centre of its decision-making processes, but the key question for policy-makers is the extent to which they should incentivise and influence shifts both in technology and travel behaviour.

The difficulty is that the future of transport is likely to be radically different from that of the present and the near past. The evidence base for policy decisions is therefore hard to find. This means that decision-making processes need to allow for a broader range of outcomes than has typically been the case in the sector. That said, tools and techniques already exist to allow a broader analytical approach[2].

Some alternative scenario modelling is already being undertaken in infrastructure sectors such as transport and power, but the range of projected outcomes modelled has been relatively limited and the tendency is for the "central case" to be focused on. A different approach to scenario modelling is needed.

Scotland's national transport strategy recognises the need to recontextualise transport and changing incentives, but transport planning is lagging behind the vision and a new transport strategy is due, which needs to make net zero carbon a central policy driver.

[1] Transport is the highest carbon emitting sector, while heat is the biggest energy user (see 4.5 below), due to differences in the fuel mix which makes a unit of energy in the transport sector more carbon intensive than in the heat sector

[2] This is discussed in more detail in Chapter 14 below

4.5 Energy

Decarbonisation of infrastructure is mostly about energy in some form. Energy has two main sub-components – electrical energy (or power) and heat. Historically, these two have been relatively easy to separate but as the decarbonisation of energy proceeds, the differences between the electricity and the heat markets are becoming blurred, with generation of electrical power becoming more localised and increasingly expected to be used for heat as well as power. This overlap is recognised in the development of Scottish Government policy.

Electricity decarbonisation needs to accelerate, notwithstanding progress so far. Gas will play a significant role in the short term.

In Scotland, heat accounts for 54% of total final energy consumption (compared with 25% for transport) which explains why heat is such an important policy focus for Scotland.

Scotland does appear to be getting more energy efficient. Consumption of energy used for heating declined by 20% between 2005 and 2013. Final energy consumption in 2015 was 157 TWh[3], a drop of 15.4% compared with the mid-2000s.

By the end of 2021, the Scottish Government will have allocated over £1bn to tackling fuel poverty and improving energy efficiency. Energy efficiency appears to have increased as a result of Scottish Government programmes combined with new building standards.

Two 2050 scenarios are modelled in the Energy Strategy:

- An **electric future**, where electricity generation accounts for around half of all final energy delivered (i.e. double the 2015 proportion), with domestic energy 80% electrical; and
- A **hydrogen future**, where natural gas has been replaced with low carbon hydrogen, through the development of carbon capture and storage and electrolysis, with hydrogen transmission pipes, 60% of the residential sector would be powered by hydrogen and the car and van fleet hydrogen powered.

The expectation is that the actual outcome is likely to be some combination of the two. The Strategy also sets two key interim targets for the Scottish energy system by 2030, namely:

- The equivalent of 50% of the energy for Scotland's heat, transport and electricity consumption to be supplied from renewable sources; and
- An increase by 30% in the productivity of energy use across the Scottish economy.

The implications of these different pathways are significant from an infrastructure perspective. There will be "no regrets" actions which do not jeopardise either pathway, particularly in the earlier years, but long-term forward planning of infrastructure will also be needed to understand where these pathways diverge. Future decarbonisation of heat relies heavily on electrification or hydrogen or both. Transportation of hydrogen is a key challenge and proactive policies appear more necessary to support hydrogen if this is to be major component of the energy mix in future.

Community ownership is key theme in the Energy Strategy. At present, however, community ownership of energy assets is a relatively small component of the energy mix in Scotland.

[3] TWh = Terawatt hours, equivalent to 1,000,000,000 kilowatt hours (kw/h)

Public engagement on the Energy Strategy appears to be low - for this milestone policy statement, the consultation process elicited just 252 responses, mostly from organisations rather than individuals.

The development and outcomes of the UK's Electricity Market Reform programme since 2010 have significantly influenced the current position in the electricity sector. EMR as a policy mechanism struggled with conflicting objectives, although it delivered a positive outcome specifically for offshore wind.

Current and recent UK policy support mechanisms for energy are complex, technology specific and subject to unpredictable budgetary constraints.

The GB transmission system is designed to spread the costs of building and maintaining the electricity networks evenly across the UK mainland population. A "locational" pricing model for generators is part of this model, thereby placing remoter generators at a disadvantage.

The conflicting objectives in energy policy are currently being expressed as a four-way challenge, namely:

- *addressing climate change;*
- *ensuring affordability;*
- *providing energy security; and*
- *developing energy policy which is "acceptable to the public, economically sustainable and just".*

It is argued that continued cooperation between the Scottish and UK Governments on energy is essential.

4.6 Housing

Residential emissions are the most significant component of the building sector and space heating accounts most of those emissions.

Progress in decarbonisation has been inadequate across the UK in recent years. Future-proofing new houses is vital. Detail on how to achieve effective mass retrofit for energy efficiency is lacking. This does not appear to be a technical challenge, rather a question of public engagement and political will. The last mass retrofit programme was the UK Government's Green Deal, which was a conspicuous failure.

Deployment of low-carbon heat cannot wait until the 2030s. In the next decade, a series of "low regrets" can be implemented, regardless of the longer-term path to decarbonising heating in buildings.

Future-proofing new homes for low-carbon heating is estimated to save £1,500-£5,500 of cost compared with later retrofit. The evidence indicates that low-carbon heat is going to be cost-effective in all new build homes by 2025 or earlier, so no new homes should connect to the gas grid beyond this date at the latest.

Household energy efficiency programmes have generally tended to incorporate social as well as environmental objectives. At times there has been a reluctance to openly acknowledge CO_2 reduction as a primary driver. "Rebound effects" can occur where the benefit of energy efficiency to individuals and households results in more energy being used; where previously the household was inadequately heated or where the money saved is spent on something else which has the effect of increasing personal carbon emissions.

It has been argued that while government policy on energy efficiency has targeted the fuel poor, there is an economic stimulus argument that might justify support to a wider segment of the population.

The early termination of the UK Green Deal and ECO programmes was a set-back for engaging people in the transition to a low carbon economy. The UK Green Deal is an example of a rational policy initiative that failed because it did not take account of legitimate motivations and concerns of consumers and because the implementation strategy was poor.

4.7 Other Sectors

While relatively small, the share of digital technologies in global greenhouse gas emissions has increased rapidly by 50% since 2013 to 3.7% of the total. The digital industry's energy intensity is increasing by 4% per annum, at a time when the energy intensity of global GDP as a whole is declining.

From an infrastructure perspective, the question is whether positive decisions can be made to encourage more energy and resource efficient usage of digital technology, when much of the footprint is in the devices themselves.

The resilience of a digitally connected infrastructure system is inherently linked to pre-existing vulnerabilities within the underlying infrastructure system (power networks, for instance), and new vulnerabilities will arise from the creation of new interdependencies, so the more digitally-connected infrastructure systems are not expected to improve systemic resilience.

The location and design of new buildings and infrastructure will affect the level of vulnerability. Extreme events can result in disruption to or even the complete loss of essential services such as water and energy supplies, and transportation and communication networks. The loss of infrastructure services can have significant impacts on people's health and wellbeing, and local economic activity.

In the water sector, investment since privatisation in England is said to have delivered some improvements to existing water supply assets, presumably with a primary focus on keeping the cost to consumers down, but little new supply infrastructure has been built. Leakage reductions have largely stalled in the last decade and daily consumption per person has only reduced gradually from 150 litres in 2000 to 141 litres during 2018 / 2019. This compares with about 115 litres per person per day in Belgium and Denmark, which are amongst the best in Europe. Around 2,900Ml/day (20%) of water put into the public supply is lost through leakage in the UK.

The average daily consumption of water in Scotland appears, however, to be higher than the UK average at around 150 litres a day. Over the last 13 years, leakage in Scotland has reduced from 1104ML/d to 480Ml/d. As this is around 16% of the total UK figure, it suggests that Scotland is performing worse than England on both leakage and water consumption.

It is considered essential that action is taken to make more properties resilient against flooding and to reduce the physical, financial and emotional impact of flooding on properties and their owners.

4.8 Approaches to Investment

The most common forms of private finance in NZCI are equity and project finance. Cleantech[4] is financed by risk-taking equity (venture capital or similar). Cleantech in the UK appears to have declined in recent years and, compared with the wider technology sector, is much smaller-scale.

Tackling the declining cleantech investment trend is critical for the next stage of decarbonisation.

For large-scale infrastructure, private finance is available either as corporate funding or as project or asset finance in standalone companies or investment funds.

Project finance works best for relatively large standalone projects with low technology risk. Asset finance works best for bundles of assets (usually smaller in size) that conform to standardised types that enable a portfolio approach to risk to be taken.

The traditional paradigm for risk equity is starting to be challenged, with the emergence of "impact investing", which looks for a broader range of outcomes than financial returns. It is still a relatively small component of the total investment market but gathering an increasing amount of attention.

An early challenge for the Scottish National Investment Bank ("SNIB") will be to construct a funding approach that drives decarbonisation and innovation while complementing available private sector financing mechanisms.

The UK Government is currently attempting to reinvigorate finance for low carbon through the Green Finance Taskforce.

The Green Investment Bank ("GIB"), established in 2012 and headquartered in Edinburgh, performed something of a pioneering role in this area. Its disposal meant the loss of significant green investment know-how from the public sector in exchange for a relatively small "premium".

Green bonds are already a well-trodden path elsewhere in Europe and sovereign Green Bonds are becoming an established financing mechanism. France is currently the world's leading issuer of green bonds. The UK doesn't appear in the top 15 list of green bond-issuing countries.

Project pipelines are seen as a fundamental component for scaling up activity and attracting private finance for low carbon infrastructure, but it has proved difficult to deliver on promises in practice. Terms like "shovel ready" and "cookie-cutter" can mislead public and private stakeholders alike. The rigidity that results from the project finance model can also act as a significant barrier.

Given expected system complexities, the level of complexity in project implementation is likely to increase rather than decrease in the future, placing further stress on standardised, de-risked financing models. The UK offshore wind sector can be seen as an example of a successful

[4] Projects or businesses developing low or zero carbon technologies where the principal risk or opportunity is the success or failure of the technology itself

project pipeline – it benefited from sustained revenue support through Electricity Market Reform, as well as targeted supply chain initiatives.

4.9 Approaches to Evaluation

The 2018 edition of the Green Book has built significant additional flexibility into the guidance to support broader evaluation approaches, but a central question remains about the suitability of discount rates as an evaluation tool for low carbon investment.

Future uncertainty means that there are a number of approaches to pricing carbon but there is no long-term government price as a guide. The Green Book Supplementary Guidance provides low, central and high carbon price scenarios, but the tendency in evaluation is to focus on a central scenario and the choice of scenario is likely to have a significant impact on the results. So how future infrastructure investment models value carbon remains a key area of consideration.

The Magenta Book is a key tool, with its emphasis on “designing in” data capture and Theory of Change thinking.

Transport guidance has certain key “hard-coded” model assumptions not designed for net zero carbon. The discrepancy between existing transport models and policy objectives is therefore likely to widen as net zero becomes a more important driver.

Fixed assumptions about the value of working and non-working time according to the purpose of the trip are embedded and determine the outcomes of transport modelling. This makes it harder to adapt the evaluation model to changing needs and priorities. Other approaches to transport modelling, such as the one taken by the Dutch Rijkwaterstaat, favour a collaborative approach that embraces uncertainty and deals with a wider range of potential variables.

In the private sector, there is a range of well-established measurement tools, together with approaches to disclosure and reporting. Performance data, however, is harder to find.

The process of decarbonising infrastructure rarely (if ever) happens without other ‘non-carbon’ factors being taken into account. Infrastructure is seen as a key enabler of economic prosperity and important for addressing social and environmental challenges, including climate change mitigation and addressing fuel poverty. We therefore need evaluation models for NZCI that are capable of factoring in a wide range of socio-economic as well as environmental criteria.

We are arguably “model rich and data-poor” – with a proliferation of measurement tools but a paucity of information on what does and doesn’t work in practice.

4.10 The role of government and Scottish Government programmes

The Scottish Government’s Programme for Government (September 2019) is the latest public policy document to address the challenge of decarbonisation. From the Programme, people can start to see what a future low carbon Scotland might look like. The Programme initiatives will need both interdepartmental and central/local collaboration to succeed.

A refresh of existing public sector governance structures may be needed to ensure that decarbonisation is placed firmly centre stage, operationally as well as strategically.

CCC commented positively on the Programme.

Local Heat and Energy Efficiency Strategies ("LHEES") are intended to determine locationally the most appropriate energy efficiency and heat decarbonisation options to meet decarbonisation and fuel poverty objectives.

Under Phase 1 of the pilot programme, LHEES have been piloted to assess methodologies and data needs for area-based plans and priorities for systematically improving the energy efficiency of buildings, and decarbonising heat.

There was little or no external community engagement during the LHEES pilots, which may be storing up problems for the future.

Warmer Homes Scotland is the Scottish Government's flagship national fuel poverty scheme and is one of a range of schemes funded and delivered by the Scottish Government's Home Energy Efficiency Programmes for Scotland (HEEPS); it has both social and environmental objectives.

The **Low Carbon Infrastructure Transition Programme** is a strategic intervention with match funding guaranteed until Autumn 2021. Its main focus is assisting projects to develop investment-grade business cases that will help secure public and private capital finance to demonstrate innovative low-carbon technologies in Scotland.

Community energy has long been viewed in Scotland as positive aspect of the renewable energy landscape and **Local Energy Scotland** is the body charged with administering the Scottish Government's CARES (Community and Renewable Energy Scheme) funding. SG set a target of 500MW of community and locally owned renewable energy capacity in Scotland by 2020, which had been beaten by the end of June 2019. However, community and locally owned renewable energy remains a relatively small proportion of the total renewable energy capacity in Scotland (about 6%) and genuine community-owned energy generation is only about 11% of this, and as such is a relatively marginal consideration in Scotland's energy landscape.

There is limited literature specifically considering the role of local government in delivering low carbon infrastructure, although they are identified as key actors in much of the UK-wide analysis.

While local authorities can perform a number of key enabling roles, there has been significant interest over the past decade in their delivery role, given their purchasing power, their "reach" within local communities and their ownership of key assets.

In Scotland, this potential is evident in the City Region Deals and Growth Deals. To date, six such deals have been signed, covering the majority of urban Scotland. Some, but not all of them are explicitly treating the transition to net zero carbon as an economic opportunity.

Public procurement has also been identified as a major route to delivering low carbon infrastructure. The Procurement Reform Act, with its Sustainable Procurement Duty, is potentially an important signal for decarbonising Scotland's infrastructure, but a review of some reports found limited mention of low carbon.

The ownership and structure of Scotland's water and river systems management is somewhat different from England's. Perhaps in part due to the relative simplicity of this infrastructure segment, decarbonisation has not only already been recognised as a priority but is being embedded in business models, showing that collaboration within industry sectors can work. For example, Scottish Water now generates and hosts around 923 GWh per annum of renewable energy, more than double its own electricity consumption.

4.11 Decision-Making Hierarchies

Hierarchies are important concepts in the development of NZCI, but it is important to distinguish between “process hierarchies” and “system hierarchies”, the former being the way we organise priorities for action and the latter being system characteristics that can be designed in to increase resilience and improve delivery risks, e.g. through the implementation of “low regrets” solutions.

Historically, policy and investment in NZCI have been sector-led, whereas the reverse is probably needed and sectors should be driven by the central purpose of decarbonising infrastructure. Adopting a systems-led approach to NZCI would enable key links between sectors to be identified and systems hierarchies should help to build resilience into the overall delivery strategy.

4.12 Spatial Considerations and Green Infrastructure

Recent decades have seen growing attention paid to the characteristics of the places in which we live. There is a correlation between the quality of a place and its sustainability. The converse is also seen to be true - that urban sprawl has wider negative social, environmental and wellbeing implications beyond simply increasing emissions.

However, this strategic thinking does not necessarily translate into policy delivery. For example, “accessibility” in geographical typography in Scotland is still defined by drive time, the underlying presumption being that most households have access to a car. The recently passed Planning (Scotland) Act looks like a missed opportunity to send a strong signal on decarbonisation as the legislation does no more than mention climate change as a consideration in planning, sending a weak signal on adaptation and no signal on mitigation at all. The Programme for Government promises a “fundamental overhaul in building regulations”; but, as we have seen, much of the decarbonisation challenge is not about the buildings themselves, but the space in between.

Cities are thought of as effective vehicles for efficient resource use and decarbonisation, due to their density of population and economic activity. However, this status is dependent on making timely and appropriate investment decisions on low carbon infrastructure. Even the C40 cities[5] face significant barriers accessing and attracting finance, while the finance industry reports a lack of understanding of the low carbon technology being deployed and limited experience in the financing models that cities use to fund infrastructure projects.

Urban areas contain significant amounts of green space. There are approximately 1.77 million hectares of urban area in Great Britain and of these, 0.55 million hectares are classified as natural land cover (31%). Scotland has the largest proportion of both natural land cover (37%) and blue space (1%) in its urban areas. The removal of air pollution by urban green and blue space in Great Britain equates to a calculated saving of £162.6m in associated health costs. The amount of carbon removed by woodland in UK urban areas was estimated to be worth £89.0m during 2017.

[5] Founded in 2005, The C40 Cities Climate Leadership Group is a group of 94 cities around the world that represents one twelfth of the world's population and one quarter of the global economy. https://www.c40.org/

There is a movement to enhance and reinforce a sense of place in our towns and cities. Central to this is the contribution of the green (and blue) infrastructure to the public realm. While Scotland is considered to have a good policy framework for planning and sustainable development, it is said to lack practical tools and techniques to help urban planners take an integrated view of their green infrastructure assets.

The case for blue-green infrastructure is both as a climate change mitigant and an adaptation measure, as well as delivering a range of wider benefits to people and wildlife. Health benefits are often quoted as a benefit of greenspace, but there is relatively little academic literature to support the presumption of a strong link between wellbeing and greenspace.

It is argued, however, that communities would be better able to adapt if they were able to work with natural processes and systems.

There is growing recognition of the potential synergies between "grey" infrastructure and natural capital ("green and blue infrastructure") and of the benefits of green and blue infrastructure.

There have been sporadic attempts, using natural capital or social return on investment principles, to place a monetary value on greenspace. But large figures for the value of natural capital quoted in isolation are not especially meaningful because green assets are unique, non-replaceable assets.

4.13 End of life assets

In general, there is relatively little publicly available literature on the carbon effects of end of life assets. This is the case for carbon emissions from nuclear decommissioning. However, data from one sample site suggested that end of life CO_2 emissions are not a material factor when compared with the operational power output.

The UK Continental Shelf (“UKCS”) is now in decline. Its production carbon intensity is correspondingly higher, with comparable emissions to Norway for less than half the production.

In 2016-17, the UK Government for the first time paid out more to oil and gas operators in tax relief than it received from them in revenue, although revenues recovered in 2017-18.

The future costs of decommissioning oil and gas assets are very uncertain. Like the nuclear sector, limited public data is available on emissions from decommissioning.

A circular economy initiative for oil and gas assets was launched by the RSA in 2015 but no evidence has been found that the recommendations of the resultant report are being acted on.

In July 2019, BEIS issued a consultation on the reuse of oil and gas assets for carbon capture usage and storage (“CCUS”), through the re-purposing of offshore oil and gas assets that have reached the end of their commercial life.

In the offshore wind sector, decommissioning costs are largely neglected in studies as the discounted value is generally regarded to be low or costs are assumed to be equivalent to the salvage value of the assets.

4.14 New Technologies

Notwithstanding policy and implementation challenges in the energy sector, the cost of key energy technologies that were once regarded as "new" has come down very rapidly in recent years, notably offshore wind, onshore wind, solar PV and lithium-ion batteries.

This rapid decline offers considerable encouragement for new technologies.

There is an important set of technological developments in the energy system itself, particularly in terms of domestic consumption and generation and flexibility and balancing services.

Wave & tidal development continues to be promoted vigorously by the Scottish Government and some technologies in this segment appear to be steadily scaling up, but the UK Government seems to have lost interest in this renewables technology.

How low carbon hydrogen will be produced and deployed is still open to question. The Royal Society argues, however, that hydrogen will ultimately play a key decarbonising role.

New development in the transport sector primarily concerns the decarbonisation of road freight. Battery electric vehicles (BEV) are commonly accepted to be the most promising technology for decarbonising the light duty vehicle sector.

However, the most cost-effective route to decarbonising the heavy-duty vehicle (HDV) sector is much less clear, with electric and hydrogen options emerging as viable alternatives to diesel. It is expected that battery electric or hydrogen HDVs could be available in the 2020s and uptake could accelerate rapidly once cost parity is reached. Scotland should be considering now how its infrastructure can support either or both of these options.

Carbon Capture, Usage & Storage is considered to have a critical role in meeting carbon budgets. There are now over 40 operational CCS projects across the world (mostly for enhanced oil recovery), so it looks as though CCS is beginning to move towards being an established technology globally. However, none of these are in the UK, notwithstanding years of research.

"Circular economy" models have significant potential for decarbonising product lifecycles and are being promoted in supply chains which use heavy manufacturing for material such as steel and concrete. "Circular economy" activities should be trying as far as possible to preserve the function for which things have originally been manufactured, preferably with a minimum of physical displacement, thereby saving on energy, new raw material and CO_2 emissions.

Negative emissions technologies (apart from reforestation) remain unproven at scale and are largely conceptual at this stage.

4.15 Conclusions and recommendations

Decarbonisation is a persistent thread through multi-sectoral policy development in Scotland but is not yet placed systemically at the heart of policy-making. Notably, decarbonisation is missing from, or only weakly referenced in key new legislative or economic initiatives – for instance the Planning Act, Procurement Reform, city-region deals, new housing standards, transport strategies and so on. The Scottish Government's organisational structures also need to reflect the central role of decarbonisation and local government and other government agencies need to follow suit.

Engaging with citizens / people and communities on the transition to NZCI is an enormous unresolved issue. Central and local government need to recognise that, beyond mandated or regulated change, more effective ways of channelling and scaling up proactive personal and community engagement need to be found. The next stage of decarbonisation journey will require more than just consent. The Scottish Government needs to be significantly bolder in the way it engages people and communities.

The route to NZCI is further complicated by the fact that the effects of extreme weather are already beginning to be felt, so the challenge for existing infrastructure is no longer just about decarbonising assets that are already operational, but how to protect them, most of which will still be with us in 2050.

It is not possible to treat decarbonisation and inclusive growth as separate parallel themes. Social value can be eroded or enhanced through a net zero carbon agenda.

It is not all bad news. Technology development has made tremendous progress in the past decade, but what the past two decades also tell us is that consistent and meaningful government support makes a meaningful difference to development trajectories.

We also know a lot more about the impact of infrastructure on carbon emissions than we used to. But we are not collecting or sharing enough operational data.

The world of private finance remains tricky to navigate. Large-scale private finance remains risk-averse and investors seem to have fallen out of love with early stage cleantech.

Transport and buildings pose the big next challenges. There is no “one size fits all” decarbonisation strategy for every place in Scotland. Over-emphasis on urban density may result in a class of suburban poor who are excluded from the benefits of decarbonisation.

Recommendations

As a literature review, the focus of this report has been on producing a synthesis and analysis of existing known thinking and practice. Much of the current work in this rapidly developing sector will not (yet) be publicly available. A number of recommendations flow from this analysis, which are offered in summary below for consideration but would need to be validated through additional (probably primary) research:

1. *Establishment of a single ministry with coordinating responsibility for everything to do with low carbon in the Scottish Government.*
2. *Development of a robust set of investment criteria for NZCI that place decarbonisation at the heart of evaluation processes with the emphasis on systems-led cross-sectoral initiatives.*
3. *A proactive and accelerated decarbonisation strategy for transport.*
4. *Development of an effective housing retrofit programme at scale for Scotland.*
5. *A new financing ecosystem for Scotland around SNIB to support Scotland’s pathway to NZCI.*
6. *Securing and developing Government’s intellectual capital and knowledge base in the NZCI arena.*
7. *Taking bold steps to enable people and communities to engage and participate in the development of NZCI for Scotland.*
8. *Integration of low carbon and inclusive growth policy drivers to enable economic growth and addressing social inequality to be delivered within a sustainable environmental envelope.*

9. *Consideration of the extent to which existing appraisal and evaluation tools for infrastructure need to be re-engineered to create a coherent toolkit to support NZCI through its development and lifecycle.*
10. *Development of a decarbonisation-led place strategy which incorporates systems thinking and blue-green infrastructure and is embedded consistently in development.*

5. Setting the Context

*Question element: A review of the robustness and relevance to the Scottish context of available research on the **carbon impacts of infrastructure**, including an assessment of the gaps in the evidence-base; a review of **carbon impacts by infrastructure sector** (Scottish Government definition which includes social and economic infrastructure) and for infrastructure overall; the relative impact of each sector within the Scottish context i.e. **the relative scale of both the particular infrastructure sector and its carbon emissions.***

Headlines
Infrastructure is broad and systemic. Carbon acts as a collective term for the greenhouse gases that are causing global warming. As such it acts as a proxy for an unsustainable future. The question of social inequality is closely bound up with decarbonisation. Decarbonisation strategies are heavily influenced by the question of who pays for and who benefits from the infrastructure. Trying to tie renewable energy policy to fossil fuel pricing has in the past given rise to unsustainable green development policies and future policy-making has to recognise this legacy. Approaches are shifting: adaptation is becoming an increasingly important part of the policy narrative.

5.1 Introduction

We should be clear about the scope of the subject before focusing on specific sectors and questions.

Scotland has committed itself to becoming a net-zero society by 2045 – five years before the rest of the UK and in line with the advice from the government's independent expert advisors, the UK Committee on Climate Change.

The Scottish Government has also adopted an interim target of reducing emissions by 75% by 2030 – the toughest statutory target of any country in the world for this date, going beyond what the Intergovernmental Panel on Climate Change said is required worldwide to limit warming to 1.5 degrees.

The Infrastructure Commission for Scotland ("ICS")'s brief is to provide "independent, informed advice on the vision, ambition and priorities for a long-term, 30-year, strategy for infrastructure in Scotland" to meet future economic growth and societal needs, supporting the Scottish Government's delivery of its National Infrastructure Mission and development of the next Infrastructure Investment Plan.

The ICS will advise on the key strategic and early foundation investments to boost economic growth and support delivery of Scotland's low carbon objectives and achievement of its climate change target.

This literature review supports the second of the Infrastructure Commission for Scotland's overarching objectives: "Managing the transition to a more resource efficient, lower carbon economy". Within specific guidelines that have informed the development of the individual chapters that follow, the purpose of this literature review is to consider the linkages between "low carbon" and "infrastructure".

The subject matter for this review into the links between low carbon and infrastructure draws heavily on the extensive body of work undertaken by the UK Committee on Climate Change, whose composition and function are set out below.

Committee on Climate Change
The UK's Committee on Climate Change is an independent, statutory body established under the Climate Change Act 2008. Its purpose is to advise the UK Government and Devolved Administrations on emissions targets and report to Parliament on progress made in reducing greenhouse gas emissions and preparing for climate change. Its strategic priorities are to: • Provide independent advice on setting and meeting carbon budgets and preparing for climate change • Monitor progress in reducing emissions and achieving carbon budgets and targets • Conduct independent analysis into climate change science, economics and policy • Engage with a wide range of organisations and individuals to share evidence and analysis CCC comprises a Chairman and eight independent members. It is jointly sponsored by the Department for Business, Energy and Industrial Strategy (BEIS), the Northern Ireland Executive, the Scottish Government and the Welsh Government. The **Adaptation Sub-Committee** (ASC), which is part of the CCC, was also established under the Climate Change Act 2008 to support the CCC in advising and reporting on progress in adaptation. Its work is led by a Chair, who also sits on the main Committee, and six expert members. It is jointly sponsored by the Department for Environment, Food and Rural Affairs (Defra), the Northern Ireland Executive, the Scottish Government and the Welsh Government.

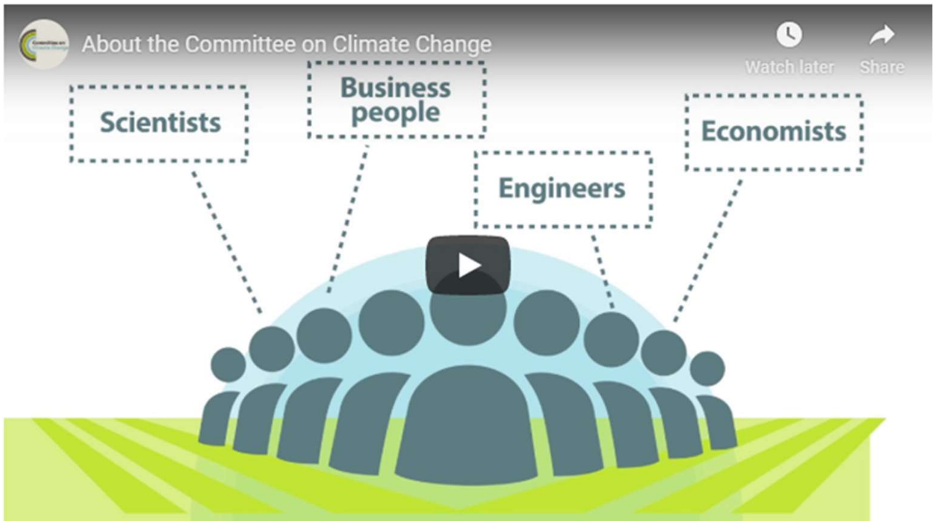


Figure 1 – composition of the CCC

5.2 Defining infrastructure

Scotland's Infrastructure Investment Board's terms of reference define "infrastructure" as:

"The physical and technical facilities, and fundamental systems necessary for the economy to function and to enable, sustain or enhance societal living conditions. These include the networks, connections and storage relating to enabling infrastructure of transport, energy, water, telecoms, digital and internet, to permit the ready movement of people, goods and services. They include the built environment of housing; public infrastructure such as education, health, justice and cultural facilities; safety enhancement such as waste management or flood prevention; and public services such as emergency services and resilience"[3]

The Office of the Chief Economic Adviser echoes this definition, while recognising that it goes beyond the standard economic definition of infrastructure, which focuses on utility networks, transport and digital communications and says that the rationale for extending this definition is to align with the Scottish Government's inclusive growth strategy.[4]

The dictionary definition of infrastructure separates the two components - "infra" ("inside", or "within") and "structure", and dates the origin of the word to the early 20th century[5]. The concept of infrastructure was critical both to Keynesian economics and New Deal policies in the USA. In the early 21st century, not only have categories of infrastructure expanded, so has the interconnectedness of infrastructure. The growing complexity of our infrastructure has brought with it questions of resilience (how does the system deal with failure?) and this sits alongside decarbonisation as a major question for infrastructure in the coming decades.

Systems thinking has developed over the past 50 years to try to explain this complexity and interconnectedness, but simply recognising the systemic nature of our world does not in itself ensure predictive accuracy, as Dana Meadows, one of the best-known systems thinkers pointed out:

"People who are raised in the industrial world and who get enthused about systems thinking are likely to make a terrible mistake. They are likely to assume that here, in systems analysis…is the key to prediction and control."[6]

Some characteristics of systems are relatively intuitive, such as reinforcing and balancing feedback loops, delays and information flows; others, such as the power of self-organisation and the role of paradigms, perhaps less so.

An understanding of how systems related to infrastructure work is vital to addressing the NZCI challenge and a plethora of analytical tools for evaluation and measurement of the relationship between infrastructure and carbon has developed (See Chapter 14 below). However powerful they may be, such tools will never provide complete certainty and the information they do provide is less likely to be of value if the tools themselves fail to recognise that uncertainty and unpredictability are fundamental to the relationship between infrastructure and carbon.

Infrastructure needs to be thought of as a series of systems connected with one another and embedded in broader physical, economic and societal systems while these lie within a still bigger system – our planet.

This is why it makes sense to adopt a broad definition of infrastructure, such as the one used by the Scottish Government. There will always be areas of uncertainty at the margins and around the boundaries of its sub-sectors.

The UK's National Infrastructure Commission ("NIC") is very clear about the systemic connection between carbon and infrastructure. In a recent article for Business Green[6], Sir John Armit, the NIC's chair, expressed the connection as follows:

"Today climate change is our biggest challenge. It demands we overhaul the systems we rely on to go about our daily lives. Not just to reach net zero, but to protect families and businesses from increasingly frequent extreme weather. It's clear to me that we find ourselves at a critical juncture. A year ago, we published the UK's first-ever National Infrastructure Assessment. Looking ahead to the next three decades, it sets out recommendations on transport, energy, recycling, water, flood management, and digital connectivity….The Commission is currently working on an in-depth study of the resilience of the UK's infrastructure - including its ability to withstand natural hazards - and we will report our findings next spring. Our report provides the blueprint. Now it needs ambition, leadership and action."

5.3 Defining carbon

In common use, the term "carbon" doesn't just mean the element itself, but its compound carbon dioxide. As a measure of the "greenhouse effect", we generally mean a group of gases, of which carbon dioxide is the most common (while others, such as methane, are more potent).

The greenhouse gas effect is a phenomenon which was discovered over a century ago - well before the term infrastructure started to be used. [7][7].

---

[6] https://www.businessgreen.com/bg/opinion/3080165/climate-proofing-the-uks-infrastructure-must-be-a-government-priority

[7] Worked out mathematically (by hand) by Swedish Nobel-prize winning scientist Svante Arrhenius in 1896

This report generally uses “carbon” to mean carbon dioxide emissions (CO_2e) and greenhouse gases in general.

We are concerned about the greenhouse gas effect primarily because of the impact that it will have on the habitability of the planet. The planet is the biggest system of all. While anthropogenic (man-made) carbon dioxide emissions are a dominant consideration, other forms of environmental degradation are also taking place (such as air pollution and the penetration of micro-plastics into environmental systems), many of which result directly from carbon-intensive activity. It is no surprise, therefore, that we find the concepts of decarbonisation and low or zero carbon nested in a broader environmental sustainability agenda. This reflects both the critical role that “carbon” plays in our world and its interconnectedness within the environmental system. Decarbonisation, in effect, becomes a proxy for a sustainable future.

5.4 Sustainable development

Environmental factors are increasingly being considered in conjunction with economic and social factors. The ultimate articulation of this is the UN Global Goals or Sustainable Development Goals (“SDGs”) as they are still more commonly known, on which the Scottish Government’s own National Performance Framework is modelled.

Scotland was one of the first countries to adopt the SDGs in 2015.

Figure 2: The Sustainable Development Goals and the National Performance Framework

There are two important aspects to this relevant to this review. Firstly, with society globally heavily dependent on CO_2-emitting fossil fuels, widespread societal acceptance and consensus are likely to be required to remove this dependency and achieve successful decarbonisation in time to avoid catastrophic climate change. This need for consensus holds true both within countries and between them.

Secondly (and this is something that policy-makers have perhaps only come recognise in more recent years), the detrimental effects of climate change are not evenly distributed across society. It is self-evident that those with greater resources at their disposal are likely to cope better with the effects of environmental degradation.

A question for this review is whether and how this inequality manifests itself in infrastructure. Are the vulnerable in society likely to be made more vulnerable as a result of climate change? What new barriers does climate change create towards addressing inequality? How do infrastructure investment decisions make either of these more or less likely?

That the Scottish Government is aware of this dimension is evident from the creation of the Just Transition Commission, whose brief is to advise on “a net-zero economy that is fair for all”[8]. That infrastructure does not have a role to play in ensuring there is a “just transition” is inconceivable. Decarbonisation of infrastructure and a “just transition” are therefore intimately linked.

The Scottish Government’s “Climate Change Plan - Third Report on Proposals and Polices 2018-2032 Summary Document”[9] explains the rationale for the JTC: ”Climate justice is based on the core principle that the poor and vulnerable at home and overseas are the first to be affected by climate change, and will suffer the worst, yet have done little or nothing to cause the problem”.

The JTC background report[10] presents publicly available data and information for Scotland on what is currently known and projections for population, labour market, business and industry, household income distribution, skills and skills development and greenhouse gas emissions, without explicitly addressing infrastructure inequalities (such as access to transport). This might be a useful next stage as the different policy strands of economic growth, addressing inequality and remaining within a sustainable environmental envelope come together.

The UNEP report, "Integrated Approaches to Sustainable Infrastructure"[11] proposes that an integrated approach is the most effective way of meeting the SDGs.

The report's objective is to motivate development planners to urgently invest in governments' technical and institutional capability to apply integrated approaches, to match the rapid expansion of infrastructure worldwide.

For the UNEP report, integrated approaches to infrastructure have the following characteristics:

- *They consider the interconnections among infrastructure systems, sectors, levels of governance, spatial scales, and the environmental, social, and economic aspects of sustainability across the entire lifecycle of infrastructure systems (i.e. early planning to decommissioning);*
- *They do so as far upstream in decision-making processes as possible, when alternatives are still technically, politically and economically feasible; and*
- *They incorporate stakeholder consultation and public participation from the outset, so that as wide a range of potential opportunities and challenges as possible are captured in the analysis.*

Historically, analytical tools such as cost-benefit analyses (CBA), environmental impact assessments (EIA), and environmental and social impact assessments (ESIA) have been used to assess the sustainability of infrastructure projects. There has also been a proliferation of tools created specifically for assessing and rating the sustainability of infrastructure projects, but there is a general lack of guidance on incorporating sustainability concerns at the upstream planning phase of infrastructure development, which limits the effectiveness with which sustainability can be incorporated during later phases.

Integrated approaches have three main advantages over "siloed" infrastructure approaches that consider infrastructure projects, systems, and sectors in isolation from others:

1. *They allow infrastructure development to be optimised by considering the services that infrastructure systems deliver, and not just the assets created.*
2. *They result in longer-lasting infrastructure that is more resilient to natural and man-made disasters.*
3. *By identifying and addressing potential risks early in the planning process they increase the bankability of infrastructure projects, making them more attractive to investors.*

A report by the Economist Intelligence Unit entitled The Critical Role of Infrastructure for the SDGs[12] also illustrates how mainstream the concept of a "triple bottom line" thinking has become in infrastructure development thinking. The report argues that infrastructure is about providing the services that enable society to function and economies to thrive and that this therefore puts infrastructure at the heart of efforts to meet the Sustainable Development Goals (SDGs), most of which imply improvements in infrastructure. The EIU report also reinforces the idea that infrastructure should not be viewed as individual assets but as part of a system with a portfolio of assets that collectively hold great potential to deliver the "three pillars" of economic, environmental and social sustainability. In protecting the environment, infrastructure assets play a key role in conserving natural resources and reducing the impact of climate change. Equitable access needs to be assured – one example given is using infrastructure to advance gender equality.

It would be easy to assume that these are issues for another part of the world, but a report from Sustrans[13] in 2018 explores the barriers to active travel in Glasgow – another intersection between low carbon and inclusive growth.

Increasing resilience, the EIU report points out, runs across all three of these pillars. The infrastructure needs to be resilient to the shocks and stresses it will encounter, which enables it to make an essential contribution to sustainable development and overall societal resilience by ensuring that the vital services infrastructure provides are less vulnerable to extreme events and disruptions.

5.5 Mitigation and adaptation

The effects of climate change are increasingly perceived as an immediate rather than a future problem. Alongside trying to reduce carbon emissions for future benefit (mitigation), this raises the challenge of dealing today with the effects of increasingly volatile weather patterns (adaptation).

The first substantive phase public policy response to climate change in the UK was focused on mitigation, by seeking to reduce the carbon intensity of the energy sector. This was initially through the introduction of the Non-Fossil Fuel Obligation ("NFFO"), which was incorporated into the Energy Act 1989[8]. NFFO experienced limited success, for reasons which we don't need to examine in detail in this report, and it wasn't until the Renewables Obligation came into being in 2002 that the UK acquired a mechanism for systematically "greening" electricity generation. The policy focus up to 2010 was very much on continuing this mitigation strategy through decarbonisation of the power supply. More specifically, the primary objective was to find and fund lower carbon replacements for existing generation technologies.

Alongside the RO, the UK Government also brought in the Low Carbon Buildings Programme ("LCBP"), aimed at supporting onsite microgeneration.

From around 2010 onwards, a number of factors brought change to the policy landscape for decarbonisation. After the Global Financial Crisis, a new UK Government was preoccupied with austerity, whilst seeking to tackle decarbonisation by using less as well as generating greener, but at lowest cost to government. The RO was replaced by Electricity Market Reform (See Section 8.4) and the LCBP was replaced, after several years' delay, by the Renewable Heat Incentive (See Section 8.5). The Green Deal energy efficiency programme was also introduced (see Section 10.4).

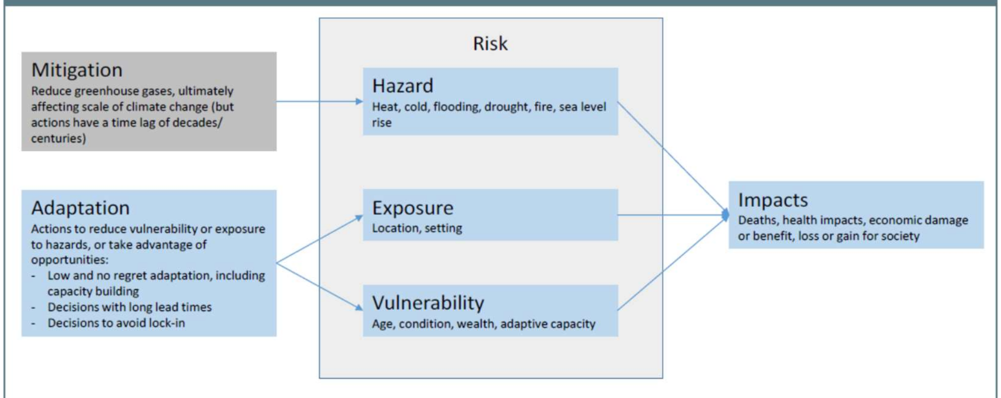
We can see from the literature review more broadly that there has been a shift of emphasis, away from single purpose strategies of reducing carbon emissions in order to minimise or even reverse global warming, to trying to tackle a much broader connected front of environmental challenges, most of which have their principal cause in the rising quantity of carbon dioxide in our atmosphere. This doesn't necessarily mean that mitigation and adaptation strategies have become systemically more coherent; actions to support both the

[8] https://en.wikipedia.org/wiki/Non-Fossil_Fuel_Obligation

delivery of NZCI and managing the environmental consequences of climate change remain piecemeal, disjointed, unsystemic and of inadequate scale.

CCC emphasises the need to tackle mitigation and adaptation in parallel, as illustrated in the graphic below from the Adaptation Committee[14]:

Figure 1.4. Adaptation Committee's indicator framework



Source: CCC.
Notes: Blue boxes denote aspects of risk and adaptation that are measured by the Adaptation Committee. Adaptation actions either reduce exposure or vulnerability, but do not have an effect on hazard (this is influenced by how successful mitigation efforts are). Positive or negative social, economic or environmental impacts provide an indication of how risk is changing, and the effectiveness of adaptation actions. Definitions of hazard, exposure and vulnerability used here are consistent with IPCC terminology from its Fifth Assessment Report (https://www.ipcc.ch/report/ar5/syr/).

Figure 3 – mitigation and adaptation

The fact that adaptation concerns are increasingly coming to the fore is important for the scope of this review - not only because in infrastructure planning mitigation and adaptation may not always be aligned (although there is potential for them to be aligned), but also because adaptation actions depend on extensive connections across and within systems and will therefore need broad sets of indicators (economic, social and environmental) to demonstrate success.

5.6 Pricing infrastructure use

The question of who pays for infrastructure and how it is paid for can be simplified as two opposing pairs:

- *Do we pay for the infrastructure to be available or by how much we use?*
- *Who pays – the user or society at large?*

The answer – generally – tends to be a mix, but it varies according to infrastructure types, technology used and governance structures. Determining what mix of these pairs works best for what kind of infrastructure is, of course, complex and the infrastructure types that that the report examines have varying proportions of both sides of each pair. The power (electricity) sector, for example, includes a variable and a fixed element in consumers' bills, and while a substantial proportion of the cost is borne by the consumer in direct relation to the amount of power used, some cost is spread on a non-usage basis, such as the cost of supporting networks to transmit electricity.

Direct housing costs can be more or less availability or usage-based (depending on whether your home is owned or rented and the duration of the tenure) and the cost of the supporting infrastructure is largely socialised (other than by variations in the applicability and scale of council tax).

Domestic water consumption, (to date, and for the domestic consumer in Scotland, at least) is largely availability-based (i.e. unmetered) and largely socialised (in that council-tax payers rather than water users pay, although there is a significant overlap between the two groups).

Road usage for consumers is almost entirely socialised, with no direct link between the “road tax” paid by vehicle owners and the upkeep of the roads network.

5.7 Building carbon into infrastructure pricing

On the face of it, one would expect the cost of carbon to be added to the “usage element” of infrastructure pricing (on the “polluter pays” principle), but being able to do this effectively not only depends on being able to accurately quantify the volume of carbon emitted, but also on being able to attribute a robust value to it ***and*** to successfully attribute responsibility for its emission. This is conceptually more straightforward where user charges account for the dominant element of payment (electricity, for example) and harder for availability-based infrastructure (e.g. housing, roads).

Moreover, the balance between and within these two opposing pairs (availability / usage, user / society) is not fixed by infrastructure type. This is often an important consideration, but other factors such as ownership, governance and technology type within infrastructure sectors also come into play. And these factors can shift over time.

The distribution of the benefits of infrastructure in general - and decarbonising infrastructure in particular - is similarly complex. Which is why we not only need careful consideration of the different factors in determining pricing and benefits for infrastructure assets and how they are influenced by an overarching decarbonisation agenda. We also need transparency, fairness and (just as importantly) the sense of fairness, because the balance of the opposing pairs will be both approximate and variable.

5.8 The effect of market uncertainties

The cost of predominantly user and usage-financed infrastructure class such as electricity will have a closer correlation to market uncertainties. It would therefore seem logical, on the face of it, to try to design policy mechanisms for decarbonisation in this sector that align with expected market behaviours.

In practice, however, a market-led approach to policy support in the power sector (which to date has been the main focus for decarbonisation in infrastructure) has proved complex and difficult to sustain.

Electricity’s commodity benchmark has historically been oil prices but trying to anticipate market prices for oil created serious difficulties for policy-makers looking to design green support mechanisms, in part because there was an assumption that the status quo in the relationship between these “opposing pairs” would continue.

This is analysed by Professor Dieter Helm[9] in his book "Burnout – the Endgame for Fossil Fuels" (2017)[15], which provides both a caustic critique of governmental climate change policies and a prediction that low carbon energy will ultimately triumph – notwithstanding these early policy errors.

Helm argues that green energy policies were based on a fundamental misunderstanding of the oil & gas sector – more specifically, on a concept of "Peak Oil"[10], which led policy-makers to believe that oil prices would continue on a sustained, upward trajectory.

If this was the case, it was reasoned, renewables would become progressively more cost-competitive as the cost of fossil fuel generation rose ever higher. This proved not to be the case. In reality, the oil and gas sector has suffered from a sustained period of low prices in recent years.

The reliance on rising fossil fuel prices for green energy policy support can be seen, for instance, in the fossil fuel projections produced by the UK's Department of Energy & Climate Change ("DECC") in 2013[16]. The table below summarises the DECC projections to 2020 for the price of crude oil, compared with a recent projection by Statista[17]:

(prices per barrel in US$)

Year	DECC 2013 "Low"	DECC 2013 "Medium"	DECC 2013 "High"	Statista
2014	93.7	111.3	128.3	98.9
2015	92.4	112.7	131.7	52.3
2016	91.1	114.0	135.2	43.7
2017	89.9	115.4	138.8	54.2
2018	88.6	116.8	142.5	71.2
2019	87.4	118.2	146.2	66.5
2020	86.2	119.7	150.1	67.0

Table 1: DECC 2013 oil price predictions vs actuals and current predictions

Whether low oil prices in recent years are indicative of a permanent market shift will no doubt continue to be debated.

The important point to note is that if the continuing upward progression of oil prices is taken as a given, then to achieve a lowest cost green support policy it makes sense to seek to bridge the gap between wholesale electricity prices (which were assumed to continue to be closely correlated with the oil price) and the cost of green generation. This had direct implications for

[9] Helm is also chair of the Natural Capital Committee (NCC), which performs a comparable role to CCC, provides advice to the government on the sustainable use of natural assets including forests, rivers, land, minerals and oceans. The committee's broad remit also covers the benefits from natural assets, such as food, recreation, clean water, hazard protection and clean air.

[10] The theory that the world was starting to reach the peak of oil production and that this would soon start to decline

the implementation of Electricity Market Reform, which is covered in more detail in Section 9.4.

For the purposes of this section, two general observations can be made:

- ***Firstly**, policy based on the status quo can create obstacles rather than pathways as past performance may not be a model for the future; and*
- ***Secondly**, external factors may mean that what appeared to be basic assumptions diminish in relevance over time.*

The debate about who pays for the transition to a net zero carbon economy and the price of carbon are closely linked, as pricing carbon is the obvious differentiator between technologies. This was picked up in a recent article in Utility Week, entitled “Who should pay for the energy transition” by Professor Richard Green. The chart below shows that at present, the price of electricity wholesale market closely matches the cost of fuel (e.g. gas), as long as the cost of carbon is included.

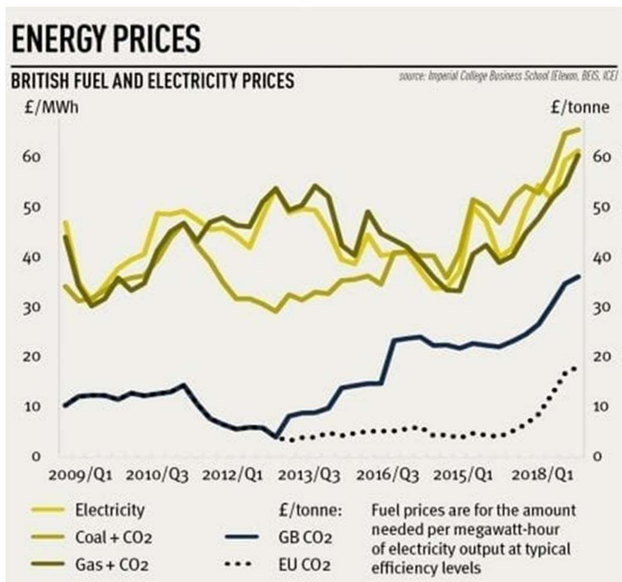


Fig 4 – current wholesale prices with carbon included[11]

Professor Helm’s book also identifies a longer term structural trend, however, which is an important consideration for how infrastructure could and should be priced in the future. As the carbon intensity of the generating mix becomes lower, the correlation between the price of oil and the price of wholesale power should become less relevant. The basic parameters for price support models will therefore shift.

Helm’s key insight is the potential for electricity to become an availability-based rather than a commodity-based service, driven by the emergence of an increasing proportion of zero marginal cost generation[12]. There should therefore be a tipping point where commodity comparisons become irrelevant and the original pricing or benchmarking models redundant.

[11] https://utilityweek.co.uk/pay-energy-transition/

[12] broadly, generation capacity that does not require feedstock or fuel (most notably wind and solar) can be described as “zero marginal cost”

At this point virtually all the cost is sunk into the creation and maintenance of the infrastructure. This becomes a different paradigm of power provision.

Helm notes that the development of the IT and digital sector is instructive: "There is no deep liquid market in voice calls, or markets for individual Internet searches. From Skype to WhatsApp, the notion of zero marginal cost is widely apparent in almost all broadband and communications services[13]. This *zero marginal cost model* carries over to energy, or at least to the electricity part, and it is electricity that will gradually drive everything else. The market here is for contracts and capacity, not units of energy.[18]"

5.9 Inclusive growth and low carbon

More or less simultaneously, and to some extent triggered by the same event (the Global Financial Crisis in 2008), we start to see an increasingly prominent line of thinking that re-examines the nature and value of economic growth in public policy (e.g. the Big Society, community benefits, the Social Value Act, etc.) and in socio-economic literature (such as Tim Jackson's Prosperity without Growth, 2009). This is coupled with the notion of a planet as a finite set of resources (e.g. Stewart Brand, Whole Earth Discipline, 2010) and the idea that excessive concentrations of financial wealth and widening social inequality are intrinsically damaging to society (Thomas Piketty, Le Capital au XXI^{e} Siècle, 2013).

Piketty's central argument in his rigorous and extensive analysis of the relationship between capital and revenue, is that this relationship is key to understanding inequality. In essence, he argues that inequality is greater when the value of capital is higher relative to the value of revenue. While the mid-20th century saw a significant diminution in the ratio of capital to revenue, this ratio has subsequently and steadily risen from its low point in 1950 and will continue to rise for the rest of the 21st century, as shown in the chart below. By 2030, the world will be back to the same capital: revenue ratio as the previous peak, just before the First World War. The "more equal" world of the mid-20th century (which among other things, saw the birth of the European Union), looks increasingly like an anomaly.

[13] See, for example, the growth of "all you can eat" data services by mobile providers as an example of zero marginal cost infrastructure in action

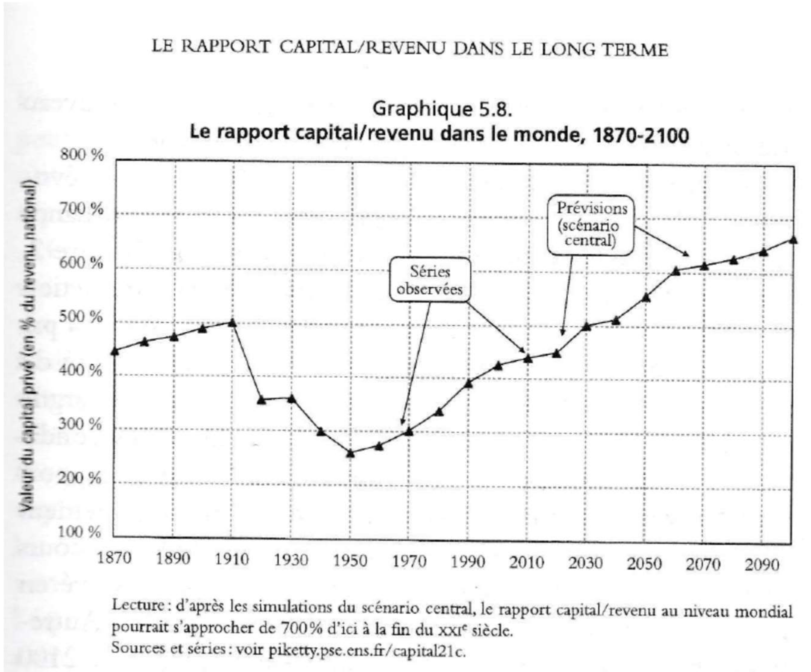


Figure 5 – Piketty: the changing relationship between capital and annual revenue since 1870

Piketty projects that the asset-owners in society will own an increasing share of wealth and the relative value of labour will continue to decline. If this ratio is as significant an indicator of inequality as Piketty argues, then the fact that trends towards NCZI appear to be predicated on a greater level of importance of the value of the assets (as opposed to the value of the commodities that pass through them) suggests that there is a risk that decarbonisation will increase levels of inequality unless governance and ownership structures are also addressed.

The interplays between the environment, technology and social justice continue to be developed by the latest generation of socio-economic thinkers, such as Mariana Mazzucato (The Value of Everything, 2018), Kate Raworth (Doughnut Economics, 2017), Hilary Cottam (Radical Help, 2018), Aaron Bastani (Fully Automated Luxury Communism, 2019) and Katherine Trebeck (The Economics of Arrival, 2019). Some of this thinking is already reflected in Scotland's Economic Strategy (2015)[19].

Raworth, for example, makes the point that higher levels of national inequality go hand in hand with increased ecological degradation, in part, she argues, because social inequality creates status competition and conspicuous consumption but also because inequality erodes social capital, undermining the collective action needed to deal with environmental issues[20].

A broad, integrated definition of sustainability, economic and social as well as environmental, presents a number of questions and challenges for policy-makers and investors in infrastructure. Subsidising the wealthier members of society to reduce their carbon emissions (e.g. by generalising the availability of home energy saving incentives) might achieve a bigger short-term impact in terms of carbon reduction but could divert resources away from targeted fuel poverty measures, thereby increasing inequality and building up problems for the longer term.

On the other hand, a high-carbon emitting piece of trunk road infrastructure (the expansion of a key road junction, for example), might be primarily beneficial to better-off commuters, who are likely to be car owners, as opposed to lower income earners who may be more reliant on public transport and less able to fund longer journeys to work because of their lower income levels.

Alternatively, a community-managed greenspace project in a poorer neighbourhood might create greater respect for the environment, and enhanced carbon sink and natural water management, and higher levels of wellbeing and confidence.

Low carbon and inclusive growth objectives in infrastructure projects may conflict, coincide or be mutually enhancing. It may sometimes be a simple case of identifying the trade-offs, but the meaningful options or choices are often likely to be more complex and potentially require an element of systems redesign. There is a little literature in this review which looks at the interface between low carbon and inclusivity but not much, which suggests that while the interrelationship between social and environmental wellbeing may be well-established at theoretical and political levels, it is some way from being business as usual in delivery. But it is there as a key trend nevertheless.

5.10 A Paradigm Shift?

The term "paradigm shift" seems a reasonable description of what has been happening[14] in terms of infrastructure and decarbonisation over the last few years. There seem to be three strong trends taking place broadly simultaneously, and the interaction of these three has profound implications for infrastructure development:

a) ***Trend 1** – increasing weight is being placed behind adaptation as well as mitigation (we will see this in subsequent chapters)*

b) ***Trend 2** – the socio-economic consequences of decarbonisation are becoming a critical consideration*

c) ***Trend 3** – infrastructure development is becoming recognised as a systems-based project (or as a connected series of these)*

It goes beyond the scope of this review to explore these trends in extensive detail, but as part of the process of setting the context for the research, they seem important to provide the framework for the analysis to follow.

[14] See Thomas Kuhn, The Structure of Scientific Revolutions. A scientific paradigm is a framework for the puzzles and problems on which the scientific community works. The paradigm works until a cluster of anomalies arises that it is unable to cope with. This creates a crisis until a new discovery or achievement redirects the research activity and becomes the new paradigm. This change is the "paradigm shift".

6. Framing the Challenge

*<u>Question element</u>: A review of the robustness and relevance to the Scottish context of available research on the **carbon impacts of infrastructure**, including an assessment of the gaps in the evidence-base;... and for infrastructure overall; the relative impact of each sector within the Scottish context i.e. **the relative scale of both the particular infrastructure sector and its carbon emissions***

Headlines
Mitigation and adaptation mean examining both the effects of infrastructure on carbon and the effects of carbon on infrastructure. CCC identifies the critical role of infrastructure and the policy deficits that exist in respect of 2050 targets. Net zero will require "shared infrastructure", combining electricity, hydrogen and CO_2 technologies. Scotland has made good progress overall on reducing carbon emissions, largely due to decarbonisation of electricity supply – but transport, agriculture and heat for non-residential buildings are areas where progress is not currently being made. The call is for consistency and immediate action on both short and long-term actions.

6.1 Scope

In the previous chapter we defined carbon and infrastructure. In this chapter we consider how these two concepts are physically linked. Carbon and infrastructure are connected in two ways. Firstly, the creation and usage of infrastructure creates CO_2 emissions. Secondly, infrastructure has to respond to the climatic effects of rising levels of CO_2e in the atmosphere. This is illustrated in the simple diagram below. This report is about both these aspects which are becoming increasingly intertwined as the effects of global warming become more immediate.

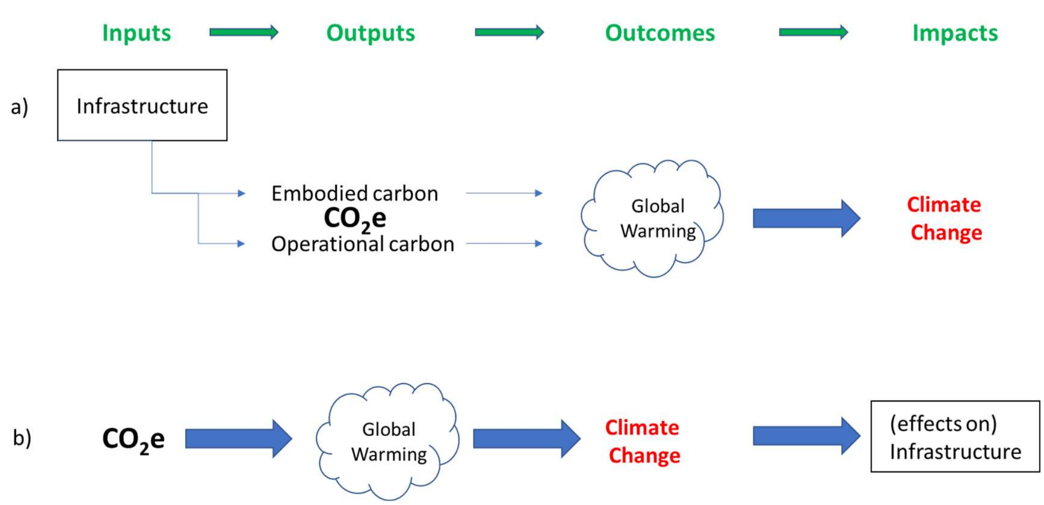


Fig 6 – infrastructure's 2-way relationship with carbon *a) is a new project (where much of the direct and indirect carbon might come through in the construction phase) or an operational project where its ongoing use produces emissions (a road, for example)*

b) is any aspect of existing infrastructure but particularly aspects of infrastructure that connect, convey and distribute (electrical wires, bridges, etc)

This chapter is a review across infrastructure as a whole – subsequent chapters examine the main sub-sectors within infrastructure.

6.2 Policy Context

We start with the work by the Committee on Climate Change ("CCC") on infrastructure. CCC has produced a body of work that is impressive both in its breadth and depth. Infrastructure is a major component of any decarbonisation pathway identified by CCC.

Extensive reference is made to CCC work throughout this review.

The CCC report "Net Zero: The UK's contribution to stopping global warming", (May 2019)[21], provides a good introduction to the question of infrastructure and low carbon. There are at least 117 references to infrastructure in the report. The main relevant findings and recommendations are summarised below.

In the report, CCC argues that the UK "should set and vigorously pursue" an ambitious target to reduce greenhouse gas emissions (GHGs) to 'net-zero' by 2050, ending the UK's contribution to global warming within 30 years. Reflecting their respective circumstances, Scotland should set a net-zero GHG target for 2045 and Wales should target a 95% reduction by 2050 relative to 1990.

This is achievable with known technologies, alongside improvements in people's lives, and within expected economic cost but this is only possible if "clear, stable and well-designed policies" to reduce emissions further are introduced across the economy without delay.

There is a serious policy deficit identified for the achievement of targets at the UK level:

Transport
2040 is "too late" for the phase-out of petrol and diesel cars and vans, and current plans for delivering this are insufficiently detailed. If properly implemented, decarbonisation can cut the annual costs of UK transport by around £5 billion, while maintaining transport's tax contribution and allowing for the costs of charge-points and other infrastructure. To achieve this, UK Government will need to make a decision on the required infrastructure for zero emission HGVs in the mid-2020s ready for deployment in the late 2020s and throughout the 2030s. For that, trials of zero emission HGVs and associated refuelling infrastructure are now needed.
Heat
There is still "no serious plan" for decarbonising UK heating systems and no large-scale trials for either heat pumps or hydrogen.
Carbon capture (usage) and storage

This is seen by CCC as "crucial" to the delivery of zero GHG emissions and strategically important to the UK economy, but this programme has "yet to get started"[22]. While technological development is challenging in this area, CCC notes that there are now 43 large-scale projects operating or under development around the world, but none of these are in the UK. The CCC scenarios involve aggregate annual capture and storage of 75-175 $MtCO_2$ in 2050, which would require a major CO_2 transport and storage infrastructure servicing at least five clusters and with some CO_2 transported by ships or heavy goods vehicles.
Housing
Energy efficiency retrofit of the 29 million existing homes across the UK should now be a "national infrastructure priority".
Buildings and industry
The need for strategic decisions, repurposing/upgrading of infrastructure and the turnover of the capital stock mean that it is difficult to see how these sectors could contribute major emissions reduction much earlier than 2050
Afforestation
Targets for 20,000 hectares/year across the UK nations are not being delivered, with less than 50% of target planted on average over the last five years (although as we see later in the report, Scotland is ahead of its target).

Reaching "net-zero" emissions will, CCC argues, require development or enhancement of shared infrastructure such as electricity networks, hydrogen production and distribution and CO_2 transport and storage.

Partnership and co-ordination are considered necessary across central government and the regions. Planning frameworks are a useful lever over infrastructure that need to be well aligned to decarbonisation objectives (e.g. through encouraging active travel and use of public transport, ensuring readiness for or installation of electric vehicle charging points in new developments, and a favourable planning regime for low-cost onshore wind).

Low public engagement is identified as a key barrier, as well as the more technological and socio-economic requirements for supporting infrastructure and coordinated decisions, misaligned incentives, access to capital, slow technical innovation and availability of workers with the required skills.

6.3 The effects of global warming (across the UK)

What follows is a summary of the analysis undertaken on the impact of climate change and on the response that government at the Scotland and UK levels is making to these changes, drawing on the detailed work undertaken by the Committee on Climate Change.

For this section, given the mix of responsibilities and the scope of the available literature, we did not helpful think it would be to try and place UK elements and Scottish elements in separate sections. Instead we have aimed to highlight the geographical scope of individual reports as appropriate.

The CCC's 2017 Climate Change Risk Assessment (January 2017) has a UK-wide remit and focuses[23] on adaptation, stating that greatest direct climate change-related threats for the UK are large increases in flood risk and exposure to high temperatures and heatwaves, shortages in water, substantial risks to UK wildlife and natural ecosystems, risks to domestic and international food production and trade, and from new and emerging pests and diseases.

Heavier rainfall and more and more widespread frequent flooding are expected. Higher temperatures will affect public health, infrastructure, business, farming, forestry and the natural environment. Dry periods, when combined with higher temperatures, are likely to result in more droughts. Projected sea level rises of 50-100 centimetres by 2100 will exacerbate flood risks and accelerate the process of coastal change for exposed communities.

CCC has also said that milder winters should reduce the costs of heating homes and other buildings, helping to alleviate fuel poverty and reduce the number of winter deaths from cold; UK agriculture and forestry may be able to increase production with warmer weather and longer growing seasons; and Economic opportunities for UK businesses may arise from an increase in demand for adaptation-related goods and services.

In its response[24], the UK Government broadly endorsed the six priority areas identified with some reservations of detail and identified particular issues for Scotland, including more action needed on risks to species and habitats from the changing climate and to soils and natural carbon stores. It also identified as a "research priority", risks to people, communities and buildings from flooding; health and wellbeing; coastal areas from sea-level rise combined with extreme weather; marine species from ocean changes.

The focus of the 2019 Report[25] was again on adaptation and noted that infrastructure is increasingly interconnected, with failure of one asset likely to trigger failure across sub-sectors.

More recently (March 2019), CCC published its assessment of the first Scottish Climate Change Adaptation Programme[26]. It said that the most notable progress in managing current and future climate risk since the first assessment related to peatland restoration, actions to increase marine resilience and an improved understanding of the number of people in Scotland living in areas at flood risk.

The areas of greatest continued concern included increases in pests and diseases in Scottish forests, declines in seabird populations and soil health. There were also key data and evidence gaps that made it difficult to assess progress for a number of priorities.

Key messages in respect of buildings and infrastructure networks were that action continues to be taken to support resilience of buildings and infrastructure networks to flooding, including the consideration of climate change in design and location of new infrastructure. More work is needed, the report says, to assess and plan for coastal risks.

Investment in resilient energy, transport and water services continues to be encouraged and indicators of vulnerability show good progress in areas such as energy and water supply resilience. Flooding is at present a relatively minor issue but there are up to date building standards in place for flood resilience, moisture penetration from heavy rain, heating and ventilation, but no strategy for retrofitting existing buildings with adaptation measures and only limited guidance on overheating in buildings.

Gaps were also identified in terms of flooding and digital infrastructure. A lack of metrics and targets against which to assess vulnerability continues to be an issue, particularly in relation to the design and location of new infrastructure and the use of sustainable drainage. There is still no evidence, says the report, on whether new infrastructure is designed and located according to the sustainability and adaptation principles set out in the National Performance Framework.

6.4 Decarbonisation (mitigation) in Scotland

In its Climate Change Plan, Third Report[27] (2019), the Scottish Government noted that in 2015, Scotland had reduced its emissions by 41% from the 1990 baseline. In 2017 Scotland generated 68.1% of its electricity requirements from renewables. Scotland's success in decarbonising electricity, it argued, paved the way for transformational change across all sectors of the economy and society, particularly as electricity will be increasingly important as a power source for heat and transport.

Data for sources of Scottish greenhouse gas emissions up to 2017 were published in June 2019[28]. This shows transport (including international aviation and shipping) as the largest emitter, followed by agriculture, with forestry acting as a significant carbon sink. The diagrams below (Charts B1 & B2) are extracted from the report.

The overall trend since 1990 is downwards, with the energy sub-sector showing the most dramatic reduction in CO_2 emissions (because of the decarbonisation of electricity generation through renewables), but significant reductions are also seen in business and industrial processes (down 40% - perhaps a combination of more efficient operation but also the rising importance to the economy of services sectors); waste (down 72%) and agriculture (down 29%).

International aviation and shipping is a relatively small component, accounting for just 1.9 $MtCO_2e$, but in percentage terms has the biggest increase (43%), the rise perhaps due in part to the wider availability of air travel to consumers.

Domestic transport showed a very slight reduction in emissions of 0.5%. In effect, domestic transport is as carbon intensive as it was in 1990. This is an important point to note for this review given that transport can form a major element of any infrastructure policy, programme or investment strategy.

The latest Scottish Transport statistics[29] estimate that in 2016, road transportation accounted for around 68% of the transport total, with passenger cars contributing around 40% and the remainder largely accounted for by heavy and light goods vehicles (12.4% and 12% respectively) – with the balancing item presumably from the bus fleets.

One issue with carbon data is that there are significant time lags and misalignments. The overall 2017 greenhouse gas data for Scotland were only published in June 2019, while the 2018 Scottish Transport Statistics, published in January 2019, have to rely on the 2016 data. CCC comment that better and quicker reporting of emissions data would be helpful, suggesting that greater investment in this activity is needed from Scottish Government.

If change were slow, delays and lack of coordination of datasets might be less of a concern, but with aggressive decarbonisation strategies and potentially rapid penetration of new technologies (for example, electric drive-trains for both passenger and goods vehicles), timeliness, as well as consistency and quality of data will become more of an issue for infrastructure policymakers in coming years.

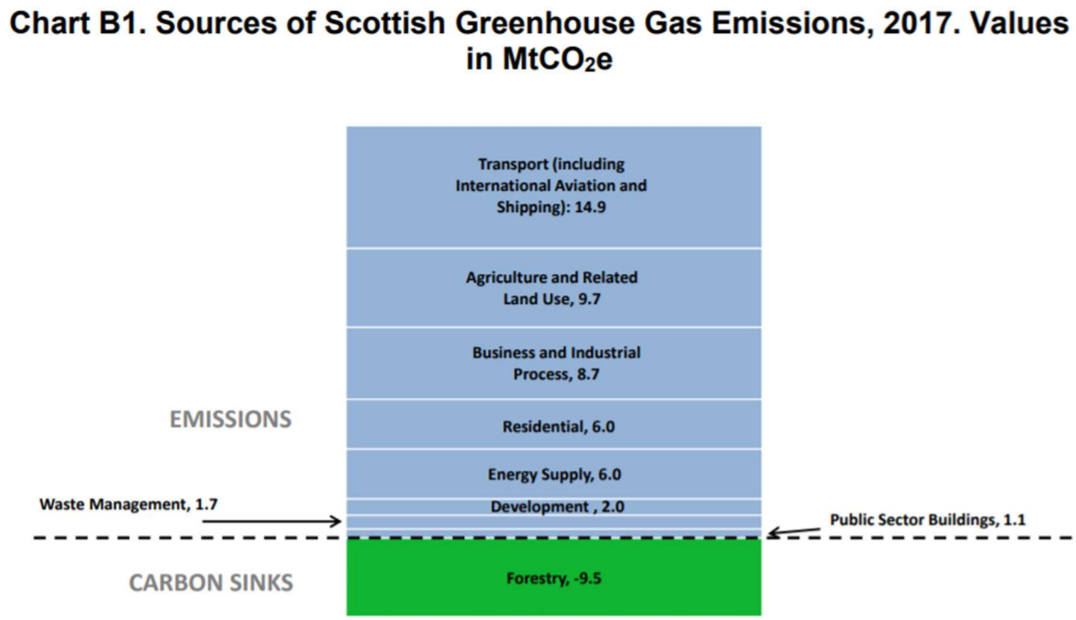


Fig 7 – Sources of Scottish greenhouse gases 2017

Chart B2. Main Sources of Greenhouse Gas Emissions in Scotland, 1990 to 2017. Values in $MtCO_2e$

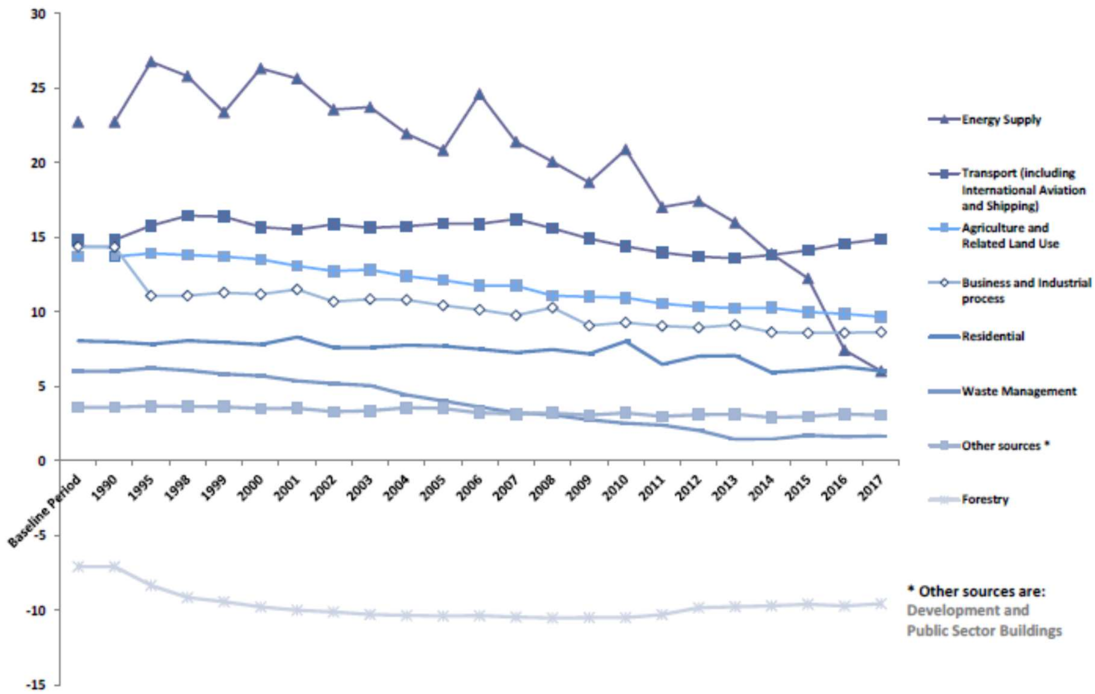


Fig 8 – Changing sub-sector contributions 1990 - 2017

At the time of undertaking the main research for this review, CCC had not yet had the opportunity to review Scotland's 2017 emissions. The latest publicly available report was on the 2015 figures[30].

CCC noted that Scotland had met its ‘net’ emissions annual target in 2015 but commented that more effort was needed in sectors other than power as there had not been significant emission reductions in most sectors outside electricity generation in recent years. Transport, agriculture and heat for non-residential buildings were identified as areas in which little progress was currently being made.

While the UK was seen as not on course to meet its carbon budgets[31], Scotland was nevertheless considered to be performing well compared with other countries in the UK and with the UK as a whole.

CCC subsequently published its 2019 progress report for Scotland on 17th December 2019[32]. While publication deadlines for this review have not permitted a detailed analysis of this report, as a key milestone report, it is important to note that it both reinforces and develops the messages from the previous analysis.

This graphic below, taken from the 2018 report, clearly showed that were it not for the decarbonisation of electricity, the decarbonisation strategy in the UK would be in severe difficulty.

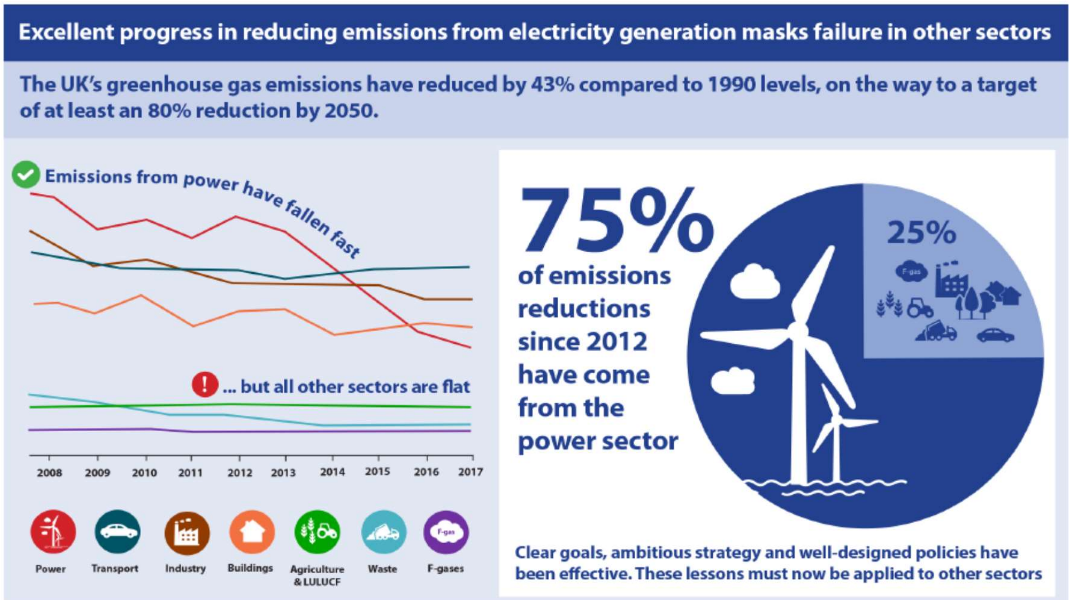


Fig 9 – The contribution of the power sector to decarbonisation in the UK

The progression chart for Scotland in the latest report broadly reflects these trends:

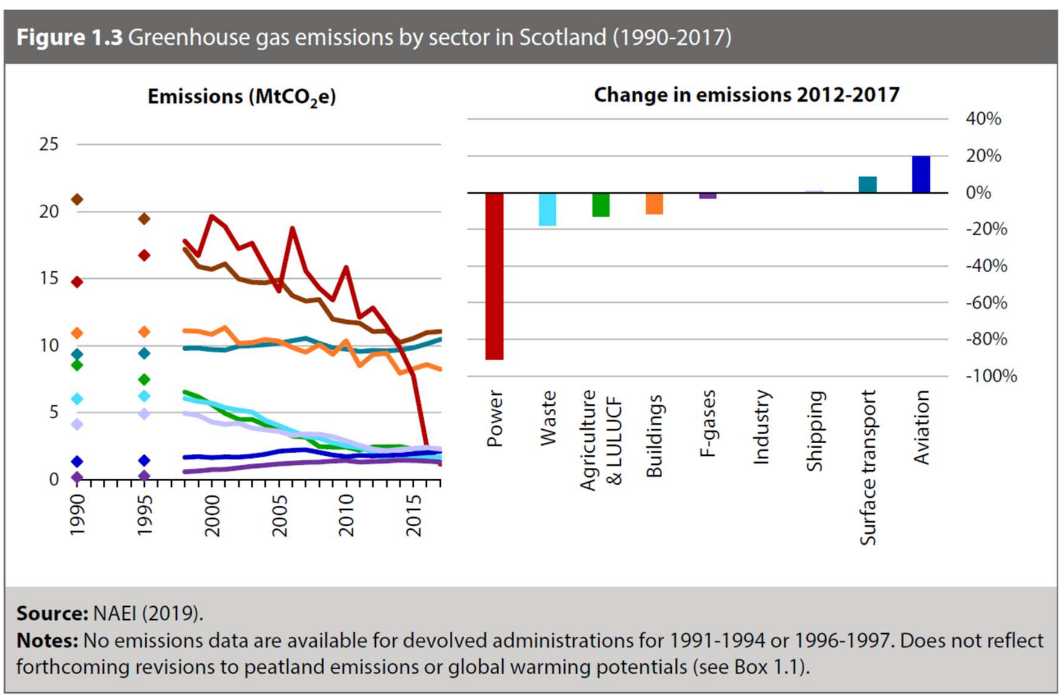


Fig 10 – The contribution of the power sector to decarbonisation in Scotland

The good news is that Scotland's economy is decarbonising, but this is largely down to the power sector, which has seen a 91% fall in emissions since 2012. The waste sector is also a success story for Scotland, with a 50% reduction in landfill methane emissions over the past decade and a strong set of policies and targets which are consistent with achieving net zero[33].

The poor progress in buildings emissions (-4% since 2012) and the worsening of surface transport emissions (+9% since 2012) are, however, thrown into even sharper relief. CCC calculates that Scotland must reduce its emissions by an average of 1.8 $MtCO_2e$ per annum to reach net zero by 2045, while 2017 saw a fall of 1.4 $MtCO_2e$. This may not seem too challenging a shortfall to make up, but CCC argues that while low carbon generation will continue to play a key role in enabling other sectors of the Scottish economy to decarbonise, there is very little scope for further direct emissions from electricity generation[34], so other sectors now need to take up the challenge.

Scotland missed its net annual target in 2017.

Central to the report's findings is a set of governance recommendations, which have also emerged from this review and are reflected in this review's recommendations:

- *Net-zero policy must be embedded across all levels and parts of government, with strong leadership and coordination at the centre;*
- *The public must be engaged in the challenge and policy should be designed to put people at its heart;*
- *Policy should provide a clear and stable direction and a simple investable set of rules and incentives that leave room for businesses to innovate and find the most effective means of switching to low-carbon solutions[35].*

6.5 Adaptation in Scotland

Key risks to infrastructure

The Evidence Report for the second UK Climate Change Risk Assessment (CCRA2) identified 14 areas of risk and opportunity for infrastructure. Key risks are shown in the graphic below, taken from the 2017 report to Parliament[36]. The principal risks are related to changes in temperature, rainfall, water availability and wind speeds (although projections of future wind speeds are uncertain). Secondary weather-related effects such as subsidence, humidity, fog, storms and lightning are also identified but uncertain at this time.

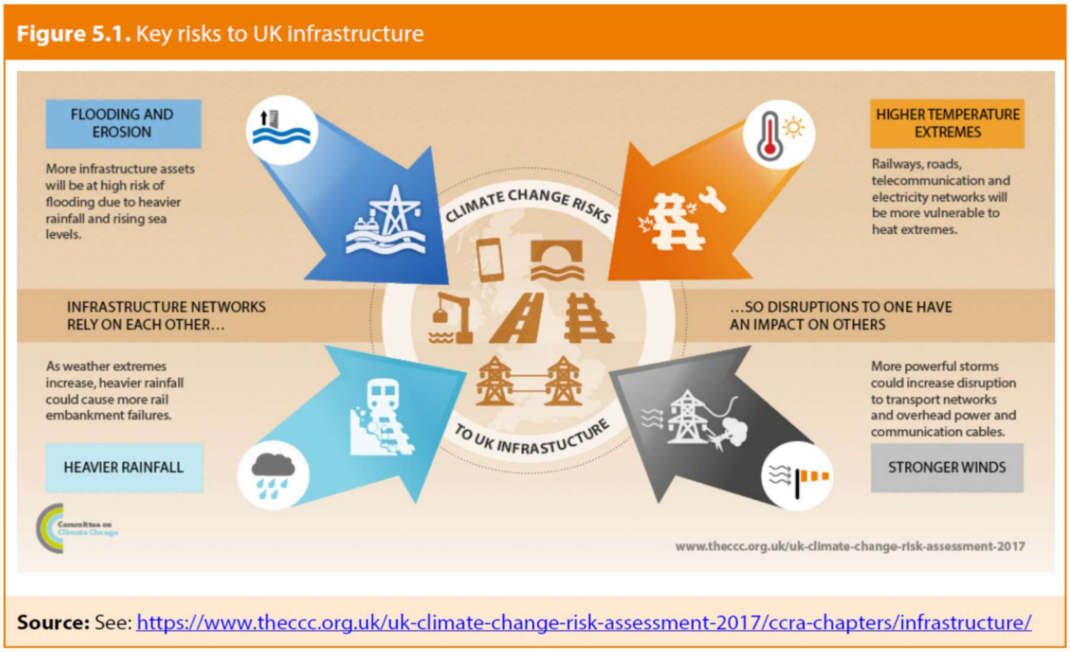


Fig 10 – Key risks to infrastructure in the UK

The National Infrastructure Assessment that was launched in July 2018[37] places considerable emphasis on resilience: floods and drought are both cited as key risks.

Performance

The Adaptation Sub-Committee's report, "How well is Scotland preparing for climate change?"[38] found that Scotland was making good progress in raising awareness of adaptation, building capacity and incorporating consideration of climate change into several aspects of long-term decision-making, for example in land use planning and building regulations, marine planning, health, and forestry.

However, it said that was not clear how long-term climate impacts were explicitly being taken into account, for example in planning and designing new national infrastructure, such as that required for delivering Scotland's renewable energy programme or the latest information technology (broadband).

The adaptation framework does not, on the other hand, give sufficient weight to Scotland's contribution to global efforts to safeguard the billions of tonnes of carbon stored in its peatlands, which are vulnerable to climate change, particularly when degraded.

There was a mixed picture on the uptake of "low-regret" adaptation actions. For example, there was a reportedly high deployment of sustainable drainage systems in new development but a low uptake of property-level flood protection measures in existing buildings.

The conclusion was that the impact of Scotland's policy framework was mixed. A number of recommendations followed from this in terms of assessing effectiveness of policy, enabling "low regret" adaptation actions, strengthening adaptation in some areas and ensuring policy-makers explicitly consider adaptation in long-term plans.

Plan

The Scottish Government's draft Strategic Environmental plan programme[39] (February 2019) is intended to address the impacts identified in the second CCRA report made under the UK Climate Change Act (2008) (the 2008 Act). It is structured around a vision and seven high level outcomes which are underpinned by sub-outcomes and key policies. The draft programme does not itself set out new policies or proposals, but rather provides a high-level framework that draws together existing Scottish Government polices relating to climate change adaptation and seeks to ensure that they take account of climate change adaptation.

The policy mapping from the report is included in Appendix A. Lack of policies is clearly not the issue – on the other hand, policy overload may be a risk. The challenge, as the SEA identifies, is ensuring effective alignment between these policies and achieving cooperation across sectors.

Communication

"Climate Ready Scotland", a consultation draft for Scotland's Climate Adaptation Programme and published in parallel, is part of the Government's public dialogue. The vision is a "win-win": by 2032, Scotland will have reduced its emissions by 66%, relative to the 1990 baseline, while growing the economy, increasing the wellbeing of the people of Scotland and protecting and enhancing our natural environment.

The language is one of outcomes, painting a picture of success: a healthier society; an enhanced and protected natural environment; a diversified, resilient and sustainable economy.

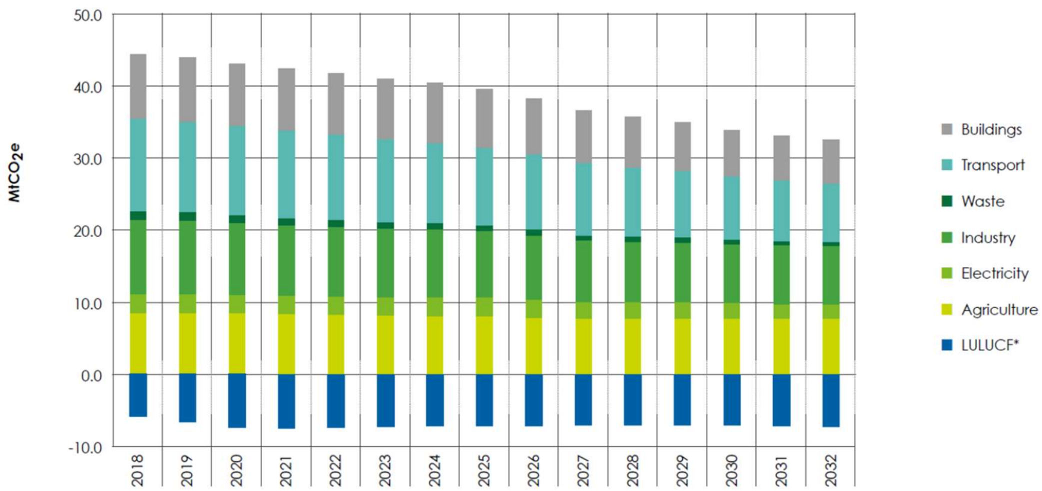
Scotland's electricity system, already largely decarbonised, will be increasingly important as a power source for heat and transport. Scotland's buildings will be insulated to an appropriate level and will increasingly be heated and cooled by low carbon technologies.

Scotland will have phased out the need to buy petrol and diesel engine cars and vans, implemented low emission zones in Scotland's largest cities and made significant progress in reducing emissions from buses, HGVs and ferries. The industrial sector will be more energy efficient, more productive, and increasingly use more innovative technologies, presenting significant economic and competitive opportunities.

Landfilling of biodegradable municipal waste will have ended, food waste will have reduced, more of Scotland's waste will be recycled and a more circular economy will present significant economic opportunities. Scotland's woodland cover will have increased, and peatlands will be restored to good condition, benefiting people, biodiversity and ecosystems. The Scottish agriculture sector will be among the lowest carbon and most efficient food production systems in the world.

The Climate Change Plan shows Scotland's Pathway to 2032[40]:

Figure 2: Pathway to 2032



*Land Use, Land Use Change and Forestry

Source: Scottish TIMES model results

Fig 11 – Sectoral pathway to 2032

We could contrast this optimistic narrative with technological worldviews of the difficult challenges we face (see, for instance, the RSE report in Section 9.6). Public engagement also seems low and there is even a reluctance in some parts of government to engage with the public at all (see social evaluation report on LHEES in Section 14.3).

There is an important "translation" question inherent in decarbonising infrastructure – how to translate the complex, challenging narratives that are developed by policy-makers and industry / sector experts into something meaningful, informative and engaging for non-expert, "ordinary" people. It is perhaps one of the great societal challenges of our era, but particularly acute for infrastructure, which is the basis on which virtually all human life rests (in Scotland and the UK, at least) and where decisions taken have such lasting effects.

"Climate Ready Scotland" relies on tone rather than specifics. While described as an "outcomes-based" approach, the outcomes are highly generalised. What detail there is focuses largely on organising existing policies. It would appear that more work is needed to bridge the gap between the expert analysis and the general public.

The Climate Ready Scotland[41] document lists 28 relevant policies (see Appendix A) – if carbon is tucked away as one consideration amongst many in each of these, using carbon as a strategic driver will be difficult, even if it is a material consideration in every one of these documents.

CCC's report to Parliament in 2018[42] is a call to action. It contains four key messages to the UK Government:

(i) support the simple, low cost options;

(ii) end the "chopping and changing" of policy;

(iii) commit to effective regulation and strict enforcement;

(iv) act now to keep long term options open.

To this we should perhaps add a fifth: namely to start an informed discussion with the general public.

7. Linkages between Infrastructure and Carbon Emissions - Overview

*<u>Question element:</u> A review of evidence on **carbon impacts of adapting/upgrading/maintaining** existing infrastructure assets*

Headlines
Infrastructure is made up of long-term, intergenerational assets. The need to protect existing assets from climate change and make them more resilient is recognised, but there is a risk that we do not have a mechanism for deciding on how and to what extent we do this and where it might conflict with long-term decarbonisation objectives. Much "new" low carbon infrastructure also depends on connecting up effectively to the old, and these interfaces have perhaps not been examined closely enough. How we organise infrastructure is highly complex and we need to look at effective models of working with that complexity.

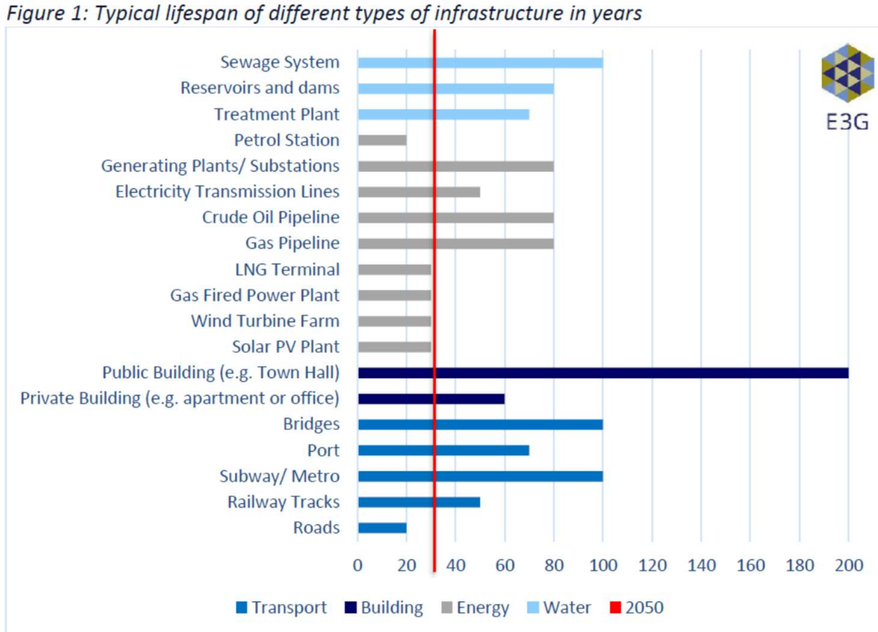
7.1 Infrastructure for the long-term

Infrastructure assets are mostly intergenerational. In some cases, we are still using infrastructure that is 150 – 200 years old. Much of 2050's infrastructure asset base has therefore already been built.

Faced with a range of long-term climate scenarios, adaptation planning needs to be able to reflect this, which means modelling a range of climate scenarios. Major cross-cutting risks include the consequences of rail and road electrification, but as yet there is no systemic national assessment of interdependency risk or plan to improve resilience. We return to this point later.

The graphic below from climate change think-tank E3G, which undertook a worldwide infrastructure review[43], shows their estimate of the average life of the world's infrastructure assets.

Figure 1: Typical lifespan of different types of infrastructure in years



Sources: Gibson (**2017**); Historic England (***2016***); Granovskii et al. (***2006***); PwC (***2014***); DECC (***2014***); Forbes (***2016***); Weinzettel et al. (**2009**); Zieglera et al. (**2018**); Branker et al. (**2011**); Mundada et al. (**2016**); Dias (**2013**); Gkountis et al. (**2015**); Rodrique (***2017***) Kelly (**2007**); Stripple & Uppenberg, (**2010**);

Fig 12 – Lifespans of different infrastructure types

In the UK, we see this infrastructure legacy particularly in our rail and water assets and, to a lesser extent in our roads and built environment.

Naturally, with existing infrastructure, thoughts turn to how it should be protected. There is a risk – although we have not seen anyone frame it in these terms during the course of this review – that the sense of urgency around protecting our existing assets not only diverts attention and resources away from decarbonisation of infrastructure, but leads us to protect assets that we don't need any more or that lock in high carbon behaviours.

Extreme weather is putting some elements of this under severe pressure, notably (but not exclusively, as we shall see later) at the more exposed edges. For example, the landslip on the A83 at the Rest and be Thankful in Argyll in October 2018[15] or the seawall that was breached at Dawlish in Devon in 2014, which took 2 months to reinstate[44].

Understandably, immediate action was seen as essential. CCC comments that the reinstatement did not, in the case of the Dawlish seawall, eliminate the risk that it might happen again. Ideally, reinstatement should make assets better able to cope with similar, future events.

While this thinking appears to be permeating through the infrastructure sector (for example, CCC comment that there is evidence of good quality plans that account for climate change in the assessment of the UK's needs[45], CCC also says that, in the case of the rail network, for instance, while there is evidence of site-specific measures being incorporated across the country, "reductions in vulnerability are not strongly evident across the railway network"[46]. The

[15] https://www.bbc.co.uk/news/uk-scotland-glasgow-west-45836792

legacy of ageing infrastructure, much of which was not designed to modern engineering standards and inadequate historic investment have created a backlog that will require sustained investment over several decades.

Other sectors also present resilience issues. Although it is not clear to what extent this is replicated in Scotland, CCC say that urgent investments are needed in the water sector and Ofwat should be feeding this into the 2019 and 2024 price review[47].

7.2 Carbon in the asset lifecycle

Infrastructure's carbon footprint can be considered at three principal stages:

- **"Embodied carbon"** – the carbon that is built in during the construction phase and comes not just from direct construction emissions but also indirectly from the supply chain;
- **"Operational carbon"** – the carbon emitted during the operational phase of the asset
- **"End of life"** carbon – (in effect, part of the operational carbon). This is the carbon emitted from the process of decommissioning the assets, which for some assets (e.g. nuclear plants) may be considerable.

Infrastructure is a means to an end. We can define this end philosophically – such as: the creation of a more successful society through the provision of modes of connection and conveyance: knowledge, data, energy, water, goods, vehicles etc.

Or we can define it more pragmatically as something physical or fixed, which is designed to meet defined policy objectives, such as the National Performance Framework, of the Sustainable Development Goals.

Either way, what determines the carbon effects of infrastructure is not just how it is designed and constructed, but also the way it is used and then taken out of use.

Strictly speaking, the most carbon efficient form of infrastructure is infrastructure that doesn't exist at all, as all forms of artificial infrastructure have a positive carbon footprint, however small.

The level of operational carbon is not entirely pre-determined, because operational assets perform according to their use. Nevertheless, in the built environment, while building to a certain environmental standard and setting Key Performance Indicators ("KPIs") to make it a contractual obligation are becoming increasingly common during construction, it remains less common to follow this through with an operational measurement regime. The interface between people and buildings is infinitely variable, with the result that management of building systems without involving the occupants is unlikely to deliver the desired results.

Who controls carbon?

One way of looking at this is to consider the split between the carbon that infrastructure asset managers can directly own or "control" and the carbon that is determined by the users of that infrastructure.

In 2013 the UK Government and the Green Construction Board proposed a broad breakdown of infrastructure's share of the UK's overall carbon footprint and the proportion which the "infrastructure industry" could be expected to (a) control and (b) influence[48]. This is shown in the diagram below and is replicated in the more recent UK Green Building Council report “Delivering Low Carbon Infrastructure” (July 2017)[49].

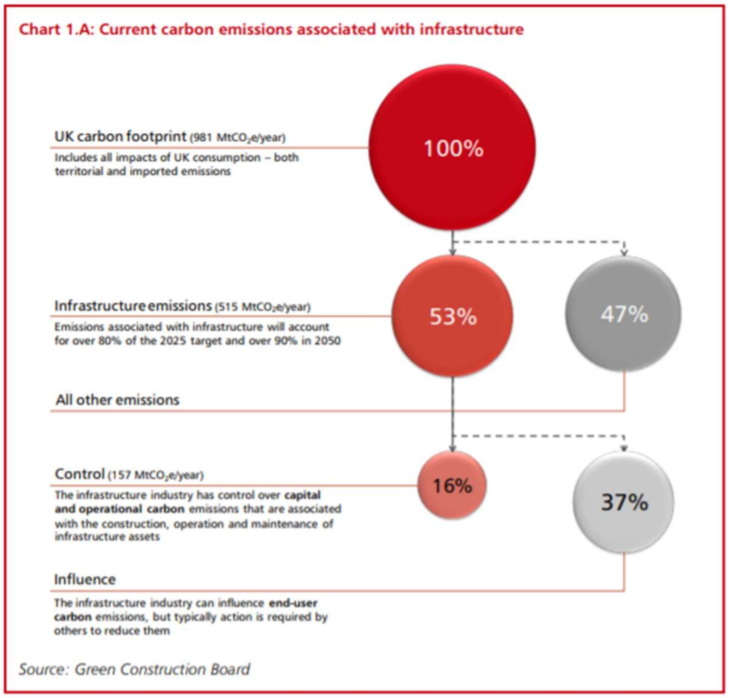


Fig 13 – Infrastructure’s share of carbon emissions and how much it controls[50]

Infrastructure is estimated in both reports to account for 53% of total UK emissions. The UKGBC report does not explicitly define “infrastructure” and this is quite a broad-brush figure. The definition may be somewhat narrower than the Scottish Government definition we have adopted for this report. Under the broader SG definition, the percentage of carbon emissions attributable to infrastructure may therefore be higher.

UKGBC observes that, without action, infrastructure’s share of the carbon budget will rise to 80% of carbon targets by 2025 and 90% by 2050, leaving little room for much else in the economy to emit carbon. As the figures are drawn from the earlier HM Treasury report (“Infrastructure Carbon Review”[51]), this shows that we are probably dealing with broad brush estimates. Infrastructure’s percentage share in 2019 may be lower as a result of the decarbonisation of the electricity sector, but we are not aware that the analysis has been revisited in these terms more recently, which is a pity, as this a useful high-level indicator.

Within the 53% total, just 16% is identified as being directly within the “control” of the infrastructure “industry” (which includes the supply chain as well as the primary asset operators), so while the process of breaking down carbon responsibility in this way helps to visualise the role of infrastructure, it also has the effect, on the face of it, of reducing the scale of the industry’s responsibility to a mere 16% of the problem, suggesting that it is mostly someone else’s issue.

If we then consider the relationship between infrastructure and the user, it becomes apparent that this share of carbon “responsibility” may vary from sector to sector. The nature and type of “influence” may also vary between sectors. If the housing sector stops connecting new houses to the gas grid, for instance, and consistently implements a combination of renewable and Passvihaus-type measures for all new builds, then a number of high carbon domestic energy options fall away and the level of "direct control" over carbon would presumably go up in housing. Similarly, installation of a comprehensive network of charging points would change the balance of control and influence in transport, albeit less predictably, because people could still choose to buy fossil-fuel powered cars (until government formally legislates to remove this option[16]).

Boundary lines between control and influence are likely to be fuzzy for a number of reasons but designing in low carbon creates the greatest certainty. The ultimate solution, as the first chart illustrates, is not to build it at all.

If we examine different infrastructure types, we will see that the immediate connection between infrastructure and everyday lives is different in each case. With "harder" or core infrastructure (generation and processing plant, pipes and wires, for instance) the perceived connection is less direct, perhaps because it is simply hidden from view[17.]

Housing, on the other hand, has extremely strong personal connections, and roads perhaps somewhere in between these two extremes. These linkages between people and infrastructure don't necessarily predetermine the ease with which radical change can be achieved to decarbonise, but it should shape the thinking around the engagement, collaboration and governance needed to achieve the transition.

In terms of approach, therefore, analysis of infrastructure is needed both ***generically*** (recognising the interconnectedness of systems) and ***sectorally*** (to pick up the distinguishing features between types of infrastructure).

The aim of the HMT report at the time in 2013 was to "make carbon reduction part of the DNA of infrastructure in the UK"[52]. The evidence collected for this report suggests that there is progress on this path but that we are not there yet.

A taxonomy of carbon

The carbon impacts of infrastructure need to be considered in terms of both mitigation (reducing CO_2e) and adaptation (responding to the effects of climate change). Increasingly, the resilience of infrastructure (its ability to withstand external climatic shocks or "bounce back") is becoming a prime concern.

The **UK Green Building Council** outlines a "taxonomy" of carbon in its report[53]. In short:

- It confirms that carbon is used as shorthand for the carbon dioxide equivalent of all greenhouse gases and quantified as 'tonnes of carbon dioxide equivalent' (tCO2e);
- "Capital" carbon, or 'CapCarb', refers to emissions associated with the creation of an asset. UKGBC says that capital carbon is being adopted within the infrastructure sector because it accords with the concept of capital cost for an asset, while the related term "embodied carbon" will continue to be used at a product-level, whereas capital carbon will have greater relevance at an asset-level);

[16] The UK Government is now trailling the idea of bringing the end of the sale of new petrol and diesel cars forward to 2035 (from 2040). Scotland is currently sitting at 2032. See, for instance, https://www.autoexpress.co.uk/car-news/105032/uk-petrol-and-diesel-car-ban-could-move-to-2035

[17] Water pipes, for instance. In the UK, we hide a lot of stuff. Other countries sometimes less so. For instance, in Copenhagen, for example, the energy from waste plant is a few minutes' walk from the city centre.

- Operational carbon, or 'OpCarb', describes emissions associated with the operation and maintenance of an asset and is analogous to operational cost and quantified in tCO2e/year;
- Whole life carbon combines both capital and operational carbon and is analogous to whole life cost;
- End-user carbon, or 'UseCarb' describes emissions from the end-users of infrastructure assets. Although not directly controlled by infrastructure asset owners, UseCarb can be influenced.

The UKGBC report assesses the CapCarb / OpCarb mix and suggests that OpCarb will become less of an issue as the operational phase decarbonises (which will happen in part because of the declining carbon intensity of the energy supply). While overall emissions from infrastructure need to reduce, the share of this reducing contribution that is attributable to CapCarb will increase, as illustrated in the graphic below.

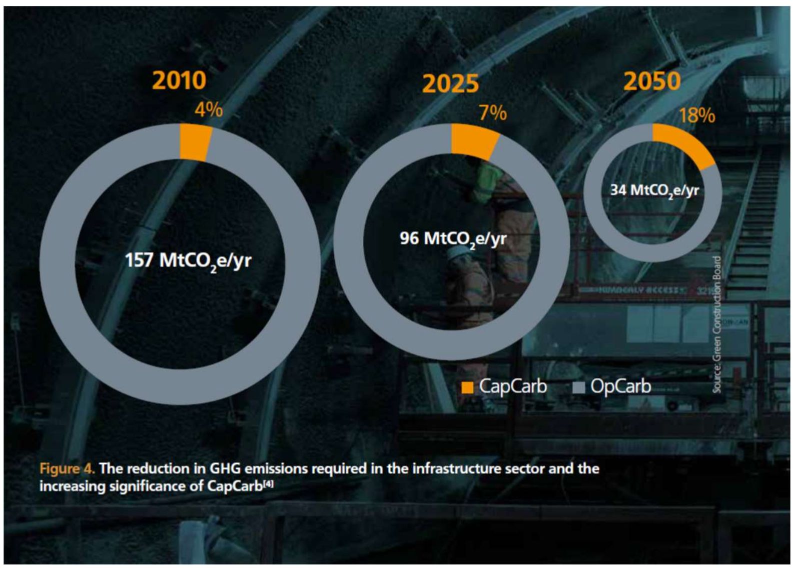


Fig 14 – Capital Carbon's increasing share of carbon emissions to 2050

This, of course, relies on three key assumptions, namely:

1. The direct electricity supply decarbonises (on the basis of current performance, the most certain outcome of the three)
2. Space heating / cooling also decarbonises (which in part is dependent on the first assumption)
3. Building energy performance continues to improve so the quantum of energy required goes down.

There may also be a net reduction of emissions as a result of green infrastructure (see Chapter 15) but we have not found any evidence that this effect has been estimated on an aggregated rather than a single building basis for the building sector or parts of it and in the absence of this, we assume that this effect is currently considered to be relatively marginal.

The high-level findings of the UKGBC report are that:

- There is no specific target for the infrastructure industry which organisations and projects can work towards;
- There is little similarity in ambition, duration and scope of the targets being set in the infrastructure industry;
- There is no single method used by all the surveyed clients to set their carbon targets.

Regulators play a role in addressing carbon; however, they are not explicit in setting targets for carbon reductions and driving performance. While the tools exist to measure carbon performance and are being used at asset level (particularly for strategic or high profile assets) (see Chapter 14 below), it looks as though they are not being used consistently or comparably across the infrastructure sector.

7.3 Present and future infrastructure

The challenge with existing infrastructure is not simply how or whether to protect it, but how to connect all the new infrastructure to it in a way that is cost effective, sustainable and doesn't simply compound existing resilience issues.

In order to meet this challenge, we perhaps need to get better at learning from our mistakes. At the inquiry for the Edinburgh Tram (the full report is yet to be published), the problem of underground utilities was cited. No doubt when the report is published, the focus will be on management and corporate failings, but one of the key problems, it seems, is that nobody knew what lay beneath the road surface. According to reports[18], it was originally anticipated that 27,000m of diversions were needed, whereas in practice it turned out to be 59,000m, because the records were wrong. This is probably not an isolated incidence – mapping what is underneath the ground is probably a major challenge for all large conurbations as stuff has been progressively added by a plethora of operators and contractors over the years. This complexity is baked into the system by our use of the road network as a primary "blueprint" for routing many of the other infrastructure networks that are essential for modern life.

CCC frets about our ICT infrastructure, for instance, saying: "given ICT's pervasive and 'unseen' interdependence with all other infrastructure systems, and its role in underpinning business activities and public safety, it is crucial to assess the vulnerability of the UK's ICT networks and systems, and the interdependencies, particularly with the energy sector in the context of a changing climate"[54].

The question of the interface between old and new doesn't appear to be addressed at present – at least, this review has not identified any literature that examines this in detail. Rather, there seems to be a working assumption that the new and the old can somehow be made to work together.

CCC have produced a number of reports relevant to specific infrastructure segments. These are referenced in the relevant chapters after this one. In addition, CCC produced a briefing note in 2017 on infrastructure as a general asset class[55] and discussed what infrastructure development is needed to achieve the target of 80% emissions reductions from 1990 to 2050 at a UK level. We comment on this below.

[18] https://www.edinburghnews.scotsman.com/our-region/edinburgh/edinburgh-trams-utilities-project-hardest-task-ever-for-official-1-4590584

The definition used for "infrastructure" in the briefing note was specifically:

- *electricity generation,*
- *heat,*
- *CO2 ;*
- *transport networks and their associated components.*

It stressed the need for infrastructure decisions to account for interactions between sectors and across the economy as a whole system (including supply chains), to avoid "locking-in" high-carbon infrastructure or behaviours.

The broad lines of this proposed approach are as follows:

Transport
Electric vehicle charging infrastructure, at home, in towns and cities and rapid chargers for longer distance routes (an estimated 16,000 needed across the UK; Hydrogen infrastructure for HGVs (to sit alongside electrification). Modal shift – more rail, more public and more active transport. Adaptation - the risks to infrastructure from climate change, but this is covered more extensively in other CCC work through the work of the Adaptation Sub-committee and this document does not go into detail on infrastructure adaptation strategies.
Heat
At present, 85% of residential buildings are connected to the gas grid. To reduce heat emissions by 2030, a range of technologies need to be deployed, including hydrogen boilers and networks, heat networks and electric heat pumps (a million heat pumps need to be installed in buildings off the gas grid). The strategy can be a "patchwork" of solutions that allow flexibility to develop options over the long term. Heat networks are a "low regrets" element of this. Hydrogen also needs to be rolled out as a replacement for natural gas and might entail a switchover programme similar to the switch from town gas to North Sea gas in the early 1970s. For hydrogen to become a low carbon solution CCS is needed to capture the carbon that results from the process. Ofgem need to ensure that the next price control review for the gas transmission and distribution networks (for the period from 2021) reflects the wide range of possible pathways for heat supply, including a move rapidly away from fossil fuel use and a shift to hydrogen in the 2030s and 2040s[19].
Carbon capture (usage) and storage
A great deal rests on the successful deployment of CCS. Towards 2050, CCC believes the UK energy system will increase its reliance on the power system as transport and heat are

[19] Ofgem, in its Future Insights series, addresses the decarbonisation of heat, and raises a number of challenges, including the difficulty of a domestic switchover and says that the future decarbonisation of heat is "inherently uncertain".

gradually electrified, moving from liquid fuels for transportation, and natural gas for heating in households. CCS infrastructure will be critical for this transition because it will enable negative-emission hydrogen to be produced. Longer term (e.g. from the mid-2030s) CCS may also be needed as a route to greenhouse gas removals – removing CO_2 from the atmosphere and storing it permanently, which will need its own transport and storage infrastructure.

Smart low-carbon electrical power

To increase from 50% today to 75%, requiring more grid infrastructure (including a near-trebling of interconnection capacity and another 2,000km of transmission capacity reinforcements costing an estimated £6.3bn) and more flexibility. A consequence of this increased flexibility will be greater interaction with the end user as smart grids become more responsive. The electricity generation scenarios for 2030 include a continuing role for unabated gas generation at around its 2014 level (i.e. around 100 TWh), with new nuclear[20], CCS and renewables - around 45- 55% from renewable sources.

All of these come with major costs, although CCC argue that the budget is reasonable as an order of magnitude when set alongside the cost of doing nothing or as a proportion of GDP. And while regulators such as Ofgem are aware of the need for infrastructure systems to evolve to achieve decarbonisation for future generations[21], their remit arguably makes it difficult for future needs to be prioritised over present ones.

National Infrastructure Commission ("NIC")

The UK's first National Infrastructure Assessment, launched in July 2018[56], makes the point that infrastructure has broadened in scope (it adds digital to water, roads and rail).

The key overarching message is that the UK's historic approach to infrastructure development won't do:

"Over the last 50 years, the UK has seen an endless cycle of delays, prevarication and uncertainty. These have been driven in part by short term considerations, and the lack of a cross-sectoral approach to infrastructure. This approach has limited growth, undermined job certainty, and restricted innovation. And too often the UK has ended up playing catch up.[57]"

The NIC's core proposals include:

- *Nationwide full-fibre broadband by 2033*
- *Half of the UK's power provided by renewables by 2030*

[20] The 2019 World Nuclear Industry Status report (see https://www.worldnuclearreport.org/The-World-Nuclear-Industry-Status-Report-2019-HTML.html#_idTextAnchor004) argues that nuclear power is simply not moving quickly enough to be a cost competitive solution for decarbonisation. "It meets, says the report, no technical or operational need that these low-carbon competitors cannot meet better, cheaper, and faster. Even sustaining economically distressed reactors saves less carbon per dollar and per year than reinvesting its avoidable operating cost (let alone its avoidable new subsidies) into cheaper efficiency and renewables". See also Chapter 17 below.

[21] Ofgem's mission statement says: "Our mission is to make a positive difference for all energy consumers, both now and in the future"

- *Three quarters of plastic packaging recycled by 2030 (while a worthwhile objective, it is not clear why this an infrastructure issue)*
- *£43 billion of stable long-term transport funding for regional cities*
- *Preparing for 100% electric vehicle sales by 2030*
- *Ensuring resilience to extreme drought through additional supply and demand reduction*
- *A national standard of flood resilience for all communities by 2050.*

The NIC declares that the UK "can and should" have low cost and low carbon electricity, heat and waste. Ten years ago, it says, it seemed almost impossible that the UK would be able to be powered mainly by renewable energy affordably and reliable way. But there has been a "quiet revolution" going on.

There is plenty of scope to build on this. Highly renewable, clean, and low-cost energy and waste systems increasingly appear to be achievable, says the Commission.

This needn't lead to higher bills. Today, consumers pay an average of £1,850 per year for their energy. The services could be delivered at the same cost (in today's prices) in 2050 by a low carbon energy system if the "right decisions" are taken now. Increasing deployment of renewables is crucial. The Commission's modelling shows that a highly renewable generation mix is a low-cost option for the energy system compared with further nuclear power plants after Hinkley Point C, and cheaper than implementing carbon capture and storage with the existing system.

Renewables have now become cost competitive; battery prices have fallen 80% since 2010 and burning natural gas for heating and hot water is not a long-term option. Given the balance of cost and risk, a renewables-based system looks like a safer bet at present than constructing multiple new nuclear power plants. But, the Commission concedes, a large amount of uncertainty does remain[58].

In all scenarios, says NIC, extra flexibility, which includes technologies such as storage, interconnection and demand side response, is a "low regrets investment" which reduces estimated total energy system costs by between £1-7bn per year on average between 2030 and 2050[59].

7.4 Resilience shift?

It is perhaps not surprising that much of the thinking on adaptation and resilience comes from the private sector. There is plenty of commentary on the immediacy of the effects of climate change - this is very much in the public domain and it is influencing the way the sector is being considered from an investment perspective[22]. In short, environmental disasters make headlines.

In March 2018, for example, the Green Finance Taskforce's report "Accelerating Green Finance" noted that over the last 10 years, an average of 19,000 homes have made flood-related insurance claims each year; two million people lost power in the 2013/14 floods, and

[22] For a futuristic take on adaptive green finance after multiple catastrophic rises in sea levels, see Kim Stanley Robinson's novel, New York 2140

power outages disrupted trade through Gatwick airport and three major ports, while floods in December 2015 directly affected 17,000 properties, leading to £1.3bn of damage[60].

To use a well-worn phrase, we are looking at a "perfect storm" for infrastructure, which means that it is not simply a case of shoring up or strengthening our asset base. We have to deal with:

- *Worsening / more extreme weather conditions*
- *Increased societal dependence on infrastructure*
- *More complex infrastructure*
- *Greater interdependence between infrastructure elements*

It is clear from the literature that more is known and provided for in some areas than in others. The power sector, for instance, is long used to dealing with difficult weather conditions. Levels of digital resilience (against climate- and non-climate related attack) are less well known (although this may in part reflect a reluctance to disclose as opposed to lack of preparedness). Over time, greater resilience may be built in through the way systems are designed to sub-divide, and the concern is both about how to protect what we have and develop a better approach for the future.

The Resilience Shift (RS) was established in 2016 to address the recommendations of the Lloyd's Register Foundation's "Foresight review of resilience engineering". Arup is the host institution for the initial 5-year programme. RS is seeking to effect "a shift in critical infrastructure resilience thinking and practice so that engineered structures and infrastructure will be not only safer but also better"[61]. Resilience in infrastructure systems is described as "the ability to prepare for identified shocks and stresses, to respond to and recover positively from those events that you cannot predict or avoid and adapt to changing conditions". Resilience must focus on the ability of the system to continue to function, considering technical resilience alongside community and organizational resilience.

RS argues that resilience has emerged as a "critical agenda" for the 21st century. This is in response to growing recognition of the diversity of shocks and stresses associated with environmental, economic, social, and technological pressures which is compounded by the uncertainty associated with rapid urbanisation, climate change and resource limitations and the complexity of interdependent systems [62]. Resilience Shift is trying to build an understanding of what this means in practice, within and between key critical infrastructure sectors globally by creating new approaches to change the way that infrastructure is planned, designed, constructed and operated.

RS says there are "converging imperatives" to rethink the way we plan, fund, design and operate critical infrastructure[63]. These are characterised by the changing scale and nature of critical infrastructure systems, and the changing pattern of shocks and stresses experienced by these systems.

On the one hand, more critical infrastructure is being built globally so there is a greater potential for loss. On the other, underlying patterns of shocks and stresses to critical infrastructure systems are changing. There is also the perception of risk - we seem increasingly preoccupied with managing risk. There are interrelationships between these factors, placing stress on economic activity, community safety, public resources and infrastructure insurability.

RS say there is a tentative shift in thinking on resilience, emphasising the importance of learning from disruptions and adapting to change: not merely 'bouncing back' but 'bouncing forward'. This may result in more green - blue infrastructure and less "grey" in cities, for instance. For critical infrastructure systems, RS say this also means transitioning from a 'fail-safe' and managerial approach, towards a *'safe-to-fail'* approach.

7.5 The fragmentation of infrastructure management

The economic structure of the infrastructure sector resulting from the privatisations in the 1980s and subsequent layers of regulation, reform as well as market activity have left a complex landscape where the allocation of specific responsibilities for the necessary changes is far from clear. This is further complicated in Scotland's case by the devolution settlement.

One legacy is a complex decision-making landscape about which it is not easy to generalise. For instance, energy is generally is generally thought to be a reserved matter, but SG still has a number of policy levers. The UK Government designs the wider electricity market and the main subsidy mechanisms to promote renewable electricity and has oversight responsibility for regulating both the energy sector and energy networks via Ofgem, the UK-wide independent energy regulator, but devolution gives SG control over planning, the environment and economic development and SG has used this to good effect in consenting and support for sectors such as marine renewables[64].

Water, on the other hand, is entirely separated from UK influence. Transport governance has UK, Scotland and regional-level actors. And so on.

Defra, for the UK Government, acknowledges the complexity in the infrastructure system, albeit obliquely, in its National Adaptation Plan: "In general, infrastructure operators are private businesses, accountable directly to their customers, stakeholders and regulators, and as such are responsible for their own business continuity measures, including the provision of essential services which enable them, and their customers, to function. Government has a responsibility to ensure that there are no policy or regulatory barriers which prevent infrastructure operators from jointly or collectively managing interdependent risks arising from climate change. We also recognise that more action is needed to encourage information sharing between infrastructure operators to improve overall risk management."[65]

The "market" (if such a generalised term can be used meaningfully) is a major player in most, if not all elements of infrastructure. In the past, some policy initiatives have arguably trusted the market too unquestioningly to deliver change in general and decarbonisation in particular. The "market" also includes private individuals and businesses as users, so regardless of how government is organised, there will always be complexity in the system. Complexity can, of course, breed resilience, if what it means in practice is more redundancy and stronger sub-components.

It is not within the scope of this review to suggest new or alternative governance structures for the infrastructure sector. Moreover, it would be naïve to believe that a few simplifying strokes would suddenly join all of this together again. However, we would suggest that if decarbonisation is a defining parameter (which it needs to be to deliver NZCI), then logically, however infrastructure is organised, it ought to be at the centre of all decision-making on infrastructure.

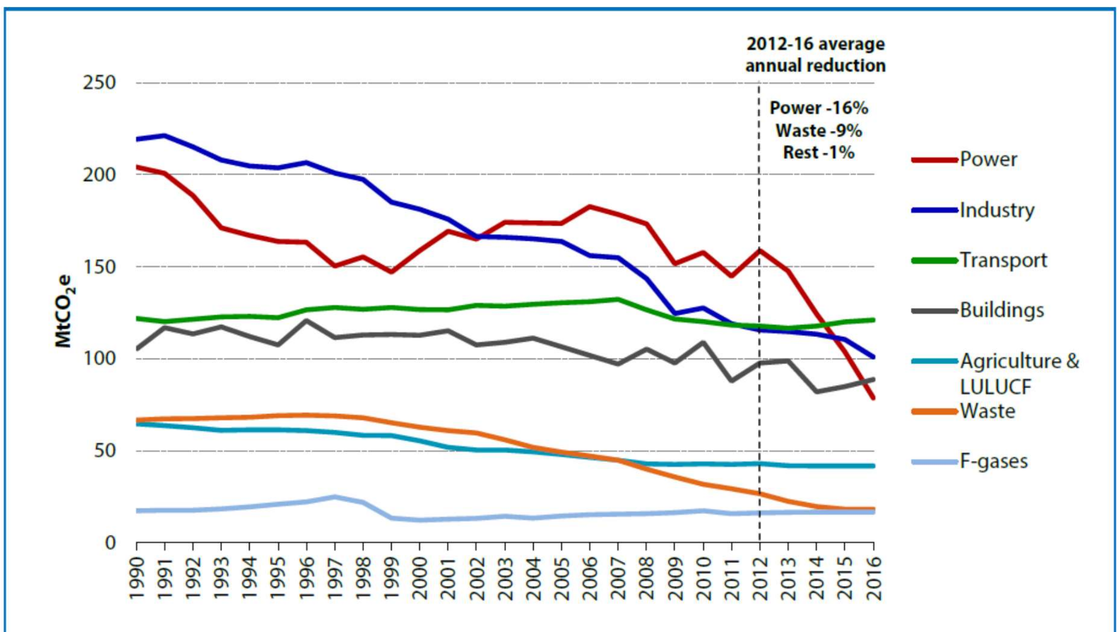
8. Transport

<u>Question element:</u> the relative impact of each sector within the Scottish context i.e. ***the relative scale of both the particular infrastructure sector and its carbon emissions***

Headlines
Transport poses a major sectoral challenge; the data are pointing the wrong way at the moment. Predicting the future for transport at the moment is difficult. However, there appear to be some accelerating technological trends and possibly also behavioural shifts. Policy implementation in this area needs to place carbon at the centre of the decision-making process.

8.1 Introduction

Transport poses a big challenge for progress towards the 2050 targets. In its report to Parliament in 2017 ("Meeting Carbon Budgets Closing the Policy Gap")[66], CCC stated that transport was the largest emitting sector of the UK economy at 121 $MtCO_2e$, with 26% of UK greenhouse gas (GHG) emissions in 2016. It had gone from being the third largest emitter a decade earlier to the highest, as the graph below shows.



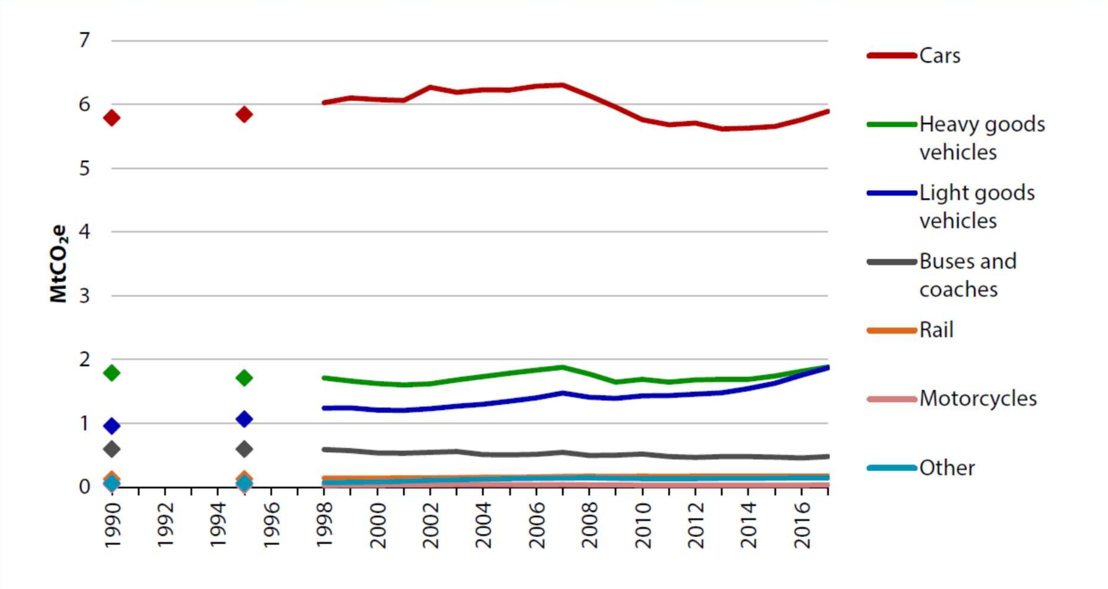
Source: BEIS (2017) *Provisional GHG statistics for 2016*; BEIS (2017) *Final GHG statistics for 1990-2015.*
Notes: 2016 emissions are provisional estimates and assume no change in non-CO_2 emissions from 2015.

Fig 15 – Transport is now the largest emitter in the UK

Emissions in domestic transport rose for the third consecutive year in 2016. Demand for travel continued to grow, fleet efficiency reductions were slowing and biofuel usage had reduced.

CCC's latest report for Scotland provides a breakdown that illustrates that, after what appears to be a GFC-induced reduction in emissions after 2008, cars, heavy goods and light goods vehicles are all now showing upward trends, due to increased mileage. New car CO_2 efficiency has improved, although the rate of improvement has slowed recently.

Figure 3.2. Emissions from surface transport in Scotland (1990-2017)



Source: NAEI (2019).

Fig 17 – Transport emissions on the rise in Scotland[67]

The global market for electric vehicles (EVs), however, is looking increasingly positive, and significant opportunities exist to reduce emissions in this sector, but CCC argue that this requires stronger policies and signals over the longer term to provide incentives for efficiency improvements in conventional vehicles, switching to ultra-low emissions vehicles and changing travel behaviour. Scotland's share of all new ULEV registrations in the UK at 6% is lower than its share of all new registrations[68].

In the same report, CCC also notes that there has been no significant behavioural shift away from cars towards public transport, with static or slightly declining rates for walking to work and school and using the bus as the main mode of transport and an increase in rail use for commuters.

The reality of the UK's EV charging infrastructure, however, appears to be lagging behind the ambition for electric vehicles. The House of Commons Business, Energy and Industrial Strategy Committee noted in October 2018[69] that poor provision of charging infrastructure was one of the greatest barriers to growth of the UK EV market. The existing charging network, said the Committee, is lacking in size and geographic coverage, with substantial disparities in the provision of public charge points across the country. The Committee strongly recommended that the Government make full use of powers introduced in the Automated and Electric Vehicles Act 2018.

The report showed that there were also wide regional disparities across the UK, as illustrated in the table below:

Region	# charge points by region	people per charge point
North East	664	3,931
Scotland	743	7,127
Northern Ireland	185	9,789
South East	572	15,372
London	497	17,682
South West	262	20,382
West Midlands	206	27,549
North West	244	28,902
East Midlands	142	31,923
East	172	33,994
Yorkshire	103	51,825
Wales	31	98,806
Total	**3,821**	**16,787**
Source: HSBC survey data, published in "Lack of chargers delays switch to electric cars", The Times, 26 March 2018		

As this shows, Scotland is faring well compared with other parts of the UK, with the second highest number of charging points per head of population. Recently, Scotland passed the milestone of 1,000 charging points[23]. At the end of August 2019, the Scottish Government announced a £7.5m collaborative project with Scotland's two distribution network operators, SP Energy networks and Scottish & Southern Electricity Networks to deliver more electric charging points[24]. However, the fragmentation of the infrastructure sector has also enabled industry players to indulge in some finger-pointing over who is to blame for lack of progress[25].

As the network evolves, the distribution will clearly be important – the expectation will be for a concentration of charging points in the more densely populated and urbanized areas of Scotland, although these are areas with more travel alternatives to the private car, because of shorter travel distances more suitable for cycling and walking and the availability of public transport. This screenshot from ChargePlace Scotland[26] shows that there is a heavy concentration south of Loch Ness but that the remoter rural areas are not without their charge-points either (the black circles show the number of charge-points in a particular area).

[23] https://www.theconstructionindex.co.uk/news/view/scotland-passes-1000-electric-vehicle-charge-points

[24] https://www.gov.scot/news/more-electric-vehicle-charging-points/

[25] https://www.theguardian.com/business/2019/oct/18/uk-energy-watchdog-accused-of-stalling-action-to-tackle-climate-crisis

[26] https://chargeplacescotland.org/ as at 14th October 2019

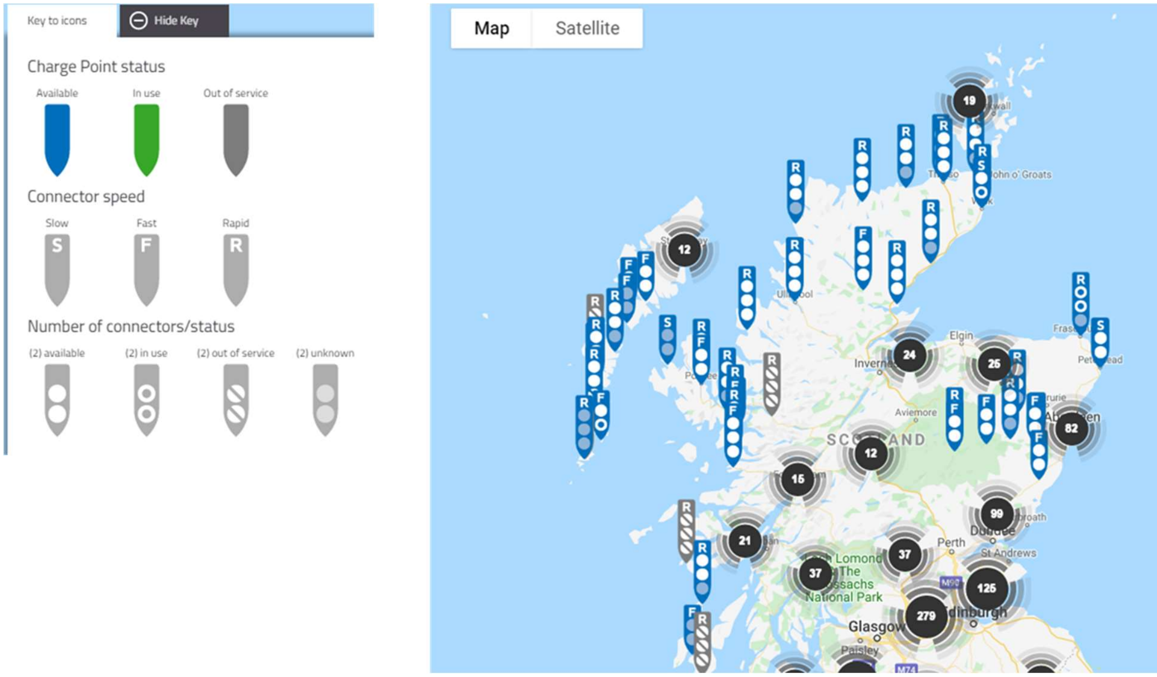


Fig 16: Scotland's current charging network

The approach to decarbonising transport has multiple strands. CCC's requirements for the "least cost pathway" to 2025 for the transport sector are summarised in the table below[70]:

Carbon emissions in 2016:	121MtCO_2e
% reduction required	44%
Share of ULEV in new car and van sales	60%
Improvement in efficiency of conventional vehicles	32%
Sustainable biofuels in road fuel	11%
Reduction in travel demand below baseline	5%

8.2 Going backwards?

Decarbonisation of the transport sector in Scotland is a major challenge. This is evident from the table below, taken from the Scottish Transport Statistics[71] publication:

	2012-13	2017-18	Change over 1 year	Change over 5 years
Car Traffic (m/veh km) on all roads	33,777	36,206	2.4%	7.2%
Pedal Cycles (m/veh km) on all roads	310	290	0.7%	-6.5%
ScotRail Passengers (millions)	83.3	97.8	3.8%	17.4%
Bus Passengers (millions)	420	388	-1.5%	-7.6%
Air Passengers (millions)	22.2	28.8	7.1%	29.8%
Ferry Passengers (millions)	9.7	10.3	1.8%	5.7%
Source: STS 2018, Table S1 except Traffic estimates from table 5.3. Note pedal cycle estimates are based on small sample sizes, see chapter 1 for more detail.				

Fig 17 – Car use in Scotland is on the increase. Bus use is going down

From a decarbonisation perspective, most of the figures are going the wrong way. Car traffic is up, bus travel is down, cycling is down, air travel is up. The one bright spot is the increase in rail passengers.

48bn vehicle kilometres were travelled on Scotland's roads in 2017, up from around 35bn in 1993. The volume of traffic on major roads in Scotland has more than doubled since 1975. 62% of people drove to their place of work in 2017, compared with just under 10% who took the bus and 5.1% who travelled by train.

While rail is part of the answer, it has its limitations in terms of the number of people it can serve due to current geographical coverage and the cost of new infrastructure (requiring relatively high passenger densities) and the figures, not surprisingly, show that bus transport is much more significant in terms of passenger numbers. The contrasting fortunes of bus and rail services in recent decades in Scotland are shown in the chart below. It also gives a sense of scale – there are still 3 times more passenger journeys by bus than rail.

5.1 Local bus and rail services

Figure 4: Bus and rail passenger numbers in Scotland

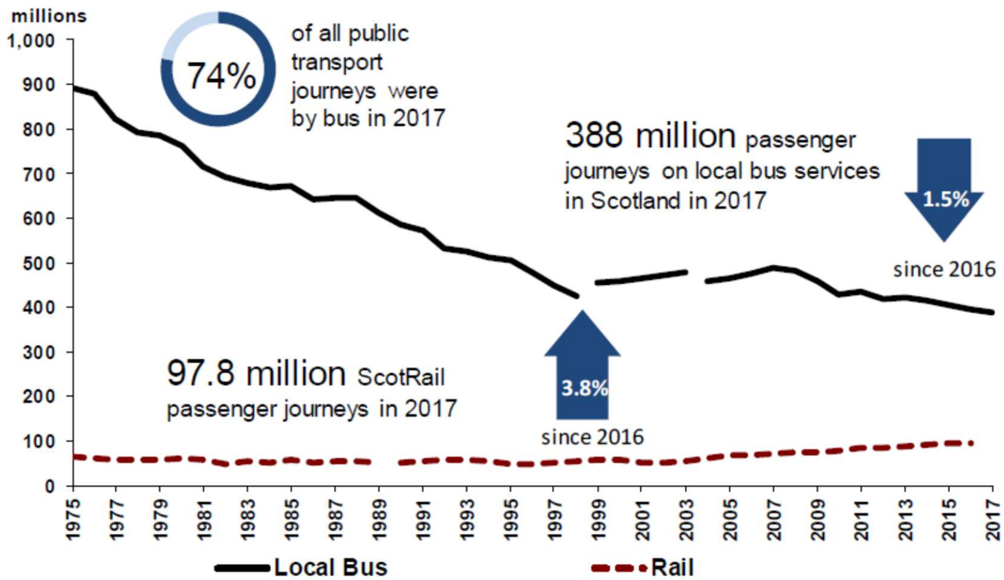


Fig 18 – The contrasting fortunes of road and rail use in Scotland

The Transport Scotland projects website[27] at the time of writing showed that their current infrastructure agenda is all about roads. Of the 25 projects listed as being “in preparation”, 24 of them are roads – the only other one being a somewhat high-level discussion (at present) with the UK Government on high speed rail. Whatever the economic merits of roads improvements, one thing is certain – new roads projects are unlikely to be carbon-reducing.

8.3 The Future of Travel

Leaving aside the decarbonisation imperative for a moment, there appear to be some major shifts emerging in terms of how people use transport.

The Commission on Travel Demand is an independent group which assembled as part of the Research Council UK funded DEMAND Centre[28]. It was established to bring together the state-of-art in understanding how travel demand is changing and may change in the future, recognising controversies which exist over current forecasting practice. The commissioners include academics and practitioners, not just from transport but covering social futures and the urban realm.

DEMAND itself is a research centre that looks at end use energy demand, recognising that energy is not used for its own sake but as part of accomplishing social practices at home, at work and in moving around.

The first report from the Commission on Travel Demand (May 2018)[72] challenges some accepted wisdoms about the demand for transport. It says that we travel substantially less today, per head of population, than we did a couple of decades ago, making 16% fewer trips

[27] https://www.transport.gov.scot/projects/?projectstatus=1277&page=1
[28] http://www.demand.ac.uk/commission-on-travel-demand/

than in 1996, travelling 10% fewer miles than in 2002 and spending 22 hours less travelling than we did a decade ago. This, says the report, was not anticipated in transport modelling at the time, nor is it fully explained by our current models.

CTD's assessment is that it is a combination of longer-term societal shifts in activities such as how people work and shop, in demographics, income across the population as well as policies in the transport sector which have encouraged urbanisation.

While the chart below is for England, it does illustrate the kinds of modal shift that are taking place. However, it also shows that the biggest shifts are taking place in London, where there has been a decline both in car driver and passenger numbers in all London areas, but increases in car and van numbers in other areas, most notably in industrial hinterlands and manufacturing towns. It would be necessary to examine causality in more detail (what is the correlation between levels of wealth and car use; are the increases in car traffic due to declines in public transport provision, for example?) – but it does suggest that London and other major metropolitan areas are distorting the picture.

This London bias is also implicit from the Scottish Transport tables, which show a 7.2% increase in car traffic by km travelled in the 5 years from 2012 to 2017. Some, but not all of this can be attributed to an increase in population, which rose by around 2% in the same period – but per head of population it still looks as though Scotland is travelling by car more than it did 5 years ago.

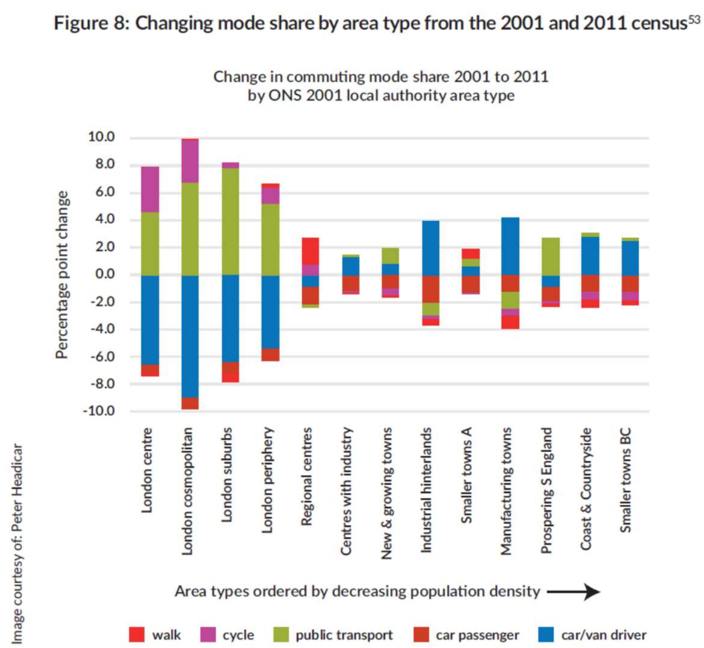


Fig 19 – Modal shifts in England

Some of these predicted shifts in demand did show up in national scenario modelling. The Department for Transport's 2015 national road traffic forecasts produced a scenario that showed if trip rates were to continue to decline, for example, then by 2040 travel would be 70bn vehicle miles per year lower than the core scenario. Over the period to 2040, this would equate to a difference of more than one trillion vehicle miles.

However, these alternative scenarios were not then taken into account, the preference being to opt for a single "core scenario" as being a reasonable mid-point between two extremes. This style of appraisal approach is also evident, for example, in the power sector (where the focus was on a single line mid-price forecast). We examine the way in which current analytical approaches can affect decision-making on decarbonisation in Chapter 13.

The CTD report calls for a completely different approach to demand modelling in the transport sector, away from "predict and provide[29]" to asking what sort of places we want to live in, what kinds of activities we need to travel for and what sorts of actions need to be taken to bring that about[73].

The difficulty for policymakers and others responsible for future generations as well as the present one is that the future of transport (and especially of personal transport) is so radically different from the present and the near past. The evidence to support for future policy implementation is limited at the moment. Transport is very much a leading edge in terms of decarbonisation, but an area that needs to start progressing fast.

CTD predict "Three Revolutions" in transport technology:

i. ***Electrification*** *of the vehicle fleet, reducing the per mile costs of driving substantially due to the high duty on petrol and diesel and low VAT on domestic energy, the additional purchase price very quickly being offset by these 'in-use' benefits;*

ii. ***Automation*** *of the driving task – reducing the workload on drivers on long-distance journeys and opening up greater travel possibilities to people who currently find accessing the transport system, such as the disabled;*

iii. *Widespread adoption of "**shared mobility**" – increased sharing of vehicles, which could reduce peak hour congestion and trigger a shift away from individual ownership.*

Significant factors external to transport which are therefore expected to affect future demand include:

- *Changes to healthcare technology (new treatments and remote diagnostics) and the means of access to health services;*
- *The potential for changes to trading patterns and the balance of industrial growth and migration*
- *The continuing divergence between housing prices and household incomes*
- *Changing social preferences for communication*
- *Changes to the retirement age as life expectancies rise.*

There is a perception that generational shifts in attitudes and work/life patterns are also reducing the demand for personal private transport, but this has yet to show through in the data. For example, the Scottish Transport Statistics show that the proportion of people with a

[29] "Predict & provide" is a well-used term to describe transport growth policy in the last century. See, for example, "Beyond 'predict and provide': UK transport, the growth paradigm and climate change" – Goulden, Ryley, Dingwall (2014). The paper signals that, while it was thought this kind of policy had been abandoned at the end of the 20th century, it appears to have revived in areas of transport policy such as airport expansion and HS2. A London-centric transport policy in itself is argued to be evidence of "predict and provide".

full driving licence has remained constant over the past 5 years and has increased slightly since 2007[74].

Table 11.12 Frequency of Driving[1,2] for people aged 17+

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
										column percentages	
Every Day	45.2	44.9	43.4	41.4	40.7	42.0	41.9	40.9	40.9	42.2	41.9
Per Week:											
At least 3 times	10.0	10.4	11.9	12.8	13.3	13.1	13.3	13.9	14.5	14.3	14.7
Once or twice	5.1	5.6	5.6	6.0	6.2	6.0	5.6	5.9	5.9	6.0	6.1
Per Month:											
At least 2 or 3 times	0.9	1.0	0.9	0.9	0.9	0.8	1.0	0.9	0.8	1.0	1.0
At least once	0.6	0.4	0.4	0.4	0.4	0.3	0.5	0.7	0.5	0.5	0.5
Less than once	1.7	1.3	1.6	1.8	1.7	1.7	1.6	1.8	1.4	1.6	1.3
Holds full driving licence, never drives	3.5	4.0	4.2	4.3	4.1	4.5	4.5	4.3	4.0	3.4	4.0
Total with a full driving licence	67.0	67.6	68.0	67.6	67.3	68.3	68.4	68.5	68.0	69.0	69.5
Doesn't have a full driving licence	33.0	32.4	32.0	32.4	32.7	31.7	31.6	31.5	32.0	31.0	30.5
Sample size (=100%)	*12,152*	*12,263*	*12,447*	*12,361*	*12,801*	*9,828*	*9,838*	*9,720*	*9,340*	*9,570*	*9,760*

Source: Scottish Household Survey

Fig 20 – Steady demand for driving in Scotland

8.4 Electric or hydrogen?

By 2050, says CCC, there is scope for near-full decarbonisation of “surface transport”, making use of electric and hydrogen fuel cell vehicles powered by low-carbon electricity and hydrogen. Use of these vehicles will require significant infrastructure investment, mainly to allow vehicles to refuel in different locations[75].

The cost of a hydrogen car refuelling station is currently £1 million. It is estimated that this could fall by two-thirds given mass adoption, but hydrogen faces the classic scaling-up / adoption challenge. In general, CCC says, hydrogen production with low carbon emissions will be much cheaper with CCS available.

Hydrogen use in buildings would facilitate the use of hydrogen in transport, while if there is no CCS and hydrogen has to be produced using electrolysis, then hydrogen consumption is likely only to be cost-effective in those vehicles that cannot easily be electrified. In this scenario, the gas grid would not be available to transport hydrogen so this would either have to be done by tanker or by distributed production via electrolysis.

In all of these situations, new types of vehicle refuelling infrastructure will be required if hydrogen proves to be the cost-effective option for large trucks[76].

McKinsey is bullish about the prospects for the electrification of road freight. They say that the adoption of electric vehicle (EV) technology in the freight sector appears to be progressing faster than expected, potentially presenting a major challenge to the diesel-fuelled truck market[77]. The consultancy reckons that eTruck market share could reach 15% by 2030, with more attractive segments such as urban light duty trucks reaching sales as high as 25-35% in China and Europe.

Their report says that the majority of commercial vehicles can reach cost parity with diesel-powered trucks within the next 10 years, assuming continued improvements in battery cost and power density. The most cost-effective application seems to be in the light duty truck (LDT) segment that drive a relatively constant distance of 100 to 200 km per day, which is a sufficient range but avoids battery costs being too high. This segment is expected to reach cost parity with diesel in Europe between today (regional application) and 2021 (urban application). The supply of eTrucks is likely be the bottleneck for freight transport electrification in the next few years. This will change as new models are launched and production comes online.

Several established OEMs (Original Equipment Manufacturers) have already reported that they are developing their first eTruck models and are making significant investments in R&D. However, the other element of electrification readiness is charging infrastructure. Early adopters will mainly charge their fleet overnight at their own depots or warehouses, so they will not be dependent on public infrastructure. The inability to charge while on the road means battery size needs to match daily range, which pushes vehicle cost up. However, once eTrucks become more mainstream, the expectation is that the roll-out of supercharging infrastructure at distribution centre and along the main highways will enable long-haul “refuelling” along popular routes.

Aberdeen Hydrogen Bus Project
The Aberdeen Hydrogen Bus Project is made up of two separate European funded projects, both of which are supported by the Fuel Cells and Hydrogen Joint Undertaking (FCHJU). The project will deliver hydrogen infrastructure in Aberdeen, including production of hydrogen from a 1MW electrolyser, establishing a state-of-the-art hydrogen refuelling station (Scotland's first commercial-scale hydrogen production) and bus refuelling station that will include hydrogen production through electrolysis. A fleet of 10 hydrogen buses are operated by First Group and Stagecoach; the buses only emit water vapour, reducing carbon emissions and air pollution, as well as being quieter and smoother to run. This project aims to enable the development and deployment of hydrogen infrastructure and open the way for new and innovative hydrogen technology projects and accelerate the commercial use of hydrogen as a fuel, offering green transport solutions. The energy used to power this process, will initially be provided from renewable sources via the National Grid. The ultimate aim of the project is to link the process directly to a wind turbine in the region.

8.5 A Business Perspective

The **Aldersgate Group** describes itself as “an alliance of leaders from business, politics and civil society that drives action for a sustainable economy”[30]. It published a call in March 2019 to decarbonise the UK transport system[78] and accelerate the transition to low and zero emission mobility.

Its “asks” of government are to:

(i) *Establish an integrated transport network strategy by bringing together road and rail strategies to ensure that the most environmentally and economically beneficial schemes are taken forward;*

(ii) *Provide devolved, long-term funding to local and regional authorities;*

(iii) *Ensure public transport is the most attractive form of transport for most journeys and support other forms of low carbon mobility where public transport is not viable;*

---

30 http://www.aldersgategroup.org.uk/

(iv) Improve the efficiency of freight transport by moving more goods onto the UK rail network;

(v) Deliver an "ambitious active travel strategy" to increase the uptake of cycling and walking in urban areas;

(vi) Support local government to implement a national network of ambitious Clean Air Zones (CAZs);

(vii) Accelerate the uptake of ZEVs by guaranteeing upfront purchase grants until EVs reach cost parity

(viii) Deliver an "affordable, efficient and widely accessible EV charging infrastructure"

(ix) Encourage greater innovation in more complex areas of the transport sector, such as for long distance journeys and HCVs;

(x) Introduce new fiscal measures and leverage private investment to deliver sustainable transport. This should include developing a new system of road pricing, which utilises improvements in connectivity and charges users based on distance travelled.

Reducing demand for road transport - Oslo

One example of a city that adopted what conventional road planning might see as a counter-intuitive to demand management[79] is the city of Oslo.

To deliver a less car dependent and transport demanding city, densification of land use and reduction of sprawl, alongside improvements in public transport services and conditions for walking and cycling, Oslo deliberately imposed fiscal and physical restrictions on car usage. Plans for significantly increasing urban motorway capacity were dropped. Capacity in 10 tunnels on urban main roads was reduced due to maintenance and the council noticed that it made virtually no difference to commuter satisfaction levels. An insurance company relocated from a nodal point to the city centre and the share of the commute made by car for this company dropped from 48% to 9%. Previously, expanding road capacity had always looked the answer because other objectives always trumped reducing traffic volumes. Realistic 'traffic reducing alternatives' had never been introduced because assessed growth was seen as inevitable. Transport models could not handle traffic reducing measures and in assessments, 'time savings' strongly affected the cost benefit results, which meant that expanding road capacity was then the only possible outcome.

Oslo's objective is to create a city centre where pedestrians and cyclists take precedence over cars. The primary focus is to reduce traffic from private cars. Between 2015 – 2019 1.3km^2 of space will be transformed, with the elimination of around 700 street parking spaces[31].

[31] https://www.oslo.kommune.no/politics-and-administration/green-oslo/best-practices/car-free-city/

8.6 Scotland's Transport Strategy

Transport Scotland's strategy[80] acknowledges the decarbonisation imperative and sets out a number of elements to meet this:

- *low carbon vehicle procurement such as 'green buses';*
- *new technology such hydrogen buses and hybrid ferries;*
- *a national charging network for electric vehicles;*
- *continued investment in public transport; and*
- *enhanced funding for sustainable and active travel, including cycling and walking infrastructure and behaviour change initiatives such as Smarter Choices Smarter Places.*

The national landscape, the strategy says, has "changed significantly" since 2006, recontextualising the transport strategy. Scotland's Government, through legislation – the Climate Change (Scotland) Act 2009 – and key strategic approaches (such as Scotland's Economic Strategy) and regulatory regimes have also changed, "incentivising significantly different outcomes in the real world".

The Programme for Government (see Section 14.2) places a strong emphasis on decarbonising transport. We understand that a refresh of the transport strategy is due shortly.

8.7 Conclusions

There are a lot of unknowns in the transport sector. What the future demand for transport looks like, how effective the solutions will be, whether people can be persuaded to change their travel habits, to name a few. However, technology appears to be progressing rapidly and there are some inherent attractions in ultra-low emission electric vehicles (low running costs and maintenance, for example) which are also becoming more cost competitive. This means that if infrastructure issues are resolved, it will be the market that puts the pressure on to change. The key question for policy-makers is the extent to which they should incentivise and influence this shift. Perhaps this needs some clear parameters that make carbon a determinant rather than an output of transport policy.

Key policy considerations include:

- *How to achieve an appropriate balance of public sector intervention and market momentum in decarbonising transport*
- *Recognising that remoter parts of the country have fewer transport options and may therefore be in greater need of EV network infrastructure;*
- *Acknowledging that the private car is a dominant mode of transport in Scotland (and still on the increase)*
- *How to ensure that hydrogen can make a meaningful contribution to decarbonising transport*
- *Whether to introduce greater legislative or regulatory constraint (e.g. limiting vehicular access to town and city centres) alongside incentives to adopt lower carbon modes of transport.*

9. Energy

<u>Question element:</u> the relative impact of each sector within the Scottish context i.e. ***the relative scale of both the particular infrastructure sector and its carbon emissions***

Headlines
Electricity decarbonisation needs to continue at a significant rate, notwithstanding progress to date. Gas will continue to play a role in the decarbonisation pathway as renewables starts to accelerate through the 2020s. Scotland's energy strategy takes an integrated approach – electricity and heat, energy efficiency and innovation, with continued support for the oil & gas sector, wave & tidal and opposition to new nuclear. The development and outcomes of Electricity Market Reform are explored, which struggled with conflicting objectives but delivered a positive outcome for offshore wind. Future decarbonisation of heat relies heavily on electrification or hydrogen or both. Current UK support mechanisms are complex, technology specific and subject to unpredictable budgetary constraints.

9.1 Introduction

For man-made infrastructure at least, decarbonisation is mostly about energy in some form. Energy has two main sub-components – electrical energy (or power) and heat. Historically, these two have been relatively easy to separate.

Electricity has in recent modern history functioned largely as a standalone sector, the level of separation reinforced by the centralising, transmission-based generation model that became the norm after the Second World War. There are reasons to suppose that this might evolve into something quite different or change radically in the not-too-distant future, but today electricity remains largely dependent on the transmission grid.

Heat is different. If its feedstock is gas, that can similarly be moved over long distances, but heat itself can only travel relatively short distances, so it is much more closely connected with an asset or a set of assets or processes. This accounts for the structural differences in these two sub-sectors and in large measure for the different strategies adopted for decarbonisation.

As the decarbonisation of energy proceeds, however, these distinctions are becoming more blurred, with generation of electrical power becoming more localised (through ULEVs, for instance or houses with solar panels feed power back into the grid) and increasingly used for heat and, potentially, for the production of the principal feedstock alternative to natural gas, namely hydrogen.

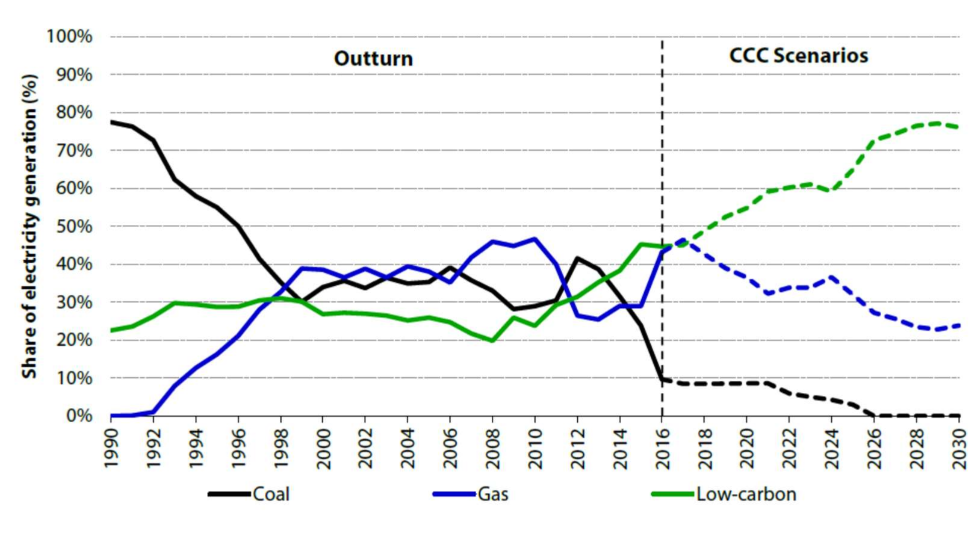
There are arguments, therefore, both for and against separating out electricity from heat in this report. We've taken the view that the linkages are more important than the differences. As a result, there may be some overlap between some of the sectors in this report.

9.2 Overview

CCC's 2017 report[81] set out the decarbonisation requirements for power, buildings and industry. We address generation in this chapter and return to housing in Chapter 10.

While electricity has been relatively successful in decarbonising to date, it is clear that the sector is expected to do much more in its contribution to net zero carbon. A chart from CCC's 2017 progress report[82] illustrates a steep trajectory in the coming decade for low carbon electricity as gas declines up to 2030 and coal disappears altogether:

Figure 2.4. Share of generation by source (1990-2030)



Source: CCC analysis based on BEIS (2017) *Energy Trends*; CCC *Fifth Carbon Budget* scenarios, BEIS (2017) *Energy and Emissions Projections*.
Note: The rate of increase in share of low-carbon generation in the CCC's scenarios is comparable to the rate of increase in low-carbon generation since 2008. Variability in projected generation in the CCC's scenarios reflects uncertainty over retirement dates of existing coal and nuclear generation in BEIS's *Energy and Emissions Projections* scenarios.

Fig 21 – decarbonisation trend for electricity generation

Looking closely at the chart, we can see that coal has to disappear from the mix by 2026 and that gas is actually expected to rise from 2020 to 2024 to balance out the drop in coal and compensate for a lag in renewables, which are projected to rise steeply from 2024 onwards. By 2030, renewables need to be just short of 80% of the energy mix.

CCC specify that the power sector in particular needs to deliver a 62% reduction in CO_2e from 2016 to 2030.

9.3 Scotland's Energy Strategy 2017[83]

The energy sector has been the major field of activity for decarbonising infrastructure in the past decade for Scotland, and this shows through in the emissions figures (see Chapter 6). Scotland's approach to decarbonising the energy sector has operated in tandem with the UK's energy strategy, both because of the technical interconnectedness of the systems and the manner in which policy responsibilities are allocated.

Prior to 2017, Scottish Government policy had focused on specific segments (primarily generation) or geographical variants of the UK energy policy which it felt required adaptation for Scotland's needs.

The Scottish Energy Strategy in 2017 for the first time sought to develop a coherent approach for Scotland that recognised the systemic nature of energy provision, covering heat, transport, electricity and energy efficiency, building on the Decarbonising Heat policy statement (2015)[84]. This "whole system" view is linked to:

- *An "inclusive energy transition" – achieving the transition to a low carbon economy in a way that tackles inequality and poverty and promotes a fair and inclusive jobs market*
- *A smarter local energy model – linking local generation and use by combining heat, electricity, transport and energy storage both in in urban and rural economies*

Scotland does appear to be getting more energy efficient. Final energy consumption in 2015 was 157 TWh, a drop of 15.4% compared with the mid-2000s. By the end of 2021, the Scottish Government calculates that it will have allocated over £1 billion since 2009 on tackling fuel poverty and improving energy efficiency. Energy efficiency appears to have increased as a result of Scottish Government programmes combined with new building standards. The Scottish House Condition Survey shows that just over two-fifths (43%) of homes in 2016 rated EPC band C or above, an increase of 77% since 2010. Scotland now has proportionately 38% more homes with a good EPC rating (C or above) than England[85].

Over roughly the same period, the cost of energy for consumers has gone up, with around a quarter of households in fuel poverty in 2016. The Energy Strategy says that domestic consumers are now paying over 50% more for an average dual fuel bill than they were in 1998. The percentage of total Scottish energy consumption from renewables doubled between 2015 and 2009 to 17.8% - most of that was renewable electricity. By 2018 the renewable share of total electricity production had risen to nearly 75% as more renewables came onstream. By contrast, in 2016, only about 5% of Scotland's heat came from renewable sources.

Major concerns have been expressed over the past decade about the availability of predictable power generation as renewables penetrate the system[32]. Most renewable sources are seen as unpredictable (dependent on rainfall, sun or the wind) and at risk of not being available when they are most needed. Longannet, Scotland's last coal-fired power station, closed in 2016[33], leaving Scotland's two nuclear power stations, Hunterston and Torness, and Peterhead CCGT as its last major fuelled "baseload[34]" providers.

The prevailing wisdom has historically been that this "gap" in reliable baseload generation could only be provided by nuclear energy or by power from renewable feedstock (biomass) and in the short term by bringing feedstock-powered plant (including diesel) onto the system for short period of time – hence the UK Government's Capacity Market mechanism[35].This continues to be a major area of policy debate (see, for example, the RSE report in Section

[32] https://www.telegraph.co.uk/news/earth/energy/11139853/Scotland-power-shortage-warning-as-coal-plant-faces-closure.html

[33] https://www.power-technology.com/news/scotland-renewable-energy-record/

[34] "Baseload" being steady, "predictable" power (assuming availability of feedstock and no technical failures). For a rough sense of scale, the last two coal-fired power stations, Cockenzie and Longannet, had a combined capacity of 3.6GW. The two nuclear power stations have a combined capacity of over 2.5GW. Peterhead has a production capacity limit of 1.5GWe but is configured for regular generation use at between 220 – 400MWe, with 750MWe reserved for occasional back up over the winter. The next biggest is Steven's Croft biomass station with a capacity of 44MW

[35] See Section 9.4

9.6) but greater attention is also being focused on energy storage. If the surplus energy generated by renewables can be trapped and stored when generated, this can even out the peaks and troughs on the system. Solid batteries, hydrogen and pumped storage[36] are all part of the discussion. Power availability is thus the main factor in the security of supply "leg" of the "energy trilemma"[37] .

The Energy Strategy recognises the significance of digital technology and applications in Scotland's energy future – both as an enabler for new energy solutions and in terms of the effect it will have on system resilience. The fact that electricity will supply an increasing proportion of heat and transport demand will increase this dependence.

In 2015, Scotland's final energy consumption was split roughly 50% heat; 25% transport and 25% electricity, as illustrated in the graphic below:

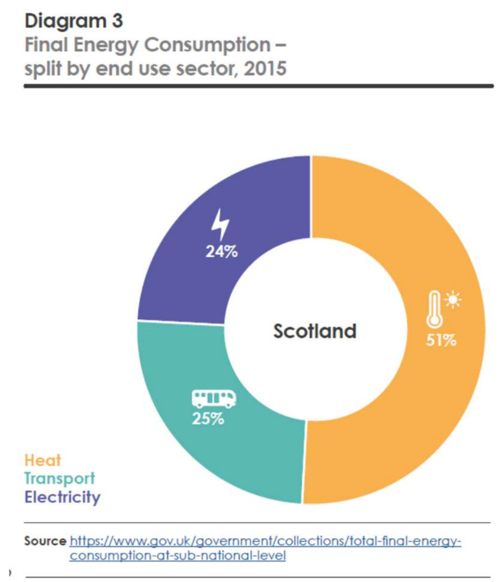


Fig 22 – Scotland's final energy consumption 2015

Two 2050 scenarios are modelled in Scotland's energy strategy:

- *"**An electric future**", where electricity generation accounts for around half of all final energy delivered (i.e. double the 2015 proportion), with domestic energy at 80% electrical. New pumped storage and electrical energy storage is a key part of the mix; the Scottish car and van fleet is fully electrical. Final energy demand is reduced by 30%.*
- *A "**hydrogen future**", where natural gas has been replaced with low carbon hydrogen, through the development of carbon capture and storage and electrolysis, with hydrogen transmission pipes, 60% of the residential sector powered by carbon and the car and van fleet hydrogen powered.*

[36] Scotland has two pumped storage stations – which are hydroelectric power stations that in effect act as giant batteries, powering up off-peak and releasing power at times of peak demand. One of them, Cruachan, has 12 hours reserved for "black start"; power to be released in the event of failure to power up off-peak from the grid.

[37] See Section 9.4

As the Energy Strategy acknowledges, these are just scenarios for discussion, not predictions[86]. "Progress, it says "over the next five years will have a huge bearing on our decisions about which technologies should form part of the future energy system"[87]. It also notes the need to work with the UK Government through the latter's Clean Energy Strategy.

The Energy Strategy also sets two new interim targets for the Scottish energy system by 2030:

- *The equivalent of 50% of the energy for Scotland's heat, transport and electricity consumption to be supplied from renewable sources; and*
- *An increase by 30% in the productivity of energy use across the Scottish economy.*

The priorities in the Energy Strategy[88] reveal the Scottish Government's concern about addressing the energy "trilemma" and show how inclusive growth is threaded through decarbonisation strategies.

The priorities start with "consumer protection" – addressing fuel poverty and smart metering, moving on to building energy efficiency through Scotland's Energy Efficiency Programme (see below); building standards; industrial energy efficiency, bio-technology and carbon capture & storage.

The Scottish Government says it will also continue to support the development of renewable energy, citing the existing REIF (Renewable Energy Investment Fund) fund and the Low Carbon Transition Infrastructure Programme, and proposes a £20m Energy Investment Fund as a successor to REIF and a £60m Low Carbon Innovation Fund as a successor to LTICP.

Community ownership is also a key theme. The Scottish Government wants to see a significant increase in the shared ownership of renewable energy projects in Scotland – "putting energy into the hands of local communities" and delivering a lasting economic asset to communities across Scotland. This goes beyond "community benefits" which, in the renewable energy sector, describes agreed levels of payments to local communities to enhance community infrastructure, in recognition of the impacts of renewable energy projects (usually onshore wind farms). SG's ambition remains to ensure that, by 2020, at least half of newly consented renewable energy projects will have an element of shared ownership[89]. Presumably the intention is for this target to be sustained beyond 2020, although the strategy is not explicit about this.

The strategy emphasises the continuing opportunities in onshore and offshore wind, technology development, "island wind[38]", wave & tidal, solar PV, bioenergy and hydro. A key challenge has been the setting of non-domestic rates for renewable energy projects, which appears to have been a particular issue for the hydro sector[39] and illustrates how other government policies can conflict with decarbonisation objectives.

There is a promise to take the opportunity of the new Planning Bill to review the planning system in the light of decarbonisation objectives, although (see Section 17.3), the resultant Planning Act lacked any overt signals in this direction.

Notable in terms of sector positioning are a clear statement of SG's continued opposition to new nuclear plants and support for "investment, innovation and diversification" across the oil

---

[38] Not a different technology category, but characterised by the higher cost of exporting the power (as a result of undersea cabling costs) and therefore, SG argues, meriting a higher level of support through the UK Government's Contracts for Difference programme

[39] See, for instance, the relief subsequently announced by SG in March 2018 http://www.british-hydro.org/business-rates-review-hydro-sector-response/

& gas sector.[90] A "strong and vibrant" domestic oil and gas sector is seen as playing an "essential role" in the future energy system, over the long term potentially as a fuel for "clean" hydrogen[40] . SG is also committed to maximising economic recovery from the North Sea.

While the argument is made that North Sea oil & gas is less polluting and less carbon-intensive than alternative imported options, continued support for this carbon-intensive sector in effect increases the decarbonisation requirement elsewhere, although no doubt SG will argue that this resource is an essential component of the transition to a low carbon economy.

That said, the apparently open-ended commitment to the oil & gas sector might be seen to confuse an otherwise clear sense of purpose to decarbonise Scotland's energy.

The strategy also expresses strong support for carbon capture & storage and hydrogen as future decarbonisation options.

12 Key Actions from the Energy Strategy[41]

- *Create a publicly owned energy company that could be operational by 2021*
- *Publish a "SEEP" (Scottish Energy Efficiency Programme) roadmap and introduce the transition programme*
- *Look at options to attract new investment in industrial energy efficiency or decarbonisation*
- *Establish a Low Carbon Innovation Fund (£60m) and an Energy Investment Fund (£20m)*
- *Implement the new Onshore Wind Policy Statement[91] (which principally recognises that Scotland will continue to need more onshore wind development and capacity, states that the industrial opportunity is a "top priority" for Government and says that new onshore wind nevertheless needs to operate without subsidy)*
- *Target support for local and small-scale renewables, notably through rates relief*
- *"Champion" wave & tidal in Scotland*
- *Support the development of low carbon heat supply and heat demand reduction through existing funding programmes (e.g. District Heating Loan Fund, LCITP), and the new funding under SEEP.*
- *Develop district heating regulation*
- *Phase out the need for new petrol and diesel cars and vans by 2032*
- *Introduce large scale pilots across the country to encourage private motorists to use ULEVs*
- *Develop a roadmap towards a Carbon Dioxide Utilisation Strategy for Scotland.*

[40] Although if hydrocarbons are burned to get the hydrogen, this is unlikely to help carbon targets

[41] This is not the full list – we have highlighted what we think is likely to be of most interest to this review

At a conceptual level, the major challenge for policy-makers is to shift thinking from an approach that focuses on driving value from highly replicable large-scale programmes (offshore wind, for instance) to multi-faceted approaches where the unit sizes may be smaller and more dispersed, and which somehow need to connect up - and where technology development is an embedded risk – at least, in the immediate future.

Engagement

We would note in passing that the level of engagement in the debate on energy sustainability and decarbonisation appears still to be at relatively low level.

For this milestone policy statement, the consultation process elicited just 252 responses - 200 from organisations and 52 from individuals, which are broken down in the table below[92]: It is clear from the response numbers that the standard consultation process is not the mechanism for mainstreaming a debate on Scotland's energy future.

Respondent Groups	Number
Academia / research / training	17
Community	7
Business / industry	68
Network / professional / trade	48
Local Government	21
Public Sector / Delivery Agency / Regulator	14
Third Sector / NGO	24
Other	1
Total organisations	200
Individuals	52
Total responses	**252**

Consultation does, however, elicit useful contributions from sector experts. One such response came from Dr Keith Baker, Ron Mould, & Dr Geoff Wood, from the School of Engineering and the Built Environment, Glasgow Caledonian University; School of Law, University of Stirling; and Centre for Energy Petroleum and Mineral Law and Policy (CEPMLP), University of Dundee, respectively.

Editors and authors of A Critical Review of Scottish Renewable and Low Carbon Energy Policy (2017)[93], which is referenced elsewhere in this report, their consultation response to the consultation on Scotland's Future Energy Strategy, said that while Scotland has already established a long-term strategy to address climate change, primarily through the Climate Change (Scotland) Act 2009, and evidenced considerable success in deploying renewable energy, in particular renewable electricity at the commercial and community/local levels, "what has been conspicuously absent to date" has been a similar vision for energy policy matching the scale of planning, investment cycles and asset longevity and management required to meet renewable energy and climate change targets.

There is, they say, also a "strategic energy role" to be gained in the integrated planning of the different technologies in the draft Energy Strategy. The devolutionary settlement regarding renewable energy and wider energy issues is "largely individualistic, piecemeal and arbitrary" in terms of what is reserved and devolved to the UK and Scottish Governments.

The Scottish Government, they argued, has neither a comprehensive nor a cohesive set of devolved powers over energy policy and practice. Critically, the ad hoc nature of current energy policy powers in Scotland "inhibits Scotland from driving forward innovation", rather than being merely an implementer of energy policy and practice[42].

One obvious area of complication is the devolution settlement, which has left a split in energy-related decision-making structure between Scotland and the UK (to which we also refer in Section 9.6), but the distributed nature of policy responsibility for decarbonisation within the Scottish Government itself makes policy coherence more difficult as well.

9.4 Electricity Market Reform

If electricity has been the most active component of the energy sector to date, the most influential recent policy mechanism has almost certainly been Electricity Market Reform ("EMR") and Contracts for Difference ("CfD").

While the preceding mechanism, the Renewables Obligation ("RO"), had been successful since its inception in 2002 in underpinning a growing portfolio of renewable energy assets in the UK, its very success was creating a policy headache for the UK Government. By offering a fixed price support mechanism, the Government was facing the prospect of an ever-increasing long-term liability and a risk that the decarbonisation programme for electricity generation would face affordability problems. Its own projections, meanwhile, were that in the process of transitioning to a low-carbon economy, wholesale energy prices would continue to rise (see Section 5.6).

The UK Government's White Paper "Planning our electric future" (2011), had as its subtitle: "a White Paper for secure, affordable and low carbon electricity"[94]. In effect, this introduced the concept of a triple constraint that became known as the "energy trilemma". The paper stated that electricity prices were expected to rise, as a result of increases in wholesale costs, as well as carbon prices and environmental policies.

The RO was a fixed amount of support for every MWh of power generated. It worked as a supplement to whatever the generator could earn by selling its power on the wholesale markets, which could vary enormously, both as a result of market conditions and the selling power of the generator (because they had to persuade a company to buy the power from them).

This, it was argued, wasn't helpful either for investors (because revenues were difficult to predict), for generators (because they had to give up much of the "upside" in order to secure the contractual certainty their investors needed) or to the Government (because it was giving

[42]https://consult.gov.scot/energy-and-climate-change-directorate/draft-energy-strategy/consultation/view_respondent?uuId=794054245

away the same amount of subsidy whatever the generators were making on the wholesale markets.

The Contract for Difference seemed like an ideal solution. Instead of guaranteeing a fixed payment, the CfD guaranteed the total revenue for the generator, so that if wholesale prices were low, the element of government support would be high - and vice versa.

In an ever-rising fossil fuel market, of course, it must have seemed like a one-way bet, as rising oil prices pushed wholesale electricity prices upwards. The support mechanism would be a progressively reducing liability for government as renewables moved steadily to cost parity with increasingly expensive fossil fuels.

The corollary was that the UK Government had in effect pegged its market support to fossil fuel prices (and perversely now had an ongoing interest in seeing wholesale electricity costs rise, in effect making it more difficult to address affordability, one of the three legs of the trilemma). Moreover, predicting how much subsidy the UK Government would have to provide had suddenly become much more difficult.

Prudence would presumably also have dictated that reasonably conservative assumptions about the Government’s exposure should be made, so predictive budgeting would have built in more contingency, thereby bringing the effective budget ceiling even lower.

In reality, as we saw earlier, oil prices went down rather than up and have consistently been below the DECC 2013 Low scenario in every year except 2014, and generally less than half the “high” scenario.

The other radical new feature of the CfD was the introduction of reverse price auctions, which were designed to create competition between technologies that were at a comparable stage of the development curve (the more experimental technologies, notably wave and tidal, were shielded to some extent from competitive market pressures through the creation of a separate “pot” for less well-developed technologies).

There were three inter-connected elements to EMR:

1. *Contracts for Difference (“CfD”), as described above*
2. *FID (”Final Investment Decision”)- Enabling for Renewables, which fixed a “strike price” through bilateral negotiation for individual projects (2 biomass and 6 offshore wind) ahead of full implementation, thereby locking down a substantial proportion of the available budget for renewables*
3. *The Capacity Market (“CM”) – a periodic reverse auction process to guarantee additional capacity to absorb the increased intermittency risk from more renewable energy on the system.*

“FID-Enabling for Renewables” was a pipeline-management solution born out of the assessment that the CfD auction process could not be brought in quickly enough to avoid a hiatus in project implementation on major renewables projects. As a result, a substantial amount of support budget was committed outside the parameters of the new system. This is discussed in more detail below.

Two independent evaluations were undertaken by Grant Thornton and Poyry (“GTP”) on the three connected programmes in 2014 / 2015. These evaluations were based on access to programme documents and extensive stakeholder consultation, both within DECC (which was subsequently incorporated into BEIS), the commissioning ministry at the time, and across the industry. The reports were published in the wake of early implementation of the first CfD and CM auctions.

In a number of ways, implementation of EMR in its early stages was found by the evaluators to be a success. They found[95] that the first-round delivery "exceeded expectations in many areas" and managed the tensions between cost and delivering capacity. It was also concluded that the fundamental structures of EMR should be retained and industry focus should be on streamlining processes and evolving policy detail.

However, the evaluators also questioned the coherence of the CM and CfD programmes in the context of overall EMR objectives. This question arose because each instrument was designed to be agnostic or neutral on certain key aspects.

The Capacity Market was only concerned with the cost of capacity provision, regardless of how the capacity was provided (so high-emitting diesel generators could and were part of the mix). This in turn potentially increased the pressure on the CfD to low carbon intensity generation than would otherwise be the case, with the potential for higher costs. At the same time (although the evaluation doesn't specifically mention this), despite these principles of neutrality, the UK Government did make decisions about how the budget should be divided up, so the programme was not technology neutral.

However, the evaluators argued that the CfD process did not reflect the characteristics of the low carbon generation that it supported. Reliability of output was not a distinguishing factor, nor was a focus on lowest cost, other than within the technology pots (so offshore wind, for example, was not exposed to competition from onshore wind). The contribution of reliable capacity from low carbon sources was then found to have a bearing on the requirement under the Capacity Market. Greater volumes of "reliable" (or baseload) low carbon generation would reduce the Capacity Market requirement, while greater volumes of variable low carbon generation would increase the Capacity Market requirement.

There have been fewer CfD auctions than anticipated by the industry[43] and the complexity and mixed signals of the mechanism have perhaps contributed to uncertainty regarding the UK Government's appetite to support renewables financially. The approach may nevertheless have provided a significant boost to the offshore wind sector, which received a strong allocation at the outset and appears to have been successful in driving down unit costs.

The cost of offshore wind has dropped significantly over the life of the CfD (see also Section 13.12).

FID-Enabling for Renewables[96] resulted in a series of bilateral arrangements to fix the "strike price" on 8 specific projects, covering 17% of the expected required renewable generation by 2020[97] which at an early stage committed 71% of the residual budget for renewable CfDs[98], thereby limiting the Government's subsequent ability to benefit from reducing technology costs by competitive auction, as a significant proportion of the budget had already been locked up, quite apart from the separate and well-publicised decision to commit low carbon budget in the award of a CfD at a strike price of £92.50[44] to Hinkley Point C.

[43] The results of Round 3 were announced on 20th September 2019

[44] See, for instance, https://www.4coffshore.com/news/uk-launches-third-contracts-for-difference-auction-nid13711.html

The Hinkley Point C strike price is more than double the offshore wind strike price in the latest CfD Round (3), which ranged from £39.65 to £41.61 MW/h.

It is important to note that in its latest report on Scotland's progress, CCC states that it believes the existing system, to be working well, with the current package of instruments – notably the carbon price support Contract-for-Difference mechanism and Capacity Market – having delivered low-cost emissions reductions while maintaining security of supply[99].

9.5 The effect of geography

Scotland's abundance of green energy comes from its distinctive geography and topography. From the hydroelectric power stations to wind energy and (potentially) wave and tidal power in the future, this is all made possible by Scotland's mountains and coastlines. At the same time, these areas are often hard to reach, so the costs and technical challenges of transmitting power from remote locations to population centres have been a material consideration for decades.

A Critical Review of Scottish Renewable and Low Carbon Energy Policy[100] ("CRSLCEP") notes that the transmission and distribution network is considered a key barrier to deployment, with an unprecedented amount of grid capacity required to connect new renewables. Historically, of course, the locations for Scotland's new generation of green power stations would never have been considered in need of substantial grid capacity. The development of onshore wind in Scotland in particular has been accompanied by piecemeal reinforcements and lengthy queues for capacity (which add to cost and risk for developers), together with occasional major upgrades, most notably Beauly-Denny.

CRSLCEP notes that grid problems particularly affect onshore wind farms but increasingly offshore wind and future marine renewables as they continue to be deployed at scale. However, with the exception of planning, the Scottish Government has very little power over either the onshore transmission or distribution networks, which are controlled by Ofgem, National Grid[45] and the Distribution Network Operators ("DNOs"). It has no regulatory powers to allocate new upgrades and extension of the network or change access rules to the grid or the charging regime. This is the remit of the pan-UK energy regulator OFGEM, with an important role for National Grid as the system operator.

The GB system is designed to spread the costs of building and maintaining the transmission networks across the UK mainland (Northern Ireland operates under a different system) evenly, without disadvantaging consumers in any particular location. It seems logical on the face of it that power should cost more the further it has to travel (both because of the cost of the infrastructure required to transmit it and because of power losses that occur during transmission), but it is the generator rather than the consumer which bears this cost, which is the reason a "locational" pricing model exists that arguably places remoter generators at a disadvantage. There is plenty of scope, of course, for debate about the quantum of losses to be expected and the baseline assumptions used in such a pricing model.

There is support in the UK CfD system for renewable energy projects on the Scottish islands – island projects were successful in Round 3. The CfD support mechanism therefore

[45] National Grid is a regulated publicly quoted (FTSE-100) company which manages both the electricity and gas transmission networks in the UK, including Scotland

compensates to an extent for the locational disadvantages inherent in the GB system, although this is not available to remote mainland generation.

SG, in its "Vision for Scotland's electricity and gas networks" (March 2019)[101] makes the point that the electricity system is changing radically. With the closure of Scotland's last coal power stations at Cockenzie and Longannet and renewable generating capacity exceeding 10 GW in 2018, supplies within Scotland have become more variable, increasing the importance of the transmission network linking Scotland with England and Wales. Two major projects are therefore in the process of increasing the capacity of the Scottish transmission network:

The **Western HVDC1 Link**, which connects Hunterston to Deeside in North Wales via an undersea cable, adding around 2,200 MW of new capacity to the transmission network – allowing more electricity generation in Scotland to connect and meet demand across Britain; and

The **Caithness-Moray HVDC Link**, a 1,200 MW undersea connection between Spittal in northern Caithness and Blackhillock in Morayshire, which was commissioned in January 2019. This link increases the capacity available to transport renewable electricity generated in northern Scotland, including Orkney and Shetland, into the wider transmission network.

But more investment is needed in new transmission infrastructure to connect the levels of renewable generation needed by 2030. This will require regulatory and investment decision processes capable of identifying, agreeing and delivering these in a timely way. It appears that forums for collaboration on electricity networks largely function on a UK-wide basis – perhaps there is an argument for a government / cross-industry collaboration specifically focused on Scotland's electricity network needs.

The conclusion of the March 2019 "Vision" report is essentially a call for greater innovation and recognition of the effect of innovation on the network. It says: "We committed £60 million in 2017 to support innovative low carbon energy infrastructure solutions across Scotland, such as electricity battery storage, sustainable heating systems and electric vehicle charging. Innovation over the next decade will need to focus on integrating new technologies and business models coherently across an evolving energy system…the regulator provided £500m million to support network innovation between 2010 and 2015 and has made innovation a key component of funding for the networks through its price controls. But there is still more that can be done to make innovation business as usual".

9.6 The Energy Quadrilemma

RSE recently published a high-profile report (June 2019) on the challenges faced by energy policy in Scotland. Building on the concept of an energy "trilemma" (energy security versus affordability versus addressing climate change) that emerged in UK Government thinking around 2011 / 2012[46], the RSE frames its arguments not as a trilemma, but a four-legged 'quadrilemma', namely:

- *addressing climate change;*
- *ensuring affordability;*
- *providing energy security; and*

[46] it was alluded to in the UKG July 2011 White Paper

- *developing energy policy which is "acceptable to the public, economically sustainable and just"[47].*

Framing the complexity of decarbonising electricity as a set of choices might have made good sense in the short term back in 2011. Framing them as three apparently conflicting objectives, in effect polarising the debate by placing the perceived needs of the current generation (cheap power, security of supply) in direct opposition to those of the next generation (mitigating climate change) has left a longer and arguably pernicious policy legacy.

More openness and transparency about the difficult choices that needed to be made was and remains clearly desirable, but (intentionally or otherwise) the "trilemma" soured the tone of the green energy narrative which (EMR notwithstanding) continues to affect UK energy policy today.

It might be argued that a less generous support regime was exactly what was needed to drive cost down in the industry. Certainly there have been impressive cost reductions in low carbon energy since then, notably in offshore wind, solar and batteries. But it might also be argued that offshore wind was to some extent shielded from undiluted market effects through FID Enabling for Renewables, which fixed a strike price for a number of early projects, and through the sub-division of the CfD which ensured that offshore wind only competed against the same technology. Battery storage was never subject to a market-based support mechanism, while the UK was hardly the most significant or stable market for solar PV.

Proponents of a high concentration of renewables on the system might also argue that these were always false choices, as they were predicated on a number of structural and technological assumptions that didn't have to endure. In fact, while the renewable energy sector still faces significant challenges in terms of policy acceptance at the UK level, increased innovation in terms of system flexibility and improving technology for storage options (solid state batteries, hydrogen) indicate that there are ways of reconciling, rather than opposing, the three corners of the challenge.

If a "trilemma" is tricky, then by implication a quadrilemma is even more difficult to resolve. The RSE report rehearses some well-trodden themes: it says that decision makers will need to be "honest with the public" about what is achievable, what choices must be made, and what changes will need to occur. It recognises that "significant progress" has been achieved in energy for Scotland over the last decade but asks the question about how to navigate the next stage as the difficult tasks of decarbonising heat and transport start to be addressed, while recognising that there are still plenty of issues for electricity generation.

The RSE report identifies a series of weaknesses in the system, but without having much to offer in the way of solutions. "While there have been significant successes, it says, progress has been hampered by a systemic lack of transparency; weak planning, monitoring and implementation; and problems with delivering cost-effectiveness and protecting consumers' interests".

It reflects on the need for continued cooperation between the Scottish and UK Governments to maximise the effectiveness of the governance structure and to achieve common objectives.

---

[47] The quadrilemma must be a strange-looking animal, because it appears to have one very long leg. Strictly speaking, RSE added 3 new considerations, so perhaps it is really a *sextilemma*

All of the choices available to Scotland to meet its energy needs, says the RSE report, require trade-offs and it is imperative, it says, that the compromises that need to be made are understood, discussed and accepted.

The purpose of the report appears to be to trigger a debate between the merits of different energy solutions but doesn't aim to provide a new frame of reference for the debate. It also appears to be somewhat at odds with the more positive technological assessments of both CCC and NIC.

Reading between the lines (necessary because the report seems to make some of its main points only obliquely), the two key takeaways seem to be that, from the RSE's perspective, nuclear has to be part of the low carbon mix in Scotland and that government is currently failing to face up to the inevitable compromise in its policy stance in this area; although, in this report at least, RSE offers no compelling evidence as to why it has reached this conclusion.

9.7 Heat

Current position

According to BEIS[102], heat was the largest energy consuming sector in the UK in 2017 by final energy consumption at 44% in 2017, but by some measures the UK has become more efficient, which should have helped to reduce heat use.

Total household electricity and gas consumption has fallen by 17% over the last decade despite a growth in the number of households in the UK over this period. The energy efficiency of non-domestic buildings has also improved, with emissions 18% lower in 2015 compared with 1990 levels. Annual domestic fuel consumption in 1970 was 104 TWh, rising steadily to peak at 396 TWh in 2004 and has dipped back to 297 TWh in 2017.

In Scotland, heat accounted for 54% of total final energy consumption, compared with 25% for transport. The split between domestic and industrial / commercial was 41% and 59% respectively[103]. Consumption of energy used for heating has declined from 102 TWh in 2005 to 81 TWh in 2013. It is difficult to compare exactly on a like for like basis, but it looks as though Scotland accounts for significantly more of the domestic heat consumption on a per capita basis than the UK as a whole, which explains why heat is such an important policy focus for Scotland.

Renewable heat in Scotland

The Energy Savings Trust, drawing on its database of renewable heat installations, produced a report for the Scottish Government on renewable heat in the context of the Scottish Government's target for 11% of non-electrical heat demand[104]. EST estimated that 2GW of renewable heat capacity was operational in 2017, producing just under 5 TWh, which they reckoned to be around 5.9% of Scotland's non-electrical heat demand. This appears to tally with the estimate provided in the paragraph above. The output was 28% higher than 2016, although 2016 was unusually low, so EST also compared with 2015, which showed an increase of 14%. The average annualised increase between 2015 and 2017 therefore works out at about 6.75%, which suggests that the rate of increase needs to step up significantly if the 11% target is to be met, assuming heat demand remains at current levels.

EST calculate that renewable heat output would need to increase by between 68% and 84% (depending on the heat demand scenario), in order to reach the Scottish Government's target at 2020. This would be equivalent to an annual increase in output of between 19% and 25%.

The average annual increase in output is 21%, although as indicated above, this was not seen in the preceding two years.

The majority of both capacity and output (81% / 82%) in 2017 came from biomass primary combustion and biomass CHP. The total energy from waste output was 449 GWh, or just under 10% of the total. Heat pump output was around 374GWh. Heat demand has been falling on average since 2008/9 (although it rose slightly in 2015 / 2016).

Future Heat Decarbonisation

CCC's work on heat identified a number of decarbonisation pathways for low-carbon heating. It commissioned Imperial College in August 2018[105] to review these. Each of the three "central" pathways brings with it significant challenges and it is unclear whether there is a dominant "preferred option".

The Integrated Whole-Energy System (IWES) model was applied to assess the technical and cost performance of alternative decarbonisation scenarios for low-carbon heating in 2050 to understand the implications these pathways on electricity and gas infrastructure in the UK energy system in 2050.

The study focused on three core heat decarbonisation pathways:

- *A core hydrogen pathway based on the application of end-use hydrogen boilers at consumer premises to decarbonise heat demand. It was assumed that consumers that do not have access to gas would use electric heating;*
- *An electric pathway where heat demand is met by the optimal deployment of end-use electric heating appliances including heat pumps (HP) and resistive heating (RH);*
- *A hybrid pathway based on the application of combining the use of gas and electric heating systems, i.e. hybrid heat pumps (HHP). The gas heating system in the hybrid system uses natural gas or carbon-neutral gas such as biogas or hydrogen to reduce emissions from gas.*

The key findings were that forecast costs start to diverge significantly the closer the scenario gets to a zero-carbon solution. Specifically:

- *The hybrid pathway is the least-cost under central assumptions while the cost of the hydrogen pathway is found to be the highest cost, compared to the other pathways;*
- *Electric and hybrid pathways have greater potential to reduce emissions to close to zero at a reasonable cost, compared to the hydrogen pathway*
- *The costs of low-carbon systems are dominated by capital expenditure (capex) while operating expenditure (opex) is significantly lower.*
- *The costs of the core decarbonisation pathways are relatively similar (cost difference is within 10%) except the hydrogen 0Mt case (+30% higher than either the next most expensive 0Mt case or the 10Mt H2 case) and hence the overall cost of alternative pathways may change when different assumptions apply.*

In addition to the core heat decarbonisation pathways, a range of alternative strategies was also investigated[106]. This included:

- *implementation of regional decarbonisation strategies combining one decarbonisation pathway with a different regionalised pathway, with the use of hydrogen in the North of GB (Scotland, North of England and North of Wales) while the rest of the system is decarbonised through Hybrid Heat Pumps (HHP), in order to minimise investment in hydrogen networks.*
- *Use of hydrogen in urban areas while rural areas are decarbonised through HHP.*
- *use of industrial HP-based district heating in urban areas. (ii) District heating, consisting of two scenarios (iii) Micro-CHP - 10GW of micro-CHP is deployed in the Hybrid system that can displace end-use HHPs and power generation.*

To achieve zero-carbon emissions without nuclear generation, there is a need for 3.6 TWh of hydrogen energy storage to provide both support for short-term energy balancing and long-term storage. The volume of hydrogen storage needed is around 1100 mcm, which is around 30% of the volume of the recently closed Rough gas storage facility[48]. The annuitized investment cost of the hydrogen storage across GB in this scenario is estimated at around £3.2 bn/year[107].

The optimal choice for decarbonising heat, the report concludes, may depend on the level of heat demand in the future which could be influenced by many factors, e.g. improved housing insulation and climate change[108].

The Imperial College report adds that the maximum capacity of low-carbon generation assumed to be available by 2050 will be sufficient to reach the zero-carbon target, but energy system flexibility and interactions across different energy systems significantly influence the power generation portfolio and a significant capacity of “firm” low-carbon generation is needed in all pathways with a 0Mt carbon target;

The total capacity of electricity generation in the electric pathways is significantly larger than in other pathways. In the electric pathway there is a significant amount of peaking plant (OCGTs) that are supplied by biogas and operate at very low load factors (operating during high peak demand conditions driven by extremely low external temperatures).

Key drivers will be energy efficiency, the domination of overall system costs by (front-end) capex rather than opex, system flexibility and storage.

Importing low-cost hydrogen could potentially make the hydrogen pathway cost competitive against electrification pathways, but it doesn’t look as though this has been tested to date. This could, of course, make the verification of decarbonisation more challenging.

CCC in its latest report says that the Scottish Government now needs to develop a fully-fledged strategy for decarbonised heat[109]. Existing SG initiatives with regard to low carbon heat are covered in Chapter 15.

[48] Which was c70% of the UK’s gas storage capacity (9 days) https://en.wikipedia.org/wiki/Rough_(facility)

9.8 The Renewable Heat Incentive

The UK Government's financial support scheme for heat is the Renewable Heat Incentive (RHI). The **Domestic Renewable Heat Incentive** (RHI) opened for applications on 9 April 2014. The scheme is for people across England, Scotland and Wales who install eligible renewable heating systems in their homes[110]. The intent was to bridge the gap between the cost of fossil fuel heating sources and renewable heating alternatives by providing financial support for homeowners, private and social landlords, and people who built their own homes. The scheme was also designed to help build and support the supply chains needed to deliver the UK's targets for renewable heat in 2020 and beyond.

Ofgem administers the scheme on behalf of BEIS. In the year to March 2019, there were 7,597 accreditations, bringing the total since scheme launch to 67,971, of which accreditations in Scotland account for around 17%. The first quarter of this year brought the figure up to 71,604. A total of £437m has been paid out under the RHI to date[111]. Around 22.5% of accreditations across the UK were for Registered Social Landlords. Audit appears to be an ongoing issue, with a compliance rate for desk audits of 72% and for site audits of 76%, although the confidence level in the audits has increased from 80% to 90%[112].

The current tariffs for domestic RHI are shown in the table below.

BEIS announced on 31 May that there will be no degression on 1 July 2019.

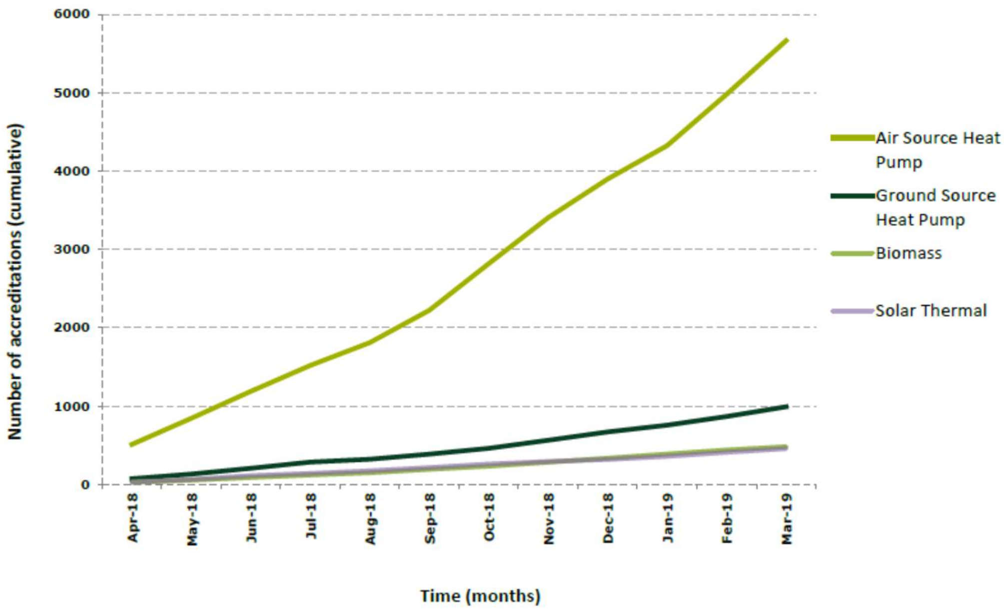
Current and future tariffs | Historical tariffs | Other DRHI tariff information

Applications submitted	Biomass boilers and stoves (p/kWh)	Air source heat pumps (p/kWh)	Ground source heat pumps (p/kWh)	Solar thermal (p/kWh)
01/01/2019 - 31/03/2019	6.74p	10.49p	20.46p	20.66p
01/04/2019 - 30/06/2019*	6.88p	10.71p	20.89p	21.09p
01/07/2019 - 30/09/2019	6.88p	10.71p	20.89p	21.09p
01/10/2019 - 30/12/2019	If any new tariff changes are to be made due to degression, the announcement by BEIS would be made by 1 August 2019.			

Figure 23: Current domestic RHI tariffs[49]

The dominant technology at present for domestic RHI is air source heat pumps, whereas in the past there appears to have been a greater preference for biomass and ground source heat pumps, as illustrated in the charts below:

49 https://www.ofgem.gov.uk/environmental-programmes/domestic-rhi/contacts-guidance-and-resources/tariffs-and-payments-domestic-rhi/current-future-tariffs



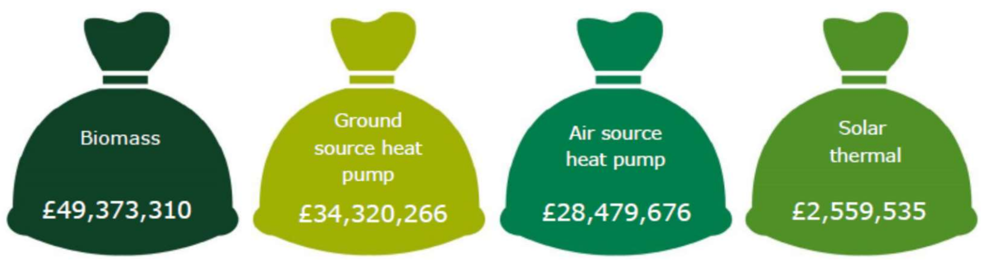


Figure 24 – accreditations and pay-outs under Domestic RHI[113]

The **Non-Domestic Renewable Heat Incentive (RHI)** is a government environmental programme that provides financial incentives to increase the uptake of renewable heat by businesses, the public sector and non-profit organisations. Through the non-domestic RHI, generators of renewable heat for non-domestic buildings are per kWh for the hot water and heat which they generate and use themselves, according to system type, scale and technology.

Eligible installations receive quarterly payments over 20 years based on the amount of heat generated. The scheme covers England, Scotland, and Wales. The Department of Enterprise, Trade and Investment suspended the Northern Ireland RHI Scheme to new applicants from 29 February 2016.[50]

Tariffs for both schemes are subject to a "degression" mechanism which allows the Government to cut support to manage budgets and affects all installations accredited after 1st July 2013 (which includes all domestic RHI installations). In effect this means that the

50 https://www.ofgem.gov.uk/environmental-programmes/non-domestic-rhi/contacts-guidance-and-resources/public-reports-and-data

beneficiary is unable to predict with certainty the level of support that will be received[114]. Domestic installations are also subject to an effective cap, called a “heat demand limit”, which comes into play of the assessed heat demand on the Energy Performance Certificate is higher.

The annual subsidy lasts for 20 years for non-domestic buildings, and seven years for domestic buildings.

9.9 Public Engagement

In its 2019 report on Scotland’s progress, the CCC notes that the general public currently has a low awareness of the need to move away from natural gas heating and of the alternatives. There is a timeframe, it says, to engage with people over future heating choices and to factor this into strategic decisions on energy infrastructure. CCC also notes that solutions to heat decarbonisation in some areas of Scotland, particularly those without access to the gas grid, could be different from elsewhere in the UK.

10. Housing

Question element: the relative impact of each sector within the Scottish context i.e. ***the relative scale of both the particular infrastructure sector and its carbon emissions***

Headlines
Residential emissions are the most significant component of the building sector and space heating accounts for the majority of those emissions. Progress in decarbonisation has been inadequate across the UK in recent years. Future-proofing new houses is vital and new homes need to stop being connected to the gas grid. Detail on effective mass retrofit is lacking. The last such programme (the Green Deal) was a conspicuous failure. Adaptation in terms of water management and flood prevention appears to require more work. Scotland appears to be performing worse than England in terms of water consumption and leakage.

10.1 Introduction

Buildings emissions are dominated by the residential sector. As the chart below[115] shows, the two sectors have been broadly in synch for the past 3 decades in terms of direct emissions. As a share of total emissions in 2017, the residential sector accounted for around 20%, of which 14% was "direct" (likely to be almost entirely from heat) and 6% the share of grid electricity.

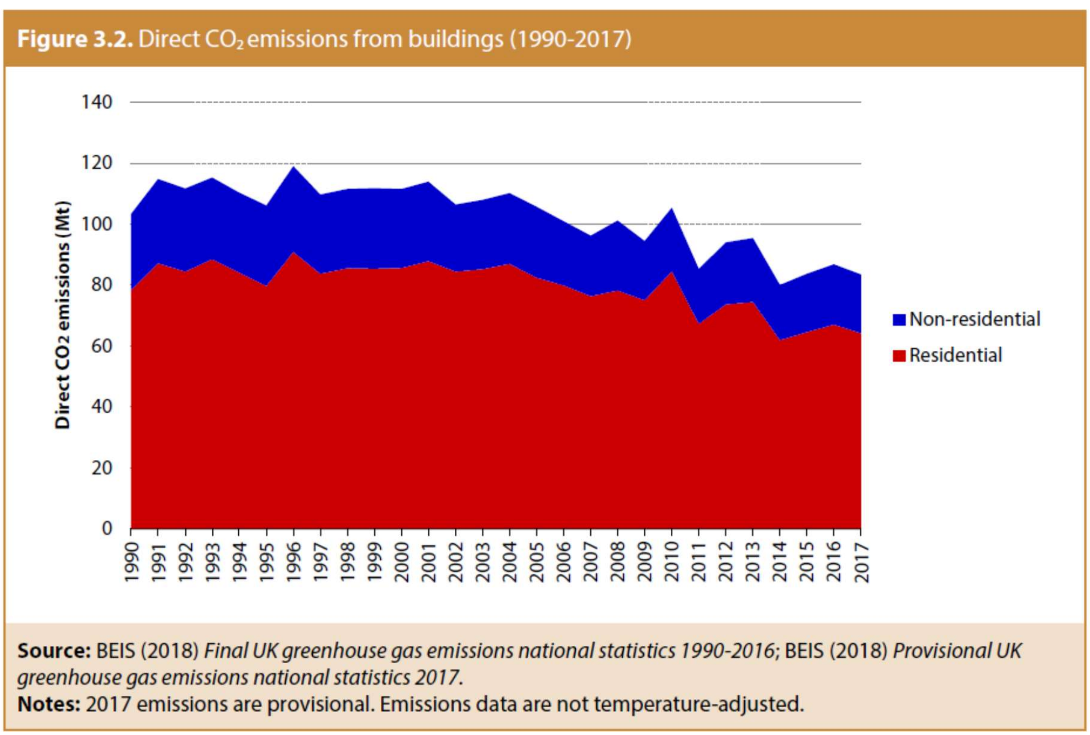


Fig 25 – Direct CO_2 emissions from buildings (UK)

10.2 The Future of Housing

In its report, "UK Housing: fit for the future?"[116], CCC clearly answers its own question. UK homes are not, it believes, fit for the future. Greenhouse gas emission reductions from UK housing, it says, have stalled and efforts to adapt the housing stock for higher temperatures, flooding and water scarcity are falling far behind the increase in risk from the changing climate.

The UK will not meet targets for emissions reduction without near complete decarbonisation of the housing stock[117]. These emissions need to fall by at least 24% by 2030 from 1990 levels and the UK is currently off track. In 2017, annual temperature-adjusted emissions from buildings actually rose. Direct emissions from homes were 64Mt CO_2e in 2017; when adjusting for annual temperature variation, this was an increase of 1% on the previous year.

There is perhaps no better example of the policy vacillations on decarbonisation than the housing sector. UK policy took a major retrograde step in 2015, when the Government announced the scrapping of the Zero Carbon Homes Policy, first launched in 2006, which would have come into force in 2016[51]. The Scottish Government now has an aspiration to zero-carbon homes, although it is not articulated in quite these terms in the Programme for Government:

"We will set new standards to reduce energy demand, and associated carbon emissions, within new buildings by 2021. In addition, we will require new homes consented from 2024 to use renewable or low carbon heat. For non-domestic buildings, our ambition is to phase in this approach from this date"[52]

We might therefore see the implementation of a zero carbon new homes policy in Scotland a full 8 years after the target date that was originally set in 2006 for the whole of the UK.

Emissions in housing were just 9% below 1990 levels. This compares to a 13% reduction in residential emissions required on CCC's "cost-effective pathway" for meeting carbon budgets, on the way to a 24% reduction by 2030. Whilst energy use per household and per person have fallen since 1990 – by 21% and 14% respectively, there has been no progress since 2014.

Space heating is the dominant driver of energy consumption in existing homes (making up 63% of annual energy consumption), followed by hot water demand (17%) and appliance demand (13%)[118].

This is not just about decarbonisation. The housing stock is poorly adapted for the current or future climate. Around 20% of homes (4.5 million) currently overheat even in cool summers, 1.8 million people live in areas which are at significant risk of flooding and the average daily water consumption per person across the UK is around 140 litres, above the sustainable level in a changing climate and higher than many other European countries[119].

In Scotland, around 1% (or 24,000) of all dwellings fell below the Scottish Government's Tolerable Standard[53] in 2017.The Scottish Housing Quality Standard (SHQS), applicable only

[51] https://www.theguardian.com/environment/2015/jul/10/uk-scraps-zero-carbon-home-target

[52] https://www.gov.scot/publications/protecting-scotlands-future-governments-programme-scotland-2019-20/pages/5/

[53] The Tolerable Standard is the minimum standard (now a statutory requirement for all housing), and a house which is below this standard is considered to be unfit for human habitation. https://www.gov.scot/publications/regulations-to-modify-repairing-standard-summary/

to social housing, has a 37% failure rate in the social sector (not allowing for abeyances and exemptions), an improvement on the 60% failure rate in 2010. In social housing, 80% of homes are compliant with the Energy Efficiency Standard for Social Housing (EESSH). There were estimated to be 613,000 fuel-poor households in 2017, equivalent to 24.9% of all households[120].

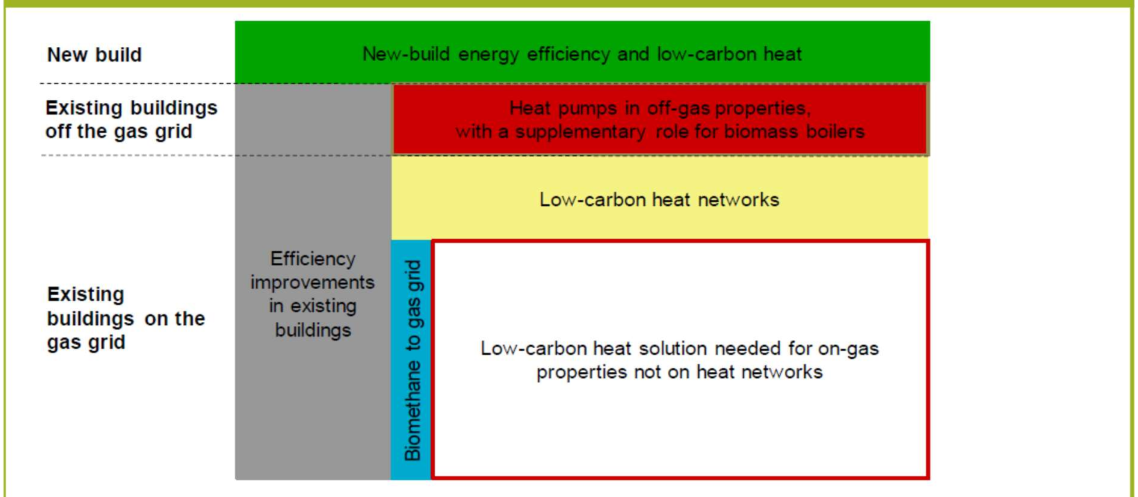
Reading between the lines, it looks as though there are significant data gaps for private housing - in particular for Scotland.

Major change is needed, not least that new housing should cease to be connected to the gas grid by 2025, which is recognised in the Scottish Government's latest Programme for Government (see 14.2).

Deployment of low-carbon heat, says CCC, cannot wait until the 2030s. In the next decade, there is a set of measures that are sensible to implement ("low regrets" measures), regardless of the longer-term path to decarbonising heating in buildings. These are illustrated in the graphic below, taken from the report.

Future-proofing new homes for low-carbon heating, through the use of appropriately-sized heat emitters and low-temperature compatible thermal stores, has been estimated to save £1,500-£5,500 of costs compared to later having to retrofit low-carbon heat from scratch. All new homes should therefore be future-proofed for low-carbon heating at the earliest opportunity. The evidence indicates, says CCC, that low-carbon heat is now cost-effective in all new build homes by 2025 or earlier. This is achievable through regulation. Last year, for example, the Dutch Government introduced regulations which by default prevent new homes connecting to the gas grid.[121] It seems that policy for decarbonising housing stock needs to move a number of options forward simultaneously at this stage.

Figure B2.1. Low-regret measures and remaining challenges for existing buildings on the gas grid



Source: CCC (2016) *Next steps for UK Heat Policy*.
Notes: The sizes of the blocks broadly reflect the scale of emissions reduction, but not precisely. Some potential for heat networks will be in new build and off the gas grid, rather than all on-grid as presented.

Fig 26 – Solutions for housing stock

The quality, design and use of homes across the UK, argues the CCC, must be improved now to address the challenges of climate change. This will also improve health, wellbeing and comfort, including for vulnerable groups such as the elderly and those living with chronic illnesses, something that echoes the Welsh Government's energy efficiency strategy (2016) (see below).

The CCC report identifies five priorities for government action:

1. ***Performance and compliance.*** *New homes and retrofits are falling short of design standards.*
2. ***Skills.*** *The "chopping and changing of UK Government policy" has inhibited skills development in housing design, construction and in the installation of new measures.*
3. ***Retrofitting existing homes.*** *The 29 million existing homes across the UK must be made low-carbon, low-energy and resilient to a changing climate. This is a UK infrastructure priority and, the CCC argues, should be supported as such by HM Treasury.*
4. ***Building new homes***. *There are plans for 1.5 million new UK homes by 2022. These new homes must be built to be low-carbon, energy and water efficient and climate resilient. From 2025 at the latest,* ***no new homes should be connected to the gas grid****.*
5. ***Finance and funding.*** *There are urgent funding needs which must be addressed now with the support of HM Treasury: low-carbon heating (currently only funded up to 2021), and resources for local authorities, in particular building control.*

How mass retrofit can be delivered at a scale that decarbonises 29 million homes is not explored in detail by CCC, but the retrofit technologies have been around for some time. It seems as though the challenge is more about how to implement.

A report by the Centre for Low Carbon Futures ("The Retrofit Challenge"[122]) at the University of Leeds in 2011 set this out as six themes:

1. *Retrofit isn't simple – performance isn't predictable and future needs have to be taken into account*
2. *Building energy performance is not well understood – measured and predicted heat loss often differ*
3. *Building fabric changes the solution (as we see below, DECC's decision to target solid wall insulation pushed costs up for the Green Deal)*
4. *Micro generation and low carbon technologies – what works on site*
5. *People use energy – rebound effects*
6. *The importance of ICT and monitoring*

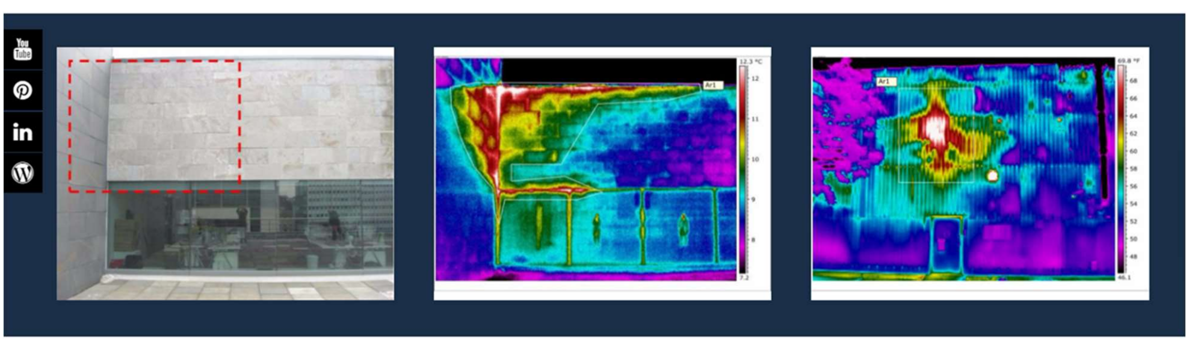


Fig 27: thermal imaging from IRT Surveys, Dundee

Clearly a shift from gas as the primary feedstock to electricity or hydrogen would help, but the implication is that energy usage needs to fall as well.

The UK Government's Green deal was the last attempt at mass decarbonisation – this is discussed in more detail below.

Given that about 25m existing homes will still need to be heated in 2050, intervention in the existing stock is essential for significant decarbonisation. Experience shows that more centrally determined change processes can be intrusive (see, for example, Ofgem[123]). Smart meter roll-out is a current example where significant efforts are being made to address concerns over cost, security and privacy and health, and ultimately this is not (yet) a mandatory switch.

Options for decarbonising heat include:

- *Improved energy efficiency;*
- *Adaptation of natural gas networks through blending in lower carbon gas;*
- *Electrification of heating through heat pumps;*
- *Further development of heat networks; and*
- *Hydrogen networks.*

These options, says Ofgem, are all based on current technology. The most efficient approach to decarbonisation will depend on the rate of future cost reduction, which is inherently uncertain. By 2050, Ofgem argues, it is quite possible that other technologies not currently available will be important – we should expect technological developments to surprise us.

CCC[124] in "UK Housing Fit for the Future?" outline a range of broadly similar options, although they place greater emphasis in building efficiency and identify the need to move away from gas as quickly as possible.

With the additional physical disruption that might be involved with converting heating systems, the task could prove extremely challenging. However, Ofgem cites recent successful retrofit projects such as the Wyndford Estate district heating project in Glasgow, which have shown that well-designed intervention on an area-based level can be successful and potentially more efficient than targeting individual households.

Passivhaus – RIBA Stirling Prize Winner 2019
The Passivhaus and high-density Goldsmith Street social housing scheme designed by Mikhail Riches with Cathy Hawley has been awarded the RIBA Stirling Prize 2019. London studio Mikhail Riches, led by architects David Mikhail and Annalie Riches, has won the biggest prize in UK architecture for the residential scheme in Norwich. Goldsmith Street has provided Norwich City Council with 105 low-energy homes and was hailed by the jury as "a ground-breaking project and an outstanding contribution to British architecture". The estate, which was designed by a London firm, Mikhail Riches, is built to German *Passivhaus* standards, a rigorous system that reduces a building's ecological footprint. The houses are designed to be as airtight as possible, with a mechanical heat and

ventilation system that circulates air through the rooms. Heating bills should theoretically be about £150 a year.

Not all the feedback from tenants is good. Many complained that the house fittings were breaking and they had struggled to keep their homes cool during the record-breaking temperatures this summer. One tenant said her toilet leaked and her taps had broken. “The longer we live here, the more I notice little things that are wrong, but it’s stuff that we can improve on,” she said.

Laura, 23, a personal assistant and carer with two children, has her issues with the Passivhaus system. “They’ve given us a ring-binder of instructions to understand it, but I’m not very good at understanding paperwork. You kind of need someone to talk you through it,”[54]

Fig 28: Stirling Prize-winner - Goldsmith Street, Norwich

Ofgem recognises that many Local Authorities are becoming active in developing heat networks, giving planning permission and coordinating with customers such as leisure centres, schools and social housing developments to provide a baseload of heat demand but the high capital costs of projects and need to secure a baseload of customers have led to difficulties in securing the required investment for widespread take-up.

10.3 Balancing Multiple Outcomes

Household energy efficiency programmes have generally tended to incorporate social as well as environmental objectives. In fact, there has been a reluctance at times to openly acknowledge CO_2 reduction as a primary driver.

[54] https://www.theguardian.com/society/2019/oct/11/spacious-and-green-norwich-award-winning-new-council-houses-goldsmith-street

For instance, the Welsh Government, in its energy efficiency strategy (2016), chooses to downplay this aspect, focusing instead on the arguments that improving the energy efficiency of the homes of low income households is important, not just to reduce household energy use and energy bills, but also because living in a cold home has a detrimental impact on people's health and wellbeing. Cold homes can lead to increases in respiratory illnesses and the risk of heart attack and stroke, as well as contributing to excess winter deaths, worrying about paying energy bills increases stress and mental illness. Fuel poverty increases social exclusion and there are wider impacts on the economy through increased days lost to sickness and reduced disposable household income[125].

Researchers at Fraser of Allander Institute ("FoA") were interested in the effect of targeting household energy efficiency measures as evidenced by studies of direct and indirect "rebound effects".

Rebound effects[55] occur in relation to energy efficiency where the benefit of installing energy efficiency measures results in more energy being used (where previously the household was inadequately heated, for example) - these might be termed "direct" rebound effects - or where the money saved is spend on something else which increases personal carbon emissions ("indirect" rebound effects).

The studies that FoA examined estimated the rebound effect as a measure of the extent to which technically possible energy savings are eroded by economic responses.

Much of the rebound literature, FoA found, neglected the wider range of potential economic benefits associated with increased energy efficiency. Stimulating higher income households, for instance, may free up more spending on non-energy goods and services and deliver greater benefits through increased wage and capital incomes, which, the FoA paper argues, could ultimately support a national infrastructure argument.

FoA presents an interesting challenge to policy-makers solely focused on targeting measures on addressing fuel poverty and wider social deprivation. While it may be argued that government funding should be directed at helping those less able to pay for energy efficiency improvements themselves, if it could be shown that the economic stimulus generated by support of wider-ranging energy efficiency programmes would deliver sufficient economy stimulus to justify the initial levels of funding required, then there is an argument for incentives not based on need as a strategic investment in energy efficiency.

FoA's research suggested that in order to stimulate economic activity by focusing on more deprived segments of society, quite large proportionate increases in residential energy. efficiency in low income household would need to be achieved. In contrast, where the introduction of increased energy efficiency is spread over a wider range of households, even where there is a cost to supporting energy efficiency improvements, the return via the impacts of economic expansion is likely to provide what justification for support.

One point to note, of course, is that SG's targeted intervention for the fuel poor is part of a wider set of initiatives, which provide support for other households in different ways. In Chapter 14, we discuss the Scottish Government's housing energy efficiency programmes which pursue these twin objectives.

[55] See, for instance, https://blog.ucsusa.org/peter-oconnor/energy-efficiency-what-is-the-rebound-effect-946

The UK Government's ill-starred twin Green Deal and ECO programmes had similarly dual objectives, although the NAO was critical of the UK Government for not being specific about its objectives for the Green Deal programme. The Green Deal is discussed in more detail in the following section.

10.4 The Green Deal and ECO

While Scotland has its own energy efficiency strategy, it would be difficult to talk about the role of government in low carbon infrastructure without some reference to the UK-wide Green Deal and Energy Company Obligation ("ECO") programmes that were launched by the UK Government in 2013 and intended to address the challenge of retrofitting existing housing stock to make it more energy efficient across the UK. The early termination of these programmes represented something of a "bump in the road" for the process of engaging people in the transition to a low carbon economy – at best they were a missed opportunity and at worst a material set-back.

The **Green Deal** was a finance mechanism which enabled homeowners to borrow money to improve the energy efficiency of their home, making repayments through their energy bills (Green Deal finance). A Green Deal loan needed to meet the 'golden rule', whereby repayments had to be at least offset by the prospective reduction in energy bills resulting from the improvement. It was thought that this approach would give householders the confidence to commission the measures. The cost to Government when the programme was terminated had reached around £240m[126].

Green Deal finance was complemented by a broader framework of advice, accreditation and assurance that sought to build homeowners' trust in the supply chain for home improvements.

ECO was an obligation placed on energy suppliers and subdivided into the following categories:

- *Carbon Emissions Reduction Obligation, which required suppliers to save 17.8 $MtCO_2$ between 1 January 2013 and 31 March 2015. The Department initially stipulated that suppliers improve 'harder-to-treat' homes, requiring more expensive and time-consuming improvements.*
- *Carbon Saving Communities Obligation, which required suppliers to save 5.8 $MtCO_2$ between 1 January 2013 and 31 March 2015, by installing measures in deprived areas.*
- *Affordable Warmth (AW): measures, mostly replacement boilers, to low-income households and households vulnerable to the effects of inadequate heating. The Department required suppliers to achieve overall notional bill savings of £4.2 billion by March 2015.*

The total cost to suppliers (which was "socialised" through energy bills) was around £3bn.

The Green Deal was introduced with great fanfare as part of the 2011 Energy Act. The then Energy Minister told Parliament that it had the potential to improve 26 million homes, almost the entire housing stock. He said the Green Deal "will set a new paradigm and will certainly become the biggest home improvement scheme since the Second World War"[127]

Having struggled to gain traction, the Green Deal was terminated in July 2015, having been taken out for energy efficiency measures in what the Government said were around 50,000 homes (although NAO could only find evidence for 14,000).

ECO was scaled back significantly, as the average cost per tonne of CO_2e saved was nearly 3x comparable previous schemes (£94 per tonne compared with £34 per tonne) – what appears to have happened is a form of “carbon inflation” as energy suppliers chased a finite amount of available labour and materials.

Among the key findings from the National Audit Office (“NAO”) report were that the Department failed to set clear success criteria for the Green Deal, that the schemes saved substantially less CO_2e than previous schemes and there were information gaps in terms of cost and how many people were saved out of fuel poverty.

Most significantly, realised demand for Green Deal finance turned out to be only a tiny fraction of the Government’s expectations. The NAO described what it found as follows:

“Many stakeholders warned the Department that it would be difficult to persuade people to pay for measures themselves. Its own consumer survey did not provide a strong case for schemes like the Green Deal creating demand. The Department understood these concerns, but implemented the scheme anyway, as it believed its market-led model held little financial risk for the government. Even where there was consumer interest, people were initially put off by the complexity of the process of arranging a loan. Only 50% of loan applications ultimately resulted in one being arranged. The Department simplified the process in late 2013 and uptake of Green Deal finance subsequently increased.[128]*”*

The Green Deal is an example of a supposedly rational policy initiative that failed to account for legitimate motivations and concerns of consumers. This was exacerbated (although the NAO report doesn’t explicitly say this) by a refusal on the part of government to actively engage until it was too late to promote the scheme. In this case, the design philosophy seems very much to have been to let the “market” do the running (which was also the case with ECO as responsibility was offloaded to suppliers) and it was only relatively late in the day that the UK Government engaged in some ineffectual marketing of the Green Deal scheme.

What are the main lessons to be learned from the Green Deal? One would hope that future green policy designers would not choose to wilfully ignore stakeholder feedback in this way, but there were also some missed opportunities, most notably to localise and communitise the buy-in and governance structures for delivery. With the best will in the world (and there was a lot of goodwill), large national corporates were not the appropriate face for the programme and the specialist intermediaries that sprang up to service the demand who were able to establish closer connections did not have deep enough roots or resources to carry the day.

“Community” and “local” are key to many parts of the decarbonisation agenda. SG has conceptually embraced and supported these ideas but it needs to be much bolder in scaling up this approach and providing the resources to allow local and community groups to develop. The relevant sectors are far too corporatized and institutionalised for this to happen without significant intervention and support.

11. IT, digital, communications

Question element: *the relative impact of each sector within the Scottish context, i.e. the relative scale of both the particular infrastructure sector and its carbon emissions*

11.1 Mitigation

Digital infrastructure as a source of carbon emissions is an area where literature is lacking. What little we found seems principally concerned with resilience and interdependence with other systems.

That said, Think Tank called the Shift Project produced a report in March 2019 entitled "Towards Digital Sobriety"[129]. The report notes that digital technologies are not only seen as critical for economic and social development, they are also thought of as a key tool for reducing energy consumption to the point that they now seem critical for tackling climate change.

At the same time, however, there is the potential for damaging environmental trends caused by the overuse of digital technologies. This is not sustainable, argues the report, either in terms of energy or raw materials. Some key figures include:

- *An increased share of greenhouse gas emissions by 50% since 2013 for digital technologies, to 3.7%*
- *The digital industry's energy intensity is increasing by 4% per annum, compared with global GDP as a whole, which is declining by 1.8% per annum*
- *CO_2 emissions have increased by 450 $MtCO_2e$ in the digital sector since 2013, compared with an overall decline globally of 250 $MtCO_2e$ over the same period.*
- *By 2020, emissions attributable to digital technology are projected to be 4% of total emissions (by comparison, light vehicles accounted for around 8% and civil aviation 2% in 2018).*

Digital consumption is highly polarised and caused by high income countries. The Shift Project calls for "digital sobriety", which involves a more conscious digital procurement and management strategy, for example:

- *Reducing the number of devices*
- *Extending the lifetime of use*
- *Reduce the volume of traffic by email in favour of shared servers (e.g. Dropbox)*

The diagram below, for example, shows the change in carbon footprint of Apple technologies.

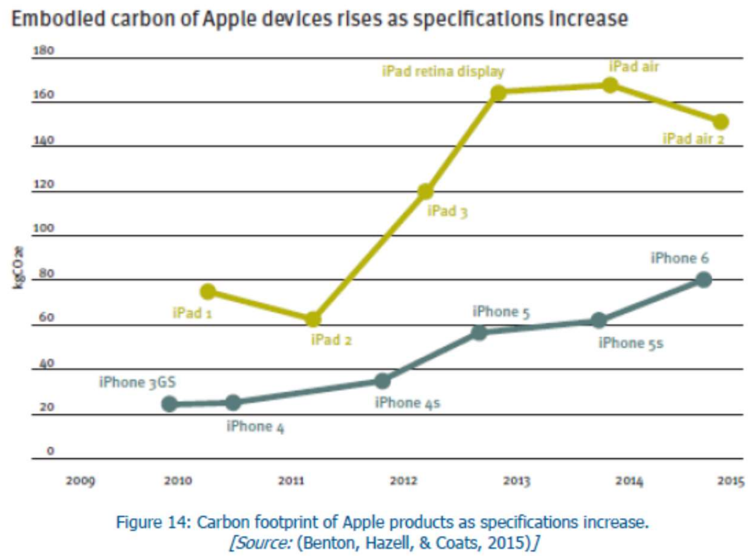


Fig 29: increased embodied carbon in IT devices

From an infrastructure perspective, the question is whether positive decisions can be made to encourage more energy and resource efficient usage of digital technology, when much of the footprint is in the devices themselves. The Meygen tidal project is a good example of joining digital technology and renewable energy, for example see Section 19.3.

11.2 Adaptation

The NIC report "Infrastructure and Digital Systems Resilience" (November 2017)[130] specifically looks at interdependencies between digitally-connected infrastructure systems, the tendency for normal accidents to affect these systems and how to prepare for, respond to, and recover from such events.

The case study of "cascading infrastructure failures" in Lancaster as a result of Storm Desmond illustrates the complexity of systems relationships and the role that digital systems play within this.

Interconnected systems – the domino effect
In December 2015, Storm Desmond brought unprecedented flooding to parts of central Lancaster. At 10.45pm on Saturday, 5 December, electricity supplies to 61,000 properties in the city were cut and power cuts continued to cause disruption from the 5th to the 9th December. This resulted from the flooding of just one substation. The failure of electricity supply caused widespread and unanticipated consequences: • *Mobile phone coverage was lost over most of the city, and while landline phone services were available, many households had replaced their handsets with cordless phones that rely on electricity to operate.*

- *Local digital radio services were lost so only FM services were on air. However, many people did not have battery or wind up radios capable of receiving FM signals.*
- *The FM services that were on air provided limited useful reporting so the local community were not kept aware of the wider impacts and operational response that was taking place.*
- *High rise buildings where booster pumps are used to get water to higher floors lost water supply. Buildings that use 'grey water' (second-hand water from showers or washing) to flush toilets found that without electricity they were unable to flush toilets.*
- *The rail station could not be opened after dusk as there was no lighting on the platforms.*
- *Retail and banking were severely affected by the floods and the power cut. Card payment terminals were not working so any shops that were open relied on cash only.*
- *Some ATMs that used a conventional phone line to contact the bank and had back up electricity (e.g. through a diesel generator) were operational.*

The consequences listed above could have been predicted; that they were not expected shows how planning and response does not always consider full 'system-of-systems' failures[131].

The challenge that the NIC report presents is expressed as follows:

The resilience of a digitally-connected infrastructure system is inherently linked to pre-existing vulnerabilities within the underlying infrastructure system and vulnerabilities within digital technologies as well as new vulnerabilities from the creation of new interdependencies between the digital technology and infrastructure system that comprise the digitally connected infrastructure system.

Therefore overall, while digital technologies will enhance specific aspects of resilience, the move towards digitally-connected infrastructure systems will have little positive impact on the systemic resilience or inherent vulnerabilities in underlying infrastructure systems, as well as introducing new vulnerabilities and increasing interactive complexity and tighten system coupling. In other words, systemic resilience will continue to decline.

Clearly if a consequence of decarbonisation is increased electrification of our infrastructure (which looks highly likely), this is going to be a significant component in the weakening resilience of our infrastructure systems, presenting us with something of an infrastructure headache.

Some of the recommendations from the report are both reasonable and self-evident: work together, plan ahead, learn from resilient organisations, etc.

The recommendations on data are particularly noteworthy. Data, says the NIC report, should be valued explicitly[132] and the benefits of collecting, storing and using data should be considered at project planning stages. Organisational tools are needed to purposefully convert data into meaningful information that enables more effective decision making as well as ensuring that data does not stay in silos and data is actively transferred between, within and beyond infrastructure systems in a safe way, in order to fully realise its decision-making potential. In other words, infrastructure investment strategies would do well to invest in data and data storage as part of their brief.

CCC, in their report "The infrastructure needs of a low-carbon economy prepared for climate change"[133] (2017), note that climate-related risks have the potential to disrupt the ICT sector and push up operational costs for users. ICT networks typically exhibit considerable resilience due to diversity of systems and their network topology and redundancy but at the edges of networks where diversity is at its least – typically near low population regions, or remote locations such as islands, loss of ICT can cause the greatest problems.

CCC say it is difficult to assess the vulnerability of ICT services to extreme weather events, as for security reasons there is limited information on the location and connectivity of ICT infrastructure in the UK. In the 2017 Progress Report, CCC were unable to gather evidence on resilience measures and noted that this was a concern[134].

12. Water supply and flood prevention

Question element: the relative impact of each sector within the Scottish context, i.e. the relative scale of both the particular infrastructure sector and its carbon emissions

12.1 Water

CCC (talking about England & Wales) say that the investment provided since privatisation has delivered some improvements to existing water supply assets, but little new supply infrastructure has been built. Leakage reductions have largely stalled in the last decade and daily consumption per person has only reduced gradually from 150 litres in 2000 to 141 litres today. This compares with about 115 litres per person per day in Belgium and Denmark, which are amongst the best in Europe[135]. Around 2,900Ml/day (20%) of water put into the public supply is lost through leakage in the UK[136].

According to SG[56], the average daily consumption of water in Scotland is around 150 litres a day. Over the last 13 years, Scottish Water says it has reduced leakage from 1104ML/d to 480Ml/d[57], around 16% of the total UK figure quoted by CCC. On both measures, it would appear that Scottish Water is performing worse than its English counterparts.

The CCRA found that an estimated 1.8 million people are living in areas of the UK at significant (1% annual chance) risk of river, surface water or coastal flooding. The population living in such areas is projected to rise to 2.5 million by the 2080s under a 2C scenario and 3.5 million under a 4°C scenario. The Environment Agency's Long-Term Investment Scenarios show that it will not be cost effective to build community flood alleviation schemes to protect all of these properties. Making properties more resilient and resistant to flooding, says CCC, can be a cost-effective way to manage flood risk when community-scale defences are not affordable, and can also help to reduce residual risk if defences fail[137].

Unlike Scottish Water (see Section 14.9), decarbonisation does not appear to be an explicit feature of regulatory policy in England's water sector at present. Nor does this show in the water resources management plans of the individual companies. The concerns seem to be more around efficiency, resource scarcity and environmental degradation.

12.2 Flood Prevention

CCC say that the location and design of new buildings and infrastructure could either increase vulnerabilities or help to tackle them. Extreme events, such as the winter storms of 2013/14 and 2015/16, are associated with disruption to or even the complete loss of essential services such as water and energy supplies, and transportation and communication networks. The loss of infrastructure services can have significant impacts on people's health and wellbeing, and local economic activity. Current variability in weather already impacts the performance of the UK's infrastructure and climate change is expected to lead to an increase in the frequency and severity of severe weather including flooding, higher temperatures and possibly drought[138].

Coastal infrastructures, particularly ports, are at risk from rising sea levels and a consequential increase in the height of onshore waves and storm surges. High onshore waves will also

[56] https://www2.gov.scot/resource/buildingstandards/2016Domestic/chunks/ch04s28.html

[57] https://www.scottishwater.co.uk/en/Your-Home/Your-Water/Leakage

accelerate rates of coastal erosion and put increasing lengths of the UK rail network at risk, as well as sea walls that protect coastal settlements[139].

The Property Flood Resilience ("PLR") Plan was produced for Defra in September 2016[140]. It identified that flooding is the most common and widespread natural source of damage to properties in the UK.

The report argues that there will always be some properties that are particularly difficult or uneconomic to protect with large defences and that for these properties PLR has a valuable role to play in managing the flood risk. The typical range of measures have a cost- benefit ratio in excess of £5 for every £1 invested in terms of reduced damages. However, there is still relatively low uptake in England, with people at high flood risk still not routinely installing resilience measures in their homes and businesses.

Key recommendations for improving the position include:

- *Further exploration of whether Building Regulations can be better used.*
- *A programme to provide the evidence base over time to understand how householders and insurers can be supported and potentially incentivised in the future to manage the risk of flooding and reduce the cost of claims.*
- *Independent standards with proper certification processes for flood products.*
- *An independently run on-line information portal and data warehouse to inform householders and small businesses about what to do to make their properties resilient to flooding*
- *A strong partnership between industry participants to encourage and enable the take-up of flood resilience measures and develop more flood resilient behaviour by householders and small businesses.*

The current estimate of properties at risk from flooding in Scotland, from the first National Flood Risk Assessment published in 2011, is 108,000. This figure will increase with climate change and as we gain a better understanding of surface water flooding impacts. Despite best efforts, flood protection schemes are not always able to protect all at risk properties from flooding. Currently the Flood Re scheme provides affordable insurance for those at the greatest flood risk in the UK but this scheme will end in 2039.

The report argues that it is crucial that action is taken now to make more properties resilient against flooding and to reduce the physical, financial and emotional impact of flooding on properties and their owners.

The aim is to set up a Property Flood Resilience Delivery Group (PFRDG) will be set up in Scotland in 2019.

The failure of infrastructure is also a useful indicator of its economic value. For example, in 2013, when the Dawlish sea wall in south-west England was destroyed during storms, the repairs to the wall itself cost £35m, but the loss of a critical transport connection to the south west of England was estimated to cost the UK economy £1.2bn[141].

Should we legislate for resilience?
Resilience planning for infrastructure is increasingly important. The question is being posed as to whether this should become a statutory duty. Resilience Shift explored the effect of legislating for resilience by examining the effects of the Emergency Management Amendment (Critical Infrastructure Resilience) Act 2014, implemented in Victoria, Australia[142]. The key insights from the work related to the implications of legislating aspects of critical infrastructure resilience (i.e. coercive rather than voluntary policy instruments) and understanding what works well in practice. Some key aspects of the Act itself include participation in a resilience improvement cycle; annual submission of a Statement of Assurance that identifies emergency risks and specifies risk mitigation actions; a requirement to develop, conduct and evaluate annual simulated emergency exercises; establishment of Sector Resilience Networks to promote collaboration and knowledge sharing between the Victorian Government and infrastructure owner/operators. The researchers concluded that legislation had brought better resilience practice, including planning, reporting, and sharing knowledge and best practice with other organisations. Compliance with the Act also had an impact on the structure of organisations through either creating new roles or modifying existing roles. On the other hand, compliance with the legislation could take priority over other activities, without providing flexibility for organisations to prioritise themselves, based on their individual needs.

In Scotland, and in support of SEPA's wider obligations, SEPA and Scottish Water signed a Sustainable Growth Agreement in June 2018. This commits the parties to develop, trial and then seek to deliver (with partners) innovative ways of:

- *Managing rainwater and waste-water drainage to help protect the social, economic and environmental wellbeing of Scotland's towns and cities*
- *Helping generate wealth, not waste by maximising the recovery of resources from Scotland's sewage and cycling them back into a circular economy.*

Making choices about how to invest in protecting the quality of Scotland's water environment that minimise energy and resource use and maximise social and economic benefit now and for the future. Sustainable Growth Agreements are voluntary, non-legally binding, formal agreements[143].

13. Approaches to Infrastructure Investment

*Question element: "A high-level critique of **types of infrastructure investment[s] approaches** that operate as a **barrier** to the transition to a net zero carbon economy, and those that **accelerate** the transition"*

*"The fact is that even our artificial infrastructure operates on fuzzy economics. Nearly all large-scale projects – bridges, dams, tunnels, railroads, airports, power plants, wind farms, transmission lines – come in way over budget and behind schedule, and they don't pay out as expected…The norm is: We make grand plans, we build stuff, we're mostly glad we did, and the money gets sorted out awkwardly over decades" **Stewart Brand, Whole Earth Discipline***

Headlines
SNIB represents a significant opportunity to support the transition to a zero-carbon economy in Scotland. The Social Stock Exchange presents a complementary private sector financing mechanism. The UK Government is attempting to reinvigorate finance for low carbon through the Green Finance Taskforce and has proposed a series of funding programmes for heat, cleantech and charging infrastructure, but the level of cleantech investment is actually declining in the UK. This compares with rapid growth in the digital technology sector. Sovereign Green Bonds are becoming an established financing mechanism elsewhere in the world. Project pipelines are key - two examples are given of where successful project pipelines have been created.

13.1 Introduction

Faced with the climate challenge and the imperative to decarbonise, a key question is whether the financial and measurement tools that policymakers and investors have at their disposal are adequate and fit for purpose. The following two chapters examine some of the available information in this area. Where it is thought to be helpful, commentary is provided against functional sector headings; otherwise the analysis is undertaken for infrastructure as an overarching sector.

The level of awareness of the need to decarbonise and the role of infrastructure and finance in that process is unquestionable; the big question is on delivery. Similarly, there is a wide range of general and bespoke tools for measurement and evaluation, but what appears to be less in evidence is substantial quantities of meaningful supporting data and analysis.

This will in part be due to the relatively recent momentum around decarbonisation, but there will be a number of other factors at play that are well known: fragmented industry structures, silo-ed policy-making, competing commercial interests, etc.

The most common forms of private finance in NZCI are equity and project finance. These are covered in the chapter below, along with significant developments in the finance sector, both at home and abroad.

13.2 The Green Investment Challenge

UK Government set up a Green Finance Taskforce towards the end of 2017 to help deliver the investment needed to meet the UK's Industrial Strategy and Clean Growth Strategy. The aspiration was to "further consolidate the UK's leadership in financing international clean investment"[144] and maximise business opportunities.

The Taskforce was asked to present Government with a report including up to ten "ambitious and practical policy recommendations" on how UK Government could best support the finance sector in achieving these objectives[145].

The Green Finance Taskforce ("GTF") reported in March 2018[146] . It described a difficult climate for green finance in the UK. While investment in UK clean energy infrastructure has grown in recent years, it said, UK investors consistently cited a lack of UK-based green infrastructure investment opportunities as a major barrier to deploying more capital to these assets. Increasingly, it says, other countries are taking a lead – both in shaping the global policy agenda and on developing and marketing new green finance products[147]. This is apparent from the research undertaken for this report, some of which is cited elsewhere.

According to GTF, investors and project developers cited a litany of challenges for UK green investment: insufficient policy detail and a lack of clear economic incentives for infrastructure operators to develop a pipeline of clean assets for private investment; fears of policy uncertainty affecting returns due to the effect of 2015 solar feed-in tariff adjustments[58]; scrappage of the zero carbon homes targets; insufficiently attractive risk-return profiles on some next generation clean infrastructure investments; the dual challenge of high transaction costs and complexity of technology or infrastructure; and the lack of clarity on what assets and activities should be considered green.

13.3 Equity

If the value of green infrastructure investment has been sustained in recent years in the UK, it is likely that this is due to the forward momentum created by large programmes such as offshore wind.

Where these programmes are financed off-balance sheet (see 13.4 below), care has been taken to ensure that the project risks are carefully managed so that the risk of loss to the financiers is minimised. This enables them to provide large amounts of capital at a relatively low cost (for established renewables technologies, for example, this is likely to be a single-digit project IRR).

"Cleantech" investment, by contrast, is financed by risk-taking equity (venture capital or similar). By "cleantech" we mean projects or businesses developing low or zero carbon technologies where the principal risk or opportunity is the failure or success of the technology itself – in other words, NZCI's leading edge. A venture capitalist might typically expect there to be a split in his portfolio of roughly 1/3 successes, 1/3 failures and 1/3 where the investment is recovered but no return is made[59], so in order to make what the VC deems to be an acceptable return, the successful companies have to be extremely successful, perhaps giving

[58] See, for example, https://www.theguardian.com/environment/2016/apr/08/solar-installation-in-british-homes-falls-by-three-quarters-after-subsidy-cuts
[59] See, for instance, https://www.nexitventures.com/blog/vcs-seek-10x-returns/

the VC a 10x return on investment. It follows that, for the investee company, this VC money is very expensive.

While general technology investment is booming (see 13.5 below), cleantech in the UK appears to have struggled in recent years. This chart taken from the GFT report shows cleantech clearly heading in the wrong direction in the UK:

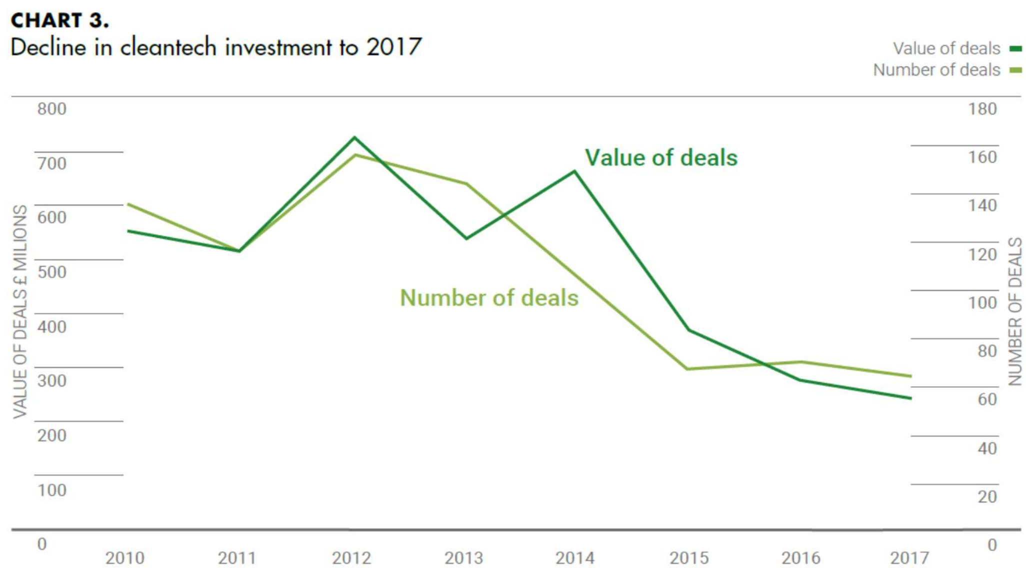


Fig 30: decline in cleantech investment in the UK since 2010

13.4 Project and Asset Finance

There are essentially three ways of financing large-scale infrastructure:

1. *Directly by the public sector (e.g. most roads and bridges)*
2. *Directly by corporate entities (e.g. fibre optic cabling, some renewable energy projects)*
3. *Indirectly by financial markets (e.g. PPPs, some renewable energy projects)*

The first two can be described as “on balance sheet” finance and are constrained by the entity’s access either to cash resources or to lines of credit. On balance sheet finance has a number of attractions – if the credit rating of the sponsoring entity is good, then the cost of finance is relatively low, the procedures for putting the finance in place are relatively straightforward and the sponsoring entity retains full control of the underlying project.

However, the volume of finance needed for infrastructure is such that there is not enough on balance sheet finance to meet the requirement. This creates the need for financial instruments that rely on the project itself for their return or repayment (category 3 above). This is generally known as project or asset finance, the distinction between the two being that project finance tends to refer to a single project where finance is raised to fund the construction of the project, while asset finance usually relates to a portfolio of projects which are operational – which may well previously have been project-financed.

Project finance dates back to the 19th century – the first recorded use was for the US railroads. It was used to develop oil & gas fields in the 1970s, then for transport projects such as bridges and tunnels from the 1980s onwards and then for social infrastructure (schools, hospitals, residual waste projects, housing, street lighting, etc.) as PPP structures were developed.

It is generally agreed that project finance has two primary characteristics:

- *the use of a special purpose vehicle (SPV), which is legally and commercially self-contained and serves only to deliver the project; and*
- *the concept of "limited recourse", whereby the SPV is financed with limited guarantees from the project sponsors, such that lenders to the SPV depend mainly on future project cash flows don't (in theory, at least) have recourse to the sponsors' other businesses.*[148]

A project finance SPV is also likely to be highly "leveraged" or "geared", which means that a very significant proportion of its capital comes from bank debt or its equivalent, which is highly risk-averse, so it follows that the cashflows in the SPV need to be predictable and that there needs to be a slice of the SPV's financial capital (equity) that is there to absorb most, if not all of the expected risk before the bank is exposed. For infrastructure sectors where revenue is unpredictable (such as onshore wind), only the amount of debt which is adequately covered under a conservative forecast is allowed into the structure.

Risk management is key to understanding the world of project finance. Large amounts of capital are at stake, most of which needs to be preserved if the principal providers of capital (the banks) are to avoid a loss.

As infrastructure sectors get larger and more liquid, the level of sophistication in financing structures tends to rise, but this is largely about sub-dividing the perceived "risk envelope" more finely – this might be seen in the form of mezzanine finance, for example, which takes more risk than bank debt, but not as much as sponsor equity, which is at the bottom of the heap, but the overall risk profile of what is being privately financed largely stays the same. Mezzanine finance was a commonly used structure for smaller independent renewable energy developers who had successfully achieved planning consent but didn't have the financial resources to build the project.

Perceptions of risk also change. With the introduction of new asset classes, new risks are progressively dealt with, initially by increasing the free cash in the structure (which increases the overall financing cost) or by looking for external support (such manufacturers' guarantees for wind turbines). From time to time, additional products are introduced that enable the structure to take more risk (construction delay insurance, for example).

Project finance was a standard model of finance for the Green Investment Bank (see 13.2 above) because, for the first time in two decades, conventional bank finance channels had seized up and the Green Investment Bank was able to use the Government's balance sheet to fund SPVs in the absence of private sector liquidity, which kept the project finance market moving but arguably detracted from the opportunity to innovate and take more risk to support emerging technologies.

Project finance works best for relatively large standalone projects with low technology risk, as the set-up costs are high and the due diligence process is time-consuming. It is a key part of the infrastructure finance toolkit and is likely to remain so, because of the sheer volume of finance needed for infrastructure globally. It can be relatively rigid because the quantum of finance provided is predicated on a certain set of assumptions and "risk investors" (whether project sponsors or third parties) will find that their dividends are withheld or locked up if performance falls below specified contracted levels (which are set to provide a cushion above the point at which bank finance is at risk).

Through PFI / PPP, investment companies emerged, specialising in providing equity for SPV projects – in effect, another form of project finance but just taking a more risk and a higher return. This concept then moved into financing renewables. Most of these investment companies are largely out of public view and many are registered offshore, although one notably – John Laing Investments (which was Guernsey-registered), existed as a quoted company up to August 2018, when it was acquired by two other infrastructure investment companies, Dalmore and Equitix[60].

The significance of project finance in the renewable energy sector (as opposed to “corporate” or on balance-sheet finance) is illustrated by the table below[149]:

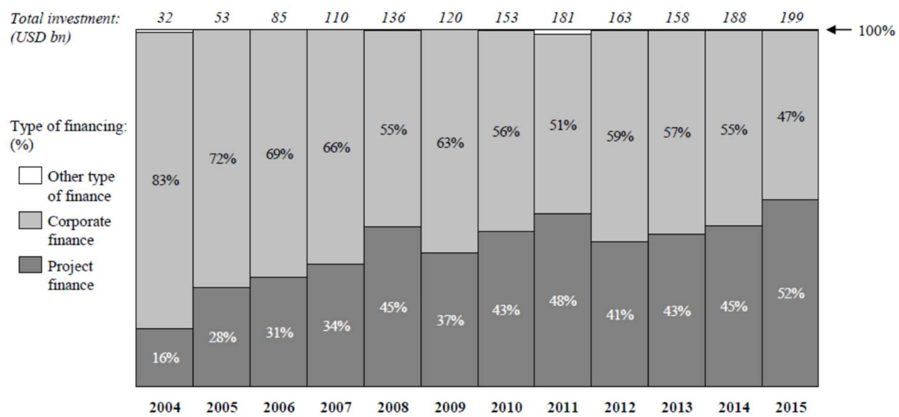


Figure 1: Global asset financing of new investment in renewable energy
(based on BNEF data provided by (OECD, 2016))

Fig 31 : split between corporate and project finance in renewables

Asset finance works best for bundles of assets (usually smaller in size) that conform to sufficiently standardised type to enable a portfolio approach to risk to be taken. Funders acquire rather than lend to the projects, which are likely to have been “de-risked” (by being built), although established portfolios may well have an element of construction risk, but not so much that it upsets the overall risk profile of the portfolio. These portfolios of assets are generally marketed to investors as providing a steady return on investment.

Octopus – an Asset Management Company in Low Carbon Infrastructure
Since entering the renewables market in 2010, Octopus Renewables[61] has grown to become the largest investor/owner of solar power in Europe, as well as growing to become a leading investor in onshore wind. It currently manages a global portfolio of renewable energy assets valued at more than £3 billion. The team works closely with institutional investors to create bespoke portfolios of large-scale renewable energy assets. Recent international expansion has also seen significant new renewable investments in Australia, Finland, France and Italy.

[60] https://en.wikipedia.org/wiki/John_Laing_Infrastructure_Fund
[61] https://octopusgroup.com/insights/octopus-renewables-clean-energy-future/

These investment companies tend to be intermediaries, enabling holders of funds who generally (but not always) avoid direct investment into projects and assets to meet their appetite for low or zero-carbon assets. One such infrastructure investor specialising in low carbon assets, Zouk, is the UK Government's funding partner for the CIIF electric vehicle infrastructure charging fund, a £400m investment fund with the first £70m part provided by Abu Dhabi Future Energy Company ('Masdar')[62].

Zouk is a fund that targets a diverse range of sectors across Europe, including emerging utility-scale battery storage projects as well as wind, solar, waste-to-energy, electric vehicles and geothermal.

Left to itself, it seems likely that private finance, both equity and debt, will gravitate towards opportunities with lower risk and higher potential returns – and there is no evidence that this focus will align with deliver the strategic focus that is required for sustainable long-term investment in NZCI.

The traditional private finance "paradigm" is starting to be challenged, however, with the emergence of "impact investing". Impact investing is defined by the Global Impact Investing Network[63] as having the following characteristics:

1. Intentionally contribute to positive social and environmental impact
2. Use evidence and impact data in investment design
3. Manage impact performance
4. Contribute to the growth of impact investing

The GIIN estimates the current size of the global impact investing market to be $502 billion, which sounds large, but impact investing is still considered to be a relatively small fraction of the total investment market, albeit one with an increasingly high profile.

Impact investing covers a wide spectrum of risk and return, as illustrated by this GIIN diagram below:

Fig 32 – impact investment spectrum[64]

It will be interesting to see what forms of financing for new NZCI assets emerge. Clearly an early challenge for SNIB will be to construct a funding approach that drives decarbonisation and innovation without either duplicating the finance that the private sector is willing to offer or

[62] https://www.zouk.com/news/38-infrastructure/212-over-500m-new-investment-in-green-technologies-for-a-cleaner-and-healthier-future
[63] https://thegiin.org/assets/Core%20Characteristics_webfile.pdf
[64] https://thegiin.org/impact-investing/need-to-know/

becoming the lender of last resort for projects and programmes that are fundamentally unviable.

13.5 Competing with tech

At the UK level, recent years have been a turbulent time for green infrastructure policy and it is possible that the investment community is experiencing a degree of “green fatigue”. It is some time since the UK has been seen as the “go to” location for green investment. Granted, it still ranks 8th in the EY Country Attractiveness Index for renewables[150], but it ranks not only behind the countries that might be expected to have a scale advantage (China, US, India), but countries which might be expected to be more comparable, such as France, Germany and Japan.

It has also been long recognised that the global scale of the low carbon infrastructure opportunity is enormous, so investors have plenty of opportunities to choose from. It appears to be the case that green technology is developing rapidly, which is exciting globally, but economically only good news for the UK if some of the technological development takes place here; this has been consistently recognised in Scottish Government policy. On the other hand, while Scotland is able to some extent to pursue its own policies and initiatives, non-UK investors will often tend to consider the attractiveness of the UK as a whole, rather than differentiate between regions.

In the UK, it is not just a case of other countries potentially being more attractive for clean/green tech investment. This sector needs to be viewed in the context of the wider tech space, which appears to be booming. Despite climate change being the world’s most pressing problem, it seems strange that the growth in cleantech investment is not at least keeping pace with the wider digital technology sector. As this report shows in a number of areas (see, for instance, Chapter 19), the next stage of progression towards NZCI is critically dependent on digital technology.

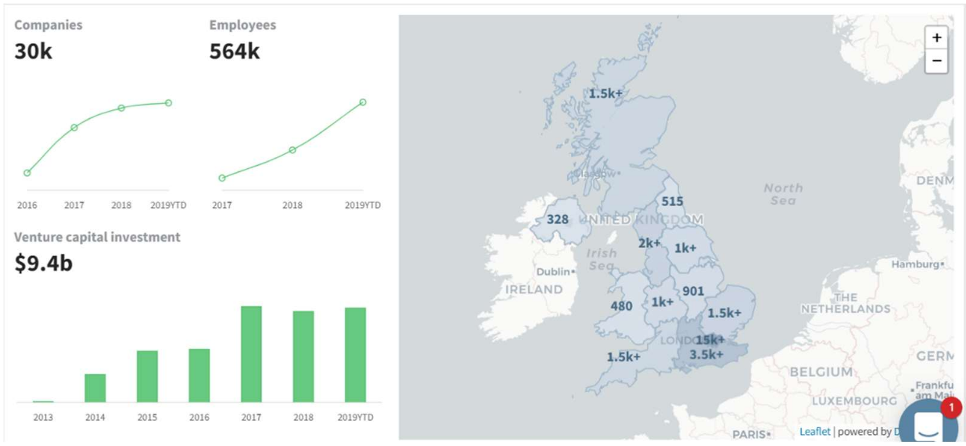
The pace of general technological development in digital and IT applications (AI, blockchain, super conductivity, sharing economy platforms, etc) is extraordinary and the investment opportunities are enormous. At the same time, we see that the energy intensity of digitisation is increasing (see Chapter 11), so the technology sector is at risk of contributing more to the problem than to the solution.

To get a sense of scale, investment in digital tech in the UK (Scotland in brackets) rose 433% (+243%) from $2.1bn ($127m) equivalent in 2013 to $9.1bn ($309m) in 2018 and is currently sitting at $9.4bn ($256m) in 2019[65].

This is illustrated in the two charts below, taken from the TechNation database:

[65] https://datacommons.technation.io/dashboard

UK:



Scotland:

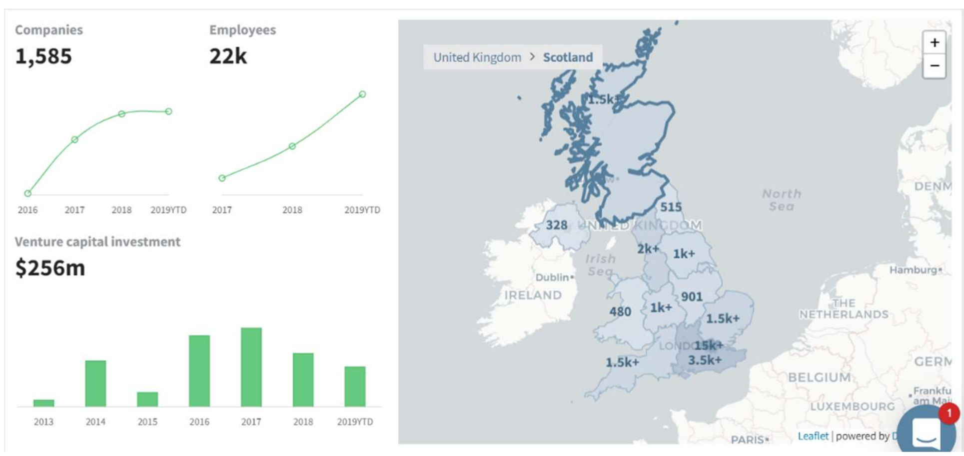


Fig 33: growth in tech investment in Scotland and the UK

At the UK level, £300m of cleantech deals in 2017 compares with around £7bn[66] of tech investment in the same year (= around 4%). How it is that the cleantech investment trend is down when tech investment has increased so rapidly is a question that a zero-carbon infrastructure programme needs to tackle, because new digital technology development is critical to the next stages of decarbonisation.

[66] US$9.5bn @ £0.73992 at 31/12/17 https://www.exchange-rates.org/Rate/USD/GBP/12-31-2017

13.6 Finance - Scotland

Scottish Government funding programmes are dealt with in Chapter 15 of this report. Below are the principal Scottish investment initiatives for decarbonisation in recent years.

The Green Investment Bank

The Green Investment Bank ("GIB"), established in 2012 and headquartered in Edinburgh, performed something of a pioneering role in the financing of low carbon assets in range of sectors in the aftershocks of the Global Financial Crisis, including renewables, energy from waste and energy efficiency. Its purpose was to try and "crowd in" private finance by showing leadership without taking risks that were incapable of being financed by the private sector.

It was operational for 3.5 years before the sale process was launched which resulted in it being sold to Macquarie as the Green Investment Group in August 2017. It remains to be seen how innovative the institution will be in private ownership, but during its pre-sale years, GIB developed a rigorous process for assessing the carbon performance of its investments, not just in terms of future projections, but also for operational phase assessment. The clear focus was on mitigation, with the "double bottom line" being the key term.

As part of this, the Green Investment Handbook was developed, of which a summary is now publicly available. Described a "proprietary tool", it was developed by GIG to provide a consistent and robust means of assessing, monitoring and reporting the green performance of investments. The online guide gives an overview of the practical tools and best practice methodologies to support the large-scale mobilisation of climate finance required from the mainstream investment community to achieve both financial and green returns.

One useful contribution that GIB / GIG made was to codify green investment in terms of sound banking principles. The brief online guide gives a flavour of this, through the assessment and monitoring steps that it describes.

The National Audit Office report on the Green Investment Bank[151] does not conclude whether the GIB as an intervention represented value for money overall – only time will tell, it says. NAO notes simply that the sale was within the valuation range, albeit at the lower end, noting drily that the Government needs to be clear on what it means by an "enduring institution", having sold it off within 3.5 years of commencement of operation. What the NAO does say is that the Department (for Business, Innovation and Skills) had no way of judging whether GIB was achieving its intended green impact.

NAO doesn't comment on the loss of green investment knowhow from the public sector in exchange for a "premium" of £186m, which seems small change, compared with the scale of the green investment challenge.

Low Carbon Infrastructure Taskforce

This appears to have been a Scottish Government-led initiative started in 2015 that no longer functions. The idea appeared to have been to create a taskforce to enable delivery of Scotland's targets under the Climate Act in the infrastructure sector and meet its objectives under its Economic Strategy and Infrastructure Investment Plan by creating "a strong pipeline of large-scale, shovel-ready green infrastructure projects".

Among the projects mentioned were a major district heating network in Glasgow, dualling and electrifying the Perth-Inverness railway line and insulating homes across Scotland, to ensure that the capital budget is investing for a green future. The Taskforce brought together “key figures from across the infrastructure lifecycle in Scotland”, from the public and private sectors, construction and finance industries, trade unions and academia[152].

Work commissioned by the Low Carbon Infrastructure Task Force found that there were significant social and economic benefits to investing in low carbon infrastructure and that low-carbon infrastructure investment decisions need to be taken now to avoid locking Scotland into an unsustainable and expensive high-carbon pathway.

Independent research found that, currently, only 52% of Scotland’s current infrastructure investment pipeline could be described as ‘Low Carbon’.

The Scottish Government’s next Spending Review, it argued, needed to make a significant shift in Scotland’s capital spending, away from high-carbon projects and towards low-carbon projects. The Scottish Budget for 2016-17 should begin this transition.

The Scotland’s Way Ahead Project, led by the Low Carbon Infrastructure Task Force, recently published a longlist of “Ten Projects for a Low Carbon Future” for Scotland. At the same time, the Scottish Government recently committed to making the improvement of building energy efficiency a National Infrastructure Priority.

There is no further public information beyond a launch presentation and an initial internal SG report.

SNIB

The Scottish National Investment Bank[67] has been in development for around 2 years. The intention is that it will be a public body but will operate commercially and be operationally and administratively independent from government. This provides the Bank with the scope and freedom to decide what products it offers and how it delivers the missions set. The Bank’s Board will set out how they intend to meet the missions through an Investment Strategy. This represents a significant opportunity to influence and support the transition to a zero-carbon economy in Scotland.

In March 2019 a “mission-orientated framework” for the Scottish National Investment Bank was presented by the Institute for Innovation and Public Purpose from UCL, which clearly links the mission of the Bank to the National Performance Framework and threads the concept of low carbon through the narrative.

The five key criteria for the framework represent a fresh approach to defining purpose. If these are followed through when the Bank is actually established, it will be well positioned to support the transition. The last two are particularly important when thinking about the nature of infrastructure investment needed:

1. ***A clear direction**: missions should be broad enough to engage the public and attract cross-sectoral interest; and remain focused enough to involve industry and achieve measurable success. Rather than ‘picking’ sectors or technologies, missions pick the problem and encourage solutions by stimulating multiple forms of cross-actor activity to work to address those problem.*

[67] https://www.gov.scot/policies/economic-growth/scottish-national-investment-bank

2. *Targeted, measurable and time-bound [activities].*
3. ***Ambitious but realistic**: setting missions unrealistically high will result in a lack of buy-in, while setting the objective too low will not incentivise activity.*
4. ***Cross-disciplinary, cross-sectoral**: missions that address clear challenges that stimulate the private sector to invest where it would not have otherwise invested ("additionality") and spark activity across different industrial sectors and different types of actors.*
5. ***Multiple bottom-up solutions**: missions should not be achievable by a single development path, or by a single technology.*

Social Stock Exchange

Project Heather[68] is awaiting regulatory approval to launch and is Scotland's first new stock exchange in nearly 50 years. It will launch during 2019 to list securities - tradeable assets, such as bonds, funds and stocks and shares - with measurable environmental or social outcomes, requiring listed companies to report the impact they have along with their financial results. At present limited information is available about this initiative (it is privately funded, although has benefited from around £750,000 of Scottish Government support according to press reports), but it could become a useful conduit for private sector low carbon infrastructure investment in due course.

13.7 UK Plans

The Green Finance Taskforce report has a significant focus on managing the risks of climate change, making recommendations that included a centre for "Climate Analytics" and implementation of the recommendations of the Taskforce on Climate-related Disclosures and a proposal to work on the development of resilience products and services. The full list of recommendations reads like a shopping list for prospective green investors:

(i) *Relaunch UK green finance activities through a new "unified brand";*

(ii) *Improve climate risk management with advanced data and analytics;*

(iii) *Implement the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD);*

(iv) *Drive demand and supply for green lending products;*

(v) *Boost investment into innovative clean technologies;*

(vi) *Clarify investor roles and responsibilities;*

(vii) *Issue a Sovereign Green Bond;*

(viii) *Build a green and resilient infrastructure pipeline;*

(ix) *Foster inclusive prosperity by supporting local actors;*

(x) *Integrate resilience into the green finance agenda.*

[68] https://projectheather.scot/

Resilience, the report concludes, is not a “nice to have” benefit.

The BEIS response (“Green Finance Strategy Transforming Finance for a Greener Future”[153].) (July 2019) is an even longer shopping list - of 17 items: The stated objectives are threefold: “greening finance”, “financing green” and “capturing the opportunity”. The main “ambitious” actions the Government is planning to take are set out below. A number of them express an intent to support or influence rather than to lead or intervene.

Green Finance Strategy Transforming Finance for a Greener Future (BEIS proposals)
Greening finance: *(i) “Expectation” for all listed companies and large asset owners to disclose in line with the TCFD recommendations by 2022;* *(ii) Joint taskforce with UK regulators, chaired by Government, to examine “the most effective way to approach” disclosure* *(iii) Support for quality disclosures through data and guidance* *(iv) Clarification of responsibility of financial regulators to have regard to the Paris Agreement* *(v) Work with industry and the British Standards Institution on standardisation;* *(vi) Consider potential or actual barriers to the growth and effectiveness of green finance markets* **Financing green:** *(i) Package of measures to “mobilise green finance” for home energy efficiency;* *(ii) Place the 25 Year Environment Plan on a statutory footing;* *(iii) Engagement with local actors to accelerate green finance across the country;* *(iv) Working with the GFI (“Green Finance Institute”) to address market barriers; and* *(v) Examine with NIC the resilience of the UK’s infrastructure.* **Capturing the opportunity:** *(i) Launch GFI to cement the UK’s position as a “global hub for green finance”;* *(ii) Enhance climate-related and environmental data and analytics;* *(iii) Promote adoption and mainstreaming of green finance products and services, including a Green Home Finance Fund (£5m) to pilot products such as green mortgages; and* *(iv) Engage with professional bodies to drive green finance competencies.*

While most of the Taskforce’s requests appear to have been addressed, the requests for an infrastructure pipeline, the integration of resilience and perhaps most notably the sovereign green bond, appear to have been missed.

Nevertheless, there are funding proposals for a number of sectors (some of which are firmer than others), based largely on the principle of "leverage" (i.e. using public money to attract in private sector finance):

Programme	Description
Heat Networks Investment Project	'Gap funding' to grow the market; aims to have a "transformative impact on the development of cost-effective carbon savings". With a public investment of £320m, the project is aiming to lever in around £1bn of private and other capital by 2021
Clean growth venture capital fund	£20m capital contribution from BEIS, looking to attract a matching or potentially greater capital sum from the private sector;
Natural Environment Impact Fund	BEIS is working with stakeholders to explore potential
£400m Charging Infrastructure Investment Fund	To accelerate rollout of charging infrastructure by providing access to finance companies to deliver public charge points. The Government will invest up to £200m in the Fund, to be matched by private investors (see 12.4 above);
Industrial Energy Transformation Fund	Under development - up to £315m of investment to support businesses with high energy use to transition to a low carbon future.
Increase the size of the Public Sector Energy Efficiency Loan Scheme (managed by Salix Finance).	Under consideration

It remains to be seen how the new UK Government will take these forward.

13.8 Sovereign Green Bonds

As we saw above, the Green Finance Taskforce recommended the launch of a Sovereign Green Bond, which BEIS appears so far to have ignored.

The sovereign green bond is already a well-trodden path elsewhere in Europe. France is currently the world's leading issuer of green bonds, with a total issuance value of over €15bn, just ahead of the US[69], as illustrated in the chart below. Around 40% of this issuance was from

[69] https://www.euractiv.com/section/energy-environment/news/france-returns-to-top-of-global-green-bond-ranking/

state-controlled entities. The UK doesn't currently feature in the top 15 list of green bond-issuing countries.

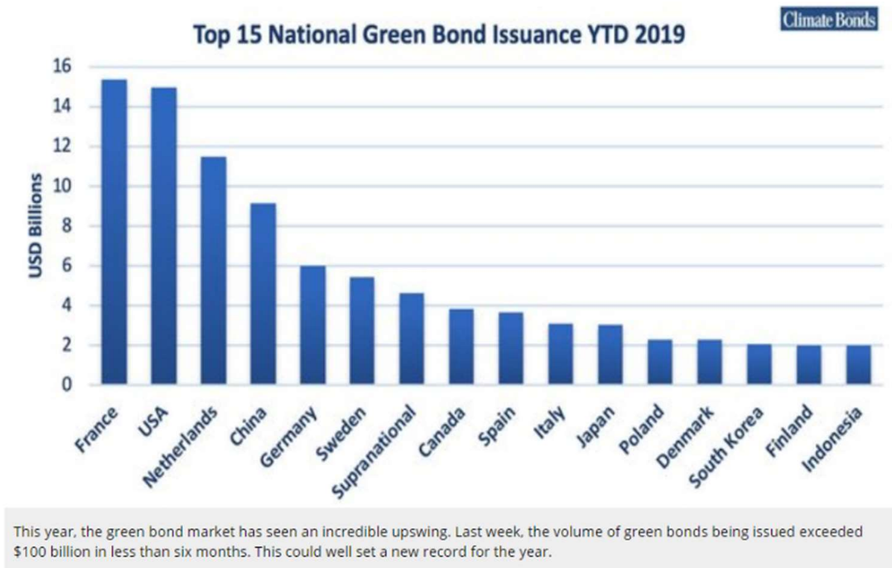


Fig 34: National Green Bond issuance. Source: Euractiv, 26/06/19

The conglomerate Engie is the largest French issuer of green bonds, having issued €8.75bn since 2014. In June 2019, state-owned transport operator RATP issued its second green bond for €500m.

On 24 January 2017, France became the first country to issue a Sovereign Green Bond.

Agence France Trésor launched the *Green OAT70 1.75% 25 juin 2039* for an issuance amount of €7bn. France's Green OAT funds central government budget expenditure and expenditure under the "Invest for the Future" programme to fight climate change, adapt to climate change, protect biodiversity and fight pollution.

The proceeds are managed in compliance with general budget rules and finance an equivalent amount of Eligible Green Expenditure across six programmes: **Building, Energy, Transport, Living resources, Pollution and Adaptation**. In other words, substantially for infrastructure, particularly in its broader definition.

These programmes cover economic sectors that are heavily affected by greenhouse gas emissions (e.g. building, energy production, transport and agriculture), and other issues directly related to Green OAT objectives (e.g. preserving living resources, controlling pollution and adapting to climate change).

For instance, about 30% of the total issuance proceeds are allocated to the building sector and the majority of the building sector funding was €1.6 billion in funding through the energy transition tax credit (CITE). The CITE is a household income tax credit for energy-saving renovation of a primary residence. Typical examples are thermal insulation, high efficiency water heaters, thermostats and equipment using greener power sources such as renewable energy[154].

[70] OAT = Obligation Assimilable du Trésor

The Netherlands issued its first sovereign green bond in May 2018.

The Swedish Government, considering the case for a green bond, published a paper[155] in February 2018 on the benefits of green bonds, based on the French issue. It concluded that green bonds equated to less than one per cent of the total value of all issued bonds[71] and to date, the value in owning or issuing green bonds is mainly in signalling an intent. A party issuing or buying a green bond wants to convey its desire to be part of the transition towards a more sustainable world.

In financial terms, the paper noted, the added value of the green bond was limited or even negative. Green bonds had not unlocked a lower financing cost for the issuer, or reduced risk for the investor. The extra costs for certification and reporting made green bonds a more expensive financing source than regular bonds, albeit only marginally. Liquidity on the secondary market was also been poorer for green bonds.

That said, the French sovereign green bond was three times oversubscribed. The Swedish Treasury concluded that green bonds would eventually account for a substantial share of the bond market, and the extra costs associated with an issue today should be seen as an investment in the learning curve (the additional costs of issuing the French sovereign bond were tiny relative to the sum raised – equivalent to 0.0004% of the issued amount).

Moreover, the kudos of being an early mover could be significant.

On 18th July 2019, the Swedish Government issued a press release to say that it had instructed the Swedish National Debt Office to issue green bonds by 2020[156].

13.9 Other Finance Initiatives

The Green Growth Platform (which also appears to call itself the Green Growth Partnership)[72] is an initiative hosted by the Cambridge Institute for Sustainability Leadership, which brings together European Ministers with businesses and parliamentarians to "catalyse and champion a European policy and economic framework" for a resilient low carbon economy.

A ten-point "action plan" was developed to mobilise private capital, with many similarities to the BEIS strategy above:

Green Growth Platform 10-point Action Plan
1. *Mobilise the funds managed by institutional investors;* 2. *Enable investors to discriminate between high carbon and low carbon assets;* 3. *Ensure financial regulators recognise and respond to the risks to financial stability posed by the economy's structural bias towards high carbon infrastructure;* 4. *Require state-owned finance institutions to demonstrate their investment strategies are consistent with national INDC and climate pledges;*

[71] Euractiv state that the issuance to date (up to 26 June 2019) is 2% of the total, which, if true, suggests significant growth in recent green bond issuance, albeit from a very small base

[72] https://www.cisl.cam.ac.uk/business-action/low-carbon-transformation/green-growth-partnership

5. *Provide savers with choice and incentives to invest in a low carbon future;*
6. *Provide clarity on the forward infrastructure investment pipeline and a long-term and stable policy framework that makes investment in low carbon infrastructure attractive;*
7. *Work with the finance industry to improve and help standardise new mechanisms to facilitate low carbon investment;*
8. *Introduce mechanisms to share risk between the public and private sector;*
9. *Use procurement and planning policies to support investment in low carbon infrastructure and innovation;*
10. *Reassure the private sector that governments intend to work systematically to build a green economy*[157]

The 2018 summit talks of a "growing wave" of support from EU business and policy leaders for a zero emissions future[73].

The EU "Action Plan for Sustainable Finance" argues that urgent action is needed to adapt public policies to the new reality of climate change[158], that the financial system has a key role to play and as it is being reformed to address the lessons of the financial crisis, it can also be part of the solution towards a greener and more sustainable economy. But reorienting private capital to more sustainable investments requires a "comprehensive shift" in the way the financial system works.

On 31 January 2018, the expert group published a report arguing that there are two imperatives:

1. *Improving the contribution of finance to sustainable and inclusive growth by funding society's long-term needs;*
2. *Strengthening financial stability by incorporating environmental, social and governance (ESG) factors into investment decision-making.*

Europe, this report says, has to close a yearly investment gap of almost €180 billion to achieve EU climate and energy targets by 2030. The overall investment gap in transport, energy and resource management infrastructure has reached an annual €270 billion.

Investors, the report says, are not clear what constitutes a "sustainable" investment.

13.10 Project pipelines

Project pipelines are seen as a fundamental mechanism for scaling up activity and attracting private finance for low carbon infrastructure, but it has proved difficult to deliver on promises in practice. Terms like "shovel ready" and "cookie-cutter" can mislead public and private stakeholders alike, underplay the complexity in implementation and introduce an unhelpful level of optimism bias into the process. The rigidity that results from the application of a project finance model can also act as a significant barrier. Given the discussions around system complexities and dependencies elsewhere in this report, the level of complexity in project

[73] https://www.cisl.cam.ac.uk/news/news-items/a-growing-wave-of-support-from-eu-business-and-policy-leaders-for-a-zero-emissions-future-at-the-green-growth-summit

implementation is likely to increase rather than decrease in the future, placing further stress on standardised, de-risked financing models.

The solutions to unblocking project pipelines are not easily to articulate in general terms without them sounding bland and obvious. The essential message is to do the homework before looking for the money. We have limited this section to the observation that this issue is understood, at a high level at least, at all levels of the global economy.

The OECD publication, "Developing Robust Project Pipelines for Low Carbon Infrastructure"[159] attempts to get under the skin of the project pipeline challenge. It concludes that governments can develop robust project pipelines if they:

- *Link policy-making to forward-looking objective-setting and the programmes and institutions to deliver them*
- *Focus on strengthening the interface and mechanisms that governments employ to disseminate information and convene key players*
- *Take a holistic "whole of government" approach to planning infrastructure*
- *Fast track the suitable infrastructure project investment that can deliver carbon and energy targets*
- *Foster a diverse set of bankable projects and business models suitable for private sector needs.*

OECD introduces the concept of "dynamic adaptability" – which is the capacity of governments to keep project pipelines aligned with policy objectives over time.

SPRUCE
The SPRUCE is the 'brand name' for the Scottish JESSICA Initiative (Joint European Support for Sustainable Investment in City Areas). It is an evergreen fund originally co-financed with £50m from SG and EU funds and managed by the EIB. Amber, a private sector fund manager seek to secure investments aligned to an agreed investment strategy for which there is a mandate to 2021. The ethos of the strategy is to ensure that SPRUCE can effectively contribute to and marry up with regeneration projects which are consistent with Scottish Government objectives and locally driven policies right across Scotland. The fund is focused on supporting revenue generating projects that support urban regeneration. All investments have a requirement for the recipient to deliver community benefits[74].

The report recognises the tendency to make well-meaning recommendations for governments to have "better pipelines", which fails to recognise that the reality is a great deal more complex.

Some of the examples of creating successful project pipelines are interesting, coming from countries around the world:

Columbia – citied because of the creation of an "Inter-sectorial Commission on Climate Change", linking government departments and regional "climate change nodes" around the

[74] https://www.gov.scot/publications/scottish-national-investment-bank-implementation-plan/pages/12/

country, co-ordinated by one ministry – the Ministry of the Environment and Sustainable Development (see Section 15.2).

Viet-Nam – for the level of transparency in its efforts to secure investment in low-carbon urban mobility

The UK – for the creation of policy incentives and institutions to support large-scale low carbon investment, by the creation of bankable offshore wind energy projects. The offshore wind sector in the UK is discussed in more detail below.

13.11 Pipeline – Energy efficiency in Germany

Programme level finance case studies for low carbon infrastructure investment are not too readily available publicly. One such study was undertaken by Climate Policy Initiative (CPI), which assessed how much money is being invested in Germany to reduce GHG emissions, with a focus on those investments relevant to the Energy Transition (Energiewende). The result was a comprehensive snapshot of the German climate finance landscape in 2010. The published report shows both the large scale of domestic investment in residential energy efficiency measures at the time, but also the gap that remained between the level of take-up and the trajectory required to meet the targets.

Germany's decarbonisation strategy required a 20% reduction in building sector heat demand by 2020 and an 80% reduction in building sector primary energy demand from the building sector by 2050.

Private investment was seen as key to the transition, as the public sector could not carry the burden alone and the report aimed to gain an understanding of current investment levels, potential investment gaps, and how to leverage private investment. The paper[160] presented the findings of CPI's assessment for the residential sector, looking at who financed sector mitigation activities, how much they invested, what they financed and what were the key factors that supported these investments.

The paper concluded that in 2010, climate-specific investment in the German residential sector was at least €16.3 billion. The dominant share, €13.8 billion, was invested by households (at 50,000 houses, the UK Green Deal can have deployed not much more than £500,000), showing that it is possible to mobilise substantial numbers of households using a finance-based mechanism.

The public bank KfW played a key role in facilitating private investment through the provision of concessional loans and grants. The level of actual investment was believed to be higher; the non-residential buildings sector was not covered in the review, due to gaps in the data. Nevertheless, the report believed that this level of investment was inadequate to meet the Energy Concept targets, although data gaps meant that the actual investment gap was unclear.

Aventia CONSULTING

13.12 Pipeline – UK Offshore Wind

The UK offshore wind sector now consists of 2,016 turbines spread amongst around 37 operational projects and 17 OFTOS[75], with an operational capacity of around 8.5GW[76]. The industry is targeting 30GW by 2030, although the pace of completion was slower in 2018 than the previous year. The UK has 43% of Europe's offshore wind capacity, with Germany not too far behind on 35%[161]. Offshore wind accounted for 8% of the electricity generation mix in the UK in 2018 (with onshore wind accounting for 9%, solar 4% and bioenergy nearly 11%).

By any standards, offshore wind is a low carbon infrastructure success story and one that involves a number of Government agencies coming together, covering policy, technology development, development rights, revenue support and regulation to deliver a strong pipeline of bankable projects (both the wind farms themselves and the OFTOs) and create a major component of the UK's energy mix in less than a decade.

The Centre for Public Impact is a not-for-profit founded by the Boston Consulting Group. Its review of the offshore wind sector in the UK[77] concluded that, from a public policy perspective, the impact of the programme has been significant.

Estimates for the levelized cost of energy ("LCoE") of offshore wind vary considerably (partly because of the time lag between studies, because the cost seems to be dropping rapidly), but in March 2019 Windpower Monthly[78] estimated the cost to be below $100 MW/h (or around £80 MW/h at current exchange rates. The projected lifetime cost of energy from offshore wind in 2011 has come down from £136/MWh in 2011[79]. As noted previously, the strike price of offshore wind in the latest CfD round has now dropped to around £40 MW/h (see Section 9.4).

This compares with a guaranteed strike price for Hinckley Point C nuclear power station of £92.50 MW/h (at 2012 prices)[80] and a report in 2015 suggesting LCoE for new nuclear would be around £87 MW/h[81].

---

[75] Offshore Transmission Owners – investor-owned transmission operators responsible for the onshoring of the electrical power from the offshore wind farms
[76] https://www.renewableuk.com/page/UKWEDhome/Wind-Energy-Statistics.htm
[77] https://www.centreforpublicimpact.org/case-study/wind-farm-investments-uk/
[78] https://www.windpowermonthly.com/article/1580195/offshore-wind-batteries-lcoe-falling-sharply
[79] https://www.centreforpublicimpact.org/case-study/wind-farm-investments-uk/
[80] https://en.wikipedia.org/wiki/Hinkley_Point_C_nuclear_power_station
[81] https://www.carbonbrief.org/new-nuclear-power-in-uk-would-be-the-worlds-most-costly-says-report

14. Approaches to Evaluation

*Question element: A high-level critique of **types of evaluation** approaches that operate as a barrier to the transition to a net zero carbon economy, and those that accelerate the transition*

"Everything we think we know about the world is a model. Every word and every language is a model. All maps and statistics, books and databases, equations and computer programs are models…None of these is or ever will be the real world." Dana Meadows, Thinking in Systems[162]

Headlines
NIC have a system-led hierarchy for infrastructure. "Net zero" at a project level requires offsets. Other, non-carbon, factors are being taken into account. The 2018 edition of the Green Book has built significant additional flexibility into the guidance, but a central question about the suitability of discount rates for low carbon investment remains. Future uncertainty means that there are a number of approaches to pricing carbon but there is no long-term government price. The Magenta Book, with its emphasis on designing in data capture and Theory of Change is a vital tool. While transport guidance follows a logical structure, it has certain key assumptions "hard-coded" in which may conflict with decarbonisation objectives and increase the disparity between model and evolving reality. The Dutch Rijkwaterstaat has developed a new collaborative transport modelling approach that embraces uncertainty. On the private sector side, there is a range of measurement tools and disclosure and reporting approaches which are well-established – the risk is rather of confusion between them. Performance data, however, is hard to find.

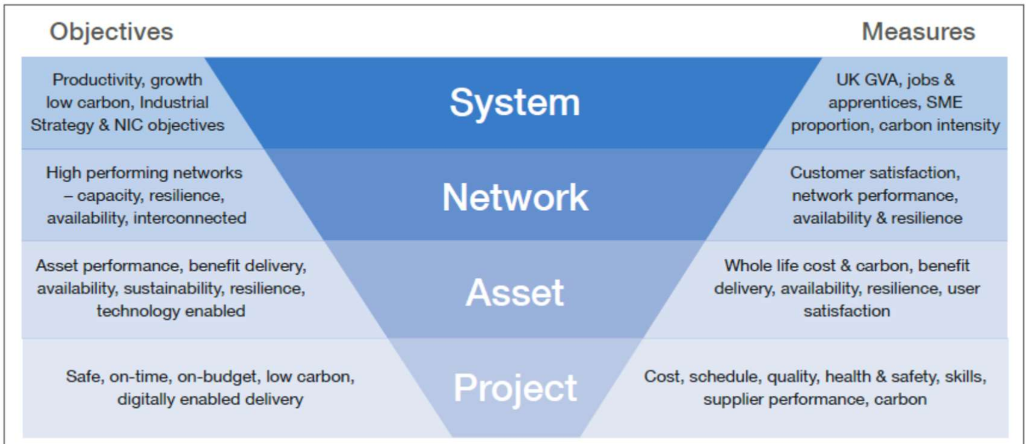
14.1 The infrastructure "hierarchy"

The UK Infrastructure and Projects Authority report, Transforming Infrastructure Performance, set out its aspirations for the UK's Infrastructure in 2017[163]. This was the government's plan to increase the "effectiveness" of investment in infrastructure – both economic infrastructure such as transport and energy networks, and social infrastructure such as schools and hospitals – by improving productivity in design, build and operation of assets. It sets out a "substantial change programme" with a ten-year horizon and responds to three strategic challenges:

- *Prioritising investment in the "right" projects (in this context, those that deliver economic growth).*
- *Improving productivity in delivery.*
- *Maximising the overall benefits of infrastructure investment.*

The first section of this report – ***"Benchmarking for better performance"*** – covers the use of cost, schedule and performance benchmarks to support the selection, budgeting and design of projects. The second – ***"Alignment and integration"*** – covers interventions to ensure that projects and programmes are planned in an integrated way. The third – ***"Procurement for growth"*** – covers building smarter commercial relationships between clients and the supply chain to drive "long-term value" for taxpayers and the users of infrastructure and ensure a sustainable supply chain. The fourth – ***"Smarter infrastructure"*** – covers interventions to increase the use of technology and innovation to drive more productive delivery and smarter operation of our infrastructure assets. Importantly, the report sets out a multi-level approach to performance measurement, with carbon threaded through each level, which is set out in the diagram below:

Figure 3: Example Objectives and Measures



Source: IPA

Fig 35: Carbon at different levels of the infrastructure hierarchy

The Smarter Infrastructure section makes it clear that carbon reduction is a key element of infrastructure performance.

14.2 Defining "net zero"

In "Net Zero Carbon Buildings: A Framework Definition"[164] (April 2019), UK Green Building Council gets to grips with a definition of "net zero carbon" for in-use energy and for construction.

The report outlines an overarching framework of consistent principles and metrics that can be integrated into policy, but primarily can be used as a tool for businesses to drive the transition to a net zero-carbon built environment.

Construction net zero carbon is defined as "When the amount of carbon emissions associated with a building's product and construction stages up to practical completion is zero or negative, through the use of offsets or the net export of on-site renewable energy."

The operational definition is "When the amount of carbon emissions associated with the building's operational energy on an annual basis is zero or negative. A net zero carbon building is highly energy efficient and powered from on-site and/or off-site renewable energy sources, with any remaining carbon balance offset."

The amount of offsets used, the report says, should be publicly disclosed, but it doesn't set any guidelines as to the quantum, proportion or type of offsets, which may turn out to be a weakness in the proposed framework.

14.3 Carbon Pricing

There are many aspects of this literature review to which it is not possible to do justice within the time available. Carbon pricing is one of them. The headline to note is that there is a wide range of different assumptions available for the cost of carbon. This is hardly surprising, given the huge uncertainties around the effects of climate change, but it does present a significant challenge to promoters of infrastructure projects with long-term term positive or negative carbon effects.

The Green Book Supplementary Guidance on the valuation of energy use and greenhouse gas[165] is supported by the DECC / BEIS methodology for carbon values. It is a hybrid approach, using market-based futures prices to produce short-term carbon values for a central scenario, and fundamentals-based high and low scenarios for sensitivity purposes[166]. In the low scenario, carbon prices are entirely driven by market fundamentals up to 2020. This reflects a situation of continued oversupply of allowances in the market driven by depressed economic activity in recent years. The Supplementary Guidance does not directly advise on how to use the different scenarios, although the implication in the BEIS paper is that the central case will be adopted. Clearly the choice of scenario is likely to have a significant impact on the results.

These values (in real 2018 prices) were last published in April 2019. They are summarised in the following table:

Year	Low	Central	High
2018	2.33	12.76	25.51
2019	0.00	13.15	26.30
2020	0.00	13.84	27.69
2021	4.04	20.54	37.04
2022	8.08	27.24	46.40
2023	12.12	33.94	55.75
2024	16.17	40.64	65.11
2025	20.21	47.33	74.46
2026	24.25	54.03	83.82
2027	28.29	60.73	93.17
2028	32.33	67.43	102.53
2029	36.37	74.13	111.88
2030	40.41	80.83	121.24

Fig 36: 2018 BEIS updated short-term traded sector carbon values for policy appraisal, £/tCO2e

An "interim" guidance note continues to be made available on the UK Government website estimating carbon values beyond 2050, but it dates back to 2011 and, as the values for the overlapping years do not correlate (the above values are materially lower), this interim guidance is not a great deal of use.

14.4 Non-carbon criteria

As we indicate earlier in the report, the prevailing attitude to evaluating impacts in low carbon infrastructure has two additional drivers:

1. *infrastructure needs to be considered in a systemic, networked context; and*
2. *impacts need to be evaluated across a "triple bottom line" (economic, social, environmental) spectrum.*

These elements are prevalent in recent academic literature on the subject. For example, the article *"Low carbon infrastructure investment: extending business models for sustainability"* by Foxon et al[167], examines infrastructure as a "key enabler of economic prosperity", but also as important for addressing social and environmental challenges, including climate change mitigation and addressing fuel poverty. This paper argues that current methods of assessing the costs and benefits of infrastructure investment, and the subsequent design of the necessary business models tend to prioritise "partial economic gains" over social and environmental objectives. The paper argues for the inclusion of social and environmental "value streams and propositions" as well as economic values in the business model in order to facilitate genuinely sustainable infrastructure investment.

It cites smart grids and district heating networks as segments of low carbon infrastructure which will require significant levels of investment, co-ordination between public, private and regulatory actors, from which a range of economic, social and environmental costs and benefits for these stakeholders will result.

Drawing on interviews with local players involved in smart grid and heat network developments, and recent work on valuation and business model analysis, the paper challenges the traditional view of a business model as only creating one form of value. Accounting for multiple types of value, it argues, helps to identify business models that are more likely to achieve the environmental and social goals of infrastructure transformation and opens the door for new players. It proposes that the 'value proposition' could be split into four sections for infrastructure investments. These four value 'propositions' are:

- *direct consumption value,*
- *economic development value,*
- *ecological value; and*
- *social value.*

The paper also introduces an approach to complex systems modelling of infrastructure investment decisions to take into account the range of actors and the diversity of motivations of these players and concludes that investment in infrastructure is important, not only for contributing to national economic prosperity, but also for furthering social and environmental objectives, such as mitigating climate change and addressing fuel poverty.

14.5 Green Book

In recent years, standard government guidance has to some extent caught up with the challenges posed by climate change, but some issues remain.

The Green Book[168] (Central Government Guidance on Appraisal and Evaluation) is the longest-established of the UK's public sector evaluation tools. Dating back over 40 years, it has defined the approach to public sector cost : benefit analysis and, even allowing for an inevitable tendency to shape the usage of tools to arrive at desired policy outcomes, can be said to have had a major impact on infrastructure investment decisions in the UK, as infrastructure investment projects generally follow the procedures set out in the Treasury's Green Book.

2018 saw the first major update to the Green Book since 2003 and, the updated version, without altering the fundamental methodological structure, contains some important new thinking, about incorporating environmental and non-economic factors, as well as moving further away from pure market valuation principles and providing greater flexibility on the application of discount rates.

The introduction emphasises that the Green Book is not a "mechanical decision-making device", but exists to provide approved methods, tools for developing options and standard values in order to support "transparent, objective and evidence-based advice for decision-making that is consistent across government".

A key section for evaluation of infrastructure projects is the section on Non-market Valuation and Unmonetisable Values, which provides a range of approaches on environmental evaluation techniques; land values, energy efficiency and greenhouse gases, life and health and travel time.

"Economic appraisal", says the 2018 edition, "is based on the principles of welfare economics – that is, how the government can improve social welfare or wellbeing, referred to in the Green Book as social value"[169].

Discount rates remain key to Green Book appraisal. They are important because over the long life-time of most forms of infrastructure investment, variations in the discount rate will have a material effect on the financial values produced by analytical tools and therefore could be potentially ***the*** significant determinant of whether certain types of investment go ahead or not.

Net present value analysis (which uses discount rates as its core element) remains central to the way the Green Book appraisal methodology is conducted. This approach mirrors established private sector investment appraisal techniques and, while the private sector uses the concept of an internal rate of return ("IRR")[82], the Green Book equivalent is a "social time preference rate" (STPR).

This is intended to reflect the value of having something now rather than in the future and is broken down in the latest edition of the Green Book to show that it comprises an allowance of time plus an allowance for catastrophic risks on the one hand (ρ) and (μg), the latter being the marginal utility of consumption (μ) times the wealth effect (g), such that:

$$STPR = \rho + \mu g$$

Green Book methodology proposes:

- *a value of 1.5% for ρ, which further subdivides into an allowance for time preference (δ) at 0.5% and an allowance for systemic risks (L) at 1%; and*
- *2% for μg, with μ equal to 1 and g (the implied growth rate, based on a combination of historic growth rates and forecasts) at 2%.*

[82] Which is the discount rate at which a given set of cashflows modelled over time sum to zero

These elements collectively add up to 3.5%. In theory each of these elements could vary, but in practice, the overall STPR has remained unchanged since 2003.

Importantly, however, Green Book also recognises that discount rates should decline over the long term "due to uncertainty about future values of its components."[170] What this means in practice is that the "standard" discount rate in the guidance reduces to 3% after Year 30 and 2.5% after year 75, but also allows a "non-standard rate" to be used as a comparison. The non-standard rate should be used where the appraisal involves "very substantial or irreversible wealth transfers between generations". Here the "pure" social time preference of 0.5% (δ) is removed, leaving a lower set of discount rates, namely 3.5% up to Year 30, 2.57% Years 31 – 75 and 2.14% after Year 75.

It is important to understand that this is a "real rate" – in other words it does not take into account inflation. The market equivalent is "real interest rates", which, similarly, strip out inflation. Index-linked bonds, for instance, are priced using a fixed "real" rate plus a variable element which changes according to the prevailing rates of the selected inflation index.

For comparison, real interest rates globally (historical UK data are harder to come by) ran at around 2% per annum through the 1940s, rising gently to peak at 2.5% in 1980, then starting to decline to the point where they reached 0.5% in 2016[83].

Why does any of this matter? The effect of a discount rate is to reduce future cashflows compared with today's. Therefore, the higher the discount rate, the greater the supposed preference for something today over something tomorrow.

To take a simple example: if I expect a benefit in 30 years' time and I am considering whether to invest now to achieve that benefit, I can use the discount rate to tell me how much I should be willing to invest now. The annual percentages might seem small, but as can be seen from the table below, the amount I should invest varies enormously according to the discount rate assumption that I make, because of the compounding effect year on year.

How much will I invest now to earn £500 in 30 years' time?				
discount rate				
0%	1.50%	2.50%	3.50%	4.50%
£ 500	£320	£238	£178	£ 134

As the table shows, I should be willing to invest almost double the amount to get £500 if I assume a discount rate of 1.5% than if I assume a discount rate of 3.5% (which is the Treasury Green Book standard). So setting the discount rate is critical. What we can also see is that at 3.5%, my money needs to work quite hard to make me want to choose the future option.

One element that doesn't appear to have changed in HMT's thinking is the growth assumption, ("g"), which is assumed to be 2% per annum, effectively in perpetuity. Thinking on the nature of growth, however, has been starting to shift in recent years, and it is more widely recognised

83 https://voxeu.org/article/global-trends-interest-rates

that higher growth rates in recent decades might be something of an anomaly. Commentators[84] have called into question the use of GDP growth as an automatic "good" (not least because it might simply be reflecting the unsustainable use of resources). So it is interesting to note that there is an immutable and material economic growth assumption underpinning the STPR, but there isn't room to explore this in more detail in this review.

It is worth noting, however, two further developments in the discussion around social discount rates:

- *A blog from March 2018, also by the Grantham Research Institute[171], recognises that social discount rates are very important for trying to work out how today's society should invest to tackle climate change in the future, noting that the effect of applying discount rates to intergenerational issues is to prioritise the problems of today's society over those of tomorrow's. It goes on to state that it is now widely accepted, for this reason, that social discount rates should decline over time (as recognised by the Green Book) and notes that a survey of 200 economists in 2015, which derived a mean social discount rate of 2.27% (this has not been not adopted by the Green Book).*

- *A paper from the University of Michigan, in January 2018, argues that using a near-zero social discount rate is justifiable[172]. It should be noted that this paper has not been reviewed in detail for this report*

To conclude this section, while there will be continued debate about the appropriate STPR for long-term public sector investment, consideration should be given to how applied discount rates can affect outcomes and therefore the options selected for investment. Also, while allowance is made for alternative scenarios, as we have previously noted (see Section 8.3), there is likely to be a tendency to focus on the base case or core scenario (which will include the standard rate), so this flexibility may in practice not greatly affect decision-making.

14.6 Magenta Book

The Magenta Book, the Green Book's companion volume, is less well-known, but extremely useful as a standard of good practice in conducting evaluations.

Evaluation is typically seen as an *ex post* exercise, although it is clear that unless targets and objectives are set at the beginning of a project or programme, it will be difficult to measure success, as NAO observed in respect of the Green Deal (see Section 10.4).

The relative uncertainty of outcomes and the need to learn as much as possible from first wave projects should lead policy-makers and project promoters to use a Theory of Change ("ToC") approach as part of the business case for a low carbon infrastructure intervention.

The Magenta Book provides a useful framework for a ToC process and a general understanding of the issues faced when undertaking evaluations of projects, policies, programmes and the delivery of services, applying the ROAMEF (Rationale, Objectives, Appraisal, Monitoring, Evaluation, Feedback) cycle.

84 See, for example, Katherine Trebeck, "The Economics of Arrival" (2018)

ROAMEF ties the evaluation back to an underlying logic model (ToC), emphasises that evaluation needs to be built into policy design and places data capture firmly at the centre of the process.

There is no doubt that rigorous adherence to this kind of process will increase the chances of success for any programme of low carbon infrastructure investment.

14.7 Horizon Scanning

Horizon scanning offers another tool for evaluating options over long time periods where there is a high degree of uncertainty. It is a technique for long term scenario-planning which aims to detect early signs of potentially important trends and weak indicators through a systematic examination of potential threats and opportunities, with emphasis on new technology and its effects on the issue at hand. The method requires an understanding of what is constant, what changes, and what changes over a given time period. It explores novel and unexpected issues as well as persistent problems and trends, including matters at the margins of current thinking that challenge past assumptions.

Horizon scanning is often based on desk-top research from a wide variety of sources but can also be informed by primary research and focus groups. Horizon scanning can also be undertaken by small groups of experts who are at the forefront in the particular area of concern, sharing perspectives and knowledge so as to 'scan' the horizon for the effect of new phenomena.

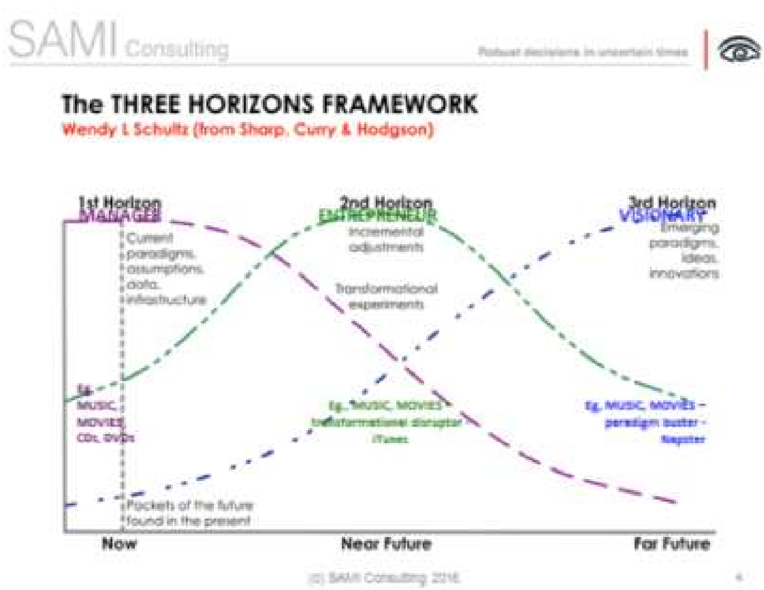


Fig 37: SAMI Consulting 3 Horizons Framework[85]

In March 2018, Dr John Carney, Principal Scientist within the Systems Thinking and Consulting Group of the Defence Science and Technology Laboratory (Dstl) wrote a blog

85 https://samiconsulting.wordpress.com/2017/11/22/three-horizon-mindsets/

presenting "10 Commandments" – his view of the lessons learned carrying out Horizon Scanning within a UK Government Department:

1. *Horizon Scanning isn't about predicting the future –it is about changing mind-sets, challenging assumptions and providing more options.*
2. *Don't look for 'what you know or want' – scanning is not the same as searching. Horizon Scanning is more about asking the 'unasked questions' or identifying the "unknown unknowns".*
3. *The major challenge for a Horizon Scanning analysis is in overcoming cultural resistance.*
4. *Sustain the evidence base – a systematic and comprehensive scanning process provides a degree of (scientific) robustness which is important for credibility.*
5. *There is a lack of a common understanding within the Horizon Scanning and Futures community and a common language. Horizon Scanning is widely used and, in many cases, misused. Define terms and meanings.*
6. *Watch out for thinking that there is only one way that you do. Asking other teams to review the work is a great way to introduce new approaches and views.*
7. *Use a dedicated cadre of 'generalists', ideally recruited from very different academic backgrounds (including the arts and the sciences). Consider the wider team. Externals to the area or consultants can often present an uncomfortable conclusion more effectively.*
8. *Don't negate the need for impact – focus on the implications (the 'so what') rather than the process or detailed content. Uncertainty and risk (or opportunity) are not the same thing.*
9. *Don't expect to be thanked – Horizon Scanning is a challenge function and it may feel like a war zone. The most important contribution a futures project makes is likely to be invisible.*
10. *Don't give up the day job – for some, Horizon Scanning may become a full-time or even life-long profession, but for most it can be a useful adjunct to a more mainstream activity. Be wary that Horizon Scanning can at times seem like a cult but treat it not as a single bullet but one tool useful of many in the Futures armoury*[86]*.*

A solid 'scan of the horizon' can provide the background to develop strategies for anticipating future developments and thereby gain "lead time". It can also be a way to assess trends to feed into a scenario development process.

14.8 Transport Guidance

The Scottish Transport Appraisal Guidance[173] has been the established form of transport evaluation guidance in the sector since 2008.

STAG is one process comprising four phases – Pre-Appraisal, Part 1 Appraisal (qualitative), Part 2 Appraisal (quantitative) and Post Appraisal. There are two components – the STAG Guidance itself and the accompanying Technical Database.

STAG as a process has a rational progression through each of the stages above, starting with the setting of Transport Planning Objectives. These, the guidance says "should express the outcomes sought for the study and will describe (while avoiding indications of potential solutions) how problems will be alleviated."[174].

The Transport Planning Objectives provide the basis for the appraisal of alternative options and, during Post Appraisal are central to Monitoring and Evaluation.

[86] https://foresightprojects.blog.gov.uk/2018/03/08/the-ten-commandments-of-horizon-scanning/

Environmental considerations need to be factored into both Part 1 and Part 2, although this is very much about the specific location of the project rather than broader decarbonisation objectives. Accessibility and social inclusion are also required to be considered in both Parts.

A key concept in transport appraisal is “transport economic efficiency” (TEE). Cost benefit analysis techniques are used to show the net welfare effect, as measured by costs and benefits, of options. Underlying this is the value of working and non-working time by purpose of trip. These are fixed values in the guidance and are drawn from the UK TAG database, so in effect, these assumptions are “hard-coded” into the transport sector across Scotland and England.

If transport decarbonisation is to be pursued seriously and systematically, it seems likely that both the input analysis and the prioritisation of different types of benefit and cost should to change over time. A large amount of “hard-coding” in the assumptions will make transport appraisal less well suited to significant changes in policy priorities and modalities and usage of transport – and as we have seen, this change could happen relatively rapidly.

The STAG guidance document itself is non-prescriptive about priorities and weightings of different socio-economic-environmental considerations, which allows flexibility but may also result in a model-driven appraisal approach, where the outputs from a spreadsheet become the determining factor in the process.

There are just two references to carbon in the guidance, both in respect of the Part 2 (quantitative) Appraisal. Neither the Option Sifting process that leads into the Part 1 Appraisal nor the Part 1 (= qualitative) Appraisal itself make any mention of environmental considerations or low carbon, when arguably decarbonisation should be a predetermining factor rather than a late-stage output.

We identified one carbon measurement model specifically for transport, namely the Energy Research Centre’s UK Transport model[175]. Intended to bridge the gap between short-term forecasting and long-term scenario “models”, the UK Transport Carbon Model (UKTCM) was developed as a strategic transport, energy, emissions and environmental impacts model, covering a range of transport-energy-environment issues from socio-economic and policy influences on energy demand reduction through to lifecycle carbon emissions and external costs. Developed under the auspices of the UK Energy Research Centre (UKERC) the UKTCM can be used to develop transport policy scenarios that explore the full range of technological, fiscal, regulatory and behavioural change policy interventions to meet UK climate change and energy security goals. This reference guide describes the model in detail, including functional relationships, data flows and main data sources. It is not clear from the review how widely this model has been used since its launch in 2010.

It is also worth noting that the Office of Rail and Road has asked Network Rail to “measure and reduce the amount of carbon embedded in new infrastructure and to publish regular, accurate data on carbon emissions and energy efficiency for both traction (train-related) and off-track operations such as offices and stations.”[176] However, there is no explicit target for Network Rail to meet.

The big risk in transport modelling and appraisal seems to be that some key assumptions about need and usage, based on historic data, get “baked into the system”. Quite apart from the pressing need to decarbonise and the policy objective of inclusive growth, there is a risk that transport modelling gives rise to assets that are simply not fit for purpose in terms of need and usage. A key problem is how “demand” is dealt with. The Commission on Travel Demand report argues that travel demand is not just “out there”, waiting to be fulfilled [177] .

Rijkwaterstaat (Dutch Ministry of Infrastructure and Water Management) – embedding uncertainty in transport modelling
The Rijkwaterstaat was asked to develop more transparent modelling results with greater clarity about uncertainties[178]. They came up with a new broader approach to understand uncertainty and to sift options. It comprises several elements: • *A **Dutch Futures Lab** - a cross-governmental initiative which creates a series of societal scenarios within which policy will unfold. Factors include shifts in the energy sector, in digitalization, sharing economy, spatial development as well as transport.* • *Each government department then takes these scenarios and interprets their significance in their own sectoral terms in more detail.* • *A simpler scenario model is being developed and tested which allows initial assessment of the significance of a range of different assumptions in the scenarios to enable decision-makers to focus down on key uncertainties.* Rather than 'black boxing' uncertainty, as happens with more model-led approaches, this approach is developed to encourage broader and more participative engagement with the planning process. The approach makes use of a range of modelling tools, from the more exploratory to the more established but does not privilege modelled inputs to the same extent as current processes. Other knowledge sources are also given importance, which is particularly important when debating future developments. Whilst this creates the risk of different biases being brought to the decision-making process, a participatory and deliberative approach can counter these.

14.9 Models and standards for sustainability

There is a wide range of tools, particularly in the built environment and more recently in infrastructure.

Measuring sustainability in the construction phase is more familiar territory than the operational phase, while incorporating wider "triple bottom line" or social value measures is very much an emerging area. There may at times be an inbuilt presumption that the operational phase will take care of itself.

WRAP, for instance, commented back in 2011 that as building regulations reduce operational emissions towards zero, the embodied carbon in the supply chain was likely to be as much as 50% of total emissions over a building's lifetime[179].

Green Certification Models

There are numerous asset-level technical models for measuring carbon emissions, but this is an area where there is a reasonable level of standardisation. Probably the best-known measurement framework in the UK is BREEAM (Building Research Establishment Assessment Method), established in 1990, which makes it the world's longest established method of assessing, rating and certifying the sustainability of buildings. More than 250,000 buildings have been BREEAM-certified and over a million are registered for certification in 50 countries worldwide[87]. From this methodology has developed an extensive "family" of tools, covering master-planning, new build, refurbishment and in-use.

Assessment and certification can take place at a number of stages in the built environment life cycle, from design and construction through to operation and refurbishment.

In the case of BREEAM, third-party certification involves the checking – by impartial experts – of the assessment of a building or project by a qualified and licensed BREEAM Assessor to ensure that it meets the quality and performance standards of the scheme. At the heart of this process are certification bodies – organisations with government approval (through national accreditation bodies) to certificate products, systems and services.

A key area to consider is whether the BREEAM certification awarded during construction is retested during operation – at present, this appears not always to be the case.

Recently CEEQUAL, the evidence-based sustainability assessment for non-building infrastructure, has been brought into the BREEAM family and CEEQUAL version 6 was launched in July 2019. CEEQUAL is a rating and awards scheme for civil engineering, infrastructure, landscaping and public realm projects.

The objectives of CEEQUAL are to "create a climate of sustainability awareness – and of continuous improvement – in the profession and industry". It is available as two schemes:

• CEEQUAL for Projects for civil engineering, infrastructure, landscaping and public realm works.

• CEEQUAL for Term Contracts for maintenance of infrastructure networks and assets.

Globally, the principal alternative to BREEAM in this area is LEED ("Leadership in Energy & Environmental Design", which similarly has a green building rating system. Developed by the US Green Building Council, LEED provides building owners and operators "a concise framework for identifying and implementing practical and measurable green building design"[88] LEED claims to have more than 90,000 certified projects and has recently launched its v4.1.

Standards - BSI

BSI (British Standards Institute) has a standard on sustainability of construction works (BS EN15978), which is part of a suite of European standards covering the building lifecycle. BRE have published a guidance document explaining how their measurement approach is consistent with these standards[180].

BSI recently developed a Publicly Available Standard ("PAS2080[181]") on Carbon Management in Infrastructure with the Construction Leadership Council, which was launched in June 2018.

A PAS is not yet a formal standard. It is a consultative document rather than a formal British Standard and remains open to comments from interested parties without necessarily incorporating them. The idea behind PAS 2080 is that infrastructure organizations have the power to use it to provide a sustainable national legacy, with all parties involved across the value chain "working collaboratively towards a common goal of reducing carbon, which will

[87] https://en.wikipedia.org/wiki/BREEAM
[88] https://www.bu.edu/sustainability/what-were-doing/green-buildings/leed/

delivering more sustainable solutions, at lower cost and enhance the reputation of the infrastructure industry".

PAS 2080 is targeted at leaders and practitioner-level individuals in different value chain organizations (asset owners/managers, designers, constructors and product/material suppliers) responsible for delivering infrastructure and provides a common framework for all infrastructure sectors and value chain members on how to manage whole life carbon when delivering infrastructure assets and programmes of work.

The individual value chain requirements in the carbon management process are structured around the following components:

- *setting appropriate carbon reduction targets;*
- *determining baselines against which to assess carbon reduction performance;*
- *establishing metrics (e.g. Key Performance Indicators) for credible carbon emissions quantification and reporting;*
- *selecting carbon emissions quantification methodologies (to include defining boundaries and cut off rules);*
- *reporting at appropriate stages in the infrastructure work stages to enable visibility of performance; and*
- *continual improvement of carbon management and performance.*

Presumably the idea is that as an overarching framework it provides a complementary level to the more "technical" BREEAM and CEEQUAL certifications and is more focused on organisational behaviours.

Royal Institute of Chartered Surveyors ("RICS")

Unlike the BSI standard, the RICS standard, published in November 2017, is mandatory for members. This is important because adherence to professional standards is a key factor when accusations of professional negligence are considered.

The specific objectives of this professional statement are to:

- *provide a consistent and transparent whole life carbon assessment implementation plan and reporting structure for built projects in line with EN 15978*
- *enable coherence in the outputs of whole life carbon assessments to improve the comparability and usability of results*
- *make whole life carbon assessments more 'mainstream' and encourage greater engagement and uptake by the built environment sector*
- *increase the reliability of whole life carbon assessment by providing a solid source of reference for the industry*
- *promote long-term thinking past project practical completion, concerning the maintenance, durability and adaptability of building components and the project as a whole; and*
- *promote circular economic principles*

Conducting whole life carbon assessments in accordance with this professional statement, it is argued, will put all studies on the same basis and provide consistency among results enabling meaningful comparisons at different level, thereby enabling benchmarking to take place.

Collection of carbon outputs in a structured fashion to populate a database will allow a "bar" to be set for carbon performance in the built environment industry. RICS will be providing an online data gathering platform for the results of the assessments.

There are two aspects to benchmarking; comparing a project against itself over time ('dynamic') and comparing a project against other similar projects ('static')[182].

14.10 Disclosure and reporting

Some of the developments in corporate-level accounting and reporting, if they become standard practice, will set the context within which the supply chain, asset managers and private investors can be expected to frame their low carbon approach. This section is not intended to be comprehensive in its scope, but is intended to show the broad lines of development in terms both of general and specific disclosure. As with many other aspects of this agenda, further harmonisation is needed.

Greenhouse Gas Accounting

The International Financial Institution (IFI) Framework for a Harmonised Approach to Greenhouse Gas Accounting, supported by the World Bank, and a number of global financial institutions such as the European Bank for Reconstruction and Development, the European investment Bank, Inter-American Development Bank and Green Investment Bank, set out a framework in 2012 for project-level harmonised greenhouse gas accounting[183], covering the policy commitment, screening, methodology and reporting approach to be taken.

The methodology should be based on "established methodologies for ex-ante GHG accounting". All Scope 1 (direct) and Scope 2 (indirect from energy used) emissions would be included and Scope 3 (other indirect – e.g. supply chain) was optional.

Based on this, a standard approach for the GHG emissions of energy efficiency (EE) projects was proposed[184], primarily focused on accounting for the reduction of energy intensity induced by investments in the rehabilitation, retrofitting and/or replacement with more efficient technologies at the recipient facility.

Taskforce on Climate-related Financial Disclosures ("TCFD")

The **TCFD**[89] was founded and is chaired by Michael Bloomberg and aims to develop "voluntary, consistent climate-related financial risk disclosures for use by companies in providing information to investors, lenders, insurers, and other stakeholders". It is very much a risk-orientated disclosure strategy, reckoning that, as momentum builds, financial markets will drive change and force companies respond to climate change risks and align their disclosures with investors' needs.

This year's TCFD status report[185] notes that companies are still seeing the implications of climate change as something for the long term and not today. TCFD believes that these views, driven by the investor community, are beginning to change, who are increasingly demanding "decision-useful", climate-related financial information.

[89] https://www.fsb-tcfd.org/about/#

As evidence of this demand, more than 340 investors with nearly $34 trillion in assets under management have committed to engage the world's largest corporate greenhouse gas emitters to strengthen their climate-related disclosures by implementing the TCFD recommendations as part of Climate Action 100+.

However, the Task Force reviewed—using artificial intelligence technology—reports for over 1,000 large companies in multiple sectors and regions over a three-year period and some of the results of its disclosure review and survey (showing an increase in disclosure since 2016) were encouraging, not enough companies are disclosing decision-useful climate-related financial information yet.

Global Reporting Initiative ("GRI")

The **GRI[90] Sustainability Reporting Standards** (GRI Standards) were the first and (according to GRI), the most widely adopted global standards for sustainability reporting. Since GRI's inception in 1997, it has now become widely adopted by global corporations – companies with revenues larger than the GDPs of entire countries and supply chains that stretch the globe, reporting on social well-being, through better jobs, less environmental damage, access to clean water, less child and forced labour, and gender equality.

GRI says "the practice of disclosing sustainability information inspires accountability, helps identify and manage risks, and enables organizations to seize new opportunities".

The GRI Reporting Principles are fundamental to achieving high quality sustainability reporting. They are summarised in the graphic below.

Reporting Principles for defining report content	Reporting Principles for defining report quality
• Stakeholder Inclusiveness	• Accuracy
• Sustainability Context	• Balance
• Materiality	• Clarity
• Completeness	• Comparability
	• Reliability
	• Timeliness

Fig 38: Global Reporting Initiative Principles

The GRI Standards, last updated in 2016, function as a set of interconnected guidance notes (37 in total, including the glossary). Carbon is dealt with in two of these, GRI-305 (emissions) and GRI-201 (economic performance).

International Integrated Reporting Council ("IIRC")

The IIRC[91] is a global coalition of regulators, investors, companies, standard setters, the accounting profession, academia and NGOs. The coalition promotes communication about value creation as the next step in the evolution of corporate reporting. The IIRC's mission is to establish integrated reporting and thinking within mainstream business practice as the norm in the public and private sectors and its vision is to align capital allocation and corporate

90 https://www.globalreporting.org/Pages/default.aspx

91 https://integratedreporting.org/the-iirc-2/

behaviour to wider goals of financial stability and sustainable development through the cycle of integrated reporting and thinking.

An "integrated report" is a concise communication about how an organization's strategy, governance, performance and prospects, in the context of its external environment, lead to the creation of value in the short, medium and long term.

The Integrated Report is, in effect, a system-led approach to defining the value that an organisation creates, through the lens of 6 "Capitals": Financial; Manufactured; Intellectual; Human; Social and Relationship and Natural (see fig 39 below). "The ability of an organization, says the IIRC, to create value for itself is linked to the value it creates for others. This happens through a wide range of activities, interactions and relationships in addition to those, such as sales to customers, that are directly associated with changes in financial capital".

Natural capital is defined by IIRC as "All renewable and non-renewable environmental resources and processes that provide goods or services that support the past, current or future prosperity of an organization. It includes: air, water, land, minerals and forests, biodiversity and eco-system health."[186.]

Figure 2: The value creation process:

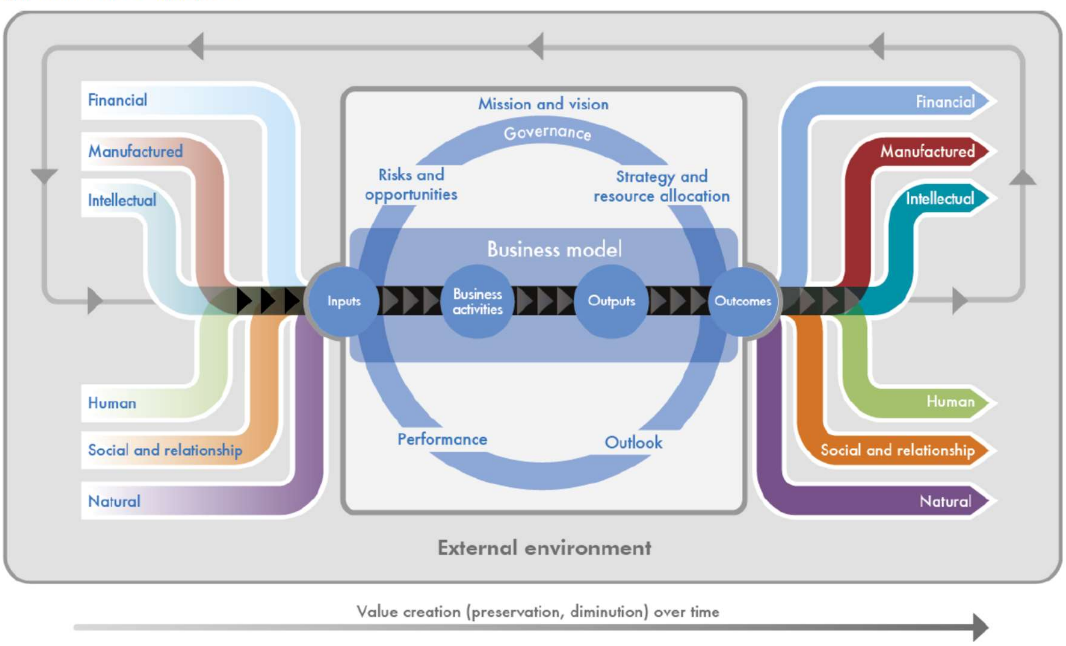


Fig 39 – the 6 Capitals

Scottish Water, in its annual report, essentially follows the Integrated Reporting model (see Section 15.9).

Natural Capital

While full integration of financial and non-financial reports for companies may be some way off, there appears to be increasing interest in Natural Capital as a means of quantifying the value of our biosystem. While there may be objections in principle to placing a financial value on nature, it represents one option for creating a standard or benchmark against which the environmental impact of infrastructure assets can be assessed. On the face of it, a natural capital “balance sheet” represents a logical approach to establishing a standard or benchmark against which degradations or improvements in the environment can be assessed.

The principal risk arises if the monetisation of these assets leads people to believe that this in effect creates a valid rate of exchange between environmental and non-environmental assets. As Kate Raworth puts it, “it [calling something natural capital] may give a stray dog a name, but the chosen name simply shifts the living world from being man’s material means to being an asset on his balance sheet”.[187]

Creating a balance sheet, however, is not primarily what the Natural Capital Committee, chaired by Professor Dieter Helm CBE, is aiming to do. Set up by the UK Government eight years ago, in response to a White Paper, The Natural Choice, committing to the objective “to be the first generation to leave the natural environment of England in a better state than it inherited”, the Natural Capital Committee (NCC) to advise on how best to achieve it.

It is, however, looking for market solutions to fix the problem. The Natural Capital Committee declares, for instance, that “an economically efficient market is one in which all the costs (and benefits) are included so that the price sends the right signal to allocate resources. Making the polluter pay improves market efficiency and hence increases properly measured economic growth.”[188] However, the Committee notes with regret that natural capital appears not yet to be a significant element in government policy, and the Committee, although tasked with ensuring the National Infrastructure Commission considers green and blue infrastructure within wider infrastructure discussions, doesn’t seem to be making much headway.

14.11 Multi-criteria analysis

To support Energy Efficient Scotland, the cornerstone programme for delivering Scotland’s low carbon heat and energy efficiency priorities, the Scottish Government proposed that local authorities would be required to undertake a socio-economic assessment to help develop their LHEES (Local Heat & Energy Efficiency Strategies). It also proposed a district heating consents and licence regime, under which developers would be required to undertake a project level socio-economic assessment.

The Carbon Trust[189] provided methodology and guidance on how to appraise the socio-economic impacts of LHEES, through the implementation of Multi-Criteria Analysis (MCA). A similar but separate document details the methodology and guidance for assessing the socioeconomic impacts of district heating projects, through the application of Cost Benefit Analysis (CBA).

A review of the first of these two documents sets out a relatively high-level approach. It defines MCA as follows: “Multi-Criteria Analysis (MCA) quantifies all identified direct and indirect impacts by applying user-defined weightings to the identified impacts of a project, reflecting their relative effect on the overall welfare of society.”

The benefits of a multi-criteria analysis this approach are twofold – firstly that a diverse set of impacts can be grouped together to produce a single, defined outcome, and secondly that the predefinition process ensures that the criteria are is applied fairly and rigorously across all options to produce a rationally defensible outcome.

Extensive academic research exists in respect of MCA which can lead to highly complex models that are applicable to a number of sectors, such as software development. Some analysis has been undertaken with respect to its application in the renewable energy sector, where a variety of MCA models have apparently been applied successfully to a range of projects across Europe[190]. MCA models are characterised by a series of acronyms such as ELECTRE[191] and PROMETHEE[192] . The challenge with this kind of approach is that it appears to require highly specialist modelling capability (which is unlikely to be readily available either to local authorities or many developers of district heating projects) and will produce results which will not be easy for non-specialists to interrogate.

Flood prevention – long-term investment scenarios
An example of how standard approaches are being used for long term environmental assets is the Long-Term Investment Scenarios (LTIS)[193] published by the Environment Agency, setting out the total national level of investment required if they were to invest in all places where the "benefits" are assessed as are greater than the costs. While the assessment was undertaken specifically for England, it is of interest to note the methodology adopted. The analysis determines the economic optimum level of investment for FCERM (Flood and Coastal Erosion Risk Management). The LTIS analysis used current government guidance, including the Green Book. It assessed investment in FCERM activities over the long-term to achieve the greatest reduction in flood and coastal damage per pound invested. In some places this meant that the ratio of benefits to costs was only slightly higher than 1 but across the whole LTIS 2014 baseline investment profile the overall ratio was about 5:1. The analysis was based on a net present value (NPV), which showed how much the long-term benefits were greater than the long-term costs (in today's prices). This was calculated over 100 years. Benefits were valued according to the economic damages avoided by making the investment, including the benefits of protecting homes and businesses, farmland and infrastructure. The "baseline scenario" had a set of variables, covering: climate change; development on the flood plain; cost reductions; and investment in FCERM activities. It does not appear that the discount rate was varied as part of the sensitivity analysis (notwithstanding the revised Green Book guidance on intergenerational effects), nor that the benefits calculation was varied, either. Green Book guidance also suggests Monte Carlo modelling for projects such as flood prevention, but again, this approach does not seem to have been adopted here. As a general principle, it might be said that the greater the scope for variability (both in terms of number of variables and their individual level of uncertainty, the stronger the case for testing single point or low-number scenarios against an alternative such as a Monte Carlo simulation. However, a more "traditional" modelling approach based around a range between a small number of pathways or options has been used. With the high levels of uncertainty inherent in the effects of climate change and decarbonisation, there appears to be a strong case for more sophisticated modelling techniques to become standard practice for infrastructure. The counter-argument might be that this approach will effectively detach the analysis from policymakers and other stakeholders, including the general public, by creating a "black box" that no-one can understand. It should be noted that LTIS 2019 was subject to an independent peer review.

14.12 Concluding remarks

As we have seen in this chapter, there is no shortage of measurement tools, metrics and frameworks. In Whole Earth Discipline (2010), Stewart Brand put the problem succinctly. “We are, he said, model rich and data-poor.”[194]. This is probably less true now than a decade ago – we have more data and probably understand the scale of the climate challenge better (CCC’s work is testimony to that). It still seems fair to say, however, that data is relatively hard to come by and the myriad of proven and less proven approaches risk adding confusion where clarity is needed – exacerbated, of course, by the systemic nature of the problem.

15. The role of government and Scottish Government programmes

*<u>Question element:</u> Any relevant analysis of **the role and ability of Local Government, Scottish government and its agencies to influence infrastructure carbon emissions** to support its net-zero-carbon ambitions. The analysis should include consideration of infrastructure-related procurement procedures*

*<u>Question element:</u> Consideration of **Scottish Government programmes such as the LHEES/EES** and related whole area planning to integrate energy efficiency upgrades and low carbon heat transition in building stock.*

Headlines
The recent Programme for Government clearly fixes the direction of travel towards a net zero economy. The main themes are heat, transport and innovation. Scotland's Energy Efficiency Route-map provides a direction of travel to 2050. LHEES introduces a new role for local authorities in relation to district heating. Warmer Homes Scotland has fitted measures to around 11,600 households and around 100,000 homes overall now have warmer and more cost-effective homes since 2013. LCITP continues to support a range of projects and programmes, most recently a £30m heat fund. Local and community energy has significantly exceeded targets but not much of it is community energy as such. Local Government's main opportunity to support low carbon infrastructure comes through the City Region Deals but coverage is mixed. Procurement is potentially a useful tool. SEPA and Scottish Water are ensuring low carbon approaches and sustainability are embedded in water and flood management.

15.1 Introduction

This chapter covers both the roles of government agencies as actors in a low carbon infrastructure strategy in general terms, by reference to implementation policies and by type of government agency. There is important relevant literature relating to the activities of government bodies outside Scotland, namely from the UK and the EU, so that is also included here, as Scotland is clearly connected to the rest of the world in numerous ways and to a great extent we are looking at global solutions for a global problem (although local implementation is key).

15.2 Programme for Government

The Programme for Government (September 2019)[195] is the latest public policy document to address the challenge of decarbonisation and offers some of those specifics. From this document people can start to see what a future low carbon Scotland might look like.

Decarbonisation and sustainability more widely play a central role in the framing of the programme, occupying the first two chapters. The Scottish Government, along with a large number of public sector organisations across the UK, have acknowledged the Climate Emergency. The Scottish Government was an early mover in this regard, with the First Minister declaring in April 2019. It is estimated that 70% of the population of the UK now live in areas that have declared a Climate Emergency; the question, of course, being to what extent this will transform the approach to decarbonisation across society and the economy.

The introduction to the Programme talks about an "embryonic" Scottish Green Deal, with commitments from Government to:

- *invest over £500 million in improved bus priority infrastructure to tackle the impacts of congestion on bus services and raise bus usage*
- *put the Highlands and Islands on a path to becoming the world's first net zero aviation region by 2040, including a commitment to zero emissions from Highland and Islands Airports Limited's operations through low or zero emission flights*
- *reduce emissions from Scotland's railways to zero by 2035 through electrification, battery-powered trains and potentially hydrogen-powered trains*
- *provide additional funds (£17m) to support the demand for ultra-low emission vehicles (ULEVs) through the Low Carbon Transport Loan scheme and expand the scheme to include used electric vehicles*
- *ensure that from 2024, all new homes must use renewable or low carbon heat through a fundamental overhaul in building regulations to increase energy efficiency and the efficiency of construction from 2021 and a £30m investment in renewable heat projects*
- *put the transition to "net zero" at the heart of the Scottish National Investment Bank's work*
- *develop a Green Growth Accelerator, a 'Green City Deal' – combining public and private investment*
- *bring to market a £3bn portfolio of projects, including renewables, waste and construction, for green finance investment*
- *support on skills development for this new economic paradigm*

The "Green New Deal", is about finance through the new Scottish National Investment Bank, a place-based approach to unlocking initiatives on new green infrastructure and attracting in green private finance. As we have seen, these kinds of initiatives are not new in themselves, but there does appear to be a renewed vigour and drive to "mainstream" decarbonisation and the willingness to put key economic policy instruments into play.

It is clear that these initiatives will need both interdepartmental and central/local collaboration to work. A question to consider will be whether a refresh of existing public sector governance structures is needed to ensure that decarbonisation is placed as firmly centre stage operationally as well as strategically.

Central and local government also need to face up to the challenge that they are institutional authority structures and the limitations that this imposes on their role. While they clearly have a key role to play in delivering NZCI, much of the agenda requires very personal changes to the way people and communities function. Behavioural change can to some extent be mandated (provided those in power are willing to take the political risk), but more and more effective ways of channelling "grass roots" engagement need to be found if large areas of the decarbonisation agenda (collaborative design of new infrastructure, domestic retrofit, modal transport shifts, consumption of digital services, valorisation of greenspace etc) are to succeed.

CCC have offered a strongly positive comment on the programme, saying the Scotland's leadership continues and that the Programme for Government suggests the vision is "alive and well". There is plenty to do but, CCC says, it is clear that "Scotland is serious about its commitment to tackle climate change and aware of the associated benefits for the planet, the Scottish people, and the economy."[92] A key challenge will be turning this policy focus into a co-ordinating driving force throughout Government.

Leadership in delivery[196]
Columbia is cited as a successful governance model, through a systemic, whole-of-government approach with a clear defining mission. Columbia established a National Climate Change System (SISCLIMA), within which an "Inter-sectorial Commission on Climate Change" (CICC) was the co-ordinating body, not just between the various central government ministries, but also through a series of "regional climate change nodes", through which it engaged with local actors, including private and public sector, academia and NGOs. Four technical committees act as source of knowledge and advisory hubs. Each of the technical committees is chaired by a different ministry with specific expertise With the CICC in the driving seat, the National Policy on Climate Change was approved in 2017. Key leadership qualities identified by OECD include: Delegating responsibilities; improving coherence; linking national to regional action; mainstreaming climate into government planning processes; transparency and improving access to information.

92 https://www.theccc.org.uk/2019/09/03/ccc-welcomes-action-to-tackle-climate-change-in-scottish-programme-for-government/

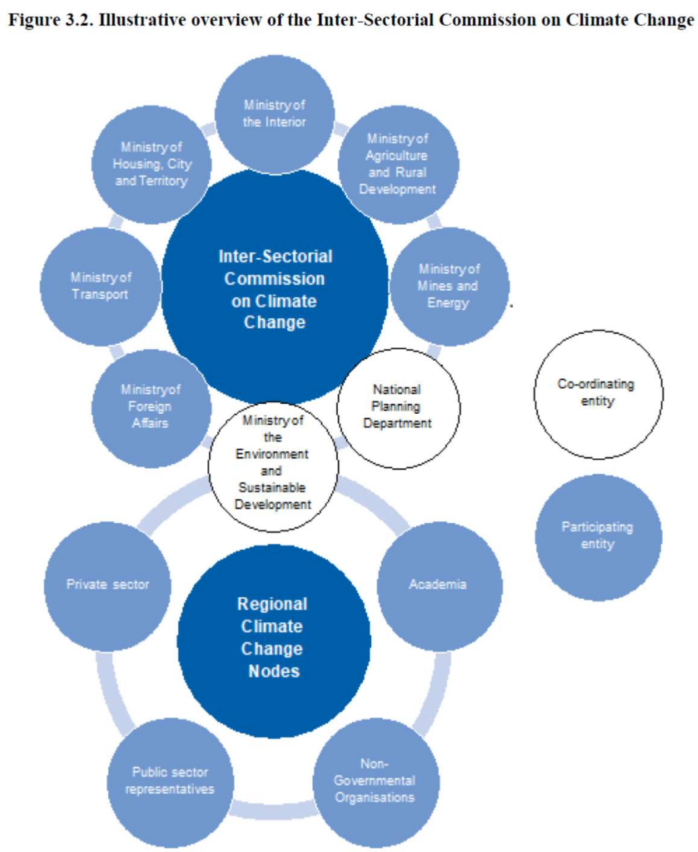


Fig 40: Climate Change at the centre of Columbia's central and regional governance

15.3 Scotland's Energy Efficiency Programme

Energy Efficiency Route-map

Energy Efficient Scotland is a 20-year programme containing a set of actions aimed at making Scotland's existing buildings near zero carbon wherever feasible by 2050, and in a way that is "socially and economically sustainable". By the end of the programme, it is intended that Energy Efficient Scotland will have "transformed the energy efficiency and heating of Scotland's buildings."[197]

It has two main objectives:

(i) Removing poor energy efficiency as a driver for fuel poverty;

(ii) Reducing greenhouse gas emissions through more energy efficient buildings

The graphic below, taken from the Routemap document, summarises both the overarching objective to 2050 and the intermediate steps.

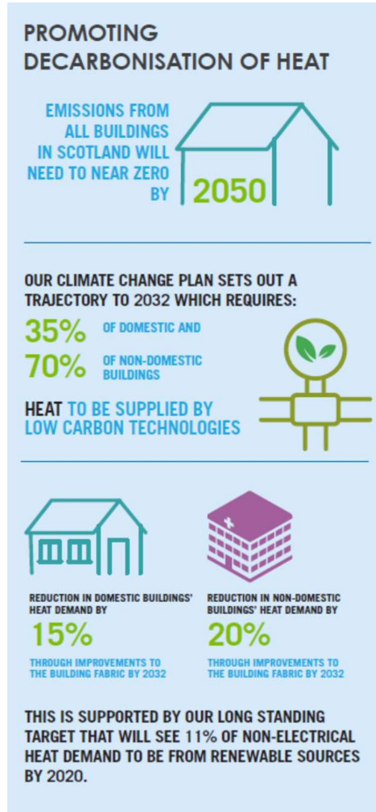


Fig 41: Energy Efficiency Route-map

The stated objective of the programme is underpinned by seven principles to guide decisions on policy and delivery:

(i) *Provide long term stability and certainty;*

(ii) *Be transformational, removing poor energy efficiency as a driver of fuel poverty and decarbonising the heat supply;*

(iii) *Be well-known and trusted, maintaining quality and high standard installations;*

(iv) *Operate throughout Scotland and be delivered to meet local needs;*

(v) *Ensure that heated buildings are comfortable to use, live and work in;*

(vi) *Support jobs across Scotland;*

(vii) *Attract investment in energy efficiency and low carbon heat*

(viii) *It is interesting to note that SG proposes to move to a benchmarking system - where the performance of a building is assessed using a "notional specification" to an existing building*[198]*.*

It might be argued that well-established standards already exist for benchmarking energy efficiency (see Chapter 13) and that the development of a new SG system risks "reinventing the wheel".

There are clearly a number of ways of developing a new system and the preferred option is likely to seek to benefit from established good practice. There are also a number of drivers for adopting a new standard. In addition to technical accuracy, there will also be questions of transparency, usability and independence to consider, which may lead the Government to conclude that commercial benchmarking models offer part but not the whole of the solution.

Local Heat and Energy Efficiency Strategies ("LHEES")

Local Heat and Energy Efficiency ("LHEES") Strategies are a key element of the plan. They will require close collaboration between national and local government and would set out a costed delivery plan for a local authority area, showing how the local authority intends to provide a service to households and businesses to assist them in improving the energy efficiency of their properties to meet the Programme Long Term Standards.

The intent is that local authorities build on their existing area-based approach and expand into sectors that they are not currently covering, in order to offer an integrated, area-based approach. No doubt there will be extensive debate about what additional resources are required to meet these new responsibilities.

In a 2017 consultation, Scottish Government asked about how best to deliver the Energy Efficient Scotland programme. One of the messages it received was the potential need for a "national delivery mechanism" to oversee the delivery of the programme. A strategic outline case was subsequently developed to assess governance options for the delivery body[199].

With the recommendation that district heating should be regulated, and that each local authority is required to develop and publish a strategic plan for developing district heating, and taking forward the wider development of integrated energy efficiency and heat decarbonisation programmes within SEEP, the Scottish Government saw an opportunity to create a new regulatory framework to support this. Considering the delivery of energy efficiency and heat decarbonisation at the same time would help to ensure that overspecification is avoided.[200] Local authorities would have a statutory duty to develop a Local Heat and Energy Efficiency Strategy over a 15 – 20 year period, with capacity and support offered to develop this.

The LHEES will determine zones which set out the most appropriate energy efficiency and heat decarbonisation options to meet overall decarbonisation and fuel poverty objectives.

Data for developing the LHEES will be developed at a national level and a socio-economic assessment would be used to assess the viability and impacts of the local strategy.

Developers will need to obtain a district heating consent and a licence to develop and / or operate.

The public sector will be required to assess the potential scope for connecting to district heating in collaboration with local authorities.

The second consultation on the proposals, which contained the detail, elicited 71 responses from organisations and individuals, 50 of which were from business & industry, local authorities or trade bodies and professionals. The input from "non-expert" sources to the consultation was therefore relatively low. The response was broadly positive.

Under Phase 1 of the pilot programme, LHEES were then piloted to establish area-based plans and priorities for systematically improving the energy efficiency of buildings, and decarbonising heat.

12 local authorities around Scotland were awarded funding to trial the development of a LHEES. The funding was used to provide resource in the form of staff time, to procure consultancy services to carry out aspects of the work, and to conduct stakeholder engagement. The pilots ran from September 2017 to March 2019.

Based on a series of interviews with officers in the pilot authorities and other key stakeholders, and examination was undertaken of the social and organisational implications of delivering LHEES and published in September 2019.[201]

The key lessons were:

- *A need for greater certainty about the resources available to deliver LHEES and a shared understanding between local and national government about the scope and focus of the programme*
- *Government should provide greater clarity about the direction of travel for LHEES*
- *Much of the necessary data is available but there are still gaps (e.g. some types of building stock, with commercial buildings still providing a problem)*
- *Geographic and urban / rural characteristics have a significant impact on the deliverability of LHEES*
- *The functions provided by Home Energy Scotland and resource Efficient Scotland needed to continue*
- *Development and implementation needed to be part of the statutory duty*

One important point to note was that there was little or no external community engagement during the pilots. This is potentially storing up problems for the future. The lack of community and consumer buy-in has repeatedly proved a problem for implementing programmes and projects in the low carbon sector.

Home Energy Efficiency

Warmer Homes Scotland is the Scottish Government's flagship national fuel poverty scheme and is one of a range of schemes funded and delivered by the Scottish Government's Home Energy Efficiency Programmes for Scotland (HEEPS), so it has both social and environmental objectives.

Through the scheme, Scottish Government provides grant funding to cover the cost of installing energy efficiency measures in fuel poor households.

For owners that are able to pay and for private sector landlords the Scottish Government provides interest free or low-cost loans helping to spread the cost of making energy efficiency improvements and installing home renewables. These are also available to registered social landlords.

Home Energy Scotland (HES) is the offer for owners and occupiers. This provides free and impartial advice on energy efficiency and energy saving measures to all households in Scotland on funding and support available and on switching tariffs.

According to the Energy Efficient Scotland Route Map[202], almost 100,000 households in Scotland (just over 4% of the total number) now live in homes which are warmer and cheaper to heat due to the measures installed between 2013 and 2016. HEEPS' 2016/17 and 2017/18 programmes should help almost another 50,000 households improve their homes. SG calculates that between 2013 and 2016, over £248m was paid out under HEEPS and £618m has been invested in domestic energy efficiency overall, a leverage rate of 2.5x. In addition, £24m has been paid out under the SME loan scheme and £38m on over 600 public sector energy efficiency projects.[203]

The stated objectives of Warmer Homes Scotland are to:

1. *reduce fuel poverty by reducing heating costs to vulnerable households;*
2. *contribute to a reduction in the emissions of carbon dioxide from Scottish homes;*
3. *improve Scotland's housing stock;*
4. *offer good value for money by leveraging additional funding into the scheme;*
5. *provide benefits to the wider community through vocational training and employment opportunities.*

Although not stated, the list of objectives could be taken as an implicit hierarchy, with fuel poverty taking precedence over CO_2 emissions. Objectives 1 and 2 are the primary objectives and the other three ancillary benefits.

The Home Energy Efficiency Programme Annual Review 2018[204] found that the largest group of beneficiaries in 2017/2018 was people in receipt of Disability Living Allowance or Personal Independence Payments, closely followed by people in receipt of a qualifying benefit supporting a child under 16 (which together accounted for about 70% of beneficiaries). An average fuel bill saving of £318 per household was achieved. However, these are modelled savings and do not take account of a possible "rebound effect".

Most of the beneficiaries of the scheme are owner occupiers (social housing tenants are not eligible). The Repairing Standard also imposes a duty on landlords in the Private Rented Sector to ensure that heating in properties is in good working order.

The table below illustrates the number of installations and the split by tenure.

Table 1 – Warmer Homes Scotland completed installations by tenure type

Year	Owner-occupied	% of Total	Rented (private)	% of Total	Total
2015-16	1159	83.5	213	15.5	1372
2016-17	4329	81	1025	19	5354
2017-18	4055	82.7	848	17.3	4903
Total	**9543**	**82.1**	**2086**	**17.9**	**11,629**

Fig 42: Completed Warmer Homes installations

The total represents about 2% of the estimated number of households in fuel poverty[93]

[93] https://www.gov.scot/news/no-real-change-in-fuel-poverty-in-2017/

It is interesting to see the distribution geographically. As the table below shows, South East and Strathclyde & Central accounted for 58% of the installations, which is slightly less than their share of the population (65%) – the "islands" (Western Isles, Orkney and Shetland) have by far the highest installations per head. The islands are also where the highest levels of fuel poverty will be found[94].

15.4 Low Carbon Transition Infrastructure Programme (LCITP)[95]

The LCITP was launched in 2015. It is a strategic intervention supported by European Structural and Investment Funds. European match funding is guaranteed until Autumn 2021. It provides a range of support, from expert advice to financial support to assist the development and delivery of private, public and community low-carbon projects across the country. Its main focus is assisting projects to develop investment-grade business cases that will help secure public and private capital finance to demonstrate innovative low-carbon technologies in Scotland.

The programme is designed to create the conditions to attract commercial investment in innovative low-carbon infrastructure projects, which could be replicated elsewhere in Scotland to maximise our potential in the low-carbon sector.

Projects include: Island-based generation and storage; industrial fermentation using waste instead of crops; tackling fuel poverty and grid balancing; low carbon heat; industrial heat pumps; district heating; residual waste and battery storage, with estimated capex between £300k and £18m[205].

The latest element of the LCITP is a fund to create low-carbon heating infrastructure, which is now open for applications[96].

The Scottish Low Carbon Heat Funding Invitation is making £30m available to businesses and organisations for innovative solutions to heat buildings.

The support will provide financial assistance for up to 50% of the total eligible costs of a capital project, up to a maximum of £10m, where that project can demonstrate innovative and low carbon ways of heating our buildings, including heat pumps, as well as supporting industrial projects focused on reducing emissions.

15.5 Renewable Energy Investment Fund (REIF)[97]

The Renewable Energy Investment Fund (REIF) was set up to provide financial assistance for projects that could deliver energy from a renewable source or reduce the cost of renewable energy, while benefiting the Scottish economy. There needed to be a demonstrable funding gap for REIF to consider. The fund closed in March 2016. Examples of areas that REIF could support included: marine energy, community owned renewables, and renewable district heating.

The Energy Investment Fund ('EIF') is a Scottish Government Fund managed and delivered by the Scottish Investment Bank and building on the success of the Renewable Energy

[94] See, for instance, SG "Fuel Poverty in Scotland", February 2016
http://www.parliament.scot/ResearchBriefingsAndFactsheets/S4/SB_16-18_Fuel_poverty_in_Scotland_2016.pdf
[95] https://www.gov.scot/policies/renewable-and-low-carbon-energy/low-carbon-infrastructure-transition-programme/
[96] https://www.gov.scot/news/gbp-30-million-for-low-carbon-projects/
[97] http://www.hie.co.uk/growth-sectors/energy/energy-support/renewable-energy-investment-fund/

Investment Fund, providing commercial investment for renewable and low carbon energy solutions.

EIF aims to provide flexible investment and debt funding for energy projects in Scotland that will facilitate, catalyse and accelerate Scotland's transition to a low carbon economy. EIF is a gap funder and will only invest where there is a demonstrable funding gap in a project's funding package. A total of £20 million has been allocated to EIF for distribution by 31 March 2020[98].

15.6 Community energy

Community energy has long been viewed in Scotland as positive aspect of the renewable energy landscape. It is supported by Community Energy Scotland[99], a charity dedicated to supporting all aspects of community energy development by SG as a key part of the renewable energy mix in Scotland. Local Energy Scotland is the body charged with administering the Scottish Government's CARES (Community and Renewable Energy Scheme) funding. A range of grants and loans (up to a maximum of £150k) are available.

SG set a target in 2011 of 500MW of "community and locally owned" renewable energy capacity in Scotland by 2020. Energy Savings Trust was tasked with monitoring progress towards the target and reported in June 2018[206].

'Community and locally owned' is very broadly defined as including:

- *Community groups*
- *Local authorities*
- *Housing associations*
- *Other Scottish public bodies*
- *Charities, including faith organisations*
- *Further and higher education establishments*
- *Local businesses*
- *Scottish farms and estates*

The target had been beaten by end of June – capacity stood at 697MW, representing a 6% increase on the previous year. This operating capacity comes from 18,830 installations (so many of them must be very small). Scottish Government has now set a new target of 1 GW of community and locally owned power for 2020 and 2 GW by 2030. About 60% of the 1,700-odd GW/h of output was electricity, with most of the rest being heat and a small amount from Combined Heat & Power plant.

The largest proportion of operational capacity was on Scottish estates (40%), with the next largest being local authorities (18%) and the third local businesses (13%). Community projects accounted for 80MW of capacity – around 11%. So genuine community-owned energy generation is to date a marginal consideration in the energy landscape in Scotland.

---

[98] https://www.scottish-enterprise.com/support-for-businesses/funding-and-grants/accessing-finance-and-attracting-investment/energy-investment-fund

[99] https://www.communityenergyscotland.org.uk/what-we-do.asp

15.7 Role of local government

There is a limited amount of literature explicitly considering the role of local government in delivering low carbon infrastructure, although they are identified as key actors in much of the UK-wide analysis.

The Scottish Government's LHEES programme (see Section 14.3) expands the potential role of local government by making it responsible for low carbon energy master-planning in its area and giving it a regulatory role for future district heating networks.

There are a number of clearly identifiable roles that a local authority can play in delivering low carbon infrastructure, notably:

- *Procurement of goods, works and services on its own behalf.*
- *Planning*
- *Economic development*
- *A broader community engagement and interface role through its activities and services*

The local government landscape is evolving in Scotland and England, with the creation of regional collaborative structures, driven in large measure by the idea that greater and more inclusive economic opportunity can be unlocked by multi-authority working. This has come through in a series of City Region Deals that now cover all of the main urban areas of Scotland. Most of Scotland now has a City Region Deal or a Growth Deal[100] and with this come both challenges and opportunities for local authorities in terms of their role in helping to deliver NZCI. City Region Deals are discussed further below.

While local authorities can perform a number of key enabling roles, there has been significant interest over the past decade in the question of their delivery role for a decarbonised future, given their purchasing power, their "reach" within local communities and their ownership of key assets. Between 2009 and 2013 there was a surge of interest in this area, particularly for larger cities and for energy and energy efficiency assets, on the back of policy initiatives including the ill-fated Green Deal. We do not propose to examine this period in detail as much of the momentum was not sustained, for a variety of reasons. What has developed and appears to be a sustainable trend, however, is collaboration between local authorities to form a variety of regional partnerships with an economic development purpose at their core.

In Scotland, this manifests itself in the City Region Deals and Growth Deals, which in essence are a three-way collaboration between regional local authorities, the Scottish Government and the UK Government around a specific programme of long-term investment to support the development needs of the region in question. To date, six such deals have been signed, covering the majority of Scotland's population and all of Scotland's 7 cities. Given the criticality of the transition to a low carbon economy at a national level, these deals are an obvious vehicle for implementing this strategy.

Some City Region Deals seem to be grasping the low carbon opportunity: Edinburgh from an innovation perspective, building on existing expertise and closely linked to the role of the University, for instance. However, to date, the decarbonisation driver in these structures appears to be highly variable, as illustrated by review of the signed deals to date, which shows that coverage of the decarbonisation agenda within their programmes is mixed. We have

[100] See https://www.deliveringforscotland.gov.uk/investment-projects/city-region-deals/#

looked for references to carbon and low carbon in the City Deal documentation and the results are summarised in the table below.

City Region Deal	LC references	Source	Date
Glasgow	None	Annual performance report	Dec-18
Edinburgh	Range of innovation activities associated with the low carbon economy	City Deal Document	Aug-18
Aberdeen	Sustainability is a key theme - opportunities associated with circular economy and CCS. OGTC working with oil & gas sector to position itself for LCE.	Annual performance report	Dec-18
Highland	None. Mentions sustainable economic growth	Annual performance report	Dec-18
Stirling & Clacks	None	Heads of terms	May-18
Tay Cities	"Preparing for a low carbon future" - development of the Scottish Centre for Clean Energy Storage and Conversion; low carbon transport and active travel hubs	Heads of terms	Dec-18

Of the six signed deals, three (Edinburgh, Aberdeen and Tay Cities) set out a clear role for low carbon in their development strategies, identifying projects and programmes around innovation, circular economy, carbon capture and storage, energy storage, low carbon transport and active travel. Three, however, make no reference to carbon whatsoever, perhaps most surprisingly Highland, given its available energy and environmental resources.

The Case for a Decarbonisation Mission in Regional Development

In the North of England, decarbonisation is being explicitly linked to sustaining traditional heavy industry. A report by the Institute for Public Policy research (IPPR)[207] , argues that the north of England, with a more carbon intensive economy than the English average and its many carbon-intensive industries face a challenging transition, also suffers from a lack of investment relative to other regions, particularly London.

However, it says, the North of England has a large economic potential, more of which could be unlocked from directed investment. In order to realise the North of England's potential, IPPR argues that the government's industrial strategy should include a mission to secure the greatest socio-economic benefit to the UK from a reduction in greenhouse gas emissions to net-zero by 2050. To this end, IPPR argues, an "explicit decarbonisation mission" within the industrial strategy would provide a strong organising basis and a devolved carbon budget would provide a clear regional demand side focus for the North.

15.8 Procurement

Procurement has been identified as a major "tool in the box" for delivering low carbon infrastructure. The OECD[208], for example, says that public procurement is an important instrument of innovation policy. It can create 'lead' markets, for instance where government demand is significant (e.g. transport, construction) and spur innovation without engaging new spending. By 2013, sustainable public procurement had been introduced by at least 56 national governments and many more local governments.

At the time of the report (2016), however, it was thought to be "by no means a universal practice" and the report identified many barriers to mainstreaming "green" purchasing, including: fragmented national systems, concerns about access to opportunities for SMEs, the technical capacity and resource availability of procuring officers, and the way budgets are allocated.

Better monitoring and evaluation, says the report, would also help improve green procurement.

A number of practical suggestions are made, but they can be summarised from this report as representing a coherent effort to embed green measures in procurement on a number of fronts.

While in Scotland, the public sector directly procures only some elements of infrastructure (it is a major procuring body in transport, for instance, but not so much in energy), procurement is a feature of most asset-intensive aspects of infrastructure and large privately owned companies generally competitively tender (= procure) their supply chains.

If low carbon is part of an integrated approach to sustainable public sector procurement this could have a "ripple effect" such that not is it only cascaded down the supply chains for that particular project, but starts to embed in the other activities of public and private sector players, so that developers of private projects start to embed it in private sector supply chains and it becomes possible to transpose it into planning and economic development on the public sector side. This appears to be happening in England, for example, as "triple bottom line" social value measurement frameworks such as the National TOMs[101] (Themes, Outcomes and Measures) are becoming an increasingly standard component of local authority procurement.

So while the obvious first opportunity is for the public sector to use its buying power through procurement to influence the development and growth of low carbon infrastructure, it can also "lead by example" and have an indirect influence on wider activities and areas of the infrastructure agenda that fall outside the direct control of the public sector.

Procurement Reform Act

Both the OECD report above and the EU GPP programme cited below talk about "mainstreaming" green or sustainable procurement. If the economy is to be decarbonised, it is clearly not enough to support a few specialist or bespoke green projects, or to wrap

[101] https://socialvalueportal.com/national-toms/

otherwise carbon-heavy projects in a green cloak. Decarbonisation needs to shape every significant decision taken. This is why the Procurement Reform Act is potentially an important signal for decarbonising Scotland's infrastructure.

The Act applies to all "regulated contracts", namely public contracts where the value is greater than £2,000,000 if it is a works contract and £50,000 for any other type of contract. The Act imposes a "sustainable procurement duty" on public sector bodies procuring regulated contracts. Before carrying out a regulated procurement, the public body must consider how in conducting the procurement process it can

(i) improve the economic, social, and environmental wellbeing of the authority's area,

(ii) facilitate the involvement of small and medium enterprises, third sector bodies and supported businesses in the process, and

(iii) promote innovation,

The authority then has to follow this up in procurement. A procuring authority which is expected to have significant procurement expenditure (defined as one or more contracts exceeding £5m) in a given year needs to prepare a procurement strategy that reflects these considerations. In doing so, the contracting authority must consider only matters that are relevant to what is proposed to be procured and the extent to which it is "proportionate" to take those matters into account.

While this is helpful legislation, from a decarbonisation perspective, there is a potential weakness in that this is very much framed in terms of what matters for the specific area. Global warming is a generalised phenomenon but a local authority could take the view that the localised effects of reducing CO_2e are minor compared with other more immediate positive or negative effects locally. There is also no guidance on how these considerations should be weighted (primary legislation would be unlikely to do this), so the extent to which the legislation can be used to drive decarbonisation through procurement is very much left to the discretion of the procuring body. The same could be said of the Act's comparable legislation in England, the Public Services (**Social Value**) Act 2012.

Scottish public authorities are also required to produce annual procurement reports (if they meet the criteria set out above) showing how they have delivered this objective.

Despite its name, the Sustainable Procurement Obligation does not appear to be interpreted yet as a vehicle for decarbonisation by Scottish public sector bodies. A review of a sample of 16 reports found that carbon was only mentioned in 6 of them and mostly in in a fairly limited context, although the reports of two of the local authorities did suggest that they saw low carbon as an important consideration. Not to use this key tool to support the delivery of NZCI seems like a missed opportunity.

Perhaps surprisingly, the councils of Scotland's two largest cities made no mention of carbon in their procurement reports, nor did the environmental agency SEPA. This in spite of the fact that climate change is the first item listed for consideration in the Scottish Government's guidance for completion of the procurement annual reports[209], suggesting that a stronger signal is needed from Government.

Using procurement to deliver low carbon infrastructure[210]

The Department of Public Works of the Dutch Ministry of Infrastructure and the Environment (Rijkswaterstaat, or RWS) has developed an approach to encourage the minimisation of environmental impacts related to infrastructure building.

Following a requirement from Parliament to include green criteria in all tenders, RWS works from a Most Economically Advantageous Tender (MEAT) methodology which includes both price and quality attributes, but the quality attributes are fully monetised in the quoted price and the contract is awarded to the bidder with the lowest adjusted price.

RWS tenders combine two sustainability criteria in the quality attribute:

(i) "The CO2 Performance Ladder" rates companies on a scale from one to five on the basis of energy savings, efficient use of materials and use of renewable energy. A rating of five requires that the evaluation is conducted in collaboration with an environmental NGO. More ambitious contractors, as rated by the ladder, benefit from a discount applied to their tendering price, going from 1 to 5%.

(ii) The Sustainable Building Calculator (DuboCalc) is also provided to tenderers to assess the environmental impacts of the use of materials specified in a contract. DuboCalc was developed to provide a transparent assessment of environmental impacts, and to help contractors 'optimise' on the basis of various environmental costs rather than mandating specific levels of performance. The costs are derived from an authoritative life-cycle analysis of materials (from extraction to demolition and recycling) including CO2 emissions and ten other impacts. The aggregate environmental cost is translated into a monetary value which is combined with the tender price to award the contract[211].

Co-ordinated Low Carbon Procurement

The EU's "GPP 2020 procurement for a low-carbon economy" programme[212] appears to have generated positive results. GPP 2020 aimed to "mainstream" low-carbon procurement across Europe through the following activities:

(i) Project partners implemented more than 100 low-carbon tenders by over 40 public authorities in eight countries to achieve a significant amount of CO_2 emission reductions

(ii) Training and networking events were provided - both for procurers and procurement training providers - on the implementation of energy-related GPP in Austria, Croatia, Germany, Italy, the Netherlands, Portugal, Slovenia and Spain;

(iii) Permanent GPP support structures were created or supported in: Austria, Croatia, Germany, Italy, the Netherlands, Portugal, Slovenia and Spain;

(iv) Over the course of three years, calculated savings of over 900,000 tonnes CO2e and 140,000 toe (tonnes of oil equivalent) were achieved.

15.9 Water and Flood Management

While still subject to a regulatory regime, the ownership and structure of Scotland's water and river systems management is relatively simple and somewhat different from England's, as are the climatic conditions and topography in much of the country. Flood management is also a devolved matter. This means that a considerable amount of adaptation coverage produced by the UK Government, or by independent organisations such as CCC, while interesting in terms of the perceived challenges and the industry position on related matters, is not directly relevant to Scotland and is therefore not directly within the scope of this review.

There are three main actors in Scotland: Water Industry Commission for Scotland (WICS), the independent regulator, whose primary focus is the protect the interests of consumers and which is a Non-Departmental Public Body ("NDPB"), Scottish Environment Protection Agency ("SEPA"), also an NDPB, whose primary roles are to ensure that the environment and human health are protected and that resources are used sustainably, and Scottish Water, a statutory corporation owned by the Scottish Government, who manage Scotland's water and waste water. SEPA also has a duty to enable sustainable economic growth.

Unlike most regulated infrastructure sectors, therefore, operational control rests with a single corporate body, with consumer and environmental checks and balances.

Perhaps in part due to the relative simplicity of the industry structure, this infrastructure provides strong evidence that decarbonisation is not only recognised as a priority but is being embedded in business models.

In Section 11.2, we references the Sustainable Growth Agreement signed between Scottish Water and SEPA in June 2018.

Scottish Water is one of the biggest users of electricity in the country and consumes about 440 GWh per year of grid electricity at sites such as water and waste-water treatment works[102]. It provides over one billion litres of drinking water each day and plays a key role in taking more than 900 million litres of waste-water and returning it to the environment.

Its sustainability report[213] says that through a combination of investment in renewable energy installations and hosting private investment on its estate, Scottish Water now generates and hosts around 923 GWh per annum of renewable energy, more than double its own electricity consumption. This impressive result was achieved in approximately 3 years.

Scottish Water has adopted the integrated reporting approach, as can be seen from its 2018/2019 Annual Report[214], building its report around the "six capitals", namely: Financial; Manufactured; Intellectual; Human; Social & relationship and Nature (see also Section 13.9).

In its sustainability report, Scottish Water describes Natural Capital as "the stock from which we draw the environmental services that support society – the water we drink, the air we breathe, the food we eat and the land on which we live, work and play."[215]

Social capital, it says "represents our impact on, and the engagement and trust we have with, customers, individuals, communities and stakeholders".

Reduction in the carbon footprint, it says, a highlight of the year. As well as reducing its carbon footprint, Scottish Water launched a Capital Carbon Accounting Tool as part of a new

[102] https://www.waterbriefing.org/home/company-news/item/15090-scottish-water-renewable-energy-generation-now-more-than-double-electricity-consumption

approach to managing carbon in the capital programme, as well as starting to incorporate the Sustainable Development Goals into the long-term planning process.

Scottish Water sees a clear role for itself in the circular economy, although neither the Annual report nor the Sustainability Report is clear on what that entails. As one of the biggest investors in Scotland's infrastructure, Scottish Water is clear that the choices it makes in developing the Strategic Plan for the next investment period (2021-27) are an important contribution to the future of Scotland.

Flood risk management

SEPA[216] argues that considering climate change adaptation in land use planning is essential as an early understanding of potential future impacts reduces risk associated with long term investment decisions. It says that SPP (Scottish Planning Policy) recognises that climate change will increase the risk of flooding in some parts of the country, and that the planning system should promote a precautionary approach to flood risk, taking account of the predicted effects of climate change.

Changes in sea level rise are driven by the thermal expansion of the ocean as well as the addition of water through global ice melt and while within Scotland, these impacts are being partially offset by glacial isostatic rebound - the ongoing rise of land formally depressed by the huge weight of ice sheets during the last glacial period, given that sea level rise will continue well beyond the end of the 21st century, SEPA recommend that an additional allowance of 0.15m per decade after the year 2100 be applied where the design life of a development is known to extend beyond that date. It is also expected that sea level rise will increase the rate of coastal erosion.

SEPA says that planning authorities are ideally placed to address pressures on the water environment associated with land use. As well as ensuring future development does not result in further downgrading of the water body, land use planning can ensure improvements in the water environment by addressing existing historical pressures.

The River Basin Management Plans (RBMPs) have identified that the key pressures affecting Scotland's water environment are as follows:

- *Physical Condition (e.g. modifications to beds, banks and shores as the result of historical engineering, electricity generation, urban development, land claim);*
- *Barriers to fish movement;*
- *Water quality (e.g. rural and urban diffuse pollution, wastewater, land contamination, point source pollution)*
- *Flows and Levels (e.g. alterations to water flows and levels as the result of electricity generation, public water supplies, agricultural irrigation, business water use); and*
- *Invasive non-native species.*

Supporting the implementation of the RBMPs will ensure the healthy and productive functioning of economically significant water uses and supply safe and healthy drinking water. Natural biodiversity will benefit, supporting fish and shellfish stocks and enabling Scotland to mitigate and adapt to the pressures of climate change[217]. SEPA's overarching objectives in providing advice to planning authorities on the protection and enhancement of the water environment are to ensure appropriate protection and enhancement of Scotland's water environment in accordance with the Water Framework Directive and other relevant legislation.

Flood Risk Management by Householders

The Social Market Foundation describes itself as "a non-partisan think tank which believes that fair markets, complemented by open public services, increase prosperity and help people to live well"[103], produced a report entitled "Incentivising household action on flooding"[218], which is of interest not only in respect of specific area of research but also more generally because it appears to be one of a relatively small number of papers that examines behavioural aspects of infrastructure.

Its report acknowledges that while the greatest benefit of resistance and resilience measures will be felt by households that are at high risk of flooding, particularly for lower cost interventions, all households could benefit, and there is a strong argument for a much wider set of properties taking up this action. There are a number of reasons for this:

- *The properties may be at risk, but not currently judged to be. For example, around two thirds of the residential properties flooded in the major event in summer 2007 were not previously identified as high risk on flood maps;*
- *Risk is always changing, as the built and natural environment change, meaning that low risk properties may experience higher risk in future. It could therefore be more cost effective for these properties to take on low / zero cost measures now, rather than wait;*
- *Ultimately, all properties are at some risk of flooding – meaning that if resistance / resilience measures are costless, it would make sense to improve resilience for the whole housing stock.*

However, there are currently a range of barriers: Motivation: Households need to believe both that they are at risk of flooding and that they are responsible for protecting their property; accessing and assessing information about the various products available in the market; affordability; behavioural biases.

Building regulations should also be changed to support the needed action. There should be a presumption of "resilient repair". Building regulations could require a set of resilience standards that need to be met when properties that have been flooded are being reinstated. Secondly, negligible and low-cost resilience measures could become mandatory for all new and renovated properties.

[103] http://www.smf.co.uk/

16. Decision-Making Hierarchies

*<u>Question element:</u> "What evidence is available to support use of a **hierarchy of principles** to guide infrastructure investment to achieve a net-zero carbon future"*

"All models are wrong, but some are useful" George E. P. Box

16.1 Introduction

At first glance, it may not be immediately obvious how a question about hierarchies plays into a literature review of the linkages between infrastructure and low carbon. However, as we have examined tools and processes, we also need to ask whether basic principles exist and are being applied to guide their application, and it is not unreasonable to suppose that these principles could (or should) be organised as decision-making hierarchies.

However, one clear point from this review is that systemic approaches to delivering NZCI are not yet common, let alone the norm and, since systems and hierarchies are closely connected, it should not be surprising to see that well-established hierarchies are not a regular feature of this landscape. As a consequence, the discussion about hierarchies in this review is largely theoretical and relatively short.

16.2 What do we mean by a hierarchy?

A "hierarchy", according to Oxford, "is a system in which members of an organization or society are ranked according to relative status or authority[104]".

Wikipedia describes a hierarchy as "an arrangement of items (objects, names, values, categories, etc.) in which the items are represented as being "above", "below", or "at the same level as" one another[105]".

Hierarchies are everywhere in society, but frequently implicit or concealed. This is the case with infrastructure and low carbon. There seem to be two types of implicit hierarchies:

- *"Oxford" hierarchies, which we can call "process" hierarchies; and*
- *"Wiki" hierarchies, which we can call "system" hierarchies.*

In principle, either type can be deployed for decision-making purposes – in effect, becoming a decision-making hierarchy.

16.3 Process hierarchies

A process hierarchy says that we always should take one type of action first, before another. Process hierarchies can be subdivided further, either because:

[104] https://www.lexico.com/en/definition/hierarchy
[105] https://en.wikipedia.org/wiki/Hierarchy

i. *it is always better to do the first thing than the second (a dominant process hierarchy), or because*

ii. *if we don't do the first thing first, we miss a vital step (a causal process hierarchy).*

Type (i) – the dominant process hierarchy - appears to be relatively rare in the area of infrastructure and low carbon. The most familiar is perhaps the Reuse, Reduce, Recycle hierarchy, or variants thereof. The graphic below shows the Scottish Government variant[106]:

Fig 58: the waste hierarchy

A similar idea (that first it is best to do nothing first, then there is a progressively less desirable and more resource-consuming or carbon-emitting series of choices) emerged from our review of carbon and buildings, initially in the Infrastructure Carbon Review[219] in 2013, which was then taken up again by the UK Green Building Council[220]. This is shown in the graphic below:

[106] https://www.environment.gov.scot/media/1217/natural-resources-waste.pdf

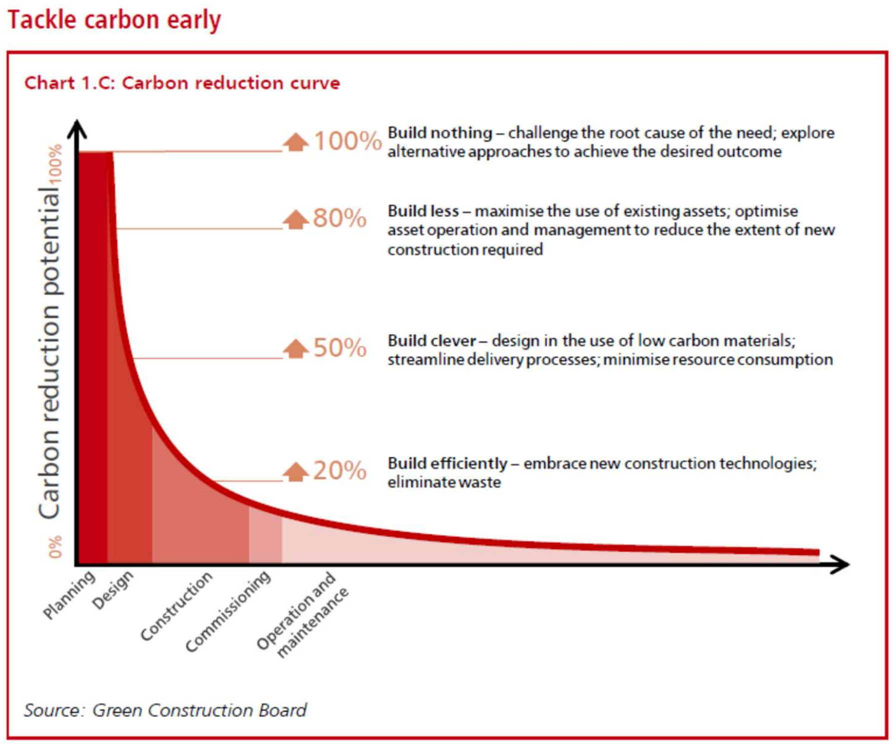


Fig 59: the carbon reduction in buildings hierarchy

A dominant process hierarchy is a highly generalising and simplifying decision-making tool. The fact that they are not frequently encountered in infrastructure and low carbon implies that confidence levels as to their applicability are not high. This may be due to the relative immaturity of thinking in this area or it may be that decision-making hierarchies of this type are limited in their usefulness in an area where there are too many unknowns and intersecting pathways.

The second form of process hierarchy – the causal process hierarchy - is common in appraisal and evaluation literature – the Green Book, the Magenta Book, transport guidance, etc – which we discuss earlier in this review. In effect, the hierarchy is a logic tree – a pathway to an outcome. An important refinement of this concept is where this becomes a circular process, recognising the role of feedback and continuous development, such as the Magenta Book's ROAMF policy cycle:

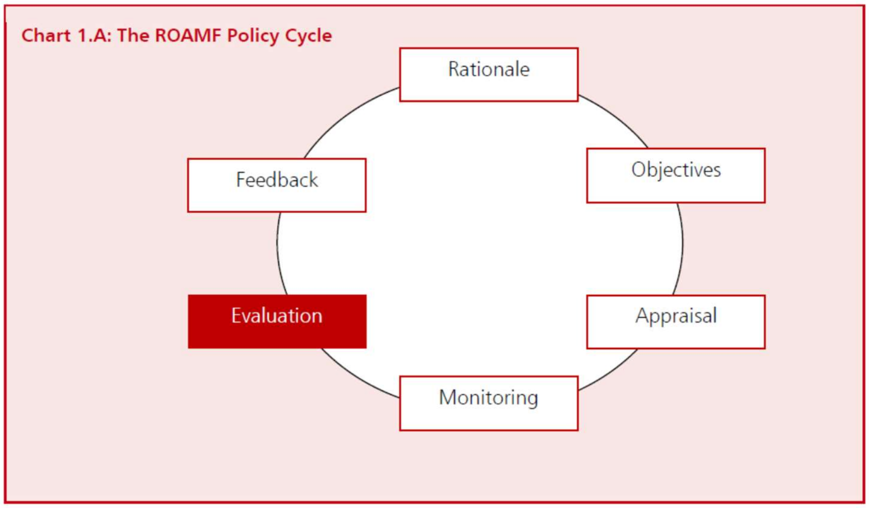


Fig 60: Magenta Book ROAMF cycle

These hierarchies will become problematic where they are not cyclical and their point of departure is incompatible with a decarbonisation agenda. We see this in transport appraisal, for example, when journey time is the primary "good" and therefore the starting point for the appraisal and no feedback loop exists to test whether this was the correct point of departure. We see this in regulated industries when current consumer cost is the point of departure for the logic tree. We saw it in renewable energy policy development, when wholesale fossil fuel price forecasts were the point of departure. And so on.

It will never be possible to get exactly the right point of departure for a decision-making process. This is essentially a hypothesis. Today's well-intentioned (and, as far as we know, well-informed) points of departure will prove to be wrong at some point in the future. Decision-making therefore has to be a cycle, not a straight line, so that we can monitor, correct, adjust - and ask at any stage what we should:

- *Do more of*
- *Do less of*
- *Keep doing*
- *Stop doing.*

16.4 System hierarchies

Some system hierarchies at first glance look like process hierarchies. However, it is not difficult to see that they are more complex, with greater scope for connectivity between elements. For instance, the UK Government's Transforming Infrastructure Performance[221] diagram is clearly a system hierarchy:

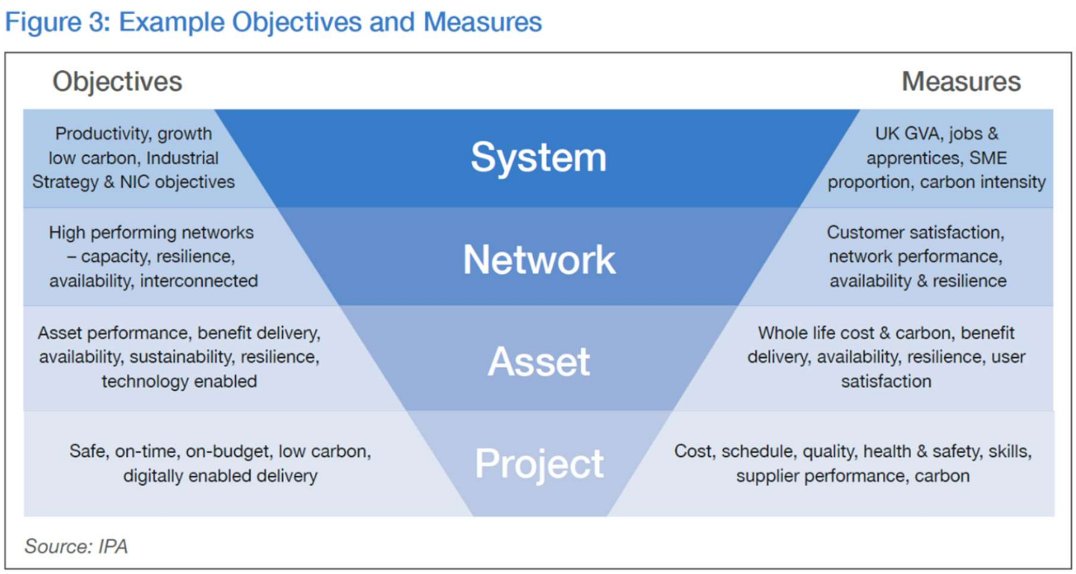


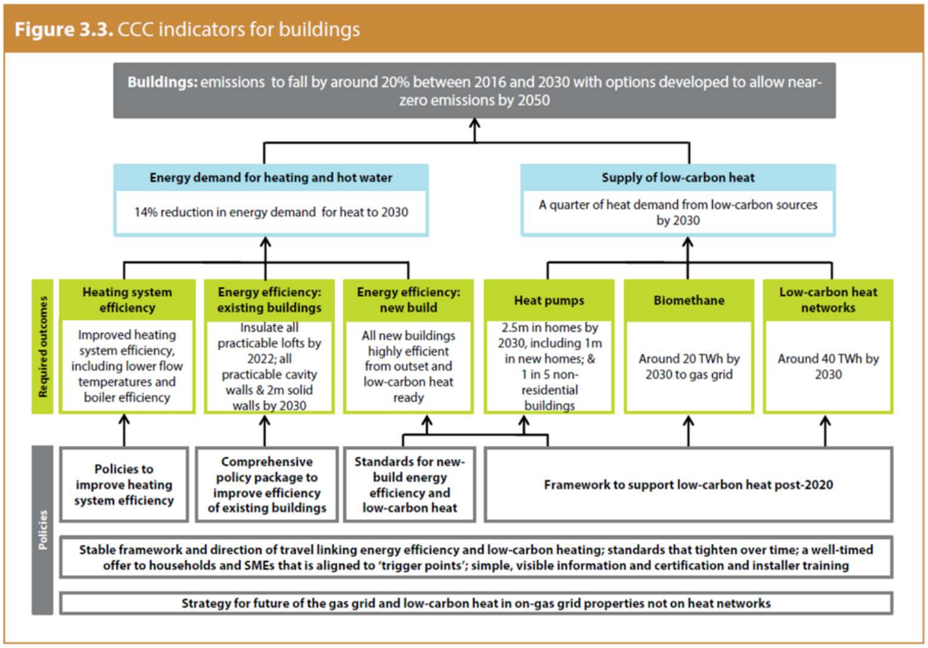
Fig 61: system hierarchy - carbon in infrastructure

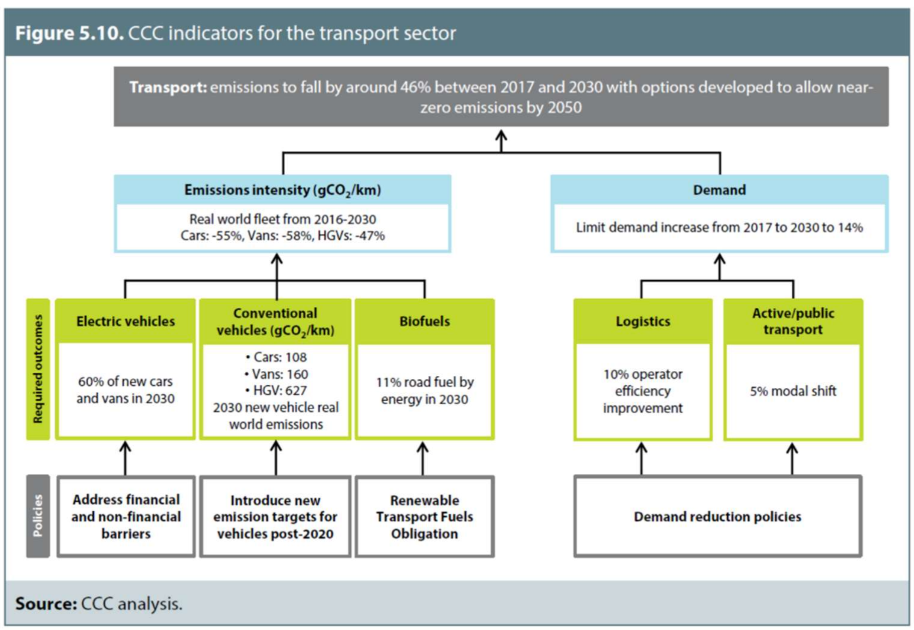
This is clearly a system hierarchy and not a process hierarchy as it identifies levels, relationships between them and interventions / actions necessary at each level. What it doesn't do is set out a relative order of importance – all levels are important.

Hierarchies, says Dana Meadows, "are brilliant systems inventions, not only because they give a system stability and resilience, but also because they reduce the amount of information that any part of the system has to keep track of".[222] In systems, hierarchies mean that sub-systems can be created which are to some extent self-sustaining but they are nevertheless connected up to and supportive of the wider system.

This has profound implications, not only for the way we think about resilience, but the way a patchwork of different sub-sets of initiatives (and we have seen this pattern throughout the decarbonisation agenda in this report) can contribute to the ultimate net zero objective. The prevalence of "low regrets measures" in building, transport and heat strategies shows these system hierarchies in play. Low regrets measures are bundles of initiatives that can happen regardless of the longer term pathway – in that sense they are independent of and yet contributing to the whole.

Below are CCC's building indicator and transport hierarchies[223], for example. We can start to see how low regrets measures can be slotted into different aspects of these hierarchies and how self-sustaining sub-hierarchies can exist, while supporting the overall programme.





Figs 62 & 63: CCC transport and buildings hierarchies

System hierarchies also work for local energy systems and blue-green infrastructure, balancing independence and inter-dependency between different components. They can help us to develop effective decarbonisation pathways, but the ultimate system, of course, is the planet, which draws a line around the whole system.

17. Spatial Considerations and Green Infrastructure

*<u>Question element:</u> Any **spatial considerations** i.e. urban/rural/other spatial categorisation as appropriate*

*<u>Question element:</u> A consideration of the role of **green infrastructure** i.e. trees; other carbon sinks and negative emissions tech such as **peatland restoration/bio-energy carbon capture**, use and storage*

Headlines
"Accessibility" is still defined in terms of drivetime, implying a car-based society in Scotland. Planning legislation and place guidance currently send weak signals in relation to carbon reduction. Cities have a natural density that should make them more "carbon efficient" but the reality is more nuanced and more variable by location. There are signs of a potential suburban poverty trap as city centres become more attractive places to live and property values rise. There is a lot of greenspace in towns and cities but the signs are that often it may not be looked after or valued effectively. Blue-green sustainability solutions have a number of attractions and can be self-renewing.

17.1 Introduction

In the past decade and a half we have seen greater attention in policy-making paid to the defining characteristics of the places in which we live. There seems to be a recognition that there can be a correlation between the quality of a place (whatever that means) and its sustainability. The converse is also thought to be the case – that urban sprawl, for instance, has wider negative social, environmental and wellbeing implications than simply increased emissions. These trends in thinking have emerged as the global population becomes progressively more urbanised.

Sustainable places (both cities and non-cities) would be a justifiable subject for review in its own right and there isn't time to do it justice in this review.

Instead, this chapter focuses mainly on the context and on identified literature that either links low carbon, infrastructure and place or which specifically covers blue and green infrastructure.

17.2 Scotland's geography

SG uses a 6- and 8-fold urban-rural classification system to understand the density of physical connections between communities. The 6-fold classification is set out in the table below, which shows that around 70% is "large urban" or "other urban".

	Urban Rural Classification	% of Scotland's population
1 Large Urban Areas	Settlements of 125,000 or more people.	34.6%
2 Other Urban Areas	Settlements of 10,000 to 124,999 people.	36.2%
3 Accessible Small Towns	Settlements of 3,000 to 9,999 people and within 30 minutes' drive of a settlement of 10,000 or more.	8.5%
4 Remote Small Towns	Settlements of 3,000 to 9,999 people and with a drive time of over 30 minutes to a settlement of 10,000 or more.	3.5%
5 Accessible Rural	Areas with a population of less than 3,000 people, and within a 30-minute drive time of a settlement of 10,000 or more.	11.2%
6 Remote Rural	Areas with a population of less than 3,000 people, and with a drive time of over 30 minutes to a settlement of 10,000 or more.	5.9%

"Accessibility" is defined by drive time, so the core underlying presumption is that most households have access to a car. If a significant model shift is required for decarbonisation, this assumption will need to be changed (e.g. public transport or broadband connectivity should be taken into account).

The map below illustrates the distribution of "accessible" areas across Scotland, which are mostly in the Central Belt and up the East Coast.

Map 2.2: Scottish Government 3-fold Urban Rural Classification 2016

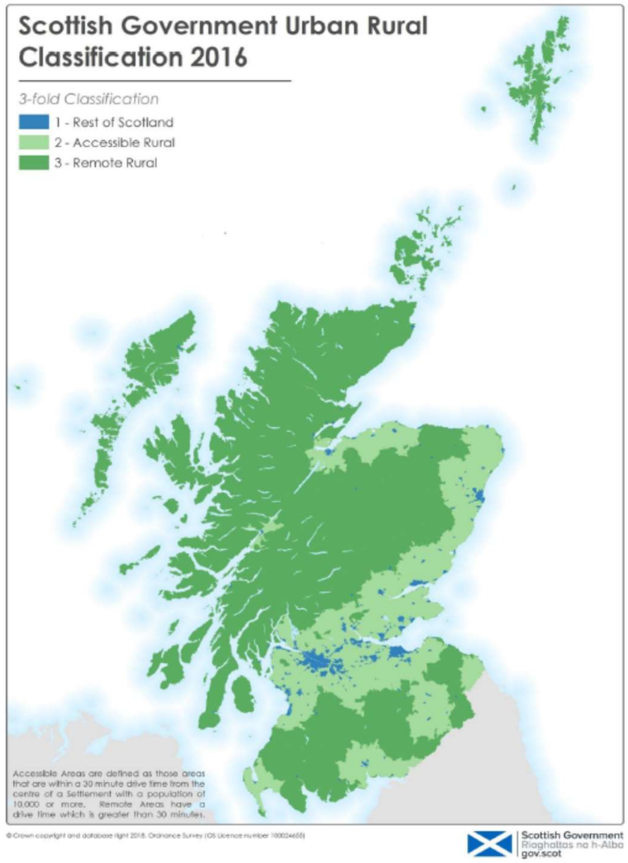


Fig 43: Accessibility in Scotland

It goes without saying that location is a critical determining factor for the suitability and sustainability of infrastructure development. It follows, therefore, that how we define accessibility has implications for how we move to NZCI. It also follows, of course, that how we plan places directly impacts on the carbon efficiency of those places.

There may also be tensions between perceived need (whose need?), expected impact and distributional fairness, and these will be played out in different ways for each element of infrastructure. Distinguishing "need" from "demand" may also be problematic (for example, when faced with the question of whether to build a new road to accommodate expected higher levels of vehicle traffic from a new development), and failure to do so may result in a higher carbon solution or greater inequalities, or both. What criteria will be used, for instance, to determine where the £500m proposed bus priority infrastructure in the Programme for Government should be spent?[224]

The distribution for economic development strategies for locations such as city region deals will also have a significant impact. As we have seen, there is an opportunity to build decarbonisation into these, but it is not obvious that this opportunity is being taken up systematically. There may well be conflicts from such an approach – if, for example, development in a particular area does not make sense from a national decarbonisation perspective. There is no evidence that these potential conflicts are being tackled systematically at the moment.

Major aspects of decarbonising infrastructure that are highly space / place dependent include: energy generation, housing and building energy efficiency; transport and integrated economic development (e.g. City Region Deals and Growth deals) and green and blue infrastructure.

While the concept of "place" is increasingly common in parts of infrastructure (for instance, housing developers like to think of themselves as "place-makers"), it is not apparent that there is a coherent "theory of place" that could be applied to infrastructure as a whole across Scotland.

Understanding what "place" means in policy terms appears still to be something of a work in progress (perhaps it always will be). This chapter looks at three areas – firstly, the very physical considerations arising in the electricity sector from the separation between locations for generation and use, secondly on cities as drivers for decarbonisation or resource use, and finally on blue and green infrastructure as the infrastructure type whose frame of reference is most clearly determined by ideas of "place".

17.3 Planning and Place

It is widely accepted that Scotland needs to be on a path to a low carbon society. If this is an objective to be seriously pursued, then low carbon needs to be a strong guiding principle within the country's legislative framework, in order to provide the necessary underpinning for policy.

This is not yet the case for the built environment - the recently passed Planning (Scotland) Act could have presented such an opportunity, but the final legislation does no more than mention climate change as a consideration in planning, sending a weak signal on adaptation and no signal on mitigation at all[225].

SG's Draft Planning Delivery Advice[226] is similarly non-committal. It makes two references to carbon in a 78-page document as follows:

"Planning authorities should provide leadership by looking ahead to identify how development strategies can be future-proofed by anticipating and making provision for new and emerging technologies, particularly those which can contribute to lower carbon living.[227]" and "Planning can play an important role in improving connectivity and promoting more sustainable patterns of transport and travel as part of the transition to a low carbon economy"[228].

The Scottish Government's Place Standard (see below) provides a clear standard from a place-making perspective, but there remain questions as to how it should be applied. Moreover, while "natural space" considerations are an element of the Standard, there is no mention of carbon and the Standard falls short of treating sustainability as a dominant driver.

At present, therefore, the Scottish planning system as a whole does little more than acknowledge carbon as a factor. This doesn't seem adequate. It should be noted that the Programme for Government promises a "fundamental overhaul in building regulations" – but, as we have seen, much of the decarbonisation challenge is not about the buildings themselves, but the space between them.

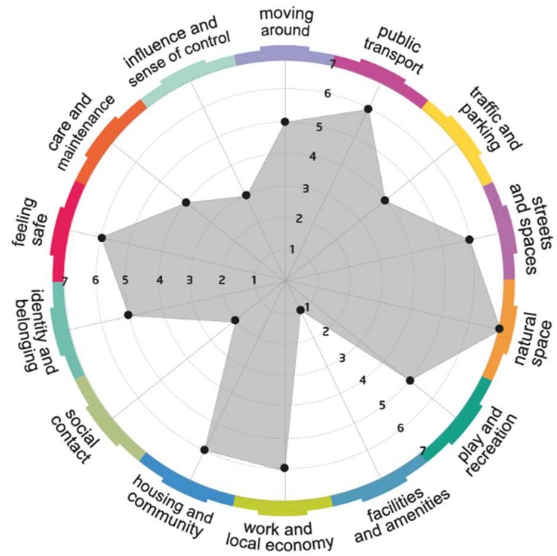


Fig 44: The Place Standard

17.4 Cities

The world is rapidly urbanising. But it is important to bear in mind the obvious point that the UK, along with the other early industrialised nations, had an early head start and is already largely urbanised. When the world as a whole passed the 50% urbanisation mark in 2008, the UK was already at 80%. However, the UK's urbanisation levels are still projected to increase and reach 90% by 2050[229].

Connecting everything up to deliver resource efficiency makes sense in a dense city context, as this graphic from Grant Thornton's 2011 Sustainable Cities report illustrates, although how and whether this networked approach can be replicated in suburban and remoter rural areas is another question.

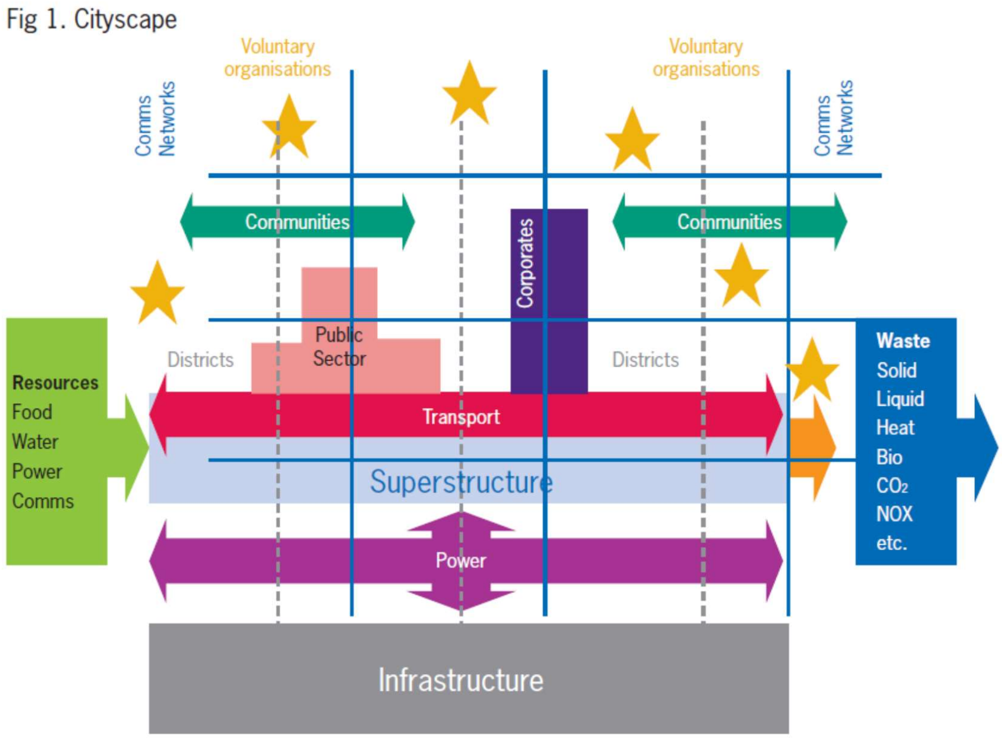


Fig 45: Networked "CityScape"

A report by the **Global Green Growth Institute** ("Infrastructure Finance in the Developing World")[230] showed how metropolitan densities have a significant impact on carbon emissions. The graphic below shows two cities, Barcelona and Atlanta, with similar populations and levels of wealth, but significantly different levels of transport emissions per person. In a way, this is self-evident (as sprawl creates a greater need for private personalised transport), but the graphic illustrates the point well.

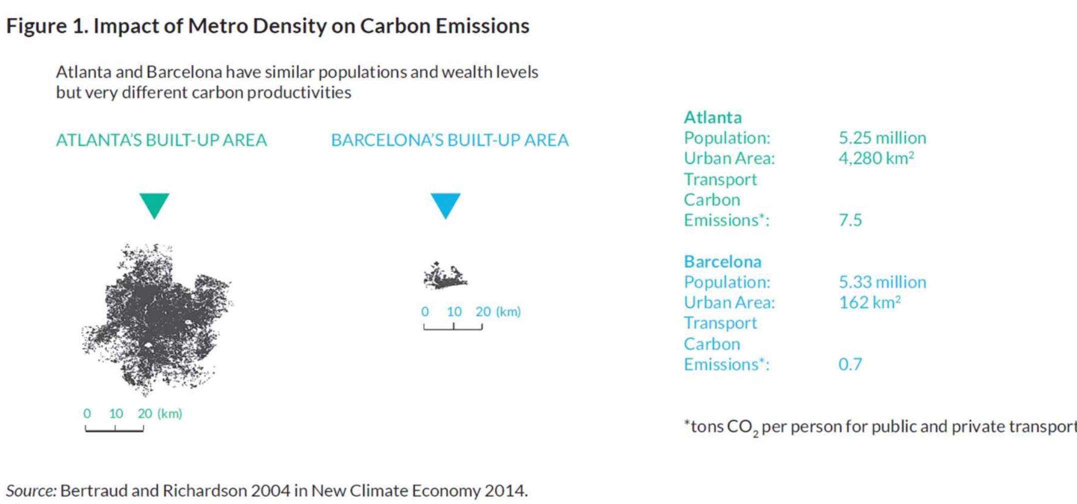


Fig 46: Urban densities and CO_2 emissions

Cities have, since about the turn of the century, been thought of as effective vehicles for efficient resource use and decarbonisation[107], due to their density of population and economic activity. However, this status is dependent on making timely and appropriate investment decisions on low carbon infrastructure.

Cities in the past 200 years have not always been the favoured vehicle for societal development. We have seen a roller-coaster of changing perceptions of cities, as this graphic from "the Future of Cities"[231] illustrates.

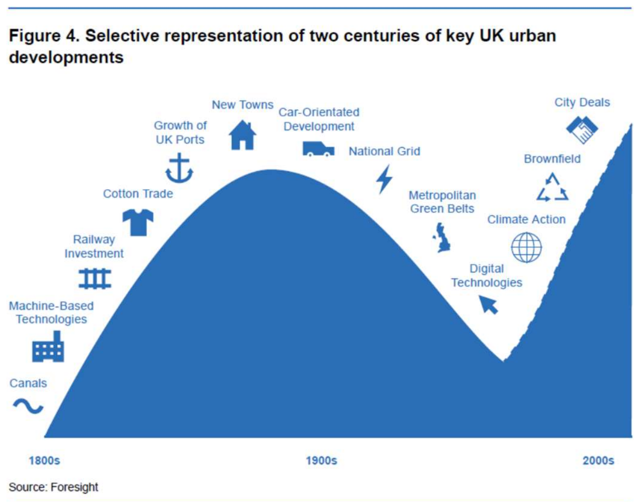


Fig 47: Cities rollercoaster

One pervasive idea that emerged about a decade ago was that cities would be a magnet for low carbon investment. A report in 2017 on the low carbon investment landscape for the global C40 group of cities (London is the sole UK member) [232] suggests that amongst this group, the picture is mixed: on the one hand, the scale of investment looks significant, while on the other a number of barriers to greater deployment remain.

Between 2011 and 2015, C40 cities reported having invested US$1.5bn in low carbon infrastructure projects and programmes. C40 cities disclosed capital costs for roughly 15% of the sustainable infrastructure projects currently being developed. Even this fraction of projects amounts to a planned investment of US$15.5 billion – implying that the total investment across C40 may be much greater.

But the C40 research also indicated that mayors face significant barriers accessing and attracting finance, while the finance industry reports a lack of understanding of the low carbon technology being deployed and limited experience in the financing models that cities use to fund infrastructure projects.

A key step in increasing the interface between cities and financial institutions is seen as cities improving project pipeline development information and communicating climate change-

[107] Stewart Brand, in Whole Earth Discipline, dates the "good news" story about cities back to 2003 with the 2003 UN—HABITAT report "The Challenge of Slums", although readers of Jane Jacobs will know that she was writing about the capacities of cities in 1961 ("The Death and Life of Great American Cities").

related projects to the finance industry – for instance, through CDP's annual disclosure platform.

South & West Asia reported developing, on average, the most projects per C40 city – with 110 low-carbon infrastructure projects compared to an average of 20-40 new projects per C40 city in other regions.

Notwithstanding the density arguments, one area that may be worthy of further research is the extent to which the industrial and / or architectural legacies of cities can affect their ability to decarbonise, and how progress is distributed across different types and locations of cities worldwide.

Are we living more densely?

ONS data show that the way populations shift across the UK is complex and regionally defined – and not necessarily a binary question of cities versus the rest[233]. All the UK's city regions have grown in population since 2011 and are projected to continue to grow, but Greater London has had, and is projected to have, the most rapid growth. On average the city regions outside London have grown slightly more slowly than non-city region areas in the UK (2.3% vs 2.5%) but there is considerable variation, with the fastest growth in Bristol and the slowest in Glasgow.

The variation in growth rates results from a number of factors. The size of different age cohorts in the population is especially important in explaining changes to the numbers in each age group, most notably the rapid growth in the population aged 65 and over. Patterns of internal (from the rest of the UK) and international migration are very different. While some city regions, notably Bristol and Edinburgh, have had population increase from internal migration, on average there has been a net outflow to the Rest of the UK, which suggests that despite all the commentary and analysis of the benefits of greater population density, suburbanisation is continuing.

On the other hand, all areas have seen growth from international migration, with a concentration of immigrants in the 22- to 29-year-old age group. For all the components of population change presented in the report, there are city regions falling either side of the average for the rest of the UK, with the difference between city regions and the UK average varying less than the difference between city regions. This suggests that although they may differ in physical characteristics from other areas of the country, city regions are not inherently distinctive in terms of population dynamics. Instead they vary considerably, but with Greater London markedly different from the rest. All of this suggests that urban decarbonisation initiatives need to be understanding of the specific places in which they take place. There is no "one size fits all" for every city.

Inequalities of urbanisation

Moreover, an analysis[234] by the Urban Studies Centre at the University of Glasgow suggests that a process of suburbanisation of poverty may be taking place. In early-industrialising countries, suburbanisation occurred as more affluent groups moved out to the suburbs as higher income groups are moving into central urban areas and displacing poorer communities, either through direct replacement of poor households by the non-poor, or indirectly, as poorer people are priced out of certain neighbourhoods. While the picture is complex and care needs to be taken to avoid over-generalising, if this outward migration of poorer people is taking place, if city centres retain (and potentially increase) their role as providers of employment, decarbonisation strategies whose success is based on a dense urban paradigm may place people on lower incomes at a disadvantage. It may be that market-based city decarbonisation strategies will tend to "follow the money" in this respect, leaving it to government to provide the compensating mechanisms.

From a regional perspective, a paper from the Bennett Institute at the University of Cambridge ("The Imperial Treasury: appraisal methodology and regional economic performance in the UK")[235] also argues that a centralising development perspective exacerbates the disparity between the least and most productive regions in the UK is extreme by the standards of most other OECD economies.

While there are many contributory factors, this paper argues that an important aspect is the concentration of public investment in and around London and the South East (so that growth becomes a self-fulfilling prophecy). The appraisal process for infrastructure investment projects follows the procedures set out in the Treasury's Green Book, with major funding allocation decisions almost wholly centralised.

The authors argue that the official methodology has reinforced the regional imbalance of the UK economy and that recent changes to the appraisal methods (See Chapter 14) are welcome but unlikely to redress the London bias in infrastructure decisions. While evidence-based appraisal is important, infrastructure investments also need to be based on a strategic view about economic development for the whole of the UK.

The CBA methodology as set out in the Green Book, the paper argues, skews the analysis, meaning that it a poor tool for taking a long-term view about the economy and in particular about the spatial aspect of growth (see Section 14.5).

17.5 Greenspace

Marlowe Road, London[236]
The plan's aim was to demonstrate how integrated blue-green solutions can be employed to deliver a traditionally planned neighbourhood with a premier, 21st century sustainability level. Key Performance Indicators for the design included urban heat island mitigation, low building energy consumption, enhanced outdoor microclimate, indoor comfort and the efficient use of water. Applying the BG systems approach yielded a solar load reduction of 38 per cent, a heat island effect reduction of 33 per cent and an outdoor microclimate reduction of 3.5ºC for summer temperatures, relative to a standard development. As a result, the buildings' summer energy consumption was reduced by 24 per cent. Moreover, these above benefits were realised without incurring substantial additional costs.

Urban areas represent an estimated 8% of the total UK land area.

ONS[237] calculates that here are approximately 1.77 million hectares of urban area in Great Britain and of these, 0.55 million hectares are classified as natural land cover (31%).

Scotland has the largest proportion of both natural land cover (37%) and blue space (1%) in its urban areas. Both Wales and England have 30% natural land cover in urban areas. On average 23% of natural land cover in urban areas has a specific function, for example, a park or bowling green and 68% of this is publicly accessible.

England has the largest proportion of functional green space relative to urban natural land cover (24%), compared to 16% in Wales and 20% in Scotland. Wales had the largest proportion of functional green space sites that were publicly accessible (73%), this compares to 61% in Scotland and 68% in England. So overall, Scotland appears to be fairly well-placed in terms of greenspace as a proportion of urban area, although it looks as though considerably less is publicly accessible compared with either England or Wales.

In 2017, ONS[238] calculated that the removal of air pollution by urban green and blue space in Great Britain equated to a saving of £162.6m in associated health costs. The amount of carbon removed by woodland in UK urban areas was estimated to be worth £89.0m during 2017. This looks fairly constant since 2010 but may be concealing a volume decline if the carbon price has been rising. Noise mitigation by urban vegetation in the UK led to a saving of £14.4m in avoided loss of quality of life years during 2017. Recreation spent in nature in the UK urban environment was valued at £2.5bn in 2017.

A Sense of Place

The Royal Scottish Geographical Society[239] says that there is a movement to enhance and reinforce a sense of place in our towns and cities. Central to this is the contribution of the green (and blue) infrastructure to the public realm. This approach has been gathering momentum in Scotland.

The Scottish Government produced Green Infrastructure: Design and Place-making in 2011[240]. More recently, the RSGS says, National Planning Framework and Scottish Planning Policy also seek to protect, enhance and promote green infrastructure as an integral component of successful place-making. 2011 saw the publication of Scotland's Greenspace Map (SGM), believed to be a world first. It was the culmination of years of partnership working to 'stitch together' 32 separate local authority greenspace datasets into a single GIS dataset. The data shows the type and extent of greenspace in urban Scotland, categorising greenspace into 23 different open space-types (e.g. parks, private gardens, play areas, semi-natural and allotments). The dataset has been used to inform strategy and planning in local authorities, climate change adaptation opportunities mapping in Glasgow, and open space and health research in urban Scotland.

Scotland has a "great policy framework" for planning and sustainable development but lacks practical tools and techniques, it suggests, to help urban planners take a strategic view of their GI assets.

Better strategic planning of urban green infrastructure, however, is needed to ensure the provision of critical ecosystem services in the right places. Strategic planning should recognise and enable project-level activities that work with nature. Using a GI planning modelling tool, it is possible to highlight 'hotspots' of ecosystem service demand. This approach enables recognition of the multiple benefits of GI in urban spaces at strategic through to project level, thus delivering a key component of the Scottish Government's land-use strategy, namely that "Opportunities for land use to deliver multiple benefits should be encouraged."

The Scottish Government's Green Infrastructure: Design and Place-making[241] says that green infrastructure is not just about greenspaces like parks and open spaces, it also incorporates blue infrastructure including sustainable urban drainage, swales, wetlands, rivers and canals and their banks, and other water courses.

Considering green spaces or connections as infrastructure arises because simple things like trees, greenspaces and watercourses can provide valuable services in an ecological way.

Green infrastructure can deliver on functions and services such as shelter, access and travel, sustainable urban drainage, pollution mitigation and food production – as part of a wider ecosystem. This approach has the added benefit of enhancing habitats and creating attractive places. The multifunctional nature of green infrastructure is one of its intrinsic benefits (and its complexities) and can operate at differing levels.

When green infrastructure components are linked together to form green networks, further combined benefits can be achieved at a strategic level. Green infrastructure should be thought about at every scale of planning, from the strategic framework (allowing cross boundary issues to be considered) right down through neighbourhoods and within streets to the individual house or flat.

17.6 Green and Blue Infrastructure

What is not clear is how much of city infrastructure investment is in green and blue infrastructure as opposed to the traditional "grey". The CCC says that at present infrastructure mostly comprises hard engineering assets and the systems that operate and maintain these assets. Built infrastructure can impact upon the natural environment, and there is growing recognition of the potentially synergistic interplay between "grey" infrastructure and natural capital ("green and blue infrastructure").

Vulnerability and exposure to climate change are increasing in terrestrial and freshwater habitats; development in flood risk areas; risks to health from heat and cold; and risks to health from changes in air quality.

The UK's declining urban greenspace
Urban greenspace, says CCC, continues to decline, from 63% of urban area in 2001 to 55% in 2018[242]. The proportion of impermeable surfacing in towns and cities, which increases flood risk, has risen by 22% since 2001. The number of people with chronic respiratory conditions that make them more vulnerable to poor air quality is increasing. Woodland and farmland birds, butterflies and pollinators are declining. In addition, the condition of terrestrial and freshwater habitats is not improving quickly enough to meet Government targets. More greenspace means better resilience. For example, enhancing the quality of water in rivers can reduce costs at downstream water treatment works; improving the resilience of intertidal wetlands in estuaries reduces the need for costly sea walls[243].

However, a global recognition of the benefits of green and blue infrastructure as a more sustainable solution for cities is beginning to emerge. For instance, UNEP's Green Infrastructure Guide for Water Management[244] focuses on Green Infrastructure ("GI") solutions.

UNEP defines "green infrastructure" as "natural or seminatural ecosystems that provide water utility services that complement, augment or replace those provided by grey infrastructure" and a "Green Economy" as "(…) one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" (UNEP 2010). In a Green Economy, the value of nature is fully recognized, and growth is resource efficient and socially inclusive. This includes recognizing not only the monetary and nonmonetary value of ecosystem services, but also the costs that society would bear, due to the degradation or loss of ecosystems”[245].

GI solutions, it says, involve a “deliberate and conscious effort” to use the provision of ecosystem services to provide primary water management benefits, as well as a wide range of secondary co-benefits.

As a result, GI solutions can be used to support multiple policy objectives. For example, floodplains can reduce flood risk and simultaneously improve water quality, recharge groundwater, support fish and wildlife and provide recreational and tourism benefits.

While the value and function of grey infrastructure can be expected to depreciate over time, many GI solutions can *appreciate in value* and function over time as soils and vegetation generate or regenerate (which is why care needs to be taken when applying measurement frameworks that are more used to valuing depreciating assets). The report gives the example of an investment in wetland rehabilitation for shoreline protection services. If the area is well managed and protected, a wetland will literally grow and expand its ecosystem services, providing, for example, increased shoreline protection services, whereas seawalls and levees will depreciate in value[246].

The guide addresses the general lack of awareness of GI solutions and associated cost/benefits and includes an outline methodology for water management options assessment. While in some cases planners may directly compare the advantages of “green versus grey” water infrastructure solutions, this guide places greater emphasis on understanding how green solutions can be integrated within an overall system of water management, composed of appropriately sited and designed elements of both green and grey water infrastructure. The methodology, therefore, provides meaningful evaluation of water infrastructure options – consisting of green and grey alternatives, or mutually supportive green and grey elements.

A detailed list of potential green infrastructure solutions is suggested, and shown in the graphic from the report below:

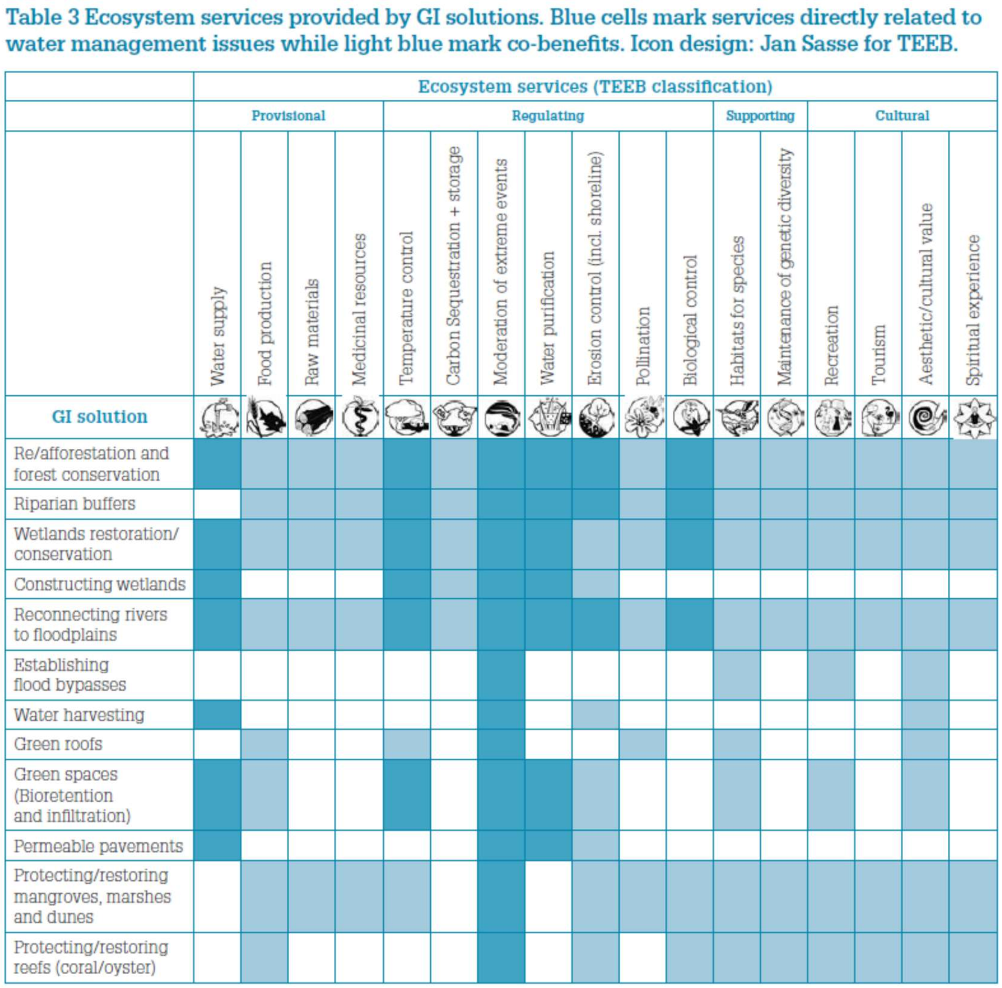


Fig 48: Ecosystem services provided by Green Infrastructure Solutions

UNEP argues for economic valuation of green infrastructure which, it argues, can help to place GI on a more equal footing with grey infrastructure for water management and allow decision-makers to adequately weigh economic trade-offs alongside other considerations and enhancing transparency in decision-making[247].

Valuation can also be used to optimize the allocation of resources across green and grey infrastructure options (either individually or together). Additionally, the quantitative case for GI investments can provide powerful support to decision-makers.

There are, it says, multiple valuation methodologies available to capture both market and non-market benefits from GI - for example, market prices and stated or revealed preference. Past economic studies can be used to approximate non-market values. Carbon sequestration can be valued as a public good. Alternatively, carbon credits can be valued based on market prices and subtracted from the total GI project costs.

However, the report also recognises that, relative to “grey” infrastructure, GI has relatively little historical cost data on which to base analysis and forecasts[248].

17.7 Wellbeing

Health benefits are often quoted as being a benefit of greenspace, but an Aventia report on West Princes Street Gardens in Edinburgh[249] found that there was surprisingly little academic literature on the strength of the link between wellbeing and greenspace.

A frequently quoted report is one from Japan, published in 2002[250], where the authors analysed the five-year survival rate of 3,144 people born in 1903, 1908, 1913, or 1918, who consented to a follow up survey from the records of registered Tokyo citizens in relation to baseline residential environment characteristics in 1992.

The main findings were that the probability of five-year survival of the senior citizens studied increased in accordance with their ability to taking a stroll near their residence in parks and tree lined streets near the residence, as well as in accordance with their preference to continue to live in their current community.

The principal component analysis identified two environment related factors: walkable green streets and spaces near the residence and a positive attitude to a person's own community. After controlling the effects of the residents' age, sex, marital status, and socioeconomic status, the factor of walkable green streets and spaces near the residence showed significant predictive value for the survival of the urban senior citizens over the following five years ($p<0.01$). The report concluded that living in areas with walkable green spaces positively influenced the longevity of urban senior citizens independent of their age, sex, marital status, baseline functional status, and socioeconomic status. Greenery filled public areas that are nearby and easy to walk in should therefore be further emphasised in urban planning for the development and re-development of densely populated areas in a megacity.

Green Prescribing[251]
James Hutton Institute researchers have produced a new report examining the barriers that older people face in getting out and about, and outlining measures aimed at removing or reducing such barriers. Outdoor activity is beneficial for physical and mental health and well-being, but the report found that less than 50% of over-60s and 40% of over-75s participated in outdoor pursuits one or more times a week, and said that GPs and medical professionals could help by encouraging older people to exercise more outdoors. Report co-author Dr Margaret Currie said that they had been able to identify a number of potential interventions, such as green prescribing which should be integrated with existing initiatives like health walks that offer opportunities for overcoming social and motivational barriers."

CCC's 2019 report on Scotland's progress[252] identifies healthy lifestyle choices as a key opportunity for improving public engagement in the decarbonisation agenda.

17.8 Peatland Restoration / Bio-carbon capture

The Committee on Climate Change notes that Land is a critical natural asset and that fundamental changes are required to land use if carbo reduction targets are to be met[108].

Deep emissions reductions entail releasing agricultural land for other uses. CCC's analysis suggests that emissions reductions of as much as 35 - 80% (20 - 40 MtCO2e) by 2050 compared with 2016 levels are possible while maintaining current per capita food production.

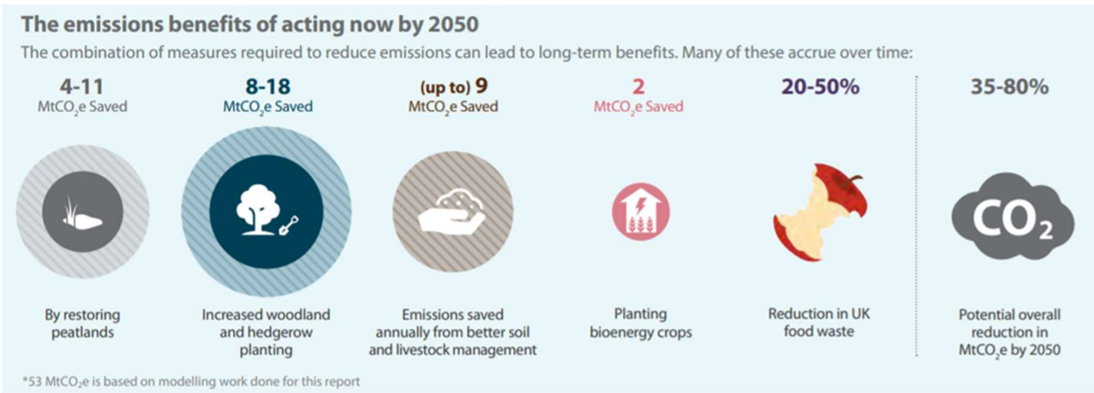


Fig 49 – potential emissions reductions from changes in land use[109]

Afforestation (increasing forest cover from 13% of all UK land today to up to 19% by 2050), restoring 55 - 70% of peatlands, catchment-sensitive farming and agricultural diversification can all contribute to meeting these reductions.

According to Scottish Natural Heritage ("SNH")[110], Scotland's soils contain more than 3,000 MtCO2e, about 60 times the amount of carbon held in our trees and plants, making soils Scotland's main terrestrial store of carbon.

Since 2012, PeatlandACTION has restored more than 15,000ha of Scotland's degraded peatlands. Scottish Government provided funding of £8 million to spend in 2017/18 to restore another 8,000 hectares of damaged peatlands and the Scottish Rural Development Programme has a £10 million funding stream devoted to peatland restoration.

More than 20% of Scotland is covered by peat soil. Scotland's peatlands hold over half (53%) of its terrestrial carbon store. Restoring peat-forming habitat previously drained or damaged ensures that the bog remains a long-term carbon sink rather than a greenhouse gas source.

Other soils are also an important carbon sink. Agricultural soils have the greatest potential to hold more carbon – an estimated 115 MtCO2e, which would be equivalent to 22% of total carbon dioxide (CO2) emissions from Scotland's energy sector.

A wide range of materials, from farm manures to non-agricultural composts, is used in farmland, forestry, land restoration, landfill reclamation, landscaping and gardens. Applying

[108] https://www.theccc.org.uk/wp-content/uploads/2018/11/Land-use-Reducing-emissions-and-preparing-for-climate-change-CCC-2018.pdf

[109] ibid

[110] https://www.nature.scot/professional-advice/land-and-sea-management/carbon-management/managing-nature-carbon-capture

organic materials to land could boost the carbon stock of Scottish soils, which appear to be losing carbon at unprecedented rates.

To meet recycling targets, production of composts from green waste and other organic materials diverted away from landfill is likely to increase. But the availability of a suitable landbank will affect how feasible it is to recycle more non-agricultural materials in Scotland.

Biochar (a charcoal-like biomass by-product) can also be used to help tackle climate change, as it enhances soil carbon sequestration and limits carbon flux exchange. Biochar can also improve soil fertility, though this matters less for carbon-rich soils like our peatlands and wetlands.

Land management: vegetation

SNH thinks 50 MtCO2e of carbon is locked in Scotland's vegetation – most of it held in natural woodland and forest. Woodland and forest covers more than 1.3 million hectares in Scotland (about 16% of our total land area).

Growing more trees is one way to increase the natural carbon reservoir. Exactly how much carbon a forest can hold depends on the tree species and the length of the crop rotation. But it varies between 700 to 800 tonnes of carbon per hectare.

Young forests grow rapidly and soak up carbon more quickly than mature forests. In mature forests, the carbon balance may reach a steady state as carbon storage is matched by decay.

The Scottish Government aims to increase woodland coverage to up to 25% of Scotland's total land area. The official target is 21% cover by 2032 (up from 18.7%). SNH notes that it is important that this should avoid releasing potential greenhouse gases from soils in the process. According to Scottish Government statistics, 11,200 hectares of new planting was undertaken in Scotland last year – above the current annual target of 10,000 hectares and 84% of all new planting across the UK[111].

17.9 Accounting for Green Infrastructure

There have been sporadic attempts, using natural capital or social return on investment principles, to place a monetary value on greenspace.

One of the more recent is the Natural Capital accounts for London's greenspaces (2017)[253]. This exercise found that London's public parks have a gross asset value in excess of £91bn and that for each £1 spent by local authorities and their partners on public parks, Londoners enjoy at least £27 in value.

The estimated avoided costs to Londoners in health costs from park usage were £950m per annum and the value of recreational activities was estimated to be £926m per year.

These large figures taken in isolation are not especially meaningful, partly because they refer to unique assets that are not readily replaceable (roads, in many parts of Scotland, have the same characteristic). They are therefore difficult to value and, as civic assets, it is not at all clear that a revealed preference method[112] works, either. But money is only a means of real

[111] See, for instance, https://forestry.gov.scot/news-releases/tree-planting-targets-smashed-say-ewing

[112] Revealed preference theory is a method of analysing choices made by individuals, mostly used for comparing the influence of policies on consumer behaviour. Revealed preference models assume that the preferences of consumers can be revealed by their purchasing habits.

or notional conversion, so this would not necessarily be a problem if there was enough analysis undertaken on a comparable basis of comparable assets.

As an isolated report, however, there is no comparison or measure of change (it might be more interesting, on the other hand, if we knew whether this figure of £27 had increased or decreased over a 10-year period). In the published report, there is no detailed explanation of the methodology used, so it is difficult to form a view on the robustness of the analysis.

Aventia Consulting, in its 2017 report on the West Princes Street Gardens in Edinburgh[254], found that city parks have been consistently associated with enhanced property values since they first became a feature of modern industrialised cities, although an at times conflicting[113] civic trend of widening public access to green spaces was a strong element of city identities between about the mid-19th century and Second World War[255].

It noted that Edinburgh had, like London, attempted to place a monetary value on its parks; in this case through a Social Return on Investment ("SRoI") calculation[114]. While the Edinburgh methodology is different from London's, the report similarly suffers from being an isolated piece of work, so there is no way of comparing the claimed benefit of £12 for every £1 invested. This apparently high return, the Aventia report suggested, could just as easily be due to underspend (i.e. the denominator in the SRoI calculation) as to achievement of high benefits. The basic problem in the greenspace / parks sector, certainly at the time of the West Princes Street report, was a lack of up to date analysis of the benefits of parks and civic amenities more widely, occasional reports often seeming to have the specific purpose of justifying spend on parks and amenities compared with other items of public expenditure.

The London report also found that the economic benefits from parks are not spread equally across or within London's boroughs. While the average density (park area to total area of the borough) in London's boroughs is 20%, there are wide variances – 40% of Richmond's area is parkland, while Newham, in the east, has only 7%. Perhaps not surprisingly, there is a correlation between income, property and access to parkland, with the value of parks as amenity services showing through in higher property values.

In conclusion, accounting for green infrastructure has not yet reached a stage where it can be considered a reliable comparative (let alone absolute) framework for measuring value.

[113] The "conflict" arises because rising property values can be predicated on a degree of exclusivity, whereas the civic instinct is to provide open access for all (for instance, Edinburgh's Princes Street Gardens were originally private). Central Park in New York throughout its history has felt the tug of these two forces.
[114] See: http://www.edinburgh.gov.uk/info/20064/parks_and_greenspaces/1300/the_value_of_council_parks

The Urban Tree Challenge Fund

The Urban Tree Challenge Fund (UTCF) has been developed in response to the UK government's commitment to provide £10 million for planting both large and small trees in and around towns and cities in England. This two-year fund will support a number of objectives in Defra's 25 Year Environment Plan, and also contribute towards meeting the government's commitment to plant one million urban trees by 2022. The fund will provide up to 50% of published standard costs for planting large and small trees and their establishment costs[256].

The eligibility criteria are complex. Among other things: there are higher scores if planting sites are in an area with Low Canopy Cover or in a Priority Place; an individual planting site must consist of a minimum of 150 "feather or whip size trees"; for large trees a minimum of 10 trees will need to be planted in one area; the total gross area for an individual planting site will not exceed 0.5 hectares; the minimum application value for a block bid is £500,000; the land must be free of trees and existing tree pits must have been empty for a period of 3 years[257].

17.10 The case for Green and Blue Infrastructure

Two reports from Imperial College: "Integrating green and blue spaces into our cities: Making it happen" (July 2019)[258] and "Blue Green Solutions- A Systems Approach to Sustainable, Resilient and Cost-Efficient Urban Development" (2017)[259] put the case for adopting urban blue-green infrastructure development.

(BGI) is defined in the later report as "a network of nature-based features situated in built-up areas that form part of the urban landscape". These features are either based on vegetation (green), water (blue), or both. They might include: green roofs and walls, grassed areas, rain gardens, swales (shallow channels, or drains), trees, parks, rivers and ponds.

The case for BGI is both as a climate change mitigation and an adaptation measure, together with a range of wider benefits to people and wildlife. There is widespread evidence, the paper argues, that communities would be better able to adapt if they were able to work with natural processes and systems.

Coming up with an "economically-optimal" standard amount of blue-green infrastructure, based on a precise assessment of costs and benefits, is not possible, however. This is because the specific costs and benefits of BGI solutions are dependent on local circumstances.

An alternative approach is proposed – to define a set of 'win-win' BGI solutions that are likely to have net benefits and very few negative trade-offs in most situations; in effect much like the "no regrets" strategies that we have seen for energy efficiency.

The shading of four trees can save 25% of the energy needed for cooling a building. In doing so, they offset about 3-5 times more carbon than a tree in a forest[260].

17.11 Scottish Policy Initiatives

Scottish Natural Heritage (SNH) leads on the Scottish Government's Green Infrastructure Strategic Intervention (GISI)[261], part of the 2014–2020 European Regional Development Fund (ERDF) programme.

The GISI aims to create better places and enhance the quality of life by improving the quality, accessibility and quantity of green infrastructure in Scotland's major towns and cities. In the first round £15m of ERDF money was made available through two competitive funds: the Green Infrastructure Fund, and the Green Infrastructure Community Engagement Fund.

Both funds target urban areas in Scotland that have a deficit of good quality greenspace and suffer from multiple-deprivation and an excess of vacant and derelict land. As funding was provided at a maximum intervention rate of 40%, the GISI delivers a total value of £37.5m of investment throughout the course of the programme.

Communities in these areas should benefit from the improvement and creation of green infrastructure to help to deliver successful multifunctional places, address inequalities, provide opportunities for better health and support sustainable economic growth. The ambition is to raise people's satisfaction with the quality of green infrastructure in their local urban areas.

The Scottish Land Commission and SEPA have launched an initiative to tackle the problem of vacant and derelict land[115]. Scotland currently has around 11,600 hectares of vacant and derelict land across 3,700 sites; roughly equivalent to twice the size of Dundee or over 9,000 football pitches. A register of disused property was set up 30 years ago and various projects have re-used land productively, but the total area of vacant and derelict land has barely changed.

Vacant and derelict land, whatever the size, affects communities and their potential. Over time it can damage an area, resulting in social, economic and environmental harm. While not solely aimed at creating greenspace, this is clearly a significant potential element of project solutions.

The Land Commission has signed a Sustainable Growth Agreement with SEPA to work together to deliver a substantial reduction in Scotland's long-term vacant and derelict land.

[115] https://landcommission.gov.scot/notsoprettyvacant/

18. End of life assets

*<u>Question Element</u>: A review of evidence on carbon impacts of **adapting**/upgrading/maintaining existing infrastructure assets*

There are three main energy-related areas which are of a sufficiently large scale to have merited notable studies on their end of life processes in the UK. These are (in declining order of practical experience) as follows:

- *Nuclear power plants*
- *Oil and gas extraction facilities*
- *Offshore wind installations*

Each of these is commented on below.

18.1 Nuclear

There is limited publicly available literature on the carbon emissions from nuclear decommissioning.

A report for the EU's Science for Environment Policy[262] produced in 2014 suggests that the greenhouse gas emissions produced during the decommissioning process may be underestimated in previous assessments. The study estimated that the decommissioning process for a German plant resulted in 1,651,265 tonnes of CO_2e, or 0.825 tonnes of CO_2e equivalent per tonne of waste. This was higher than studies which had been based on an assumed lifespan of 40 years, whereas for this particular plant, the average lifespan of all reactor vessels was only 14 years. A comparable study in the UK, the report says, produced higher emissions per tonne of waste (1.18t CO_2e) and this may have been because recycling was not considered in the latter project. Unfortunately, only a synopsis is publicly available, so we are unable, for instance, to examine the component parts of this assessment.

Not surprisingly, the focus has tended to be on managing nuclear waste when considering the decommissioning of nuclear assets, which is not within the scope of this review. However, the decommissioning process also takes time and energy, so the question that does fall within the scope of this review is whether the CO_2e from the decommissioning process is material relative to the power produced by the plant during its operational life.

It would be a relatively straightforward exercise to examine the energy use during the decommissioning phase and compare it with energy generated during operation for the fleet of non-operational power stations in the UK that are now undergoing decommissioning. However, we have not located any industry-wide study that has been conducted on this basis.

By way of example, we examined the Hunterston A Strategic Environmental Assessment Site Specific Baseline for 2014[263], from which we could see the energy use for the year, which gave an initial sense of scale in comparing operational generation with energy use during decommissioning.

Hunterston A was operational from 1964 to 1990, a total of 26 years. It had two reactors, each with a capacity of 180MWe, which were de-rated latterly to 150MWe. Averaging the capacity over the 26-year operational period and assuming an 80% load factor gives an estimated annual average output of 2,312 GWh.

The main decommissioning phase will be similar (slightly longer, as it is scheduled to run from closure in 1994 to 2022), when the site goes into Care & Maintenance[264], at which point on-site energy usage will become very low.

The 2014 report says that energy use at the site in 2012 was 5,698 MWh - around 0.2% of the average operational phase annual output. Even allowing for the likelihood that energy intensity was higher during the earlier decommissioning years, it would appear that end of life CO_2 emissions would not be a material factor when compared with the operational power output.

However, this is just a snapshot of one power station and this kind of data would need to be examined consistently across the fleet before firm conclusions could be drawn.

18.2 Oil & Gas Decommissioning

The UK Continental Shelf ("UKCS") is now in decline. Oil & Gas UK reported[265] in 2018 that as a consequence, by comparison with international counterparts, UKCS has a higher carbon intensity, despite recent efforts by companies on the UKCS during late-life asset management.

In 2017, the UK Continental Shelf emitted 14.2 million tonnes of CO_2. This is comparable to Norway which released a total of 12.2 million tonnes of CO_2, down from 12.8 million tonnes in 2016. However, Norway's production was over twice that of the UK in 2017, meaning it produced at a lower carbon intensity.

The National Audit Office reported at the beginning of 2019[266] that oil and gas operators in the UK are increasingly decommissioning their assets as they are reaching the end of their useful economic lives. Operator expenditure on decommissioning is rising: they have spent more than £1bn on decommissioning every year since 2014.

Decommissioning affects the Government's finances because operators can recover some of their costs through tax reliefs, enabling operators to deduct decommissioning costs from their taxable profits and potentially claim back tax previously paid. With decommissioning activity increasing, the Government is paying out more in tax reliefs at the same time as tax revenues have fallen due to a combination of lower production rates, a combination of falling oil and gas prices and operators incurring high tax-deductible expenditure.

In 2016-17, the government paid out more to oil and gas operators in tax reliefs than it received from them in revenues for the first time, although revenues recovered in 2017-18 and were greater than tax relief payments.

The government, says the NAO, wants operators to maximise the potential economic value of remaining oil and gas reserves and the government is committed to supporting the industry to maximise extraction due to its role in the economy, supplying energy and providing employment. This is what most CCS projects around the world are used for (see Section 19.6).

The future costs of decommissioning oil and gas assets are very uncertain. The OGA expects 49% of operators' estimates to be accurate to within -20% to +100%. It expects an additional 40% of estimates to be accurate to within -15% to +50%. There is the potential for some oil and gas assets to be reused for carbon capture usage and storage, for example, rather than being decommissioned.

It is not easy to find industry-wide information about decommissioning; probably because of the commercial confidentiality of the data. However, like the nuclear sector, occasional individual decommissioning reports can be found online, which provide an insight into the profile of these processes.

For example, a report is available on the decommissioning of the infrastructure associated with Dunlin, Merlin and Osprey fields[267].

Fairfield Betula Limited (Fairfield) is the operator of the Greater Dunlin Area, located in United Kingdom Continental Shelf (UKCS) Block 211/23 of the northern North Sea.

Termination of Production from the Greater Dunlin Area was announced in May 2015, having achieved Maximum Economic Recovery (MER) from its fields. Termination of Production was agreed with the Oil & Gas Authority (OGA) on 9th July 2015. The 24-inch Dunlin Alpha to Cormorant Alpha oil pipeline (PL5) currently transports crude oil from Dunlin Alpha to the Sullom Voe Terminal (Shetlands). Following conditioning and flushing operations, the PL5 pipeline will be taken out of service from 30th June 2019.

The Dunlin Alpha to Cormorant Alpha Pipeline Environmental Appraisal report, which was published in March 2019, indicates that atmospheric emissions are concluded to have no significant impact and are usually extremely small, especially when considering subsea decommissioning scopes such as these proposed for the PL5 pipeline.

The majority of emissions relate to the vessel time or the hypothetical remanufacture of material decommissioned in situ. As the decommissioning activities proposed are of short duration this aspect was not anticipated by the report to result in significant impact. CO_2e generated by the recommended decommissioning option was predicted at 47,483.6 tonnes. This level of emissions was considered to be “not worth further assessment”.

The US Environmental Protection Agency reckons that a typical car emits around 4.6 metric tonnes of CO_2 a year, so this decommissioning process could be thought of roughly equivalent to another 1,000 cars on the road for a year[116].

By comparison, the upstream production of oil & gas produced 15.7m tonnes of CO_2e in 2017 – 3% of the UK’s total[117]. On average, 64,567 tonnes of CO_2e were produced per production installation on the UKCS in 2017, compared with the average of 72,500 tonnes in 2016[268].

The opportunity for a circular economy strategy for decommissioned oil & gas assets was identified in 2015 by RSA, working with Zero Waste Scotland. Called the “Great Recovery”, the project identified opportunities to reduce the environmental impacts associated with recycling/disposal of materials; reduce the net cost of decommissioning; and develop new oil and gas industry sub-sectors which could offer additional market and job creation opportunities for supply chain companies in a lower oil price economy.

The total value of decommissioning across the North Sea to 2040 is estimated to be £46bn, with 40 platforms being decommissioned by 2017 at an estimated average annual cost of £1.8bn. Over 50% of the assets will come from the UK sector of the North Sea, comprising of over 470,000 tonnes of topside, substructure and subsea installation.

[116] https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle

[117] https://publications.parliament.uk/pa/cm201719/cmselect/cmscotaf/996/99609.htm

Currently the majority of the materials and equipment from these platforms is recycled, with very little re-use or remanufacturing. The potential value inherent in re-use of platforms has been shown to be significantly higher than recycling.

18.3 Reuse / Circular Economy for end of life O&G assets

The RSA Great Recovery & Zero Waste Scotland Programme (2015) sets out a circular economy (as opposed to recycling) strategy for the O&G sector.

The opportunities identified in the report are illustrated in the graphic below and fall into two categories:

Component re-use
1. Steel sections from both jacket & topsides. (Together, the jacket and topsides account for around 97% of materials from the platforms.)

2. Pipelines (noting the expectation that buried pipelines will be exempted from the need for removal)

3. Anchor chains & cables

Equipment reconditioning and re-use
4. Vessels and tanks

5. Accommodation blocks

6. Winches

Concrete mattresses were excluded from the analysis as they were the subject of a separate study being undertaken for ZWS.

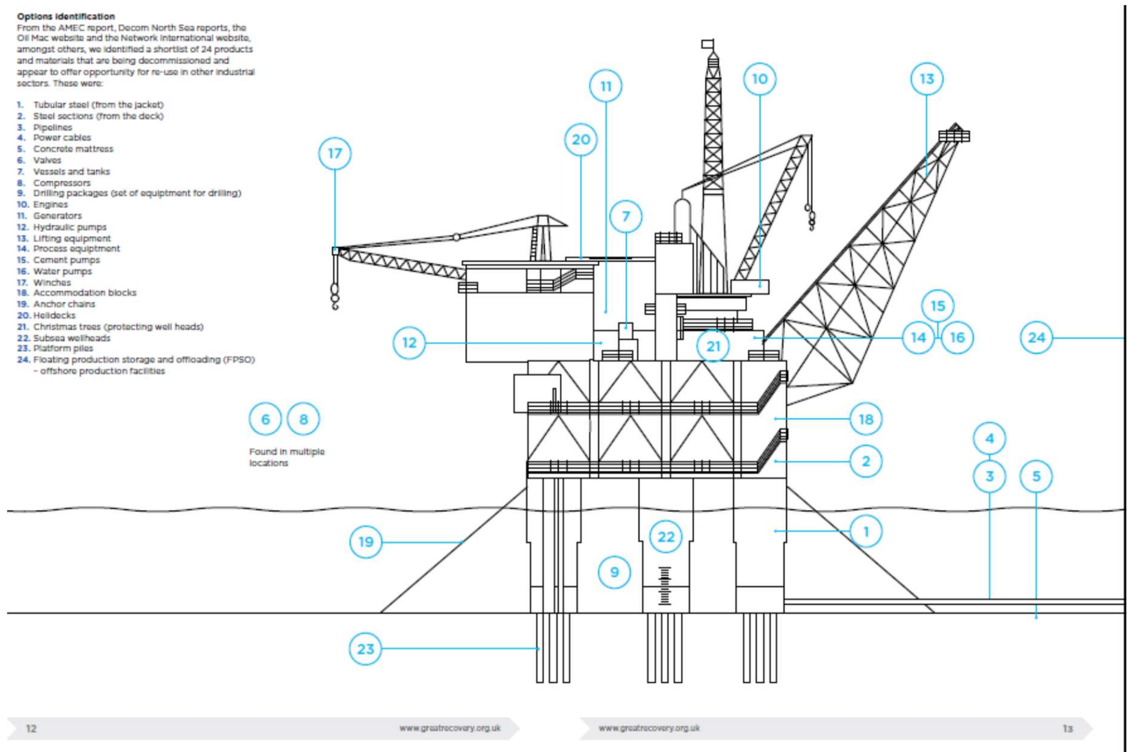


Fig 50: Circular economy options for O&G decommissioning

We have not found any evidence that these opportunities are currently being acted on.

In July 2019, BEIS issued a consultation on the reuse of oil and gas assets for carbon capture usage and storage ("CCUS")[269]. A small number of the 300-odd platforms and 1,000 pipelines in the North and East Irish Seas could, the UK Government believes, be re-used as part of the transport and storage infrastructure of a CCUS project.

Putting in place carbon dioxide infrastructure to transport and permanently store the carbon dioxide is essential for the success of CCUS and its ability to scale up.

Government has been working to examine new business models for carbon dioxide transport and storage but the development of a transport and storage network for carbon dioxide will require large upfront capital expenditure to construct carbon dioxide offshore and onshore pipelines and develop carbon dioxide storage sites and wells, alongside associated infrastructure including compressor stations and injection equipment. Whilst these initial construction costs are likely to be relatively high, operating costs would be relatively low.

There is the potential to reduce the costs of deploying carbon dioxide infrastructure through the re-purposing of offshore oil and gas assets that have reached the end of their commercial life to be part of a carbon dioxide transport and storage network.

This presents an opportunity to both CCUS projects and to oil and gas operators, which has been highlighted in a number of recent reports to Government.

Project Acorn is a CCUS project in North-East Scotland centred at the St Fergus gas terminal. The project is proposing to commission in the early 2020s, initially capturing carbon dioxide from the St Fergus gas terminal.

Apart from the question of suitability of assets, there are some challenges or barriers to the adoption of oil and gas assets for CCUS, most notably timing (they may be required for CCUS at a time that the owner still wishes to extract oil) and the decommissioning liability regime, which means that previous owners can be made liable for decommissioning, which may act as a disincentive to transferring ownership[270]. BEIS is proposing to remove this barrier in respect of assets which have been transferred to a CCUS project.

The results of the consultation had yet to be published at the time of writing.

18.4 Offshore Wind

A briefing paper from the University of Edinburgh's Climate Exchange[271] (2015) examines whether offshore wind farms actually achieve a net carbon emissions saving over their lifetime. It is necessary to bear in mind the time lag in collecting evidence, as offshore wind has progressed considerably in the last decade and this briefing paper will only have been able to use information from the early part of this period. Perhaps more importantly, the experience of decommissioning offshore wind farms is largely non-existent.

The paper also finds that decommissioning costs are largely neglected in studies as, the discounted value is generally regarded as low or costs are assumed to be equivalent to the salvage value of the assets. In studies that include such costs for wind, they are included as a percentage of capital cost, e.g. 5% (IEA, 2010); or as a per kW cost. Crown Estate (2012) included the costs of removing the turbines and infrastructure above the seabed but ignored any residual value.

One estimate quoted by the brief places the share of lifetime CO_2e places the end of life share at 1.2%, as illustrated below.

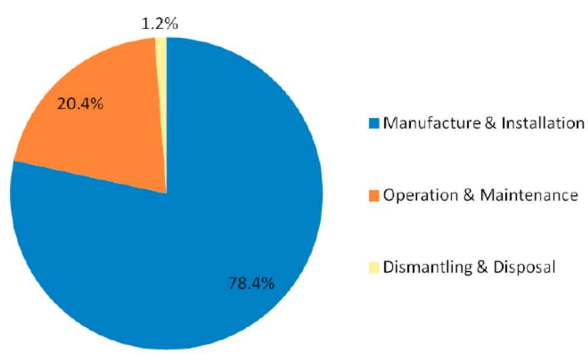


Figure 13 - Contribution of each life cycle stage to carbon emissions (from Wagner et al. (2011))

Fig 51: Lifecycle contribution to CO_2 emissions for offshore wind

Recycling can make a significant difference to the end of life stage, due to varying assumptions about the use of recycled materials and the recyclability of any waste.

There are different ways in which the impacts (or benefits) of recycling are dealt with when assessing the life cycle emissions of a wind turbine, as recycled materials may be used in the initial manufacturing stage, and materials may also be recycled at the end-of-life.

Both of these practices may affect the costs and emissions at both the manufacturing and decommissioning stages but are open to double counting. Irrespective of which recycling method is used, assumptions about the end-of-life recyclability will affect the costs and emissions associated with disposal of the waste materials, as recycled material will not need to undergo waste treatment. The majority of studies do not explicitly state the emissions savings due to assumptions about recycling; however, in a study of an onshore turbine this was examined, and it was found that the inclusion of recycling credit (using the recycled content method) decreased the overall carbon emissions by 44%[272].

19. New Technologies

Question element: *Consideration of any role of **'new tech'/earlier stage negative emissions technologies** which are significant factors in the UK CCC Net Zero analysis related to recommendations for Scottish Gov net zero 2045?*

Headlines
Key new low carbon technologies (as opposed to existing established ones): energy system innovation through smart grids, peer to peer and flexibility services; wave & tidal; hydrogen for heat and transport; electric road freight; circular economy. Negative emissions technologies (apart from reforestation) unproven at scale.

19.1 Introduction

This chapter will attempt to highlight the principal identified new technologies required to meet 2050 targets – i.e. those that are still largely at the development stage. For simplicity we are using the term "technology" in a broad sense; in effect, to denote areas of technological development.

The mainstream renewables technologies: onshore and offshore wind, biomass, solar PV, together with ULEVs for private non-commercial and public transport – are therefore not covered here.

The first point to note, however, is that notwithstanding some of the policy and implementation challenges that have been detailed in this review, the cost of some key energy technologies has come down very rapidly in recent years notably offshore wind, onshore wind, solar PV and lithium-ion batteries.

The rapid cost progression of these technologies is potentially a positive signal that the targets are achievable, despite the need for new technological development.

We covered the decline in the cost of offshore wind in Section 13.10. The decline in solar PV costs is well documented, but the rather busy chart from Lazard[273] below shows that utility-scale solar PV at $36 / MWh is now competitive with most forms of conventional generation. Onshore wind, at the bottom end of its cost range is the lowest cost energy option apart from fully depreciated nuclear energy at $29 / MWh (and even cheaper than fully depreciated coal), while offshore wind, at $92 / MWh, is competitive with nuclear at full absorption cost.

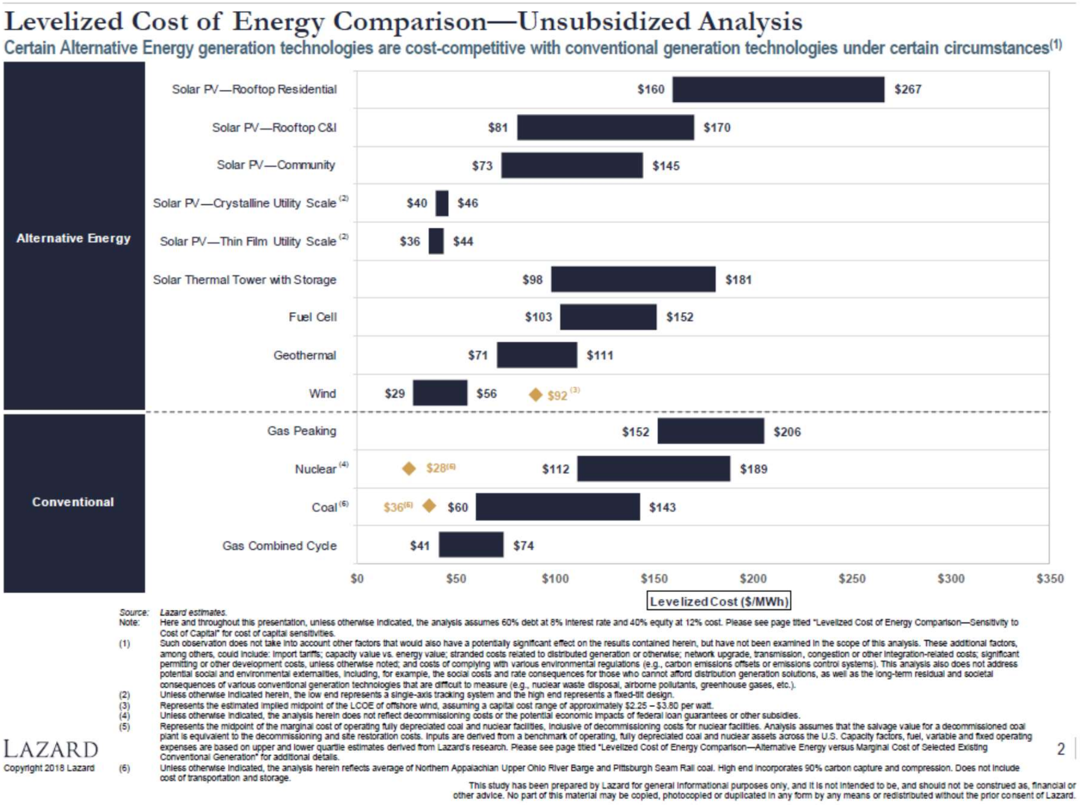


Fig 52 – levelized cost of energy, Lazard, October 2018

This is potentially transformational, and it offers considerable encouragement for new technologies, which may be able to achieve a similar pathway.

The cost of transitioning to net zero carbon economy by 2050 was recently publicly estimated by the then Chancellor of the Exchequer Philip Hammond at £1 trillion – or around £70bn a year. This figure was then rebutted by one of the panel members who reported to CCC on net zero[118], who argued that Hammond is simply incorrect, because he fails to take account of the "learning curve" for new technologies. This is illustrated, for example, in the chart below from the Frauenhofer Institute.

[118] See: https://www.theccc.org.uk/wp-content/uploads/2019/05/Advisory-Group-on-Costs-and-Benefits-of-Net-Zero.pdf

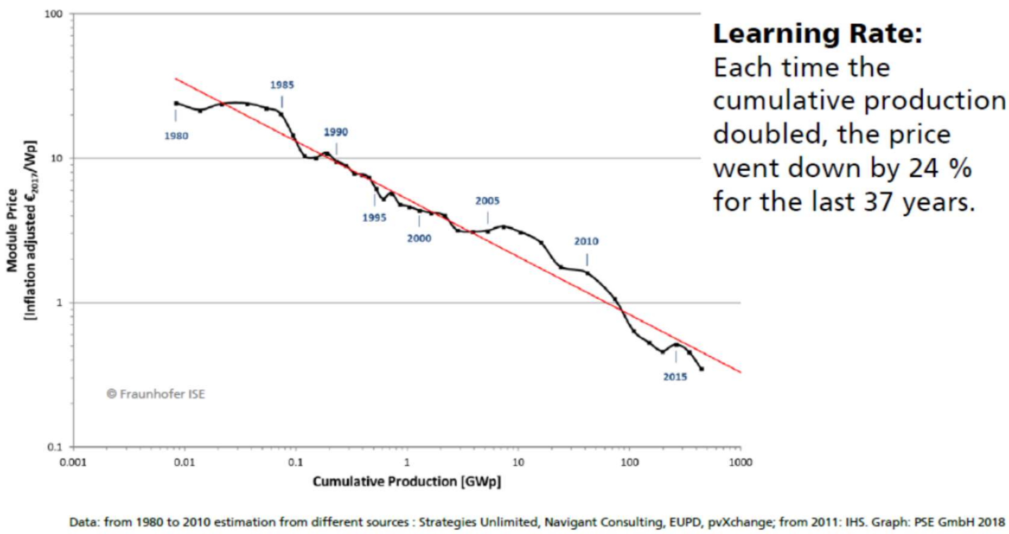


Fig 53 – learning rate for solar PV

While the only certainty is that both Hammond and CCC will probably turn out to be incorrect, it is worth quoting the rationale used in the CCC report, as it is fundamental to the principle of the dynamics of technology development which underpins their apparently more optimistic projection (than that of Mr Hammond):

“Once a technology becomes sufficiently competitive, it starts to change the entire environment in which it operates and interacts. New supply lines are formed, behaviours change, and new business lobbies push for more supportive policies. New institutions are created, and old ones repurposed. As costs fall and expectations of market size increase, additional investment is induced and the political and commercial barriers to a transition begin to drop away. A tipping point is eventually reached where incumbent technologies, products and networks become redundant.”[119]

The cost progression for lithium-ion batteries is little short of astonishing, as this chart from Bloomberg NEF shows[274]:

[119] ibid

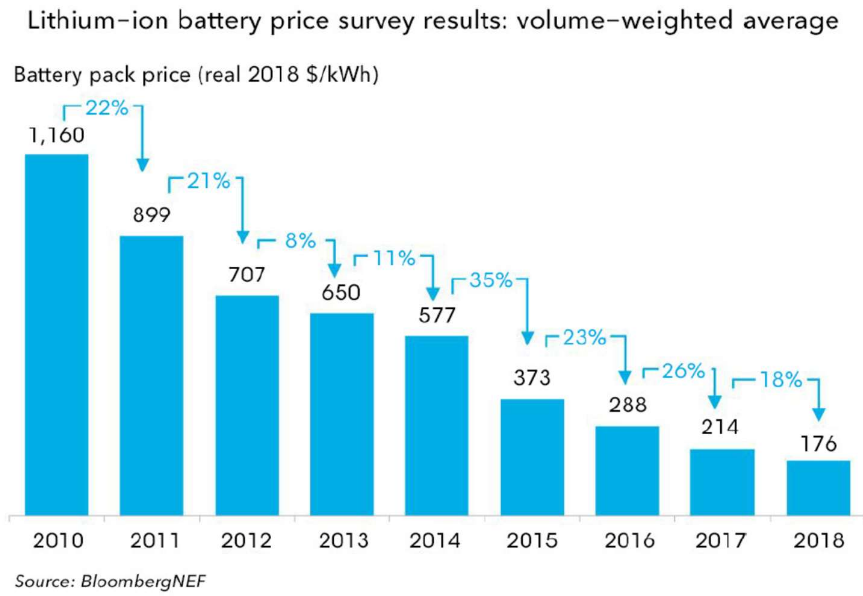


Figure 54 – lithium-ion battery cost curve

Assuming an 18% learning rate, the implied battery price by 2030 will be $62/kWh. One common assumption is that the availability of metals will push battery prices up. However, Bloomberg's view is that while this could have some effect, it will be less material than some think. Their modelling indicates that a 50% increase in lithium prices would result in a 4% increase in the price of the battery pack, while a doubling of cobalt prices would add 3% to the overall pack price[275].

Some of the apparently high current costs of technologies covered here should be considered in this light; and, of course, in the context of the global cost of failing to meet carbon budgets.

Regardless of the infrastructure sector, while the "technologies" considered here range from systemic innovation to new modes of generation and fuel sources, as well as the impact of technological innovation from other sectors and new ways of managing waste outputs, it could be argued that this is ultimately all about how we power a sustainable civilisation of the future.

19.2 Energy system innovation

Over the past three years, Ofgem has produced a series of "Future Insights" papers, covering a range of emerging issues and opportunities for the energy system. As the energy regulator, this is clearly the principal preoccupation.

Ofgem says that the energy sector is undergoing fundamental change. The overarching paper[276] outlines some of the main drivers of change and the resulting uncertainty about the future shape of the energy system. Ofgem considers the role of consumers in the development of the energy system; while technological changes are already beginning to give consumers greater control over how the energy system, they also create risks that some groups will be left behind.

Some of the key changes looking likely include:

- *the development of a smarter and more flexible system with greater responsiveness of demand to price changes;*
- *more decentralisation of the energy sector (with more distributed generation and more suppliers operating locally rather than nationally);*
- *increasing interdependence of services;*
- *a more diverse commercial environment, at least in the medium term; and*
- *better service for consumers enabled by new and smarter technology.*

These changes, says Ofgem, could begin to blur the boundaries of the energy system and challenge the way that Ofgem operates as a regulator.

Domestic Energy Consumption

The 4th in the series, "The Futures of Domestic Energy Consumption"[277] says that many consumers have already become energy producers and service providers in their own right by installing micro generation equipment such as solar panels. There are around 900,000 photovoltaic installations across the UK, with a cumulative capacity of over 11GW. Over 90% of these installations are of a small-scale, domestic size (0 to 4kW).

The next phase of the technological revolution will take place in the home through the appliances and platforms that control energy services. In the short term, smart tariffs, appliances and battery storage should allow consumers to manage their demand more flexibly. Longer term, big data, accompanied by machine learning, could enable both more personalisation of services and more automation of the relationship between consumers and firms. Developments such as blockchain could redefine domestic consumption practices, for instance by enabling consumers to trade with each other on a peer-to-peer basis, without the need for third parties.

The regulatory and policy framework will need to support innovation while recognising the need to protect consumer interests. This includes a more flexible and consumer-focused system for changing the energy industry "rulebook" where necessary.

The "sharing economy" has changed the ways that people buy goods and services. Services such as Uber, Zipcar and Airbnb allow individuals to "share" infrastructure. Energy services could be tied to individuals rather than a physical meter, with costs allocated and payments made through smart technology.

Vulnerability could also manifest itself in different ways. As the energy system develops, middle-income families with limited time or assets may find it harder to get a reasonable energy deal. Not all consumers may want to or be able to participate in an energy system based on real-time transactions and active management of energy usage and generation and some groups are at risk of being left behind. Social enterprises and local authorities could play a crucial role in spreading the benefits of energy system innovation more widely across society.

Flexibility services

Vehicle-to-grid models
Upside Energy has partnered with Good Energy, the University of Salford and Honda for the Innovate UK funded HAVEN project. The project will test how electric vehicle batteries and other battery storage units can impact home efficiency. Vehicle-to-grid (V2G) technologies are a way of tapping into the storage capacity of electric vehicles. By conducting tests within the controlled environment of the Energy House, the project will investigate different configurations to build a suite of models for the value of EV and other battery storage systems within an integrated home energy storage system. Upside Energy's innovative, cloud-based platform can connect with a multitude of devices across commercial, industrial and domestic sites. This includes battery storage systems, electric vehicle charge points, UPS and heating and cooling systems. It uses advanced algorithms and artificial intelligence to match energy demand with the available supply, helping the electricity grid deal with fluctuations and times of peak usage. Supporting the grid in this way, opens the doors to additional revenue streams for customers, who also benefit from significant reductions in energy costs and carbon emissions. The platform can manage demand response for more than 100,000 devices running in parallel.

Flexibility services are a key area of technological development, very much recognising the changing nature of the energy system in the UK, with the reduction in fossil-fuel based baseload power, increase intermittent renewable power, more localised energy solutions and, more recently, the growing prospect of widespread electrification of road-based transport. In May 2017, Imperial College and the energy consultancy Pöyry produced a report for CCC on the development of flexibility services to 2030[278].

In it they argued that the GB electricity system will undergo a fundamental transformation over the next few decades in response to tightening energy sector decarbonisation targets. Meeting the targets will require an increase in the provision of flexibility services to enable the cost-effective integration of the new system. This will give rise to the deployment of innovative technologies and new business models and service offerings.

While there are various possible configurations of demand and supply, in any future low carbon electricity system, Pöyry says we should anticipate:

- *more renewable energy*
- *growth driven by electrification of segments of the heat and transport sectors;*
- *growth in the capacity of distribution-connected (i.e. localised) flexibility resource;*
- *an increased 'flexibility' requirement to ensure the system can efficiently maintain secure and stable operation*
- *opportunities for energy storage facilities at both transmission (national grid) and distribution levels; and*
- *an expansion in the provision and use of demand-side response across all sectors of the economy.*

System flexibility will be the key enabler of this transformation to a cost-effective low-carbon electricity system. The report estimates significant cost savings from new sources of flexibility, including reduced investment in low-carbon generation (between 25% and 60% of the total savings depending on the scenario); reduced system operation cost (between 25% and 40% of the total savings); and reduced requirement for distribution network reinforcement (between 10% and 20% of the total savings) and backup capacity.

Ofgem, in its Future Insights series, includes a recent (August 2019) analysis of the prospects for flexibility services, and raises challenges regarding the current stage of technological development[279].

Ofgem similarly argues that Great Britain's electricity system in the future will be more decentralised, smarter, and lower carbon and that this transition is already happening. A lot of the required flexibility, it says, can be provided by existing assets within the system and are connected to distribution and transmission networks.

Flexibility platforms, it says are one of the mechanisms for unlocking this inherent flexibility. Ofgem have found that despite the involvement of key stakeholders such as government, Platform Operators and UK distribution network operators, as well as a significant amount of engagement and discussion, at the moment a number of different proprietary technologies are being simultaneously developed. There is duplication in activity and the risk of a suboptimal future system. Ofgem argues that there could be significant benefits from a coordinated approach, focussed on delivering the most beneficial outcomes and that there is a collective view on the need for operational standards for data, processes and interoperability.

Ofgem's Future Insights Paper ("Implications of the transition to electric vehicles") (July 2018) says that the transition to EVs should provide substantial benefits to energy consumers, but also challenges. Electricity flows will become increasingly complex and bi-directional, particularly if EVs are used to feed power back to the grid through Vehicle-to-Grid (V2G) technology. There will be regulatory challenges as well – the regulations that govern the energy sector were not explicitly designed with the foresight of EV charging and bundled energy and transport services.

Regulation will need to adapt to provide predictability to the EV market and protection to EV users, which is looking challenging given how little is known at present about levels of uptake and charging behaviours, particularly with the blurring of typically separated sectoral boundaries (energy and transport), this represents a challenging prospect.

Industry, Ofgem says, should focus on minimising overall system costs for all consumers (including non- EV users), by seeking to make more efficient use of existing assets before considering reinforcement. If EV users choose to charge during peak times, under current arrangements they will impose considerable costs on the system which will be borne by all consumers. The charging regime should ensure costs are distributed fairly, and EV users should face charges that are reflective of the costs (or benefits) they are imposing on the system. Vulnerable consumers, or those who are currently unable to share in many of the benefits of EVs, are likely to object to subsidising more affluent early adopters of EVs.

19.3 Wave & Tidal Power

Tidal power for data-centres[120]
SIMEC Atlantis Energy Limited ("Atlantis"), Meygen's owners, announced in September (2019) ambitions for a tidal-powered data centre in Caithness. The power supply for such a data centre would include electricity supplied via a private wire network from tidal turbines at the existing MeyGen project site. This would be the first ocean powered data centre in the world, with the potential to attract a hyperscale data centre occupier to Scotland. It is expected that the data centre would be connected to multiple international subsea fibre optic cables, offering a fast and reliable connection to London, Europe and the USA. Further connectivity to the central belt using domestic terrestrial networks could significantly improve Scottish data and connectivity resilience. The MeyGen project has a seabed lease and consents secured for a further 80MW of tidal capacity, in addition to the 6MW operational array which has now generated more than 20,000MWh of electricity for export to the grid. The target operations date for the data centre is expected to be 2024, in line with the expansion plans for the tidal array.

In its energy strategy[280], SG argues that Scotland continues to lead the world in developing and supporting wave and tidal energy technologies. That, it says, is due partly to consistent and committed support from the Scottish Government and its enterprise agencies, but mainly due to the "passion, expertise, investment and Innovation" of the industry.

Although securing further cost reductions and a route to market remain big challenges, Scotland has a number of "world firsts":

- *Scotrenewables – developer of the world's most powerful floating tidal turbine – is exporting power to the Orkney grid.*
- *Nova Innovation successfully deployed a third turbine at the Shetland Tidal Array.*
- *The first phase of the MeyGen tidal project is now operating at full 6 MW capacity.*
- *The European Marine Energy Centre (EMEC) has tested 30 different wave and tidal energy devices to date – more than any other single site in the world.*
- *The Wave Energy Scotland (WES) technology programme has supported over 60 projects.*

The sector, SG says, is already integrating storage, grid management and transport solutions into demonstration projects and has also developed an impressive Scottish supply chain, providing "high value" jobs and creating diversification opportunities for Scotland's marine services, subsea and oil and gas sectors.

[120] https://simecatlantis.com/2019/09/09/plans-announced-to-build-the-worlds-largest-ocean-powered-data-centre-in-caithness-scotland/

The publicly available literature on wave and tidal development lacks currency: Scottish Renewables has a report on opportunities for the sector and its supply chain published in February 2014[121] and a report commissioned by BVGA "Wave and Tidal Supply Chain Development Plan" published about a year later.[122]

At a UK level, in contrast, perhaps, to the picture in Scotland, there appears to be a task to convince policy-makers of the merits of supporting this sector. Renewable UK's Wave & Tidal page[123] supports the "Ocean Energy Race Campaign" which seeks to strengthen political support for developing wave and tidal energy in the UK, arguing that this sector has the potential to contribute around 20% of the UK's current energy needs.

However, it appears that development activity is progressing, as these extracts from the respective companies' websites illustrate:

Now rebranded **Orbital Marine Power**, Scotrenewables reported in September (2019) that the main manufacturing contract for the company's first commercial O2 tidal turbine has been awarded to a manufacturer in Dundee[124]. The O2, says the company, is of generating over 2 MW from tidal stream resources and will become the world's most powerful tidal turbine when it enters operation later next year (2020) as part of a long term project at EMEC and features several innovations focused on further reducing the cost of energy from the company's disruptive technology.

Nova Innovation was a regional winner in the Shell Springboard 2017 awards for low-carbon innovation. It reported in August (2019) that the new technology from the ground-breaking Tidal Turbine Power Take-off Accelerator (TiPA) project, had successfully completed subsea testing at Babcock's Rosyth Site in Scotland[125].

The Hendry Report (produced by former Energy Minister Charles Hendry)[281], was published in December 2016 and offers a detailed analysis specifically of the role of tidal lagoons. In it, he echoes Stewart Brand's point that decisions made in the long-term interests of the country often don't stack up in purely commercial terms. "Our energy landscape, he says, is full of examples of power plants which would never have been built on a purely commercial basis, but for which we have had grounds to be extremely grateful for decades that they were constructed"[282]. Building the first tidal lagoon today, he says, is in the same category. However, most of the tidal lagoon resource is thought to be on the west coasts of England & Wales, so his report is not directly relevant to the considerations of the IC in Scotland.[283]

It is perhaps worth noting that the National Infrastructure Committee appears to disagree that tidal lagoons are likely to be an important part of the energy mix. In its National Infrastructure Assessment, it says[284]: "The Commission's analysis suggests that tidal lagoon power will remain an expensive technology in the future. The extra benefits which arise from its predictability are not enough to offset its higher capital costs. And it will never be a large-scale solution: an entire fleet of tidal lagoons would only meet up to 10 per cent of current electricity demand in the UK".

[121] "Capitalising on capabilities", https://www.scottishrenewables.com/publications/capitalising-capabilities-mepb-report/

[122] "Wave and tidal supply chain development plan" https://www.scottishrenewables.com/publications/bvga-wave-and-tidal-supply-chain-development-plan/

[123] https://www.renewableuk.com/page/WaveTidalEnergy

[124] https://orbitalmarine.com/flotec/press-release-orbital-o2-to-be-built-by-texo-group-in-dundee/

[125] https://www.novainnovation.com/post/advanced-technology-for-tidal-energy-successfully-powers-through-testing

19.4 Hydrogen

Hydrogen for heat[285]
The H21 Leeds City Gate project identified the system requirements (at feasibility level) to convert one city in the UK to 100% hydrogen. The report concluded that it would be possible to reuse the city's existing gas grid and low-carbon hydrogen could be credibly provided, with hydrogen provided through a production capacity of 1,025 MW via four 256 MW Steam Methane Reformers located at Teesside, "intraday" storage of circa 4,000 MWh via salt caverns in the Teesside region and "inter-seasonal" storage of 700,000 MWh via salt caverns in the Humber region. 1.5m tonnes of CO_2 would be sequestered per annum. The H21 Leeds City Gate report suggested that the UK gas grid could be converted to 100% hydrogen. Considerable work is required to prove this concept but conversion of UK cities could be achieved incrementally up to 2050 and that appliances could be converted to operate on 100% hydrogen. *(See below for schematic)*

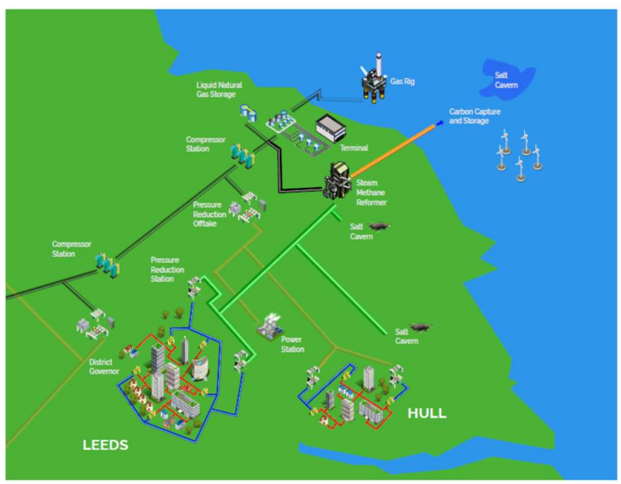


Image 1.6. *H21 Leeds City Gate – Amended Concept*

Fig 55 – H21 Leeds City Gate Hydrogen Concept

Hydrogen is seen by CCC as critical to meeting the 2050 decarbonisation targets. The Committee specifically address the role of hydrogen in its report "Hydrogen in a low carbon economy", published in November 2018.

How hydrogen is used, the report suggests, remains an open question. The existing gas grid does not preclude other solutions for heat decarbonisation - the "sunk costs" of having an extensive gas grid do not automatically mean that it will be lower cost to switch it over to hydrogen and use it in boilers as we do with natural gas.

The costs of a range of pathways for heat decarbonisation are similar, including those in which the gas grid has a much-reduced role or is even decommissioned.

While there is some opportunity to utilise some 'surplus' electricity (e.g. from renewables generating at times of low demand) for hydrogen production, the report argues that the quantity is likely to be small in comparison to the potential scale of hydrogen demand. Producing hydrogen in bulk from electrolysis would be expensive and would entail extremely challenging build rates for zero-carbon electricity generation capacity.

Hydrogen from fossil fuels with CCS, CCC argues, is low-carbon but not zero-carbon. Gas with CCS has a potentially important role, especially in scaling up a hydrogen industry; however, it is low-carbon rather than zero-carbon, providing lifecycle emissions savings of 60-85% relative to natural gas use in boilers[286].

If hydrogen from gas with CCS is deployed in very large quantities, the emissions savings may be insufficient to meet stretching long-term emissions targets. Imported hydrogen is one option, but an uncertain one. The international trade in low-carbon hydrogen may develop over time, but it is not certain either that it will or that the costs will be no lower than domestic low-carbon hydrogen production. It would therefore not be sensible for decisions taken now on the UK's energy infrastructure to rely on large-scale imports.

CCC therefore concludes that hydrogen is best used selectively, where it adds most value alongside widespread electrification, improvements to energy and resource efficiency, and use of CCS in industry and on bioenergy. This means using hydrogen where the alternative is continuing to burn unabated fossil fuels or where there are limits to feasible electrification.

The Royal Society’s report, “Options for producing low-carbon hydrogen at scale”[287] (November 2018) presents a strong case for hydrogen, arguing that hydrogen has the potential to play a significant role in tackling climate change and poor air quality.

It is not a “cure all” and should be seen as one of the possible pathways to a low carbon energy future. There are barriers to a hydrogen-based economy which include:

- *production at scale;*
- *infrastructure investment;*
- *bulk storage;*
- *distribution; and*
- *safety considerations.*

There is also the issue of how to create a simultaneous demand and supply for hydrogen technologies.

Four groups of hydrogen production technologies are examined by the Royal Society in order of technology readiness.

- *The first group of technologies has a process known as steam methane reforming, which has been used to produce hydrogen from fossil fuels for decades (Currently, around 95% of the global production of hydrogen is generated from fossil fuels), primarily from natural gas with steam methane reforming and coal gasification. The technology is well understood and is operated on an industrial scale around the world. Carbon capture and storage will be essential if this method is to be used to produce low-carbon hydrogen. Biomass gasification with carbon capture also provides a possible route to reduced carbon emissions.*

- *Electrolysis comprises the second group of technologies. This process separates hydrogen from water using electricity in an electrolysis cell. Electrolysis produces pure* *hydrogen which is ideal for fuel cell electric vehicles. It has a high efficiency though many current facilities are small. This technology shows great potential to be scaled up.*

- *The third group is biological methods whose key features are lower operating temperatures and relatively simple technology. These primarily relate to a variation of anaerobic digestion that uses microbes to convert biomass to hydrogen instead of methane, together with emerging biotechnologies that allow a greater hydrogen yield from the original biomass. These microbial processes are being developed at both laboratory scale and at demonstration level and have potential to make a small but valuable contribution to the hydrogen economy.*
- *The final group of technologies is known as solar to fuels. This technology harnesses sunlight to split water into hydrogen and oxygen and has been referred to as 'artificial photosynthesis'. Solar to fuels is an active area of scientific innovation, with potential to lead to a disruptive future process; however, it is currently a subject of basic research with elements undergoing technological development. There are no current estimates for potential output and questions over ultimate cost and efficiency.*

The Royal Society briefing challenges the established view that steam methane reforming is the only solution to producing hydrogen at scale for the next 30 years. The science, it is argued, tells a different story. Electrolysis has the potential to be deployed to produce low-carbon hydrogen in the near to mid-term alongside steam methane reforming, provided the challenges above are met.

19.5 Low Carbon Freight Transport

Procuring the world's first electric ferry[288]
In 2010, the Norwegian Ministry of Transport launched a competition for an energy efficient and low-emission car ferry to link two villages in the Sognefjord. The successful bidder would be awarded a ten-year concession contract. The Norwegian Public Roads Administration, in charge of the competition, required a minimum 15-20% improvement in energy efficiency over that of the existing diesel-powered ferry. Four consortia, each comprising a ferry operator, a shipyard and an engineering company, competed for the contract. The winning consortium of Norled, a ferry operator, the Fjellstrand shipyard and Siemens, proposed Ampere, the world's first electric car ferry. Ampere offered a 37% reduction in energy use per passenger car-km, a 60% reduction in total energy use, the elimination of NOx emissions and an 89% reduction in CO_2. Unusually, the ferry is made of aluminium and is lighter than steel-made vessels. A catamaran (i.e. two slim hulls instead of one), it also offers less resistance than traditional ferries, allowing total engine power to be cut by half. The charging system brought another innovation: batteries are replaced at each pier, saving the higher voltage necessary for a single battery onboard and the time it would take to recharge it. Competition was also encouraged with compensation of NOK 3 million to the three unsuccessful bidders.

There is fairly extensive literature on the decarbonisation of road freight. Ricardo's report commissioned for CCC, "Zero Emission HGV Infrastructure Requirements"[289] (June 2019), says that battery electric vehicles (BEV) are commonly accepted to be the most promising technology for decarbonising the light duty vehicle sector.

However, the most cost-effective route to decarbonising the heavy-duty vehicle (HDV) sector is much less clear, with electric and hydrogen options emerging as viable alternatives to diesel. It is expected that battery electric or hydrogen HDVs could be available in the 2020s, and with rapid uptake possible once they reach total cost of ownership (TCO) parity with diesel, uptake of zero emission options could accelerate rapidly. This would have a significant impact on the UK's transport infrastructure.

The technologies considered in the report are:

(i) Hydrogen refuelling stations (HRS) for hydrogen fuel cell electric vehicles (FCEVs);

(ii) Ultra-rapid charge points at strategic locations for battery electric vehicles;

(iii) Electric road system (ERS) infrastructure, i.e. overhead catenaries for battery electric or battery hybrid vehicles;

(iv) Hybrid solutions, combining elements of the above.

The report analysed six scenarios:

• Scenario 1 – Hydrogen

• Scenario 2 – Battery electric vehicles [BEV]

• Scenario 3 – Battery ERS

• Scenario 4 – Hydrogen ERS [H2 ERS]

• Scenario 5 – Hydrogen range extender [H2 REX]

• Scenario 6 – Plug-in hybrid electric vehicles [PHEV].

These were compared with a baseline which assumes continuing diesel use across the sector.

The most cost-effective option in terms of infrastructure costs was the hydrogen scenario, which had a cumulative capex cost of £1.72bn in 2060, compared to £10.65bn for the BEV scenario and £10.41bn for the ERS scenario (with depot chargers comprising a large CAPEX proportion for each of the scenarios). However, when the fuel costs are included, there is much less difference in the scenarios – the BEV option is around 4% lower than hydrogen on an annualised basis. But clearly the capital commitments for the BEV option are much larger.

The annualised costs (including fuel) for all scenarios were lower than the baseline. This shows that although the zero-carbon options (i.e. excluding PHEV) have high up-front costs, their annualised costs are 44% to 51% lower from a societal cost perspective than the fossil fuel comparator by 2060. This is driven by higher efficiencies (particularly for BEV & ERS scenarios) and lower unit costs of zero carbon fuels and highlights another area of infrastructure where the balance between availability and usage costs may be about to shift.

A comparative analysis of the infrastructure options for various decarbonisation options was carried out by Julich Forschungszentrum in Germany in 2018[290].

The goal of the study is to perform a detailed design analysis of the required infrastructure for supplying battery and fuel cell electric vehicles in Germany at multiple scales, considering the implications of establishing an infrastructure capable of supplying between one hundred thousand to several million vehicles with hydrogen or electricity.

The scenario analyses demonstrated that, for low market penetration levels of a few hundred thousand vehicles, the costs of infrastructure roll-out are essentially the same for both technology pathways. Hydrogen is found out to be more expensive during the transition period to electricity-based generation via electrolysis and geological storage, both of which are needed to access renewable hydrogen from surplus electricity.

The mobility costs per km are roughly same in the high market penetration scenario at 4.5 €ct/km for electric charging and 4.6 €ct/km for hydrogen fueling. Because hydrogen permits the use of otherwise unusable renewable electricity by means of on-site electrolysis, the lower efficiency of the hydrogen pathway is offset by lower surplus electricity costs. The conclusion is drawn that electric charging and hydrogen fueling are key to realising low carbon, clean and renewable energy-based transportation concepts.

A smart and complementary combination of the electric charging and the hydrogen refueling infrastructure could combine the strengths of both and avoid non-sustainable solutions with low systems relevance or efficiency. In short, a hybrid strategy for the roll-out of both hydrogen and electrical infrastructure will probably help to maximize energy efficiency and to optimize the use of renewable energy resources while minimizing CO_2 emissions.

19.6 Carbon Capture & Storage

Carbon capture and storage could be argued for as a negative emissions technology, although strictly speaking, it is a zero emissions technology as it neutralises new emissions and sequesters them (so in fact it is only provisionally zero carbon for as long as it stores the CO_2).

Nevertheless, CCC considers it to have a critical role in meeting carbon budgets. There are now over 40 operational CCS projects across the world, none of which are in the UK, notwithstanding years of research. This is another area where fluctuating UK Government support has created a stop-start effect in development.

In Scotland, the Acorn CCS Project at St Fergus, supported by Scottish Government and EU funding is ongoing, and aims to demonstrate a lowest cost, full-chain CCS project that targets industrial emissions. The project is currently at a feasibility stage and aims to stimulate a new pathway to securing CCS in Scotland, with the following milestones:

- *2020-2025 – Demonstrator project at St Fergus exemplifying the viability of full-chain CCS, at lowest cost;*
- *2025-2030 – Pipeline investment to connect early adopted industrial emitters to North Sea storage;*
- *2030-2040 – Extend pipeline investment to enable UK-wide connection to Scottish storage, and bring online second phase industries, which could include the energy sector;*
- *2040 onwards – Commercialisation/privatisation, with access opened up to storage on the international market.*

In the North of England, Zero Carbon Humber[126] is a project to develop carbon capture usage and storage at the UK's most carbon-intensive industrial cluster, currently emitting 14m tonnes

[126] https://www.zerocarbonhumber.co.uk/

of CO_2e a year. Drax Group, Equinor and National Grid Ventures signed an MOU in May 2019, committing to work together to explore opportunities for creating a zero-carbon cluster in the Humber.

The screenshot from the website below illustrates the process.

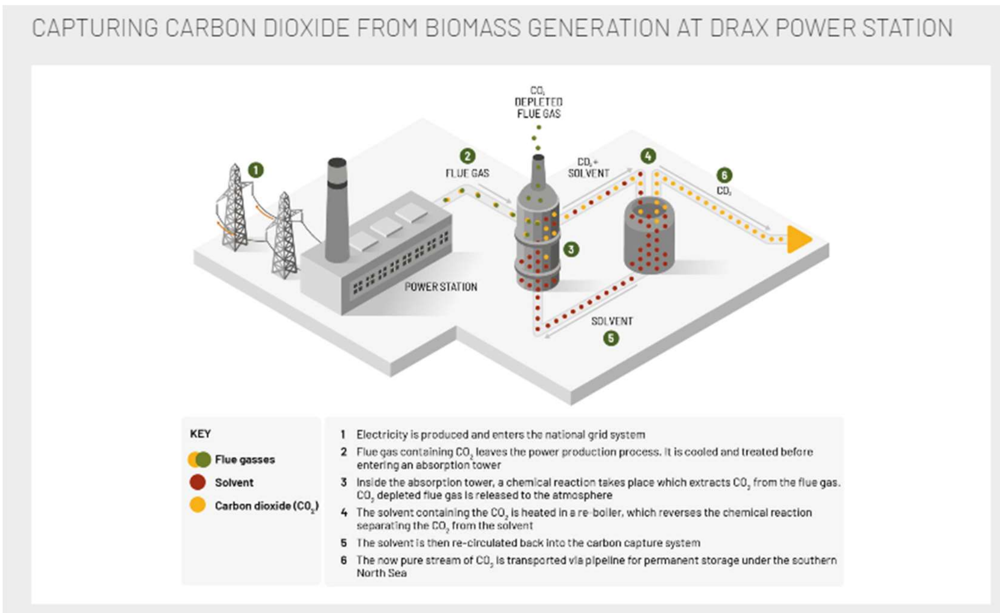


Fig 56: Zero Carbon Humber

A report issued by the Global CCS Institute towards the end of 2018 and timed to coincide with COP24, argued for the key role of CCS in beating climate change. The website NS Energy[127] says that 18 of the world's large-scale CCS plants are capturing approximately 40m tonnes per annum of CO_2 ("mtpa"). Most of the activity is in the USA and is being used for enhanced oil recovery (in other words, getting hard to reach oil out of the ground). The projects listed are:

- *Century Plant, West Texas – 8.4mtpa*
- *Shute Creek Gas Processing Plant, Wyoming - 7mtpa*
- *Great Plains Synfuels Plant, Dakota – 3mtpa*
- *Petra Nova, Texas – 1.6mpta*
- *Boundary Dam, Saskatchewan, Canada – 1mpta*

In August 2018, China announced the 18th large CCS facility at Jilin, north-eastern China. It is capturing CO2 from aa natural gas processing plant and transporting it by pipeline to onshore injection sites[128] .

[127] https://www.nsenergybusiness.com/features/top-carbon-capture-storage-projects/
[128] https://www.gasworld.com/china-establishes-worlds-18th-ccs-facility/2015265.article

Pre-combustion[129] CCS generating plant is more attractive from an emissions perspective than post-combustion CCS.

19.7 Circular Economy

The essence of a circular economy strategy is a shift from linear processes which start with a raw material and end with waste, to an economy where valuable resources and products are repurposed to minimise the extraction of new raw materials and the manufacturing energy and concomitant emissions required to turn them into finished products.

A review of available literature suggests that (where the circular economy is actually defined), there are degrees of "circularity" and achieving a truly circular economy is a long-term goal. Scotland's Circular Economy Strategy 2016[291] draws on work by the Ellen MacArthur Foundation to examine how Scotland can start on this journey by focusing on four sectors: Food & Drink, Remanufacture, Construction and the Built Environment and Energy Infrastructure. In each of these sectors, the circular economy approach is different.

In the construction and built environment sector, the approach is about waste reduction but the Strategy itself gives little indication as to what this means as distinct, for example, from an intelligent recycling strategy.

The waste sector hierarchy (Reduce, Reuse, Recycle) nevertheless remains a reasonable reference point. While the ideal solution is simply to use less, reuse of materials in a way that is close to their original function without transporting them a significant distance away from their original site, this can generate significant carbon savings, retain value in the local economy and can thus be described as supporting a circular economy.

"Circular economy" is more about reuse than recycling, which often includes processes that downgrade materials from their current function and potentially in an energy intensive, CO_2-emitting way (e.g. oil recovery from plastics). If products are being "downcycled", i.e. being recycled lower value use (e.g. high-quality steel ending up as lower quality construction products), this does not advance a circular economy strategy.

Progression to a circular economy entails less "downcycling" as part of the overall process. "Circular economy" activities should be trying as far as possible to preserve the function for which things have originally been manufactured, preferably with a minimum of physical displacement, thereby saving on energy, new raw material and CO_2 emissions.

For the construction sector, the circular economy concept is perhaps most usefully applied to strategies which minimise the introduction of new basic materials into the supply chain (e.g. virgin steel and concrete).

The Energy Transitions Commission, whose membership includes large global industrial emitters (e.g. Saint Gobain, BP, Drax, Tata, Veolia) sets out a decarbonisation strategy in its November 2018 report ("Mission Possible")[292] for heavy industry and transportation which is heavily dependent on circular economy principles - recovering and reusing steel, scaling up plastics recycling, reducing cement production through eliminating construction waste, reusing building materials and greater materials efficiency through design. Actions supporting circular

[129] Pre-combustion capture refers to removing CO2 from fossil fuels before combustion is completed. For example, in gasification processes a feedstock (such as coal) is partially oxidized in steam and oxygen/air under high temperature and pressure to form synthesis gas. See, for instance: https://www.energy.gov/fe/science-innovation/carbon-capture-and-storage-research/carbon-capture-rd/pre-combustion-carbon

economy solutions should therefore focus on these areas if they are seeking to maximise decarbonisation.

The ETC report is a valuable contribution to the question of supply chain (often referred to as “Scope 3”) decarbonisation.

The biggest challenge, it says, in meeting the Paris Agreement lies in the major harder-to-abate sectors. These are heavy industry and heavy-duty transport. There are three main routes to decarbonisation: reducing demand (ETC reckons a 40% reduction can be achieved in HI emissions through circular economy strategies and a 20% reduction in HDT through modal shifts and logistics efficiency); improving energy efficiency and deploying decarbonisation technologies. These technologies include electricity, biomass – with a focus on using this for aviation and plastics feedstock; carbon capture – an essential but limited role; hydrogen – a major role.

In heavy industry, says ETC, primary plastics can be cut by 56% and primary steel by 37% versus BAU. Aluminium production can be cut by 40% and cement demand can be reduced by 34%. In heavy road transport, electric drivetrains will almost certainly eventually dominate, given their efficiency advantage over internal combustion engines, with energy storage either in battery or hydrogen form. Electric trucks are likely to become cost-competitive with diesel or gasoline vehicles during the 2020s. As a result, any role for biofuels and natural gas will and should be only transitional.

CCC, in its report “UK Housing – Fit for the Future?[293]”, says that between 27,000 – 50,000 new homes (15%-28%) built in the UK each year already use timber frame construction systems and wood is also widely used in traditional masonry systems. Timber frame construction can reduce embodied emissions by up to around 3 tCO_2e per home through the displacement of high-carbon materials such as cement and steel, although there are uncertainties related to end-of-life processes. Increasing this to 270,000 each year could result in annual net carbon storage of around 3 Mt CO_2e by 2050, accounting for losses due to demolition and disposals. This level of timber construction could also reduce embodied emissions in the residential sector by 0.5-1 Mt CO2e per annum in 2050.

19.8 Negative emissions technologies

Just now, the only proven negative emissions technology is to plant more trees[130]. The Scottish Government has recognised this and in its Programme for Government, notes that Scotland planted 84% of the new woodland created in 2018-19, exceeding the target of 10,000 hectares. It plans to plant another 12,000 hectares in the coming year.

Without question, it is always possible to do more. The Programme notes: “Greening of the urban environment improves quality of life in our towns and cities, enhances their environmental performance and climate resilience, as well as supporting regeneration and acting as a catalyst for economic investment”[294].

Stewart Brand tackled the question of negative emissions technologies back in 2010. He calls these technologies “geo-engineering”[295]. These included at the time (as at 2009 – a decade ago):

[130] While there are counter arguments in terms of effectiveness, tree-planting remains a major option under consideration, as this recent blog from NASA shows: https://climate.nasa.gov/news/2927/examining-the-viability-of-planting-trees-to-help-mitigate-climate-change/

- *Global dimming with stratospheric sulphates*
- *Brightening the earth with clouds from ocean spray*
- *Feeding iron to ocean photo-plankton to increase their fixation of carbon*
- *Floating vertical pipes in the ocean for the same purpose*
- *Converting agricultural waste into biochar*
- *Massive air capture of atmospheric carbon*
- *Global dimming with mirrors in space*

Brand comments on each of these and says we are going to need them. It will become painfully apparent, he says, that "mitigation is not going to succeed"[296].

Natural negative emissions
Some technologies have already been proven to work in nature. In 1991, a volcano, Mount Pinatubo, erupted, sending 20m tons of sulphur dioxide 20miles into the stratosphere, where the material oxidised into tiny sulphate droplets that absorbed and reflected sunlight. The following year, the entire plant cooled by half a degree Celsius. The sea ice in the Arctic was particularly durable that year and the polar bear cubs born that year were unusually large and healthy – so they were dubbed the "Pinatubo cubs".[297]

In 2018, a series of studies was published, summarising the status of negative emissions technologies[298]. The science behind negative emissions technologies is too complex for this review, but fortunately, a blogger summarised the key findings in layperson's terms[131]. The chart below summarises the role of negative emissions technologies on CO_2 emissions pathways:

[131] See https://qz.com/1416481/the-ultimate-guide-to-negative-emission-technologies/

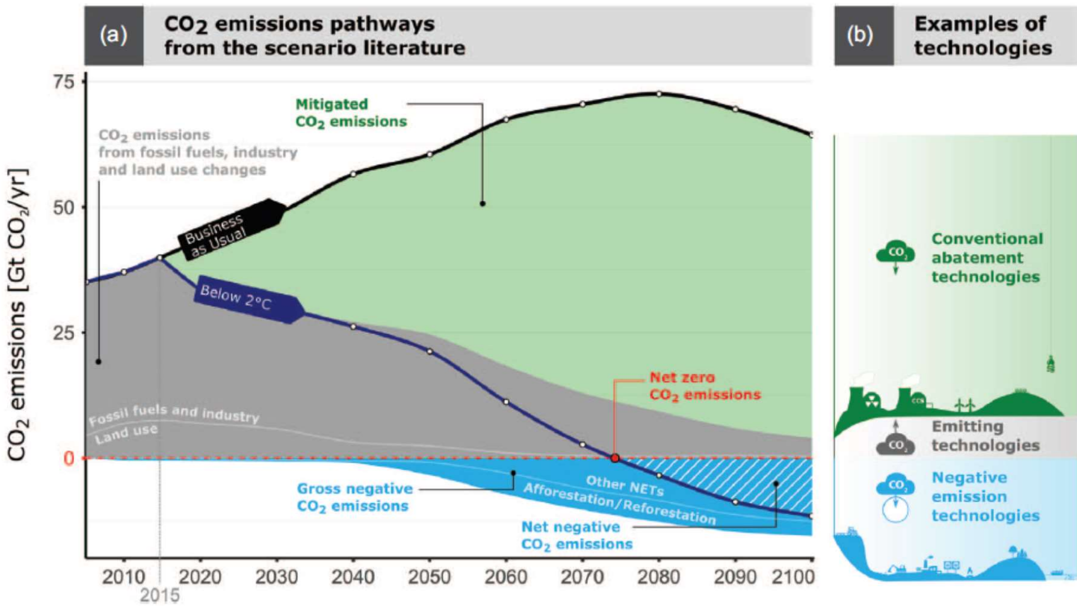


Fig 57: the role of negative emissions technologies

The graph juxtaposes emission reductions from conventional mitigation technologies (panel A) with the removal of carbon dioxide via negative emissions technologies (panel B) in a scenario that is consistent with a 66% chance of keeping warming below 2 ◦C relative to a baseline scenario. Global emission levels turn net negative towards (hatched blue area) the end of the century to compensate for earlier carbon budget overshoot. Cumulative gross negative emissions are represented by the entire blue area.

The key negative emissions technologies listed by the paper are as follows. Only 2 of Stewart Brand's are on the 2018 list, suggesting that the others remain highly conceptual at the moment:

1. *Afforestation and reforestation*
2. *Annual capture potential: between 0.5 and 3.6 billion metric tons. Current estimated cost of capture: between $5 to $50 per metric ton.*
3. *This is the simplest and most mature technology. However, trees need a lot of land and soil and over time. Converting large pieces of arid land into forests will reduce the amount of light and heat that is currently reflected back into space, known as the "albedo effect," which reduces the carbon-cutting effect of new forests. And, forests only store carbon dioxide for decades to centuries at most.*
4. *Bioenergy with carbon capture and storage (BECCS)*
5. *Annual capture potential: between 0.5 and 5 billion metric tons. Current estimated cost of capture: between $100 and $200 per metric ton.*
6. *Some 19 plants around the world currently store approximately 40m metric tonnes underground each year. As we have seen, most climate scenarios require carbon capture to mitigate emissions form power and industry. In theory, if we accept that biomass is carbon neutral, then storing carbon from biomass plants is arguably carbon negative. However, it is not clear that biomass is carbon neutral. Apart from the time taken to replace*

the carbon-absorbing properties of the tree that has been felled, felling a tree also tends to release carbon that has previously been trapped in the soil around it. Drax is currently trialling what it calls "negative emissions technology"[132]

7. *Direct air capture*
8. *Annual capture potential: between 0.5 and 5 billion metric tons. Current estimated cost of capture: between $200 and $600 per metric ton.*
9. *One from Stewart Brand's 2009 list, This technology literally sucks carbon out of the air and stores it underground. At the moment the costs are extremely high, but as we have seen, there can be some impressive cost progression for clean technologies once development switches to implementation.*
10. *Soil carbon*
11. *Annual capture potential: up to 5 billion metric tons. Current estimated cost of capture: between $0 and $100 per metric ton.*
12. *The amount of carbon contained in the soil is a balance between carbon inputs—litter, residue, roots, manure, etc.—and carbon outputs—respiration or soil disturbance. To increase the amount of soil carbon, inputs need to be more than outputs.*
13. *The methods of achieving the goal vary, including adding manure, decreasing soil disturbance, grazing optimization, and the planting of legumes among many others. Each of the techniques is designed to help add more carbon to the soil.*
14. *Biochar*
15. *Annual capture potential: between 0.5 and 2 billion metric tons. Current estimated cost of capture: between $90 and $120 per metric ton.*
16. *Biochar is created by the thermal degradation of biomass, usually wood, in the absence of oxygen. When added to soil, it has the ability to increase the amount of soil carbon—more than what can be achieved through conventional means. Beyond storing carbon, the use of biochar leads to greater retention of water in soils and reduction in methane and nitrogen emissions. The difficulty identified by Stewart Brand remains – it is not clear whether the technology can scale up.*
17. *Enhanced weathering*
18. *Annual capture potential: between 2 and 4 billion metric tons. Current estimated cost of capture: between $50 and $200 per metric ton.*
19. *Some minerals have the ability to react with and capture carbon dioxide, as the natural forces cause the rock to break apart and expose unreacted parts. Enhanced weathering accelerates the process by grinding the rock and then spreading it on a piece of land to increase its exposure to the atmosphere. As a side effect, the alkalinity (opposite of acidity) of weathered rocks can also help improve soil quality. In Oman, for example, peridotite exists in vast quantities. When exposed to air, it reacts and forms carbonate minerals that can be seen as white-colored veins in rocks. It is estimated that the region could help store as much as 1 billion metric tons of carbon dioxide each year.*

[132] See: https://qz.com/1283166/drax-power-station-will-build-a-negative-emissions-plant/

20. *As with biochar, there are no large-scale studies of enhanced weathering's impact on geochemical cycles and on the biomass and carbon stocks in the soil and in plants. The cost is also highly dependent on where the rocks are mined, and where and how they are crushed and spread.*

20. Conclusions and Recommendations

Self-evidently, the links between decarbonisation and infrastructure are many and complex. The policy history of decarbonising infrastructure is unevenly balanced, at times misdirected and sometimes poorly executed. One of the most frustrating aspects of this is the time lost – who knows, for example, how many of the UK's 29 million homes (now described as a "UK infrastructure priority") would now be contributing to the decarbonisation target if the UK Government had designed a half-sensible Green Deal policy?

Scotland's policy environment generally appears so far to have been more proactive and more consistently supportive of decarbonising infrastructure than that of the UK overall, which, with successive governments since the turn of the century, has been subject to hesitation, compromise, inconsistency, hiatus and oscillation, with the task made more complicated by the structure of the UK's regulated industries, which are responsible for much of the UK's infrastructure. Scotland is pegged to UK infrastructure systems in a number of ways, not simply as a result of the devolution settlement on energy.

Notwithstanding any achievements to date (and those in the power sector are notable), the scale of the future challenge is enormous and the silo-ed, piecemeal and unsystemic approaches to decarbonisation that have prevailed so far are inadequate for the task.

Even Scotland, where decarbonisation is a persistent thread through multi-sectoral policy development, is not yet placing decarbonisation systemically at the heart of everything it does, which is essential if net zero carbon is not to remain a distant vision.

The challenges posed by the devolution settlement (particularly in energy) are well known, but continuing to sprinkle the responsibility for carbon reduction across Scottish Government departments (see, for example, the daunting list of 28 different policies with low carbon consequences at Appendix A) seems likely to risk institutional paralysis. If decarbonisation is genuinely the most important issue facing the Scottish Government (which, judging by the Programme for Government, it appears to think is the case), then its organisational structures need to reflect that, through the creation of a single ministry responsible for everything to do with low carbon and placed, like the Columbian model, at the centre of decision-making. That said, the rest of the UK weighs heavy in the power sector in particular and there should be Government / cross-industry collaboration specifically focused on Scotland's electricity network needs.

Local government and other government agencies need to follow suit. Outside the water sector in Scotland, there is little evidence of a consistent drive for decarbonisation. It is not enough to give existing strategies a slightly green hue and carry on as if the transformation needed is still tomorrow's problem.

If local authorities see an economic opportunity in low carbon, they will take it, but will they turn away an apparently attractive economic activity because it is too carbon intensive? The sustainable procurement duty in the Procurement Reform Act is being used to secure plenty of benefits, but decarbonisation doesn't appear to be one of them.

Engaging with citizens / people and communities is an enormous elephant in the room. Central and local government need to recognise that as institutional authority structures they have limitations in securing engagement. Beyond mandated or regulated behavioural change, more effective ways of channelling "grass roots" engagement need to be found.

On the next stage of the decarbonisation journey, not just willing, but proactive on-the-ground support will be needed. And people need some "skin in the game". While SG has long championed communities and community energy, the reality is that the community sector is too small at the moment to have any material impact. SG needs to be an order of magnitude bigger and bolder in engaging people and communities. An effective consultation strategy would be a good start, but it needs to go much further than that. The UK Government's Green Deal was a missed opportunity for community participation; perhaps the Scottish Government could make this work.

The journey to NZCI is further complicated by the fact that the effects of extreme weather are already beginning to be felt, so the challenge for existing infrastructure is no longer just about decarbonising assets that are already operational, but how to protect these assets, most of which will still be with us in 2050. While basic core infrastructure (power, rail, roads) seems to be reasonably well protected, we are layering on new forms of digital infrastructure and creating greater interdependencies between infrastructure types, so our resilience is likely to get worse in the years to come, unless we take a different approach that focuses on the ability of infrastructure to bounce back rather than, Canute-like, trying to hold back the waves. In the years to come, it seems likely that there may be some tough choices to be made between asset preservation and the transition to a new, more flexible, lower carbon infrastructure paradigm.

Just as it is not possible to decouple climate mitigation from adaptation, nor is it possible to treat decarbonisation and inclusive growth as separate parallel themes. Social value could be eroded or enhanced through a net zero carbon agenda. The highest per capita emitters are generally the wealthiest in society, but they also have the most resources to deal with change. Social inequality erodes social capital, potentially undermining the collective action needed to deal with environmental issues, while alternative governance and ownership structures could give communities a clearer stake in their future.

There are already significant infrastructure inequalities (such as access to transport) and an effective decarbonisation strategy will need to tackle these. An important next stage will be to bring together the different policy strands of economic growth, addressing inequality and remaining within a sustainable environmental envelope to identify "Net Zero, Net Positive[133]" pathways.

One consequence of the greater visibility of the effects of climate change ought to be a greater and smarter role for carbon valuation in cost-benefit analysis, but the Scottish public sector does not seem to be well served just now either in terms of measuring emissions or carbon forecasting. No doubt there is extensive expertise in the private sector, but this seems to be a fundamental toolset that needs to be readily accessible to policy-makers, not a service to be purchased on an ad hoc and commercial basis.

It is not all bad news. The challenge does not appear insurmountable. The technology for retrofitting existing homes to reduce energy use is not all new – the challenge is persuading people to go with it. This has to be preferable to trying to produce even larger amounts of low carbon heat. From a policy perspective, while alleviating fuel poverty is essential, the question of how to get the rest of the population who don't live in new homes onto a lower carbon pathway remains.

[133] "Net Positive" in social terms

Technology development in terms of energy generation and storage has made tremendous progress in the past decade or so and renewable energy is now quite simply the cheapest form of energy generation, despite depressed commodity prices for fossil fuels, which should have made it harder for renewables. New nuclear as a cost-effective low carbon technology appears to be a pipe dream at the moment. Digital technologies have the potential to supercharge the decarbonisation effort, although there is a sting in the tail here as the digital sector is rapidly consuming more and more energy.

It would be naïve to think that market forces will necessarily on their own sort out the right technologies for decarbonisation. What the past decade and a half tells us is that sustained and significant government support makes a difference. And hydrogen technology, for instance, looks as though it is going to need a significant amount of help to be in a position to contribute to NZCI.

We also know a lot more about the impact of infrastructure on carbon emissions than we used to. There are sophisticated asset-level tools that can give us lots of useful information. The trouble is, we seem to be better at developing tools than using them at the moment ("model rich and data poor"). We need to use the tools consistently and relentlessly, gather the data and share the data.

There also still seems to be a misconception that we can come up with the right answer that tells us exactly what to aim for and how to get there. It is an uncertain world and we need to embrace the uncertainty in the way we plan for the future. We also have legacy evaluation tools that may no longer be fit for purpose, which may need to be re-engineered.

As well as measurement and data, the question of how infrastructure is paid for and who benefits is critical. This will become exposed as the basis for existing pricing models shifts (from commodity pricing, for example), taxes need to be recalibrated and more value or cost embeds itself in the asset itself.

While infrastructure needs to be understood both ***generically*** (recognising the interconnectedness of systems) and ***sectorally*** (to pick up the distinguishing features between types of infrastructure), reaching "net-zero" emissions give rise to shared and connected infrastructure, such as electricity networks, hydrogen production and distribution and CO_2 transport and storage – which will blur the lines still further

The world of private finance remains tricky to navigate. The market needs pipelines of projects and transactions. Large-scale private finance remains risk- averse and investors seem to have fallen out of love with early stage cleantech – in the UK, at least. An entity like SNIB has a pivotal role to play. It won't just be a case of bridging a risk here and offering a guarantee there. An entire new financing ecosystem is needed, focused on Scotland's pathway to NZCI and SG needs to think about how it can introduce "dynamic adaptability" - keeping project pipelines aligned with policy objectives over time.

The loss of the Green Investment Bank to the public sector is a depressing example of the failure to understand the value of intellectual property in the public sector. This needs to change, or policy-makers will be perpetually hamstrung and bemused at their inability to see their vision through. Government needs to build its own knowledge base in the NZCI arena.

We talk about major challenges in terms of transport and buildings. Transport is the biggest emitter (because of its carbon intensity) and has barely decarbonised since 1990, while buildings are the biggest sector in terms of energy use. Perhaps we are better articulating the challenge as one of "place" – because these two come together. Amending building regulations is useful, for instance, but it is not strategic enough and there is no point in doing this unless we also think about the spaces in between. Scotland has started on buildings (for instance, it now has proportionately 38% more homes with a good EPC rating (C or above) than England), but there is everything to do in transport. On the other hand, despite positive noises, the Planning Act is silent on decarbonisation.

There are things we need to stop doing in housebuilding / property development. Connecting houses to the gas grid, for example (which is recognised by SG).

Lack of clarity on the drivers for green infrastructure, continuing to build residential streets wide enough for cars to travel in two directions at 30 miles an hour (regardless of official speed limits), or housing developments with no facilities so that a car ride is essential to reach the shops, severing pathways and cycle routes by roads all perpetuate high carbon behaviours.

"Accessibility" is still defined by the Scottish Government by drive time, the underlying presumption being that most households have access to a car. If a significant modal shift is required for decarbonisation, this needs to be revisited. But there is no "one size fits all" decarbonisation strategy for every place in Scotland. Over-emphasis on urban density may result in a class of suburban poor who are excluded from the benefits of decarbonisation. Overall, an overarching, decarbonisation-led strategy of place needs to come into being.

Historically, policy and investment in NZCI have been sector-led, but sector lines are becoming blurred and in future the reverse probably needs to happen – NZCI needs to be the overarching objective that then flows into infrastructure sectors. Adopting a systems-led approach to NZCI should identify key links between sectors, and system hierarchies should help to build resilience into the overall delivery strategy.

Despite Scotland's policy framework for planning and sustainable development, blue-green infrastructure does not appear to be a key component of urban planning, although it is potentially a "win-win" in terms of aesthetic and community space.

Recommendations

It should be re-emphasised that this is only a literature review and as such presents a partial picture in this very rapidly evolving sector. A valuable next step would be to test the findings of this "desk-top" exercise through primary research, as well as developing more detailed lines of enquiry in key subject areas. However, based on the scope of this review, and recognising that the IC itself is only a short-life body, we would recommend that the IC, Scottish Government and subsequent delivery bodies (e.g. SNIB) give consideration to the following:

1. *Establishment of a single ministry with coordinating responsibility for everything to do with low carbon in the Scottish Government*
2. *Development of a robust set of investment criteria for NZCI that place decarbonisation at the heart of the process within a systems-led assessment framework that values cross-sectoral initiatives*
3. *A proactive and accelerated decarbonisation strategy for transport, components of which include management of road traffic volumes, scaling up public transport networks and densities and driving a rapid shift from fossil-fuel vehicles to ultra-low emission vehicles*
4. *Development of an effective housing retrofit programme at scale for Scotland.*
5. *Building a new financing ecosystem for Scotland around SNIB to support Scotland's pathway to NZCI, including consideration of how aggregated finance models could be used to manage risk and create growth opportunities for cleantech*

6. *Putting in place steps to secure and develop Government's intellectual capital and knowledge base in the NZCI arena*
7. *Taking bold steps to enable people and communities to engage and participate in the development of NZCI for Scotland.*
8. *Integration of low carbon and inclusive growth policy drivers to enable economic growth and addressing social inequality to be delivered within a sustainable environmental envelope*
9. *Examining existing appraisal and evaluation tools for infrastructure to see to what extent they need to be re-engineered, and from there a coherent toolkit assembled to support NZCI throughout its development and lifecycle.*
10. *Development of a defining decarbonisation-led strategy of place, which incorporates systems thinking and blue-green infrastructure and is embedded consistently in development.*

"Scotland is serious about its commitment to tackle climate change and aware of the associated benefits for the planet, the Scottish people, and the economy" Committee on Climate Change

Appendix A – 20 Big Questions

1. ***What is the context for decarbonisation in infrastructure development and maintenance?***
   Scotland is committed to becoming a net-zero society by 2045. Reducing the carbon impact of infrastructure is not a single issue or focus. It is interconnected with managing the impacts of carbon, environmental sustainability and the effects of social inequality.

2. ***How well is Scotland doing so far on decarbonisation?***
   Scotland is currently on track and performing better than the rest of the UK due to performance in the electricity sector.

3. ***What sectors pose the big challenges in the decades to come?***
   Transport and buildings (predominantly space heating) both pose major challenges, but transport is now the largest emitting sector and there is also significant uncertainty over the pathways to decarbonisation in both sectors.

4. ***To subsidise or not to subsidise?***
   That is the question. The legacy of policy decisions in the energy and energy efficiency sectors at a UK level shows that it is difficult to intervene effectively, predictably and consistently to support a decarbonisation trajectory. How people use and pay for infrastructure is a critical consideration.

5. ***How well is Scotland (as distinct from the UK as a whole) served in terms of NZCI literature?***
   Scotland has benefited from extensive policy development across a range of sectors, but policy development and implementation strategies that are independent of Government appear harder to come by. Literature that is supposedly intended to cover the whole of the UK has a heavily English focus.

6. ***Do the analytical tools exist to enable delivery of NZCI?***
   A great deal of work has gone into developing tools specific to decarbonisation (such as BREEAM), but data from the use of these tools is not generally available, so it is not easy to learn from the application of these tools. Some work has gone into adapting existing appraisal and evaluation tools (such as Treasury Green Book CBA) to meet the new priorities of a decarbonisation agenda, but it probably doesn't go far enough.

7. ***What can be learned from experience globally?***
   For example: governance structures that place decarbonisation at the heart of decision-making, using green infrastructure to increase resilience, linking decarbonisation to social development strategies, for instance.

8. ***Do we have the technology to deliver NZCI?***
   It would appear so, in principle, although significant uncertainties remain over the role of hydrogen and carbon capture and storage, in particular. Technologies that enable flexible system use are also going to be key.

9. ***Do we have a map?***
   With multiple possible decarbonisation scenarios rather than a single defined "route-map", heavy emphasis is placed on "low regrets" strategies – essential shorter term actions that will contribute positively, regardless of the final pathway, while keeping options open.

10. ***How well is green infrastructure embedded in placemaking?***
    While greater focus is being given to resilience and decarbonisation, green infrastructure still appears to be a discretionary element of placemaking strategies. In the meantime, investment in urban greenspaces continues to decline. Scotland is doing well on afforestation (the only proven negative emissions technology) but the UK isn't.

11. ***Does the literature make a strong case for nuclear being a key part of NZCI?***
    Not especially, although nuclear offers the prospect of large amounts of low carbon baseload. However, new nuclear looks uncompetitive compared with most established renewables technologies.

12. ***Is renewable energy cost effective?***
    Renewable energy has seen a major improvement in the cost effectiveness of its established technologies. Globally, onshore wind and solar PV are amongst the most competitive generating technologies available, while offshore wind has also become significantly more cost effective in recent years.

13. ***How will digitisation and interconnectedness of infrastructure affect its resilience?***
    There appears to be a knowledge deficit in terms of inter-system resilience, but on the face of it, facing the challenges of climate change whilst increasing the complexity of our infrastructure appears to increase resilience risks in future.

14. ***Do we need to be concerned about emissions from digital infrastructure?***
    Not a great deal has been written about the energy intensity of digital infrastructure. There appears to be something of a knowledge gap here.

15. ***How engaged is the public in Scotland's decarbonisation strategy?***
    While climate change has become a highly public issue, input from the public specifically on the Scottish Government's strategies to address the challenge appears limited to date.

16. ***Does economic development in Scotland prioritise decarbonisation?***
    The picture appears to be mixed. At times strategies (such as City Region Deals) target a transition to a low carbon economy, but decarbonisation is not a "red line".

17. ***Is finance stepping up to meet the challenge?***
    In the UK, green finance appears to have gone backwards in recent years. Green technology appears to be underfinanced and the Green Investment Bank has been lost as a strategic financing instrument for government. Globally, green bonds, including sovereign green bonds, appear to be gathering momentum. If the Scottish National Investment Bank successfully places decarbonisation at the heart of its activities, this is likely to represent a significant step forward.

18. ***Are the interfaces between infrastructure types well understood?***
    There appears to be extensive literature on new types of NZCI and on managing existing infrastructure, but little to date on how they will work together.

19. ***How important are local and community energy?***
    Scotland is exceeding its targets for local energy and new policies should encourage this further. But community energy remains a small sub-element.

20. ***How well is Scotland performing in terms of managing water resources?***
    Scottish Water appears to have pursued an effective decarbonisation agenda in terms of energy usage, but per capita usage and leakage appear to be relatively high.

Appendix B - Climate Ready Scotland SEA: relationship between draft programme and other plans[299]

	Plan, programme or strategy	Summary
1	UK Climate Change Act 2008 (‘the 2008 Act’)	· Basis for the UK’s approach to tackling climate change mitigation and adaptation; · The Act requires CCRAs to be prepared, the latest of which will inform the draft programme
2	UK Climate Change Risk Assessment 2012	First CCRA produced in response to the requirements of the 2008 Act · Identified main priorities for adaptation in the UK, focusing on five themes: agriculture and forestry; business, industries, and services; health and wellbeing; buildings and infrastructure; and natural environment
3	UK Climate Change Risk Assessment 2017	· Updates the 2012 CCRA · Outlines UK and Devolved Governments’ views on the key climate change risks and opportunities that the UK faces · Endorses six priority risk areas identified in the independent evidence report by the Adaptation Committee: from flooding and coastal change; to health and well-being from high temperatures; due to water shortages; to natural capital; to food production and trade; from pests and diseases and invasive non-native species · Scotland-specific evidence has also been collated into a ‘Scotland Report’
4	UK Climate Projections 2018	Explores how the UK’s climate could change over the next century under three different greenhouse gas emissions scenarios including temperature, rainfall, and sea level rise forecasts · Serves to equip the UK with information to help adapt to the challenges and opportunities of climate change
5	Climate Change (Scotland) Act 2009	Sets the statutory framework for greenhouse gas emissions reductions · Scottish Ministers are required to report regularly to the Scottish Parliament on emissions and progress being made towards targets set in the Act and in secondary legislation · The draft programme is a requirement of the Act

6	Low Carbon Scotland – Meeting the Emissions Reduction Targets 2010-2022: Report on Proposals and Policies (RPP1)	Laid out specific measures for reducing emissions in line with statutory targets for the period 2010-2022 · Structured around key sectors of energy supply, homes and communities, business and the public sector, transport, rural land use, and waste
7	Low Carbon Scotland – Meeting Our Emissions Reduction Targets 2013-2027: Second Report on Proposals and Policies (RPP2)	· Laid out specific measures for reducing emissions in line with statutory targets for the period 2013-2027 · Structured around the same key sectors as RPP
8	Climate Change Plan - Third Report on Proposals and Policies (2018-2032) (RPP3)	· Sets out actions towards a low carbon economy in the context for the Scottish Government's climate change proposals and policies and its statutory duties · Provides information on sector emissions envelopes and reduction trajectories
9	Annual Progress Report to Parliament	· Compiled by Committee on Climate Change to report on UK's progress towards reducing emissions in line with established carbon budgets and the 2050 target, as required by the 2008 Act · Also describes what further progress is needed to meet those budgets and target and whether they are likely to be met
10	The 2020 Challenge for Scotland's Biodiversity	· Aims to protect and restore biodiversity and support healthier ecosystems; and recognises the potential impacts of climate change on the biodiversity resource; · Takes an 'ecosystem approach' to conservation and enhancement; · Recognises the pressure on ecosystems that population growth and climate change bring; and · Recognises that climate change adaptation can improve ecosystem resilience.

11	The Scottish Rural Development Programme (SRDP) 2014 – 2020	· Includes economic, environmental and social measures designed to support rural Scotland; · Through SRDP there are a large number of activities which land managers can use in responding to climate change.
12	Farming For A Better Climate	· Works with farmers and land managers in Scotland to encourage and advise on the uptake of practices that will help the sector to become more profitable whilst moving towards a low carbon sustainable future whilst also adapting to a changing climate and securing farm viability for future generations · Its five key action areas involve are using electricity and fuels efficiently, the development of renewable energy, locking carbon into soils and vegetation, making the best use of nutrients, and optimising livestock management
13	The Scottish Forestry Strategy 2006 and 2019 – 29 (Draft)	· Sets out the long term vision for Scottish Forestry within the context of wider land use aspirations; · Focuses on the sustainable creation and management of Scotland's woodlands and forests; · Opportunities that will support climate change resilience and adaptation are recognised.
14	Scotland's Economic Strategy 2015	· Sets out how to achieve a more productive, cohesive and fairer Scotland; · Prioritises boosting investment and innovation, supporting inclusive growth and maintaining focus on increasing internationalisation; and · Recognises climate change as a key challenge for economies.
15	Good Places, Better Health 2008	· Promotes partnership working which shares knowledge and understanding of how the physical environment impacts on mental health and wellbeing; and · Climate change adaptation responses may impact on the quality of our physical surroundings both positively and negatively.
16	The Scottish Soil Framework 2009	· Sets out the Scottish Government's vision for soil protection; · Formally acknowledges the important services soil provide to society; · Recognises that climate change and loss of organic matter are the most significant threats to Scottish soils; and · Adaptation actions need to recognise the vulnerability of soils to climate change and ensure that they contribute to the protection of the soil resource.

17	Scotland's National Marine Plan 2015	· Covers the management of both Scottish inshore waters (out to 12 nautical miles) and offshore waters (12 to 200 nautical miles); · Considers climate change in terms of how plan actions can mitigate GHG emissions and how actions need to be adapted to account for climate change effects; · Marine planning and conservation measures could provide opportunities to manage conflicting demands on the marine environment as a result of climate change adaptation.
18	The Flood Risk Management (Scotland) Act and Flood Risk Management Plans (FRMPs)	· The Act provides a comprehensive flood risk information base which will support the identification of locations where adaptation responses will be required to address flood risk; · Adaptation responses will need to make a positive contribution to flood management and adaptation actions will need to have due regard to FRMPs.
19	The Water Framework Directive (WFD), The Water Environment Water Services (Scotland) Act 2003 (WEWS), and River Basin Management Plans (RBMP)s	· Scotland fulfils its water protection obligations under the WFD primarily through the WEWS which defines the establishment of RBMPs; · These plans provide an assessment of the condition of Scotland's water environment, and identify where efforts for protection and improvement must be targeted.
20	Cleaner Air for Scotland – The Road to a Healthier Future 2015	· Notes the importance of clean air for health, wellbeing and the environment and sets out a series of actions and frameworks to improve air quality in Scotland. Adaptation measures have the potential for secondary effects on air quality.
21	Historic Environment Scotland Policy Statement 2016	Sets out how Historic Environment Scotland fulfils its regulatory and advisory roles; and · How it expects others to interpret and implement Scottish Planning Policy.
22	Scottish Natural Heritage Landscape Policy Framework	· Sets out an overarching aim for landscape based on four propositions of "to safeguard and enhance the distinct identity, the diverse character and the special qualities of Scotland's landscapes as a whole, so as to ensure tomorrows landscape contribute positively to people's environment and are at least as attractive and valued as they are today".

23	The Scottish Energy Strategy: The future of energy in Scotland (2017)	· Sets out the Government vision for the future energy system in Scotland; · Articulates six priorities that consider both energy use and supply for heat, power and transport; · Energy priorities and actions will need to be consistent with adaptation actions where relevant.
24	The National Transport Strategy (2006)	· Highlights the importance of travel to our society and sets out strategic transport outcomes; and · Meeting these will require adaptation responses which support the transport network.
25	A Land Use Strategy for Scotland (2016-2021)	· Sets a framework for sustainable land use; · Required to contribute to obligations under the Climate Change (Scotland) Act (2009) on emissions reduction targets, to climate change adaptation objectives and to sustainable development.
26	National Planning Framework (NPF3)40 and Scottish Planning Policy (SPP)	· NPF3 is a long term spatial expression of the Government's Economic Strategy, plans for development and investment in infrastructure; · Identifies national developments and other strategically important development opportunities in Scotland; and · It supports development that facilitates adaptation to climate change, reduces resource consumption and lowers greenhouse gas emissions. · SPP is Scottish Government Policy on how nationally important land use planning matters should be addressed.
27	Making things last: A Circular Economy Strategy for Scotland (2016)	· Sets out priorities for moving towards a more circular economy. Which will benefit the environment, economy and communities; · It builds on Scotland's progress in the zero waste and resource efficiency agendas; and · Waste reduction is fundamental to helping tackle climate change and to preserve national capital. · Climate change adaptation responses should support the protection of waste management facilities and infrastructure.
28	Realising Scotland's full potential in a digital world: A Digital Strategy for Scotland (2017)	Sets out a vision for Scotland as a vibrant, inclusive, open and outward looking digital nation.

Appendix C – Procurement Reform Act

Results from a sample review of procurement reports

Report	References to Carbon?
Aberdeen 2017 - 2019	No
City of Edinburgh March 2019	No
Clackmannanshire 2017 - 2018	No
Dumfries & Galloway 2018 - 2019	No
Dundee 2018	Yes - including planning guidance to require all new buildings to incorporate measures to reduce the level of carbon emissions / identify sustainable risks and opportunities relevant to our spend profile including reducing carbon
Glasgow Caledonian University Jan 2017 –July 2018	No
Glasgow City Council Jan 2017 – March 2018	No
Historic Environment Scotland 2017 - 2018	Yes - reduced energy consumption by 6% in 2017 in our highest energy using sites, saving 145 tonnes of carbon. Low carbon alternatives in construction of the Engine Shed building
Orkney	Yes - climate change (carbon and energy consumption, carbon in production, adaption, carbon in vehicle emissions) referred to as a community benefit award criterion. References Climate Change Scotland Act. Orkney separately producing a Climate Change Duties report. One contract – specifically about low carbon travel
Perth & Kinross 2017 - 2018	No
Scottish Natural Heritage	Yes – reference to tender for Weatherproof, Field Work Gear & Corporate Clothing (carbon footprint)
SEPA 2018 – 2019	No
Skills Development Scotland	Yes – reference to forthcoming procurement (Property, Facilities & Carbon Management)
Sport Scotland Jan 2017 – March 2018	No
University of Strathclyde	Yes – in CRC Phase 2 Carbon Allowance Payment
West Dunbartonshire May 2019	No

Appendix C – Blue-green infrastructure “win-wins”[300]

Benefit from blue-green infrastructure	Examples from individual studies
Water regulation	Green sustainable urban drainage solutions (SuDS) such as swales, water gardens and green roofs to increase the infiltration and slow removal of rainfall into the drainage system, reducing the risk of surface water flooding. Installing a green roof could absorb up to 100% of incident rainfall Looking at a regional scale, with only ten per cent of roofs greened, a 2.7% overall reduction in storm water runoff was achieved in one study, with a 54% average reduction in runoff per individual building.
Cooling effects	Trees positioned next to buildings lowered internal summer temperatures by 4°C and raised winter temperatures by 6°C compared to a ‘no tree’ scenario, with a corresponding decrease in energy consumption of 26 per cent. Increasing the current area of green infrastructure in Greater Manchester by ten per cent (in areas with little or no green cover) could result in a cooling of up to 2.5°C under a high emissions world compared with a ‘no action’ scenario. Green roofs retrofitted to existing buildings reduced surface temperatures on roofs by around 20°C in one study. (Stuttgart is a good example at the city scale). Green walls in the UK were found to reduce indoor temperatures by 4-6°C in the summer.
Improving air quality	Green infrastructure can improve urban air quality in some situations but be ineffective or even detrimental to air quality in others. Hedges between roads and pedestrians, green walls in street canyons, and ‘green oases’ (without internal pollution sources) are all noted as win-win air pollution measures. In contrast, trees can slow down or prevent dispersion of traffic pollutants and emit compounds that react in the air to form ozone. The long-term benefits of trees in urban areas – in terms of health benefits from removing air pollutants, cooling, and carbon storage benefits – have been calculated to be more than twice their planting and maintenance costs.

Accessing greenspace and improving health	Benefits to mental health through increases in physical activity. Being in a greenspace has been shown to lead to lowered muscle tension, improved attention and emotional state. In one study, the difference in diastolic blood pressure of people sitting with tree views vs no tree views was 2-8mmHg15. Senior citizens' survival rates were higher if they had a walkable greenspace within easy reach of their residence – the five-year survival rates were 73 per cent for those with access to a walkable greenspace compared to 56% without, and 74% for those with parks and tree-lined streets near their residence compared to 66% without.
Cultural value	High quality (well-maintained) greenspace leads to a greater attachment to community while untidy or poorly kept greenspace is associated with increased anxiety caused by fear of crime.
Carbon storage	A study of four neighbourhoods in Merseyside found that one with 10.7% tree cover stored around 17 tonnes of carbon per hectare, compared to another at 0.3% cover only storing 0.5 tonnes per hectare. Trees were identified to be a particularly important green infrastructure component for carbon storage, even though the storage benefits will be relatively small compared to trees in rural areas.
Biodiversity benefits	The relationship between urbanisation and biodiversity is complex. Increased urbanisation can be detrimental to habitat size, connectivity and condition, which are key components of resilience to climate change. One study has examined a possible greenspace biodiversity indicator based on extent, heterogeneity and connectivity. The indicator results suggested an area with 52% green cover had almost double the biodiversity potential of a site with only 33% cover.

Appendix D - Bibliography

Code	Document title	Author(s)	Organisation	Date
AFT01	GREEN OAT ALLOCATION AND PERFORMANCE REPORT FOR 2018		Agence France du Trésor	Aug-19
Ald01	SHIFTING EMISSIONS INTO REVERSE GEAR: PRIORITIES FOR DECARBONISING TRANSPORT		Aldersgate Group	Mar-19
AV01	West Princes Street Gardens Impact Assessment	Goode	Aventia Consulting	Feb-17
BEIS01	2018 UK GREENHOUSE GAS EMISSIONS, PROVISIONAL FIGURES		BEIS	28/03/2019
BEIS02	Green Finance Taskforce: Terms of Reference		BEIS	
BEIS03	Green Finance Strategy Transforming Finance for a Greener Future		BEIS	Jul-19
BEIS04	Clean Growth - Transforming Heating		BEIS	Dec-18
BEIS05	UPDATED SHORT-TERM TRADED CARBON VALUES for policy appraisal		BEIS	Apr-19
BEIS06	RE-USE OF OIL AND GAS ASSETS FOR CARBON CAPTURE		BEIS	Jul-19

	USAGE AND STORAGE PROJECTS - Consultation			
BIPP01	The Imperial Treasury: appraisal methodology and regional economic performance in the UK	Coyle, Sensier	Bennett Institute, University of Cambridge	Jul-18
BITC01	WATER RESILIENT CITIES - A business case for Greater Manchester		Business in the Community	Jul-18
BLO01	A Behind the Scenes Take on Lithium-ion Battery Prices		Bloomberg NEF	Mar-19
BRE01	BRE Global launches CEEQUAL Version 6 to support infrastructure project teams' sustainability goals		BRE	27-Jun-19
BRE02	CEEQUAL Version 6 Technical Manual | UK & Ireland Projects		BRE	Jun-19
BRE03	BRE Global methodology for the Environmental Assessment of Buildings using EN 15978:2011		BRE	Jan-18
Broo01	BLENDING CLIMATE FUNDS TO FINANCE LOW-CARBON, CLIMATE-RESILIENT INFRASTRUCTURE	Meltzer	Brookings	Jun-18
BSI01	PAS 2080 Carbon Management in Infrastructure		BSI	2016
BRA01	Whole Earth Discipline	Brand	Atlantic	2010
CCC01	Progress in preparing for climate change 2017 Report to Parliament		Committee on Climate Change	Jun-17
CCC02	Progress in preparing for climate change 2018 Report to Parliament		Committee on Climate Change	Jun-18

CCC03	Progress in preparing for climate change 2019 Report to Parliament		Committee on Climate Change	Jun-19
CCC04	2017 Letter to Lord Adonis at the National Infrastructure Commission from the Climate Change Committee		Committee on Climate Change	Mar-17
CCC05	Building a low-carbon economy in Wales Committee on Climate Change Setting Welsh carbon targets		Committee on Climate Change	Dec-17
CCC06	Zero Emission HGV Infrastructure Requirements	Ricardo	Committee on Climate Change	26/06/2019
CCC07	Extension to Fuel Switching Engagement Study (FSES) Deep decarbonisation of UK industries Assumptions log		Committee on Climate Change	Apr-19
CCC08	UK housing: Fit for the future?		Committee on Climate Change	Feb-19
CCC09	UK Climate Change Risk Assessment 2017 Synthesis report: priorities for the next five years		Committee on Climate Change	
CCC10	The infrastructure needs of a low-carbon economy prepared for climate change		Committee on Climate Change	Mar-17
CCC11	Reducing emissions in Scotland 2017 Progress Report to Parliament		Committee on Climate Change	Sep-17
CCC12	Net Zero The UK's contribution to stopping global warming		Committee on Climate Change	May-19

CCC13	How well is Scotland preparing for Climate Change?		Adaptation Sub-Committee	Nov-11
CCC14	Final assessment: The first Scottish Climate Change Adaptation Programme		Committee on Climate Change	Mar-19
CCC15	Hydrogen in a low carbon economy		Committee on Climate Change	Nov-18
CCC16	Reducing emissions in Scotland 2019 Progress Report to Parliament		Committee on Climate Change	Dec-19
CDP01	The Low Carbon Investment Landscape in C40 Cities		CDP	Apr-17
CE01	Crown Estate Offshore Wind Report January 2018 - December 2018		Crown Estate	
CFC01	Collected case studies: Going low carbon		Centre for Cities	Sep-17
CIC01	Guidelines of Sustainable Infrastructure for Chinese International Contractors		China International Contractors Association	
CLI01	Life Cycle Costs and Carbon Emissions of Offshore Wind Power	Thomson, Harrison	Climate Exchange, University of Edinburgh	Jun-15
COL01	Water Infrastructure - Equitable deployment of resilient systems	Sarte & Stipisic	Columbia University	2016
CPI01	The landscape of climate finance in Germany: a case study on the residential sector	Novikova, Amecke, Stelmakh, Buchner & Juergens	Climate Policy Initiative	Jun-13

CTD01	ALL CHANGE? The future of travel demand and the implications for policy and planning		Commission on Travel Demand	May-18
CUFE01	Multi-Criteria decision making based on PROMETHEE method		Central University of Finance and Economics, Beijing	Jun-10
DCLG01	Planning Act 2008: Guidance on the pre-application process (Nationally Significant Projects)		Department for Communities and Local Government	Mar-15
DEC01	Overarching National PolicyStatement for Energy (EN-1) Planning for new energy infrastructure		DECC	Jul-11
DEC02	National Policy Statement for Fossil Fuel Electricity Generating Infrastructure (EN-2)		DECC	Jul-11
DEC03	National Policy Statement for Renewable Energy Infrastructure (EN-3)		DECC	Jul-11
DEC04	National Policy Statement for Gas Supply Infrastructure and Gas and Oil Pipelines (EN-4)		DECC	Jul-11
DEC05	National Policy Statement for Electricity Networks Infrastructure (EN-5)		DECC	Jul-11
DEC06	National Policy Statement for Nuclear Power Generation (EN-6) Volume II of II - Annexes		DECC	Jul-11
DEC07	National Policy Statement for Nuclear Power Generation (EN-6) Volume I of II		DECC	Jul-11

DEC08	DECC Fossil fuel price projections		DECC	Jul-13
DEC09	Planning Our Electric Future		DECC	Jul-11
DEF01	National Policy Statement for Waste Water		Defra	Mar-12
DEF02	National Policy Statement for Hazardous Waste		Defra	Jun-13
DEL01	Delta Programme 2018		Delta Programme (NL)	2017
DFT01	Airports National Policy Statement: new runway capacity and infrastructure at airports in the South East of England		Department for Transport	Jun-18
DFT02	National Policy Statement for Ports		Department for Transport	Jan-12
DFT03	National Policy Statement for National Networks		Department for Transport	Dec-14
E3G01	SUSTAINABLE INFRASTRUCTURE AND THE MULTILATERAL DEVELOPMENT BANKS CHANGING THE NARRATIVE		E3G	Jun-18
EA01	Draft National Flood and Coastal Erosion Risk Management Strategy for England – consultation document		Environment Agency	May-19
EA02	Flood and coastal risk management - Long-term investment scenarios (LTIS) 2019		Environment Agency	May-19
EA03	Draft National Flood and Coastal Erosion Risk Management Strategy for England		Environment Agency	May-19

EC01	Action Plan: Financing Sustainable Growth		European Commission	Mar-18
EE01	The importance of project finance for renewable energy projects.	Steffen, B.	Energy Economics 69, 280–294.	2018
EEA01	Environmental indicator report 2018		European Environment Agency	2018
EFT01	ENVIRONMENTAL VALUE LOOK-UP TOOL		eftec	Oct-15
EFT02	DEVELOPMENT OF 'LOOK-UP' ENVIRONMENTAL VALUE ESTIMATES FOR INITIAL APPRAISAL WITHIN COST-BENEFIT ANALYSIS Technical Report		eftec	Oct-15
EFT03	VALUING BIODIVERSITY Discussion PaperFor Department for Environment Food and Rural Affairs (Defra)		eftec	Nov-15
EFT04	APPLYING VALUES IN ECOSYSTEM ACCOUNTING Discussion Paper For Department for Environment Food and Rural Affairs (Defra)		eftec	Oct-15
EFT05	ENVIRONMENTAL VALUE LOOK-UP TOOL (spreadsheet)		eftec	Oct-15
EIB01	Environmental and Social Standards		European Investment Bank	Oct-18
EIU01	The critical role of infrastructure for the Sustainable Development Goals		Economist Intelligence Unit	2019

EPA01	Equator Principles Strategic Review		Equator Principles Association	Dec-18
ERC01	UK Transport Carbon Model Reference Guide	Brand	UK ENERGY RESEARCH CENTRE	Jan-10
ERL01	Negative emissions—Part 2: Costs, potentials and side effects	Fuss, Lamb, Callaghan, Hilaire, Creutzig, Amann, Beringer, Garcia, Hartmann, Khanna, Luderer, Nemet, Rogelj, Smith, Vicente,Wilcox, Zamora, Minx	Environmental Letters	Mar-18
EST01	Energy Savings Trust Renewable Heat Report 2018		Energy Savings Trust	Oct-18
EST02	Community and locally owned renewable energy in Scotland at June 2018		Energy Savings Trust	Jun-18
ETC01	Mission Possible - REACHING NET-ZERO CARBON EMISSIONS FROM HARDER-TO-ABATE SECTORS BY MID-CENTURY		Energy Transitions Commission	Nov-18
EU01	EU Action Plan for Sustainable Finance		European Commission	Mar-18
EU02	Decommissioning is a significant part of nuclear power's GHG impact		European Union	Dec-14

EY01	EY Renewable Energy Country Attractiveness Index		EY	Apr-19
FCE01	Urban Tree Challenge Fund (UTCF): Terms and Conditions		Forestry Commission England	
FRP01	Framework for delivering property flood resilience in Scotland		Flood Resilient Properties Advisory Group	Nov-18
GBC01	Delivering Low Carbon Infrastructure		UK Green Building Council	Jul-17
GBC02	Net Zero Carbon Buildings: A Framework Definition		UK Green Building Council	Apr-19
GCB01	Infrastructure Carbon Review Technical Report		The Green Construction Board	Nov-13
GFT01	ACCELERATING GREEN FINANCE		Green Finance Taskforce	Mar-18
GGGI01	Infrastructure Finance in the Developing World	Brown, Kim & Romani	Global Green Growth Institute	Jun-15
GGP01	Financing the Global Low Carbon Transition		Green Growth Platform	
GIG01	A guide to the Green Investment Handbook		Green Investment Group	
GIG02	Smarter, greener cities: Ten ways to modernise and improve UK urban infrastructure		Green Investment Bank	2015

GIS02	Community Engagement Projects		Green Infrastructure Scotland	
GIS03	Useful Links & Research		Green Infrastructure Scotland	
GIS04	Green Infrastructure Fund Projects		Green Infrastructure Scotland	
GPP01	GPP 2020 procurement for a low-carbon economy final results		GPP 2020	30/04/2016
GRI01	Social time discounting: Institutional and analytical perspectives: working paper	Spackman	Grantham Research Institute	Mar-15
GRI02	What are social discount rates?		Grantham Research Institute	Mar-18
GRI03	Discounting disentangled: working paper	Drupp et al.	Grantham Research Institute	
GT01	Independent evaluation of Electricity Market Reform		Grant Thornton, Poyry	Oct-15
GT02	Independent evaluation of FID Enabling for Renewables		Grant Thornton, Poyry	Oct-15
HEL01	Burnout - the endgame for fossil fuels	Helm	Yale	2017
HEN01	The Role of Tidal Lagoons	Hendry		Dec-16
HMT01	Infrastructure Carbon Review		HM Treasury	Nov-13

HMT02	The Green Book Central Government Guidance on Appraisal and Evaluation		HM Treasury	2018
HMT03	Social Discount Rates for Cost-Benefit Analysis: A Report for HM Treasury	Freeman, Groom and Spackman	HM Treasury	Feb-18
HMT04	The Magenta Book		HM Treasury	Apr-11
HMT05	Valuation of Energy Use and Greenhouse Gas Supplementary guidance to the HM Treasury Green Book		HM Treasury	Apr-19
HOC01	Tidal Lagoons briefing paper 7940 June 2018		House of Commons	Jun-18
IC01	Analysis of Alternative UK Heat Decarbonisation Pathways		Imperial College	Aug-18
IC02	Integrating green and blue spaces into our cities: Making it happen	Brown and Mijic	Imperial College	Jul-19
IC03	Blue Green Solutions- A Systems Approach to Sustainable, Resilient and Cost-Efficient Urban Development		Imperial College	Mar-17
IFC01	The IFC Global Infrastructure Project Development Fund		International Finance Corporation	
IISD01	LOW-CARBON INNOVATION FOR SUSTAINABLE INFRASTRUCTURE - THE ROLE OF PUBLIC PROCUREMENT		IISD	
IPA01	Annual Report on Major Projects 2018-19		Infrastructure and Projects Authority	Jul-19
IPP01	NET-ZERO NORTH		IPPR	Dec-17

IR01	Integrated Reporting Framework		International Integrated Reporting Council	Feb-14
JCET01	Multi-Criteria Decision Making Using ELECTRE		Jayaram College of Engineering and Technology, Thuraiyur and VIT University, Chennai, India	May-16
JECH01	Urban residential environments and senior citizens' longevity in megacity areas: the importance of walkable green spaces	Takano, Nakamura, Watanabe	Japan Epidemial Community Health	2002
JTC01	Just Transition Commission - Background report		Scottish Government	Apr-19
JUL01	Comparative Analysis of Infrastructures: Hydrogen Fueling and Electric Charging of Vehicles		Julich Forschungszentrum	2018
KUH01	The structure of scientific revolutions	Kuhn, Thomas		1962
LAZ01	Lazard's Levelized Cost of Energy Analysis version 12.0		Lazard	Nov-18
LED01	On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground	Arrhenius	London, Edinburgh & Dublin Philosophical Magazine	April 1896
LEE01	Leeds City Gate H21 Project		Northern Gas Networks	Jul-17
LES01	LOW EMISSION STRATEGIES GUIDANCE: Using Public		LOW EMISSION STRATEGIES	Sep-11

	Procurement to Reduce Road Transport Emissions			
LON01	Natural Capital Accounts for public greenspace in London		Mayor of London	Oct-17
MAC01	Appraisal of private debt opportunities:A holistic approach for UK pension funds		Macquarie	Oct-16
MAG01	Hunterston A Site Strategic Environmental Assessment Site Specific Baseline		Magnox	Sep-14
MCK01	BRIDGING GLOBAL INFRASTRUCTURE GAPS		McKinsey Global Institute	Jun-16
MCK02	New reality: electric trucks and their implications on energy demand		McKinsey Insights	Sep-17
MEA01	Thinking in Systems	Meadows		2008
MIC01	Social Discounting and Intergenerational Pareto	Feng, Ke	University of Michigan	Jan-18
NAO01	Green Deal and Energy Company Obligation		National Audit Office	Apr-16
NAO02	Oil and gas in the UK – offshore decommissioning		National Audit Office	Jan-19
NCC01	State of Natural Capital Annual Report 2019		Natural Capital Committee	Jan-19
NIC01	Preparing for a drier future		National Infrastructure Commission	2018
NIC02	Climate-proofing the UK's infrastructure must be a government priority	Armitt	Business Green	08-Aug-19

NIC03	Annual Report on Major Projects 2018 -2019		NIC	
NIC04	Infrastructure and Digital Systems Resilience		National Infrastructure Commission	Nov-17
NIC05	NATIONAL INFRASTRUCTURE ASSESSMENT		National Infrastructure Commission	Jul-18
NIC06	Next Steps for Cities		National Infrastructure Commission	Dec-18
NIC07	National Infrastructure Assessment Handout		National Infrastructure Commission	Jun-19
NOR01	Norway's Environmental Targets		Norwegian Ministry of the Environment	2011
ODI01	Leveraging private investment: the role of public sector climate finance	Brown & Jacobs	Overseas Development Institute	Apr-11
OE01	GLOBAL CITIES: THE CHANGING URBAN HIERARCHY		Oxford Economics	Dec-17
OEC01	The Role of Public Procurement in Low-carbon Innovation		OECD	Apr-16
OEC02	Developing Robust Project Pipelines for Low-Carbon Infrastructure		OECD	2018
OFG01	Ofgem’s Future Insights Series Overview Paper		Ofgem	Oct-16
OFG02	Ofgem’s Future Insights Series the decarbonisation of heat		Ofgem	Jul-18

OFG03	Ofgem's Future Insights Series: Local energy in a transforming energy system		Ofgem	Jan-17
OFG04	Ofgem Future Insights Series: The futures of domestic energy consumption		Ofgem	Mar-17
OFG05	Ofgem's Future Insights Series: Implications of the transition to electric vehicles		Ofgem	Jul-18
OFG06	Ofgem Future Insights Series: Flexibility Platforms in electricity markets		Ofgem	Sep-19
OFG07	Domestic Renewable Heat Incentive Annual report 18/19		Ofgem	Jul-19
OFG08	Domestic Renewable Heat Incentive Quarterly report May to july		Ofgem	Sep-19
OFG09	Non-domestic RHI Guidance Vol 2		Ofgem	May-19
OFG10	Domestic RHI Factsheet 2017		Ofgem	Sep-17
OGU01	Oil & Gas UK ENVIRONMENT REPORT 2018		Oil & Gas UK	
ONS01	Population dynamics of UK city regions since mid-2011		Office of National Statistics	12/10/2016
ONS02	UK natural capital: ecosystem accounts for urban areas		Office of National Statistics	Jul-18
ONS03	UK natural capital: urban accounts		Office of National Statistics	Aug-19

PAL01	A Critical Review of Scottish Renewable and Low Carbon Energy Policy		Palgrave	2017
POY01	ROADMAP FOR FLEXIBILITY SERVICES TO 2030		Poyry / Imperial College	May-17
RAM01	FORGING SCOTLAND'S WAY AHEAD TEN PROJECTS FOR A LOW CARBON FUTURE	Steen	Ramboll	Dec-15
RAW01	Doughnut Economics	Raworth		2017
RES01	Critical Infrastructure Resilience Understanding the landscape		The Resilience Shift	Jul-19
RES02	EARTH EX® - London and Glasgow Building resilience for global scale complex catastrophes		The Resilience Shift	May-19
RES03	The role of public policy in critical infrastructure resilience		The Resilience Shift	Apr-19
RES04	The role of legislation in critical infrastructure resilience		The Resilience Shift	Jul-19
RICS01	Whole life carbon assessment for the built environment		RICS	Nov-17
RIJ01	Dealing with Uncertainty in Transport Planning	Verroen	Rijkswaterstaa t	21-Nov-17
ROY01	Options for producing low-carbon hydrogen at scale		Royal Society	Jan-18
RSA01	The RSA Great Recovery & Zero Waste Scotland Programme		RSA / Zero Waste Scotland	Oct-15
RSE01	Scotland's Energy Future		Royal Society of Edinburgh	Jun-19

RSG01	Green and Blue Infrastructure		Royal Scottish Geographical Society	Autumn 2016
RUK01	Wave & Tidal Energy webpage		Renewable UK	Sep-19
SEP01	Climate change allowances for flood risk assessment in land use planning		SEPA	26/04/2019
SEP02	Planning Background Paper Water Environment		SEPA	Jan-17
SGAA	Draft Second Scottish Climate Change Adaptation Programme		Scottish Government	Feb-19
SG01	Energy Efficient Scotland - route map		Scottish Government	May-18
SG02	Energy Efficient Scotland Strategic Outline Case for Proposed Development of a National Delivery Mechanism		Scottish Government	Apr-19
SG03	Planning (Scotland) Bill [as passed]		Scottish Government	2019
SG04	SCOTTISH TRANSPORT APPRAISAL GUIDANCE		Transport Scotland	2008
SG04	Scottish Transport Appraisal Guidance (STAG) Technical Database		Transport Scotland	Dec-18
SG05	Scottish Greenhouse Gas Emissions 2017		Scottish Government	
SG06	Guidance on strategy level socio-economic assessments		Scottish Government	Feb-17
SG07	Energy Efficient Scotland: Analysis of Second Consultation on Local Heat & Energy Efficiency		Scottish Government	Apr-18

	Strategies, and Regulation of District and Communal Heating			
SG08	Low Carbon Infrastructure Task Force		Scottish Government	Nov-15
SG09	GREEN INFRASTRUCTURE Design and Placemaking		Scottish Government	Oct-11
SG10	CLIMATE READY SCOTLAND: Scottish Climate Change Adaptation Programme 2019-2024 A Consultation Draft		Scottish Government	Feb-19
SG11	CLIMATE READY SCOTLAND: Draft Second Scottish Climate Change Adaptation Programme Strategic Environmental Assessment Environmental Report		Scottish Government	Feb-19
SG12	CLIMATE CHANGE PLAN Third Report on Proposals and Polices 2018-2032 Summary Document		Scottish Government	Sep-18
SG13	Scottish TIMES Model - an overview		Scottish Government	Sep-16
SG14	Exploring the Economic Rationale for Infrastructure Investment (Office of the Chief Economic Adviser)		Scottish Government	Dec-18
SG15	Infrastructure Investment Board Terms of Reference		Scottish Government	May-18
SG16	Scotland's Economic Strategy		Scottish Government	Mar-15
SG17	Scottish Transport Statistics No 37 2018 edition		Transport Scotland	Jan-19
SG18	National Transport Strategy		Transport Scotland	Jan-16

SG19	Making things last - A circular economy strategy for Scotland		Scottish Government	Feb-16
SG20	Energy in Scotland 2016		Scottish Government	Feb-16
SG21	Mission-orientated framework for SNIB		IIPP, UCL	Mar-19
SG22	Guidance of the development of business cases		Transport Scotland	Mar-16
SG23	Scottish Energy Strategy		Scottish Government	Apr-18
SG24	Decarbonising Heat - Policy Statement		Scottish Government	
SG25	LCITP 2017 projects list		Scottish Government	Mar-19
SG26	Local Heat and Energy Efficiency Strategies: Phase 1 PilotsSocial Evaluation Report	Wade, Webb, Creamer	University of Edinburgh	Sep-19
SG27	Second consultation on Local Heat and Energy Efficiency Strategies		Scottish Government	Nov-17
SG28	Procurement Reform (Scotland) Act 2014		Scottish Government	Jun-14
SG29	LG - Annual Procurement Report - Guidance & Template		Scottish Government	
SG30	The Government's Programme for Scotland 2019-20		Scottish Government	Sep-19
SG31	Home Efficiency Programme Scotland - Annual Review		Scottish Government	Jun-19
SG32	Scottish Government Urban Rural Classification 2016		Scottish Government	Mar-18

SG33	A vision for Scotland's Electricity & Gas networks		Scottish Government	
SG34	Onshore wind policy statement		Scottish Government	Dec-17
SG35	Scottish Energy Strategy Consultation - analysis of responses		Scottish Government	Nov-17
SG36	Scottish Household Survey		Scottish Government	
SG37	Draft Planning Delivery Advice: Housing and Infrastructure		Scottish Government	
SMF01	Incentivising household action on flooding	Oakley	Social Market Foundation	Feb-18
SPR01	Low carbon infrastructure investment: extending business models for sustainability	Foxon et al	Springer	2015
SPR02	Multi-criteria analysis in the renewable energy industry	Mateo	Springer	2011
SSE01	Climate Change Adaptation Report Second Round		Scottish and Southern Energy Power Distribution	Jul-15
STA01	Brent Crude Oil Prices 2014 - 2020		Statista	Sep-19
STW01	Draft Water Resources Management Plan		Severn Trent Water	Dec-17
SUS01	Are we nearly there yet? Exploring gender and active travel		Sustrans	Feb-18
SW01	Sustainability Report 2018		Scottish Water	
SW02	Sustainable Growth Agreement with SEPA		Scottish Water	Jun-18

SW03	Annual Report & Accounts 2018/19		Scottish Water	
SWG01	Discussion paper on green bonds		Swedish Govt	Feb-18
SWG02	Green bond press release		Swedish Govt	Jul-19
SWW01	Draft Water Resources Management Plan Statement of Response		South West Water Bournemouth Water	Sep-18
TCF01	Task Force on Climate-related Financial Disclosures: Status Report		TCFD	2019
TCF02	Mike Bloomberg and FSB Chair Mark Carney Announce Growing Support for the TCFD on the Two-Year Anniversary of the Paris Agreement		TCFD	Dec-17
TOI01	Less car dependent cities Planning for low carbon in Oslo	Tennøy	Institute of Transport Economics (TOI)	
TSP01	Lean ICT Report		The Shift Project	Mar-19
UCL01	Low Carbon Urban Infrastructure Investment in Asian Cities	Jupesta and Wakiyama	UCL	2016
UKG01	UK Climate Change Risk Assessment 2017		HM Government	Jan-17
UKG02	Transforming Infrastructure Performance		Infrastructure and Projects Authority	Dec-17
UKG03	THE PROPERTY FLOOD RESILIENCE ACTION PLAN	Bonfield	Defra	Sep-16

UKG04	The National Adaptation Programme and the Third Strategy for Climate Adaptation Reporting		DEFRA	Jul-18
UKG05	A Green Future: Our 25 Year Plan to Improve the Environment		HM Government	2018
UKG06	Creating a great place for living Enabling resilience in the water sector		Defra	Jun-16
UKG07	The Road to Zero Next steps towards cleaner road transport and delivering our Industrial Strategy		HM Government	Jul-18
UKG08	Climate change adaptation reporting: secondround reports		HM Government	Jul-17
UKG09	List of organisations reporting under adaptation reporting power: third round		HM Government	Dec-18
UKG10	GUIDANCE ON ESTIMATING CARBON VALUES BEYOND 2050: AN INTERIM APPROACH		HM Government	Jul-11
UKG11	Future of Cities: An Overview of the Evidence		Government Office for Science	Apr-16
UN01	World Urbanization Prospects: The 2018 Revision File 2: Percentage of Population at Mid-Year Residing in Urban Areas by Region, Subregion, Country and Area, 1950-2050		United Nations	2018
UNEP01	GREEN INFRASTRUCTURE GUIDE FOR WATER MANAGEMENT		UNEP	2014
UNEP02	INTEGRATED APPROACHES TO SUSTAINABLE INFRASTRUCTURE		UNEP	

UOL01	The Retrofit Challenge - delivering low carbon buildings		University of Leeds	2011
UOG01	The suburbanisation of poverty in British cities, 2004-16: extent, processes and nature	Bailey, Minton	University of Glasgow	Oct-17
UOS01	Making the case for supporting broad energy efficiency programmes: Impacts on household incomes and other economic benefits		Centre for Energy Policy, Fraser of Allander Institute, University of Strathclyde	2017
UOS02	Sustainable decommissioning of an offshore wind farm	Topham, McMillan	University of Strathclyde	Nov-16
USG01	Social Cost of Carbon for Regulatory Impact Analysis		US Government	Feb-10
UTC01	Expanding urban forests: The Urban Tree Challenge Fund		Forestry Commission England	2019
WB01	Low-Carbon Infrastructure Private Participation in Infrastructure (PPI) 2002 TO H1 2017		World Bank	
WB02	Green Infrastructure Finance		World Bank	2012
WB03	IFI Approach to GHG Accounting for Energy Efficiency Projects		World Bank	Nov-15
WB04	International Financial Institution Framework for a Harmonised Approach to Greenhouse Gas Accounting		World Bank	Nov-15
WG01	Energy Efficiency in Wales A strategy for the next 10 years 2016–2026		Welsh Government	2016

WG02	Schedule 3 of the Flood and Water Management Act 2010 for sustainable drainage, explanatory memorandum, incorporating the regulatory impact assessment and explanatory notes		Welsh Government	Oct-18
WIC01	Capital Maintenance Decision Paper 5		WICS	2018
WIC02	Investment planning and prioritisation		WICS	2018
WIC03	Meeting long-term investment needs		WICS	2018
WRA01	Cutting embodied carbon in construction projects		WRAP	
WUK01	Water resources long term planning framework		Water UK	Jul-16
www07	Definition of infrastructure		https://www.lexico.com/en/definition/infrastructure	
www22	Just Transition Commission website		https://www.gov.scot/groups/just-transition-commission/	
WWF01	The Building Blocks for a Greener Scotland - Low Carbon Infrastructure		WWF	
XO01	Dunlin Alpha to Cormorant Alpha Pipeline Decommissioning Environmental Appraisal Report		Xodus	Mar-19
ZCH01	Zero carbon homes Impact assessment		Department for Communities and Local Government	May-11

Endnotes

To balance the flow of the report with ease of reference, we have coded each of the documents referred to. The endnotes are listed here and can be cross-referenced to the bibliography that precedes the endnotes.

---

1 CCC16

2 CCC16 p10

3 SG15

4 SG14

5 www07

6 MEA01

7 LED01

8 www22

9 SG12

10 JTC01

11 UNEP02

12 EIU01

13 SUS01

14 CCC03

15 HEL01

16 DEC08

17 STA01

18 HEL01, Ch 11, p232

19 SG16

20 RAW01, p46, Ch5

21 CCC12

22 CCC12, p12

23 CCC09

24 UKG01

25 CCC03

26 CCC14

27 SG12

28 SGO5

29 SG17

30 CCC11

31 CCC02

32 CCC16

33 ibid, p30

34 ibid, p23

35 ibid, p26

36 CCC01

37 NIC05

38 CCC13

39 SG11

40 SG12

41 SG11

42 CCC02

43 E3G01

44 CCC01, p171

45 CCC03, Ch 4, p178

46 CCC01, page ref?

47 CCC01, Table 2, p21

48 ibid

49 GBC01

50 ibid

51 HMT01

52 ibid, executive summary

53 GBC01

54 CCC01 Ch5, p175

55 CCC10

56 NIC05

57 ibid, p3

58 ibid, pp32, 38

59 ibid, p39

60 GFT01

61 RES02

62 RES01

63 RES03

64 PAL01

65 UKG04

66 CCC16

67 CCC16, p51

68 ibid, p54

69 HOC01

70 CCC10

71 SG17

72 CTD01

73 Ibid, p6

74 SG17, p190

75 CCC10, p18

76 ibid, p21

77 MCK02

78 Ald01

79 TOI01

80 SG18

81 ibid

82 CCC01

83 SG23

84 SG24

85 ibid, p19

86 SG23, p25

87 ibid, p30

88 SG23

89 ibid, p45

90 ibid, p62

91 SG34

92 SG35

93 PAL01

94 DEC09

95 GT01

96 GT02

97 ibid, 2.37

98 ibid, 2.41

99 CCC16, p43

100 PAL01

101 SG33

102 BEIS04

103 SG20

104 EST01

105 IC01

106 ibid, p10

107 ibid, p30

108 ibid, p35

109 CCC16, p66

110 OFG07

111 OFG08

112 ibid, p7

113 OFG07

114 OFG09

115 CCC01

116 CCC08

117 ibid, p11

118 ibid, p59

119 ibid, p11

120 ibid, p34

121 ibid, p53

122 UoL01

123 OFG02

124 CCC08

125 WG01

126 NAO01

127 ibid, p26

128 ibid, p11

129 TSP01

130 NIC04

131 NIC04

132 ibid, page 28

133 CCC10

134 CCC01, p175

135 CCC08

136 NIC01, p11

137 Ibid, p117

138 CCC09

139 ibid, p60

140 UKG03

141 EIU01

142 RES04

143 SW02

144 BEIS02

145 ibid

146 GFT01

147 Ibid, 16

148 EE01

149 ibid

150 EY01

151 NAO01

152 WWF01

153 BEIS03

154 AFT01

155 SWG01

156 SWG02

157 GGP01

158 EU01

159 OEC02

160 CPI01

161 CE01

162 MEA01, Ch 4, p86

163 UKG02

164 GBC02

165 HMT05

166 ibid

167 SPR01

168 HMT02

169 ibid, Section 2.3

170 ibid, A6.19

171 GRI02

172 MIC01

173 SG04

174 ibid, 2.2.3

175 ERC01

176 GBC01, p15, 4.1

177 CTD01

178 RIJ01

179 WRA01

180 BRE03

181 BSI01

182 RICS01

183 WB04

184 WB03

185 TCF01

186 IR01

187 RAW01

188 NCC01

189 SG06

190 SPR02

191 JCET01

192 CUFE01

193 EA02

194 BRA01, Ch9 p227

195 SG30

196 OEC02, Ch 3, p77

197 SG01, p5

198 ibid, p46

199 SG02

200 SG27

201 SG26

202 SG01, p33

203 ibid p45

204 SG31

205 SG25

206 EST02

207 IPPP01

208 OEC01

209 SG29

210 OEC01

211 OEC01

212 GPP01

213 SW01, p6

214 SW03

215 SW02

216 SEP01

217 SEP02

218 SMF01

219 HMT01, p11

220 GBC02

221 UKG02

222 MEA01, Ch 3, p83

223 CCC02

224 SG30

225 SG03

226 SG37

227 ibid, 91

228 ibid, appendix 1

229 See UN Population Division World Urbanisation Prospects: The 2018 Revision

230 GGGI01

231 UKG11, p21

232 CDP01

233 ONS01

234 UOG01

235 BIPP01

236 IC03

237 ONS02

238 ONS03

239 RSG01

240 SG09

241 ibid

242 CCC03, p12

243 CCC01, 5.1

244 UNEP01

245 Ibid, pp8&9

246 Ibid, p58

247 Ibid, p53

248 Ibid, p67

249 AV01

250 JECH01

251 RSG01

252 CCC16, p31

253 LON01

254 AV01

255 ibid, Ch4

256 UTC01

257 FCE01

258 IC02

259 IC03

260 Ibid

261 GIS01

262 EU02

263 MAG01

264 MAG01

265 OGU01

266 NAO02

267 XO01

268 OGU01, p37

269 BEIS06

270 ibid, p13

271 CIC01

272 ibid, p33

273 LAZ01

274 BLO01

275 ibid

276 OFG01

277 OFG04

278 POY01

279 OFG06

280 SG23, p49

281 HEN01

282 ibid, p7

283 HOC01

284 NIC05, p41

285 ROY01

286 CCC15, p7

287 ROY01

288 OEC01

289 CCC06

290 JUL01

291 SG19

292 ETC01

293 CCC08

294 SG30, p59

295 BRA01, Ch 9, p281

296 ibid, p281

297 ibid, p283

298 ERL01

299 SG11

300 IC02