LEDBURY TOWN COUNCIL

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2 February 2024

To: All Councillors
Non-Councillors: Al Braithwaite, Beverly and Paul Kinnaird

Dear Member

You are invited to attend a meeting of the **Climate Change Working Party on Wednesday, 7 February 2024 at 6.00pm at Ledbury Town Council Offices, Church Lane, Ledbury**, for the purpose of transacting the business below.

Yours faithfully

Angela Price
Town Clerk

FILMING AND RECORDING OF COUNCIL MEETINGS

Members of the public are permitted to film or record meetings to which they are permitted access, in a non-disruptive manner. Whilst those attending meetings are deemed to have consented to the filming, recording or broadcasting of meetings, those exercising the rights to film, record and broadcast must respect the rights of other people attending under the Data Protection Act 1998.

AGENDA

1. **Apologies**

2. **Declarations of Interests**

   To receive any declarations of interest and written requests for dispensations. *(Members are invited to declare disclosable pecuniary interests and other interests in items on the agenda as required by the Ledbury Town Council Code of Conduct for Members and by the Localism Act 2011)*

(Note: Members seeking advice on this item are asked to contact the Monitoring officer at least 72 hours prior to the meeting)

3. **To elect non-council members to the Climate Change Working Party**

4. **To approve and sign the minutes of a meeting of the Climate Change Working Party held on Wednesday, 6 December 2023 incorporating Action Sheet** **(Pages 25-32)**

5. **Ledbury Health Partnership** **(Verbal)**

6. **Feedback from Environment & Leisure Committee** **(Pages 33-34)**

7. **Feedback from Traffic Management Working Party in respect of report presented by Professor John Whitelegg** **(Verbal)**

8. **Malvern Hills National Landscape Consultation** **(Pages 35-80)**

9. **Absolute Zero Report** **(Pages 81-114)**

10. **Council's Carbon Footprint** **(Verbal)**

11. **Warm Spaces for Winter 2023/24 - Update** **(Verbal)**

12. **Committee Structure/Corporate Plan – Update** **(Verbal)**

13. **Date of Next Meeting**

The date of the next meeting of the Climate Change Working Party is scheduled for Wednesday, 3 April 2024 at Ledbury Town Council Offices.

LEDBURY TOWN COUNCIL

MINUTES OF A MEETING OF THE CLIMATE CHANGE WORKING PARTY MEETING HELD ON 6 DECEMBER 2023

PRESENT: Councillors: Chowns & McAll
Non-Councillors: Paul Kinnaird, Nina Shields (Chair) and Professor John Whitelegg

ALSO PRESENT: Julia Lawrence, Deputy Clerk

1. APOLOGIES FOR ABSENCE

Apologies were received from Al Braithwaite and Beverley Kinnaird.

2. DECLARATIONS OF INTEREST

None

3. TERMS OF REFERENCE FOR THE WORKING PARTY

The revised Terms of Reference for the Climate Change Working Party ("CCWP") which now incorporated an additional paragraph relating to "Quorum" was received and noted by Members of the CCWP.

RESOLVED:

That the revised Terms of Reference be received and noted by members of the CCWP.

4. TO ELECT NON-COUNCIL MEMBERS

None.

5. TO APPROVE AND SIGN, AS A CORRECT RECORD, THE MINUTES OF THE CLIMATE CHANGE WORKING PARTY MEETING HELD ON 4 OCTOBER 2023.

Members reviewed the minutes of the meeting held on 4 October 2023 and Nina Shields requested that an amendment be made to Item No. 9, that the last sentence: "*Further details to come to the next CCWP Meeting*", in the third paragraph be removed as it was not agreed as the competition had been referred to the Events Working Party.

RESOLVED:

That the minutes of the Climate Change Working Party meeting held on 4 October 2023 be approved and signed as a correct record, subject to the amendment noted above.

6. FEEDBACK FROM ENVIRONMENT & LEISURE COMMITTEE

6.1 Recommendation 7a – Report from Prof Whitelegg

CCWP had requested the Environment & leisure Committee to consider proposals set out in Professor John Whitelegg's paper for a cycle to school scheme and using an electric hopper bus. The report was considered at the above Committee on 2 November 2023 and it was agreed that this report be presented at the next Traffic Management Working Party, to be held on 31 January 2024, for further consideration.

CCWP Members requested feedback from the Traffic Management Working Party could then be fed back to the CCWP in February 2024.

6.2 Recommendation 7c – Report from Prof Whitelegg

Members of the CCWP were issued with a copy of Ledbury Town Council's S106 wish list.

6.3 Recommendation 8a / 8b – Great Big Green Week

It was noted and agreed at the Environment & Leisure Committee meeting held on 2 November 2023 that £2,000 is allocated to the Great Big Green Week for 2024/25 and the event would receive full support from the Council. It was also agreed that the Events Working Party would oversee the organisation of the event.

6.4 Recommendation 10a – Corporate Plan 2020

The CCWP requested an update on the progress on delivering actions relating to climate change in the Corporate Plan. It was noted that Ledbury Town Council is currently working through Committee Structure Changes which will pick up the concerns raised here. The Environment & Leisure Committee will be meeting later in December to review/finalise its Committee Structure.

6.5 Recommendation 11a – NMiTE to undertake a survey on how best to insulate the Town Council offices

This request was declined due to a survey being completed in 2022.

7. TRANSPORT

Professor John Whitelegg made reference to the report, "A Ledbury proposal to reduce transport's climate damaging carbon emissions", stating that carbon emissions could be significantly reduced around schools by the introduction of hopper buses. It was noted that 380,000 trips to and from John Masefield High School take place every year and so the introduction of hopper buses would make a big impact. Prof Whitelegg asked if John Masefield had a school travel plan and Nina Shields recommended that he make contact with Rebecca French at the School.

Cllr Chowns noted that the financial implications would need to be explored.

Nina Shields said that it would be important for this working party to work with the Traffic Management Working Party and looked forward to receiving feedback from their meeting. She stressed the importance of starting the dialogue given that change is not all about finance. She also appreciated that Ledbury Town Council may not be in a position to apply for grant funding. Sustainable Ledbury may be able to do so if funding is needed to progress any proposals, for example, if some external advice or research were needed.

Paul Kinnaird said that Ledbury Town Council should also have a Travel Plan.

RECOMMENDATION:

That the report presented by Prof John Whitelegg be presented at the next Traffic Management Working Party on 31 January 2024 for further consideration and that feedback is shared with the CCWP members in February 2024 at their next meeting.

8. GREAT BIG GREEN WEEK (“GBGW) 8 – 16 JUNE 2024

Nina Shields confirmed that she had met with members of Sustainable Ledbury who had put forward suggestions for events that could take place during the Great Big Green Week. These ideas included the following:

8.1 Set up a Garden Share Scheme, whereby someone who does not have a garden could have access to someone else’s.

8.2 Develop a Treasure Hunt with Town traders around Town, whereby traders would be encouraged to put models of insects and wild flowers, for example, in their shop windows, as part of the Treasure Hunt.

8.3 Ledbury Library Development Group has agreed to sponsor a Wild Play Session to be run by Herefordshire Wildlife Trust at Ledbury Library on 8 June 2024.

8.4 Herefordshire Wildlife Trust could develop a nature trail, ending the event with a picnic.

8.5 Clothes swap, which would be run in conjunction with 8.6 below.

8.6 Mayor’s coffee morning.

8.7 Litter pick.

8.8 The children's author, Catherine Barr, could run a children's event. Ledbury Library Group to sponsor – to be confirmed.

8.9 Beeswax wrap workshop.

8.10 Set up a Gardener's Question Time Panel style event on sustainability issues.

It was suggested that St Katherines Hall / Methodist Church could host some of the events. This would need to be addressed at the forthcoming Steering Group, shortly to be set up by the Community Development Officer.

Paul Kinnaird suggested that "Home Energy" could also be asked to attend to promote home improvements/renewable energy. Prof Whitelegg confirmed that Herefordshire are better placed for home energy experts than Shropshire and that there was a long list of experts available on the website, although suggested that perhaps Severn Wye Energy should be invited to attend the event, preferably on both Saturdays.

RECOMMENDATION:

That the activities/events suggested above should be put to the next GBGW Steering Group for consideration and approval, confirming which events should be pursued in order that approvals can be forwarded to the Events Working Party to progress, and before presenting the overall "offerings" to the Environment and Leisure Committee with costings for approval.

9. CORPORATE PLAN 2020

As noted in 6.4 above, work was ongoing in this regard, awaiting the outcome of the Committee Structures. However, Nina Shields felt that Ledbury Town Council needed to publicise what work had been done to date regarding climate change/sustainability and to promote future work planned, and using the Council's newsletter was considered a good platform to get the positive messages out.

RESOLVED:

That members of the CCWP await the outcome of the Committee Structure.

10. COUNCIL'S CARBON FOOTPRINT

Paul Kinnaird gave an overview following the information he had previously submitted to the Clerk to help reduce the Council's carbon footprint. This included the following:

10.1 Reduction in the Council's heating costs – adopt new ways to heat the offices.

10.2 Insulation – consideration could be given to draft proofing, albeit appreciating that it may be difficult to conserve heat in listed black and white buildings.

10.3 Market House – it was noted that the cost per unit is too high for this building. It was recommended that Ledbury Town Council should consider having one energy supplier to cover all buildings. Prof Whitelegg said that the energy supplier must be able to offer a guarantee/certificate for 100% renewable energy and recommended that Severn Wye may be able to help in this process.

Paul Kinnaird stated that the installation of renewable energy generation would be in either two forms, namely solar panels or windmills. Solar panels could be considered at the Cemetery and a windmill in Dog Hill Wood. Investing in PV solar generation over 10 years would cost 15p per KW/hour as opposed to 27p to 30p general rate.

Nina Shields stated that it still may be beneficial for the Council to engage with NMiTE as the University has project based learning opportunities whereby the Council could ask the students to undertake a project on how to insulate a building such as the Market House. Cllr Chowns was asked to talk to his daughter to see if she had a contact for NMiTE.

RECOMMENDATIONS:

1 That the CCWP requests that the Finance, Policy and General Purposes Committee are asked to investigate renewable PV energy generation in consultation with Severn Wye (who would be able to provide a free consultation).

2 That Cllr Chowns speaks with his daughter to see if she has any contact details for NMiTE.

Prof John Whitelegg left the meeting at 7.00pm.

11. WARM SPACES FOR WINTER 2023/24

Cllr McAll confirmed that warm spaces were being overseen by “Winter of Wellbeing”, and would start in January, ending in March. Potential locations for the initiative include the Rugby Club, Pot and Page and the Methodist Church. Funding has been limited to £1,500 to cover 3 to 4 days a week. It is proposed that individual organisations submit an application with the aim of entities then joining up and working together as one group.

RESOLVED:

The Working Party will keep a watching brief of developments for Winter of Wellbeing.

12. COP28

Nina Shields suggested that it might be useful for the CCWP to consider how climate change is impacting upon health and to involve Ledbury Health Partnership. Appreciating that the Working Party had no direct contacts, the Deputy Clerk is to contact Justine Peberdy to see if she could make contact on behalf of the Council and invite a representative from Ledbury Health Partnership to the next CCWP meeting. Justine Peberdy would also be invited to attend the next CCWP meeting.

It was noted that the main impacts to health would be overheating in summer months or pollution (for example, breathing fumes in between the Southend and High Street). However, it was noted that Herefordshire Council had undertaken a reading for pollution from diesel in this area and it had come in below specification.

RECOMMENDATION:

That the Deputy Clerk contact Justine Peberdy with a view to her contacting Ledbury Health Partnership to invite them to the next CCWP meeting, and that the invitation to attend the next CCWP meeting is also extended to Justine Peberdy.

13. DATE OF NEXT MEETING

The date of the next meeting of the Climate Change Working Party will be held on Wednesday, 7 February 2024 at 6.00pm.

Signed ………………………………. Date ………………………..

CLIMATE CHANGE WORKING PARTY – ACTION SHEET

No:	Item (Action Required)	Responsibility	To be actioned by (date)
7	**Transport** That the report presented by Prof John Whitelegg be presented at the next Traffic Management Working Party on 31 January 2024 for further consideration and that feedback is shared with the CCWP members in February 2024 at their next meeting.	TMWP	31 January 2024
8	**Great Big Green Week** That the activities/events suggested for GBGW should be put to the next Environment and Leisure Committee for consideration and approval, confirming which events should be pursued in order that approvals can be forwarded to the GBGW Steering Group to progress.	E & L Committee	4 January 2024
10a	**Council's Carbon Footprint** 1 That the CCWP requests that the Finance, Policy and General Purposes Committee are asked to investigate renewable PV energy generation in consultation with Severn Wye (who would be able to provide a free consultation). 2 That Cllr Chowns speaks with his daughter to see if she has any contact details for NMiTE.	Finance, Policy & General Purposes Committee Cllr S Chowns	18 January 2024 20 December 2023
12	**COP28** Deputy Clerk to contact Justine Peberdy with a view to her contacting Ledbury Health Partnership to invite a representative to attend the next CCWP meeting in February 2024. Invitation to include Justine Peberdy.	Deputy Clerk	20 December 2023

LEDBURY TOWN COUNCIL

CLIMATE CHANGE WORKING PARTY	**7 FEBRUARY 2024**	**AGENDA ITEM: 6**

Report prepared by Julia Lawrence – Deputy Town Clerk

FEEDBACK FROM ENVIRONMENT & LEISURE COMMITTEE

Purpose of Report

The purpose of this report is to update Members of the Climate Change Working Party of the outcome of these minutes that were presented to the Environment and Leisure Committee on 4 January 2024 to receive and note, together with any commentary.

Detailed Information

Please see below an extract from the Environment & Leisure Committee meeting minutes of the meeting held on 4 January 2024:-

84.2 Climate Change Working Party

To receive and note the draft minutes of the meeting of the Climate Change Working Party held on 6 December 2023.

Councillor Sinclair questioned the accuracy of the assumptions and figures within the report. He pointed out that Prof Whitelegg's report assumed that each pupil is driven to and collected from JMHS on 195 days per year. The Chair agreed that the number of journey's was a gross exaggeration. Councillor did not consider the report should not be submitted to the TMWP and pointed out that Prof Whitelegg even contradict his own calculation by quoting National Data for school runs. The vast majority walk to John Masefield High School.

Councillor Sinclair pointed out the following assumptions from within the report as being incorrect:

"The John Masefield school has 889 pupils and delivers 195 days of lessons each year. This results in 346,710 trips in the school year – 889 x 2 x 195 = 346,710 school trips can be translated into tonnes of carbon if we have data that reveals the percentage of these trips that are by car, bus, bike and walking and trip length. National data shows that 47% of trips to school are by car and 1% by bicycle.

Members of the Environment and Leisure Committee agreed that the report presented by Professor John Whitelegg be submitted to a meeting of the Traffic Management Working Party on 31 January 2024 for further consideration."

Concerns were raised about the placing of renewable PV panels on listed buildings.

RESOLVED:

1. **That the draft minutes of the Climate Change Working Party held on 6 December 2023 be received and noted.**

2. **That the report presented by Professor John Whitelegg be submitted to a meeting of Traffic Management Working Party on 31 January 2024 for further consideration.**

3. **Councillor Chowns agreed to speak to Councillor Ellie Chowns in respect of details for NMiTE.**

Recommendation

That Members of the Climate Change Working Party receive and note the contents of the report.

LEDBURY TOWN COUNCIL

CLIMATE CHANGE WORKING PARTY	**7 FEBRUARY 2024**	**AGENDA ITEM: 8**

Report prepared by Julia Lawrence – Deputy Town Clerk

MALVERN HILLS NATIONAL LANDSCAPE CONSULTATION

Purpose of Report

The purpose of this report is to request that members of the Climate Change Working Party consider the paper presented and provide a response, which is then to be submitted to Ledbury Town Council.

Detailed Information

Malvern Hills National Landscape Team have written to the Council to inform the Council that they have launched a consultation on a new draft Position Statement on "Renewable Energy in the Malvern Hills National Landscape and its Setting". Consultation documents are viewable through the following link: https://www.malvernhillsaonb.org.uk/consultations/ A copy of the draft Position Statement is attached at Appendix A.

All elected district, unitary and county councillors in the area and a wide range of consultees (including the local authorities) have also been directly consulted.

The Malvern Hills National Landscape Team has asked if this could be discussed at the next relevant council meeting. Members of the Environment and Leisure Committee were asked to either consider this documentation or whether they would prefer to request that the Climate Change Working Party review the documentation and make a response.

Members of the Environment and Leisure Committee agreed that it should be passed to the Climate Change Working Party for consideration and a response, in order that Ledbury Town Council can make a formal response before the consultation deadline date of 28 February 2024.

Recommendation

That Members of the Climate Change receive and note the aforementioned information and provide their response, no later than Wednesday, 21 February 2024, to the Clerk at Ledbury Town Council.

The Clerk will then be able to formally respond on behalf of Ledbury Town Council before the deadline date of 28 February 2024.

MALVERN HILLS NATIONAL LANDSCAPE

MALVERN HILLS AONB JOINT ADVISORY COMMITTEE

POSITION STATEMENT 4: RENEWABLE ENERGY IN THE MALVERN HILLS NATIONAL LANDSCAPE AND ITS SETTING

A quick note on terminology

On 22 November 2023, the Malvern Hills Area of Outstanding Natural Beauty (AONB), was re-branded as the Malvern Hills National Landscape. National Landscapes are designated AONBs. Consequently, the name Malvern Hills National Landscape is commonly used throughout this document. However, since 'AONB' remains the legal name for the designation, this term is also used in appropriate places, for example, when referring to the Malvern Hills AONB Management Plan which is a statutory plan or when directly quoting from older documents. The name used for the partnership associated with the designation is the Malvern Hills National Landscape Partnership.

1.0 CONTEXT

1.1 Climate Change is the biggest threat to humanity and one of the greatest threats to biodiversity[1]. Projections show a change towards warmer, wetter winters and hotter, drier summers and increasing frequency and intensity of extreme weather events, which will continue to amplify as climate change intensifies. Changes pose risks to biodiversity; soil health; natural carbon stores and sequestration; crops and livestock; the supply of food, goods and services; the economy; and human health. Collectively, we need to proactively mitigate and adapt to the impacts of climate change.

1.2 The Malvern Hills National Landscape is a landscape whose distinctive character and natural beauty is so outstanding that it is in the nation's interest to safeguard it[2]. The statutory purpose of the AONB designation is to conserve and enhance the natural beauty

[1] The National Association of Areas of Outstanding Natural Beauty (2019) The Colchester Declaration (https://landscapesforlife.org.uk/projects/colchester-declaration).
[2] Section 82 of the Countryside and Rights of Way Act (2000)

of the area[3]. Many defining features and 'Special Qualities'[4] of the AONB designation are threatened by climate change. They are also potentially threatened by responses to climate change, for example, due to visual impacts of development proposals. Action is urgent but needs to be well thought out and carefully implemented.

1.3 Within this context, the National Association for Areas of Outstanding Natural Beauty (NAAONB) committed to ensuring that by 2024, '*all AONB management plans include meaningful measures around climate change mitigation and adaptation, including clear, measurable targets to support Net Zero*'[5]. The current Malvern Hills AONB Management Plan (2019-2024) already advocates this through Objectives and Policies BDO1, BDP2 and BDP8, recognising a need to move towards a more energy efficient, low-carbon economy. The forthcoming review of the Malvern Hills AONB Management Plan will introduce further expectation, policies, and guidance to address the challenges of climate change in the Malvern Hills National Landscape and its setting whilst conserving and enhancing the natural beauty of the protected landscape.

1.4 A key component of climate change mitigation is to progress to a more sustainable energy system by applying the energy hierarchy (Figure 1). The first two priorities aim to reduce the demand for energy and will be addressed in the forthcoming Malvern Hills AONB Management Plan review. However, we recognise that there is also a need to generate energy from renewable energy sources towards achieving 'net-zero.' This includes on-site provision of renewable energy in new development and, where appropriate, retrospectively. It is Priority 3, specifically renewable energy, that is the focus of this Position Statement.

[3] Defra (2019) Areas of Outstanding Natural Beauty: technical support scheme (England) 2019 to 2020.
[4] Page 9 of the Malvern Hills Area of Outstanding Natural Beauty Management Plan 2019-2024. AONBs are designated by reason of its special qualities; those aspects of the area's natural beauty which make the area distinctive and are the key attributes on which the priorities for its conservation and enhancement are based.
[5] Refer to Footnote 1.

Figure 1. Energy Hierarchy[6]

1.5 Renewable energy has an important role in mitigating the impacts of climate change and is key to the commitment of reducing reliance on fossil fuels and achieving decarbonisation. There are various technologies available producing electricity, heat, or both. However, without good design, their implementation in the Malvern Hills National Landscape and its setting may harm the 'Special Qualities,' for instance through scale or the introduction of extraneous elements within the landscape. A key consideration is to deliver aspirations in a way which is compatible with the statutory purpose of AONB designation, and the Malvern Hills National Landscape Partnership is committed to exploring opportunities to do so.

1.6 The level of protection afforded to designated AONBs may mean that some of its renewable energy provision will need to be met outside of the Malvern Hills National Landscape or even its setting[7]. However, the Malvern Hills National Landscape Partnership recognises the need for it to contribute to renewable energy provision where it is able to as, in addition to powering and heating homes, buildings and businesses, renewable energy brings social and economic benefits through job creation in manufacturing, construction and maintenance industries.

1.7 To do this, we will need a combination of renewable energy types, at appropriate scales. A carefully considered multi-functional approach can deliver positive outcomes for natural beauty, climate adaptation and mitigation, nature recovery and related issues, such as food production, in mutually supportive ways.

1.8 This Position Statement focusses on renewable energy as a means of mitigating impacts of climate change. Measures to adapt to climate change are also important

[6] https://www.glasgowsciencecentre.org/our-blog/the-energy-hierarchy
[7] Refer to Malvern Hills National Landscape Partnership Position Statement 1 on Development and Land Use Change in the Setting of the Malvern Hills National Landscape.

although beyond the scope of this Position Statement. This is a 'live' document, which will be updated to reflect change in national policy and renewable energy technology.

2.0 PURPOSE OF THIS POSITION STATEMENT

2.1 Position Statements expand on relevant policies in the current Malvern Hills AONB Management Plan, providing further context, guidance and recommendations concerning specific policies and associated issues. They do not create new policies. They intend to help local authorities, developers, and other relevant stakeholders:

- have regard and positively contribute to the purpose of AONB designation;
- ensure the purpose of AONB designation is not compromised by development and that the natural beauty of the Malvern Hills National Landscape is conserved and enhanced;
- fulfil the requirements of the National Planning Policy Framework (NPPF) and Planning Practice Guidance (PPG) (or, where relevant, National Policy Statements) with regards to AONB designation and the factors that contribute to their natural beauty;
- take account of relevant case law;
- have regard to and be consistent with the Malvern Hills AONB Management Plan and guidance published by the Malvern Hills National Landscape Partnership;
- emulate best practice in the Malvern Hills National Landscape and other protected landscapes; and
- develop a consistent and coordinated approach to relevant issues across the whole of the Malvern Hills National Landscape and its setting[8].

2.2 Relevant authorities[9] are required by law, in exercising or performing any functions in relation to, or so as to affect, land in an area of outstanding natural beauty, to seek to further the purpose of conserving and enhancing the natural beauty of the area of outstanding natural beauty[10]. In fulfilling this, it is important that relevant authorities have regard to guidance published by the Malvern Hills National Landscape Partnership, including its position statements.

2.3 Position statements are supplementary to the statutory Malvern Hills AONB Management Plan. However, the Malvern Hills AONB Management Plan 2019-2024 at policy BDP2 states that "*development proposals in the Malvern Hills AONB*

[8] Three local authority areas overlap with the Malvern Hills National Landscape, with each with local authority having its own development plan. One of these local authorities (Malvern Hills) produces its development plan jointly with Worcester City and Wychavon in the form of a single local plan for South Worcestershire Councils.
[9] In this context, 'relevant authority' includes any: Minister of the Crown; public body; statutory undertaker; person holding public office.
[10] Section 85 of the Countryside and Rights of Way Act (2000) amended following the Levelling Up and Regeneration Act (2023).

and its setting should have regard to and be compatible with guidance produced by the Partnership".

2.4 We consider the Malvern Hills AONB Management Plan and, by extension, the Partnership guidance and position statements, should be a material consideration in planning decision-making. It is important to note that planning law requires that planning applications must be determined in line with the relevant, local authority development plan unless there are material considerations that indicate otherwise.

2.5 In some instances, guidance and/or recommendations may go further than the policies of current LPA development plans. As new iterations of LPA development plans are developed, we hope the recommendations will be incorporated into those new iterations as we believe they can positively help those who value and care for this area ensure that future developments contribute to the local distinctiveness and sense of place.

2.6 It must be acknowledged that, in a plan-led planning system, it is the policies of the relevant adopted local authority development plan that have the greatest weight. As such, within this planning system, the hierarchy is as follows[10]:

Decision-making is taken in accordance with the adopted development plan unless material planning considerations indicate otherwise. The adopted development plan comprises the Local Planning Authority Development Plan, and any 'made' Neighbourhood Development Plan.
The Malvern Hills AONB Management Plan, like the National Planning Policy Framework, is a material planning consideration but does not form part of the adopted development plan. Malvern Hills National Landscape Position Statements and guidance documents supplement the AONB Management Plan.

3.0 LEGISLATION, POLICY, AND GUIDANCE

3.1. Proposals for renewable energy development within the Malvern Hills National Landscape and its setting should have regard to:

[10] In England, Section 38(6) of the Planning and Compulsory Purchase Act 2004 states: "If regard is to be had to the development plan for the purpose of any determination to be made under the Planning Acts the determination must be made in accordance with the plan unless material considerations indicate otherwise." The National Planning Policy Framework is itself a significant material consideration, although it is acknowledged regarding the presumption in favour of sustainable development under Paragraph 11, particularly in relation to plan-making and decision-making. On Wednesday 13 September 2023, the DEFRA Secretary of State tabled a Written Ministerial Statement setting out a package of measures to support nature recovery in Protected Landscapes. The package includes a commitment to new legislation through the Levelling Up and Regeneration Act (2023), which will enhance National Park and AONB Management Plans by placing a stronger requirement on partners to contribute to their delivery.

- the statutory purpose of AONB designation, which is to conserve and enhance the outstanding natural beauty of the area;
- national planning policy/guidance, particularly paragraphs 11, 174, 176 and 177 of the NPPF (2023);
- the relevant local authority development plan (comprising Local Plans and Neighbourhood Plans, if made) and other relevant local authority guidance and evidence.

3.2 Such proposals should have regard to, and be compatible with Malvern Hills National Landscape Partnership publications, including its Guidance and Position Statements.

4.0 PROTECTING THE SPECIAL QUALITIES OF THE MALVERN HILLS NATIONAL LANDSCAPE – GENERAL CONSIDERATIONS AND ASSESSMENT REQUIREMENTS

4.1 Landscape Character

4.1.1 The Malvern Hills AONB Landscape Character Assessment describes the 10 (plus urban[11]) different landscape character types (LCTs) of this protected landscape, including their key features/characteristics. These key features/characteristics are re-iterated in the Malvern Hills AONB Landscape Strategy & Guidelines. For each LCT, the Landscape Strategy & Guidelines also summarises the landscape sensitivity, identifies some 'local forces for change' and their potential implications and sets out guidelines for avoiding or minimising adverse effects from them. Other forces for change may exist however that are not yet included in these guidelines, such as solar farms or the planting of energy crops.

4.1.2 Landscape assessments for renewable energy project proposals should refer to the landscape character areas as defined within the current Landscape Character Type, and also to the County wide Historic Landscape Characterisation. They should be able to demonstrate how the proposal responds to the existing landscape pattern and landform and how it seeks to conserve and enhance existing important landscape features such as vegetation and field boundaries. Key viewpoints of the development from within the National Landscape and its setting, to also include both looking out and into the National Landscape, should be identified and assessed, to include photomontages.

4.1.3 Regard should also be given to local authority landscape character assessments and related evidence.

[11] https://www.malvernhillsaonb.org.uk/wp-content/uploads/2022/01/landscape-strategy-map.html

4.1.4 The Malvern Hills National Landscape Partnership Position Statement on Landscape-Led Development is particularly relevant for consideration.

4.1.5 Renewable energy projects should prioritise use of previously developed (‘brownfield’) land, where possible. Where greenfield sites are proposed, projects should benefit the local rural economy; be supported and/or owned by local communities; bring net benefits to wildlife; avoid/minimise loss of productive agricultural land; and avoid adverse impacts on landscape character and/or visual amenity, tranquillity, and cultural heritage.

4.2 Other factors that contribute to natural beauty

4.2.1 The extent to which a proposed renewable energy development might affect the landscape and scenic beauty of the Malvern Hills National Landscape and its setting is obviously a key consideration and, in planning terms, these effects should be given great weight[12]. There are several additional factors that contribute to the natural beauty of the AONB designation, including, but not limited to:

- Natural heritage (including biodiversity);
- Cultural heritage (including historic environment); and Relative tranquillity:

4.2.2 More information on the factors that contribute to natural beauty is provided in Natural England’s ‘Guidance for assessing landscapes for designation as National Park or Area of Outstanding Natural Beauty’[13].

4.2.3 The following issues concerning visual effects & tranquillity should be considered:

Siting – due to the ’Special Quality’ identified in the Malvern Hills AONB Management Plan of its ’dramatic scenery and spectacular views arising from the juxtaposition of high and low ground‘, much of the designated AONB, and its setting, could be considered unsuitable for all but household and micro-scale renewable energy installations, and – potentially – some smaller scale renewable energy projects. The conditions whereby there may be opportunity, and the specific considerations that should be assessed for each renewable energy source type, are discussed in later sections of this position statement.

[12] This ‘great weight’ is a factor in planning decisions when assessing the overall planning balance. In effect, it ‘tilts the scales’ towards a decision that would avoid harm to the landscape and scenic beauty of the affected designated AONB. The significance of applying this great weight partly depends on the significance of any adverse effects on the designated AONB. The overall planning balance will depend on the weight that should be given to other considerations.

[13] Natural England (2011) Guidance for assessing landscapes for designation as National Park or Areas of Outstanding Natural Beauty - refer to Table 3 and Appendix 1.

Agricultural Land – normally renewable energy projects should not be located on useable agricultural land, particularly the most productive Grade 1, 2 and 3a land. Nor should they be on typically low-grade hillside land where their impact would be greatest. The grade should be stated on any application. As recognised within the Malvern Hills AONB Natural Capital Scoping Study 2017, much of Grade 4 land in the designated AONB is also sloping, meaning that there are further considerations in terms of visual effects.

Screening – Screening (and softening) in the form of hedges or tree belts may be appropriate to help reduce visual impact, providing it is in keeping with the local landscape character. It should be borne in mind that a hedge may well take ten years to grow to a height sufficient to provide effective concealment and tree cover longer. Also, climate change itself may have an impact on the long-term viability and health of vegetation cover/screening.

Zone of Visual Impact – Landscape and Visual Impact Assessments (LVIA) should be employed at the pre-application stage to describe local landform and key views and the likely impacts on neighbouring properties, local character of a settlement and public rights of way etc. Solar panels, frames/supports, and/or other infrastructure, should not detract from the local character of a settlement.

Materials & additional infrastructure –

a) Measures to minimise glare and visual impact should be stipulated as a planning condition.
b) Bases should be easy to remove to permit restoration of the land.
c) Security fences, if required, should be of sympathetic design and screened, as necessary. Any necessary security measures should be of minimal landscape and visual impact. Significant security fencing which is inconsistent or incompatible with the local rural environment may help to render a development unacceptable. Consideration should be given for the minimal length and height of any necessary security fencing, natural features such as hedgerows should be used to assist in site security and/or screen security fencing, where this is locally appropriate. In some instances, specialist fencing may be necessary to prevent access by deer, whilst appropriate measures should be in place to facilitate continued access by larger mammals, such as badgers and foxes.
d) Where pole mounted CCTV facilities are proposed the location of these facilities should be carefully considered and designed to minimise visual/landscape impact. In exposed landscapes such structures should be avoided.

e) The use of security lighting should be minimised. Any lighting should utilise a passive infra-red (PIR) technology and should be designed and installed in a manner which minimises glare, light pollution and impacts on biodiversity, in particular bats. Planning applications should contain full details and specifications of all security and lighting installations to allow an accurate landscape/visual/ecological assessment of the proposal to be made. Lighting features should be of a sympathetic design and installed to minimise light pollution, and which is consistent with Malvern Hills National Landscape Guidance on Lighting.
f) Buildings associated with renewable energy projects, such as transformer stations and inverter cabinets, should be unobtrusively sited, sympathetically designed, and suitably shielded to minimise visual impact.
g) Access roads – new roads and tracks should be kept to an absolute minimum, sited, designed, and built to minimise impact on the landscape.
h) Grid connection – a key constraint to local renewable energy production is the connectivity of the location of a proposed renewable energy scheme with the National Grid. Significant upgrading may need to be undertaken to provide this connectivity, which may make a scheme unviable. The consideration of renewable energy schemes, including the assessment of their acceptability, should take account of any necessary associated infrastructure such as access roads, cables (and whether these should be over or below ground) and ancillary buildings.
i) Tranquillity - the impact of noise, both in construction and operation, should be carefully considered, especially given that this may be proportionately more disruptive in otherwise quiet rural areas.

4.3 Manufacturing & De-Commissioning

4.3.1 The manufacture and construction of some renewable energy developments, as well as any decommissioning/demolition phase, has its own energy and carbon cost that should be considered when assessing the need for the development, weighing up that cost alongside other impacts against the benefits the project may bring.

4.3.2 Decommissioning of energy sites at the end of their useful life (for solar, quoted as 35 to 40 years but likely to be much less as technology progresses) also poses issues which must be planned for.

4.3.3 As a result of the temporary nature of many of renewable energy technologies, the Partnership would expect local planning authorities to apply appropriate conditions to planning permissions requiring the removal of any buildings and any other structures at the end of the life of the proposed installation or when they become obsolete, whichever is the earlier. In accordance with the NPPF, sites granted temporary permission should not be considered as constituting brownfield land.

4.3.4 In addition, local authorities should require proposals to demonstrate how solar panels and batteries will be recycled or how toxic waste will be disposed of, as part of relevant applications.

4.4 Restoring the site

4.4.1 Planning permission granted for some renewable energy projects, especially wind turbines and solar farm PV panels, is generally considered temporary and granted for a restricted time period, after which it can be renewed, as appropriate. Restricting the development lifetime is a mechanism for ensuring that outdated/inefficient/redundant development is removed.

4.4.2 A site Restoration and Reinstatement Strategy in the form of a legal agreement should be sought to ensure restoration of any relevant land to agricultural (or other) usage once the consent or use has terminated and a condition imposed that all equipment associated with the development is removed. The agreement should demonstrate how and when the site will be returned to a state that is in good landscape and ecological condition and in keeping with local landscape character.

4.4.3 Food security is relevant given the UK imports 40% of the food it consumes, and this is rising[14]. As global food prices rise, agricultural land, even of lower grades, should not be misused by change of use to inefficient renewable energy schemes and its restoration at the end of life of a scheme is important.

5. ASSESSMENT OF IMPACTS

5.1 Cumulative Impacts

5.1.1 The cumulative landscape and visual impact of a proposed renewable energy scheme (and any associated infrastructure) is a key consideration. The Government's

[14] Food Matters: Towards a strategy for the 21st Century: http://webarchive.nationalarchives.gov.uk/+/http:/www.cabinetoffice.gov.uk/strategy/work_areas/food_policy.aspx [16] https://www.gov.uk/guidance/renewable-and-low-carbon-energy

PPG for Renewable and Low Carbon Energy states that: "*There are no hard and fast rules about how suitable areas for renewable energy should be identified, but in considering locations, local planning authorities will need to ensure they taken into account … critically, the potential impacts on the local environment, <u>including from cumulative impacts</u>.* (N.B. Underlining added for emphasis)[16].

5.1.2 Cumulative landscape impacts and cumulative visual impacts are best considered separately. Cumulative landscape impacts are the effects of a proposed development on the fabric, character, and quality of the landscape. Cumulative visual impacts concern the degree to which proposed renewable energy development will become a feature in particular views (or sequences of views) and the impact this has upon the people experiencing those views.

5.1.3 With regards to cumulative visual impacts, this is particularly important for largescale wind energy proposals, which can potentially be seen from many miles away. Infrastructure that is likely to result in cumulative effects includes: other wind developments; overhead powerlines; and telecommunications masts and other vertical structures.

5.1.4 The ability for a renewable energy project to access the grid will limit suitable locations and this is likely to lead to the clustering of applications in certain areas, with associated cumulative impacts.

5.1.5 Proposals should set out suitable assessments of impacts on biodiversity, hydrology, archaeology, landscape etc. transport assessments should consider access and vehicle movements during all stages of construction and development.

5.1.6 Renewable energy development should not create a "buffer zone" or ring around the Malvern Hills National Landscape, and the potential impact of renewable energy projects close to the boundary will be a material consideration in the planning process.

5.2 Major Development

5.2.1 Consideration should be given to whether a proposed renewable energy development constitutes 'major development' in the context of paragraph 177 of the NPPF[15]. Footnote 60 of the NPPF states that '*whether a proposal is major development is a matter for the decision maker, taking into account its nature, scale and setting, and*

[15] Ministry of Housing Communities and Local Government (2023) National Planning Policy Framework - Paragraph 177 and footnote 60.

whether it could have a significant adverse impact on the purposes for which the area has been designated'.

5.2.2 Paragraph 177 of the NPPF states that '*permission should be refused for major development other than in exceptional circumstances and where it can be demonstrated that the development is in the public interest*'. The NPPF requires several major development 'tests' to be applied, as outlined below

5.2.2.1 Major Development Test A – assessing the need for the development

The priority given to climate change, through the declaration of the climate and ecological emergencies, would potentially make it easier to demonstrate 'exceptional need' for renewable energy proposals. Genuine community-led renewable energy schemes[16], which have robust evidence of need specific to the community and which have appropriate funding and administrative mechanisms in place, are more likely to demonstrate 'exceptional need' than schemes that meet a more generic need. It should be noted however that exceptional need does not necessarily equate to *exceptional circumstances*[17]. For example, there may be other, more suitable ways of mitigating the impacts of climate change (or delivering renewable energy) or less harmful locations for the proposed development.

5.2.2.2 Major Development Test B – assessing the cost of, and scope for, developing outside the designated area or meeting the need in some other way:

Case law has stated that '*no permission should be given for major development save to the extent the development met a need that could not be addressed elsewhere*'[18]. As such, all other things being equal, it could be argued that if there are areas outside the Malvern Hills National Landscape (within a local authority area) that are identified as having equal or lesser landscape sensitivity to the type and scale of renewable energy development being proposed, then preference should be given to locating the development in those locations. Consideration should also be given to whether the proposed scheme is the most effective way of mitigating the impacts of climate change or is the most appropriate form of renewable energy. Consideration should be given to whether there are suitable nature-based alternatives for mitigating the impacts of climate change.

[16] Genuine community-led schemes could include proposals included in neighbourhood plans or other projects, such as the Community Visioning schemes being piloted by CPRE and should have undergone appropriate community consultation processes.
[17] This principle is recognised in relevant case law (R (Mevagissey Parish Council) v Cornwall Council [2013] EHWC 3684 (Admin) (link), paragraph 52): '*Even if there were an exceptional need … that would not necessarily equate to exceptional circumstances for a particular development, because there may be alternative sites that are more suitable because development there would result in less harm to the AONB landscape*'.
[18] R (Advearse) v Dorset Council v Hallam Land Management Ltd [2020] EWHC 807 (link). Direct quote from paragraph 35.

5.2.2.3 Major Development Test C – assessing any detrimental effect on the environment, the landscape and recreational opportunities, and the extent to which that could be moderated:

In relation to this test, case law has stated that '*no permission should be given for major development save to the extent the development … met that need in a way that to the extent possible, moderated detrimental effect on the environment, landscape and recreational opportunities'*[19]. As such, renewable energy proposals that constitute major development should be required to demonstrate that they have a) avoided; and b) minimised any potential detrimental effects (to the extent possible) in this regard. The higher the level of landscape sensitivity associated with the scale and type of renewable energy development being proposed, the more this will weigh against permission being granted on the grounds of exceptional circumstances and public interest.

5.3 Mitigation Measures

5.3.1 Mitigation measures should be considered as an integral part of the development; they should adequately offset any adverse landscape and visual effects and be appropriate to the local landscape character. The mitigation and reduction of some adverse impacts can be achieved through considered detail design.

5.3.2 Enhancements should be linked to mitigation measures where appropriate and should seek to maintain and improve the value and condition of the landscape and contribute to local distinctiveness. For example, the development of Solar PV facilities offers the potential to create sites of local or regional ecological interest, particularly where land is removed from intensive agricultural production.

5.3.3 Applicants will be expected to maximise the ecological potential offered by such circumstances by a) avoiding areas of ecological importance or sensitivity, b) encouraging and promoting a diverse range of habitats, such as wildflower meadows, within such facilities, and c) designing and adapting built structures, such as control buildings, to encourage and promote access by nesting, roosting or hibernating animals such as bats.

5.4 Development in the setting of the Malvern Hills National Landscape

5.4.1 Renewable energy development in the setting of the Malvern Hills National Landscape has the potential to adversely affect the natural beauty of the designated AONB, particularly with regards to impacts on views from and to the Malvern Hills National Landscape.

[19] R (Advearse) v Dorset Council v Hallam Land Management Ltd [2020] EWHC 807 (link). Direct quote from paragraph 35.

5.4.2 Paragraph 176 of the NPPF states that '*great weight*[20] *should be given to conserving and enhancing landscape and scenic beauty*' in designated AONBs. Case law has clarified that this great weight should be applied to development outside a designated AONB, as well as to development within it, where the proposed development may adversely affect the landscape and scenic beauty of the AONB[21]. Application of this particular case law example would consider effects on views from the designated AONB but not impacts on views looking towards - in our case - the Malvern Hills National Landscape.

5.4.3 However, impacts on views towards the Malvern Hills National Landscape are still an important material consideration, particularly in relation to views looking towards the Malvern Hills, with these views being one of the 'special qualities' of the designated AONB. And in terms of the views from the Malvern Hills National Landscape, the topography means that a larger area may need to be considered in terms of potential effects on views than in a designated AONB without such elevations. This is especially the case for visual receptors on the Malvern Hills themselves. Other relevant considerations include the potential increase in traffic movements through the Malvern Hills National Landscape (or along its boundary) that may result from a proposed development.

5.4.4 Paragraph 176 of the NPPF states that '*development within [the setting of AONBs] should be sensitively located and designed in order to minimise adverse impacts on the designated area*'.

5.4.5 The Malvern Hills National Landscape Partnership position statement on development and land use change in the setting of the Malvern Hills National Landscape and also the Malvern Hills AONB Environs Landscape and Visual Sensitivity Study provide some relevant information on this topic.

5.5 EIA

5.5.1 Where renewable energy proposals fall under Schedule 2 of the Environmental Impact Assessment (EIA) Regulations[22], consideration should be given to whether an EIA is required, particularly if the proposals is above the 'applicable thresholds and criteria' for Schedule 2 development[23].

[20] This 'great weight' is a factor in planning decisions when assessing the overall planning balance. In effect, it 'tilts the scales' towards a decision that would avoid harm to the landscape and scenic beauty of the affected designated AONB. The significance of applying this great weight partly depends on the significance of any adverse effects on the designated AONB. The overall planning balance will depend on the weight that should be given to other considerations.

[21] Stroud District Council v Secretary of State & Gladman Developments Ltd [2015] EWHC 488 (link). Paragraphs 20-22.

[22] Schedule 2 of the Town and Country Planning (Environmental Impact Assessment) Regulations 2017

[23] It is worth noting that the 'applicable thresholds and criteria' in Schedule 2 of the Environmental Impact Assessment Regulations do not apply in designated AONBs. This is because AONBs are classed as 'sensitive areas,' in this regard. As such, Schedule 2

5.5.2 EIAs are required where it is considered that the proposal is likely to have a significant effect on the environment. In such circumstances, it is highly likely that the proposal should also be considered major development, in the context of paragraph 177 and footnote 60 of the NPPF.

5.5.3 Consultation with the Local Planning Authority and local community is encouraged at an early stage. The local community should be engaged, by the developer, at the predesign, conceptual stage, ideally utilising a local exhibition / presentation where community views can be sought and recorded.

5.5.4 As a starting point, the proposal should be assessed against the selection criteria in Schedule 3 of the EIA Regulations. In general, an EIA is likely to be needed for Schedule 2 developments if the development is in a particularly environmentally sensitive or vulnerable location. In each case it will be necessary to judge whether the likely effects on the environment of that development will be significant in that particular location. In judging whether the effects of a development are likely to be significant it is necessary to have regard in particular to the visual impact of the development on landscape character and how this will be affected by the installation of the development, and also the possible cumulative effect with any existing or approved development. This should include situations where there is more than one application for development which should be considered together. Any views expressed by consultees should be considered. Advice should be sought from consultees where there is any doubt about the significance of a development's likely effects on a 'sensitive area' as defined in the EIA Regulations, including setting.

RECOMMENDATIONS

- **The Malvern Hills National Landscape Partnership recommends that any renewable energy projects in the Malvern Hills National Landscape and its setting should prioritise 'brownfield' land where possible. Greenfield sites should be avoided except in exceptional circumstances.**
- **All renewable energy projects should seek to protect, conserve, and enhance the distinctive character and natural beauty of the designated AONB and its setting, including its 'Special Qualities' by having regard to the considerations and guidance on mitigating impacts set out in this paper and other Malvern Hills National Landscape Partnership publications.**
- **The cumulative impacts of a renewable energy development proposal should be assessed in decision making.**

development within the Malvern Hills National Landscape that is smaller than the applicable thresholds and criteria may also need to be screened to assess if an EIA is required.

- **Renewable energy proposals should demonstrate they have considered the whole-life impacts of a scheme, including construction and decommissioning phases, and restoration of the site.**
- **Larger projects should benefit the local rural economy, be supported and/or owned by local communities where possible and avoid unjustified loss of productive agricultural land.**
- **Renewable energy landscape and visual sensitivity assessments, including those commissioned by local authorities, should have regard to relevant guidance published by the Malvern Hills National Landscape Partnership.**

6.0 TYPES OF RENEWABLE ENERGY

6.0.1 This position statement identifies six main types of renewable energy: heat pumps; biomass; hydropower; solar energy; wind energy; and battery storage. These are individually addressed in this section, including relevant considerations and key constraints specific to each type of renewable energy.

6.1 Heat Pumps

6.1.1 There are three main types of heat pump:

- Ground-source heat pumps (GSHP): takes low-level heat, which occurs naturally underground, and converts it to high-grade heat using an electrically driven or gaspowered heat pump. GSHP systems collect or deliver heat using ground collectors (typically coils or loops of pipe laid in trenches in the ground or vertical boreholes), in which a heat exchange fluid circulates in a closed loop and transfers heat via a heat exchanger to or from the heat pump. Once installed, there are no externally visible features.
- Air-source heat pumps (ASHP): takes low-level heat, which occurs naturally in the air, and convert it to high-grade heat by using an electrically driven or gas-powered pump. ASHP are typically mounted on an external wall (sometimes under a window). Increasingly, manufacturers are producing internally mounted air source heat pumps which only need louvers and/or roof vents for air supply/exhaust emissions (as in a conventional boiler). Once installed, the only externally visible structure may be the ‘air conditioning unit’ associated with the heat pump facility. Depending on the manufacturer, ASHP may be no louder than a central heating boiler.
- Water-source heat pumps (WSHP): extracts heat from a body of water and converts it into useful energy to heat the home.

6.1.2 Heat pumps are generally ‘permitted development’[24], although rights are restrictive with regards to listed buildings, conservation areas, scheduled monuments, and World Heritage sites. In most cases, proposals are likely to be domestic in scale and, due to relatively limited landscape impact, will normally be acceptable and supported. Any reinstatement of land should be carefully, and sensitively undertaken and historic landscapes should, wherever possible, be avoided.

6.1.3 If buildings are needed to house equipment, this may require planning permission and should be carefully sited and designed, using appropriate materials.

6.1.4 Fitting of heat pumps is likely to be easier for new development than retrofitting. However, retrofitting may be appropriate where there is available space.

6.1.5 Heat pumps use electricity so still potentially contribute to greenhouse gas emissions (depending on the source of the electricity). However, they can offer carbon emission savings of around 30% when compared with conventional gas boilers.

6.1.6 The following checklist should be considered:

- During construction, the laying of pipes linked to GSHP should avoid disturbing ground which would be difficult to restore, such as unimproved grasslands, seminatural habitats, tree roots and archaeological remains. A Local Planning Authority may require an archaeological survey before construction.
- Underground pipework associated with GSHP should be covered with soft or hard surfaces, which reflect local soils/geology and landscape character type.
- ASHP should be on the least visible elevations, if externally mounted.
- Measures should be taken to minimise impacts on? neighbouring land uses.
- Quiet models should be selected, to minimise any impacts on tranquillity and other Special Qualities of the designated AONB.

[24] Permitted development rights allow the improvement or extension of buildings or uses of such buildings without the need to apply for planning permission, where that would be out of proportion with the impact of the works carried out.

RECOMMENDATIONS

- **The Malvern Hills National Landscape Partnership supports the use of heat pumps, in principle, provided relevant considerations have been adequately addressed, including: ○ size and siting; ○ noise impacts;**
    - **impacts on historic landscapes and archaeology; and**
    - **safeguarding existing trees/hedgerows and priority habitats, particularly during construction and operation.**
- **Underground pipework should be covered with soft or hard surfaces, which matches local soils and geology, where possible.**
- **Reinstatement of land should be carefully and sensitively undertaken, to avoid compromising the 'Special Qualities' of AONB designation.**

6.2 Biomass

6.2.1.1 Biomass refers to the use of a wide variety of organic material for the generation of heat, electricity, or motive power. The two primary types of biomass energy are:

- Woody biomass (wood and energy crops).
- Wet biomass (food waste and farm wastes).

6.2.1.2 For electricity production, the heat/steam is used to turn a turbine. There are currently three basic categories of biomass plants:

- Plants designed primarily to produce electricity. These are generally the largest schemes, in the range of 10–40 MW. Excess heat from the process is not utilised. These are major multimillion pound developments and are unlikely to be suitable within the Malvern Hills National Landscape or its setting because of scale and associated traffic movements. They are not considered further and proposals for such would not be supported by the Malvern Hills National Landscape Partnership.
- Combined Heat and Power (CHP) plants where the purpose is the generation of electricity, but excess heat is utilised. Size range is 5-30 MW thermal total energy output but smaller 'packaged' schemes of a few hundred KW are possible.
- Plants designed for production of heat. These cover a wide range of applications from domestic wood burning stoves and biomass boilers to boilers of a scale suitable for district heating, commercial and community buildings and industrial process heat. Sizes range from a few KW to above 5 MW of thermal energy.

6.2.2 Wood

6.2.2.1 Use of wood for fuel boilers is not only a renewable energy source but may have additional benefits. For example, it can provide economic incentive to bring woodlands within the Malvern Hills National Landscape back into active management. Active management of deciduous woodlands through coppicing, pollarding, ride widening, and other forestry operations helps create warm, sunlit micro-habitats that benefit insects and wildflowers and provide better nesting habitat for many of our rarest woodland birds[25]. Use of wood can have the benefit of recovering, from the waste stream, waste wood that would otherwise go to landfill. Care is needed to ensure management of woodlands does not become unsustainable (e.g. because of over-exploitation), as demand increases.

6.2.2.2 New and on-going management of woodland will be required to facilitate nature recovery and mitigate impacts of climate change[26].

6.2.3 Fuel crops

6.2.3.1 There may be potential for biofuel from other crops (i.e., energy crops) such as miscanthus and short rotation coppice (SRC). Developments are likely to have limited impacts, if undertaken on a small scale. However, careful consideration will need to be given for larger-scale use of land for growing such crops as they are likely to have an adverse impact on landscape character (for example, as a monoculture that is alien to the locally-distinctive farmed landscape), biodiversity, water quality and soil quality (for example, as a result of winter harvesting) and visual amenity due to height and semipermanent/permanent nature and, in the case of SRC, their long rotation cycle.

6.2.3.2 Large-scale fuel crop schemes would also likely conflict with other land use priorities, including food production, nature recovery and woodland planting.

6.2.3.3 Where fuel crops are being introduced, the potential for impacts on landscape character should be fully assessed, as should any potential impacts on sensitive sites, including permanent grassland, common land, SSSIs, other sites of nature conservation importance, and historic landscapes.

6.2.4 Wood and fuel crops – additional considerations

6.2.4.1 Whilst burning biomass does release CO_2 emissions, CO_2 is absorbed from the atmosphere during the growth of the source material and so the net lifecycle CO_2 emissions are zero. However, all biomass fuels also have an associated CO_2 intensity due to the additional energy required for collection, processing, and distribution, as well

[25] https://www.worcswildlifetrust.co.uk/woodlands/managing-our-woodlands

[26] It is estimated that only 55% of woodland in the Malvern Hills AONB is actively managed currently. Many tree species are coming under acute stress from new pests and diseases and periods of intense weather (e.g., storms and drought). Loss of key species such as ash will accelerate change, particularly in unmanaged woodland – taken from Malvern Hills AONB Nature Recovery Plan (2022)

as for the construction and maintenance of a biomass facility. Transportation can be a large element of this for raw fuels, whilst heavily processed fuels such as wood pellets will require additional energy input during the process stages.

6.2.4.2 For proposals involving energy production from biomass, consideration should be given to whether such proposals require an Environmental Impact Assessment (EIA), particularly where the development area exceeds 0.5ha[27]. Consideration should also be given to whether a scheme constitutes ‘major development’[30].

6.2.4.3 Biomass boilers are also a potential source of air pollution, particularly with regards to particulates. Appropriate measures would need to be put in place to protect air quality. Firewood is now required to have a moisture content of 20% or less, which should help to address this issue, but industry should be encouraged to improve the efficiency of stoves and boilers to reduce harmful emissions. Use of domestic woodburning stoves should not be encouraged, due to potential impacts on air quality.

6.2.4.4 Transport of wood or crops to any energy production plant will increase vehicle movements unless the plant is adjacent to the source of fuel. To avoid unnecessary infrastructure, plants should be as close to the settlements or facilities they serve, so an appropriate locational balance must be struck. For this reason, and to avoid greater visual and other effects likely to be caused by large-scale plants, small-scale plants would be preferable. Suitable schemes could include heating schemes for country estates and small-scale community heating schemes.

6.2.4.5 Priority should be given to using existing buildings, to house biomass facilities and to dry or process wood and other biomass. Where new buildings are required, siting, scale, design, colour, and materials used should be carefully considered and be compatible with the AONB designation and its special qualities[28].

3.2.4.6 Biomass provides a relatively small amount of energy per hectare of land used. For example, solar energy can provide over 40 times as much energy per hectare as biomass[29]. A very large area of land would be needed for energy crops to deliver significant levels of renewable energy in the Malvern Hills National Landscape. This is likely to adversely affect landscape character and scenic beauty, including tranquillity (due to related traffic movements), and may compromise food production, biodiversity, and nature recovery.

[27] Schedule 2 of the Town and Country Planning (Environmental Impact Assessment) Regulations 2017. Development type 3(a). [30] In the context of paragraph 177 of the National Planning Policy Framework (2023).
[28] Having regard to position statements other guidance produced by the Malvern Hills National Landscape Partnership: https://www.malvernhillsaonb.org.uk/our-work/planning/guidance-documents/
[29] https://www.biofuelwatch.org.uk/2018/biomass-and-land-use/

RECOMMENDATIONS

- **Wood: In principle, the Malvern Hills National Landscape Partnership would be supportive of small-scale wood fuel schemes which use locally sourced wood from sustainably managed woodlands within the Malvern Hills National Landscape, provided relevant considerations have been clearly addressed.**
- **Fuel crops: In principle, the Malvern Hills National Landscape Partnership would be supportive of small-scale fuel crop schemes, provided that relevant considerations have been clearly addressed.**
- **Biomass: Priority should be given to active management and utilisation of woodland (for supplying timber for wood fuel) in the Malvern Hills National Landscape over schemes that rely on the planting of energy crops, especially short rotation coppice.**

6.2.5 Wet biomass – anaerobic digesters

6.2.5.1 Anaerobic digestion (AD) is a process in which bacteria break down organic material in the absence of oxygen to produce a methane-rich biogas, which can be combusted to generate electricity and heat. Anaerobic digesters utilise farm and food wastes. They make a significant contribution to reducing greenhouse gas emissions, reducing the quantities of methane released into the atmosphere, and providing a low carbon energy source that substitutes for energy generated from fossil fuels.

6.2.5.2 An AD plant typically consists of a digester tank, buildings to house ancillary equipment, a biogas storage tank, and a flare stack (3–10 metres in height). The digester tank is usually cylindrical or egg-shaped, its size being determined by the projected volume and nature of the waste. It can be part buried in the ground. There are two scales of anaerobic digestion plant:

- Small scale plants dealing with the waste from a single farm (generating in the region of 10kW) with the biogas potentially used to heat the farmhouse and other farm buildings in the winter when farm wastes are available.
- A medium-sized centralised facility dealing with wastes from several farms supplemented by other feedstocks and potentially producing up to 2MW.

6.2.5.3 The effects that may arise from any development in terms of visual intrusion, noise, odour, associated traffic movements and associated infrastructure, including overhead powerlines and pylons or poles, must be carefully considered. AD plants serving a single or small number of local farms may be appropriate within the Malvern Hills National Landscape and its setting, provided the development can be incorporated within an existing farmstead; uses locally sourced, organic farm waste and/or sewage sludge material; is of an appropriate scale; is not visually intrusive; is constructed using appropriate materials; and is suitably landscaped to ensure the natural beauty of the area is conserved or enhanced, ensuring the 'Special Qualities' are not compromised.

6.2.5.4 Where crops are grown specifically as a feedstock for AD plants e.g. maize, this would raise similar issues to the growing of fuel crops in relation to competing land uses, water quality and impact on soils.

6.2.5.5 Large new buildings or structures on greenfield sites within the Malvern Hills National Landscape or its setting are unlikely to be supported by the Malvern Hills National Landscape Partnership.

RECOMMENDATIONS

- **In relation to wet biomass, in principle, the Malvern Hills National Landscape Partnership would be supportive of small-scale anaerobic digestion (AD) plant schemes that use locally sourced, organic farm waste and/or sewage sludge, provided relevant considerations have been clearly addressed, including:**
    - **Integrating or locating adjacent to existing buildings or farmsteads; greenfield sites should be avoided;**
    - **The digester tank should be part buried in the ground;**
    - **Installations should not be in prominent locations or exposed skylines – the flare stack can be prominent;**
    - **Installations should not affect the historical value of designated industrial features, historic monuments and archaeological sites and remains, or the ecological value of semi-natural habitats;**
    - **Installations should not adversely affect the character and appearance of any Conservation Areas and listed buildings;**
    - **Suitable materials (such as cladding of buildings), and colours should be used that integrate structures with their surroundings;**
    - **Tree planting (using native species) that helps filter views of the AD plant should be considered; and**
    - **Measures taken to minimise any visual, odour and noise impacts on the amenity of neighbouring land uses associated with the operation of the plant and deliveries of feedstocks.**

- **Large new buildings and structures associated with AD plants within the Malvern Hills National Landscape or its setting, and/or schemes that import large quantities of material, are unlikely to be supported, because of the scale of the development and the vehicular movements required to supply feedstock, particularly in tranquil, rural areas where human influence is limited, and in areas of semi-natural habitat and/or a strong historic character.**

6.3 Hydropower

6.3.1 Hydropower uses water flowing through a turbine to drive a generator that produces electricity. It is a highly site-specific technology, dependent on being near a water body that is both flowing and has a sufficient drop in level that can be exploited.

6.3.2 The potential for hydro-electric proposals are therefore very limited within the Malvern Hills National Landscape and its setting due to geographical and environmental restrictions, although there may be scope for micro- or small-scale projects

6.3.3 Schemes involving installations for hydroelectric energy production, consideration should be given to whether they require an EIA, particularly where an installation is designed to produce more than 0.5 megawatts and/or where the area of the development would exceed 0.5 hectares[30]. Consideration should be given to whether a scheme constitutes 'major development'[31]. Consents from the Environment Agency will also be required. Consideration is needed to be given to the impacts of infrastructure e.g. cabling required to connect the hydropower development to the grid.

[30] Schedule 2 of the Town and Country Planning (Environmental Impact Assessment) Regulations 2017. Development type 3(h) and 3(a).
[31] Refer to Footnote 15.

RECOMMENDATION

In relation to hydropower, the Malvern Hills National Landscape Partnership would be supportive of micro or small-scale schemes, provided that relevant considerations have been adequately addressed. Proposals should:

- **Ensure equipment is placed either in existing buildings or new ones of an appropriate scale and design;**
- **Use the existing head of water from existing impoundments without affecting the river flow;**
- **Ensure noise levels do not adversely affect tranquillity;**
- **Ensure river life is not detrimentally affected; and,**
- **Operate without prejudicing progress towards achieving ecological objectives under the Water Framework Directive.**

6.4 Solar Energy

6.4.1 Solar Energy – general information

6.4.1.1 There are two types of solar energy:

- Photovoltaic panels or tiles that generate electricity from the sun's energy – these can be used at both domestic and commercial scale.
- Solar panels or 'collectors' (flat plate or evacuated tubes) that use the sun's radiation to heat water – these are used at a domestic and commercial scale.

6.4.1.2 In addition to the considerations for all renewable energy schemes provided in Section 4 above, a checklist of further issues to be considered for solar energy proposals is below:

- Consider views both from and to the Malvern Hills themselves, local viewpoints, and from popular tourist and scenic routes.
- Avoid locating solar PV where they could be directly overlooked at close quarters from important or sensitive viewpoints.
- Maintain uninterrupted views from the Malvern Hills themselves to the internal landscape to preserve its remote and strong cultural and historic sense of place.
- Site freestanding solar PV development on flat landforms or on lower slopes/within folds in gently undulating lowland landscapes.
- Ensure development does not span across different landscape character types.

- Site developments in landscapes where screening is already provided by woodland, hedgebanks or high hedges. Where new screen planting is required the Malvern Hills National Landscape Partnership should be consulted on the appropriate choice of species.
- Avoid adversely affecting areas of semi-natural habitat and designated historic and archaeological sites directly or indirectly.
- Protect the character and setting of buildings within Conservation Areas.
- Ensure that any PV developments do not detract from prominent landmarks.
- Protect the ‘Special Qualities,’ as detailed within the Malvern Hills AONB Management Plan.
- Measures should be taken to minimise any visual and noise impacts on the amenity of neighbouring land uses.
- Avoid siting PV developments across multiple fields in areas with a small-scale irregular field pattern that is important to landscape character.
- Site PV development in areas that already contain signs of human activity and development.
- Consider how panels will be transported to site.
- Suitable materials and colour finishes should be used that integrate any new buildings with their surroundings. Utilise existing farm buildings to house inverters wherever possible.

6.4.1.3 Ground-mounted arrays can result in direct habitat loss, habitat changes and disturbance or displacement of species and this should be carefully considered.

6.4.2 <u>Small-scale solar energy – size thresholds</u>

6.4.2.1 When considering size thresholds, the following is relevant in this regard:

- EIA Regulations specify that proposals should be screened for an EIA if the development area exceeds 0.5 hectares[32].
- Permitted development rights cover solar PV or solar thermal equipment on, or within the curtilage of, a dwellinghouse or block of flats[36].

[32] The Town and Country Planning (Environmental Impact Assessment) Regulations 2017. Schedule 2. Development type 3(a). [36] The Town and Country Planning (General Permitted Development) (England) Order 2015. Part 14.

6.4.2.2 However, it should be noted that these thresholds do not apply within designated AONBs (i.e., permitted development rights do not apply in AONBs[33] and solar energy proposals that are smaller than 0.5 hectares could potentially be screened for an EIA[34]).

6.4.2.3 In many landscape sensitivity assessments (LSAs) for renewable energy, 'small scale' solar energy development are schemes covering an area of five hectares or less. Nevertheless, it is appreciated that given the small extent and far-reaching views from the Malvern Hills themselves, the Malvern Hills National Landscape, and its setting, is likely to have high landscape and visual sensitivity to all scales of solar energy development.

6.4.2.4 Based on the above, the following thresholds should be applied for small-scale solar energy development when considering this position statement:

- 0.5ha or less = micro-scale.
- 0.5 ha - 5ha = small/field scale.

6.4.2.5 The Malvern Hills National Landscape Team are increasingly receiving queries relating to micro- and small-scale solar PV arrays. There are several types of arrays:

1. Small-/Field-scale solar arrays on greenfield land (undeveloped/agricultural land)
2. Small-/Field-scale solar arrays on brownfield land (developed industrial/ commercial/contaminated land)
3. Micro- and small-scale solar installations over car parks, alongside air strips, and other suitable external areas
4. Micro- and small-scale solar installations on new or existing industrial/agricultural buildings and other large-scale roofs

6.4.2.6 Site justification is vital, and identification of alternative sites should be considered. Ultimately proposed schemes will be judged on their own merits however array types 2, 3 and 4 offer more significant opportunities for the mitigation of potential adverse impacts upon the Malvern Hills National Landscape and its setting.

6.4.2.7 Proposals on, and within the curtilage of, residential properties not exceeding 0.5 hectares in size would need to be considered on a case-by-case basis where they are not permitted development. However, they are, in principle, likely to be acceptable in the Malvern Hills National Landscape and its setting, if compliant with relevant regulations and the considerations outlined in this position statement.

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[33] The regulations relating to permitted development rights (PDR) for renewable energy specify that these PDR do not apply in 'Article 2(3)' land, which includes designated AONBs.
[34] The thresholds and criteria specified in Schedule 2 of the Environmental Impact Assessment Regulations do not apply in 'sensitive areas', including designated AONBs.

6.4.2.8 Proposals for small-scale solar energy schemes larger than 0.5ha but smaller than 5ha are less likely to be acceptable in the Malvern Hills National Landscape and its setting due to the potential visual and/or landscape harm they present. Depending on the nature and siting of the scheme, they also may be considered major development, and if so, they should be assessed as such. Schemes that would constitute major development (in the context of paragraph 177 of the NPPF) should only be permitted in exceptional circumstances and where it can be demonstrated that the development would be in the public interest, in line with national planning policy. However, in specific circumstances and with adequate mitigation of potential adverse impacts on the Malvern Hills National Landscape and its setting, a small-scale solar energy proposal may be acceptable.

6.4.2.9 As such, any small-scale solar energy schemes should always be considered on a case-by-case basis against relevant planning policies and with regard to relevant considerations in Malvern Hills National Landscape Partnership published guidance and robust evidence provided of how any adverse impacts will be avoided or sufficiently mitigated.

6.4.3 Micro- and Small-scale solar - relevant considerations

6.4.3.1 This guidance primarily relates to such proposals being sensitively located[35] and sited[36]. Location, siting, and design are also important considerations for schemes that relate to listed buildings, conservation areas and other heritage assets[37].

6.4.3.2 PV panels mounted on buildings are considered more suitable than those that are freestanding as they are likely to have a less adverse visual effect. PV panels can be used as a building material, integrated into the roof (or facades) of buildings e.g. using solar shingles, solar slates, solar glass laminates and other solar design solutions, and can be integrated with traditional tiles/slates[38].

6.4.3.3 Solar collectors or evacuated tubes can be incorporated into the existing roof in the same way. Ideally, these require an angle of 30-40 degrees, facing south.

6.4.3.4 Consideration should be given to the effect of installations on the appearance of the building. It is a good idea to line panels up with existing windows and roof lights, ensuring the size of the panels are complementary to existing features on the building.

6.4.3.5 Consideration should be given to the colour and design of the panels and their frames and mounts/supporting structures. For example, panels with a dull, matt finish with

[35] 'Located,' in this context, refers to the placement of the proposed development with regard to the landscape context, including the Malvern Hills National Landscape Partnership Position Statement on Landscape-led Development.

[36] 'Sited,' in this context, feres to the development's placement in relation to its immediate context.

[37] 'Relate to,' in this context, means 'on,' 'in the curtilage of' and / or 'in the setting of.'

[38] The UK Government has estimated that there are currently 250,000 hectares (approx. 625,000 acres) of south-facing commercial roofs in the UK (Part 2 of the Government's UK Solar Photo-Voltaic (PV) Strategy).

anti-glare options and non-reflective frames/grids are less conspicuous as are panels with dark surfaces which are likely to be acceptable on buildings with darker slate roofs or on new buildings in areas where black slate roofs are characteristic, to integrate into the landscape.

6.4.3.6 Rooftop solar panels can blend well with contemporary, industrial, business park and agricultural buildings. Use of panels on such buildings, including by retrofitting should be supported, where considerations such as those listed above are followed.

6.4.3.7 Small-scale freestanding solar arrays that are well screened in enclosed gardens or closely linked to existing buildings with no or minimal visual impact may be acceptable. There may be circumstances where ground mounted solar arrays to serve groups of properties, community buildings, such as village halls, agricultural properties or other businesses are acceptable, where these are clearly well screened within existing building complexes or by other existing landscape features such as hedgerows, walls or trees, and which do not detract from any architectural or historic/archaeological interest, or compromise protected species.

6.4.3.8 Arrays need to be positioned such that any associated screening does not shade the panels. Where new screening is proposed, care needs to be taken to ensure screening does not adversely affect visual amenity and/or landscape character or heritage assets. Consideration will also need to be given to the potential impact of paraphernalia associated with the installation and operation of the solar panels.

6.4.3.9 Retrofitted roof-mounted solar units on buildings can have a ‘modernising’ effect on their character and appearance, particularly when located on the principal elevation of a property. It is beneficial for panels to:

- Match roof materials;
- Lie/Be ‘flush’ with the roof and mounted at the same angle, minimising contrast;
- Mounted on an elevation where they are less visible, in the case of retrofitted panels, or incorporated as a garden feature, especially when associated with, for instance, older buildings; and
- Be at a suitable angle to maximize the capture of the sun’s energy.

6.4.3.10 Roof-top panels on buildings have the added benefit of providing generation at the point of use, reducing transmission and distribution losses, and associated infrastructure impacts. Well-designed solar technology should be added as a mandatory part of building regulations for new build houses and all business/industrial development. Local planning authorities should support rooftop PV panels generation through planning conditions to mandate it on new development and refurbishments.

RECOMMENDATIONS

- **In principle, the Malvern Hills National Landscape Partnership would be supportive of domestic and micro- (I.e. less than 0.5ha) schemes provided relevant considerations have been clearly addressed. They will still need to be considered on a case-by-case basis.**
- **Small-scale solar energy schemes (I.e. between 0.5ha and 5ha) within the Malvern Hills National Landscape and its setting, have greater potential to adversely affect the Special Qualities of AONB designation and are unlikely to be supported. Such proposals must be carefully considered on a case-bycase basis and will require robust evidence that relevant considerations have been clearly addressed. This includes having regard to visual effects, including the proximity to high ground and key vantage points within the Malvern Hills National Landscape, and consideration of effects upon landscape character. Where such schemes are considered 'major development' proposals, applicants should be required to demonstrate that exceptional circumstances apply and the scheme would be in the public interest, having regard to Paragraph 177 of the NPPF (2023).**
- **Building-mounted or roof-top panels on new and existing buildings should be at the top of the solar energy 'hierarchy' and would be considered more favourably over freestanding solar development proposals.**
- **Local planning authorities should support rooftop PV generation through planning conditions on new development and refurbishment/retrofitting.**
- **Solar technology should be introduced as a mandatory part of building regulations for new build development in local plan policies.**

6.4.4 Large-scale solar energy

6.4.4.1 We consider 'large-scale' as over five hectares (5ha) although the Partnership acknowledges that, in the context of landscape sensitivity assessments, for example, a wider range of size thresholds may be used. Main features of large-scale solar PV installations include:

- Panels being dark in colour due to their non-reflective coating, maximising absorption of light. Panels may appear paler depending on light conditions and type of panel. Panel surrounds and electric cable coverings may reflect light.
- Panels are visible from behind or the side, influencing how they are perceived.
- Panels are encased in an aluminium frame, supported by aluminium or steel stands mounted and secured either on pre-moulded concrete block 'anchors,' or

foundations. Some developments contain panels that can be manually rotated and/or tilted to enable the arrays to track the sun. Technology does exist to allow for automatic tracking.

- Panels are held at a fixed angle between 20-40 degrees from the horizontal, facing south to maximise absorption of energy from the sun
- Arrays are sited in rows with intervening gaps between them for access, and to ensure the individual panels are not in the shade of panels. The actual arrangement of the arrays varies scheme to scheme.
- The height of the racks of solar panels varies depending on manufacturer and installer but tend to be between 2-4 metres off the ground.

6.4.4.2 Commercial-scale solar energy schemes usually require an area of at least five hectares to be viable[39]. Community-led schemes may also require a substantial land area.

6.4.4.3 An important consideration is landscape sensitivity. This is a measure of the resilience of a landscape to withstand specified change arising from development types, without undue effects on the landscape and visual baseline. It has benefit by being evidence based and adding rigour to assessing development proposals.

6.4.4.4 The local planning authorities that overlap the Malvern Hills National Landscape should undertake a landscape sensitivity assessment (LSAs) for wind and solar energy, as part of their evidence base for development plans (i.e. Local Plans).

6.4.4.5 Landscape and Visual Impact Assessments (LVIAs) will help to identify the significance of landscape and visual impacts on a case-by-case basis. Cumulative effects also need to be considered. In terms of landscape value, given the designation as an AONB, the Malvern Hills National Landscape should be attributed the highest category possible in such assessment. Agricultural land that is designated, for example for the protection of wildlife, should be avoided. LVIAs should contain a clear description of the site's agricultural classification and all other relevant designations.

6.4.4.6 The Malvern Hills National Landscape has the Special Quality of 'dramatic scenery and spectacular views arising from the juxtaposition of high and low ground.' The Partnership is unlikely to support, in principle, solar energy schemes within the Malvern Hills National Landscape and its setting over 5 ha, as it is unlikely that sufficient mitigation would be possible to avoid adverse effects to the landscape and visual baseline. Hence, supporting such a scheme would not be consistent with the statutory purpose of AONB designation.

[39] Anecdotal evidence provided by consultants involved in commercial-scale solar energy proposals.

6.4.4.7 Schemes that would constitute major development (in the context of paragraph 177 of the NPPF) should only be permitted in exceptional circumstances and where it can be demonstrated that the development would be in the public interest, in line with national planning policy.

6.4.4.8 Further guidance and recommendations on landscape sensitivity assessments and how they might be applied to identify ‘suitable areas’ for renewable energy in local planning authority development plans is provided in Section 6.6. Further guidance on the issue of major development is provided in Section 4.

6.4.4.9 Many considerations outlined in relation to small-scale solar energy schemes are applicable to large-scale schemes, including EIA thresholds. In addition to the impact of the solar panels themselves, consideration should be given to the impacts of any additional infrastructure that is required for the scheme, including road access, on-site tracks, hard standings, construction compounds, electrical cabling, security fencing. lighting substations, battery storage and / or control buildings, inverters, control rooms, transformers and underground power cables, and CCTV. Consideration should be given to potential conflicts with other land uses, such as food production (particularly on best and most versatile land), nature recovery and woodland creation.

6.4.4.10 Another consideration is the proximity of the railway and road network, PROWs, and residential areas. The provision of any reflective material used on the panels should not interfere with the line of sight of train drivers and road users (for public safety reasons). In addition, potential for glare or reflection of light from the panels that may impact upon signalling should be explored and eliminated. Similarly, the impact of the siting of solar panels, particularly in terms of their reflectivity, should be considered in relation to views from the Malvern Hills and the impacts that may have on such users, as well as views from PROWs and from residential areas.

6.4.4.11 Large-scale solar PV installations occupy substantial areas of ground which may be visible, especially where sites are viewed from adjacent higher ground. Key landscape effects of large-scale solar PV developments are that they may:

- Be highly visible in open landscapes, when looking out from high ground, and on the upper slopes of hillsides, especially where covering significant areas;
- Lead to a perceived increase in human influence on the landscape;
- Result in land use change and the appearance of a field, affecting land cover patterns;
- Introduce a regular edge (to the panels) that can be particularly conspicuous in more irregular landscapes (especially where the panels do not follow contours);

- ‘Overtop’ hedgerows where panel heights rise to 3-4m, potentially reducing the visual prominence of field boundaries, a particular issue where several adjacent small fields are developed;
- Change the character of enclosure with security fencing and screen planting (including hedges allowed to grow out) around solar PV developments;
- Damage landscape features during construction;
- Result in a significant change in the character of wild or natural landscapes which are valued for their high nature conservation value and qualities of remoteness; Introduce ancillary buildings that can be uncharacteristic in the landscape; and Result in glint and glare from the panels.

6.4.4.12 Vegetation will grow under some large-scale solar development, and this will require management, particularly to avoid the site becoming overgrown with noxious weeds and assist with the eventual restoration of the site, normally to agriculture. There are various techniques for managing the vegetation; these include mowing, strimming, spraying, or mulching. Spraying should be avoided wherever possible and mulching large areas is likely to present technical challenges and may add to the landscape/visual impact of a development proposal. Few of these management techniques are regarded as sustainable, particularly on sites up to 15ha, and there is a desire, both in terms of food production and the rural scene, to continue an agricultural use on the site. Grazing is therefore to be encouraged wherever practicable. Cattle, horses, pigs, and goats are likely to be too ‘physical’ with the solar arrays, but sheep, chickens or geese should be acceptable.

6.4.4.13 The Feed in Tariff for solar PV applies for a period of 25 years therefore developments should normally be regarded as temporary, hence the need for ‘reversibility’, and the ability for all structures to be removed and the land returned to its original use. A restoration strategy should demonstrate how the site will be returned to a state that is in keeping with local character and in good condition. In order to facilitate grazing within the solar farm it is advised that solar panels are positioned at least 700mm above ground level and all cabling etc is suitably protected.

RECOMMENDATIONS

- **In relation to large-scale solar energy, the Malvern Hills National Landscape Partnership would not be supportive of solar energy schemes within the Malvern Hills National Landscape or its setting larger than five hectares in size.**
- **Applicants for large-scale solar energy schemes above 5ha should be required to robustly demonstrate that the scheme can be clearly**

accommodated without adversely affecting or compromising the natural beauty of the Malvern Hills National Landscape and/or its setting. In addition to the impact of the panels themselves, consideration should also be given to the impacts of any additional infrastructure that is required for the scheme, particularly during construction, operation, maintenance, and decommissioning.

- **Poorer grades of agricultural land that are designated, for example for the protection of wildlife, should be avoided.**
- **For 'major development' proposals, applicants should be required to demonstrate that exceptional circumstances apply, and the scheme would be in the public interest, having regard to paragraph 177 of the NPPF (2023).**

6.5 Wind Energy

6.5.1.1 Wind turbines use the wind's lift forces to rotate aerodynamic blades that turn a rotor creating a mechanical force that generates electricity. The amount of energy derived from a turbine depends on wind speed and the swept area of the blade.

6.5.1.2 Wind turbines can be deployed singly, small clusters, (2–5 turbines) or larger groups as wind farms.

6.5.1.3 Wind turbines consist of the tower; a hub; blades; a nacelle (which contains the generator and gear boxes); and a transformer that can be housed either inside the nacelle or at the base of the tower.

6.5.1.4 Wind energy developments are unique in that they introduce a source of movement into the landscape. In current designs, the turbine blades turn around a horizontal axis but can turn around a vertical axis. Two-bladed turbines are available.

6.5.2 <u>Small-scale wind energy – size thresholds</u>

6.5.2.1 The following height thresholds provide a useful starting point:

- EIA Regulations specify that proposals should be screened for an EIA if the hub height of any turbine (or height of any other structure that forms part of the scheme) exceeds 15 metres and/or the development area exceeds 0.5 hectares[40].
- Permitted development rights cover[41]:

[40] The Town and Country Planning (Environmental Impact Assessment) Regulations 2017. Schedule 2 (link). Development type 3(i) and / or 3(a). The EIA threshold also relates to wind energy development of any height (including smaller than 15m hub height) where there are more than two turbines.
[41] The Town and Country Planning (General Permitted Development) (England) Order 2015. Part 14

- Wind turbines on (i.e., attached to) detached houses, which do not exceed 15 metres in height (or protrude more than 3m above the highest part of the roof, excluding the chimney); and
- Stand-alone wind turbines within the curtilage of houses or blocks of flats that do not exceed 11.1 metres.

6.5.2.2 Such thresholds do not apply within designated AONBs (i.e., these permitted development rights do not apply in AONBs[42] and turbines in AONBs that are smaller than 15 metres in height could potentially be screened for an EIA[43]). Having regard to the 'Special Quality' of 'dramatic scenery and spectacular views arising from the juxtaposition of high and low ground ', effectively means that only stand-alone wind turbines within the curtilage of houses or blocks of flats may be acceptable in the Malvern Hills National Landscape and its setting. However, they would need to also, to comply with the relevant regulations and accord with guidance, primarily relating to proposals being sensitively located[44] and sited[49].

6.5.2.3 It is noted that the EIA threshold of 15 metres relates to the hub-height of the turbine. The blade tip height can be several metres higher. It is also worth noting that wind turbines with a blade tip height smaller than 25 metres are often classed as 'small' in landscape sensitivity assessments.

6.5.2.4 Based on the above, and for the purposes of this Position Statement, small-scale is viewed as wind turbines that are 25 metres or less, in height, to the blade tip. Wind turbines of this scale are most likely to be used for individual properties or small groups of properties, rather than commercial schemes.

6.5.3 Small-scale wind energy – location

6.5.3.1 With regards to 'location,' consideration should be given to landscape sensitivity. This means having regard to the potential sensitivity of the landscape character type/area where the development is proposed. This is addressed in more detail in relation to AONB designation considerations in (Section 4 of this position statement and in the identification of 'suitable areas' in Section 6.6).

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[42] The regulations relating to permitted development rights (PDR) for renewable energy specify that these PDR do not apply in 'Article 2(3)' land, which includes designated AONBs.
[43] The thresholds and criteria specified in Schedule 2 of the Environmental Impact Assessment Regulations do not apply in 'sensitive areas', including designated AONBs.
[44] 'Located,' in this context, refers to the placement of the proposed wind development with regard to the landscape context. [49] 'Sited,' in this context, refers to the development's placement in relation to its immediate context.

6.5.4 Small-scale wind energy – siting and design

6.5.4.1 The size of a wind turbine should relate to the scale of its surroundings. Turbines should not dominate existing buildings or landscape features but be in proportion.

6.5.4.2 The relationship between a turbine and the slope of the landform is a key consideration of wind energy development, particularly regarding the degree of landscape and/or visual impact. Ideally, turbines should be located below the skyline and towards lower slopes. The top of a steeply inclined slope is also not appropriate because the steep incline creates wind turbulence, reducing operational efficiency.

6.5.4.3 Choosing appropriate colours for the turbines (and associated infrastructure) may help reduce visual impact e.g. darker colours may be appropriate when the turbine is likely to be viewed against woodland or against a backdrop that is below the skyline.

6.5.4.4 Consideration should also be given to:

- Impacts on visual receptors: Particularly in relation to impacts on views from publicly accessible locations. Visual receptors on the Malvern Hills, on named / promoted walking, cycling or horse-riding routes and at important viewpoints (for example, those marked on OS maps, or identified in NDPs, are particularly sensitive in this regard. Where there are several potential locations for the wind turbine(s), priority should be given to the least prominent location.
- Ecology: Small-scale turbines are unlikely to impact bird species and habitats. During construction, care should be taken to avoid removal or fragmentation of existing vegetation. Consideration should be given to potential impact on bats.
- Impacts on historic environment and cultural heritage features/designations and their settings: Particularly conservation areas, listed buildings, scheduled monuments and (Un-)registered historic parks and gardens.
- Noise and shadow flicker: Wind turbines generate two types of noise – mechanical noise, created by its gearbox, and aerodynamic noise, produced by its moving blades. Shadow flicker occurs when the sun passes behind a turbine’s rotating blades and casts a shadow that appears to rapidly flicker on and off. Proximity to neighbouring properties is particularly important in this regard.
- Cumulative impacts: This includes other wind developments, overhead powerlines, and telecommunications masts and other vertical structures.

RECOMMENDATION

- **In relation to small-scale wind energy, only stand-alone wind turbines within the curtilage of houses or blocks of flats are, in principle, likely to be**

acceptable in the Malvern Hills National Landscape and its setting, provided that relevant considerations have been clearly addressed.

- **Each proposal should be assessed on a case-by-case basis and not give rise to adverse effects upon the natural beauty of the Malvern Hills National Landscape and its setting.**

6.5.5 Large-scale wind energy

6.5.5.1 'Large-scale' means turbines larger than 25 metres in height, to the tip of the turbine (taking account of the definition of 'small scale', provided above). In the context of landscape sensitivity assessments, a wider range of size thresholds is likely.

6.5.5.2 As outlined in relation to small-scale wind energy above, the issue of visual sensitivity is also an important consideration.

6.5.5.3 Landscape and Visual Impact Assessments (LVIAs) will help to identify the significance of landscape and visual effects on a case-by-case basis.

6.5.5.4 The Malvern Hills National Landscape has the Special Quality of 'dramatic scenery and spectacular views arising from the juxtaposition of high and low ground '. As a result, the Partnership is unlikely to support, in principle, large scale wind energy schemes within the Malvern Hills National Landscape, and/or its setting, as it is unlikely that sufficient mitigation would be possible to avoid adverse change to the landscape and visual baseline, and hence supporting such a scheme would not be consistent with the statutory purpose of AONB designation.

6.5.5.5 Wind energy schemes that would constitute major development (in the context of paragraph 177 of the NPPF) can only be permitted in exceptional circumstances and where it can be demonstrated that the development would be in the public interest, in line with national planning policy.

6.5.5.6 Further guidance on landscape sensitivity assessments and how they might be applied to identify 'suitable areas' for renewable energy in local planning authority development plans is provided in Section 6.6. Further guidance on the issue of major development is provided in Section 4 of this position statement.

6.5.5.7 Many of the considerations outlined in relation to small-scale wind energy schemes are also applicable to large-scale schemes, including EIA thresholds. In addition to the impact of the wind turbines themselves, consideration should be given to the impacts of any additional infrastructure that is required for the scheme, such as road access, on-site tracks, turbine foundations, hard standings, anemometer masts, construction compounds, electrical cabling, battery storage, sub-stations, and control buildings. Other relevant considerations are addressed in Section 4.

6.5.5.8 Consideration should be given for the effect of wind development upon landscape designations, geological and nature conservation designations, and historic assets near the development, and the wider landscape context.

RECOMMENDATION

- **In relation to large-scale wind energy, the Malvern Hills National Landscape Partnership would not be supportive of large-scale wind energy schemes within the Malvern Hills National Landscape and/or its setting.**
- **Applicants for large-scale wind energy schemes should be required to robustly demonstrate that the scheme could be accommodated without adversely affecting the landscape and/or scenic beauty of the AONB designation and/or its setting.**
- **For major development proposals, applicants should be required to demonstrate that exceptional circumstances apply and that the scheme would be in the public interest, as per Paragraph 177 of the NPPF (2023).**

6.6 Wind & Solar Energy – Identification of 'Suitable Areas'

6.6.1 Paragraph 155 of the NPPF states that to help increase the use and supply of renewable and low carbon energy and heat, plans should '*consider identifying suitable areas for renewable and low carbon energy sources, and supporting infrastructure, where this would help secure their development*'. In practice, identification of 'suitable areas' for renewable energy development in development plans primarily focuses on both wind and solar energy.

6.6.2 There is a strong onus on identifying 'suitable areas' for wind energy in LPA development plans, with the NPPF stating that '*a proposed wind energy development involving one or more turbines should not be considered acceptable unless it is in an area identified as being suitable for wind energy development in the development plan…*'[45]. If LPAs do not identify suitable areas for wind energy in their development plans, then they are effectively ruling out wind energy development in their LPA areas.

6.6.3 The Malvern Hills National Landscape Partnership recommends that the identification of 'suitable areas' should be based on a combination of:

[45] Ministry of Housing Communities and Local Government (2021) National Planning Policy Framework. Footnote 54.

- Landscape sensitivity assessments;
- Constraints mapping; and
- Technical consideration including wind speed and grid connectivity.

6.6.4 As stated in the PPG for Renewable and Low Carbon Energy, 'there are no hard and fast rules about how suitable areas for renewable energy should be identified, but in considering locations, local planning authorities will need to ensure they take into account '… *critically, the potential impacts on the local environment, including from cumulative impacts*.' The PPG goes on to state, in relation to the identification of suitable areas, that:

'In considering impacts, assessments can use tools to identify where impacts are likely to be acceptable. For example, landscape character areas could form the basis for considering which technologies at which scale may be appropriate in different types of location.'

6.6.5 It is important to note that the PPG says 'could' rather than 'should,' in this regard. However, in the context of nationally designated protected landscapes, such as designated AONBs, and their settings, we consider that it is essential that the identification of suitable areas should be underpinned by a landscape sensitivity assessment. Guidance on this topic has been published by Natural England.

6.6.6 When 'suitable areas' are being identified, regard should be given to the purpose of conserving and enhancing the natural beauty of the Malvern Hills National Landscape Partnership. Identification of 'suitable areas' should be underpinned by a landscape sensitivity assessment and by consideration of the constraints that relate to the natural beauty of AONB designation, including nature conservation and historic environment designations (in addition to infrastructure constraints and other technical considerations).

6.6.6.1 Wind and solar energy schemes should be steered towards areas of lower landscape sensitivity and away from key constraints. The Government's PPG on Renewable and Low Carbon Energy states, in the context of identifying '*suitable areas*,' that '*there is a methodology*[46] *available from the Department of Energy and Climate Change's website on assessing the capacity for renewable energy development'*[47].

6.6.6.2 The methodology sets out a five-step process for addressing AONB designation:

- Step 1: Identify the purposes of the landscape area (reasons for designation)

[46] LUC and SQW Energy (2010) Renewable and Low-carbon Energy Capacity Methodology. Methodology for the English Regions. Commissioned by the Department of Energy and Climate Change (DECC) and the Department of Communities and Local Government (CLG).
[47] https://www.gov.uk/guidance/renewable-and-low-carbon-energy. Paragraph 005.

- Step 2: Identify which technologies might affect these purposes/ integrity of the designation
- Step 3: Identify how each technology might affect the purposes/ integrity
- Step 4: Identify the type and level of renewable and low carbon infrastructure that could be accommodated without compromising the purposes/ integrity of the designations
- Step 5: Provide guidance on how to integrate renewable/ low carbon energy without compromising the purposes/integrity

6.6.6.3 The methodology identifies whether 'constraints,' such as infrastructure and nature conservation and heritage conservation designations, should be excluded from further consideration (i.e., not considered suitable for renewable energy development) and whether there should be a 'buffer zone' around these features. The consideration of relevant constraints and buffer zones is reflected in the evidence base of many, current development plan consultations.

6.6.7 Areas that are identified as having 'high' landscape sensitivity to the type and scale of renewable energy being proposed should be excluded from the suitable area mapping.

6.6.7.1 It is recognised that in having regard to the 'Special Quality' of 'dramatic scenery and spectacular views arising from the juxtaposition of high and low ground' means that landscape and visual sensitivity is high across much of the Malvern Hills National Landscape and its setting. Where landscape sensitivity is classed as 'High,' key characteristics and qualities of the landscape are highly vulnerable to change from the proposed scale of wind and solar energy development. Such development is highly likely to result in a significant (adverse) change in landscape character. In designated AONBs, such development is likely to have a significant adverse effect on the statutory purpose of AONB designation, which is to conserve and enhance natural beauty. The same is true for such development in the setting of designated AONBs in cases where the impact on views from and/or to the AONB designation is an important consideration in landscape sensitivity ranking[48].

6.6.7.2 In order for a landscape sensitivity assessment to have a meaningful role in the identification of suitable areas for wind and solar energy we recommend that areas within designated AONBs that have 'High' sensitivity to particular scales of wind or solar energy

[48] Case law (see also footnote 21) has clarified that the requirements of what is now paragraph 176 of the National Planning Policy Framework (NPPF) should apply to the impact of development outside a designated AONB on views from the designated AONB. In other words, great weight should be given to the impact of such development on these views. Further guidance on this can be found in the Malvern Hills National Landscape Position Statement on Development and Land Use Change in the Setting of the Malvern Hills National Landscape. Although the same principle, clarified in the case law example, does not apply to the impact of such development on views towards a designated AONB, these views may still contribute to the 'special qualities' of the designated AONB. This is especially the case for the Malvern Hills, the views towards which are considered one of the 'special qualities' of the Malvern Hills National Landscape.

development should not be included within ‘suitable area’ maps in local authority development plans. The same principle should also apply to ‘High’ sensitivity areas in the setting of a designated AONB, where the impact on views from and / or to the designated AONB is an important consideration in the landscape sensitivity ranking.

6.6.8 Consideration will also need to be given to types and scales of renewable energy that are identified as resulting in ‘moderate-high’ landscape sensitivity.

6.6.8.1 Development is likely to be ‘major development’ in the context of paragraph 177 of the NPPF, for which there is, in effect, presumption against granting planning permission, other than in exceptional circumstances.

6.6.8.2 Key characteristics and qualities of the landscape are also vulnerable to change from wind and solar energy development when the landscape sensitivity is classed as ‘Moderate-High.’ However, there may be some limited opportunity to accommodate wind turbines/ solar panels in such areas without significantly changing landscape character. Ideally, the landscape sensitivity assessment would specify the circumstances, or locations, where this might be the case. Given the fact that there may be opportunity (albeit limited) to accommodate such development without significantly changing landscape character, it might not be appropriate to automatically exclude such areas from ‘suitable area’ maps in local authority development plans.

6.6.8.3 However, where the scale of wind or solar energy development within a designated AONB (or its setting) is such that the landscape sensitivity would be ‘Moderate-High,’ such development is still likely to have a significant adverse impact on the natural beauty of the AONB designation. Such development is likely to constitute ‘major development,’ in the context of paragraph 177 and footnote 60 of the NPPF[49]. 6.6.9 Renewable energy proposals within a ‘suitable area’ will need to be assessed on a case-by-case basis against relevant policy considerations, factoring in relevant AONB designation considerations.

6.6.10 Renewable energy LSAs that are commissioned by local authorities are normally based on a local authority’s own Landscape Character Assessment. However, in fulfilling the statutory duty to have regard to the purpose of AONB designation, they should have regard to relevant documents published by the Partnership, including:

- Landscape Character Assessments;
- AONB Management Plans, with regards to policies and ‘special qualities;

[49] Footnote 60 of the NPPF specifies that ‘for the purposes of paragraphs 176 and 177 [of the NPPF], whether a proposal is ‘major development’ is a matter for the decision maker, taking into account its nature, scale and setting, and whether it could have a significant adverse impact on the purpose for which the area has been designated or defined’.

- Position Statements; and
- Other guidance relating to landscape character and landscape sensitivity e.g. Natural England's National Character Area profiles.

6.6.11 In the case of wind energy, they will also need to demonstrate that they have local community support. Where multiple renewable energy developments would be intervisible, cumulative impacts are also be a key consideration.

RECOMMENDATION

- **The Malvern Hills National Landscape Partnership supports the identification of suitable areas for wind and solar energy in local planning authority development plans.**
- **Identification of 'suitable areas' should be underpinned by a landscape sensitivity assessment and by consideration of relevant constraints and technical considerations.**
- **Suitable area maps should exclude areas of high landscape sensitivity (and least within the designated AONB and its setting) and where there are key constraints.**
- **Renewable energy schemes should be targeted towards areas of relatively low landscape sensitivity (preferably low landscape sensitivity) within the LPA area. Renewable energy landscape sensitivity assessments, commissioned by local authorities, should have regard to relevant guidance published by the Malvern Hills National Landscape Partnership.**
- **In relation to large-scale solar energy and wind energy, within the highly sensitive context of the designated AONB and its setting, a Landscape and Visual Impact Assessment (LVIA) should be carried out from pre-application stage and be submitted alongside a planning application. It should be produced to a high standard, follow best practice guidance (Guidelines for Landscape and Visual Impact Assessment 3rd Edition, 2013), and demonstrate the proposal does not compromise the AONB designation and its primary purposes. The appraisal should identify the Zone of Visual Influence (ZVI) and assess the developments impact upon key viewpoints from within the designated AONB and its setting.**

6.7 Energy Storage

6.7.1 Renewable energy is intermittent in nature. It is important to provide energy storage systems that can be charged during periods of excess renewable energy generation and discharged at times of increased demand. Energy storage can be used to store electricity bought from the grid at cheaper times of the day, with dynamic energy tariffs that vary in price throughout the day.

6.7.2 Energy storage systems include

- Pumped hydro involves pumping water uphill at times of low demand, storing it in a reservoir and, in high demand periods, releasing it through turbines to create electricity.

- Thermal energy storage involves storing excess energy to be used later for heating, cooling, or power generation; thermal energy can be stored in liquids, such as water, or solids, such as sand or rocks. Chemical reactions or changes in materials can also be used to store and release thermal energy.
- Mechanical energy storage involves harnessing motion or gravity to store electricity. For example, a flywheel is a rotating mechanical device that is used to store rotational energy that can be called up instantaneously.
- Batteries involve converting stored chemical energy into electrical energy. Advances in technology and falling prices mean grid-scale battery facilities that can store increasingly large amounts of energy are becoming common.

6.7.3 For small-scale forms of renewable energy that are advocated in this position statement, the most common form of energy storage is likely to be battery storage. In this context, battery storage solutions can be particularly attractive although battery size will depend on energy usage and the size of the technologies installed. Some, but not all, battery storage systems can be installed outdoors.

6.7.4 Where planning permission is required, relevant considerations include:

- Location and design of the structure that the batteries are to be stored in (including the potential use of existing buildings, such as barns);
- Fencing, substation, and other structures/infrastructure associated with the storage system;
- Access and maintenance arrangements;
- Noise impacts; and
- Sustainability and environmental impact of materials used (e.g. lithium).

RECOMMENDATION

In relation to energy storage, in principle, the Malvern Hills National Landscape Partnership would be supportive of energy storage schemes that provide effective storage of renewable energy that is generated in the Malvern Hills

National Landscape and its setting, providing relevant considerations have been adequately addressed.

7.0 COMMUNITY-LED RENEWABLE ENERGY SCHEMES

7.1 Account should be taken of the economic and social needs of local communities. An important component of this is how energy and heating requirements of these communities are met.

7.2 National planning policy states that 'local planning authorities should support community-led initiatives for renewable and low carbon energy'[50]. In the case of wind energy, national planning policy also states that a proposed wind energy development involving one or more turbines should not be considered acceptable unless, inter alia, the proposal has the backing of the local community[51].

7.3 As such, the extent to which a proposed renewable energy scheme: (i) explicitly helps to meet the energy needs of the individual local community; and/or (ii) is communityled, is an important consideration. Care should be taken that community-led schemes are genuine and not developer-driven. More appropriate schemes are those that may be part of Neighbourhood Plans (NDPs) or initiatives such as the Community Visioning projects being piloted by CPRE[52].

7.4 Proposals for community-led renewable energy should be supported by evidence of the current carbon footprint/energy use of the community, and the impact that the renewable energy proposal will have on reducing this.

7.5 Renewable energy schemes can support rural diversification and educational opportunities, and community-owned renewable energy projects can provide incentives and ownership, as well as promoting self-sufficiency.

RECOMMENDATION

- **In relation to community-led renewable energy schemes, in principle, the Malvern Hills National Landscape Partnership would support community-led schemes more favourably, provided that considerations have been clearly addressed, than those which are not community-led.**

[50] Ministry of Housing Communities and Local Government (2023) National Planning Policy Framework - Paragraph 156.
[51] Ministry of Housing Communities and Local Government (2023) National Planning Policy Framework - Footnote 54. The revisions to the NPPF in 2023 changed the requirement for community 'backing' to community 'support'. 'Support' is, arguably, a (slightly) lower threshold than 'backing.' However, community backing, or support is likely to remain a requirement for wind energy proposals to be approved.
[52] https://www.cpre.org.uk/what-we-care-about/climate-change-and-energy/renewable-energy/community-energy-visioningshowcasing-renewables-done-well/

- **Renewable energy schemes should demonstrate benefits to the local community.**

V1 – DRAFT produced for Malvern Hills AONB Joint Advisory Committee (JAC) meeting of 10 November 2023 to endorse as a consultation draft – October 2023 (JB/SH/PE)
V2 – DRAFT produced for consultation incorporating 'National Landscape' re-brand following endorsement of draft for consultation by Malvern Hills AONB JAC meeting of 10 November 2023 – December 2023 (JB/PE)

LEDBURY TOWN COUNCIL

CLIMATE CHANGE WORKING PARTY	7 FEBRUARY 2024	AGENDA ITEM: 9

Report prepared by Julia Lawrence – Deputy Town Clerk

ABSOLUTE ZERO REPORT

Purpose of Report

The purpose of this report is to request that Members of the Climate Change Working Party consider the paper requesting that they provide an opinion on the Report.

Detailed Information

A copy of the "Absolute Zero" report can be found at Appendix A.

As noted above, Members of the Climate Change Working Party are asked to share their opinion on this report which will be submitted to the next Environment & Leisure Committee for consideration.

Recommendation

That Members of the Climate Change receive and note the aforementioned information and provide their opinion, to be submitted to Members of the Environment and Leisure Committee for consideration at the next meeting in March.

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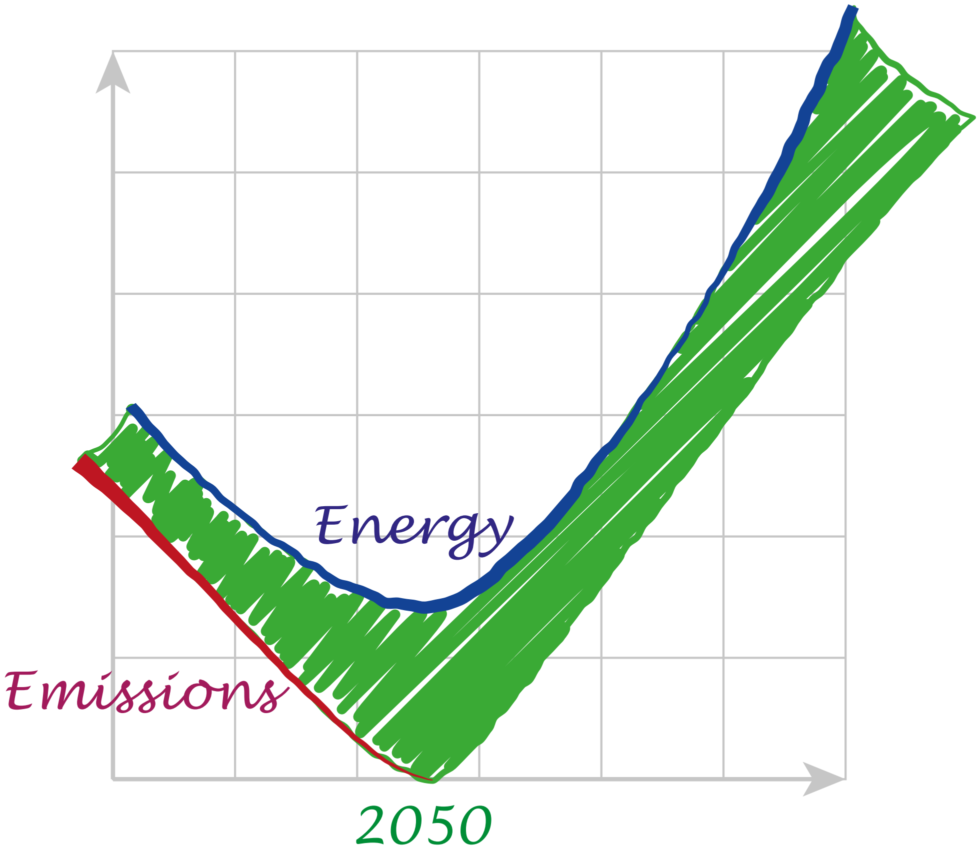
Absolute Zero



Delivering the UK's climate change commitment with incremental changes to today's technologies

UK FIRES

Absolute Zero

UK demand for energy-intensive materials is growing, driving increased emissions in the UK and abroad. UK FIRES is a research programme sponsored by the UK Government, aiming to support a 20% cut in the UK's true emissions by 2050 by placing Resource Efficiency at the heart of the UK's Future Industrial Strategy.

Industry is the most challenging sector for climate mitigation – it's energy efficient and there are no substitutes available at scale for the energy-intensive bulk materials - steel, cement, plastic, paper and aluminium. UK FIRES is therefore working towards an industrial renaissance in the UK, with high-value climate-safe UK businesses delivering goods and services compatible with the UK's legal commitment to zero emissions and with much less new material production.

UK FIRES

Engineering and Physical Sciences Research Council

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Executive Summary

We can't wait for breakthrough technologies to deliver net-zero emissions by 2050. Instead, we can plan to respond to climate change using today's technologies with incremental change. This will reveal many opportunities for growth but requires a public discussion about future lifestyles.

We have to cut our greenhouse gas emissions to zero by 2050: that's what climate scientists tell us, it's what social protesters are asking for and it's now the law in the UK. But we aren't on track. For twenty years we've been trying to solve the problem with new or breakthrough technologies that supply energy and allow industry to keep growing, so we don't have to change our lifestyles. But although some exciting new technology options are being developed, it will take a long time to deploy them, and they won't be operating at scale within thirty years.

Meanwhile, our cars are getting heavier, we're flying more each year and we heat our homes to higher temperatures. We all know that this makes no sense, but it's difficult to start discussing how we really want to address climate change while we keep hoping that new technologies will take the problem away.

In response, this report starts from today's technologies: if we really want to reach zero emissions in thirty years time, what does that involve? Most of what we most enjoy - spending time together as families or communities, leisure, sport, creativity - can continue and grow unhindered. We need to switch to using electricity as our only form of energy and if we continue today's impressive rates of growth in non-emitting generation, we'll only have to cut our use of energy to 60% of today's levels. We can achieve this with incremental changes to the way we use energy: we can drive smaller cars and take the train when possible, use efficient electric heat-pumps to keep warm and buy buildings, vehicles and equipment that are better designed and last much longer.

The two big challenges we face with an all electric future are flying and shipping. Although there are lots of new ideas about electric planes, they won't be operating at commercial scales within 30 years, so zero emissions means that for some period, we'll all stop using aeroplanes. Shipping is more challenging: although there are a few military ships run by nuclear reactors, we currently don't have any large electric merchant ships, but we depend strongly on shipping for imported food and goods.

In addition, obeying the law of our Climate Change Act requires that we stop doing anything that causes emissions regardless of its energy source. This requires that we stop eating beef and lamb - ruminants who release methane as they digest grass - and already many people have started to switch to more vegetarian diets. However the most difficult problem is cement: making cement releases emissions regardless of how it's powered, there are currently no alternative options available at scale, and we don't know how to install new renewables or make new energy efficient buildings without it.

We need to discuss these challenges as a society. Making progress on climate change requires that the three key groups of players - government, businesses and individuals - work together, rather than waiting for the other two to act first. But until we face up to the fact that breakthrough technologies won't arrive fast enough, we can't even begin having the right discussion.

Committing to zero emissions creates tremendous opportunities: there will be huge growth in the use and conversion of electricity for travel, warmth and in industry; growth in new zero emissions diets; growth in materials production, manufacturing and construction compatible with zero emissions; growth in leisure and domestic travel; growth in businesses that help us to use energy efficiently and to conserve the value in materials.

Bringing about this change, and exploring the opportunities it creates requires three things to happen together: as individuals we need to be part of the process, exploring the changes in lifestyle we prefer in order to make zero emission a reality. Protest is no longer enough - we must together discuss the way we want the solution to develop; the government needs to treat this as a delivery challenge - just like we did with the London Olympics, on-time and on-budget; the emitting businesses that must close cannot be allowed to delay action, but meanwhile the authors of this report are funded by the government to work across industry to support the transition to growth compatible with zero emissions.

Breakthrough technologies will be important in the future but we cannot depend on them to reach our zero emissions target in 2050. Instead this report sets an agenda for a long-overdue public conversation across the whole of UK society about how we really want to achieve Absolute Zero within thirty years.

Key messages for industrial sectors

Key Message: Absolute Zero creates a driver for tremendous growth in industries related to electrification, from material supply, through generation and storage to end-use. The fossil fuel, cement, shipping and aviation industries face rapid contraction, while construction and many manufacturing sectors can continue at today's scales, with appropriate transformations.

Leisure, sports, creative arts and voluntary work: These sectors can expand greatly and should have a central position in national definitions of welfare targets.

Electricity sector and infrastructure: Absolute Zero requires a 3x expansion in non-emitting electricity generation, storage, distribution and load-balancing.

Construction sector: All new builds should be to zero-energy standards of use. The impacts of construction are primarily about the use of materials: primarily steel and cement. By 2050, we will have only very limited cementitious material and will use only recycled steel, but there are myriad opportunities for radical reductions in the amount of material used in each construction.

Steel sector: All exsiting forms of blast furnace production, which are already under great pressure due to global over-capacity, are not compatible with zero-emissions. However, recycling powered by renewables, has tremedous opportunities for growth exploiting the fact that steel scrap supply will treble in the next 30 years. There are short term innovation opportunities related to delivering the highest quality of steel from recycling, and longer-term opportunities for technologies for zero-carbon steel making from ore that could be deployed after 2050.

Cement sector: All existing forms of cement production are incompatible with zero emissions. However, there are some opportunities for expanded use of clay and urgent need to develop alternative processes and materials. Using microwaves processes to recycle used cement appears promising.

Mining and material supply: Zero emissions will drive a rapid transition in material requirements. Significant reduction in demand for some ores and minerals, particularly those associated with steel and cement, are likely along with a rapid expansion of demand for materials associated with electrification. It seems likely that there will be opportunities for conslidation in the currently diffuse businesses of secondary material collection, processing, inventory and supply.

Rail: The great efficiency of electric rail travel suggests a significant expansion in this area, domestically and internationally, is likely and would see high demand. The most efficient electric trains are aerodynamically efficient, like those designed for the highest speed operation today, but travelling at lower speeds.

Road vehicles: The transition to electric cars is already well under-way, and with increasing demand, costs will presumably fall. We already have targets for phasing out non electric vehicles, but by 2050 will have only 60% of the electricity required to power a fleet equivalent to that in use today. Therefore we will either use 40% fewer cars or they will be 60% the size. Development of auto-grade steels from recycling is a priority, and the need to control recycled metal quality may require changed models of ownership. The rapid expansion of lithium battery production may hit short-term supply constraints and create environmental concerns at end-of-life unless efficient recycling can be developed.

International freight: We currently have no non-emitting freight ships, so there is an urgent need for exploration of means to electrify ship power, and options to transfer to electric rail. This would require an enormous expansion in international rail capacity.

Aviation: There are no options for zero-emissions flight in the time available for action, so the industry faces a rapid contraction. Developments in electric flight may be relevant beyond 2050.

Fossil fuel industries: All coal, gas, and oil-fuel supply from extraction through the supply chain to retail must close within 30 years, although carbon capture and storage may allow some activity later.

Travel and tourism: Without flying, there will be growth in domestic and train-reach tourism and leisure.

Food and agriculture: Beef and lamb phased out by 2050 and replaced by greatly expanded demand for vegetarian food. Electricity supply for food processing and storage will be cut by 50%.

Building maintenance and retrofit: Rapid growth in demand for conversion to electric heat-pump based heating matched to improvements in insulation and air-tightness for building envelopes.

Key messages for individuals

Key Message: The big actions are: travel less distance, travel by train or in small (or full) electric cars and stop flying; use the heating less and electrify the boiler when next upgrading; lobby for construction with half the material for twice as long; stop eating beef and lamb. Each action we take to reduce emissions, at home or at work, creates a positive ripple effect.

As individuals we can all work towards Absolute Zero through our purchasing and our influence. Each positive action we take has a double effect: it reduces emissions directly and it encourages governments and businesses to be bolder in response. Where we cause emissions directly we can have a big effect by purchasing differently. Where they are released by organisations rather than individuals, we can lobby for change.

The actions stated as absolutes below are those which will be illegal in 2050 due to the Climate Change Act.

Living well

The activities we most enjoy, according to the UK's comprehensive time-use survey, are sports, social-life, eating, hobbies, games, computing, reading, tv, music, radio, volunteering (and sleeping!) We can all do more of these without any impact on emissions.

Travelling

The impact of our travelling depends on how far we travel and how we do it. The most efficient way to travel is with a large number of people travelling in a vehicle with a small front, and we can all reduce our total annual mileage.

1. Stop using aeroplanes
2. Take the train not the car when possible.
3. Use all the seats in the car or get a smaller one
4. Choose an electric car next time, if possible, which will become easier as prices fall and charging infrastructure expands.
5. Lobby for more trains, no new roads, airport closure and more renewable electricity.

Heating and appliances:

Our energy bills are mainly driven by our heating and hot water.

1. Use the boiler for less time, if possible, staying warm by only heating rooms if people are sitting in them, sealing up air gaps and adding insulation.
2. Wear warmer clothes in winter.
3. Next time you replace the boiler, choose an electric air or ground-source heat pump if possible
4. Buy smaller more efficient appliances that last longer
5. Lobby for zero-carbon building standards, means-tested support for housing retrofit and more renewable electricity

Purchasing:

Most industrial emissions relate to producing materials, which are made efficiently but used wastefully so we need to reduce the weight of material made. The highest volumes of material are used not by households, but to make commercial and public buildings and infrastructure, industrial equipment and vehicles.

1. Lobby businesses and the government to make buildings and infrastructure with half the material guaranteed to last for twice as long.
2. When extending or modifying your home, try to choose recycled or re-used materials and avoid cement.
3. Aim to reduce the total weight of material you purchase each year.
4. Lobby for border controls on emissions in materials (like we have with food standards) to allow businesses fit for Absolute Zero to grow and prosper in the UK

Eating:

Small changes in diet can have a big effect.

1. Reduce consumption of beef and lamb as these have far higher emissions than any other common food.
2. Choose more locally sourced food if possible, to reduce food miles, particularly aiming to cut out air-freighted foods.
3. Aim to use less frozen and processed meals as these dominate the energy use of food manufacturers.
4. Lobby supermarkets to support farmers in using less fertiliser - it has a high impact, but much of it is wasted as it's spread too far away from the plants.

Why this report matters

Key Message: We are legally committed to reducing the UK's emissions to zero by 2050, and there isn't time to do this by deploying technologies that don't yet operate at scale. We need a public discussion about the changes required and how to convert them into a great Industrial Strategy.

Timelines:

In her last significant act as Prime Minister, Theresa May changed the UK's Climate Change Act to commit us to eliminating all greenhouse gas emissions in the UK by 2050. This decision is based on good climate-science, was a response to a great wave of social protest and has been replicated in 60 other countries already.

However, 30 years is a short time for such a big change. Politicians in the UK and internationally talk about climate change as if it can be solved by new energy technologies alone, and UK government reports are over-confident about how much progress has been achieved; in reality most UK cuts in emissions have been as a result of Mrs Thatcher's decision to switch from coal to gas fired electricity and to allow UK heavy industry to close. The UK has been successul in reducing methane emissions - by separating our organic waste and using it in anaerobic digesters to make gas for energy, but new energy technologies are developing slowly.

There are no invisible solutions to climate change so we urgently need to engage everyone in the process of delivering the changes that will lead to zero emissions.

Confusion about technologies

In this report we're using three different descriptions of the technologies which cause emissions:

- Today's technologies are the mass-market products of today - such as typical petrol or diesel cars.
- Incremental technologies could be delivered today if customers asked for them - for example smaller cars.
- Breakthrough technologies such as cars powered by hydrogen fuel cells, may already exist, but haven't yet captured even 5% of the world market.

Incremental technologies can be deployed rapidly, but breakthrough technologies can't. We're concerned that most plans for dealing with climate change depend on breakthrough technologies - so won't deliver in time.

Why we've written this report now

The authors of this report are funded by the UK government to support businesses and governments (national and regional) to develop a future Industrial Strategy that's compatible with Zero Emissions. To do that, we have to anticipate how we'll make future goods and buildings, and also think about what performance we want from them.

What we mean by "Absolute Zero"

The UK's Climate Change Act contains two "escape" words: it discusses "net" emissions and targets on those that occur on our "territory." However, in reality, apart from planting more trees, we don't have any short-term options to remove emissions from the atmosphere, and even a massive expansion in forestry would have only a small effect compared to today's emissions. Furthermore, shutting factories in the UK doesn't make any change to global emissions, and may make them worse if we import goods from countries with less efficient processes.

Public concern about the Climate is too well informed to be side-lined by political trickery on definitions. In writing this report, we have therefore assumed that:

- the target of zero emissions is absolute - there are no negative emissions options or meaningful "carbon offsets." Absolute Zero means zero emissions;
- the UK is responsible for all emissions caused by its purchasing, including imported goods, international flights and shipping.

Invitation to participate

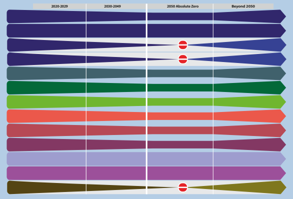
This report presents our best estimate of Absolute Zero, based on publicly reported data and peer-reviewed evidence. Undoubtedly there are more opportunities that we don't know of, and if this report proves useful, there will be other aspects of the journey to Absolute Zero that we can help to inform. We welcome contributions and comment and will provide an edited summary of any discussion on www.ukfires.org. If there is demand, we will update and re-issue the report in response.

Please contact us via info@ukfires.org and if you found this report useful, please share it through your networks.

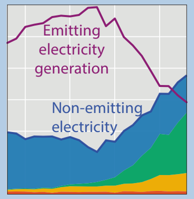
Guide to the report

Opening material

What actions can we take - as individuals and in the key sectors to reduce emissions now and to develop future choices to deliver Absolute Zero?



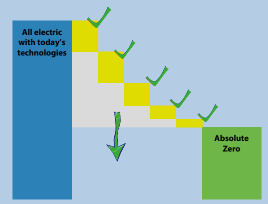
1. Absolute Zero with today's technologies



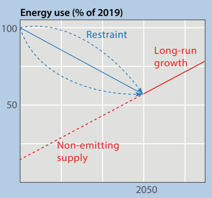
The UK Climate Change Act commits us to zero emissions in 30 years time - based on good climate science. The lowest risk way to get there is to change the way we use today's technologies.

2. Options for incremental and breakthrough innovations

The goods we buy will of course change over the next 30 years, but it takes decades for breakthrough technologies to reach full scale, so we focus on likely incremental innovations.



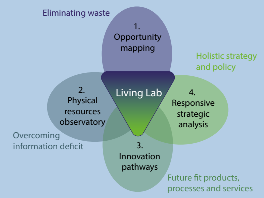
3. The process of change towards Absolute Zero



Reaching Absolute Zero requires a collaboration between individuals, government and businesses. None of them can act unilaterally, so reaching the target will be a process.

4. Opportunities created by Absolute Zero

One of the benefits of considering Absolute Zero is that it allows us to recognise how many opportunities are created by pursuing the strict emissions target.



Notes to the figures

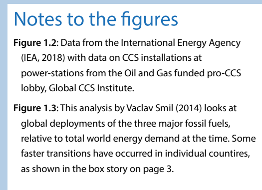

Notes to the figures

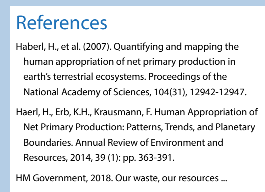
Figure 1.2: Data from the International Energy Agency (IEA, 2018) with data on CCS installations at power-stations from the Oil and Gas funded pro-CCS lobby, Global CCS Institute.

Figure 1.3: This analysis by Vaclav Smil (2014) looks at global deployments of the three major fossil fuels, relative to total world energy demand at the time. Some faster transitions have occurred in individual countries, as shown in the box story on page 3.

We've tried to make this report as easy to read as possible, but all our analysis is firmly rooted in data. These notes show how we've sourced and used the evidence

References

These references point to the sources we used for data or other evidence.


References

Haberl, H., et al. (2007). Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. Proceedings of the National Academy of Sciences, 104(31), 12942-12947.

Haerl, H., Erb, K.H., Krausmann, F. Human Appropriation of Net Primary Production: Patterns, Trends, and Planetary Boundaries. Annual Review of Environment and Resources, 2014, 39 (1): pp. 363-391.

HM Government, 2018. Our waste, our resources ...

	2020-2029	2030-2049	2050 Absolute Zero	Beyond 2050
Road vehicles	Development of petrol/diesel engines ends; Any new vehicle introduced from now on must be compatible with Absolute Zero	All new vehicles electric, average size of cars reduces to ~1000kg.	Road use at 60% of 2020 levels - through reducing distance travelled or reducing vehicle weight	New options for energy storage linked to expanding non-emitting electricity may allow demand growth
Rail	Growth in domenstic and international rail as substitute for flights and low-occupancy car travel	Further growth with expanded network and all electric trains; rail becomes dominant mode for freight as shipping declines	Electric trains the preferred mode of travel for people and freight over all significant distances,	Train speeds increase with increasing availability of zero emissions electricity
Flying	All airports except Heathrow, Glasgow and Belfast close with transfers by rail	All remaining airports close		Electric planes may fly with synthetic fuel once there are excess non-emitting electricity supplies
Shipping	There are currently no freight ships operating without emissions, so shipping must contract	All shipping declines to zero.		Some naval ships operate with onboard nuclear power and new storage options may allow electric power
Heating	Electric heat pumps replace gas boilers. and building retrofits (air tightness, insulation and external shading) expand rapidly	Programme to provide all interior heat with heat pumps and energy retroifts for all buildings	Heating powered on for 60% of today's use.	Option to increase use of heating and cooling as supply of non-emitting electricity expands
Appliances	Gas cookers phased out rapidly in favour of electric hobs and ovens. Fridges, freezers and washing machines become smaller.	Electrification of all appliances and reduction in size to cut power requirement.	All appliances meet stringent efficiency standards, to use 60% of today's energy.	Use , number and size of appliances may increase with increasing zero-emnis-sions electricity supply
Food	National consumption of beef and lamb drops by 50%, along with reduction in frozen ready meals and air-freighted food imports	Beef and lamb phased out, along with all imports not transported by train; fertiliser use greatly reduced	Total energy required to cook or transport food reduced to 60%.	Energy available for fertilising, transporting and cooking increases with zero-emissions electricity
Mining material sourcing	Reduced demand for iron ore and limestone as blast furnace iron and cement reduces. Increased demand for materials for electrification	Iron ore and Limestone phased out while metal scrap supply chain expands greatly and develops with very high precision sorting	Demand for scrap steel and ores for electrification much higher, no iron ore or limestone.	Demand for iron ore and limestone may develop again if CCS applied to cement and iron production
Materials production	Steel recycling grows while cement and blast furnace iron reduce; some plastics with process emissions reduce.	Cement and new steel phased out along with emitting plastics . Steel recycling grows. Aluminium, paper reduced with energy supply.	All materials production electric with total 60% power availability compared to 2020	Material production may expand with electricity and CCS, CCU, hydrogen may enable new cement and steel.
Construction	Reduced cement supply compensated by improved material efficiency, new steel replaced by recycled steel	All conventional mortar and concrete phased out, all steel recycled. Focus on retrofit and adaption of existing buildings.	Any cement must be produced in closed-loop, new builds highly optimised for material saving.	Growth in cement replacements to allow more architectural freedom; new steel may become available.
Manufacturing	Material efficiency becomes promiment as material supply contracts	Most goods made with 50% as much material, many now used for twice as long	Manufacturing inputs reduced by 50% compen-sated by new designs and manufacturing practices. No necessary reduction output.	Restoration of reduced material supplies allows expansion in output, although some goods will in future be smaller and used for longer than previously.
Electricity	Wind and solar supplies grow as rapidly as possible, with associated storage and distribution. Rapid expansion in electrificiation of end-uses.	Four-fold increase in renewable generation from 2020, all non-electrical motors and heaters phased out.	All energy supply is now non-emitting electricity.	Demand for non-emitting electricity drives ongoing expansion in supply.
Fossil fuels	Rapid reduction in supply and use of all fossil fuels, except for oil for plastic production	Fossil fuels completed phased out		Development of Carbon Capture and Storage (CCS) may allow resumption of use of gas and coal for electricity

1. Zero emissions in 2050 with today's technologies

Key Message: Apart from flying and shipping, all of our current uses of energy could be electrified. With tremendous commitment the UK could generate enough non-emitting electricity to deliver about 60% of our current final energy-demand, but we could make better use of that through incremental changes in the technologies that convert energy into transport, heating and products.

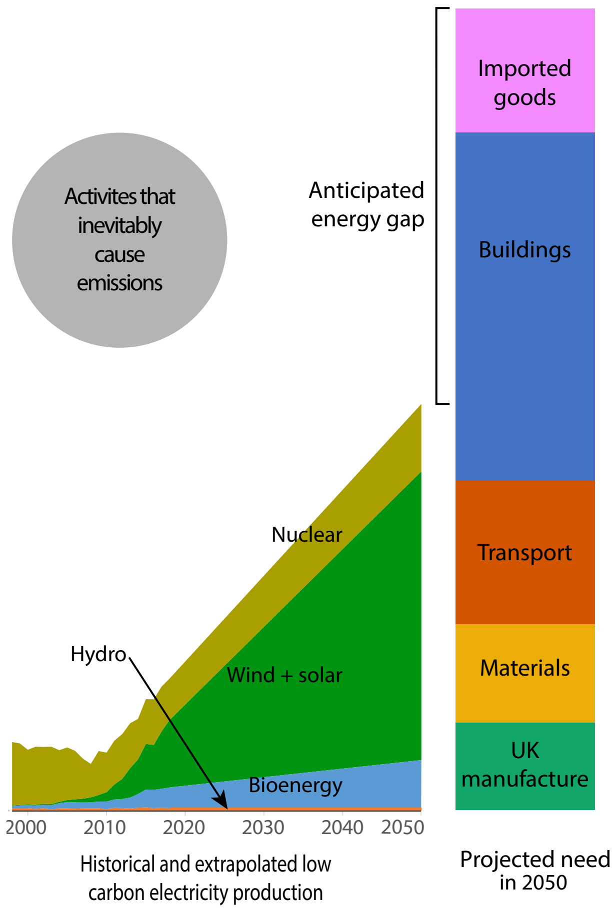
About three quarters of the greenhouse gas emissions caused by humans are emitted when we burn the fossil fuels - coal, gas and oil - and the rest arise from our agriculture (particularly cows and sheep), our conversion of land from forestry to pasture, the way we allow organic waste to decompose, and our industrial processes. Using today's technologies, all of these sources unrelated to energy have no alternative, so reducing our emissions to zero means phasing out these activities.

Our emissions related to energy come from our use of oil (as diesel, petrol or kerosene) for transport, our use of gas for heating our homes and industrial processes, and our use of coal and gas to generate electricity. Some of our electricity is also generated without burning fossil fuels - for instance by nuclear power stations, wind turbines or solar cells - and in a zero emissions future these will be our only source of energy. Most of our current uses of energy could be electrified - as is becoming familiar with electric cars - but there are currently no options for electric flying or shipping. With today's technologies, these modes of transport must therefore be phased out also.

Over the past 10 years in the UK, we have made a significant change to the way we generate electricity and about half of our generation is now from non-emitting sources. If we continue developing the generation system at the same rate, then by 2050 we will have around 50% more electric power than we have today. Data on the efficiencies of today's motors and heaters allows us to estimate that this will be enough to power about 60% of today's energy-using activities (apart from flying and shipping). However, because energy has been so cheap and abundant in the past 100 years, in many cases we could make small changes to existing technologies to make much better use of less energy.

Fig. 1.1 summarises this overview of Absolute Zero with today's technologies: the left side of the figure shows the recent history of the UK's non-emitting electricity generaton extrapolated forwards to 2050. The right side shows the amount of electricity we'd need if we electrified everything we do today, apart from those activities that inevitably cause emissions, which we'll have to phase out.

Figure 1.1: Gap between today and Absolute Zero



1.1 Energy Supply Today

The science is clear: we must stop adding to the stock of greenhouse gases in the atmosphere to control global warming. In response, the best estimates of science today predict that annual global emissions from human activities must be reduced rapidly and should be eliminated by 2050 – in thirty years' time. This target, which requires extraordinarily rapid change, is now law in the UK, and several other countries. However, despite the science and the laws, global emissions are still rising.

The critical choice in planning to cut emissions is about the balance between technology innovation and social choice. Is it possible to develop a new technology that will cut emissions while allowing people in developed economies to continue to live as we do today and to allow developing economies to develop the same behaviours? Or should we first modify our behaviour to reach the emissions target, with different aspirations for development, and then take the benefits of technology innovation when they become available later? To date, as illustrated in Fig. 1.2, every national and international every national and international government plan for responding to climate change has chosen to prioritise technology innovation, yet global emissions are still rising.

For twenty years, two technologies have dominated policy discussions about mitigating climate change: renewable energy generation and carbon capture and storage (CCS). The two renewable technologies now being deployed widely are wind-turbines and solar-cells. These critical forms of electricity generation are essential, and should be deployed as fast as possible, but Fig. 1.3 shows that, they combined with nuclear power and hydro-electricity, still contribute only a small fraction of total global energy demand. Meanwhile, although CCS has been used to increase rates of oil extraction, its total contribution to reducing global emissions is too small to be seen. The technological elements of CCS have all been proven at some scale, but until a first fleet of full-scale power-plants are operating, the risks and costs of further expansion will remain high and uncertain. To illustrate the current importance of CCS in global power generation, the total output of all CCS enabled power-generation is shown on Fig. 1.3 - still very definitely on top of the y-axis.

Figure 1.2: Acting now or waiting for new technologies

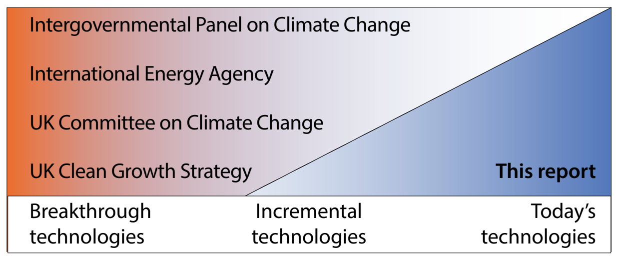
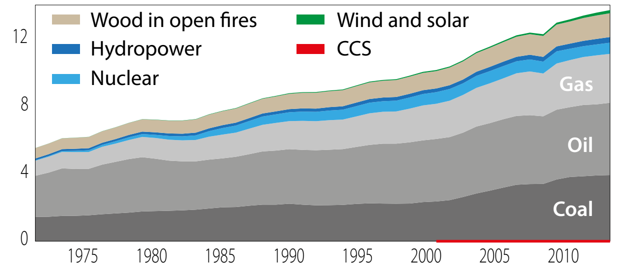


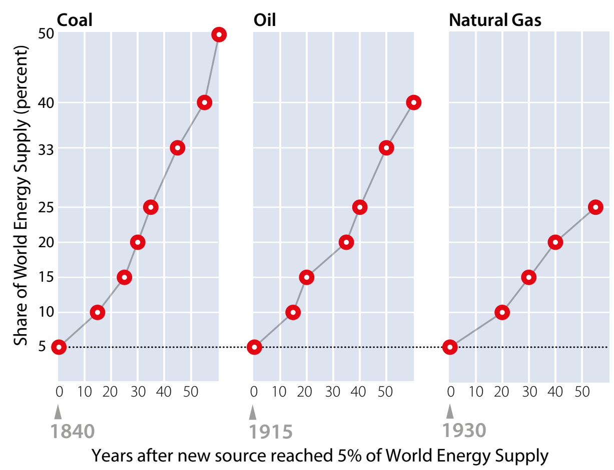
Figure 1.3: World primary energy supply ('000 Mtoe)



All previous transitions in the energy system, for example in Fig. 1.4, have occurred relatively slowly. Early installations experience problems due to human error, and the installation of large generation requires lengthy public consultation on land-rights, environmental protection, safety and financing. Despite this, CCS looks very attractive to policy makers. Twenty years ago, the International Energy Agency stated that "within 10 years we need 10 demonstrators of CCS power stations" but none are operating at full-scale today. Yet in 2019 the UK's Climate Change Committee published its plans to deliver zero emissions, requiring deployment of CCS in six of thirteen sectors within thirty years. However, the UK has no current plans for even a first installation and although CCS may be important in future, it is not yet operating at meaningful scale, but meanwhile global emissions are still rising.

The hope of an invisible, technology-led, solution to climate change is obviously attractive to politicians and incumbent businesses. However, a result of their focus on this approach has been to inhibit examination of our patterns of energy demand. Fig. 1.6a shows that the UK's demand for energy is only falling in industry. This is because in the absence of a meaningful industrial strategy, we have closed our own industry in favour of increased imports. As a result, this apparent reduction in energy

Figure 1.4: Major transitions in global energy supply



Technology Transitions in the Energy System

New computers, clothes and magazines can be put on sale soon after the are invented. However new energy technologies have typically required much longer time to reach full scale: even if the technology is well-established, building a power station requires public consultation about finance, safety, land-rights, connectivity and other environmental impacts all of which take time. For new technologies, it takes much longer, as investors, operators and regulators all need to build confidence in the safety and perfomance of the system. Figure 1.5 summarises the rates of introduction of various new energy technologies in the countries where they grew most rapidly. The green arrow corresponds to the start points of the linear periods of growth shown in Fig. 1.4.

Figure 1.5: Years to deploy energy technologies

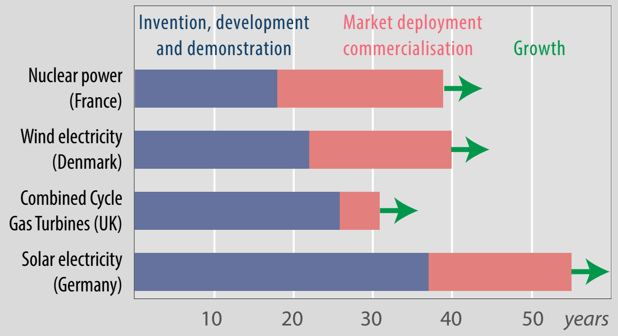
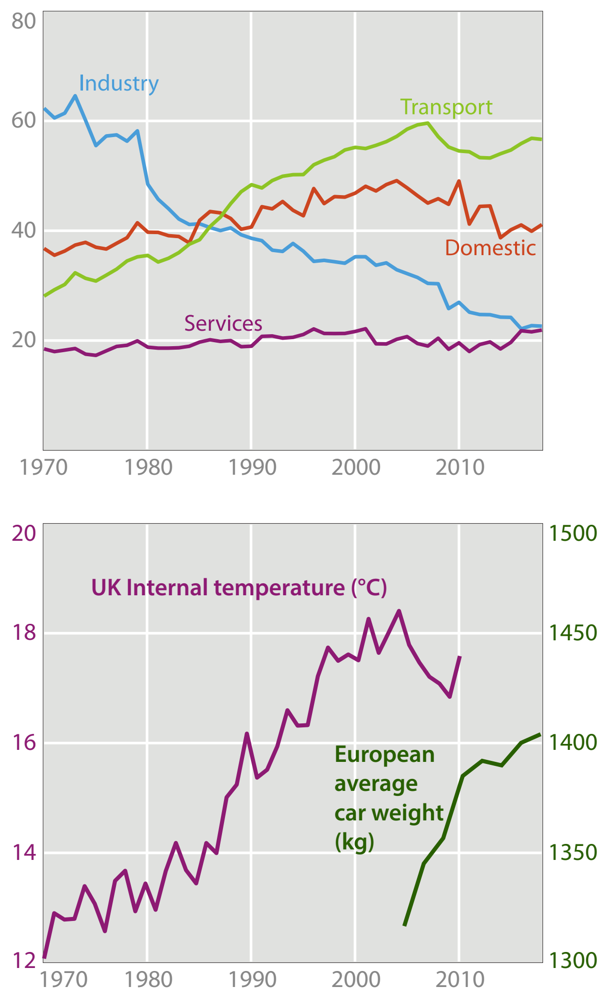


Figure 1.6: Energy demand (a) by sector (Mtoe) influenced by (b) car weight & internal temperature



use is compensated by an increase in other countries. Meanwhile, demand in other sectors is rising, driven, for example, by an increase in the weight of our cars and increased use of heating to raise internal temperatures in winter (Fig. 1.6b). With thirty years remaining to deliver zero emissions and global emissions still rising, we cannot risk waiting for a different energy system, so must have an inclusive public discussion about how we use energy.

2019 has seen a great rise in public concern about climate change, driven by science and growing evidence of changes occurring. So far, social protesters have called for dramatically increased awareness, while engaging in discussion about specific solutions has had less emphasis. However the only solutions available in the time remaining require some change of lifestyle. This report therefore aims to trigger that critical discussion. The report starts with a plan to reach zero emissions by 2050 using only technologies that are already mature today, to minimise the risk that we continue emitting beyond 2050. This is possible but requires some specific restraint in our lifestyles. Innovation can relieve this restraint so the report then presents an overview of the range of options for innovation in the way we use energy as well as how we generate it.

Global emissions are still rising and the need for action is urgent. This report aims to allow us to start an informed discussion about the options that really will deliver zero emissions by 2050.

Key Message: Global demand for energy is rising. In the UK our demand has fallen, but only because we have closed industry and now import goods elsewhere. Policy discussions have prioritised breakthrough technologies in the energy system, particularly carbon capture and storage, but it is at such an early stage of development that it won't reduce emissions significantly by 2050.

1.2 UK Energy System now and in 2050

Climate change is driven by greenhouse gas **E**missions. Most emissions arise from burning fossil fuels to create **E**nergy; some of our energy use is in the form of **E**lectricity. These three words beginning with "E" are often confused in public dialogue, but Fig. 1.7 separates them. Three quarters of global emissions (slightly more in the UK because we import 50% of our food) arise from the combustion of fossil-fuels (coal, gas and oil). Most coal and one third of gas is used in power stations to generate electricity. However, we also generate electricity by nuclear power and from renewable sources. The third column of the figure shows that nearly a half of the UK's current electricity supply is from non-emitting sources, of which nuclear power and the use of imported bio-energy pellets are most important.

Fig. 1.8 shows how the UK's energy supply has developed over the past twenty years. Total demand has fallen, due to the loss of industry shown in Fig. 1.6, but our use of oil and nuclear power has been relatively constant. (The data in both figures disguise the fact that over this period the UK's population has grown by 16% so we have improved the efficiency of our energy use by around 0.5% per year.) The other major change in the figure is the switch from coal to gas powered electricity generation which has reduced UK emissions significantly.

Fig. 1.9 extracts from Fig. 1.8 our generation of electricity – the numbers in this figure for 2018 correspond to those shown in Fig 1.7c – and divides them into emitting and non-emitting sources. This figure shows the UK making good progress in de-carbonising its current levels of electricity supply, and if the linear-trends in the figure continue, then

Figure 1.7: Emissions, Energy and Electricity in the UK

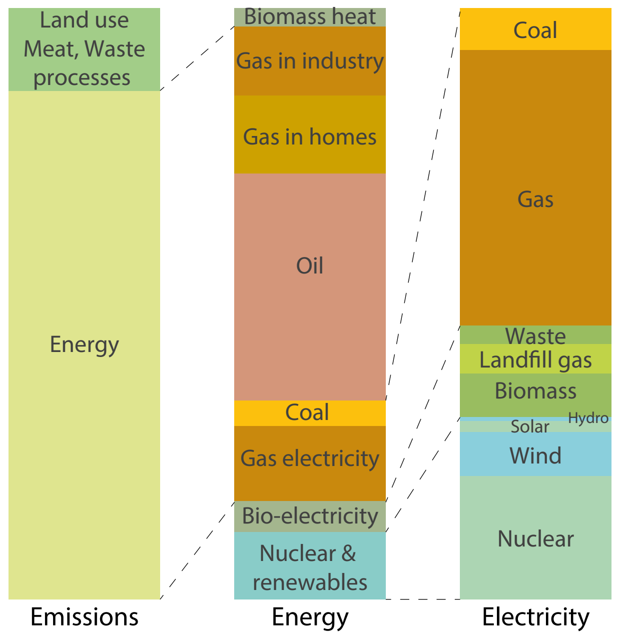
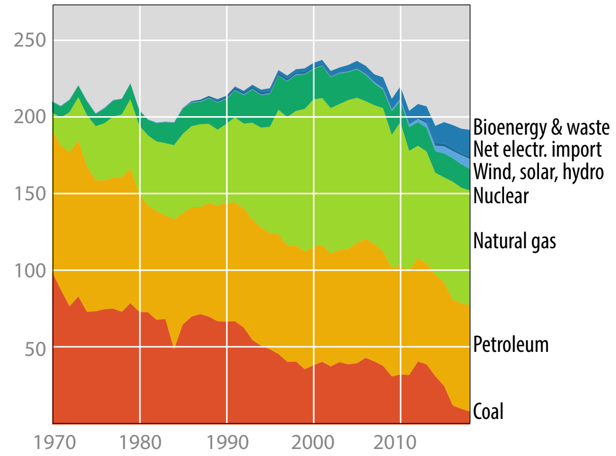


Figure 1.8: UK Primary Energy supply (Mtoe/yr)



by 2050, the UK can be expected to generate around 580 TWh of electricity without emissions. This is the figure shown on Fig 1.1 at the beginning of this chapter.

If we can manage our electricity distribution system and find ways to store electricity from windy/sunny times to be available at still/dull times this suggests that by 2050 we will have around 60% more electricity available than today, all from non-emitting sources. Physically, although the Hinckley C Nuclear Plant will probably by completed by 2030, delivering this increase will largely come from increasing wind-generation. To meet this growth from offshore wind would require an addition of around 4.5 GW of generation capacity each year of the next 2 decades (allowing time for them to be fully operational by 2050). By comparison, the Crown Estate have just launched a process to award 7-8.5 GW of new seabed leases over the next 2 years, but the Offshore Wind Sector Deal expects Government support for the delivery of only 2 GW/year through the 2020s.

Figure 1.9: UK Electricity generation (TWh/year)

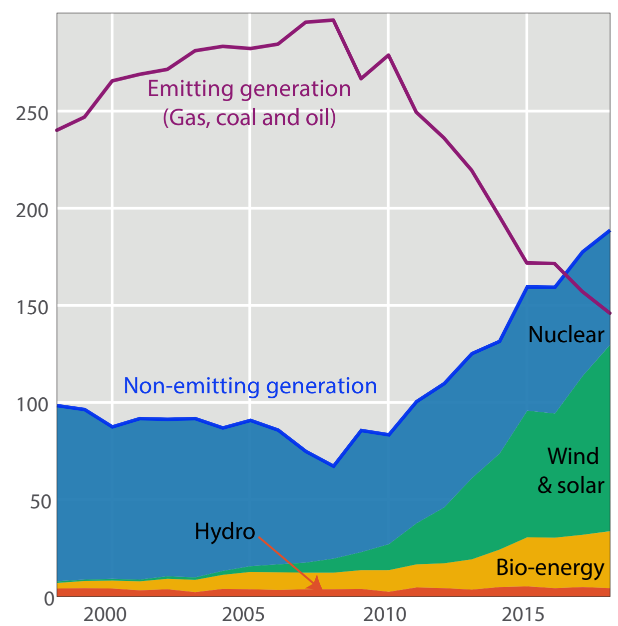
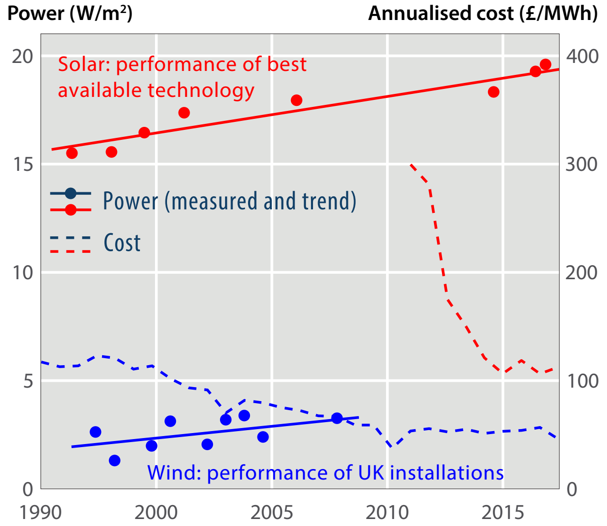


Figure 1.10: Development of wind and solar power



Meanwhile Fig 1.10 shows how the two options for on-shore generation, wind-turbines and solar power, are developing. Both technologies are becoming cheaper, although the amount of power generated from each unit of land is increasing only slowly. Replacing existing on-shore wind turbines with much taller models could increase total generation by 50%. Increasing solar generation depends on the commitment of area, but is plausible: if every south-facing roof in the UK were entirely covered in high-grade solar cells, this would contribute around 80TWh per year

Fig. 1.7 also shows a range of bio-energy sources contributing to the UK's energy supply. All these supplies are combusted, leading to the release of CO_2, but because the fuel derives from plants, these releases form part of the normal cycle so do not accelerate climate change. Waste policy has been a success in UK mitigation since 1990, with organic waste separated and largely processed in anaerobic digestors to produce methane for electricity. However, this source is unlikely to increase further. Meanwhile, bio-energy derived directly from new plant growth is in competition with the use of biomass for food so unlikely to increase (see box story on p13).

This discussion suggests that, using today's technologies and with plausible rates of expansion, the UK will in a zero-emissions 2050 have an energy supply entirely comprising electricity with about 60% more than generated than we have today.

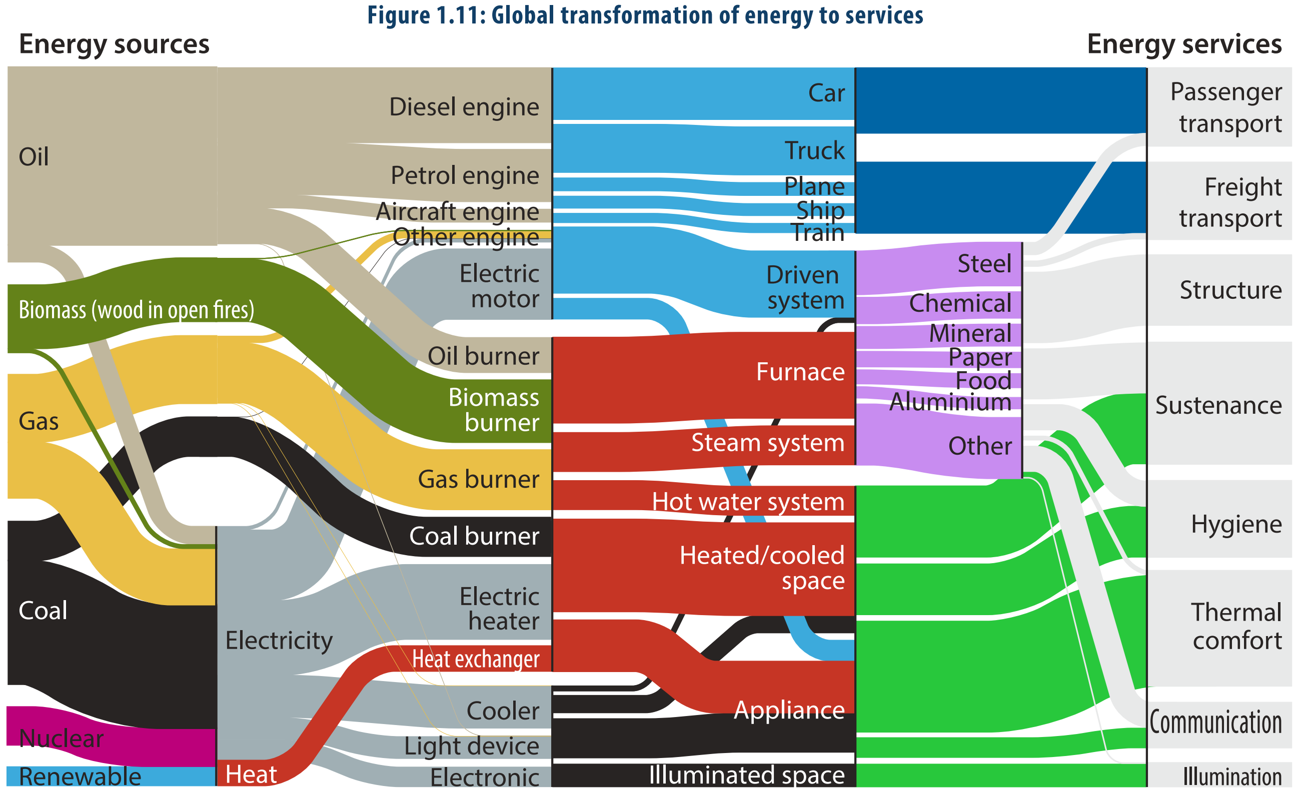
How much of the benefit of all of today's use of energy will we be able to enjoy without any fossil fuels, but with 60% more electricity? At first sight, this sounds like a significant reduction - Fig. 1.7 showed that today, electricity provides only about one third of our total energy needs, so apparently we would need a 200% increase in electricity output? In fact this isn't the case, because the final conversion of electricity into heat or rotation is very efficient compared to the fossil fuel equivalents.

If the UK is to run entirely on electricity, then all devices currently powered with fossil-fuels must be replaced by electrical equivalents. Fig. 1.11 presents a view of how energy is used globally. (We don't currently have an equivalent of this for the UK, but the UK is likely to be similar, although with less industrial use, due to our dependence on imports.) The widths of the lines in the figure are proportional to energy use, and any vertical cut through the diagram could be converted into a pie-chart of all the world's energy use. In effect Fig. 1.11 shows six connected pie-charts, each breaking out the statistics of all the world's energy use into different categories.

The figure shows that most energy is used in engines, motors, burners and heaters to create motion or heat. To estimate the electricity required if all of these devices are replaced, we use the average efficiencies presented in Fig. 1.13: for example, we know how much power is currently delivered in the UK's cars by petrol engines, so can use Fig. 1.13 to predict how much electricity would be required to provide the same power from electric motors. Combining this conversion with an estimated 11% population growth, leads to our prediction that we would need 960 TWh of electricity by 2050. (A terawatt hour, Twh, is a thousand million kilowatt hours - the unit normally used in UK energy bills.) The final requirement for electricity is split between motion, heating and appliances as shown in Fig 1.14.

If the UK is fully electrified by 2050, and we used the same final services as today, our demand for energy as electricity will be 960 TWh. However, based on a linear projection of the rate at which we have expanded our non-emitting electricity supply in the past 10 years, we estimate that we will have just 580 TWh available. Therefore, our commitment to Absolute Zero emissions in 2050 requires a restraint in our use of energy to around 60% of today's levels.

Figure 1.11: Global transformation of energy to services



What's the problem with bio-energy?

The world's poorest people stay warm and cook with wood burnt on open furnaces, and this energy source shows up significantly in the global energy supplies of Fig. 1.11. Could we use modern technology to harness even more biomass to make other fuels, such as biodiesel or kerosene? Fig 1.12 reveals that more than 20% of the world's total annual harvest of new biomass is already 'appropriated' by humans for wood, food and fodder. This annual harvest is the fundamental source of habitat and food for all non-aquatic species. Any further appropriation by humans is likely to be dangerously harmful to other species and the effect of deforestation rates is already a major contributor to the emissions in fig. 2.10. This evidence suggests that modern bio-fuels are incompatible with any wider sustainability of life on earth.

Figure 1.12: Human appropriation of biomass

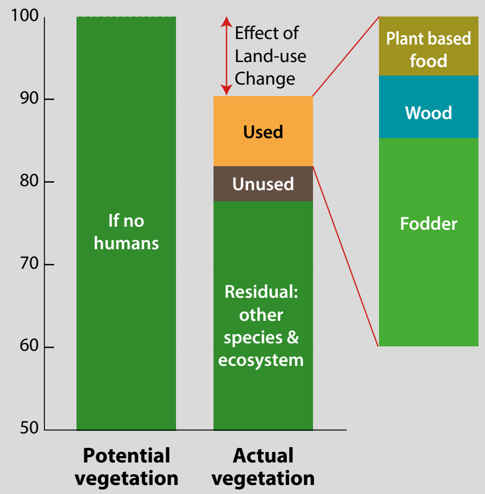


Figure 1.13: Efficiency of enegy conversion devices (%)

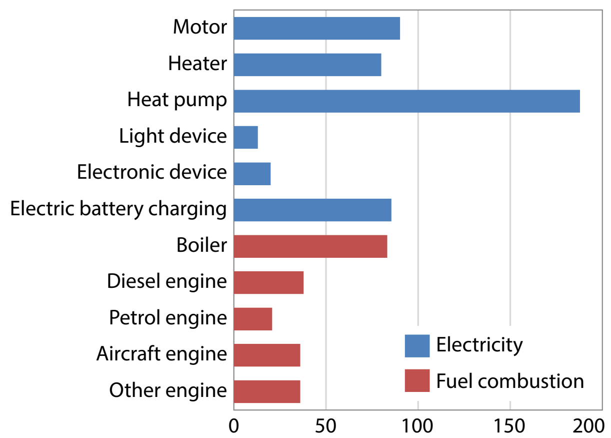
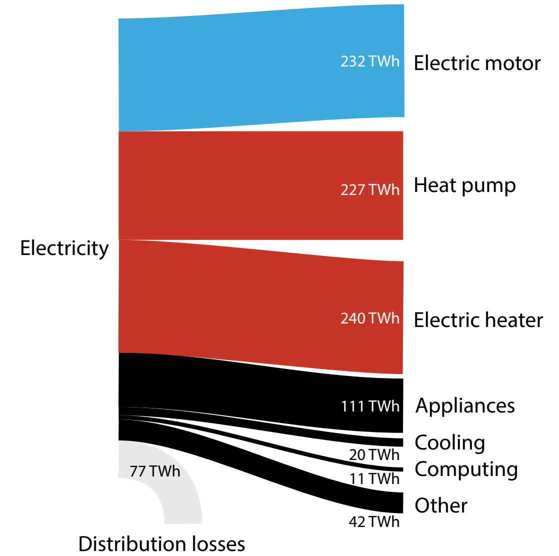


Figure 1.14: UK requirement to electrify today's services



Key Message: If we only used electricity, delivering all the transport, heat and goods we use in the UK would require 3x more electricity than we use today. If we expand renewables as fast as we can, we could deliver about 60% of this requirement with zero emissions in 2050. Therefore in 2050 we must plan to use 40% less energy than we use today, and all of it must be electric.

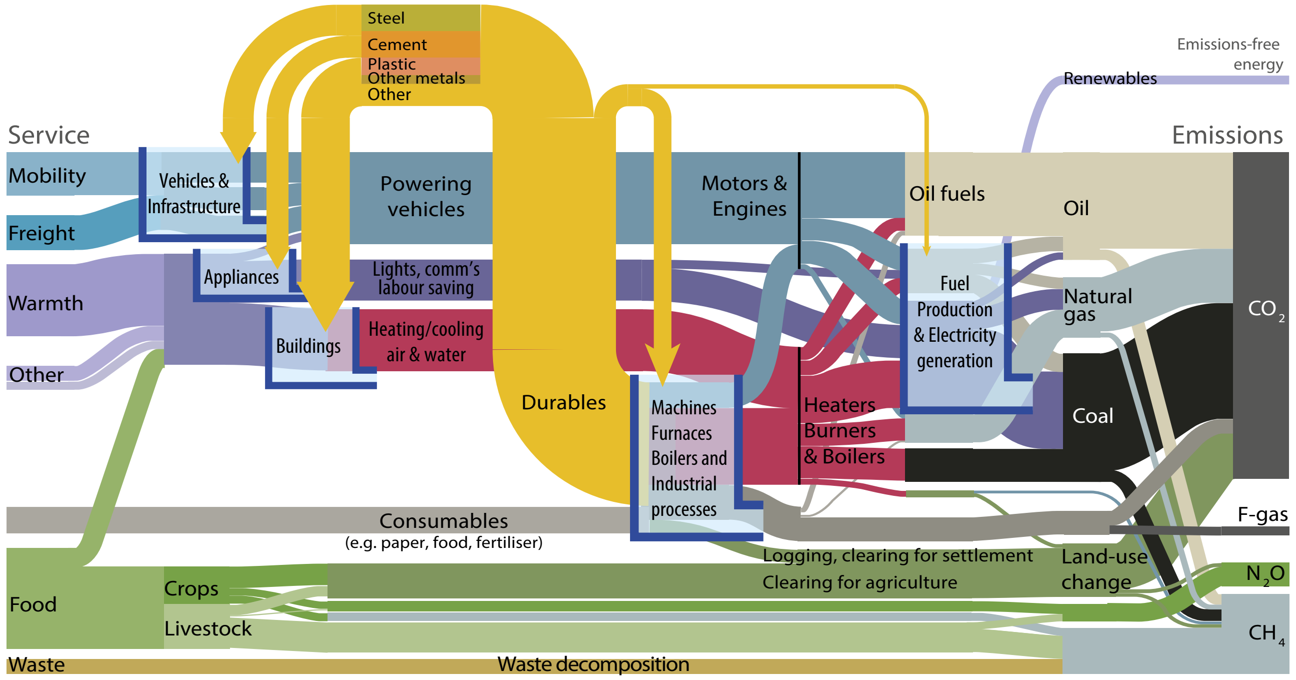
1.3 Zero emissions in the UK in 2050

In addition to restraining our energy demand to 60% of current levels, meeting our legal commitment to zero emissions will require that we phase out any energy using activities that cannot be electrified and any sources of emissions beyond fossil-fuel combustion. Planning for this requires that we make a collective decision about the scope of our responsibility. The UK's Climate Change Act was written to make commitments based solely on emissions that occur on UK territory. However, this excludes international aviation and shipping and our net imports of goods. As a result, it appears to be a success for UK climate policy when we shut UK industry and instead import goods – even though this will not reduce global emissions, and may often increase them if the closed UK processes were more efficient. Although these limitations were helpful in passing the Climate Change Act into law, they now look morally questionable, and they also fail to create the stimulus to innovation and growth in UK businesses and industries fit for a zero emissions future. This report therefore assumes that the UK should be responsible for the emissions of all its consumption.

Fig. 1.15 shows an analysis of all global greenhouse gas emissions, using a format similar to Fig. 1.11. In this case, the final services that drive the activities that cause emissions are shown at the left of the diagram, leading to the greenhouse gases on the right side of the diagram which cause global warming. The yellow-loop in the middle of the figure demonstrates that most industrial emissions are associated with producing the buildings, vehicles and other equipment which provide final services from energy, but which themselves require energy in production. This is important because most of this year's industrial output is to produce equipment (durables) that will last for several years. The services provided in one year therefore depend on the accumulation of a stock of goods made in previous years - and this long-lasting stock limits the rate at which change can be made to our total emissions. For example, if cars last on average for 15 years, then to ensure that all cars are electric in 2050, the last non-electric car must be sold no later than 2034. As with Fig. 1.11, Fig. 1.15 is based on global data - again to reflect the consequences of UK consumption, rather than its "territorial" emissions.

The top three quarters of this figure demonstrate the emissions consequences of our use of energy. The two critical forms of equipment that cannot be electrified with known technology are aeroplanes and ships. Although Solar-Impulse 2, a single-seater solar-powered electric aeroplane circumnavigated the Earth in 2016, it is difficult to scale up solar-powered aeroplanes due to the slow rates of improvement in of solar cell output put unit of area shown in Fig. 1.10. Meanwhile battery-powered flight is inhibited by the high weight of batteries, bio-fuel substitutes for Kerosene face the same competition for land with food as described in section 1.2 and there are no other ready and appropriate technologies for energy storage. As a result, under the constraint of planning for zero emissions with known technologies, all flying must be phased out by 2050 until new forms of energy storage can be created. At present we also have no electric merchant ships. There isn't space to have enough solar cells on a ship to generate enough energy to propel it, and as yet there has been no attempt to build a battery powered container

Figure 1.15: Global Greenhouse Gas Emissions - from service to emissions, with most industrial emissions adding goods to stock



ship. Nuclear powered naval ships operate, but without any experience of their use for freight, we cannot safely assume that nuclear shipping will operate at any scale in 2050. This is a serious challenge: with today's technologies, all ship-based trade must be phased out by 2050.

Fig 1.15 further reveals that the two key sources of non-energy related emissions are in agriculture and industrial processes. Agricultural emissions arise primarily from ruminant animals – in particular cows and sheep – which digest grass in the first of their two stomachs in a process that releases methane and from land-use change. Converting forestry to agricultural land leads to the release of the carbon stored in the forest and the loss of future carbon storage as the trees grow. In addition, ploughing the land releases carbon stored in the soil, and using Nitrogen based fertilisers to stimulate plant growth leads to further emissions. The motivation for this conversion of forestry land is to increase food production, but is greatly exacerbated by the demand for meat eating. Growing grain and other feed for cows, pigs and sheep is exceptionally inefficient, as up to 80 times more grain is required to create the same calories for a meal of meat as for a meal made from the original grain. As a result, our commitment to zero emissions in 2050 requires that we refrain from eating beef and lamb.

Three industrial processes contribute significant emissions beyond those related to energy. Blast furnaces making steel from iron ore and coke release carbon dioxide, and half of the emissions from current cement production come from the chemical reaction as limestone is calcined to become clinker. There are no alternative processes available to deliver these materials, and although old steel can be recycled efficiently in electric arc furnaces, there are no emissions-free alternatives to cement being produced at any scale. As a result, a zero-emissions economy in 2050 will have no cement-based mortar or concrete, and no new steel. The absence of cement is the greatest single challenge in delivering Absolute Zero, as it is currently essential to delivering infrastructure, buildings and new energy technologies.

The final source of direct industrial emissions is the group of "F-gases" which have diverse uses, including as refrigerants, solvents, sealants and in creating foams. It may be possible to continue some of these applications beyond 2050 if the gases are contained during use and at the end of product life.

Delivering Absolute Zero in thirty years with today's technologies is possible. Our energy supply will be 40% less than today, and solely in the form of electricity, but apart from flight and shipping, all other energy applications can be electrified. Socially motivated action is leading some change in both travel and diet. The most challenging restraint is on the bulk materials used in construction, in particular in the absence of cement, which will constrain the deployment of new energy supplies and economic development which depends on building.

However, despite these restraints, the most striking feature of this analysis is how many features of today's lifestyles are unaffected. Many of the leisure and social activities we most enjoy can continue with little change, many forms of work in service sectors will flourish, and the transition required will also lead to substantial opportunities for growth, for example in renewable electricity supply and distribution, in building retrofit, in electric power and heat, in domestic travel, material conservation, plant-based diets and electrified transport. Delivering Absolute Zero within thirty years with today's technologies requires restraint but not despair and of course any innovation that expands service delivery without emissions will relieve the required restraint. That's the theme of the second chapter of this report.

Key Message: In addition to reducing our energy demand, delivering zero emissions with today's technologies requires the phasing out of flying, shipping, lamb and beef, blast-furnace steel and cement. Of these, shipping is currently crucial to our well-being - we import 50% of our food - and we don't know how to build new buildings or install renewables without cement. The need for this restraint will be relieved as innovation is deployed but many of our most valued activities can continue and expand, and Absolute Zero creates opportunities for growth in many areas.

2. Innovations to make more use of less energy

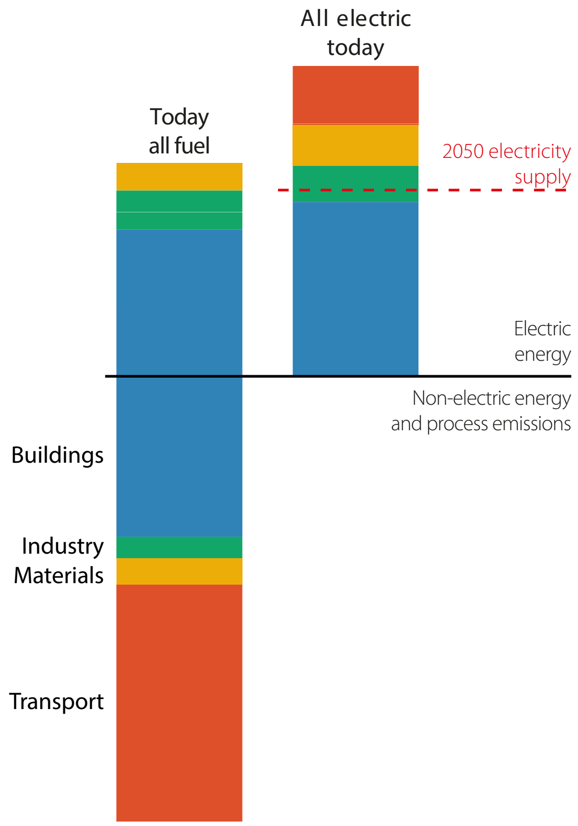
Key Message: With incremental changes to our habits and technologies, there are multiple options for living just as well as we do today, with 60% of the energy. With electric heat pumps and better insulation we can stay just as warm. With smaller electric cars we can keep moving, and by using materials better, we can make buildings and goods compatible with our zero emissions law.

This chapter starts from the analysis of electricification in chapter 1, summarised in Fig. 2.1: below the line, all of today's non-electric uses of energy must be electrified. Any activities that lead to emissions regardless of energy source or that cannot be electrified must be phased out. If we electrify all remaining activities with today's technologies, we require the amount of electricity shown in the second column - but we'll only have 60% of that amount available. For each of the sectors in Fig. 2.1, we therefore look at all the options for a more efficient future.

Section 2.1. focuses on the way we use energy directly - in buildings and vehicles - and on the way we source our food. Sections 2.2-2.4 explore how we make things - firstly looking at how we produce materials, which is what drives most of today's industrial emissions, and then in how we use them in construction and manufacturing. It turns out that we are already very efficient in our use of energy when making materials, but wasteful in the way we use the materials - so there are plenty of options for living well while using half as much material for twice as long.

For completeness, in section 2.5 we survey the "breakthrough technologies" that are unlikely to be significant by 2050, but could expand afterwards.

Figure 2.1: Absolute Zero overview



2.1 Products in-use and consumables

In the UK, the use of final products and consumables accounts for almost three quarters of current annual emissions. 12% of UK emissions come from domestic food production, waste disposal and land use changes, but two thirds are produced by our use of vehicles and buildings. These mostly come from road transport and heating in buildings, but to what extent can innovation help reduce these emissions to zero?

Using energy in buildings

Fig. 2.2 shows that most energy uses in buildings are for heating air (space) and water, mostly by combustion of gas in individual boilers in each building. Absolute Zero emissions requires a complete electrification of energy uses in buildings. Although appliances and lighting are already electric, space and water heating must change.

Heat pumps, based on principles similar to the familiar domestic fridge - but in reverse, offer a viable alternative to gas boilers. Since heat pumps are around four times more efficient than direct heat of combustion, complete deployment of best-practice heat pumps could save approximately 80% of current energy demand for heating. Heat pumps can be used in two forms: as a direct replacement for a gas-boiler they can provide hot water for a conventional radiator system. However, the best use of heat pumps is with ducted air heating - which requires a more intrusive modification of a building, but saves more energy. Deploying heat pumps would almost double the demand for electricity in buildings from current levels, so further interventions to reduce the demand for heating are also important.

New buildings are much more efficient than old Victorian houses still in use today — better insulation and design result in much smaller heating requirements. However, the turnover of the UK's building stock is very slow - we like old buildings - so refurbishment of old houses is important. Already, we have made substantial efforts to retrofit double glazed windows and to install high quality insulation in roofs and attics, and this could be completed to ever higher-standards to reduce national energy demand for heating.

For new build homes, Passive designs which only use the sun for heating, and need electricity only for ventilation, lighting and appliances are now well established. Until 2015, the UK's zero-carbon homes standards promoted this form of design, which is applied rigorously in Sweden, and at current rates of building, would affect 20% of the UK's housing if enforced now. The cost of houses built to the Passive standard is approximately 8-10% more than standard construction, and the thick walls required slightly reduce the available internal space, in return for zero energy bills.

Fig. 2.3 summarises the options for operating buildings under the conditions of Absolute Zero: whatever happens we must electrify all heating. We could then either use the heating for 60% of the time we use it today, or apply other incremental changes in building design to maintain today's comfort with 60% of the energy input.

Figure 2.2: Energy use in buildings

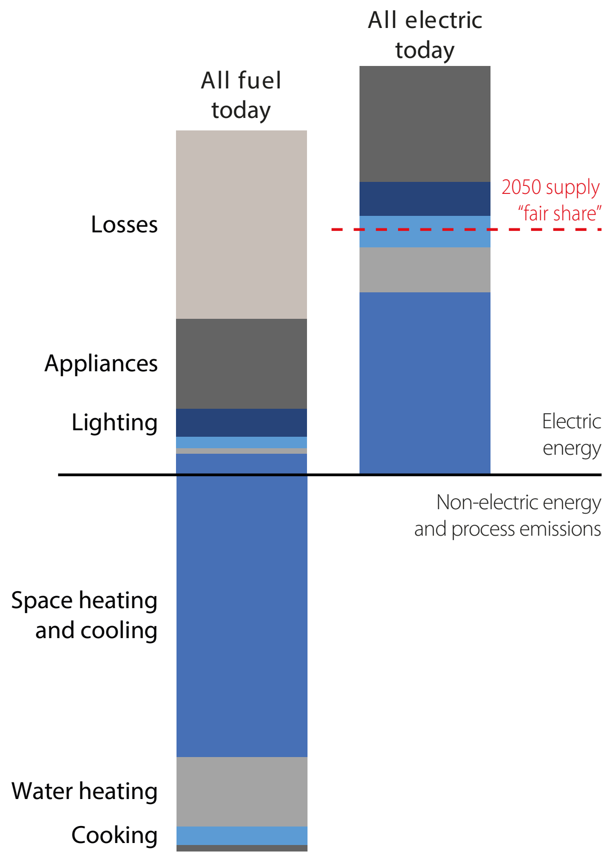
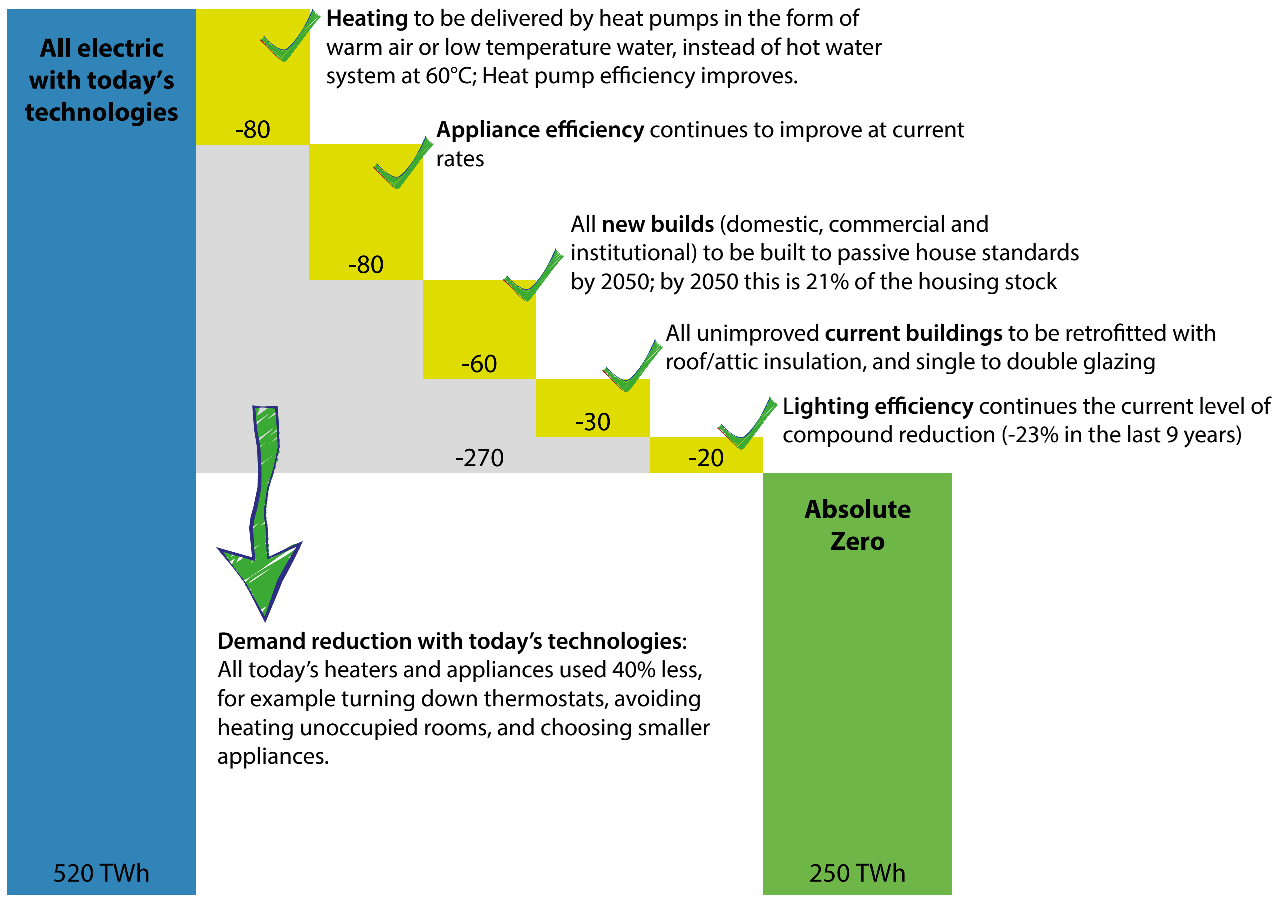


Figure 2.3: Reducing energy use in buildings with incremental technologies or reducing demand with today's technology



Using energy in transport

Fig. 2.4 shows that almost all of today's transport involves the direct combustion of fossil fuels in the vehicle, with only 1% of transport powered by electricity, in electric trains. Without technology options to replace aeroplanes and ships with electric equivalents, the second column of the figure assumes that these modes have been phased out in thirty years, so the electricity available for transport can be divided between rail and road vehicles.

Fig. 2.5 demonstrates the opportunity for energy saving through adjusting the way we travel. The figure shows both the energy and emissions consequences of a person travelling a kilometre by different modes: these two figures are closely correlated except for flight, where the emissions at high altitude cause additional warming effects. The figure underlines how important it is to stop flying - its' the most emitting form of transport and we use planes to travel the longest distances. A typical international plane travels at around 900km/hour, so flying in economy class equates to 180kgCO_{2e} per person per hour (double in business class, quadruple in first class, due to the floor area occupied.) Flying for ~30 hours per year is thus equal to a typical UK citizen's annual emissions.

The key strategies to reduce energy use in transport depend on the form of journey. Short distance travelling involves frequent stops and restarts, so a substantial

Figure 2.4: Energy use in transport

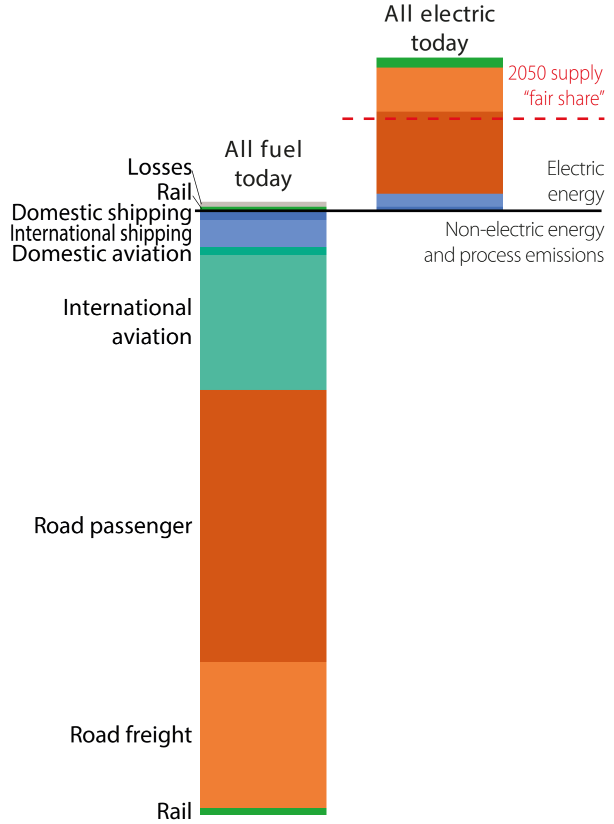
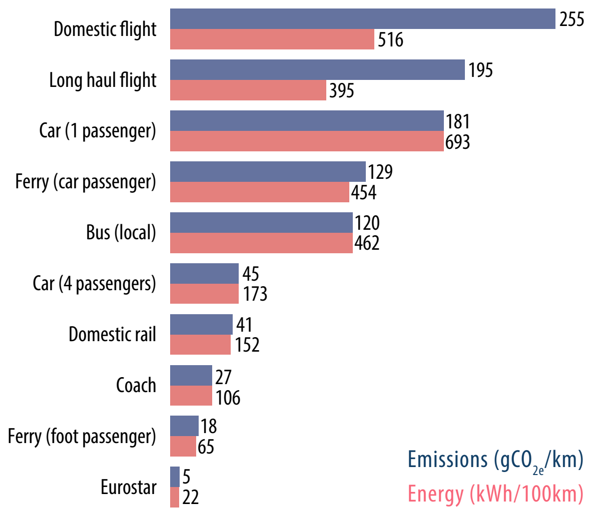


Figure 2.5: "Mode shift" for personal transport



share of energy is used to accelerate a vehicle and its contents. As a result, reducing the weight of the vehicle and travelling less become key strategies to reduce energy demand. At present UK cars are on average used with 1.8 people inside, but weigh around 1,400 kg, which is ~12 times more than the passengers, so almost all petrol is used to move the car not the people. Fig. 2.6 illustrates how reducing the ratio of the weight of the vehicle to the weight of the passengers trades off with distance travelled and energy used. Regenerative braking offers a technological opportunity to recapture some of the energy used in accelerating vehicles, and is under active development.

For long-distance travelling most energy is used to overcome air resistance, so the key to reducing energy demand is to reduce top speeds (aerodynamic forces increase with speed squared) and drag by using long and thin vehicles — trains. Rail transport is thus the most efficient transport mode for long-distance travelling, and if a higher share of trips is made by train rather than car,

Figure 2.6: Car travel - trading weight and distance

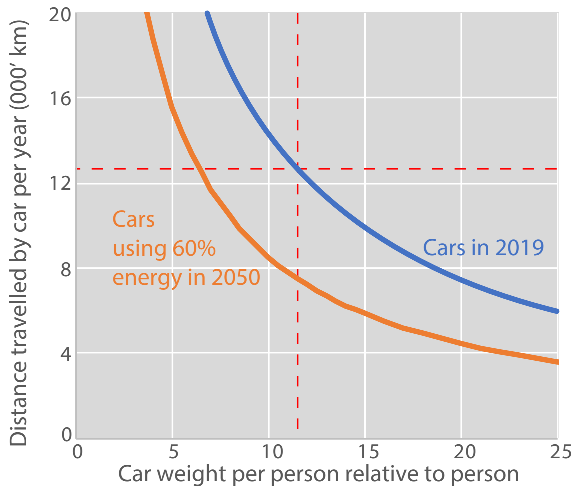
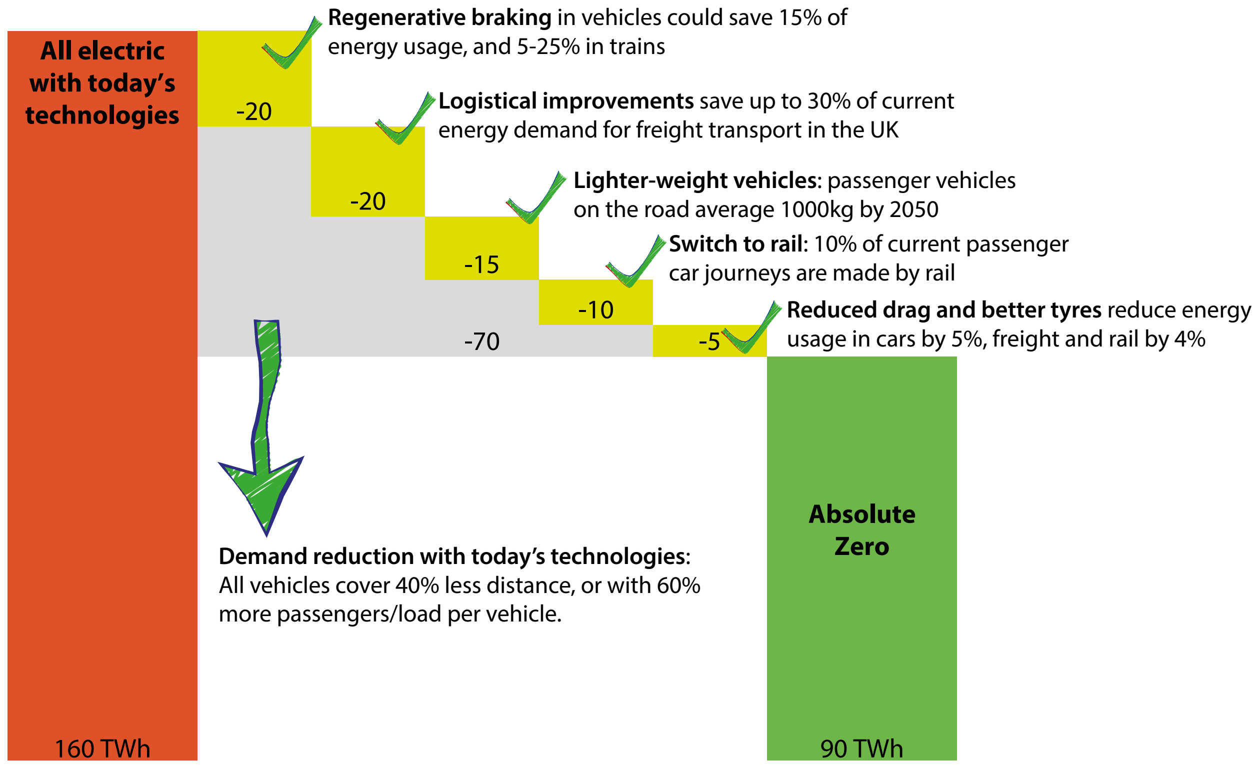


Figure 2.7: Reducing energy use in transport with incremental technologies or reducing demand with today's technology



substantial energy savings can be achieved without loss of mileage. A full electric train can move people using 40 times less energy per passenger than a single-user car.

Other modes of transport can also reduce energy demand in transport. For example, in the Netherlands, approximately 20% of all distance travelled is by bicycle, compared to only 1% in the UK.

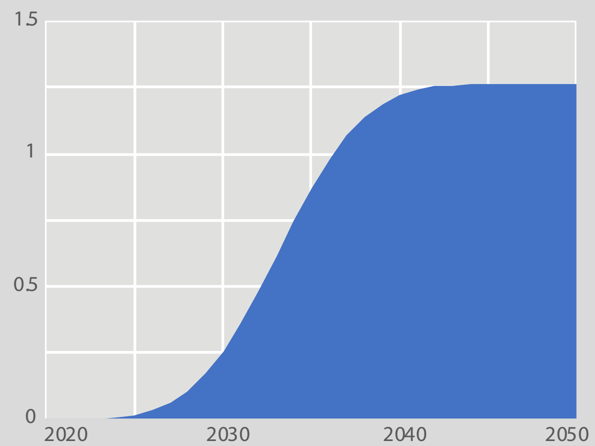
Although there are opportunities to reduce energy demand by mode shift in freight transport, substantial savings could also be achieved by logistical improvements. Up to 30% of energy demand in freight could be saved with an optimised location of distribution centres and with the creation of new collaborative networks to promote co-loading. Technology to facilitate the implementation of these logistical strategies already exists or is expected to become available over the next five years, although this also requires new corporate partnerships.

Fig. 2.7 summarises the options for electrifying UK transport and using 60% of the energy. Either vehicles are modified - with regenerative braking, reduced drag and rolling resistance (better tyres), and weight reductions, or we can choose to use them less - through ride-sharing, better freight management, or an overall reduction in distance travelled.

Can we make & recycle enough batteries?

Lithium battery manufacturing requires a wide range of metals, most of which only exist in nature at very low concentrations. Cobalt is one of the most valuable and is currently essential to the stability and lifetime of batteries. If new car sales are to be completely electric within 5 years, we will need to make 50 million batteries by 2050, just in the UK. Most cobalt production is obtained as a by-product of nickel and copper mining, so could only expand if demand for these materials expand in proportion. Batteries can be recycled, but separating the materials in them is difficult and mining new metals is tehrefore currently cheaper than recycling. There is no simple route to recycle lithium batteries at present, but the surge in old batteries shown in Figure 2.8 should trigger innovation to address this.

Figure 2.8: Estimated volumes of electric car batteries reaching their end-of-life in the UK (millions/yr)



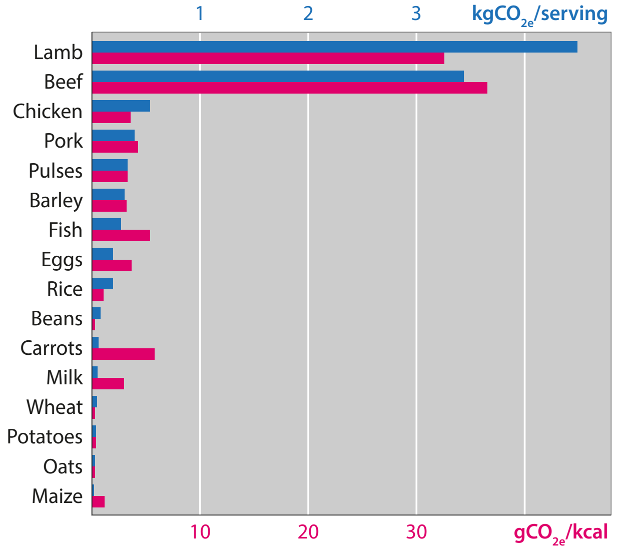
Land-use, food and waste

Fig. 1.15 demonstrated that around a quarter of global emissions arise from good production and the decomposition of organic wastes. The UK figures in Fig. 1.7 show this fraction being closer to one sixth, which reflects the fact that the UK imports around half of its food. Fig 2.10 provides more detail on these non-energy and non-industrial emissions.

As waste biomass breaks down to compost, it releases either carbon dioxide (if the biomass is in contact with air) or methane, which is a much more potent greenhouse gas and is the main driver of the emissions from waste decomposition. However, methane is the gas we use in cooking or in gas fired electricity generation, and the greatest success of recent UK climate policy has been to reduce these emissions significantly. Households across the UK now expect to discard organic wastes in their green bins, which are collected as the feedstock for anaerobic digesters which generate methane for energy production as shown in Fig. 1.7. As a result, UK landfill methane emissions have reduced by more than 50% since 1990 and will be close to zero by 2050.

The other major sources of emissions in Fig. 2.10 are largely related to ruminant animals – cows and sheep – grown for meat and dairy consumption. Ruminants digest grass in their first stomach, leading to methane emissions (enteric fermentation) while also releasing methane with their manure. In parallel, rising global demand for food is driving demand for increased biomass production, around half of which is to feed animals and in turn this drives forestry clearance. Trees are a substantial store of carbon, so clearance increases emissions either as CO_2 if the wood is burnt, or more damagingly, as methane if left to rot. The clear implication of Fig 2.10 is that eating lamb and beef will be incompatible with Absolute Zero.

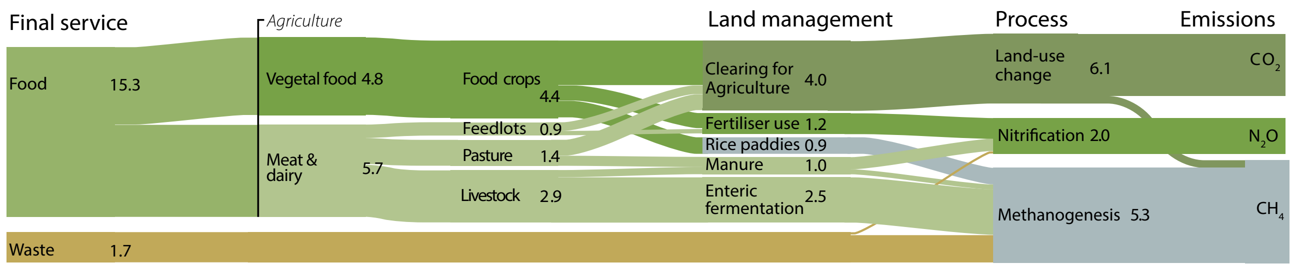
Figure 2.9: Emissions intensities of food



This message is underlined in Fig. 2.9 which gives an estimate of the emissions associated with a meal with typical portions of different diets. The figure demonstrates that a vegetarian meal isn't emissions free, and a meat-based meal (with pork or chicken) may not have much more impact than one based on pulses. However, the ruminant meats stand out so are a priority action in moving towards Absolute Zero.

The market for vegetarian food is currently growing rapidly, as rising social concern about emissions has motivated many individuals to switch to a more plant-based diet. There is significant potential for innovation in extending and developing new manufactured meat substitutes. Research has also begun to examine whether alternative feeds could eliminate ruminant emissions, but this is not yet mature.

Figure 2.10: Global emissions from agriculture, and organic waste (total in 2010: 17 Gt CO_{2e})



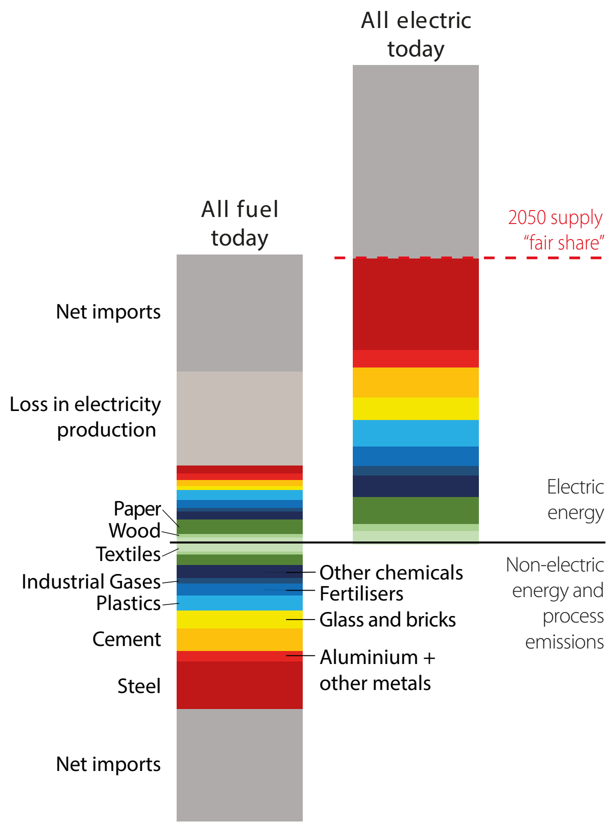
Key Message: Most of today's UK lifestyles can continue and grow within the target of Absolute Zero. Changing the way we travel (in particular not flying, and making better use of wheeled vehicles), stay warm (using electric heat pumps instead of gas boilers) and eat (cutting out lamb and beef) are the most important changes that we would notice. In parallel, small changes in the design of buildings and vehicles can make them more efficient. However the biggest challenge revealed in this section is the use of shipping for freight: at the moment we have no alternatives.

2.2 Materials and Resources

The implications of the analysis of chapter 1 for material production are summarised in Fig. 2.11. The UK imports much of our material requirement - either as materials, components or finished goods - so around half of the impact of our consumption today leads to the release of greenhouse gas emissions in other countries. Of the bulk materials that drive most industrial emissions, paper and aluminium production are the only two for which electricity is the dominant energy source. The processes that make materials can nearly all be electrified, but the challenge to Absolute Zero is to deal with the production processes that inevitably lead to emissions. Blast furnace steel can be replaced by steel recycled in electric furnaces, and this leads to the expansion of electricity for steel production shown in the figure. However, we currently have no means to avoid the emissions of cement production - even if the process were electrified - because the chemical reaction that converts limestone into cement inevitably releases carbon dioxide. Without innovation, we will be unable to use concrete or mortar - the two forms in which we generally use cement - but because this is so difficult to envisage, we have allowed some electric supply for the production of cement alternatives.

Starting from cement, this section explores the opportunity for innovation to expand the available supply of materials within Absolute Zero emissions.

Figure 2.11: Energy use in producing materials



Cement

Cement hardens when mixed with water because the solid products of the reaction (called hydrates) have a higher volume than the cement powder and thus form a solid skeleton. Only a few elements in the periodic table have this property and are also widely found in the Earth's crust. The elements available in the earth's continental crust with an abundance higher than 1% are silica (60.6%), alumina (16.9%), iron oxide (6.7%), lime (6.4%), magnesia (4.7%), sodium oxide (3.1%) and potassium oxide (1.10%). Of these, Portland cement mainly uses calcium and silica, with aluminium, iron, calcium and sulphur also playing a minor role. Calcium and aluminium together can form a heat-resistant cement used in refractory applications. Magnesium, sulphur and aluminate can also work together as a cement, but attempts at making a reliable product from them have proven unsatisfactory. Iron does not form hydrates with a high volume. Thus, the key ingredient to Portland cement is calcium, which is found mostly in the form of limestone (or calcium carbonate), as the fossilised remains of micro-organisms which have combined CO_2 and calcium to form shells for billions of years.

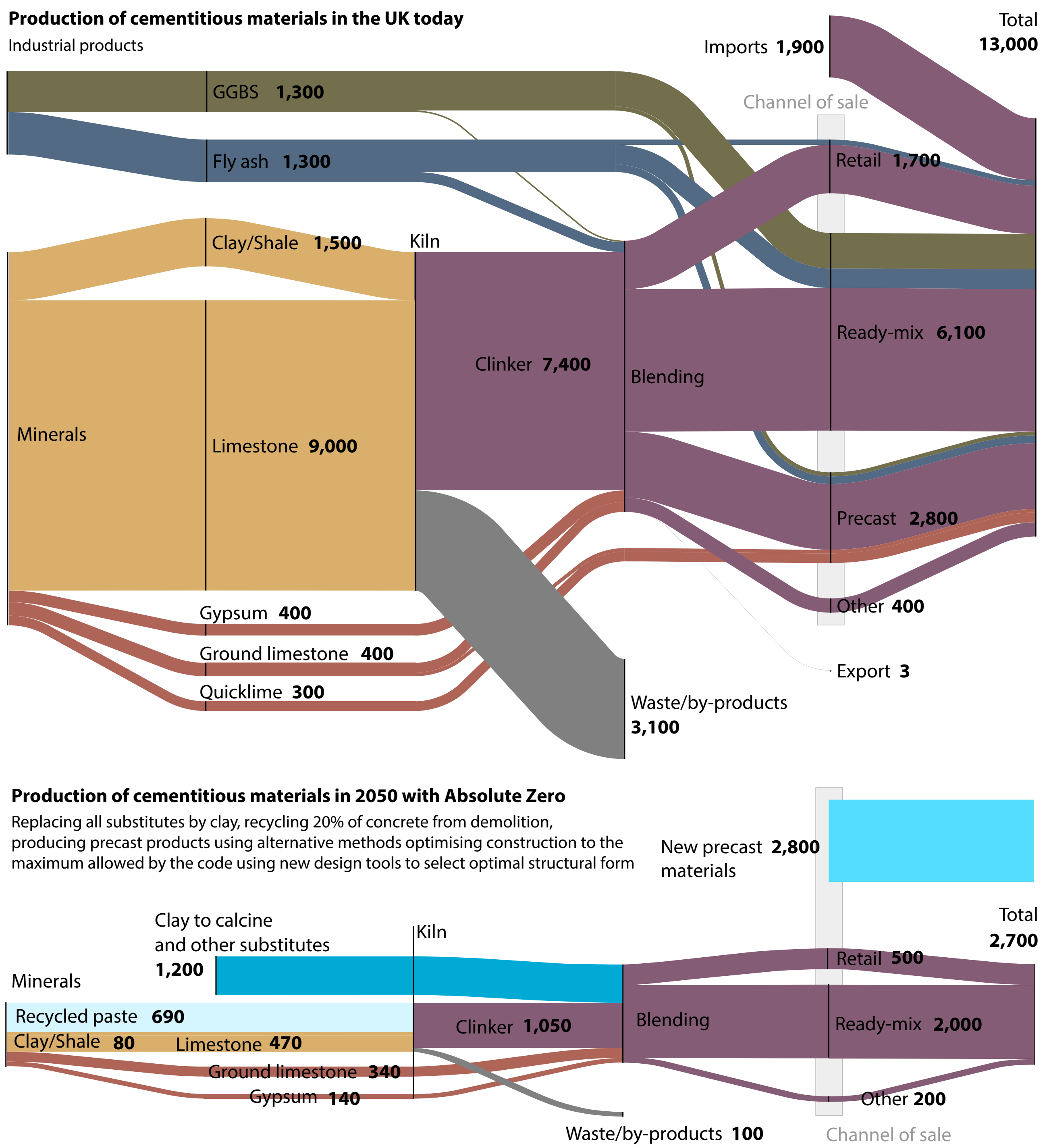
60% of emissions from cement production arise from the chemical reaction of calcination in which limestone is converted to clinker - the precursor of cement. The remaining emissions are due to the combustion of fossil fuels (and waste materials) in kilns. Although heating processes may be electrified in the future, process emissions from calcination would be unavoidable, unless alternative sources of calcium oxide are found to replace limestone in cement production. Currently it appears to be impossible to produce cement with Absolute Zero emissions. Technology innovation on the alternatives to calcination and reconfiguration of the cement industry could enable zero emissions in cement production. However, any innovation in these processes would probably require a substantial reduction in cement demand from current levels.

Currently, the construction industry makes use of many substitute materials to reduce the total demand for cement: both fly ash a by-product of burning coal, and ground granulated blast furnace slag, a by-product of the steel industry are used. Together, they reduce the need for pure Portland cement by about 20%. However, in a zero-carbon world, neither of these products would be available - as coal combustion and blast furnaces would not be possible - which leads to an increase in the need for new cement.

It is possible to produce pre-cast products (bricks, blocks, or slabs) with zero or even negative emissions, whether using micro-organisms which transform CO_2 to calcite or through bubbling CO_2 through magnesium sulfo-aluminate cement-based mixes. These could satisfy some of the construction industry's needs, but we have no alternative binders to replace Portland cement on construction sites. It is often claimed that geopolymers (fly ash or slag which react to form hydrates in the presence of alkalis) could replace Portland cement. However, this is not an option in a zero-carbon world because the base materials for geopolymer come from highly emitting industrial processes (burning coal and coking steel) which will not continue.

Pre-cast products could replace at most 14% of current uses of cement, but without binders, they could not be used for foundations or repairs even of critical infrastructure. One of the most common structural elements in today's commercial buildings, the flat slab which is cast in place from liquid concrete brought to site in mixer trucks and used to build floors, would disappear: the only available option would be pre-cast elements, but these could not be finished, as they are now, with a thin layer of concrete (called a screed). A currently popular construction method, composite construction using thin concrete slabs poured over corrugated steel sheets and beams, would also be impossible, despite being more materially efficient than the reinforced concrete flat slab.

Figure 2.12: Production of cementitious materials in the UK and with innovation for zero emissions in 2050 (kT/yr)



There are two complementary paths that might lead to reducing the emissions from cement production.

Firstly, there may be new sources of cement replacement, and new low-carbon feeds for the production. A promising source of cement replacement is kaolinite-rich clay. Kaolinite is an oxide of aluminium and silicium, which when calcined at 850 C transforms into metakaolin which is an amorphous, reactive product. Because of the lower calcination temperature, this material is about half as energy intensive as Portland cement. It has the interesting property that it can react with raw limestone to form hydrates, as well as substitute cement. Thus substitution levels of up to 65% can be achieved without lowering strength. In the UK, waste from kaolinite mining in Wales can provide a good source of clay to calcine. London clay is of a poorer quality but could still be used if the strength requirements of new construction were lowered.

The second path to producing zero-carbon cement is to eliminate limestone from the feed of cement. An abundant source of calcium which is not carbonated is concrete demolition waste. Current best practice suggests that approximately 30% of the limestone feed of a cement kiln can be replaced by concrete demolition waste. This limit is due to the presence of the concrete aggregates, but if a separation process was established, and only the cement paste from concrete demolition waste was used, then it could be possible to produce cement without chemical process emissions.

The amount of demolition waste available yearly in the UK could cover an important fraction of our yearly needs, provided heroic efforts were made to make good use of this available source of materials. 30 Mt of demolition waste is produced yearly (2007 value from the National Federation of Demolition Contractors), 59% of which is concrete of which 20% is cement paste. An 80% yield in separating aggregates from paste would then provide 3 Mt of low carbon feed for the kilns to produce new cement.

Fig. 2.12 illustrates a summary of this narrative, comparing today's UK requirements for cement (or more generally, "cementitious material") in the upper picture, and the maximum possible supply we can envisage within the constraints of Absolute Zero in the lower picture. Section 2.3 will consider the opportunities to deliver construction with the 75% reduction in cement production implied by this figure.

Finally, there are many possible options for structural elements not using concrete and steel, including rammed earth, straw-bale (ModCell), hemp-lime, engineered bamboo and timber (natural or engineered). Often, these materials claim superior carbon credentials, which may be exaggerated, but they also come with enhanced building-physics attributes, including insulation, hygrothermal and indoor air quality benefits. These could be used to substitute concrete in some applications, but would require different design processes and choices of architectural forms.

Steel

Recycling steel in electric arc furnaces powered by renewably generated electricity could supply most of our needs for steel, as it already does in the US. Almost all steel is recycled already (the exception is where steel is used underground, in foundations or pipework) and as Fig. 2.13 shows, the average life of steel-intensive goods is around 35-40 years. The amount of scrap steel available globally for recycling in 2050 will therefore be approximately equal to what was produced in 2010. Fig. 2.14 shows how the balance of global steel production can evolve in the next 30 years to be compatible with Absolute Zero: blast furnace steel making, which inevitably leads to the emissions of greenhouse gas due to the chemical reaction involved in extracting pure iron from iron ore using the carbon in coal, must reduce to zero. Meanwhile, recycling which happens in electric arc furnaces could be powered by renewable electricity to be (virtually) emissions free, and can expand with the growing availability of steel for recycling. Even without action on climate change, the amount of scrap steel available globally for recycling will treble by 2050. In order to meet the requirements of Absolute Zero, this valuable resource can be the only feedstock, as there is currently no alternative technology for producing steel from iron ore without emissions.

Figure 2.13: Life expectancy of steel by application

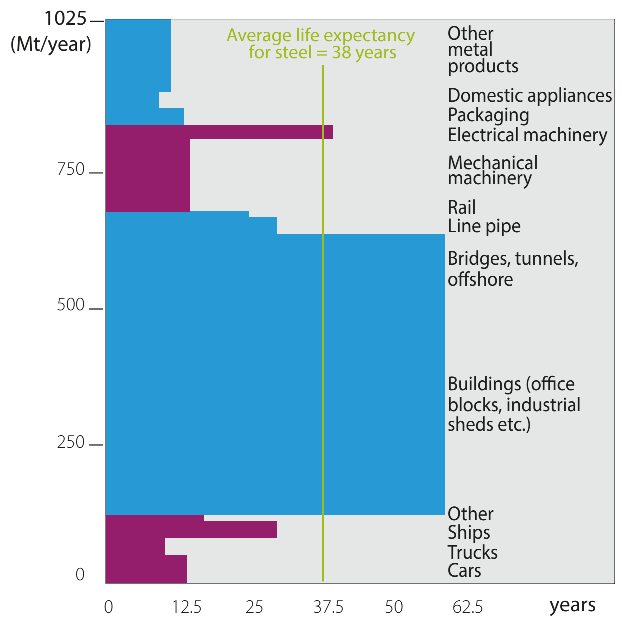
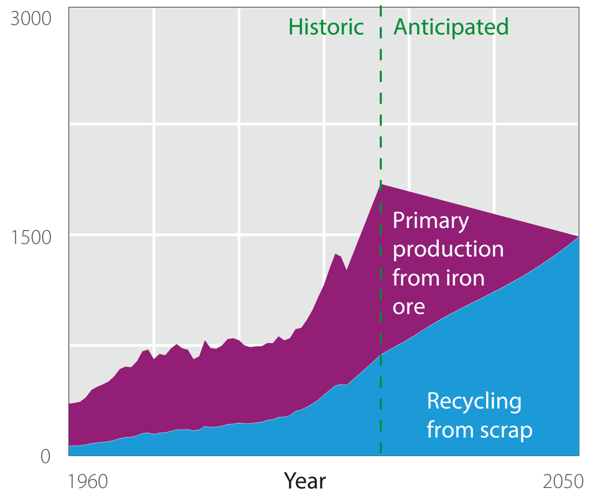


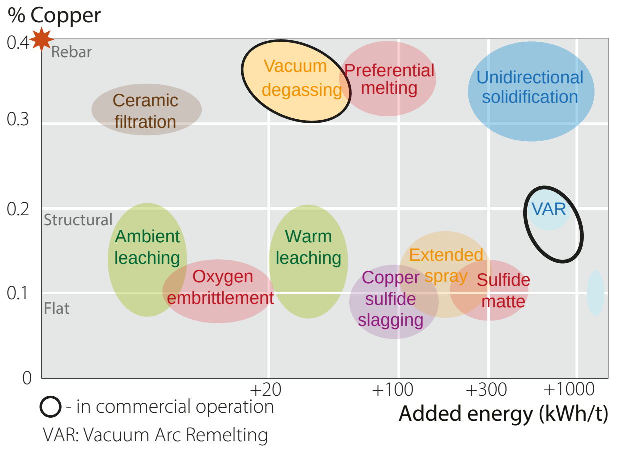
Figure 2.14: Global steel output in Absolute Zero (Mt/yr)



Recycled steel can have the same quality as blast furnace steel. In fact, some of the highest quality aerospace grades of steel used in the UK are made in Rotherham by recycling. However, the quality depends on the mix of metals supplied to the electric arc furnace, and is degraded in the presence of any significant quantity of tin or copper. Tin enters the steel recycling stream because of the use of tin-plate to make food cans, but this is relatively easily managed: these cans can be separated from other end-of-life steel and a mature process already operates at scale to separate the tin from the steel.

Copper is more of a problem in steel recycling, because current waste management involves shredding used cars and domestic appliances to separate metal from other materials, and these products contain many electric motors and associated wiring made from copper. There is a rich field of opportunity in responding to this problem, which could include: removing motors and wiring prior to shredding; improved separation of metals after shredding; metallurgical processes to remove copper from the liquid metal created by the electric arc furnace; developing new downstream processes to cope with

Figure 2.15: Options to reduce copper concentration



copper contamination in the steel; eliminating copper for example by substituting it with aluminium. Fig. 2.15 presents a survey of metallurgical processes for reducing copper concentrations in liquid steel, from 0.4% (a typical value today for average UK steel scrap recycling) to around 0.1% (the threshold for higher quality applications such as car bodies) as a function of energy input. The high grade steels made in Rotherham are purified with vacuum arc remelting, with high energy (and therefore financial) cost, but the figure demonstrates how many other opportunities could be developed given the motivation provided by Absolute Zero.

Steel production is extraordinarily energy-efficient, and consequently steel is remarkably cheap. As a result, it is used wastefully, and in most applications we could deliver the same end-user service from half the amount of steel used for twice as long – i.e. requiring only 25% of annual steel production. This strategy of material efficiency depends on practices in construction and manufacturing so is discussed further in sections 2.3 and 2.4.

Non-ferrous metals

The production of non-ferrous metals is already almost completely electrified. The most notable example is aluminium production, which alone uses 3.5% of global electricity and the demand for this metal is currently growing rapidly. In theory, Aluminium recycling requires only 5% of the energy used to produce primary aluminium, although in reality with additional processing for cleaning scrap aluminium prior to melting it, diluting it with primary metal to control quality, and with inevitable downstream processing, a more accurate figure is around 30%. However, as demand for aluminium is growing rapidly, there is currently not enough scrap available to supply current demand, so within Absolute Zero future, primary production must continue - with output reduced in proportion to the supply of non-emitting electricity. Problems of contaminations which undermine the quality of recycled aluminium, could be a basis for innovation in improved processes to separate aluminium in end-of-life waste streams or modify composition in its liquid state.

Critical metals

Critical metals are so called, because of their growing demand and risks associated to their supply. There are no problems of scarcity for these metals, but their global availability is very unequal — most reserves are concentrated in very few locations, often in countries with volatile political environments, and several critical metals are produced as by-products of other larger-volume metals. Most of the production processes for critical metals are already electrified, but these are very energy-intensive due to the need to concentrate these metals from ores in which they naturally have very low concentrations. Unfortunately, recycling critical metals may require even more energy than primary production, because they are typically used as alloys and it is more difficult to separate them from the complex mix of metals in recycling than from the more controlled compositions in which they are found in nature. Absolute Zero, which requires a significant expansion of electrification, is likely to increase demand for critical metals which enhance the performance of motors, but this demand will come at the cost of an unavoidable growth in demand for electric power.

Ceramics

Ceramics and bricks are mostly produced from clays. These need to be vitrified at high temperatures in a kiln. Currently, heat is obtained from fossil fuel or waste combustions, but electric alternatives exist for all temperatures of kiln. Some colours in ceramics require reduction firing, which requires a stage in the kiln with a reducing atmosphere. This is currently obtained by fuel combustion, and thus alternatives to this practice will required. The 60% constraint on available electricity implies a 60% constraint on ceramics production in 2050.

Mining

Mining uses energy for two main purposes: shifting rocks and mined products in heavy "yellow" vehicles, and crushing them to allow the chemical processes of extraction. Both uses can be electrified but at present, yellow vehicles largely run on diesel while the power for crushing and grinding depends on local conditions. Potentially, there may be more energy efficient technologies for crushing and grinding, but already there is a competitive market looking for these, so breakthroughs are unlikely. However, within the constraints of Absolute Zero, the elimination of coal and iron ore mining will significantly reduce the total energy demand of the sector, providing "head-room" in the non-emitting electrical-energy budget for the expansion of mining associated with wide-scale electrification.

Glass

Most current glass production uses natural gas-fired furnaces. These could be electrified, but a reduction in production would be required in proportion with the available supply of emissions-free electricity.

Fertilisers

CO_2 from ammonia production is currently captured and used for urea production. Urea is then used as a fertiliser, delivering nitrogen to the roots of plants and crops, but as urea decomposes in the soil it releases the embedded CO_2 to the atmosphere. Overall, 2 tonnes of CO_2 are produced per tonne of urea used. Ammonium nitrate is an alternative fertiliser to urea, but it is produced from ammonia, thus leading to the same emissions, although all occurring in the chemical plant.

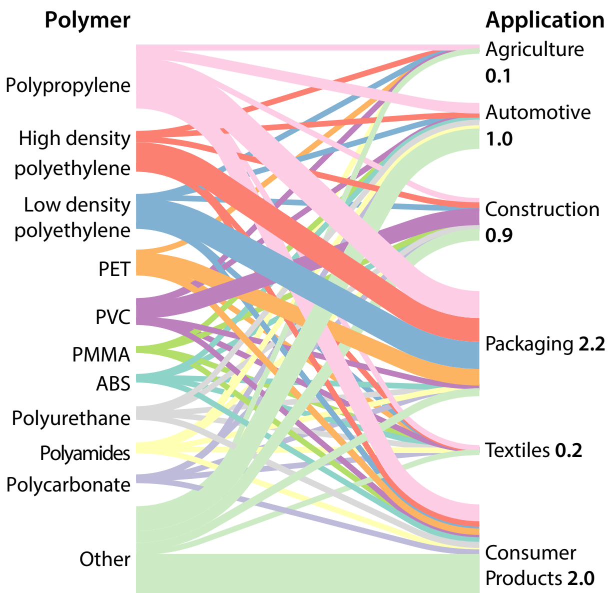
Carbon capture technologies could eventually be deployed, but this would only be compatible with a substantial reduction from current production. However, there are substantial opportunities to reduce energy use by reducing demand for fertilisers. Existing evidence suggests that more fertilisers are used than the nitrogen requirements to grow crops. For example, a study for the Netherlands shows that the use of fertilisers could be halved without loss in productivity, if used more efficiently.

Plastics

Approximately 1 tonne of CO_2 is emitted per tonne of plastic produced, but more than double this CO_2 is produced when plastic waste is incinerated. Plastics are made from oil - and they are therefore the most valuable component of existing waste streams, if the waste is burnt for energy. However, if plastic is combusted, it is in effect a fossil-fuel. As a result, plastic incineration is not compatible with the goal of Absolute Zero.

Plastic can be recycled, rather than incinerated, either by mechanical or chemical means. Mechanical recycling preserves the chemical structure and composition of polymers, and is normal practice within existing manufacturing processes: scrap at the exit of a plastic extrusion machine, for example, can be fed directly back into the machine for re-extrusion. However, this is possible only when the composition is known and under control. The great attraction of plastics is that they can be tailored to every application - with different colours, densities, textures, strengths and other characteristics according to each design specification. However, this tremendous variation is a curse for recycling: in current mechanical recycling of end-of-life plastics, the composition of the resulting product is uncontrolled and therefore of little

Figure 2.16: UK polymer applications (Mt/ year)



value. Furthermore, plastic waste is often mixed with other materials, hence the levels of purity of new plastics cannot be achieved by recycling, which therefore leads inevitably to down-cycling. A frequent example is packaging PET, which cannot be recycled back to food-grade standards and is thus used in lower-value applications.

In contrast, in chemical recycling, polymers are broken down into their constituent monomers which are then recovered to synthesise new plastics. At present, it is only economically attractive to recycle plastics mechanically, requiring less than half of the energy for new production. However, in future, chemical recycling by pyrolysis and gasification may allow plastic waste recovery for high-value applications. As yet, it has proved difficult to operate pyrolysis processes at scale, they require high temperatures, and have yield losses of up to 40%, partly due to use of part of the feedstock to generate heat.

Recyclability is also dependent on the type of polymers available in waste streams. Fig. 2.16 shows the annual flows of plastics in end-use products purchased in the UK by type of polymer and application. Although approximately 40% of annual plastics demand is used in packaging, these have short service lives and are quickly returned to waste streams. A great variety of polymers is used for each application, which hinders the identification and separation of polymers in waste streams, thus limiting the recyclability of plastics. Currently, land-filling plastics leads to almost no emissions. Plastics are stable when landfilled so do not generate methane. However, land-filling neither saves the production of new primary plastics, nor does it contribute to the future availability of material for recycling, unless it is cleaned and separated prior to landfill for storage.

Other chemicals

The chemicals industry produces a wide variety of products. Methanol, olefins and aromatics are produced in much smaller quantities than most plastics and fertilisers, but are important precursors to a variety of chemical products. Emissions arise from energy uses and chemical processes. Although most energy uses can be electrified, it may be very difficult to continue producing many of today's chemicals without releasing process emissions.

Paper

The paper industry globally uses a third of its energy from its own biomass feedstock. Yet, in Europe biomass accounts for half of its total energy requirements, suggesting a global potential for improvement. Absolute Zero emissions would require a conversion of existing fossil fuel-based combined heat and power systems to electrical power processes. Given the constraint on non-emitting electricity availability required by chapter 1, then after complete electrification, paper production would be reduced by approximately 80% of current volumes, to be consistent with UK targets.

Textiles

Most energy uses in the textile industry have already been electrified. However, leather production (which depends on cows) would not be compatible with Absolute Zero for the same reasons given for beef earlier. As washing, drying and ironing account for more than half of the energy uses for most clothing textiles, the industry could promote fabrics that need no ironing and support a reduction in the frequencies of washing and drying.

Engineering composites

Novel nano-materials offer promising properties, which could enable the substitution of some metals across different applications. However, the current total volume of these materials could probably fit into a water bottle. For this reason, it seems unlikely that these materials will have any value in reducing demand for the bulk materials by 2050.

Key Message: Because of the emissions associated with their production, cement and new steel cannot be produced with zero emissions. Steel can be recycled effectively, but we need urgent innovation to find a cement supply. Under the conditions of Absolute Zero, the availability of most other materials will be proportion to the amount of non-emitting electricity available to the sector.

2.3 Resource Efficiency in Construction

Most emissions associated with the construction arise due to the use of materials: the process of erecting buildings and infrastructure requires little energy compared with making the required materials, which are predominantly steel and cement. Under the conditions of Absolute Zero, all steel used in construction will be from recycling - which is largely the case already in the USA, and poses no significant challenge. However, as discussed in the previous section, the industry must learn to make use of considerably less cement. A parsimonious use will make the transition to Absolute Zero possible without putting the material industry under impossible strain. Furthermore, all efficiency gains in one material usually cause reduction in the use of the other, because lower loads always translate to lower structural needs. Fig. 2.17 shows the current uses of cement in the UK as a guide to the search for material efficiencies.

The causes of material *in*efficiency in construction are relatively well understood. The most common is over-specification. The amount of steel in a typical floor of a steel-framed building is about twice what the structural requirements would dictate. This is because the choice of steel beams or steel reinforcement in concrete slabs is not fully optimised and because the decking (the thickness and type of floor slab) is typically oversized.

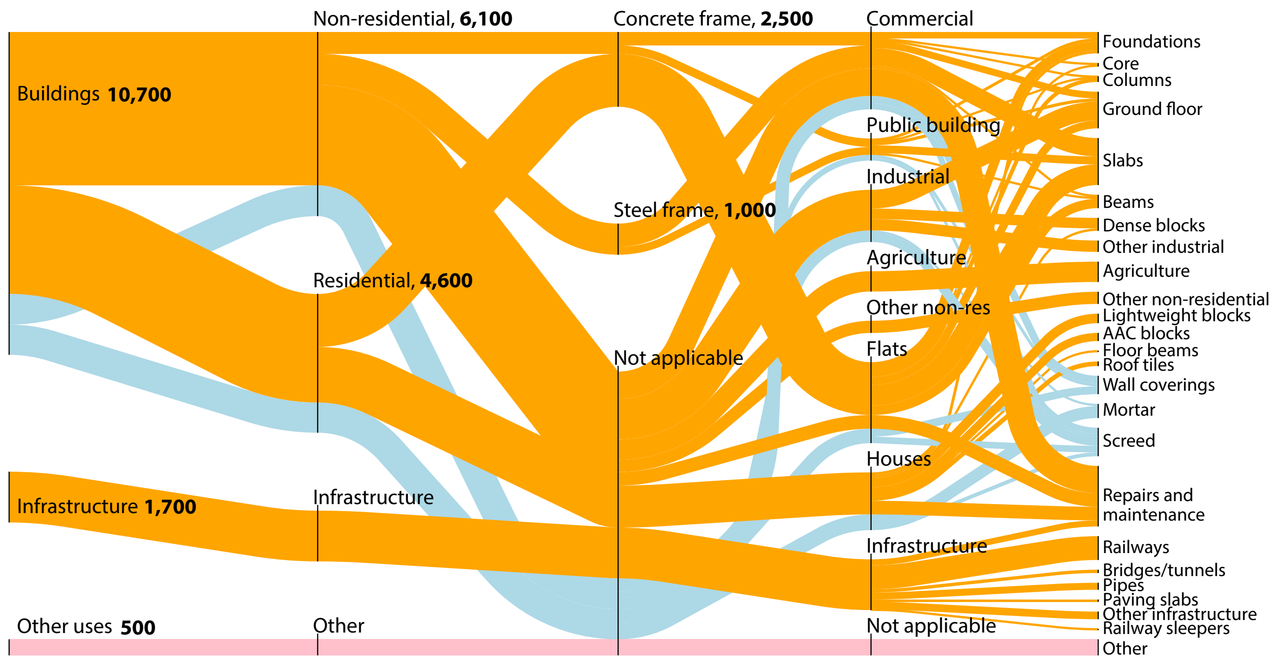
In current UK construction of steel-framed buildings, on average the steel is over-specified by a factor of two, even after accounting for our conservative safety factors. This does not mean that it would be possible to half the amount of steel, be we estimated that it was possible to save at least 15% of the mass of steel with no loss in service or safety. The deckings, are also oversized: the thickness of the concrete layer is larger than required, and the steel plate supporting the concrete in composite construction is frequently double the required thickness.

The building codes currently only specify the minimum amount of material to be used (including the margin of safety). But they could also enforce an upper limit, adding an "and no more" clause. There is also no existing benchmark to compare the embodied energy of the materials in a building per square metre of but this would help drive the efficiency of structural design.

In addition to these sources of over-specification, buildings are often designed for much higher loads than they will ever bear: gravity loading in buildings, predominantly from people, is specified to a far higher level than the physical proximity of groups of people could allow or that ventilation systems could sustain for life in the building. An overestimate of design loading leads directly to material being wasted in buildings. We do not routinely measure loading in buildings, and therefore a research effort is needed. Measuring loading in our buildings, would provide lessons from our existing buildings to transform structural design efficiency.

When specifying the vibration behaviour of buildings, which governs their "feel," engineers usually exceed the requirements of our building codes. However, in use this feel is usually governed by the choice of flooring and the location of partitions, but designers usually ignore those factors, which are not set when the structural frame is

Figure 2.17: Current patterns of cement use in the UK (kT/yr)



chosen. Therefore, a lot of effort goes into making stiff buildings, which require more material and which may be entirely wasted. Better methods of predicting the feel of buildings would help guide design towards more efficient outcomes.

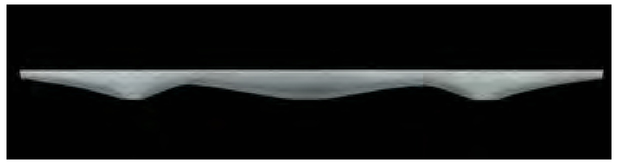
A further driver of inefficiency in our use of materials in construction, independent of over-specification, is the choice of structural form. The choice of the grid (the spacing between columns) is the most important factor in the CO_2 intensity of construction, yet there is little awareness of its importance. The carbon intensity of a building could double if very long spans are specified in preference to shorter ones, even when the users of such buildings frequently install partitions to sub-divide over-large rooms.

Scheming tools, which help guide early design towards a suitable architectural form are being developed. Currently, a designer is faced with a staggering array of options, not obviously different from each other, and will be naturally inclined to choose one with which they have experience. This is probably the cause of the over-design of decking. As the number of options grows – for example with growing enthusiasm for timber construction – the number of options in design will keep expanding, and designers may not be able to realise the promise of new constructions methods New scheming tools to support their decisions can halve the material requirements in construction.

The regularity of structures is also a currently underestimated source of in-efficiency: regular grids can be up to 20% more efficient than more complicated layouts. Novel tools can help structural designer make the right choices early in their projects, and link the choice of architectural form to the best currently available technology, as well as giving a context which may support architects to choose more efficient forms.

Resource efficiency can also be improved by using optimised structural members (slabs, beams, columns). Prismatic structural members in either concrete or steel are highly wasteful, because maximum stress in such members will only occur at one location along the entire length. Modern manufacturing processes can be used to specify appropriate structural shapes (e.g. Fig. 2.18.) Even when designing flat concrete slabs, the pattern of reinforcement is rarely optimised, in part because a complex reinforcement pattern would increase the odds

Figure 2.18: Concrete beam made with fabric formwork



of errors on the construction site. New products such as reinforcement mats which have been tailored for specific site and can be simply unrolled have appeared, but they are not yet fully integrated in the design process of the structural design firms.

Finally using alternative construction material at scale will require considerable changes in design habits. Engineered timber, if it lives up to its promise, will probably take its place besides steel and concrete as a standard frame material. However, engineers are only now being trained to design with timber, and it will take time before it can be used broadly. The trade-off between building tall (probably using high-carbon materials) with low transport requirements, and building low-rise (using low-carbon materials) but with higher transport requirements in a more sprawling approach, needs to be explored.

Steel production, even using a fully recycled route is energy intensive. It would require less energy to re-use beams rather than recycling them by melting. Currently, steel reuse is only a marginal practice, mostly because steel fabrication is an efficient, streamlined process which relies on beams being standardised products. It would be possible to increase the rate of reuse if legislation was adapted to help the recertification of steel beams, but more importantly the construction value chain must develop to accommodate the collection and reconditioning of beams to make them ready for refabrication.

Together, these material efficiency techniques can considerably reduce the need for materials in construction. This is vital to reduce the requirement for cement production to manageable levels. Putting into place all of the material efficiency techniques described here would allow us to keep meeting the needs in Fig. 2.17 with the cement supply implied by the second of Fig. 2.12a and thus to meet the challenge of Absolute Zero.

Key Message: Construction uses half of all steel and all cement, but has developed to use them inefficiently. The requirements for materials in construction could be reduced to achieve Absolute Zero by avoiding over-specification and over-design, by structural optimisation and with reuse.

2.4 Resource efficiency in manufacturing

The manufacturing of basic materials into products and goods is a major source of greenhouse gas emissions. For most products, manufacturing processes themselves cause a relatively small fraction of a product's total embodied emissions, compared to the material input – see Fig 2.19. However, constraints caused by manufacturing practices strongly influence both the material input, and emissions caused by the product during its use. Therefore, under the conditions of Absolute Zero, major changes in manufacturing are needed; driven not just by changes up and downstream of the sector, but also by the need for greater resource efficiency within it.

These changes have some impact on all products, but a critical priority in planning the delivery of Absolute Zero is to focus effort on the sectors with most impact. Having recognised that material production drives most current industrial emissions, Fig. 2.20 allocates the energy use in the first column of Fig. 2.19 to applications to reveal the specific target sectors where material demand reduction is essential. Section 2.2 focused on construction, the single biggest user, and the strategies described there are relevant also to the non-cement components of infrastructure. But the figure clearly prioritises vehicles, industrial equipment and packaging for most attention.

Figure 2.19: Energy use in Manufacturing & Construction

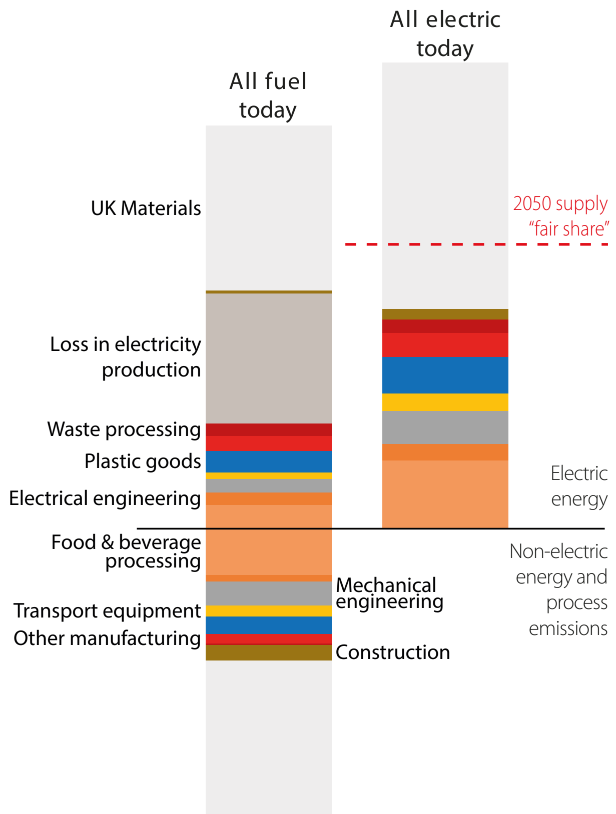
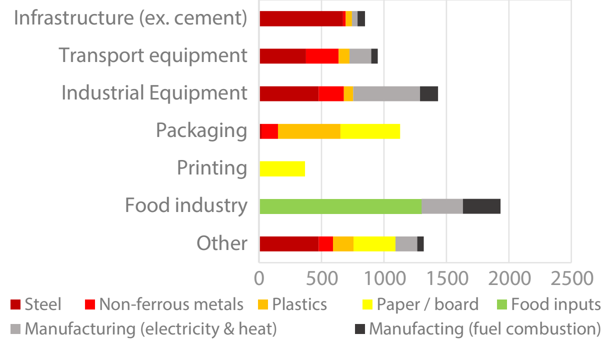


Figure 2.20: Emissions of key product categories ($MtCO_{2e}$)



Responding to changed material availability

In section 2.2 we saw that the availability of materials which today directly emit greenhouse gases in their production will be reduced by 2050. This includes major raw materials such as steel from iron ore and cement, and multiple products of the chemical industry including F-gases, solvents, lubricants, and certain types of plastics. The knock-on effects for manufacturing are huge:

Lubrication is critical for much of manufacturing; from metal forming, to motors, pumps and compressors; but almost all current commercial lubricants are derived from fossil fuels and directly emit greenhouse gases by oxidation either in production or use and so – by a strict definition of Absolute Zero – are ruled out.

Similarly, solvents which emit Volatile Organic Compounds cannot be used. Yet these play a significant role in many industries, including paper coating, degreasing, printing and textiles, but also in coating or painting manufactured goods. Alternatives will be prized and their use widely expanded by 2050. Currently most steel used in manufacturing derives from iron ore; recycled steel is used almost exclusively in construction. New methods will be needed to shape, certify and steel derived from recycled sources. Processes will need greater tolerance to input variation.

Whilst cement and concrete are not widely used in manufactured goods, they are of course ubiquitous in industrial floors, machine foundations and the like: placing a significant constraint on future factories at a time when flexibility and adaptability is key.

Meeting changed product requirements

By 2050 and beyond, the product and composition of many manufacturing industries will be significantly different. For example, Chapter 1 anticipated a 3-fold increase in non-emitting electricity generation over the next 30 years which means that the need for energy storage will sky-rocket. Section 2.1 predicted major shifts in demand for transport equipment: large uptake in electric vehicles and an end to plane or ship building. Similarly, widespread electrification of domestic and industrial heating will require a massive increase associated equipment such as heat pumps. A shift to vegetarian diets would change the food industry significantly. Increased consumption of processed meat substitutes with lower emissions embodied in the food inputs, would require new processing capability and could need more energy in processing.

The scale of material and resource input to enable these changes is significant; looking at wind electricity generation alone, increasing capacity at the rate predicted creates the opportunity for a substantial increase UK industrial output. On the other hand, Section 2.1 anticipates that by 2050 consumers will require products that last longer and can be used more intensively. This will present manufacturers with the challenge of producing higher quality, higher value products. These may be individually more materially intensive but, with a reduction in total volume of sales, manufacturers will see a reduction in their total throughput.

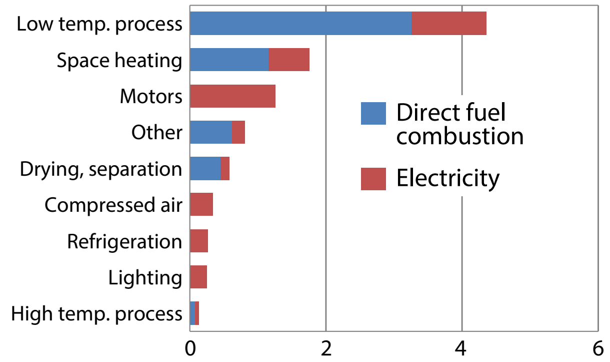
Improving resource efficiency

In a world with much-reduced primary energy availability manufacturers will need to make a step change in resource efficiency; both in material and energy input.

Material efficiency

Various material efficiency measures are technically possible in the manufacturing of goods, components and equipment, including the reduction of process scrap, optimised component design and re-use or re-purposing of components. Large emission savings are possible by reducing process scrap. In machining up to 90% of material can be wasted. For example, machining of aerospace fan blades from solid titanium can produce 90% waste in the form of machining chips. The paper industry produces pulp

Figure 2.21: Annual energy use (MToe) of key processes



residue as waste containing high cellulose fibre and high calcium oxide, both of which can be used in fired clay brick production. Other uses are for land-filling, incineration, use in cement plants and brickworks, agricultural use and compost, anaerobic treatment and recycling.

The automotive industry in the UK generated 0.5% of the total commercial and industrial waste in the UK, at 1.85 million tonnes, 41% of which is metallic, 28% is mixed ordinary waste, 8% chemical and medical waste, and the remainder mineral, paper, wood and plastic. Many nascent technologies have been proposed that could reduce process scrap such as additive manufacturing, precision casting or forging and so on. However, the significant variation in performance between companies illustrated in Fig. 2.22 suggests that the problem is just as much in the management of component and manufacturing design processes.

Shape optimisation of components could further reduce the material requirements of manufacturing. Whereas a given component - whether it is food or beverage can, drive shaft, or a structural beam – would often ideally have variable thickness along its length, or a hollow interior, current manufacturing process are not set up to produce such features. Material savings could be achieved by the development of new manufacturing processes: the economies of scale promote production of components with uniform cross-sections, but optimising material use would require a distribution, and new computer-controlled

Figure 2.22: Material utilisation rates for selected cars

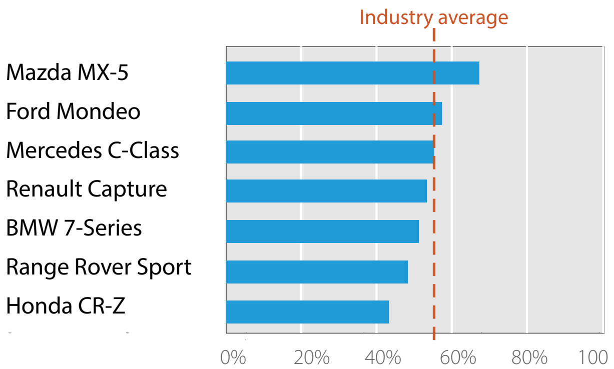
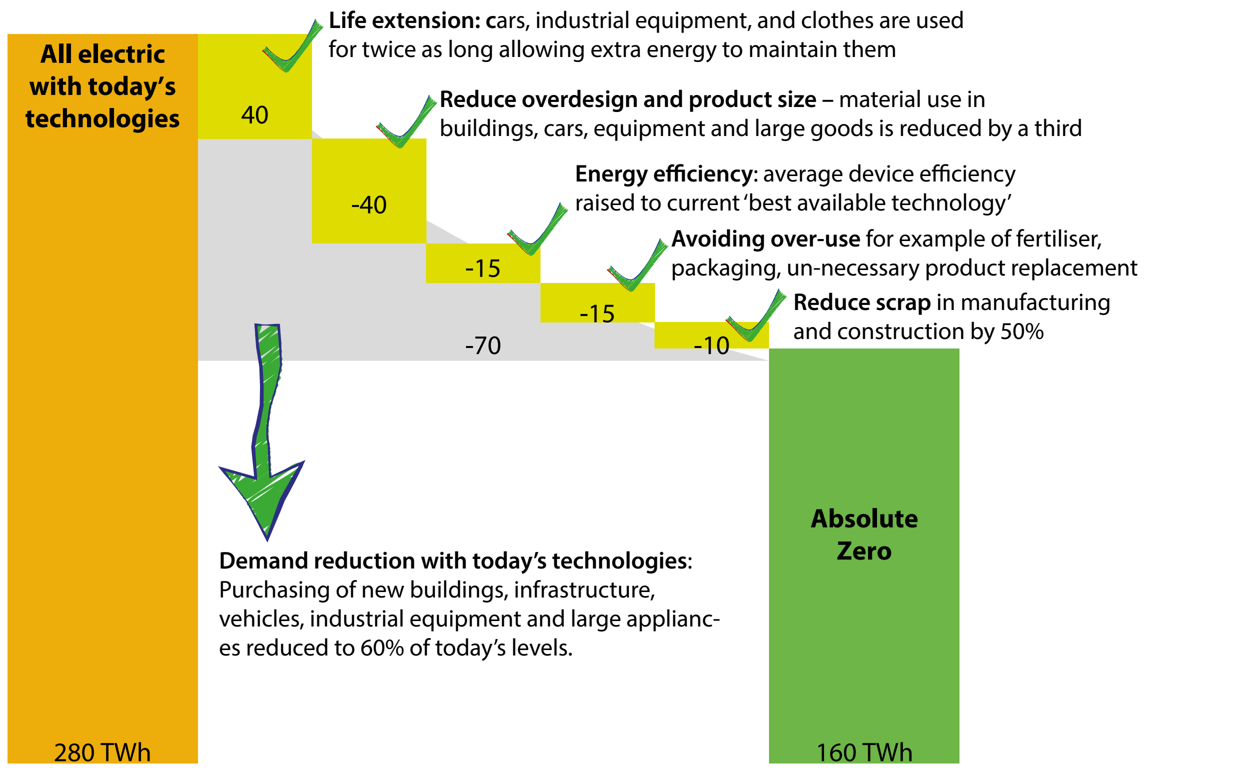


Figure 2.23: Reducing energy use in manufacturing and construction with incremental technologies or reducing demand



equipment can facilitate this change. Functional grading – generating different mechanical properties in different parts of the component - or using higher strength or lighter materials can also contribute.

Changes of the nature described have all been demonstrated at differing technical 'readiness' but their deployment requires large disruptive changes in management practices, skills and manufacturing processes.

Energy efficiency

Direct energy use in manufacturing will need to reduce if electricity supply is restricted to zero-carbon sources by 2050. Some of this reduction could be achieved by energy efficiency. In the UK, the use of energy in downstream industries is dominated by low temperature process heating, space heating and motors, with a long tail of other uses as shown in Fig 2.21. Recent estimates suggest that it may be possible to quarter electricity consumption over the next 10-15 years with the appropriate deployment of conventional technology such as motor drives, pump and compressed air efficiency measures, and the use of heat pumps.

Product standards

Many positive changes are already occurring and many others are both technically feasible and cost-saving in the long run. To deliver the rapid pace of improvement needed we propose that stretching, and imaginative embodied emissions standards are phased in for almost all manufactured product and imposed equally on UK manufacturers and imported goods. Such standards are already widely familiar within manufacturing, whether for safety, inter-operability or use-phase energy efficiency. These must now be extended to embodied emissions and – as matter of urgency - be attached to the major programmes of industrial product development delivering the widespread changes in energy, transport equipment, food infrastructure. If these are imposed fairly on traded goods, it would create a great incentive for UK manufacturers to develop and benefit from the novel products and processes compatible with Absolute Zero.

Fig. 2.23 summarises the analysis of this and the previous section: the energy required to power UK manufacturing and construction, once electrified, can be reduced by a combination of changes to product specification and design, product longevity and process efficiency.

Key Message: Driven by inventive new embodied emissions standards, manufacturing will adapt to three major changes: 1) reduced availability of current inputs, 2) radically different product composition and requirements, and 3) the existential need for improved resource efficiency.

2.5 Breakthrough Technologies

The purpose of this report is to focus attention on how we can really deliver zero emissions by 2050, using today's technologies and incremental changes in use. This is because breakthrough technologies take a long time to deploy - as shown in the box story on page 10 - and we don't have enough time left. However, beyond 2050, new technologies will emerge to transform the energy and industrial landscape, and some of them will be those under development today.

The options surveyed on this page are therefore post-mitigation technologies: after we have met Absolute Zero through complete electrification, a 40% cut in energy demand and the elimination of emitting activities without substitutes, these technologies may later grow to be significant.

Generation

Of the non-emitting technologies in current use, hydro-electricity is difficult to expand, due to geography, and as discussed earlier, the use of biomass for food will exclude its use at scale for energy generation. However, nuclear power could expand. Following the Fukushima disaster in 2011, Japan closed its nuclear reactors and Germany decided to move permanently away from them. However, France continues to generate much of its power from nuclear power, and in the UK, Hinckley Point C is under construction although this is a big, costly project with uncertain completion date. New "small" modular reactors are also under discussion. At present, none are operating world-wide, with two under construction, but potentially beyond 2050, these could make a significant addition to generation. More remotely, nuclear fusion which has been under development since the 1940's is still decades away from generating any energy even at laboratory scale, so cannot be included in planning.

Beyond wind and solar power, the other renewable generation technologies under development are geothermal, tidal and wave power. Geothermal generation which operates at scale in Iceland, New Zealand and Costa Rica is unlikely to be significant in the UK and is operated only at very small scale. Two large tidal power stations operate world-wide, in France and Korea, at a scale of about a quarter of a gigawatt, but although the Severn Estuary has been explored as an attractive site, the UK has no current plans for a first installation. World-wide there is no significant generation based on wave-power. As a result, while these are important areas for development, it is not possible to anticipate any significant new generation from these new renewable technologies.

Energy storage and transfer

Wind and solar power are intermittent, so create a challenge of matching the availability of electricity supply to demand for its use. This can be addressed by storage (for example by batteries or the pumped hydro-station at Dinorwig) or by controlling demand to match availability, for example by allowing network operators to decide when domestic appliances and industrial processes can operate. There are already many developments in this area in the UK, and we assume that they can operate at sufficient scale in 2050 to prevent the need for excess generation.

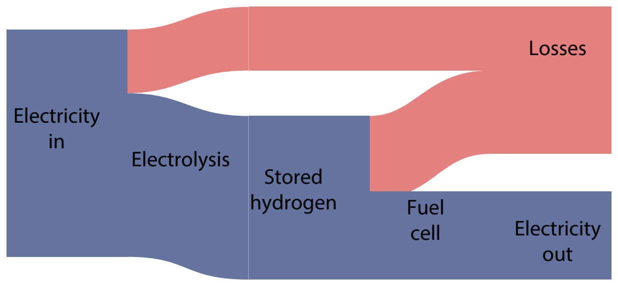
Batteries can operate at large scale, but remain heavy. For static applications this is not a problem but for transport it is constraining: the battery accounts for around one quarter of the weight of a two-tonne Tesla Model S. Technology developers have therefore looked for alternative forms of energy storage to use in transport, and found two important options: hydrogen and ammonia.

Hydrogen is currently produced mainly (95%) from fossil fuels by steam reforming methane, which leads to the release of a significant quantity of greenhouse gases offering no benefit as a form of energy storage. However, it can also be made from water by electrolysis, although as Fig. 2.24 shows, this involves losses which depend on the application, but may be higher than those in the figure depending on the form of storage used. If, in future, we have an excess supply of electricity from non-emitting sources, we could use it to make hydrogen, which could then be used to power vehicles.

Ammonia combustion for shipping may be available in the future, but it currently leads to the production of NOx, which is a powerful air pollutant. Additionally, ammonia is currently produced from fossil fuels, which results in emissions. Although it is possible to use fuel cells to produce ammonia using renewable electricity, there is currently no such process in commercial operation, and its implementation at scale would again be an additional burden to the decarbonisation of the power grid.

One further opportunity for energy storage and transfer is through heat networks which capture "waste heat" from industrial processes and use it, for example, for domestic heating. Around 1% of the UK's homes are heated by heat networks, but expanding this number has proved difficult due to the high cost of the required infrastructure.

Figure 2.24: "Round-trip" efficiency of hydrogen storage



Emissions capture

Although not all related to the energy system, several novel approaches have been proposed to capture carbon emissions. Carbon Capture and Storage (CCS) is used to a very small extent by the oil industry to increase production through the process called "Enhanced Oil Recovery": compressed CO_2 is pumped into the rocks in which oil is stored to drive more of it to the well.

For over twenty years CCS has been proposed as the key technology to allow continued generation of electricity from gas and coal. However, the only power plant operating with CCS – the Boundary Dam project at Saskatchewan in Canada, a very small 0.1GW power station – does not produce transparent figures on performance, and when last reported on by researchers at MIT, was capturing but then releasing its emissions. This technology, despite the very well-funded lobby supported by the incumbent oil and gas industry, is far from mature or ready to be included in meaningful mitigation plans.

Plans for "Bio-energy CCS" or "BECCS" claim to be carbon negative – burning biomass and storing carbon permanently underground – are entirely implausible, due to the shortage of biomass, and should not be considered seriously.

Carbon Capture and Utilisation (CCU) has become a key technology promoted by the industrial operators of conventional plant, particularly the steel and cement industry, but it requires significant additional electrical input, which clearly will not be available before 2050. In future CCU allow conventional steel and cement production to re-start, but only when we have excess non-emitting electricity.

In fact, the idea of carbon capture and storage requires no new technology, as it could be developed by increasing the area of land committed to forestry or "afforestation". We aren't short of tree-seeds, and instead the world is experiencing deforestation under the pressure of needing land for agriculture to provide food. Planting new trees is the most important technology on this page, and does not require any technological innovation.

Industrial processes

In addition to its potential application in energy storage, hydrogen creates a further opportunity in industrial processes because it is sufficiently reactive that it could be used to reduce iron ore to pig iron without releasing carbon emissions in the reaction. Steel has been produced at laboratory scale by hydrogen, and pilot plants are now being developed to demonstrate higher scale production. However, it will only be consistent with a zero-emissions future when the hydrogen is produced with non-emitting electricity, and we have no spare non-emitting electricity to allow this to happen.

Beyond 2050, the incumbent operators of blast furnace steel making, have several process concepts for making new steel from iron ore without emissions. The three main areas being discussed are: separating CO_2 from other blast furnace gases, and applying CCS to it; using hydrogen instead of coke to convert iron ore to steel; separating CO_2 from other blast furnace gases, and using it for other purposes via CCU. All three routes show rich technological opportunities, but will not be operating at scale before 2050.

Flight and shipping

Electric planes are under development, but difficult: the limited rate of improvement in solar cell efficiency shown in Fig. 1.10 suggests that solar power will be never be sufficient for multi-passenger commercial flight. Meanwhile, we have yet to find a sufficient breakthrough in battery development to anticipate sufficient light-weight storage. The most promising route appears to be synthetic jet-fuel - which, inevitably, will be important only after a substantial increase in non-emitting electricity generation.

The decarbonisation of shipping is difficult with current technologies. Although short-distance shipping can be electrified using battery-powered engines, long-distance shipping requires a combustion process. Nuclear propulsion of ships offers a viable alternative to current long-distance shipping and it is already used, although almost only in military vessels. Some commercial operators are currently exploring the opportunity to add sails to conventional ships to reduce their diesel requirements.

Key Message: The problem with breakthrough technologies is not our shortage of ideas, but the very long time required to take a laboratory-scale idea through the technical and commercial development cycle before it can begin to capture a substantial share of the world market.

3. Transitions:

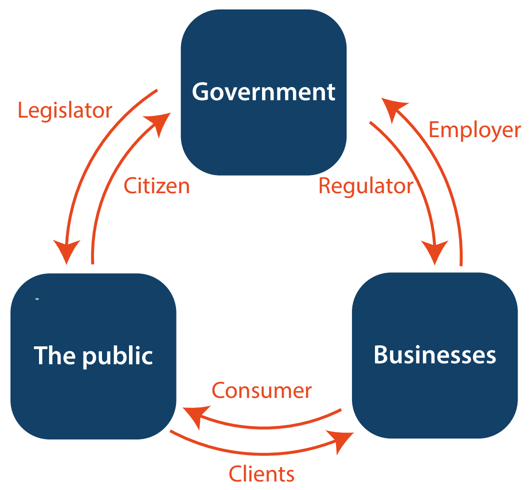
Key Message: No one actor can bring about Absolute Zero. Delivering it is a journey depending on co-operative action by individuals, businesses and governments acting on good information

Absolute Zero is a journey

Action on climate change depends on the co-operation of three "players" illustrated in Fig. 3.1. The public, the government and businesses must act jointly to transform the way we produce, consume and live. Large sections of the public are increasingly concerned with climate change, and some take individual actions such as eating less meat, looking for locally sourced products or taking the plane less often. Politically, this has translated to a growth in the support for Green parties across Europe. Businesses, driven by the demands of the public and driven to efficiency are seeking more efficient production methods and developing products consistent with a zero-emissions future. Governments embrace the drives of the public and businesses to grow the economy and gain votes.

Despite this goodwill towards change, the important transformations outlined in this report do not seem to be happening, or at least not at a sufficient pace. A key reason for this is that these transformations are attempted without the required trust building between the actors which can make them successful. The actors of change are in effect locked in a prisoners' dilemma, and the changes proposed make it seem like a static version of the game. The prisoner's dilemma is a theoretical game where the best outcome for the players cannot be achieved if the players only follow their own best interests. There are many variants to the story but in substance it runs like this: two bandits just successfully robbed a bank and were caught soon after for some minor offence. They are kept in separate cells, and each is told their accomplice has also been caught. They can defect and accuse their accomplice of the robbery, in which case they'll get at least a reduced sentence, or they can cooperate and refuse to accuse each other. Should they both defect, they'll both have a reduced sentence. Should they both cooperate, they'll both have a small fine, should one cooperate and the other defect, the defector will go out free and the cooperator will get a full sentence.

Figure 3.1: The three "players" of climate mitigation



Game theory predicts they should both defect: indeed, there is no outcome from cooperating which cannot be improved by defecting… Every day, all of us are faced with many such dilemmas – but every day we cooperate rather than defect! This is because the prisoner's dilemma when played over and over is a completely different game which is won by achieving cooperation. When considering the so-called iterated prisoner's dilemma, it's not single moves but strategies which matter. This is a well-studied problem, and the winning strategies which achieve cooperation share a number of basic characteristics: they punish defectors, they reward cooperators, they are simple enough that they can be understood by observers. Other research looking at how humans play in games compared to the predictions of game theory suggests another crucial quality of winning strategies: the cooperative strategies must also be fair. Marginally cooperative moves will be treated as defections.

Similarly, the transformation required for climate change mitigation needs to be played out like the repeated game, and not seen as a single huge step which will most likely be resisted and fail. Fortunately, three-player games favour cooperation somewhat, unlike the two-player variant. Unfortunately, having more players may drive each one individually to try and delay making changes. To achieve the scale of transformation required, small incremental changes are the immediately necessary steps to build and reinforce trust between the actors.

Case study: reusing steel

Currently, most of the steel from demolitions is recycled. There is nothing else which can be done with the reinforcing steel of concrete, but steel beams having standard sections and not being damaged from their service as structural elements could be reused. If not directly, after some sand-blasting and the fitting of new connexions the beams are as good as new. Most of the research on the barriers to steel reuse focuses on the certification problem: steel to be used in construction needs to be certified, but the process of obtaining certification assumes the beam is coming out of a mill and is not transposable to already used beams. However, is is possible for a small price premium to test the beams and guarantee that they have all the appropriate properties.

What we found is that the key obstacle in the supply chain was that steel re-use puts the buyer of the building wanting to use steel from reuse and the fabricator responsible for the conditioning of beams in a prisoner's dilemma. Reconditioning the steel takes approximately twice the amount of time to condition a new steel beam direct from the foundry. Although the fabricator can charge for this time, a project being abandoned – always a risk in construction – will translate to large losses. Therefore, all projects that we could study where the fabricator was not part of the planning, failed. Our proposed solution is for steel stockist to take on the job of reconditioning and recertifying steel so that the fabricators need never know whether the steel is from reuse or not. Acting as a trusted intermediary, this would avoid the project failures due to fabricators not wanting to shoulder all the risk. The upfront investment could be helped by government grants, and we showed that this would be overall profitable.

Case study: Cycling in the Netherlands

After the second world war, the Netherlands had, like the rest of Europe embraced cars as a symbol of freedom and mobility and had built highways and roads to accommodate this new transport mode. In 1971 alone, 300 children died in the Netherlands from accidents involving cars, leading to widespread protests. In 1973-74 the oil crisis caused oil shortages, leading the Dutch government to look for strategies which would lower the oil dependency. The protesters were demanding a return to the biking culture which had been an important part of Dutch habits until the war, and the government took this occasion to launch a number of bike-friendly initiatives: a number of car-less Sundays in the years. Some city centres were made car-free. These moves proved popular and were followed by the construction of bike-specific infrastructure.

From the mid-70s onwards, bikes were integrated in urban planning decisions, meaning not only cycles paths being built, but traffic-calmed streets would be favoured, and bike parking be available at convenient locations, and bike traffic be integrated in the general public transport infrastructure. As the bicycle is seen as a symbol of the Netherlands, it was possible to pass more stringent legislation: for example since 1992, in an accident, it is always the motorist's insurance which is liable for the costs in the Netherlands. Safe interaction with bikes is part of passing one's driving license. As the popularity of bikes grow in the 90s and 2000, larger investments in bike infrastructure became possible with the support of the public, leading to even more bikes being ridden.

Overall, the current Dutch biking culture is the result of a long process where multiple changes to legislation, habits and infrastructure were self-reinforcing, leading to today's situation where the Netherlands is Europe's leader in kilometres cycled.

3.1 Individuals – at home and at work

Protesters and school strikers have increased our awareness of the need to address climate change. An individual wanting to reduce their personal emissions can find a wealth of information on social media, websites and podcasts detailing actions they could take. Behavioural changes required to deliver zero emissions by 2050 are already being practised by some people in some places: some people already choose not to fly, to be vegan, to car share, to lower the temperatures in their homes and offices. If large scale social amplification could occur, as it did with the 'Me Too' movement, surely a cultural change could occur to enable zero emissions by 2050?

Although public awareness of the need to act has increased, the UK has not meaningfully reduced its resource use in recent decades, with the International Energy Agency reporting total final energy consumption has reduced by only 7% since 1990 levels. Individuals continue to use nearly as much energy as they did 30 years ago, suggesting that existing strategies to motivate individuals to use less energy are not generating the scale of impact required.

Social norms and individual behaviours

There is a misalignment between the scale of actions recommended by government (e.g. energy conservation) and those most commonly performed by individuals (e.g. recycling) . Actions which can have a big effect, such as better insulation in houses and not flying, are being ignored in favour of small, high profile actions, such as not using plastic straws. This is enabling individuals to feel satisfied that they are 'doing their bit' without actually making the lifestyle changes required to meet the zero emissions target. If large scale social change is to be successful a new approach is needed.

Whilst the thought of society taking radical, meaningful steps to meet zero emission targets could be criticised for being idealistic, we can learn from historical cultural changes. Not long ago, smoking cigarettes was encouraged and considered to be acceptable in public spaces that children frequented, drink-driving was practiced with such regularity that it killed 1000 people per year in the UK, and discrimination based on sexual orientation was written into law. These behaviours now seem reprehensible, showing society is capable acknowledging the negative consequences of certain behaviours and socially outlawing their practice. Focus should therefore be centred on expediting the evolution of new social norms with confidence that change can happen.

Evidence from behavioural science, and the long experience in public health of changing behaviours around smoking and alcohol, shows that information alone is not enough to change behaviour. To make the types of changes described in this report, we will have to think more broadly on the economic and physical contexts in which designers, engineers and members of the public make decisions that determine carbon emissions. At the same time, clear, accurate and transparent information on problems and the efficacy of proposed solutions is essential for maintaining public support for policy interventions.

The phrasing of communication is also important. Messages framed about fear and climate crisis have been found to be ineffective at motivating change. The longevity of the challenge of reducing emissions, and the lack of immediate or even apparent consequences of small individual actions mean it is challenging to link to them to the large-scale climate crisis. This allows individuals to make decisions which contrast with their desire to reduce emissions. Scientific description is not always the most effective means of communication, and language used to promote zero emissions should no longer focus on an 'eco-friendly' and 'green' lexicon, but rather candid descriptions of actions that appeal to human fulfilment. Evidence from time-use studies shows that human fulfilment does not strictly depend on using energy – the activities we enjoy the most are the ones with the lowest energy requirements. Consumers can be satisfied in a zero emissions landscape.

Individuals and industry

If net-zero targets are to be met, all of society needs to change, not just those motivated by the environment. Therefore, as well as persuading and supporting individuals to change with environmental campaigning and one-off sustainability projects, industry should embed a net-zero emissions strategy into business-as-usual, only offering products and services which meet their consumers' welfare needs without emissions.

This change will be driven by individuals acting in their professional capacity, as managers, designers, engineers, cost consultants, and so on. A structural engineer designing a concrete-framed building has vastly more influence over carbon emissions through their design decisions at work than through their personal lifestyle. Therefore, as well as the transitions in businesses discussed in the following section, this section applies also to individuals at work.

Key Message: Changes to social norms and individual behaviours can be positively framed to appeal to human fulfilment. Motivated individuals can be as effective at work as at home.

3.2 Transitions in businesses

Many of the opportunities and changes identified in the first sections of this report will involve businesses making changes to the types of technologies they use, or the way they use them. But this type of change can be difficult to motivate. This section examines why this is, and discusses the role of incentives, market pull, standardisation and collaboration in achieving the change required.

Challenges in changing technologies for zero emissions

We are surrounded by a constant stream of innovation in technology in some areas, such as smartphones – so why is it that some other industries have been slow to respond and to integrate relevant innovations into their operating models? In general, the reason is that new production technologies are introduced at the same as a new generation of products is launched. The new manufacturing technologies and processes are often not central to the functionality of the next product but are driven instead by improvements in cost, quality and logistics. So in areas without a rapid cycle of introducing new generations of products, it can take a long time for manufacturing innovations to be adopted.

In such cases, thorough assessment of technology merits, maturity and readiness are carried out, especially where change represents some form of risk. Without the driver of a new product launch, and associated new revenue stream, firms have displayed a risk-averse attitude towards making significant transformations in the production technologies they use. This is particularly true for safety-critical applications. In such cases, novel technologies have had to pass the test of time before being considered for full deployment. Another reason behind gradual technology adoption is the lack of propensity to invest, especially in highly established industries where the cost of new capital would be prohibitive.

Incentives for technology innovation

Using the "carrot and stick" analogy, it is easy to understand that innovation can have a difficult time permeating into an organisation without the right type of leverage and motivation. Governments can impose additional taxes, policies and regulations to achieve the desired changes but this could be short lived with the next batch of policy changes. Emissions and energy caps can be seen as a "stick" but financial rewards and customer-valued green credentials will be perceived as a "carrot".

Ideally there should be a market pull that is driven by the end customer. Organisations are more likely to adopt innovation and technology when there is a direct correlation to increased revenue and returns. They are also more likely to pursue targets that result in products and services that use less resources but still valued equally or greater by the customer. Consumers are more aware of the macro effects of their purchasing choices and there is a move towards companies that have the same brand values. However, for a business, it can be hard to benefit from this, as the relevant qualities are not easily visible to the end customer. For example, you cannot tell just by looking at a washing machine whether it was produced from renewably-powered recycled steel, or carbon-intensive steel from a blast furnace.

The achievement of Absolute Zero almost certainly requires life extension and better utilisation of certain categories of product, but with progressive insertion of more sustainable manufacturing and through-life engineering technologies throughout life in service. This creates a conflict: life extension and better utilisation of existing products implies that new products need to be introduced less frequently – but as described above, generally more sustainable production processes are difficult to introduce in the absence of new generations of products being developed. A new mechanism is therefore needed to drive forwards the adoption of positive technological changes. The most obvious means of doing this via public intervention would be the establishment, of some form of 'roadmap' which sets out progress.

The role of standardisation

Standardisation can play a significant role in reducing industrial and domestic energy use and CO_2 production. In many industries, standardisation and sharing best practice have paved the way to less resource duplication and greater customer experience. An example that is often mentioned is the light bulb but a more modern example would be the phone charger. In the early days of the mobile phone industry, not only did every manufacturer have their own chargers but every model had its own connector type. Once customer habits were analysed, it was found that customers wanted to upgrade to a new phone every few years, therefore very quickly there would be a build-up of useless chargers and connectors ending up in landfills. Several of the major manufactures developed a standard charger and connector that would be used for all models going forward. This had 4 main benefits:

- Reduction in unnecessary charger variation and legacy part production.
- Increased customer experience as phones could be charged with any charger and no longer limited to one connector.

- Phone manufacturers diverting funds and resources away from charger and connector design into other parts of the product that were more valued by the customer.
- Users investing in higher quality chargers that could be used for years without needing replacement and a reduction in E-waste.

In other industries current practice often requires specialised components and parts that are designed specifically for their intended use. With standardisation comes the reduction in design flexibility. In an already saturated market place, businesses are trying to differentiate their products and services form one another. Customisation currently allows them to achieve these goals, but as discussed above, the future environmental benefits of standardisation could provide an alternative source of differentiation.

It is possible that the progressive roll-out of standards over time could form a central and tangible element of any roadmap for achieving Absolute Zero. The development of standards which drive positive change would however be entirely reliant on some key principals of backward compatibility, such that the implementation of each new standard avoids immediate obsolescence of existing assets.

Making collaboration work

The achievement of Absolute Zero seems to be beyond the ability of individual firms, and even nations, to enact. It requires a level of cooperation which has perhaps only been seen during times of war.

Moving beyond the purely competition-based model and integrating some learning from the collaboration model can be beneficial to competitors as well as the environment. As well as eliminating obvious duplication of resources, a new level of cooperation would be needed so that the benefits of shared learning can rapidly permeate through supply chains, and horizontally across sectors. This presents a more complex legal and organisational challenge to the traditional manufacturing and business model, but one which could create new opportunities for early adopters.

The necessary transition will incorporate the current move beyond the traditional manufacturing line to more flexible manufacturing for increased agility while taking a balanced and holistic planning approach to enable through life considerations to be made. The role of analysis in this model based on increased computing power, but also the carbon impact of data storage and transfer is a complex one. Gathering information on the whole manufacturing process from all participants in the supply chain and then analysing the results to produce the holistic resource usage is one of the ways to truly understand what goes into the final product. Insights from this information will allow for the development of a valid roadmap to Absolute Zero, but there are challenges to obtaining and using this information that will be discussed later, in section 3.4.

A look to the future

Technology innovation and change readiness is becoming a desirable quality. With shortening product life cycles, organisations need to adopt a more agile approach to respond to market needs. Catering to this consumer mentality has led to the production of lower quality products that fail in the time the consumer would be looking to upgrade or replace the product. An extension of through-life engineering approaches beyond ultra-high capital value assets into more mainstream consumer products is needed. Essentially this means producing much higher quality products with parts that can be dismantled, retrieved and reused. Products could either be disassembled and reassembled with some modifications and resold, or they could be cascaded down into a completely new product. This would require forward planning, standardisation and modular design thinking.

Organisational and inter-organisational culture will need to match the aspiration of Absolute Zero over time to become, itself the great incentive and driver of a positive cadence of change. No organisation can outrun their legacy, therefore a roadmap that commits them to real change while keeping the business profitable now and in the future is desirable.

This section has focused on technology transitions in existing businesses, but successful disruptive transformations often come from outsiders and new players. Therefore, support mechanisms also need to exist for new businesses bringing zero-carbon-compatible business models and production processes as an alternative to the status quo.

Key Message: Agreed roadmaps, new forms of market pull and collaboration are needed to spread the required technological innovation through industry.

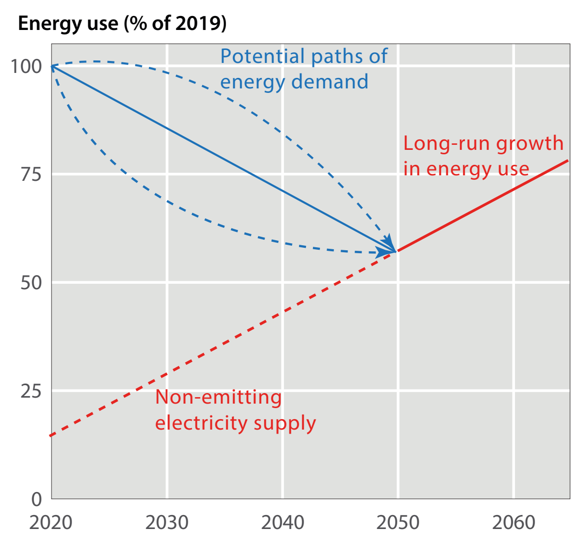
3.3 Action by Government

The government will need to act to create the context in which the individual and supply-chain changes described in the previous sections can develop. There is also a strategic choice about the speed of transition which should be pursued.

Fig. 3.2 shows three potential paths for energy reduction to reach Absolute Zero in 2050. This is predicated on growth in the supply of energy from renewables growing at the rate indicated in Fig. 1.1. This means that demand has to reduce to 60% of its current level by 2050. Growth in energy use beyond 2050 will be driven by ongoing renewable and other carbon-free technologies. The distinction between the pre-2050 and post-2050 analysis is that the steps taken to meet the 2050 target must rely on technologies which are already in existence, and have the clear mechanisms to be scaled, whereas post-2050 growth can reflect new technologies. The three potential paths for energy reduction reflect three different approaches, depending on the extent of delay. What these three paths do not show is that the cost or sacrifice needed for an extra percentage point reduction is not constant: initial reductions are likely to be much easier. This in turn implies that if the desire is to spread the cost of reduction equally over the 30 years to Absolute Zero, then the actual path needs to reflect a sharp early decline, as in the lower dashed blue line.

Absolute Zero means two things: first, that no carbon can be produced by any industry or household; second, averaged across the economy, energy consumption must fall to 30% of its current level. This distinction between the carbon reduction, which is an obligation on all industries, and an energy reduction which is on the average, leads to very different substitution possibilities: there are no substitutes for the reduction of carbon to zero, but there needs to be a mechanism for allocating scarce energy resources. Ensuring carbon is at zero is a regulation issue, with prohibitions on the use of carbon similar to prohibitions on the use of asbestos. Ensuring energy is cut in the aggregate requires an allocation mechanism, and the price of energy to reflect its scarcity. In such a scenario, the owners of the means of production of renewable energy will make very large profits. This in turn raises both efficiency and distributional issues.

Figure 3.2: Pathways of restraint and growth



We break the discussion into four components: first, on the possibilities for substitution away from carbon and energy use across different sectors; second, on the impact on the types of job and the location of jobs; third, on the overall impact on output; and finally, on the implementation.

Production Substitution

At the heart of understanding the impact on the economy of Absolute Zero is an understanding of the substitution possibilities away from carbon and energy in different industries and production processes.

Section 2.3 discusses the options for the construction sector: the production of cement involves the emission of carbon and so cement in its current form cannot be used in construction. At present there is no alternative to the use of cement and so the construction industry has to radically change its production process or close. In this case, radically change means either reverting to using wood or other natural products, or successfully developing the alternatives to current cement production described in Section 2.2. These options, however, limit the size of buildings and so the sector cannot continue as it is. This has implications for the way in which businesses and households operate. Buildings need to be reused rather than rebuilt. On the other hand, it is not clear how the existing stock of buildings will be maintained, and the conclusion is that building space (residential and commercial) will have an ever increasing premium

The difficulty of the construction industry highlights the impact on any assets being used in an industry where there are no substitutes for carbon – such as planes, or industrial plants. The value of these assets will be zero in 2050 and this should directly affect the desire to invest in those assets now. This points to the implementation issue: realising the value will be zero in 2050 may encourage greater use in the run up to 2050 – for example, putting up new buildings at a much faster rate for the next 30 years, knowing that construction must then halt. On the other hand, Fig. 1.1 makes clear that the value of investment in processes of carbon-neutral energy production will increase sharply.

Jobs and Location

There are two key implications for how we live our lives: first, buildings will become much more expensive because the restrictions on building which generate substantial scarcities; second, transport will become much more expensive because the limits on air travel will generate excess demand for other forms of transport. By expensive, we mean the direct costs to an individual or firm, but also indirect costs in terms of reduced quality. We would expect these two substantial changes to lead to pressure on the amount of space any one individual uses, and also where people choose to live and work. This points to increased centralisation, with growth in cities.

The wider problem with the changes in labour is knowing what type of labour or jobs will be in demand. Those who are starting secondary school now, in 2019/2020, will be 43 in 2050. Thinking about what education is appropriate for a very different set of industries is a key question. Should we still be training airplane pilots? Or aeronautical engineers? How are we training architects, civil engineers? Education decisions are far more persistent than capital investments. This in turn highlights the needs to take decisions on investments now where the lead times are very long or depreciation rates very low.

Overall Impact on Output

Economic growth in the industrialised world has been associated with increasing energy use. Long-term growth rates will also be constrained by the rate at which energy production can grow which depends on the growth rate of renewables. The key question in the transition is how much will output decline to reach a level where only 30% of current energy is being used and no carbon is being produced. We have discussed the direct impact of this on the construction and transport sectors. What this misses is the inter-dependence of the non-emitting and emitting sectors. Specialisation in production and the substitution of energy for labour have been key drivers for growth and increased productivity. The open question is whether specialisation can still be achieved without the reliance on energy.

These impacts on output will not be felt equally across the country. Industries are typically geographically concentrated – such as steel production – and this means that large shifts in production will have concentrated impacts. Rural or more isolated communities are likely to be disproportionately affected. The largest distributional impact, however, is intergenerational: the cost of hitting Absolute Zero will be borne by the current generation.

Implementation

The changes in behaviour to achieve Absolute Zero are clearly substantial. In principle, these changes could be induced through changing prices and thus providing clear incentives for behaviour to change. The alternative is that the government prohibits certain types of behaviour and regulates on production processes. Given the difficulty for the government of knowing what production process to change or what options for innovation are available to companies, the natural decentralised solution is for the government to either put a price on carbon or to restrict its use directly. The push for Absolute Zero means the distinction between these two approaches is irrelevant: the price of carbon must be prohibitively large by 2050 to stop all demand. In the run-up to 2050, the question is how fast must the price of carbon be increased, or equivalently, how fast must restrictions on the use of carbon be put in place. It is understanding this time-line for the price increase (or time-line for the strictness of restrictions on use) which is the key issue for the implementation.

The underlying point is that any asset which uses carbon will have essentially zero value in 2050. This in turn may encourage greater use in the run up to 2050. This sort of response is clearly counter-productive: the climate problem is about the stock of carbon, rather than the flow.

A natural question in considering implementation of the 2050 is how to evaluate the cost to the economy of various measures. For example, how to compare the cost of installing solar panels to the cost of driving smaller cars. Individuals' willingness to pay gives a measure of the value of installing solar panels (rather than take electricity from the grid) or the value of driving a small car (rather than a larger one with the same functionality).

Key Message: The effective price of carbon must be prohibitively large by 2050. A key issue for how to implement this is the timeline for how the price must grow (or restrictions must become more strict) from now to 2050.

3.4 Information

Information has a critical role to play in guiding transition to Absolute Zero emissions. Data about our present situation is needed to prioritise change and innovation, to monitor progress, and to identify 'bright spots' of good practice. We also need to understand how the future might develop and how we can make choices now that are robust to future uncertainty. However, information alone is not sufficient to cause actual changes in behaviour, and we should be aware of lessons from behavioural science to maximise the effectiveness of information.

Information on the present

Understanding the current scale of our different activities that drive emissions is key to prioritising the behaviour changes and technical innovations that would most effectively lead to emissions reductions at the scale required. Put simply, the impact of a change (whether behavioural or technical) can be represented as:

$$\text{Impact of change} = \text{Scale} \times \text{Change in flow} \times \text{Impact of flow}$$

For example, in construction it is possible to use post-tensioned floor slabs in place of the standard slab types, to achieve a 20% reduction in cement use (the 'change in flow' of cement entering construction). However, this technique is only applicable to a fraction of all the floor slabs that are constructed (the 'scale'), and the overall impact depends on the impact factor of the flow (in this case, GHG emissions per tonne of cement). Clearly, the overall impact of a change depends on all of these factors. An understanding of all three is critical to formulating a roadmap for change (Section 3.2) that can really reach Absolute Zero emissions. The same applies to research agendas, where there has been more research and policy interest in reducing food waste than on reducing meat consumption, despite the former contributing an estimated 1–2% to emissions and the latter an estimated 50% . Data on how things are currently happening can also support change through identifying 'bright spots' where good practice is already happening .

Looking to the future

However, understanding the present is not enough. Many of the decisions that will influence emissions in 2050 must be made far in advance, such as designing buildings, investing in energy infrastructure and car manufacturing plants (Section 1). These decisions should ideally be robust to a wide range of possible future outcomes, such as faster- or slower-than- expected deployment of zero-carbon energy supplies, or higher or lower loading requirements for buildings in use. When this is not done

well, the result is the situation described in Section 2.3, where structural designs are routinely excessively sized, leading to proportionally excessive carbon emissions. In contrast, it has been shown that an initially-smaller design that allows for reinforcement to be added to beams in future, if needed, would lead to lower lifetime emissions .

There are many possible pathways to zero emissions in 2050, and different reports can reach very different conclusions from by focusing on different scenarios. To provide clarity on our options to reaching Absolute Zero, we need to compare different proposals on a common basis and highlight the different starting assumptions that lead to different conclusions (see box story overleaf for an example).

Getting better information

Despite these important roles that information about our use of resources plays, the data we have is patchy and disconnected. There are two basic ways the situation can be improved: collecting better data, and making smarter use of the limited data we do have.

The UK Government's Resources and Waste Strategy has recognised that 'lack of reliable data on the availability of secondary materials is cited by industry as a barrier to their use', and proposes a National Materials Datahub to address this issue by providing 'comprehensive data on the availability of raw and secondary materials, including chemicals, across the economy to industry and the public sector, and by modelling scenarios around material availability'. The Office for National Statistics is leading the initial development of such a Datahub. As well as official statistics such as these, there is a large body of evidence contained in academic work which is currently difficult to access. Efforts towards Open Science practices ins fields such as Industrial Ecology are starting to improve the discoverability and reusability of this knowledge.

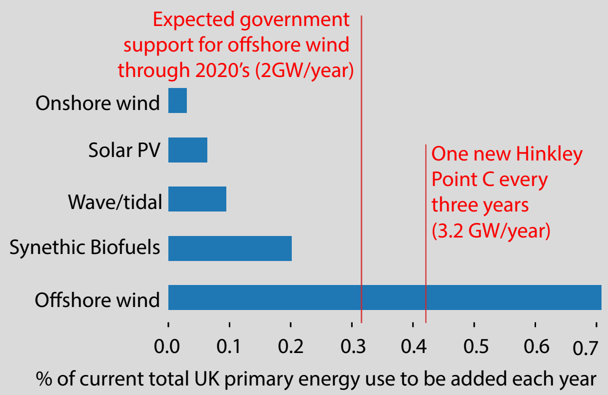
Better information will also be needed within and across supply chains, but there are challenges that will have to be overcome before this can be achieved. The first

Why aren't all plans for zero emissions the same?

Several reports have presented scenarios for how we could achieve net-zero emissions in 2050, such as the Centre for Alternative Technology's "Zero Carbon Britain" report. Unlike the need to reduce absolute energy use described in this report, they find instead that "industrial energy use is expected to remain similar to current levels". How is it possible to reach such a different conclusion on the same question?

It is easier to see the differences by looking at the different assumptions made about the energy system. The figure on the right shows the deployment rates implied by their scenario, together with some reference points to provide context. The Zero Carbon Britain report has much more optimistic assumptions about the deployment rates of renewable generation technologies, especially very early-stage technologies such as producing liquid fuels from biomass – which has not yet been proven at commercial scale – and wave & tidal generation. Assumed deployment rates for offshore wind are also high, requiring a doubling in the speed of installation envisaged in the Governments plans for support through the 2020s.

Figure 3.3: Rates of increase in "Zero Carbon Britain"



is information gathering: it is still not normal practice by suppliers to gather information on all facets of their manufacturing process. Secondly, for business to share collected data with rest of the chain rather than storing in silos. Current corporate practices mean information is often not shared even with different groups within the same organisation let alone with "outsiders". In the information age, industry has remained closed to information out-flow. This may be attributed to good reasons, but the achievement of Absolute Zero requires, possibly above all else, the will to cooperate. The final challenge is analysis of the data and making sense of it. Gathering, storing, processing and presenting data is an energy intensive and expensive task, therefore currently most organisations do not have the appetite to undertake this without proven returns.

Digital tools can potentially help to enable this position. A universal and global approach to IP law and the tracking of information using technologies such as blockchain can greatly increase the confidence of organisations into opening their doors and sharing more of their information. By doing so it is possible to dramatic reduce resource duplication whilst enhancing visibility of resource usage. This could allow businesses to make long-term strategical decisions that lead to higher profitability whilst reducing energy usage and CO_2 production.

Key Message: Good information is critical to transitions in individual behaviour, business operations and in supporting government action, but there are challenges to overcome in collecting and communicating the required information effectively to support decisions and influence behaviour.

4. Opportunity

Key Message: Absolute Zero requires societal change. This will provide opportunities for growth in business, education and research, governance and industrial strategy. To achieve zero emissions we must only pursue the right opportunities and restrain activities which are no longer compatible with a zero emission society.

4.1 Opportunities in business:

This report has revealed an overwhelming wealth of innovation potential for businesses – but not in the area that dominates current discussion about mitigating climate change. Carbon Capture and Storage or Utilisation and "the Hydrogen economy" are important development opportunities and may be significant beyond 2050, but won't play any significant part in national or global emissions reductions by 2050, because implementation at meaningful scale will take too long. Instead, taking the target of Absolute Zero seriously requires a massive expansion of wind and solar power generation, along with the infrastructure required to install, manage and deliver this power and the fertile supply chains of material extraction, production, construction and manufacturing.

The key innovation opportunities revealed in this report are not about how we generate energy, but how we use it. Meeting the target of Absolute Zero requires adapting to using around 60% of the energy we consume today, which without innovation will require restraint. However, section 2 of the report has revealed a tremendous space for business innovation and growth in expanding the benefit we receive from energy use. For the past century, our economy has grown based on an assumption of virtually unlimited energy supply without consequences. Unsurprisingly, this has led to extremely inefficient use – for example with cars weighing around 12 times more than the people within them. The more rapidly the UK commits to delivering its legally binding target, the greater the benefit it will extract from business innovation opportunities. Without question, some incumbent businesses such as the fossil fuel industries, will decline and inevitably they currently spend the most money on lobbying the government to claim that they are part of the solution. This is unlikely.

Instead, future UK growth depends on exploiting the opportunities created by the restraint of Absolute Zero. For example:

- All current aviation activity will be phased out within 30 years, which creates an extraordinary opportunity for other forms of international communication (for example using the technologies of today's gaming industry to transform today's backwards-looking video-conferencing), for the travel and leisure industry to expand more localised vacations and for developments in non-emitting mid-range transport such as electric trains and buses
- The markets for electric cars, electric heating at all scales and temperatures, electric motors at all scales, building retrofit and thermal control are certain to grow at rates far ahead of the recent past. Electric cars comprise a small fraction of new sales today, but under current regulation will, by 2040, have captured 100% of the market. Given the total energy supply constraint of Absolute Zero, the clear evidence of Fig. 2.6 is that the total market will either contract or shift rapidly towards smaller vehicles – this is a fertile and under-populated space.
- Cement and blast furnace steel production will be illegal within 30 years, yet our demand for construction and manufacturing will continue. To meet this demand our supply of bulk materials must transform and there is high-volume innovation potential for non-emitting cement substitutes, for technologies to support high-quality steel recycling, and in the open space of "material efficiency": using half the material per product and keeping the products in use for twice as long.

Beyond the 2050 target of Absolute Zero, technologies that exist at early development stages today may expand into valuable business streams. These include:

- Carbon Capture and Storage or Utilisation applied to fossil fuel power stations, steel or cement production.
- The "hydrogen economy" once there is spare capacity in the supply of non-emitting electricity
- Other forms of electrical transport, including shipping and aviation

The 100% target of the Climate Change Act creates an extraordinary opportunity for UK business to develop the goods and services that will be the basis of a future global economy. However, the biggest commercial opportunities are not breakthrough but incremental developments from today's technologies.

4.2 Opportunities in welfare and education

Today's secondary school entrants will be 43 in 2050. At that age, they will be in leadership positions, so the obvious question is what skills they should be developing now and in their subsequent higher-education years to underpin their decision-making abilities in a very different future world? The legacy of education is surely to know that it is the quality of the questions which one is able to ask which will lead to success. Asking the right questions is a sign of deep education, while answering these questions is an altogether easier proposition even if research is needed.

How do we move from answering questions as the staple of education to asking questions as the hallmark of a necessary education for future uncertainty? Climate change provides us with exactly this opportunity. Some of the current syllabi in secondary schools will be irrelevant in future, and there will be new skills that school children will require. The same is true in universities, both in teaching and in research, where a clear distinction must be made between mitigation actions that can be deployed today through chosen restraint and innovations that might ease the challenge of restraint in future. The former implies hard decision-making, while the latter implies real opportunity.

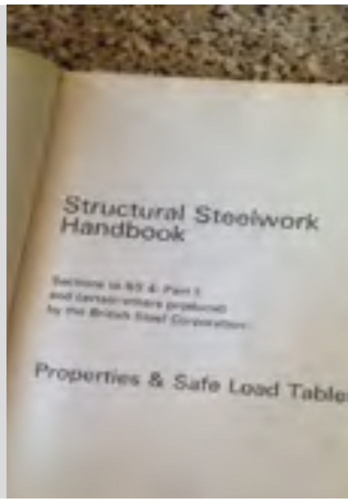
Starting with the difficult decisions, an educational setting should provide a timeline for actions to be taken by humanity in order to ensure that we hit our carbon-reduction targets by 2050. Plans cannot merely relate to actions. They must also relate to the timings of such actions, as any Gantt Chart does. By working backwards from 2050, and sequentially working out the order and timing in which key mitigation actions need to be taken, a roadmap for the necessary restraint can be established. Across the secondary school system, this roadmap is essential in eliciting the questions which will inevitably come from the school children. This will enable an exploration of real change in the mind sets of those who will need to embrace change more than ever before later in their lives. Huge questions will emerge, such as: will internal-combustion engines disappear, will aeroplanes disappear, will meat-and-dairy agriculture disappear and will we need to stop building things? By empowering school children to realise that asking the huge questions is appropriate, we will enable change to be embraced through education. The timing of the change should lead to questions of transition towards electrification, or the trade-offs between energy and labour in delivering services across a whole range of economic activities, for instance. What are the implications for consumption or ownership in a changing society, and how can we ensure that material use down to the finest granularity is all encapsulated in circularity?

Across the education system, we should be seizing the opportunity for the next generation to grow up with 'best practice': from the food available in schools, the way children get to school, to the way school buildings are used. All schools could immediately switch to providing meat-free meals – reducing emissions and promoting healthy eating. Existing efforts to change travel habits aimed at avoiding local air pollution around school gates can be extended to support parents and children in low-carbon travel to school wherever possible. Many schools already feel the need to keep heating temperatures low in an effort to make severely constrained budgets balance, which is a side-effect that could be standardised across the system to help establish the normality of lower-energy, lower-temperature heating setpoints.

Changing Building Design Practices through Education in the 1970's

In the 1970's, British Steel saw an opportunity to expand their market for structural steel sections, by persuading UK clients and the construction supply chain to switch from concrete framed buildings (which remain more common in many European countries even today) to steel framed buildings, like the one illustrated on page 35. Instead of seeking Government support to subsidise or legislate to support this change, they instead developed high quality teaching material and supported the development of new courses in all major civil engineering degree courses about design with steel. As a result, the next generation of graduate civil engineers entering the profession were equipped to use more steel, and expected it to be more normal practice.

This suggests an opportunity to develop teaching material that reconfigures society to adopt new approaches to thriving in a zero carbon economy, by changing the way we live and work.



Looking beyond the need for this kind of restraint in the short term, there are enormous opportunities in education which we could be embracing now to ensure that when the painful period of mitigation nears an end, we have an educated population ready to take advantage of the zero-carbon era. We do not have the luxury of time to wait for graduates to emerge who know something about future possibilities. We need to exploit the creativity, intelligence and ideas of our students before they have graduated. But what are the innovations which we should be teaching? We are still researching them, and research takes time.

A potential solution to this unwanted time dependency is Vertically Integrated Projects (VIP), a concept developed by Georgia Tech, and which is now also operating successfully at the University of Strathclyde in the UK. In essence, undergraduate students across all years of study are involved in major inter-disciplinary research projects, each of which is aimed at a long-term complex research question. Strathclyde ensures that the 17 UN Sustainable Development Goals are central to their VIPs. In this way, undergraduate students not only learn key skills for the future, but they are indeed themselves creating knowledge for all simultaneously. It is the combination of empowerment, inter-disciplinarity, huge research questions, confidence and space to explore without fear of failure which brings this concept alive. In an era of extraordinary change and equally extraordinary opportunity, it feels right and proper that the most fertile brains are exploited and enriched in such a manner.

There are questions which the era of restraint begs concerning research and its funding in universities and companies. Is it right, for instance, to be funding research using public funds which includes technology-developments which we know are not aligned with the 17 UNSDGs? Examples might include trying to squeeze out efficiency gains in 20th century technologies or researching products which rely on scarce materials.

Bold decisions are needed by schools, universities and funding bodies if we are to galvanise education and action towards rapid mitigation, followed by innovative opportunity. Across the span of education and research, areas of importance highlighted by this report include:

- Technologies and their constraints in efficient use of electric motors and electric heating
- The trade-offs between energy and labour in delivering services across the range of all economic activities
- Understanding of welfare dependent on self-actualisation rather than consumption or ownership
- Maximising the value of secondary materials and the realities of reduce/re-use/recycling/"circularity" etc.
- Renewable generation and the system of its efficient use.

The opportunity in education spans from preparing for the restraint required to achieve Absolute Zero to preparing for the longer-term transformation of prosperity beyond 2050. What could a world look like without cement, internal combustion engines or aeroplanes? We need to educate students for this new reality, and embrace the opportunity, rather than the threat, which this reality offers.

4.3 Opportunities in governance

The Olympic Games was one of the biggest government projects which was delivered on time and to budget. It was a great success and a source of national pride. There are parallels between hosting the 2012 Olympic Games and delivering Absolute Zero. Both commitments were made on a world stage where failure to deliver would result in national embarrassment; both projects require collaboration of multiple government departments, industry and the general public; and both require delivery processes and structures to be built from scratch. We managed to overcome these challenges for the Olympics, but delivering Absolute Zero has additional challenges.

To achieve our emissions goal we have to sustain momentum over a longer timespan than for the Olympics. We also have to consider life beyond 2050, what is the legacy of the net-zero emissions project? The Olympic legacy has been criticised for under delivering, so we must do better this time to ensure society can thrive in a zero emissions world beyond 2050. When we hosted the 2012 Olympics we could draw on the experiences of historical Olympic Games to inform decisions being made, but no country has met a zero-emissions target before, there is no precedent for us to follow. Finally the 2012 Olympic developments generated growth in the delivery of new and improved infrastructure and services. Meeting the net-zero emission targets will generate growth in some industries, but will also require the decline of others, this is likely to be met with resistance as those who benefit from the status quo resist change.

The London Olympics highlighted the following key lessons that could be transferred to emissions targets:

- Form a responsible body in government
- Limit innovation to knowledge gaps to reduce risk
- Maintain a unified cross party vision
- Have a protected and realistic budget
- Invest in programme management & delivery with discipline on time and scope change
- Empower people, with the right skills and track record to deliver against clear responsibilities
- Ensure accountability, with scrutiny and assurance given when risk is identified.

This section attempts to explore the first three of these lessons, the most relevant to Absolute Zero commitment.

Responsible body in government:

For the 2012 Olympics an executive non-departmental public body (NDPB) called the Olympic Delivery Authority (ODA) was established to deliver the infrastructure and venues required for the Olympics. In parallel the London Organising Committee of the Olympic and Paralympic Games (LOCOG) was established as a private company limited by guarantee to fund and stage the Games. The government set up the Government Olympic Executive (GOE) within the Department for Culture, Media & Sport. The GOE was responsible for other elements of the games, such as transport and security, as well as overseeing the ODA and LOCOG. Although the governance structures were considered to be complex, it has been reported that they allowed quick decision making and ensured people remained engaged throughout the delivery process.

Figure 4.1: Olympic-style governance structure for UK Climate Emergency Response:

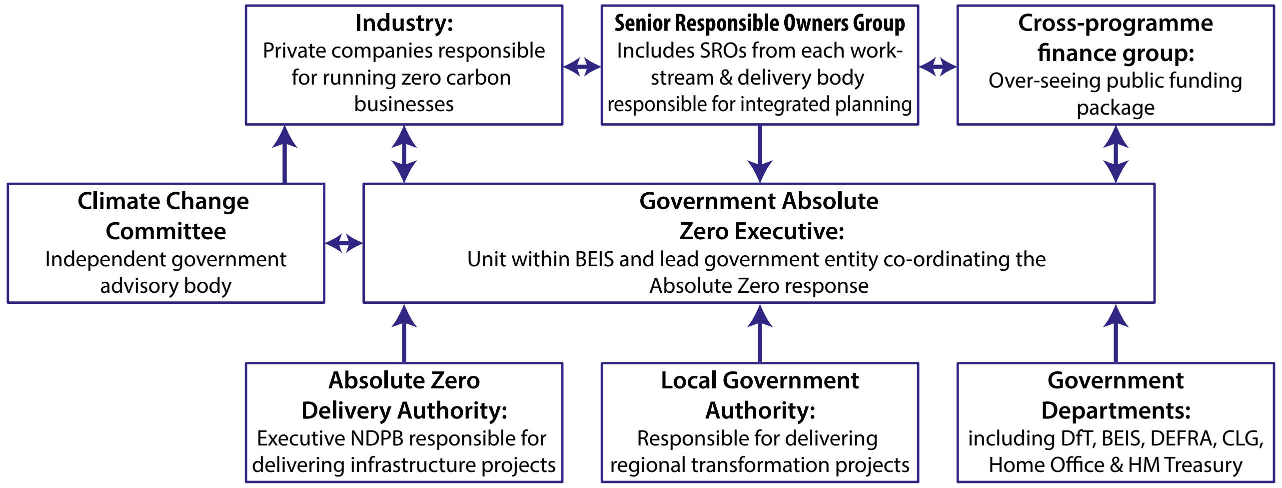


Fig. 4.1 gives an example of how this structure could be applied to delivering Absolute Zero. The proposed Government Absolute Zero Executive would be even more critical since it would be required to coordinate multiple industries and organisations, rather than just two delivery bodies as was the case in the 2012 Olympics. The governance structure proposed in Fig. 4.1 would enable fast decision making and accountability to meeting interim goals, which is essential if we are going to meet the 2050 zero emission targets.

Limit innovation:

The Government Olympic Executive deliberately limited innovation to fill knowledge gaps. This move was considered to be counter-intuitive, but it was successful. Relying only on proven technologies reduced the risk of failure and avoided the temptation to use the Games to showcase risky innovation. Although the Olympics did not innovate new ways of doing things, it did require existing activities to be scaled up to meet unprecedented demand. As Jeremy Beeton, Director General of the Government Olympic Executive explains "It was a whole new business model for London." This scaling up of proven technologies and systems was seen as a risk in itself. This lesson should be transferred to the task of meeting the 2050 zero-emission targets. We have identified in this report 'bright spots' where best practice exists and could be scaled up, if we apply the Olympic approach, this is enough of a risk, and further innovation should be limited. That said, we don't currently have all the answers to transition to a net-zero society and some innovation will be necessary, but approached with caution.

Cross party vision:

The delivery of the 2012 Olympic Games was supported by a unified cross party vision which was maintained through regular progress reports. This enabled stability throughout government changes which allowed the project to maintain momentum. The UK's approach to climate change does not currently have a unified cross party vision. For example in 2019, the Labour party proposed moving the zero-emissions targets to 2030. Whilst parties argue over goals and targets, actions are not being taken and we fall further behind on the journey to zero-emissions. It is essential that government generate a unified cross party vision to emulate the success of the 2012 Olympics which was able to create clear roles and responsibilities which fostered collaborative problem solving, not blame shifting.

If we are to learn from our previous successes, the net-zero target is more likely to be achieved through the establishment of the Government Absolute Zero Executive and the associated Delivery Authority with cross party support. The Executive should set a strategy which is realistic and risk averse, without over-reliance of innovation.

4.4 Opportunities for Industrial Strategy in the UK

With a legal target, now set by the UK government, to achieve net-zero emissions by 2050, UK business are developing organisational strategies to ensure they will prosper in a zero emissions business landscape. This report has shown how placing resource efficiency at the heart of industrial strategy can enable businesses to prosper, but this requires significant changes in the products, production processes and supply chain systems which currently make up the industrial sector.

The UK government has invested £5m in the UK FIRES research programme, bringing together the academics from six universities who have written this report with businesses across the supply-chain in a 'Living Lab'. The subscribing industrial partners pose strategic challenges to the academic research team and test emerging solutions in practice.

UK FIRES research will support businesses in developing industrial strategies to achieve zero emissions in key four areas illustrated in Fig. 4.2:.

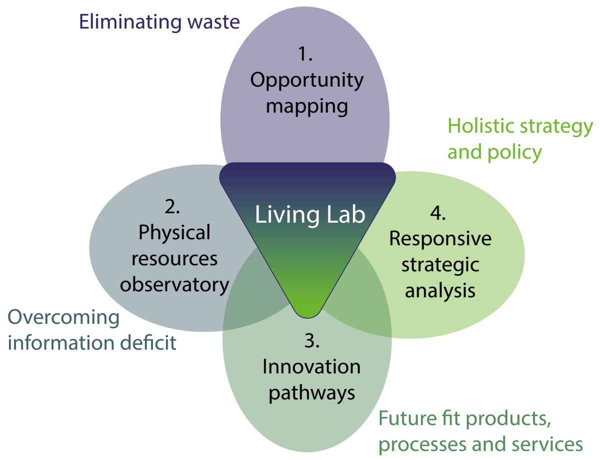
1. Opportunity mapping will identify new methods of design and manufacture which improve on existing best practices. Software tools to enumerate all options for design and delivery of resource intensive goods with today's technologies will be developed and commercialised.

2. The tools of recent advances in data science will be applied in a new Resource Observatory, to provide the highest-resolution insights into the UK's use of resources, with new metrics, scenarios and search tools used to identify opportunities for valuable innovation and efficiency gains. These tools will give UK FIRES industry partners foresight in decision making.

3. Through specific case studies of process, product and service innovation, the UK FIRES consortium will seek to define the innovation pathways by which the new practices of resource efficiency can be the basis of thriving UK businesses. The Living Lab industrial partners will be supported to exploit these opportunities in practice.

4. To support holistic industrial strategies and supply chains UK FIRES researchers will create responsive strategic analysis tools. Living Lab industrial partners can then apply these findings through the generation of new business models in collaboration with the UK FIRES Policy Champion.

Figure 4.2: UK FIRES programme structure



The output of the UK FIRES Living Lab collaboration will be published in quarterly reports, made available for government and industry, to provide reliable information to inform the development of their net zero industrial strategies. Focus themes for future Living Lab reports are now outlined.

UK FIRES connections

UK FIRES aims to provide data, tools, experience and analysis to support its partner companies in specifying new business models, diffusing innovation, giving holistic foresight to new opportunities and improving best practice as they pursue Resource Efficiency for a net-zero industrial strategy.

UK FIRES members can access the resources of the £5m programme through:

- Quarterly meetings of the Living Lab, in which members across the bulk materials supply chains specify target challenges for future work, support current activity and provide feedback on the application of programme insights in practice.
- Early access to emerging analysis of strategic opportunities
- Shared or dedicated PhD students applying the collective insights of the UK FIRES team to specific commercial contexts
- Pilot testing of new tools developed in the research programme
- Shaping the agenda and participating in the Annual UK FIRES Resource Efficiency Forum.

For more information contact info@ukfires.org.uk

Notes to the figures

Figure 1.1: Assuming an additional 400 TWh/year is needed by 2050, to be supplied by offshore wind, we need to have 115 GW of offshore wind capacity operational by 2050 (assuming an approximate capacity factor of 40% for offshore wind). The Crown Estate estimates that projects with seabed rights being awarded in 2021 would become operational by 2030, so all projects needed for 2050 would need to be started by 2040. Although current capacity is 9 GW, there is an additional 25 GW already in the pipeline. Therefore new projects need to be established and built at a rate of 4.5 GW/year for the next two decades.

Figure 1.3: Data from the International Energy Agency (IEA, 2018) with data on CCS installations at power-stations from the Oil and Gas funded pro-CCS lobby, Global CCS Institute.

Figure 1.4: This analysis by Vaclav Smil (2014) looks at global deployments of the three major fossil fuels, relative to total world energy demand at the time. Some faster transitions have occurred in individual countries, as shown in the box story on page 3.

Figure 1.5: The data in this figure come from a survey of academic reports by Gross et al. (2018) on the introductions of a range of new technologies - which generally showed that energy technology changes are among the slowest to reach full deployment.

Figure 1.6: Sectoral breakdown of UK energy demand from DUKES (2019); UK domestic internal temperature history from Official Statistics (2014); European car weight (and similar trends for all other regions) from the Global Fuel Economy Initiative a partnership with the International Energy Agency and others.

Figures 1.7–1.8: All constructed using data from DUKES (2019). n.b. there are many ways of calculating the equivalence of fuels - typically, the units of "Mega-tonnes of oil equivalent" are used, but this is not obvious when comparing primary electricity (nuclear or renewably powered electricity) which is not the result of conversion in a power station. We have attempted to be consistent in reporting the Mtoe equivalence of total UK energy demand.

Figure 1.9: Constructed with yearly data on electricity supplied in the UK from DUKES (2019). Electricity generated via non-emitting sources is shown as stacked lines whereas electricity generated from coal, gas and oil is plotted in a separate line.

Figure 1.10: The cost figures represent the weighted average of the levelized cost of electricity of commissioned solar and onshore wind projects in the United Kingdom and were obtained from IRENA (2018). For solar photovoltaic generation only cost figures after 2010 were reported. The figures were converted from US dollars to Pound sterling using yearly average exchange rates. The power density points for onshore wind were obtained using the power density of 61 wind farms commissioned between 1992 and 2007 compiled by Mackay (2009). These data-points were averaged by year of commissioning using installed capacity as averaging weight. The installed capacity and commissioning dates were obtained from Department for Business, Energy & Industrial Strategy (2019). The power density points for solar photovoltaic were estimated using best available cell efficiency data provided by National Renewable Energy Laboratory (2019) for multi-crystalline Si Cells in conjunction with the UK's annual insolation data from Photovoltaic Geographical Information System (2017) and a performance ratio of 84 % obtained from National Renewable Energy Laboratory (2013).

Figure 1.11: This chart was constructed using 2005 global energy data supplied by the International Energy Agency, and multiple sources to estimate the allocation of energy to devices and "passive systems" - the equipment (such as a car or house) in which the final form of energy (typically mechanical work or heat) is exchanged for a service. The chart is from Cullen et al. (2010), which has a lengthy Supplementary Information file giving every detail of the estimations. It is currently arduous to update this form of analysis - and a target of the UK FIRES research programme is to use the emerging techniques of Data Science to make this easier - but we assume that the proportions of energy use have remained approximately similar from 2005 to today.

Figure 1.12: Data taken from Haberl et al. (2007), subject to uncertainty due to definitions and the need for estimation of un-measurable data.

Figure 1.13: all the values represent "real world" efficiencies of conversion devices. The efficiency of electric heater, light and electronic devices was obtained by Cullen and Allwood (2010). The efficiency of electric battery charging applies to charging road vehicles and was obtained from Apostolaki-Iosifidou et al. (2017). The efficiency of heat pumps is the average of all the values reported by Shapiro and Puttagunta (2016) who quantified the coefficient of performance of these devices during use in residential buildings. The remaining values were obtained by Paoli and Cullen (2019).

Figure 1.14: Figure 1.14: This Sankey diagram was obtained using UK energy consumption data for 2018 from National Statistics (2018) and the conversion factors of figure 1.13. The data is disaggregated by energy type and sector. The total electricity demand was scaled to account for population growth using the predictions from National Statistics (2019) and the distribution losses from OECD/IEA (2018). In addition to the efficiencies of figure 1.13, the efficiency of charging electric car batteries was taken from Apostolaki-Iosifidou et al. (2017).

Figure 1.15: This analysis, building on the energy diagram of fig. 1.11 was developed in order to provide clarity for the IPCC's 5th Assessment Report, and based on global emissions data for 2010 taken from the EU's EDGAR database of global emissions. The original analysis was published as Bajzelj et al (2013) but has been modified here to clarify the difference between emissions that occur as equipment (cars, boilers, lights) are used, and those that occur in industry when making equipment that lasts for more than one year. The UK FIRES programme is largely concerned with these industrial emissions, so clarifying the way that stock of goods in service (and therefore their requirements for energy inputs) evolve over time, is of critical importance to understanding how to develop an Industrial Strategy compatible with Absolute Zero.

Figure 2.1: This figure is a summary of the analysis leading to figs. 2.2, 2.4, 2.11 and 2.19.

Figure 2.2: Today's values on energy use in buildings were obtained from UK energy statistics (HM Government, 2019). The values in the second column were calculated using the method described in the notes for Figure 1.13 and the efficiency values estimated by Cullen et al. (2010). The values in the third column were calculated considering the efficiency improvements of better insulation of roofs and attics, and the installation of double-glazed windows estimated by the IEA (2013), considering the number of surviving buildings in 2050 estimated by Cabrera Serrenho et al. (2019).

Figure 2.3: Impact of new buildings and retrofit from Cabrera Serrenho et al. (2019) and IEA (2013), use of heat pumps for space heating (MacKay, 2008), Appliance efficiency improvements (ECUK, 2019, table A1).

Fig 2.4: Today's values on energy use in transport were obtained from UK energy statistics (HM Government, 2019) and IEA energy balances (IEA, 2019). The values in the second column were calculated using the method described in the notes for Figure 1.13 and the efficiency values estimated by Cullen et al. (2010). The values in the third column were calculated considering no international aviation, the substitution of domestic shipping and aviation by rail, a reduction of energy use in passenger road transport to 60% of current levels (as demonstrated in Figure 2.6) and a reduction of 30% in road freight energy demand (Dadhich et al., 2014).

Figure 2.5: Emissions factors from the BEIS Greenhouse gas reporting conversion factors 2019. Equivalent energy intensities calculated using the BEIS values for fuel CO2e intensities, apart from rail which was calculated using the CO2e intensity factor for electric traction. Radiative forcing corrections are included in the emissions intensities for flying. Data for cars are for the current average fleet of petrol cars.

Figure 2.6: Developed assuming a linear correlation between vehicle weight and fuel consumption (there is reasonable empirical support for this) and with current vehicle weight taken from fig. 1.6.

Figure 2.7: Effect of vehicle weight reduction (Cullen et al., 2011), logistical improvements (Dadhich et al, 2014), regenerative braking (Gonzalez-Gil et al, 2014), drag and rolling resistance (Cullen et al, 2011).

Figure 2.8: developed considering the number of cars purchased and discarded in the UK estimated by Serrenho et al. (2017), with full adoption of electric cars in new sales from 2025.

Figure 2.9: This is constructed from emissions intensities reported by Scarborough et al. (2014) combined with data on portion sizes and calories per portion from the UK's National Health Service (www.nhs.uk/live-well/healthy-weight/calorie-checker/). There is significant uncertainty behind the numbers in this figure - due to the difficulty of defining the boundaries of analysis for the emissions calculation, and the arbitrary size of portions - but the scale of difference between the two foods is significant.

Figure 2.10: Is taken from Bajzelj et al. (2014) as used for fig. 1.15

Figure 2.11: Current energy consumption data from ECUK: End uses data tables, 2018, split by 2 digit SIC. Where further disaggregation was needed e.g. chemicals sector, consumption was split by the according proportions in 2007, where data is provided at 4 digit SIC level. Energy embodied in net imports for steel, cement, plastics and textiles by multiplying the energy intensity of UK production by the net imports of each material; tonnage data from Allwood et al. (2019), Shanks et al. (2019), ImpEE project and Allwood et al. (2006) respectively. Energy loss in electricity production is from DUKES aggregate energy balances, 2018. Energy for direct fuel combustion was converted to electricity using the relevant efficiency

values provided in Figure 1.11. Demand reduction interventions: 1) reduce scrap in metal processing to half of the current level, i.e. half of the savings identified in Milford et al. (2011); 2) reduce metal consumption by 20% by avoiding over-design of metal products, consistent with Section 2.3, Section 2.1 and Allwood and Cullen (2012); 3) A 75% cut in cement output based as described in Section 2.2; 4) Life extension of cars, clothes and industrial goods, reducing output of these products by 40%, 45% and 40% respectively. Proportions of steel and aluminium usage as per the global data provided in Allwood and Cullen (2012). 5) Reduction in plastic packaging by 25%; in the UK plastics packaging is 2.2Mt out of 6.3Mt total consumption estimated from the ProdCom database; 6) A 25% cut in fertiliser use, half of the reduction identified for Netherlands in Section 2.2; 7) Reduction of food waste leading to a 3% cut in output in the food processing industry as per the WRAP Courthald Commitment; 8) More efficient use of electricity in industry by improving efficiency of motors, heat pumps for space heating, process heating and lighting from 60% to 80%, 104% to 400%, 80% to 90% and 13% to 15% respectively, consistent with Cullen and Allwood (2010).

Figure 2.12: Original analysis for this report developed by C.F.Dunant

Figure 2.13: Developed from Cooper et al. (2014).

Figure 2.14: Original version of this figure published in Allwood et al. (2012) modified here to show primary production from blast furnaces declining to zero in-line with the zero emissions target.

Figure 2.15: Developed from Daehn et al. (2019)

Figure 2.16: The flows of plastics in the UK were estimated from the UK trade statistics (Eurostat, 2018), using a systematic allocation of trade product codes into the various stages of the supply chain, and by estimating the plastic content and application for each produce code.

Figure 2.17: Developed from Shanks et al. (2019

Figure 2.18: A survey of structural engineers, MEICON showed that, in general, structural engineers are prepared to over-design structures routinely in order to pre-empt any possible later changes to the brief, to deal with design risk and to cover for the possibility of construction error. Material efficient design, for example using fabric form-work, could allow substantial reduction in over-use without any increase in risk.

Figure 2.19: Current energy consumption data from ECUK: End uses data tables, 2018, split by 2 digit SIC, and where further disaggregation needed (e.g. separating primary and secondary wood processing) 2007 data at 4 digit SIC level. Energy loss in electricity production, conversion of direct fuel combustion to electricity and demand reduction interventions are all as described in Figure 2.23.

Figure 2.20: Allocation of emissions from global materials production to the six key sectors based on material flow analysis of steel (Cullen et al., 2012), cement (Shanks et al, 2019), Aluminium (Cullen and Allwood, 2013), plastic (Allwood et al, 2012), Paper (Counsell and Allwood, 2007), food (Bajzelj et al. 2014)

Figure 2.22: This data is made publicly available by the car industry. Horton and Allwood (2017) review the data, and explore several options by which this form of material inefficiency could be addressed.

Figure 2.23: Manufacturing energy efficiency imporvements (Paoli and Cullen, 2019), scrap metal reduction (Milford et al, 2011), reducing over-design and ilfe-extension (Allwood & Cullen, 2012), plastic packaging (Lavery et al, 2013), food waste (WRAP, 2018)

Figure 2.24: The proportions of losses here are indicative and based on data in Li et al (2016). The actually losses vary according to the way the hydrogen is stored and the precise pattern of demand by which electricity is extracted from the fuel cell.

Figure 3.3: The Zero Carbon Britain (Allen et al, 2013) report sets out a scenario for energy supply in 2050. We have calculated the amount that energy generation from each source would have to increase in every year from now to 2050 to achieve the target. Increases are presented as a percentage of current UK primary energy demand of about 2200 TWh (BEIS, 2019). Expectations for Government support for offshore wind in the 2020s are from the Crown Estate (2019), converted into generation values with a representative capacity factor for offshore wind of 40%. A review of Biomass to Liquid systems for transport fuel production reports that no commercial scale plants are yet operating (Dimitriou, 2018).

References

Allen et al (2013) '*Zero Carbon Britain: Rethinking the Future. Centre for Alternative Technology. Centre for Alternative Technology Publications*'. Available at: https://www.cat.org.uk/info-resources/zero-carbon-britain/research-reports/zero-carbon-rethinking-the-future/.

Allwood, J. M., Laursen, S., Rodriguez, C. M., Bocken N. M. P. (2006) *Well dressed? The present and future sustainability of clothing and textiles in the United Kingdom*, Cambridge: University of Cambridge, Institute for Manufacturing. Available at: https://www.ifm.eng.cam.ac.uk/insights/sustainability/well-dressed/.

Allwood, J. M., Cullen, J. M. and Carruth, J. M. (2012) Sustainable Materials: with Both Eyes Open. Cambridge: UIT Cambridge Ltd.

Allwood, J. M. (2018) 'Unrealistic techno-optimism is holding back progress on resource efficiency', Nature Materials. doi:10.1038/s41563-018-0229-8.

Allwood, J. M., Dunant, C. F., Lupton, R. C., Serrenho, A.C. H. (2019) Steel Arising: Opportunities for the UK in transforming global steel industry. doi:10.17863/CAM.40835.

Apostolaki-Iosifidou, E., Codani, P. and Kempton, W. (2017) 'Measurement of power loss during electric vehicle charging and discharging', *Energy*, 127, pp. 730–742. doi: https://doi.org/10.1016/J.ENERGY.2017.03.015.

Bajželj, B. *et al.* (2014) 'Importance of food-demand management for climate mitigation', *Nature Climate Change*. doi: 10.1038/nclimate2353.

Bajzelj, B., Richards, K.S., Allwood, J.M., Smith, P.A., Dennis, J.S., Curmi, E. and Gilligan, C.A. (2014) Importance of food demand management for climate mitigation. *Nature Climate Change*, 4, 924–929. doi: 10.1038/nclimate2353.

BEIS (2019). *Digest of UK Energy Statistics (DUKES) 2019*. Available at: https://www.gov.uk/government/statistics/digest-ofuk-energy-statistics-dukes-2019.

BEIS (2019) *Greenhouse gas reporting conversion factors 2019*. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019.

Cabrera Serrenho, A., Drewniok, M., Dunant, C., Allwood, J.M. (2019). 'Testing the greenhouse gas emissions reduction potential of alternative strategies for the English housing stock'. *Resources, Conservation and Recycling*, 144: pp. 267-275. doi:10.1016/j.resconrec.2019.02.001.

Committee on Climate Change (2019). *Net Zero: The UK's contribution to stopping global warming*. Available at: https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/.

Cooper, D.R., Skelton, A.C.H., Moynihan, M.C., Allwood, J.M. (2014) Component level strategies for exploiting the lifespan of steel in products. *Resources, Conservation and Recycling*, 84: pp. 24-34. doi: 10.1016/J.RESCONREC.2013.11.014.

Counsell T. A. M. and Allwood J.M. (2007) Reducing climate change gas emissions by cutting out stages in the life cycle of office paper, *Resources, Conservation and Recycling*, 49(4) 340-352. doi: 10.1016/j.resconrec.2006.03.018.

The Crown Estate (2019). *Information memorandum: introducing offshore wind leasing round 4.* Available at: https://www.thecrownestate.co.uk/media/3378/tce-r4-information-memorandum.pdf.

Cullen, J. M. and Allwood, J. M. (2010) 'Theoretical efficiency limits for energy conversion devices', *Energy*, 35(5), pp. 2059–2069. doi:10.1016/J.ENERGY.2010.01.024.

Cullen, J. M., Allwood, J. M., Bergstein, E., H. (2011) 'Reducing energy demand: what are the practical limits?' *Environ. Sci. Technol*, 45, 4, 1711-1718. doi:10.1021/es102641n.

Cullen, J. M., Allwood, J. M. and Bambach, M. D. (2012) 'Mapping the global flow of steel: From steelmaking to end-use goods', *Environmental Science and Technology*, 46, 2, 13048-13055. doi: 10.1021/es302433p.

Cullen, J.M. and Allwood, J.M. (2013). 'Mapping the global flow of aluminium: from liquid aluminium to end-use goods', *Environmental Science and Technology*, 47, 3057-3064. doi: 10.1021/es304256s

Dadhich, P., Piecyk, M., Greening, P., Palmer, A., Holden, R. (2014) '*Carbon for money model — Design and development of a decision-support tool for sustainable road freight operations*'. In 26th Conference of the Nordic Logistics Research Network NOFOMA.

Daehn, K. E., Serrenho, A. C. and Allwood, J. (2019) 'Finding the Most Efficient Way to Remove Residual Copper from Steel Scrap', *Metallurgical and Materials Transactions B*. Springer US, 50(3), pp. 1225–1240. doi:10.1007/s11663-019-01537-9.

Department for Business, Energy & Industrial Strategy (2019) *BEIS Greenhouse gas reporting conversion factors 2019*. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019.

Department for Business, Energy & Industrial Strategy (2019). *Renewable Energy Planning Database (REPD): September 2019*. Available at: https://www.gov.uk/government/publications/renewable-energy-planning-database-monthly-extract.

Department for Environment, Food & Rural Affairs and Environment Agency (2018). *Our waste, our resources: a strategy for England*. Available at: https://www.gov.uk/government/publications/resources-and-waste-strategy-for-england.

Dimitriou, I., Goldingay, H. and Bridgwater, A. V. (2018) 'Techno-economic and uncertainty analysis of Biomass to Liquid (BTL) systems for transport fuel production', *Renewable and Sustainable Energy Reviews*. Pergamon, 88, pp. 160–175. doi:10.1016/J.RSER.2018.02.023.

EUROSTAT, *Eurostat [online] Statistics on the production of manufactured goods (PRODCOM)* (2018). Available at: https://ec.europa.eu/eurostat/web/prodcom/data/database.

Global Fuel Economy Initiative, *Working Paper 17, 'Wider, taller, heavier: evolution of light duty vehicle size over generations'*. Available at: https://www.globalfueleconomy.org/data-and-research/publications/gfei-working-paper-17.

González-Gil, A., Palacin, R., Batty, P., Powell, J.P. (2014) 'A systems approach to reduce urban rail energy consumption'. *Energy Conversion and Management*, Volume 80, April 2014, Pages 509-524. doi: 10.1016/j.enconman.2014.01.060.

Gross, R., Hanna, R., Gambhir, A., Heptonstall, P., & Speirs, J. (2018) 'How long does innovation and commercialisation in the energy sectors take? Historical case studies of the timescale from invention to widespread commercialisation in energy supply and end use technology'. *Energy policy*, 123, 682-699. doi: 10.1016/j.enpol.2018.08.061.

Haberl, H. *et al.* (2007) 'Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems', *Proceedings of the National Academy of Sciences*, 104(31), pp. 12942–12947. doi:10.1073/pnas.0704243104.

Haberl, H., Erb, K.-H. and Krausmann, F. (2014) 'Human Appropriation of Net Primary Production: Patterns, Trends, and Planetary Boundaries', *Annual Review of Environment and Resources*. Annual Reviews , 39(1), pp. 363–391. doi:10.1146/annurev-environ-121912-094620.

Horton, P. M. and Allwood, J. M. (2017) 'Yield improvement opportunities for manufacturing automotive sheet metal components', *Journal of Materials Processing Technology*, 249, pp. 78–88. doi:10.1016/J.JMATPROTEC.2017.05.037.

IEA (2017) *Railway Handbook 2017*. Available at: https://uic.org/IMG/pdf/handbook_iea-uic_2017_web3.pdf.

IEA (2017) *Technology Roadmap: Energy efficient building envelopes*. Paris, France: International Energy Agency.

IEA (2019) *World Energy Balances*, Paris, France: International Energy Agency.

IPCC (2014). AR5 WG3 report: Transport. Available at: https://www.ipcc.ch/report/ar5/wg3/.

IRENA (2019). *Renewable power generation costs in 2018*, International Renewable Energy Agency, Abu Dabhi. Available at: https://www.irena.

org/publications/2019/May/Renewable-power-generation-costs-in-2018.

Lavery, G., Pennell, N., Brown, S. and Evans, S., 2013. The next manufacturing revolution: non-labour resource productivity and its potential for UK manufacturing. *Next Manufacturing Revolution Report*, pp.73-87.

Li, M., Zhang, X. and Li, G. (2016) 'A comparative assessment of battery and fuel cell electric vehicles using a well-to-wheel analysis', *Energy*. Pergamon, 94, pp. 693–704. doi:10.1016/J.ENERGY.2015.11.023.

Li, Xun. (2019) *Carbon Footprint Related to Concrete Strength*. MSc thesis, University of Bath.

Mackay, D. (2009). 'Wind farm power-per-unit-area data complete', *Sustainable Energy – without the hot air*. Available at: http://withouthotair.blogspot.com/2009/05/wind-farm-power-per-unit-area-data.html.

MacKay, D (2008). *Sustainable Energy — Without the Hot Air*. Cambridge, UK: UIT Cambridge.

Marteau, T. M. (2017) 'Towards environmentally sustainable human behaviour: Targeting non-conscious and conscious processes for effective and acceptable policies', *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*. doi:10.1098/rsta.2016.0371.

Milford, R. L., Allwood, J. M. and Cullen, J. M. (2011) 'Assessing the potential of yield improvements, through process scrap reduction, for energy and CO2 abatement in the steel and aluminium sectors', *Resources, Conservation and Recycling*. Elsevier, 55(12), pp. 1185–1195. doi:10.1016/J.RESCONREC.2011.05.021.

National Renewable Energy Laboratory (2013). *Weather-Corrected Performance Ratio*. Available at: https://www.nrel.gov/docs/fy13osti/57.

National Renewable Energy Laboratory (2019). *Best Research-Cell Efficiency Chart*. Available at https://www.nrel.gov/pv/cell-efficiency.html.

National Statistics (2018), *Energy consumption in the UK*, Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/826726/2019_End_use_tables_2.xlsx.

National statistics (2019), *Overview of the UK population: August 2019*, Available at https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/articles/overviewoftheukpopulation/august2019.

OECD/IEA (2018) *Electric power transmission and distribution losses (% of output).* Available at https://data.worldbank.org/indicator/eg.elc.loss.zs.

Office of Rail and Road (2019). *Rail emissions 2018-19*. Available at: https://www.gov.uk/government/statistics/rail-emissions-2018-to-2019.

Official Statistics (2014) *United Kingdom housing energy fact file: 2013*. Available at: https://www.gov.uk/government/statistics/united-kingdom-housing-energyfact-file-2013.

Paoli, L. and Cullen, J. (2019) 'Technical limits for energy conversion efficiency', *Energy*, p. 116228. doi:10.1016/J.ENERGY.2019.116228.

Pauliuk, S. et al. (2019) 'A general data model for socioeconomic metabolism and its implementation in an industrial ecology data commons prototype', *Journal of Industrial Ecology*, 23(5), pp. 1016–1027. doi:10.1111/jiec.12890.

Photovoltaic Geographical Information System (2017). Geographical Assessment of Solar Resource and Performance of Photovoltaic Technology. Available at https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html.

Scarborough, P. *et al.* (2014) 'Dietary greenhouse gas emissions of meat-eaters, fish-eaters, vegetarians and vegans in the UK', *Climatic Change*. doi:10.1007/s10584-014-1169-1.

Serrenho, A. C., Norman, J. B. and Allwood, J. M. (2017) 'The impact of reducing car weight on global emissions: the future fleet in Great Britain', *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 375(2095), p. 20160364. doi: https://dx.doi.org/10.1098/rsta.2016.0364.

Shanks, W., Dunant, C.F., Drewniok, M.P., Lupton, R.C., Serrenho, A.C. and Allwood, J.M. (2019) 'How much cement can we do without? Lessons from cement material flows in the UK', *Resources Conservation and Recycling*, 141, 441-454. doi:10.1016/J.RESCONREC.2018.11.002.

Shapiro, C. and Puttagunta, S. (2016) *Field Performance of Heat Pump Water Heaters in the Northeast*. Golden, CO (United States). doi:10.2172/1238325.

Smil, V. (2014) 'The long slow rise of solar and wind', *Scientific American*. doi: 10.1038/scientificamerican0114-52.

Waste and Resources Action Programme, WRAP (2018) *Household food waste*: *restated data for 2007-2015*. Available at: http://www.wrap.org.uk/sites/files/wrap/Household%20food%20waste%20restated%20data%202007-2015.pdf.

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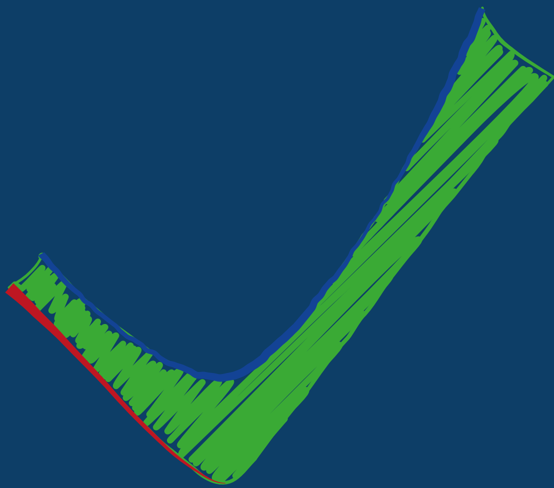

Absolute Zero: some short-term restraint in our use of energy, but no restraint whatsoever in what we most enjoy...