A417 Missing Link
TR010056

6.2 Environmental Statement
Chapter 14 Climate

Planning Act 2008

APFP Regulation 5(2)(a)
Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

Volume 6

May 2021

Infrastructure Planning

Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

A417 Missing Link

Development Consent Order 202[x]

6.2 Environmental Statement
Chapter 14 Climate

Regulation Number:	5(2)(a)
Planning Inspectorate Scheme Reference	TR010056
Application Document Reference	6.2
Author:	A417 Missing Link

Version	Date	Status of Version
C02	May 2021	Application Submission

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14.1 Introduction

14.1.1 This chapter reports the potential effects from the construction and operation of the proposed A417 Missing Link (the scheme, as detailed in ES Chapter 2 The project (Document Reference 6.2)) on climate following the methodology set out in Design Manual for Roads and Bridges (DMRB) *LA 114 Climate*[1].

14.1.2 This chapter details the methodology followed for the assessment, summarises the legislative and policy framework related to climate change and describes the existing and projected future local and regional baseline environment in the area surrounding the scheme. Following this, the design, mitigation and residual effects of the scheme are discussed, along with any limitations of the assessment.

14.1.3 To align with the requirements of DMRB LA 114 Climate, the *National Policy Statement for National Networks* (NPSNN) and the Infrastructure Planning (Environmental Impact Assessment) Regulations 2017 (the EIA Regulations) the climate assessment includes the following elements:

- **Impact of the scheme on climate** (greenhouse gas emissions (GHG) assessment): the effect on the climate of GHG emissions arising from the scheme, including how the scheme would affect the ability of government to meet its carbon reduction plan targets.
- **Vulnerability of the scheme to climate change** (climate change resilience (CCR) assessment): the resilience of the scheme to climate change, including how the scheme design has been adapted to take account for the projected impacts of climate change[2].
- **In-combination climate impacts** (ICCI) assessment: the combined effects of the impacts of the scheme and potential climate change impacts on the receiving environment.

14.2 Competent expert evidence

14.2.1 The climate lead, responsible for this chapter of the Environmental Statement (ES), is a Chartered Environmentalist (CEnv) with a Civil Engineering degree MEng (Hons) and a Doctorate in Environmental Technology (EngD). Further details are provided in ES Appendix 1.2 Competent expert evidence (Document Reference 6.4).

14.3 Legislative and policy framework

14.3.1 This section provides a review of legislative, policy and strategy positions around climate change and development of highways. They range in relevance from those that are directly applicable to the scheme and those which provide wider policy context.

Legislation

Climate Change Act

14.3.2 The Climate Change Act 2008[3] committed the UK to its first statutory carbon reduction target to reduce carbon emissions by at least 80% from 1990 levels by 2050. The Climate Change Act 2008 (2050 Target Amendment) Order 2019[4] amended the Climate Change Act 2008 by introducing a target for at least a 100% reduction of GHG emissions (relative to 1990 levels) in the UK by 2050,

following advice from the Committee on Climate Change[5]. The 100% reduction is often referred to as 'net zero' GHG emissions.

14.3.3 The Climate Change Act 2008 requires that five-yearly carbon budgets are set and not exceeded to ensure that regular progress is made towards the target. The first three carbon budgets were set in 2009, with the fourth and fifth following in 2011 and 2016 respectively, as outlined in Table 14-1. The UK Government agreed with the recommendation from the Climate Change Committee on the sixth carbon budget on Tuesday 20 April 2021. The stated intention is that this new target will be enshrined in UK law by the end of June 2021.

14.3.4 The third, fourth and fifth carbon budgets, as set out in the Carbon Budgets Order 2009[6], the Carbon Budget Order 2011[7] and the Carbon Budget Order 2016[8], are based on an 80% reduction as legislated by the Climate Change Act 2008. The recommended sixth carbon budget[9] is based on the target for 100% reduction in emissions by 2050. GHG emissions from the scheme are reported against the latest legislated carbon budgets, in line with the requirements of DMRB LA 114 and the NPSNN (Paragraph 5.17).

Table 14-1 UK third, fourth and fifth carbon budgets (as legislated by the Climate Change Act 2008 and set out in the Carbon Budgets Order 2009, the Carbon Budget Order 2011 and the Carbon Budget Order 2016)

Carbon budget	Carbon budget level - million tonnes of carbon dioxide equivalents ($MtCO_2e$)
Third carbon budget (2018 - 2022)	2,544 $MtCO_2e$
Fourth carbon budget (2023 - 2027)	1,950 $MtCO_2e$
Fifth carbon budget (2028 - 2032)	1,725 $MtCO_2e$

14.3.5 The Climate Change Act also established a requirement for UK Government to undertake a climate change risk assessment (CCRA) every five-year period and develop a programme for adaptation action in response to the risks identified. The UK Government's second UK CCRA was published in 2017[10,11]. It establishes six priority risk areas for action over the following five years: flooding and coastal change; health and well-being from high temperatures; water shortages; natural capital; food production and trade; and pests and diseases and invasive non-native species. It is based on the independent evidence report published by the Committee on Climate Change[12].

14.3.6 The CCRA identifies significant risks to national infrastructure, including transport networks, from embankment and bridge failure, river, surface/groundwater and coastal flooding, erosion, and increases in the frequency and severity of extreme weather such as high winds, high temperatures, lightening, storms and high waves. It highlights the need for infrastructure to be located, planned and designed and maintained to be resilient to climate change, including severe weather events. It also recognises that more action is needed to encourage information sharing between infrastructure operators to improve overall risk management. Section 14.9 Design, mitigation and enhancement measures, section 14.10 Assessment of likely significant effects and ES Appendix 14.2 Climate Change Resilience Assessment (Document Reference 6.4) considers identification and implementation of any adaptation measures.

National policy

National Policy Statement for National Networks (2014)

14.3.7 The *NPSNN* is the primary planning policy for the scheme and forms the principal basis for making decisions on Development Consent Order (DCO) Applications. The *National Planning Policy Framework* (NPPF) is noted as being 'important and relevant' and is to be considered, however, if there is a conflict between the *NPSNN* and *NPPF*, the *NPSNN* takes precedence.

14.3.8 The *NPSNN* establishes the need for nationally significant infrastructure rail and road projects for England and is the primary source of policy guidance relevant to the scheme. In relation to carbon[13] reduction for such schemes, Paragraph 5.16 asserts that the impact of road development on aggregate levels of emissions is likely to be very small (Paragraph 3.8 asserts less than 0.1% of annual carbon budgets) and needs to be seen against significant projected reductions in carbon emissions because of meeting the UK Government's legally binding carbon budgets. Paragraph 5.18 asserts that an increase in carbon emissions is not a reason to refuse development consent, unless the increase is large enough to have a material impact on the ability of the UK Government to meet its carbon reduction targets.

14.3.9 Table 14-2 identifies specific *NPSNN* requirements relevant to the climate assessment and specifies where in this ES chapter information is provided to address each requirement.

Table 14-2 Relevant NPSNN policies for the climate assessment

Relevant NPSNN paragraph reference	Requirement of the NPSNN	Link to where information is provided in this ES chapter to address the requirement
4.40	Paragraph 4.40 specifies the need for applicants to consider the impacts of climate change when planning location, design, build and operation. It also states that an ES should set out how the proposal will take account of the projected impacts of climate change.	ES Chapter 2 The project (Document Reference 6.2) and ES Chapter 3 Assessment of alternatives (Document Reference 6.2) document how the scheme has considered the impact of climate change when planning location, design, build and operation of the scheme. Sections 14.9 Design, mitigation and enhancement measures and 14.10 Assessment of likely significant effects consider how the scheme would account for the projected impacts of climate change.
4.41	Paragraph 4.41 specifies that where transport infrastructure has safety-critical elements and the design life of the asset is 60 years or greater, the applicant should apply the UK Climate Projections high emissions scenario (high impact, low likelihood) against the 2080 projections at the 50% probability level.	Section 14.7 Baseline conditions demonstrates application of the latest set of UK Climate Projections (UKCP18) high emissions scenario (high impact, low likelihood) against the 2080 projections at the 50% probability level.
4.42	Paragraph 4.42 specifies that applicants should consider the potential impacts of climate change using the latest UK Climate Projections and ensure the environmental statement identifies appropriate mitigation	Section 14.7 Baseline conditions demonstrates application of the latest UK Climate Projections (UKCP18). Section 14.9 Design, mitigation and enhancement measures and ES Appendix 14.2 Climate Change Resilience Assessment (Document

Relevant NPSNN paragraph reference	Requirement of the NPSNN	Link to where information is provided in this ES chapter to address the requirement
	or adaptation measures to ensure the long-term resilience of a proposed scheme.	Reference 6.4) considers appropriate mitigation and adaption measures.
4.43	Paragraph 4.43 requires the applicant to demonstrate that there are no critical features of the design which may be seriously affected by more radical changes to the climate beyond that projected in the latest set of UK Climate Projections. Any potential critical features should be assessed taking account of the latest credible scientific evidence on, for example, sea level rise and on the basis that necessary action can be taken to ensure the operation of the infrastructure over its estimated lifetime through potential further mitigation or adaptation.	ES Appendix 14.2 Climate Change Resilience Assessment (Document Reference 6.4) considers any potentially critical features of the design which may be seriously affected by climate change as projected in the latest UK climate projections. The safety of the scheme is assessed against the high emissions Representative Concentration Pathways RCP8.5[14] global warming scenario. Additionally, a resilience assessment of the safety-critical features of the scheme against H++ climate scenarios[15] has also been undertaken and is reported in section 14.10 Assessment of likely significant effects.
4.44	Paragraph 4.44 specifies that adaptation measures should be based on the latest set of UK Climate Projections, the Government's national Climate Change Risk Assessment and consultation with statutory consultation bodies. Any adaptation measures must themselves also be assessed as part of any environmental impact assessment and included in the environmental statement, which should set out how and where such measures are proposed to be secured.	Section 14.9 Design, mitigation and enhancement measures, section 14.10 Assessment of likely significant effects and ES Appendix 14.2 Climate Change Resilience Assessment (Document Reference 6.4) considers identification and implementation of any adaption measures.
5.17	Paragraph 5.17 requires that carbon impacts will be considered as part of the appraisal of scheme options (in the business case), prior to the submission of an application for a DCO. Where the development is subject to EIA, any Environmental Statement will need to describe an assessment of any likely significant climate factors in accordance with the requirements in the EIA Directive. For road projects applicants should provide evidence of the carbon impact of the project and an assessment against the Government's carbon budgets.	Section 14.10 Assessment of likely significant effects considers the carbon impacts of the scheme and reports an assessment of carbon emissions against the UK Government's legislated carbon budgets. Operational and maintenance emissions between 2033 and 2037 (the period for the sixth carbon budget) are provided in Table 14 18.

National Planning Policy Framework

14.3.10 The *NPPF* sets out the UK Government's planning policies for England and how these are expected to be applied and provides a high-level framework within which other development can come forward. The *NPPF* does not contain specific policies for NSIPs (including the scheme), which are primarily determined in accordance with the decision-making framework in the 2008 Act and the relevant national policy statement (which for the scheme is the *NPSNN*, as described in paragraphs 14.3.7 - 14.3.9), as well as any other matters that are relevant (which may include the *NPPF*).

14.3.11 The *NPPF* describes the role of planning policy in meeting the challenges posed by climate change and helping to shape places to secure radical reductions in GHG emissions as well as reducing vulnerability and providing resilience to the impacts of climate change. Section 14 of the *NPPF* states that developments should avoid increased vulnerability to the range of impacts arising from climate change and should be planned for in ways that can help to reduce GHG emissions, in line with the objectives and provisions of the Climate Change Act 2008. Section 14.9 Design, mitigation and enhancement measures, section 14.10 Assessment of likely significant effects and ES Appendix 14.2 Climate Change Resilience Assessment (Document Reference 6.4) consider identification and implementation of any avoidance and mitigation measures.

The Climate Change: second national adaptation programme (2018 – 2023)

14.3.12 The *Climate Change: second national adaptation programme* (2018 – 2023) (NAP)[16] was produced by the Department for Environment, Food and Rural Affairs (Defra) and launched in 2018. The plan sets out the UK Government's response to the second CCRA. It forms part of the five-yearly cycle of requirements laid down by the Climate Change Act 2008, with the aim of driving a dynamic and adaptive approach to building the nation's resilience to climate change. Section 3.4.4 of the *NAP* highlights the economic and strategic value of the Strategic Road Network (SRN) in the UK and notes the implications of risks to severance and safety posed by climate change. It details how Highways England is embedding resilience to climate change, based on the UK Climate Projections 2009 (UKCP09) future climate projections, including measures such as safeguarding against flooding, erosion, falling trees, instability and risk of failure across the SRN to increase safety.

14.3.13 Highways England is taking action to safeguard against climate risks on the road network through a series of adaptation plans, as set out in Section 8 of their climate change adaptation risk assessment[17]. These include adaption actions related to pavements; drainage; structures; geotechnics; non-motorised users; soft estate; vehicle restraint systems; signs and signals; and road markings. For some risks doing the minimum is appropriate because the rigorous design standards or existing procedures are already sufficient to cope with the predicted impacts of climate change. In other cases, including those relating to drainage, it has been considered necessary to act. For example, updating technical standards through the DMRB or the Manual of Contract Documents for Highway Works to ensure new designs and projects are prepared for the future climate.

Clean Growth Strategy

14.3.14 In 2017, the UK Government published the *Clean Growth Strategy*, which is a plan for meeting the legislated carbon budgets[18] as set out in the Carbon Budget Order 2016. The strategy includes a key policy to accelerate the shift to low carbon transport, which primarily focuses on a transition to low emission vehicles, investing in new technologies such as autonomous vehicles and low carbon fuels, promoting cycling and walking and shifting freight from road to rail.

Road to Zero Strategy

14.3.15 In July 2018, the UK Government launched the *Road to Zero Strategy*[19], a policy paper which includes a forward-looking route map to articulate the steps required to decarbonise and electrify road transport in line with their Industrial Strategy[20]. The document outlines 46 policy interventions to aid in the drive to decarbonise

road transport. Its main focuses are on supporting modal shift, reducing emissions from vehicles and investing in electric vehicle infrastructure.

Decarbonising Transport

14.3.16 In March 2020, the UK Government launched *Decarbonising Transport*: *Setting the Challenge*[21], a policy paper stating the current challenges and steps to be taken to develop a transport decarbonisation plan. It sets out in detail what government, business and society will need to do to deliver the significant emissions reduction needed across all modes of transport, to achieve carbon budgets and net zero emissions across every single mode of transport by 2050. It outlines six strategic priorities for the *Transport Decarbonisation Plan*, to deliver a vision of a net zero transport system.

Local policy

Gloucestershire County Council Local Flood Risk Management Strategy 2014

14.3.17 The scheme is situated within the Gloucestershire County boundary. The most directly relevant county-level planning policy and infrastructure guidance is the *Gloucestershire County Council Local Flood Risk Management Strategy 2014* (LFRMS)[22], which sets out how Gloucestershire County Council and its partner authorities intend to work together to manage flood risk from all sources and is supported by a live action plan which is reported on annually. This LFRMS has been adopted to guide the development of policy and programmes across Gloucestershire County Council's operations and in its work with other organisations, communities and stakeholders. The scheme has been designed to manage flood risk, as set out in ES Chapter 13 Road drainage and the water environment (Document Reference 6.2).

14.3.18 Further policies related to flood risk and water management of relevance to the scheme, including climate change are set out in ES Chapter 13 Road drainage and the water environment (Document Reference 6.2).

Cotswold District Council Local Plan 2011 to 2031 (adopted August 2018)

14.3.19 The scheme is situated partly in Cotswold District. The *Cotswold District Council Local Plan*[23] sets out a number of policies with respect to the built, natural and historic environment, placing emphasis on promoting the protection, conservation and enhancement of the natural environment. In line with the NPPF, the local plan asserts that the potential impacts of climate change must be considered in planning for all new development, both in terms of location and design. Plan Objective 6 aims to reduce the environmental impact of development and vulnerability to the impacts of climate change through:

"a. Maximising water and energy efficiency, promoting the use of renewable energy sources and sustainable construction methods, and reducing pollution and waste.

b. Supporting the principle of waste minimisation.

c. Locating development away from areas identified as being at high risk from any form of flooding or from areas where development would increase flood risk to others".

14.3.20 The scheme has been designed to manage flood risk, as set out in ES Chapter 13 Road drainage and the water environment (Document Reference 6.2). Further policies related to flood risk and water management of relevance to the scheme,

including climate change, are set out in ES Chapter 13 Road drainage and the water environment (Document Reference 6.2).

Gloucester, Cheltenham and Tewkesbury Joint Core Strategy 2011-2031 (adopted December 2017)

14.3.21 The western end of the scheme lies within an area covered by the *Gloucester, Cheltenham and Tewkesbury Joint Core Strategy*[24]*.* The Joint Core Strategy is a partnership between Gloucester City Council, Cheltenham Borough Council and Tewkesbury Borough Council to deliver a co-ordinated strategic development plan. The strategy identifies larger strategic issues which impact all three authorities whilst each authority retains individual local plans which provide planning guidance on smaller and local development issues. Policies of relevance to this chapter include:

- *Policy SD3*: Sustainable Design and Construction requires that "All development will be expected to be adaptable to climate change in respect of the design, layout, siting, orientation and function."
- *Policy INF2*: Flood Risk Management requires that climate change is taken into account in minimising the risk of flooding and providing resilience to flooding.
- *Policy INF6*: Infrastructure Delivery notes that "where need for additional infrastructure and services and/or impacts on existing infrastructure and services is expected to arise, the Local Planning Authority will seek to secure appropriate infrastructure which is necessary, directly related, and fairly and reasonably related to the scale and kind of the development proposal, including:... ii. Climate change mitigation/adaptation…"

14.3.22 Section 14.9 Design, mitigation and enhancement measures, section 14.10 Assessment of likely significant effects and ES Appendix 14.2 Climate Change Resilience Assessment (Document Reference 6.4) consider identification and implementation of any avoidance and mitigation measures. The scheme has been designed to manage flood risk, as set out in ES Chapter 13 Road drainage and the water environment (Document Reference 6.2).

Pre-submission Tewkesbury Borough Plan 2011-2031 (October 2019)

14.3.23 The scheme is situated partly in the borough of Tewkesbury. One of the stated objectives of the *Pre-submission Tewkesbury Borough Plan*[25] is "Meeting the challenges of climate change and resource conservation (including managing flood risk, energy efficiency, renewable energy and waste minimisation)". Specifically of relevance to this chapter is Policy ENV2 Flood Risk and Water Management, which requires that in addition to the requirements of the NPPF and the Gloucester, Cheltenham and Tewkesbury Joint Core Strategy the Council will apply the following principle: "Proposals (including surface water drainage schemes) should be designed to appropriate, locally specific allowances for climate change for peak river flood flows and rainfall intensity."

14.3.24 The scheme has been designed to manage flood risk, as set out in ES Chapter 13 Road drainage and the water environment (Document Reference 6.2).

Cotswolds area of outstanding natural beauty (AONB) Management Plan 2018-2023

14.3.25 The scheme is situated within the Cotswolds AONB. The *Cotswolds AONB Management Plan 2018-2023*[26] is a non-statutory plan, which sets out the vision, outcomes and policies for the management of the AONB. It contains seven cross-

cutting outcomes and associated policies. Of direct relevance to this chapter is Outcome 3 on climate change and Policy CC7 and Policy CC8, which state that climate change mitigation and adaptation should be a key consideration in all new development, infrastructure and transport provision. Section 14.9 Design, mitigation and enhancement measures and ES Appendix 14.2 Climate Change Resilience Assessment (Document Reference 6.4) consider identification and implementation of any avoidance and mitigation/adaptation measures.

Climate Change Strategy for the Cotswolds AONB (adopted 2012)

14.3.26 The *Climate Change Strategy for the Cotswolds AONB*[27] notes that climate change is likely to significantly affect the special qualities for which the Cotswolds are designated as an AONB. The principal purpose of the strategy is to "make the Cotswolds more resilient to the impacts of climate change, guiding landscape change in a way that will minimise adverse effects on the inherent character of the area", and was used to inform the Cotswolds AONB Management Plan 2018-2023. The strategy's three key themes are listed below. For each key theme and sub-theme the strategy provides information on the predicted impacts of climate change, along with specific strategies to meet a stated aim:

"1. Climate Change and the Special Qualities of the Cotswold Landscape
- *1a. Landscape*
- *1b. Soil and Water*
- *1c. Biodiversity*
- *1d. Historic Environment*

2. Climate Change and Living and Working in the Cotswolds
- *2a. Farming and Forestry*
- *2b. Energy*
- *2c. Development and Transport*
- *2d. The Cotswolds Economy*
- *2e. Health and Wellbeing*

3. Climate Change and our Understanding and Enjoyment of the Cotswolds
- *3a. Enjoying and Exploring*
- *3b. Awareness and Appreciation"*

14.3.27 The combined effects of the scheme and climate change on environmental receptors, including the Cotswolds AONB, are considered in ES Appendix 14.3 In-combination climate change impact assessment (Document Reference 6.4).

Standards and guidance

Impact of the scheme on climate (GHG emissions assessment)

14.3.28 The following standards and guidance have been used to guide this assessment:

- *DMRB LA 114 Climate*, which provides the requirements for assessment and reporting the effect on climate of greenhouse gas from construction, operation and maintenance of Highways England highways projects[28].
- *DMRB LA 105 Air Quality*, which provides the calculation method for regional emissions from vehicles that use the road network[29].
- *DMRB GG 103 Introduction and general requirements for sustainable development and design*[30].
- The *Publicly Available Specification 2080* (PAS 2080) on carbon management in infrastructure[31], a global standard for managing infrastructure carbon.
- *Royal Institution of Chartered Surveyors* (RICS) professional standards and guidance document on Whole life carbon assessment for the built environment (1st edition, 2017)[32].

- Department for Transport, *Transport Analysis Guidance* (TAG) *Unit A3 Environmental Impact Appraisal, Chapter 4 Greenhouse Gases*[33], which provides the methodology for consistent and transparent reporting of GHG emissions, including those resulting from the production of materials used (referred to as embedded or embodied carbon), as well as those resulting from changes to the use of transport fuels.

Vulnerability of the scheme to climate change (climate change resilience assessment)

14.3.29 The following standards and guidance have been used to guide this assessment:

- *DMRB LA 114 Climate*, which provides the methodology for assessment and reporting the effects of climate on Highways England highways projects (climate change resilience and adaptation)[34]; and
- The *Institute of Environmental Management and Assessment (IEMA) Environmental Impact Assessment Guide To Climate Change Resilience And Adaptation*[35] on climate change resilience and adaptation. This guidance provides an approach to undertaking assessments of climate change resilience within the EIA process in the UK.

14.4 Assessment methodology

14.4.1 To align with the requirements of the *NPSNN* and the EIA Regulations, the climate assessment includes the following elements:

- Impact of the scheme on climate (GHG emissions assessment
- Vulnerability of the scheme to climate change (CCR assessment)
- In-combination climate impacts (ICCI) assessment

14.4.2 ES Appendix 4.5 Changes to scope and methodology (Document Reference 6.4) outlines the changes in scope and methodology since the submission of the Scoping Report in May 2019.

Impact of the scheme on climate (GHG emissions assessment)

14.4.3 The assessment of the magnitude of carbon emissions has been undertaken in accordance with DMRB *LA 114 Climate* and the principal steps identified in PAS 2080[36] (with the exception of setting scheme level carbon reduction targets, which were not established). The Highways England Carbon emissions calculation tool[37] has been used to calculate product, construction process and maintenance/refurbishment emissions, except where specified. Consideration has also been given to Transport Analysis Guidance (TAG) *Unit A3 Environmental Impact Appraisal*, Chapter 4 Greenhouse Gases[38], which provides the methodology for consistent and transparent reporting of GHG emissions, including those resulting from the production of materials used (referred to as embedded or embodied carbon), as well as those resulting from changes to the use of transport fuels.

14.4.4 The goal of the emissions quantification exercise is to calculate the emissions anticipated to be generated or avoided by the scheme (according to the DCO Boundary and emissions scope set out in section 14.6 Study area). The purpose of this is to:

- Determine the magnitude of the scheme's emissions for the relevant scenarios - 'Do-Something' and 'Do-Minimum' (See scenario descriptions in Table 14-3).
- Enable comparison of the 'Do-Something' scenario against the 'Do-Minimum' scenario and the UK carbon reduction targets.

- Enable identification of emissions hot spots within the 'Do-Something' scenario to inform identification and prioritisation of mitigation measures.

14.4.5 Assessment has included the life cycle stages of 'product', 'construction' and 'use' as per PAS 2080, BS EN 15804 and RICS guidance. In line with DMRB LA 114, 'end of life' impacts have not been considered, as it is considered highly unlikely that the scheme would be decommissioned as the road is likely to have become an integral part of the infrastructure in the area. Decommissioning would not be either feasible or desirable and is therefore not considered further within this ES.

14.4.6 The assessment estimates four sources of carbon emissions during the construction and operation (use) life cycle stages, including:

- **Construction works and supply chain carbon emissions.** Carbon is assessed, based on information provided by design teams based on relevant drawings of the design where available. Section 14.5 Assessment assumptions and limitations outlines how assumptions were made. The Highways England Carbon emissions calculation tool is used along with its carbon factors for the calculation, supplemented with other factors where necessary as discussed in section 14.5 Assessment assumptions and limitations.
- **Operational maintenance-related emissions.** An estimation of carbon emissions associated with maintenance of the road (calculated using the same method as the construction works and supply chain carbon emissions).
- **Operational traffic carbon emissions (user carbon) from vehicle tailpipes**. These are calculated for both the "Do-Minimum" and "Do-Something" scenarios from the traffic model, with the study area being the same as that of the traffic model.
- **Emissions associated with ongoing land use change/sequestration.** These are calculated over the 60-year operational period for 'habitats lost' and 'habitats gained' as a result of the scheme.

14.4.7 Emissions from these sources are compared to a baseline 'Do-Minimum' scenario (as described in Table 14-3) to quantify the impact of the scheme. The scenarios used for the GHG emissions assessment of the scheme are summarised in Table 14-3.

Table 14-3 GHG emissions assessment scenarios

Scenario	Description
Do-minimum	The future baseline with minimal interventions and without the scheme and any new infrastructure.
Do-something	The scheme is implemented, taking into account embedded GHG mitigation measures.

14.4.8 GHG emissions in each scenario have been compared in order to assess the contribution of the scheme to climate change. Values are reported in metric tonnes of carbon dioxide equivalents (tCO_2e). This measure considers the six Kyoto Protocol gases: Carbon dioxide (CO_2); Methane (CH_4); Nitrous oxide (N_2O); Sulphur hexafluoride (SF_6); Hydrofluorocarbons (HFCs); and Perfluorocarbons (PFCs), converted into tCO_2e. This calculation normalizes the global warming potential of the main GHGs into one measure, based on the global warming potential of CO_2.

14.4.9 In accordance with DMRB *LA 114 Climate*, the third lifecycle stage for a scheme's GHG emissions (the first and second being construction and operation)

comprises opportunities to reduce the production/use of GHG emissions. Measures to reduce GHG emissions as far as practicable are considered in section 14.9 Design, mitigation and enhancement measures.

Vulnerability of the scheme to climate change (CCR assessment)

14.4.10 The CCR assessment reports a qualitative assessment of the impacts and risks of climate change on the scheme based on professional expertise and judgement.

14.4.11 In the case of flood risk, detailed planning requirements and design guidance relating to climate change exist. A Flood Risk Assessment (FRA) has been undertaken and reported in ES Appendix 13.3 Flood Risk Assessment (Document Reference 6.4) of ES Chapter 13 Road drainage and the water environment (Document Reference 6.2). This considers current Environment Agency (EA) climate change allowances for increases in peak river flow and rainfall intensity.

14.4.12 The climate change resilience assessment is composed of three main parts: the identification of climate hazards and benefits; the assessment of likelihood and consequences; and the evaluation of significance.

14.4.13 The following climate change hazards have been considered in the CCR risk assessment: high temperatures; high precipitation; and low precipitation.

14.4.14 As part of the climate change resilience assessment, the potential likelihood and consequence of climate change risks during construction and operation of the infrastructure and assets associated with the scheme are scored using a qualitative five-point scale, based on DMRB LA 114 Climate. These are set out in Table 14-4 and Table 14-5.

Table 14-4 Qualitative five-point scale of likelihood of climate change risks

Likelihood category	Description (probability and frequency of occurrence)
Very High	The event occurs multiple times during the lifetime of the project (60 years) e.g. approximately annually, typically 60 events.
High	The event occurs several times during the lifetime of the project (60 years) e.g. approximately once every five years, typically 12 events.
Medium	The event occurs limited times during the lifetime of the project (60 years) e.g. approximately once every 15 years, typically 4 events.
Low	The event occurs during the lifetime of the project (60 years) e.g. once in 60 years.
Very Low	The event can occur once during the lifetime of the project (60 years).

Table 14-5 Qualitative five-point scale of consequences of climate change risks

Consequence of impact	Description
Very large adverse	Operation - national level (or greater) disruption to strategic route(s) lasting more than one week.
Large adverse	Operation - national level disruption to strategic route(s) lasting more than one day but less than one week or regional level disruption to strategic route(s) lasting more than one week.
Moderate adverse	Operation - regional level disruption to strategic route(s) lasting more than one day but less than one week.
Minor adverse	Operation - regional level disruption to strategic route(s) lasting less than one day.
Negligible	Operation - disruption to an isolated section of a strategic route lasting less than one day.

14.4.15 As part of the risk assessment the need for any essential resilience measures to protect against the impacts of climate change have been identified for any effects assessed as significant, as per the significance matrix in Table 14-6.

In-combination climate change impacts (ICCI) assessment

14.4.16 To assess the direct and indirect significant effects on climate relevant to the scheme, including those caused by climate change, those effects of the scheme identified by an environmental factor that are also affected by climate change is assessed on a case by case basis by the environmental factors.

14.4.17 Future climate conditions have been reviewed as part of this assessment, including changes to long term seasonal averages and extreme weather events as projected by the UK Climate Projections 2018 and presented within section 14.7 Baseline conditions of this chapter.

Assessment of significance

Impact of the scheme on climate (GHG emissions assessment)

14.4.18 An assessment of significance has been undertaken in accordance with DMRB *LA 114 Climate*. The emissions assessment is based on the Highways England carbon reporting tool and assessment of road user emissions in line with DMRB LA 105 Air quality.

14.4.19 For the methodology related to quantification of user emissions (module B9), please refer to ES Chapter 5 Air quality of this ES (Document Reference 6.2). The traffic forecasting is in line with the current guidance.

14.4.20 For the calculation of GHG emissions associated with ongoing land use change/sequestration (module D), the areas of habitat losses and gains were calculated based on baseline survey information and scheme plans.

14.4.21 An estimate of the likely magnitude of GHG emissions associated with the scheme has been assessed against the legislated national UK carbon budgets. The UK Government has currently passed into law carbon budgets up to 2032:

- The third carbon budget period (2018 to 2022) allows the UK to emit 2,544 $MtCO_2e$.
- The fourth carbon budget (2023 to 2027) allows the UK to emit 1,950 $MtCO_2e$.
- The fifth carbon budget (2028 to 2032) allows the UK to emit 1,725 $MtCO_2e$.

14.4.22 In accordance with Paragraph 3.20 of DMRB *LA 114 Climate*, a significant effect occurs where the increase in carbon emissions resulting from the scheme would have a *"material impact on the ability of Government to meet its carbon reduction targets"*.

Vulnerability of the scheme to climate change (CCR assessment)

14.4.23 The evaluation of significance is a product of the likelihood and consequence of each impact as set out in Table 14-6. Significance conclusions for each impact incorporate confirmed design and mitigation measures.

Table 14-6 Significance matrix

		Measure of likelihood				
		Very low	**Low**	**Medium**	**High**	**Very high**
Measure of consequence	**Very large**	NS	S	S	S	S
	Large	NS	NS	S	S	S
	Moderate	NS	NS	S	S	S
	Minor	NS	NS	NS	NS	NS
	Negligible	NS	NS	NS	NS	NS

Note: NS = Not significant; S = Significant

Stakeholder engagement

14.4.24 The scope of the climate assessment was set out in the Scoping Report[39] for which the Planning Inspectorate (PINS) provided a Scoping Opinion, refer to ES Appendix 4.1 The Planning Inspectorate Scoping Opinion (Document Reference 6.4). Responses to comments from PINS and the relevant consultation bodies in relation to the climate assessment set out in this chapter are included in ES Appendix 4.2 Responses to Scoping Opinion (Document Reference 6.4).

14.5 Assessment assumptions and limitations

Impact of the scheme on climate (GHG emissions assessment)

14.5.1 The GHG emissions assessment has been undertaken on the basis of the information available at the time of assessment. Where assumptions have been made, they have been selected to present the worst-case scenario for the particular item/factor.

14.5.2 Assumptions/judgements in each case have been made from either:

- Emerging design detail.
- Engineering specialist knowledge.
- Environmental specialist knowledge.
- Climate change/carbon specialist knowledge.
- Manufacturer specifications.
- Proxy engineering data from previous comparable projects.

14.5.3 The materials and quantities listed in ES Appendix 14.1 Greenhouse gas assessment assumptions, methodology and emissions factors (Document Reference 6.4) are included in the assessment. This is the list of materials provided by the design team, including any embedded mitigation. A full schedule of assumptions associated with material volumes and quantities is also contained within ES Appendix 14.1 Greenhouse gas assessment assumptions, methodology and emissions factors (Document Reference 6.4).

14.5.4 Table 14-7 provides information on the PAS 2080 life cycle modules that have formed part of the assessment along with justification where modules have been excluded.

Table 14-7 Justification for inclusion or exclusion of PAS 2080 life cycle stages and individual modules within GHG emissions quantification

Life cycle stage	Boundary stage	Module	Description	Included in scope?	Justification
Before use Stage	Preconstruction	A0	Preliminary studies, consultations	×	Carbon emissions from preliminary studies and works are largely office-based and are assumed to be insignificant.
	Product	A1	Raw material supply	✓	A1-A3 emissions (i.e. from raw material extraction, product processing, and final product manufacture, its energy use, and waste management within these processes, transportation within the supply chain, and manufacture) is calculated using emissions factors from the Highways England carbon emissions calculation tool, based on information provided by design teams based on relevant drawings of the design where available.
		A2	Transport	✓	
		A3	Manufacture	✓	
	Construction process	A4	Transport to works site	✓	A4 emissions have been calculated using the RICS guidance[32], applying transport conversion factors from Defra[40]. They are calculated using emissions factors from the Highways England carbon emissions calculation tool, based on information provided by design teams based on relevant drawings of the design where available.
		A5	Construction/installation processes	✓	A5 emissions have been calculated using emissions factors from the Highways England carbon emissions calculation tool, based on information provided by design teams.
Use Stage	Installed products and materials	B1	Use	×	Carbon emitted directly from the fabric of products and materials once they have been installed as part of the scheme and it is in normal use are assumed to be insignificant.
		B2	Maintenance	✓	B2-B5 emissions associated with maintenance and refurbishment assume that the road surface would be replaced once every ten years for the duration of the assumed 60-year design life (calculated using the same method as the construction works and supply chain carbon emissions).
		B3	Repair	✓	
		B4	Replacement	✓	
		B5	Refurbishment	✓	
		B6	Operational energy use	×	The scheme has been designed to reduce the requirement for energy consuming operational equipment such as street lighting or intelligent transport systems wherever possible. Where lighting may be potentially required, for example at Grove Farm underpass, low lux demand sensitive lighting is proposed. There would be a

Life cycle stage	Boundary stage	Module	Description	Included in scope?	Justification
					negligible difference between the operational energy required for the scheme compared with the Existing A417, and therefore associated emissions are assumed to be insignificant.
		B7	Operational water use	×	Carbon emissions resulting from the consumption of water required by the scheme to enable it to operate and deliver its service are assumed to be insignificant.
		B8	Other operational processes	×	Other process carbon emissions arising from the scheme to enable it to operate and deliver its service, such as management of operational waste, are assumed to be insignificant.
		B9	Users utilisation of infrastructure	✓	For the methodology related to quantification of user emissions, please refer to ES Chapter 5 Air quality (Document Reference 6.2).
End of life stage		C1	Deconstruction	×	End of life (C1-C4) impacts have not been considered due to the long design life of the asset and given that emissions associated with end of life are commonly relatively small.
		C2	Transport		
		C3	Waste processing for recovery		
		C4	Disposal		
Supplementary Information beyond the infrastructure life cycle		D	Boundary of benefits and loads beyond the infrastructure life cycle	✓	GHG emissions associated with ongoing land use change/sequestration have been calculated over the 60-year operational period for 'habitats lost' and 'habitats gained' as follows: • Habitats lost as a result of the scheme - future loss of ability to sequester carbon over the 60 year assessment period have been included in the construction stage emissions (see Table 14-15). • Habitats gained as a result of the scheme - future ability to sequester carbon over the 60 year assessment period has been included in the operation stage emissions (see Table 14-16).

14.5.5 For transport-related emissions (module A4), data on default transport scenarios for UK projects contained within the RICS professional standards and guidance document on whole life carbon assessment for the built environment (2017), were used. For locally manufactured materials and products a transport distance of 31 miles (50 kilometres) by road has been applied. For nationally manufactured materials and products a transport distance of 186 miles (300 kilometres) by road has been applied. Emission factors from the Highways England carbon emissions calculation tool have been used exclusively, with the exception of the product emissions (module A1-A3) relating to bridges, which are derived from peer reviewed research[41]. This is due to the design maturity at the time of assessment resulting in material quantity data not being available.

14.5.6 GHG emissions related to the construction element of embodied carbon (module A5) have been calculated using emissions factors from the Highways England carbon emissions calculation tool, based on information provided by design teams. The calculation includes transport of materials and equipment on site and waste management activities (transport, processing, final disposal) associated with waste arising from the construction site.

14.5.7 Module A5 also includes consideration of emissions arising from the installation of materials and products into the infrastructure asset. At the time of assessment there was no accurate construction information available to inform the assessment of emissions from the installation of materials and products. Therefore, this assessment has been undertaken based on an average per kilometre emissions factor for emissions resulting from labour and plant, derived from a sample of comparable highway schemes (see Table 14-19) and applying this to the length of the scheme.

14.5.8 To quantify operational emissions (module B2-B5) associated with maintenance of the road surface (in both the 'Do-Minimum' (baseline) and 'Do-Something' (with scheme) scenarios) it is estimated the road surface would be replaced once every ten years for the duration of the design life. Module B2-B5 emissions are calculated using the same method as the construction works (module A5) and supply chain (module A1-A3) carbon emissions: using emissions factors from the Highways England carbon emissions calculation tool, based on information provided by design teams for the scheme.

14.5.9 For the calculation of GHG emissions associated with ongoing land use change/sequestration (module D), the areas of habitat losses and gains were calculated based on baseline survey information and scheme plans. Emissions from immediate loss/disturbance of habitats (e.g. those mobilised from vegetation or soil loss during construction) are excluded from the calculation due to their likely minor magnitude compared to sequestration, uncertainty and the limited information available on immediate losses. The calculation for 'habitats gained' is likely to moderately overestimate sequestration rates due to the time taken for the habitats to establish.

14.5.10 The methodology used to calculate the UK carbon budgets is different to that used for the calculation of lifecycle emissions from a road scheme and therefore caution should be taken when making a direct comparison. However, for the purposes of identifying to what extent the scheme may impact the ability of the UK to meet its carbon budgets it is necessary to make this comparison to put the scheme into context.

Vulnerability of the scheme to climate change (climate change resilience assessment)

14.5.11 Data on the climate baseline and future projections are based on freely available information from third parties, including the historical meteorological variables recorded by the Meteorological Office (Met Office) and UKCP18 developed by the Met Office. In addition, the assessment has been informed by a selected range of existing climate change research and literature, available at the time of undertaking this assessment.

14.5.12 Climate projections are not predictions or forecasts but simulations of potential scenarios of future climate, under a range of hypothetical emissions scenarios and assumptions. Therefore, the results from running the climate models cannot be treated as exact or factual, but projection options. They represent consistent representations of how the climate may evolve in response to a range of potential forcing scenarios, and their reliability varies between climate variables. Scenarios exclude outlying "surprise" or "disaster" scenarios in the literature, and any scenario includes, out of necessity, subjective elements and is open to various interpretations. In general, global projections are more certain than regional projections, and temperature projections are more certain than those for precipitation. Wind projections have the highest amount of uncertainty associated with them. Furthermore, the degree of uncertainty associated with all climate change projections increases for projections further into the future.

14.5.13 The CCR assessment has been informed by the following assumptions:

- The assessment has assumed that mitigation measures relevant to different assets would be implemented effectively.
- The assessment is affected by assumptions associated with climate modelling and climate change projections, incorporated in UKCP18.

14.5.14 The CCR assessment has the following limitations:

- The assessment is largely qualitative, with the exception of assessments relevant to drainage assets and flood risk, which have been informed by the EA climate change allowances for increases in peak river flow and rainfall intensity.
- There is limited methodological guidance on climate change resilience assessment in EIA from Government, and other institutions.
- There is inherent uncertainty in climate change projections. This study has been quantified using UKCP18, the latest set of probabilistic climate projections for the UK.
- There is often uncertainty in the relationship between changes in climate hazards and the respective response in terms of asset performance. This uncertainty has been assessed qualitatively.
- The evidence relating to climate change impacts for some categories of assets and infrastructure, such as the multi-function Gloucestershire Way crossing, is limited at this stage in the design. In these cases, the assessment has been informed by professional judgement.

Limits of deviation

14.5.15 This assessment has been conducted within the Limits of Deviation (LoD) as outlined within ES Chapter 2 The project (Document Reference 6.2).

14.5.16 The LoD have been considered having regard to the scope for change. The worst case has been taken into account and it is considered that the outcome of the

climate assessments contained within this chapter would not change unless the scheme or the assumptions change significantly. The proposed LoD would therefore not give rise to any materially new or materially worse adverse environmental effects from those already reported in the ES.

14.6 Study area

Impact of the scheme on climate (GHG emissions assessment)

14.6.1 The assessment of GHG emissions has considered the following emissions sources:

- **Carbon emissions during construction**, i.e. material supply including primary extraction, manufacturing, transportation and construction process and site works associated with the scheme.
- **Carbon emissions during operation**, associated with the maintenance and refurbishment of the scheme.
- **Road user carbon emissions (during operation)** arising from the use of the asset (vehicle emissions).
- **Carbon emissions associated with ongoing land use change/sequestration** over the 60 year operational period for 'habitats lost' and 'habitats gained' as a result of the scheme.

14.6.2 In line with DMRB *LA 114 Climate*, carbon emissions arising from decommissioning of the scheme have been excluded from the assessment due to the long design life of the asset and given that emissions associated with end of life are commonly relatively small.

14.6.3 In line with Paragraph 3.12 of DMRB *LA 114 Climate*, a proportionate approach is taken to calculating and reporting emissions from changes in land use. A high-level assessment of CO_2 sequestration rates was undertaken based on UK Government data on emissions/sequestration by land type (per unit area) per local authority area. It is estimated that an area of between 200-300ha of forest would be required to sequester the embodied carbon[42] impacts of the scheme over its design life. Therefore, an intervention to sequester the carbon impacts of the scheme is not considered feasible and has not formed part of the GHG emissions assessment. As noted in paragraph 14.6.1, GHG emissions associated with ongoing land use change/sequestration have been calculated over the 60-year operational period for total 'habitats lost' and 'habitats gained' within the DCO Boundary (see paragraph 14.6.9).

14.6.4 Opportunities to mitigate the effects on climate through minimising activities that generate GHG emissions, reusing and adopting low carbon materials are also considered and are outlined in section 14.9 Design, mitigation and enhancement measures.

Carbon emissions during construction

14.6.5 For the assessment of carbon emissions associated with construction of the scheme, the study area takes account of emissions associated with the extraction, processing and transport of materials (refer to paragraph 14.1.1) from outside of the DCO Boundary as well as site-based emissions that result from the construction activities within the DCO Boundary.

Carbon emissions during operation

14.6.6 For the assessment of carbon emissions associated with maintenance and refurbishment of the scheme, the study area is defined by the DCO Boundary and

takes account of emissions associated with the extraction, processing and transport of materials as well as site-based emissions that result from the maintenance and refurbishment activities within the DCO Boundary.

14.6.7 There are likely minimal direct emissions associated with operating the scheme since the scheme lighting is minimal. Power consumption has been assumed as negligible in the context of the scheme and therefore the associated carbon impact does not form part of the GHG emissions assessment.

Road user carbon emissions (during operation)

14.6.8 The study area for operational road user carbon is consistent with the Affected Road Network (ARN), as defined by the scheme's traffic model. The ARN is described in Section 5.6 Study area of ES Chapter 5 Air quality (Document Reference 6.2) and shown in ES Figure 5.1 Affected Road Network (Document Reference 6.3). This includes emissions from vehicles using the scheme and those in the wider road network which have been positively or negatively influenced by the scheme. The assessment of road user carbon includes the total emissions across the ARN model, as described in ES Chapter 5 Air quality (Document Reference 6.2) and shown in ES Figure 5.1 Affected Road Network (Document Reference 6.3).

Carbon emissions associated with ongoing land use change/sequestration

14.6.9 For the calculation of GHG emissions associated with ongoing land use change/sequestration (module D), the study area is defined by the total areas of loss and total areas of gain of habitats within the DCO Boundary. The estimated emissions were calculated based on UK Government data on emissions/sequestration by land type (per unit area) per local authority area. The scheme is located within Tewkesbury Borough and Cotswold District, and an average of these local authority figures was taken to calculate the total loss and total gain for each habitat type (per year and over the 60 year operational period).

Baseline and assessment scenarios

14.6.10 The baseline scenario is the 'Do-Minimum' approach, which represents continual operation of the existing network without the scheme. The baseline scenario includes current operational maintenance GHG emissions, operational user GHG emissions and land use change/sequestration GHG emissions. A 60 year appraisal period has been adopted in line with the methodology set out in DMRB *LA 114 Climate*. The baseline scenario is set out in section 14.7 Baseline conditions.

14.6.11 The assessment scenario is the 'Do-Something' approach, i.e. implementing the scheme. The assessment scenario includes the construction, operational maintenance, operational user and sequestration GHG emissions described in paragraph 14.6.1. GHG emissions in this scenario are compared to the baseline in order to assess the net contribution of the scheme to climate change (in tCO_2e) from construction and operation over the 60-year appraisal period.

Vulnerability of the scheme to climate change (climate change resilience assessment)

14.6.12 The study area for the CCR assessment is based on the construction footprint and includes temporary and completed works within the DCO Boundary.

14.6.13 The study includes all potential climate hazards for infrastructure and assets associated with the scheme. The assessment of climate effects on the scheme is

assessed over the 60-year operational life cycle in line with the methodology set out in DMRB *LA 114 Climate*.

Baseline and assessment scenarios

14.6.14 Assessment scenarios are based on current and future climate baselines, as described in Sections 3.26 – 3.28 of DMRB *LA 114 Climate*. The CCR assessment is based on climate trends associated with theUKCP18[43] high emissions scenario (50% probability) projection. Recent weather patterns and extreme weather events i.e. observed data have been identified and used to provide an indication of how the scheme would account for climate change in the immediate future i.e. during construction. The time periods for climate projections are selected based on the assumed lifespan and stages of the scheme (60 years), with construction assumed to commence in early 2023 and operation assumed from 2026 to 2085.

14.6.15 Additionally, DMRB *LA 114 Climate*, Section 3.30, requires that H++ (which are typically extreme) climate scenarios[44] are used to test the sensitivity of vulnerable safety critical features, to ensure that such features would not be affected by more radical changes to the climate beyond that projected in UKCP18. Safety critical features that are vulnerable to climate change have been identified for the scheme to include:

- Drainage
- Earthworks

14.6.16 A high level sensitivity test using H++ climate scenarios has been undertaken and is presented in section 14.10 Assessment of likely significant effects.

14.6.17 The integral safety of the scheme has also been considered against UKCP18 (and Representative Concentration Pathways 8.5 (RCP8.5)[45] models therein).

14.7 Baseline conditions

Impact of the scheme on climate (GHG emissions assessment)

Current and future baseline

14.7.1 This section identifies the GHG emissions without implementing the scheme for the current and future baseline (Do-minimum scenarios). In these scenarios it is assumed that no construction activity would take place on any of the roads in the area, aside from maintenance, across the study period.

14.7.2 The estimated baseline GHG emissions for the ‘Do-minimum’ scenario in the 2016 baseline year, future baseline years (2026 and 2041) and over the study period (60 years) are summarised in Table 14-8.

Table 14-8 Estimate of baseline GHG emissions for study area

GHG emissions component	Definition	2016 baseline scenario (historic) (tCO_2e)	2026 annualised (modelled opening year) (tCO_2e)	2041 annualised design (future) modelled assessment year (tCO_2e)	Cumulative estimated GHG emissions over 60-year study period (tCO_2e)
Operational maintenance-related GHG emissions	GHG emissions associated with maintenance of the existing road(s) within the study area outlined for the scheme (see section 14.6 Study area).	859 (estimated)	859	859	51,540
Operational user GHG emissions	GHG emissions from the tailpipes of vehicles driving in the ARN (consistent with the study area outlined for the scheme (see section 14.6 Study area).	180,107	178,650	196,247	11,634,050
Land use change/sequestration GHG emissions	GHG emissions associated with ongoing land use/sequestration.	-166 (estimated)	-166	-166	-9,960
Total		**180,800**	**179,343**	**196,940**	**11,675,627**

Vulnerability of the scheme to climate change (climate change resilience assessment) - current climate baseline

Historic observed regional weather data

14.7.3 The Met Office generates climatologies for different areas of the UK, known as climate districts, including historical regional climate information. The scheme is located within the Midlands climate district[46]. High-level climate observations for the Midlands over a 30-year averaging period between 1981-2010 are presented in Table 14-9.

Table 14-9 High level climate observations for the Midlands district (1981-2010)

Climatic conditions	Climate observations
Temperature	Mean daily temperatures ranged from 0°C to 1.5°C in winter, whilst summer daily maximum temperatures were in the region of 22°C.
Rainfall	Atlantic depressions or convection are the source of the majority of rain in the Midlands, particularly in autumn and winter where Atlantic Lows are more vigorous. Annual rainfall in the Cotswolds averages 800mm. Monthly rainfall is variable but is highest in winter months. The number of days with rainfall greater than 1mm are 30-35 days in winter months, dropping to an average of 20-25 days in summer.
Wind	The Midlands is one of the more sheltered regions of the UK. The strongest winds are associated with the passage of deep areas of low pressure close to or across the UK. The frequency and strength of these depressions is greatest in the winter period, when mean speeds and gusts are strongest at approximately 10 knots.

Climatic conditions	Climate observations
Sunshine	Average annual sunshine totals were between 1400 and 1600 hours. A mid-century decline in heavy industry across the region has led to an increase in sunshine duration due to reduced industrial pollution.
Air Frost	The average number of days with air frost varies from 40 to 60 days per year.

Recent weather patterns and extreme weather events

14.7.4 A Local Climate Impacts Profile (LCLIP) for Wiltshire Council[47] was developed by Climate SouthWest (in partnership with Studentforce for Sustainability and the UK Climate Impacts Programme) as part of a larger South West LCLIP (2010)[48], to support 9 upper tier local authorities in the South West. The Wiltshire LCLIP has been used as a proxy for the current local weather experienced in the neighbouring area of Gloucestershire where the scheme is located, as the Gloucester LCLIP was not available in the preparation of the ES. The profile aims to provide an understanding of the nature of past extreme weather events and the impacts they have had on the community, environment and economy. Table 14-10 summarises the primary weather events currently affecting the region and provides a high-level overview of the impacts experienced.

Table 14-10 Local climate impacts profile for Wiltshire Council

Weather event	Impacts
Heavy rain/Flash floods	• Properties across several Wiltshire towns susceptible to flooding. Health and Safety worries along with significant damage and costs. • Infrastructure disruption across county (primarily road and rail). • Services whose premises of normal operations are affected can only provide normal service with additional resources.
Snow/Frost/Ice	• Damage to infrastructure. • Services which involve travel require employment of additional resources to maintain a normal service. • Increased maintenance costs for highways.
Heatwave	• Strains on water and energy utilities. • Disruption to road and rail infrastructure. • Significant damage to infrastructure (primarily road and rail). • Excess deaths – danger to vulnerable groups is significant.
Wind	• Property damage. • Infrastructure disruption. • Power cuts. • Blocked transport routes.

Vulnerability of the scheme to climate change (climate change resilience assessment) - future baseline

14.7.5 This section presents future projected climate conditions and extreme weather events for the area encompassing the scheme for the 2020s and 2080s[49]. These time periods cover the assumed construction period (commencing in early 2023 for a period of 42 months) and the assumed 60-year operational life (2026 to 2085[50]).

14.7.6 Using the historical baseline data, two methods were implemented to establish the future climate baseline:

- The changes in average climate conditions were obtained from the UKCP18 probabilistic projections of climate change[51].
- The changes in extreme weather events were obtained using UKCP18 regional projections[52].

14.7.7 Climate change projections for a range of meteorological parameters are presented for different probability levels within the RCP8.5 high emission scenario for the near-term and long-term future time periods. Table 14-11 presents changes in extreme weather events for the 2020s and 2060s[53], such as number of heavy rain days and Table 14-12 presents expected changes in climate conditions, such as mean temperature and precipitation for the 2020s and 2080s.

14.7.8 Temperatures in the area are projected to increase in both winter and summer. The largest increase in temperature is projected to be in the mean daily maximum temperature in summer, which is expected to increase by 5.7°C to 26.4°C in the 2080s, relative to the baseline in the high emissions scenario.

14.7.9 Mean precipitation rates in the region are anticipated to change significantly throughout the century, increasing by 5%-23% in the winter and decreasing by 6%-37% in summer during the 2020s and 2080s.

14.7.10 The mean number of hot days, when the maximum temperature is above 25°C, is anticipated to increase from 11.5 to 60.5 days per year in the 2060s for the high emissions scenario. The average number of days in a given year, when the mean daily temperature is below 0°C, is anticipated to decrease from 45.2 to 17.1 in the 2060s under the high emissions scenario.

14.7.11 In the case of extreme precipitation, the number of days with heavy rain (precipitation greater than 25mm/day) in a given year is expected to increase from 1.8 in the baseline period to 2.6 in the 2060s. Similarly, the average annual number of dry spells (periods of at least ten consecutive days with no precipitation) is projected to increase from 4.5 for the baseline period to 5.8 for the 2060s under the high emissions scenario.

14.7.12 In the case of extreme wind, the number of days with wind above 10 metres per second in a given year is not expected to increase from the baseline period to 2060s. Hence no further assessment has been undertaken.

Table 14-11 UKCP18 climate change projections for extreme weather events for the local area (12 kilometre grid square) for the 2020s and 2060s (under the RCP 8.5 high emissions scenario)

Parameter		Baseline (1981-2010)	2020s (2010-2039)			2060s (2050-2079)		
			Min.[54]	Mean	Max.	Min.	Mean	Max.
Temperature	Number of frost days (daily minimum temperature equal or lower than 0°C)	45.2	23.4	33.5	49.4	11.6	17.1	24.8
	Heatwaves (2 days with maximum temperature higher than 29°C and minimum temperature higher than 15°C)	0.4	0.3	1.1	2.9	2.9	7.1	12.9
	Average summer highest daily maximum temperature (°C)	26.9	27.0	29.2	32.1	30.8	33.3	36.2
	Number of hot days (daily maximum temperature higher than 25°C)	11.5	12.2	23.8	45.7	34.3	60.5	86.4
Precipitation	Dry spells (10 days or more with no precipitation)	4.5	3.7	4.7	5.9	4.7	5.8	6.8
	Annual number of days per year when precipitation is greater than 25mm per day (Met Office definition of 'heavy rain')	1.8	1.3	2	2.7	1.6	2.6	3.6
Wind	Wind above 10 metres per second[55]	1.1	0.2	1.0	2.4	0.2	1.1	2.7

Table 14-12 UKCP18 climate change projections for average climate variables for the local area (25 kilometre grid square) for the 2020s and 2080s (under the RCP 8.5 high emissions scenario)

Parameter		Baseline (1981-2010)	Anomalies from baseline for 2020s (2010-2039)			Anomalies from baseline for 2080s (2070-2099)		
			10th percentile	50th percentile	90th percentile	10th percentile	50th percentile	90th percentile
Temperature (°C) (change from baseline)	Mean winter daily temperature	4.5	-0.1	0.7	1.4	1.1	3	5
	Mean summer daily temperature	16.1	0.2	0.9	1.7	2	4.9	8.1
	Mean daily summer maximum temperature	20.9	0.3	1.2	2.1	2.2	5.7	9.4
	Mean daily winter minimum temperature	1.5	-0.1	0.6	1.4	1	3	5.4
Precipitation (% change from baseline)	Winter mean precipitation rate	2.3mm	-4%	5%	15%	2%	23%	47%
	Summer mean precipitation rate	2mm	-22%	-6%	9%	-65%	-37%	9%

H++ scenarios

14.7.13 DMRB *LA 114*, Section 3.30, requires that H++ climate scenarios are used to test the sensitivity of vulnerable safety critical features, to ensure that such features would not be affected by more radical changes to the climate beyond that projected in UKCP18. These are typically high impact, low likelihood events.

14.7.14 H++ scenarios are a set of plausible 'high-end' climate change scenarios which are typically extreme climate change scenarios on the margins or outside of the 10th to 90th percentile range presented in the UK Climate Projections 2009 (UKCP09). The UKCP18 projections do not include an updated H++ scenario and so the H++ scenario developed from UKCP09 remains current and applicable. The H++ scenarios are shown in Table 14-13 and cover the following climate hazards: heat waves, cold snaps, low and high rainfall, droughts, floods and windstorms.

Table 14-13 A summary of the H++ scenarios (extract from Table S1 from the Met Office 2015 report on developing H++ climate change scenarios[56])

Hazard	Scenario	Scenario description
Heat waves	H++	Annual average summer maximum temperatures exceeding 30°C over most of the UK and 34°C over much of central and southern England. Hottest days would exceed 40°C in some locations, with 48°C being reached in extreme cases.
Low rainfall	H++	A 6 month duration summer drought with rainfall deficits of up to 60% below the long-term average (1900-1999). Longer dry periods spanning several years with rainfall deficits of up to 20% below the long-term average (1900-1999) across all of England and Wales, similar to the most severe and extensive long droughts in the historical record.
Low river flows	H++	A 40-70% reduction in 'low flows' (Q95) in England and Wales in a single summer. For multi-season droughts, including 2 summers, a 20 to 60% reduction in low flows in England and Wales.
High rainfall	H++	A 70%-100% increase in winter rainfall (Dec to Feb) in a single winter (from a 1961-1990 baseline). An up to five-fold increase in frequency and 60% to 80% increase in heavy daily and sub-daily rainfall depths, for both summer and winter events (all year round).
High river flows	H++	A 60% to 120% increase in peak flows at the 'lower end' of the H++ scenarios for some regions in England and Wales. The upper limit for any region is a 290% increase in peak flows (1961-1990 baseline). The scenarios are based on the average response of "Enhanced-high" catchments, which are particularly sensitive to increases in rainfall.
Windstorms	H++	A 50-80% increase in the number of days per year with strong winds over the UK (1975-2005 baseline). A strong wind day is defined as one where the daily mean wind speed at 850 hPa, averaged over the UK (8W-2E, 50N-60N), is greater than the 99th percentile of the historical simulations.
Cold snaps	L--*	In the 2020s, UK average winter temperatures (December, January and February) of 0.3°C and for the 2080s, UK average winter temperatures would be around -4°C. In the 2020s, UK average temperatures on the coldest day would be -7°C in some locations. UK average temperature of the coldest day would be around -11°C.

*Note the term L-- is used specifically for the 'cold snap' scenario to emphasise that it is at the opposite end of the scale to the extreme warm summer temperatures in H++ and linked to Low emissions.

14.8 Potential impacts

14.8.1 Mitigation measures incorporated in the design and construction of the scheme are reported as embedded mitigation in ES Chapter 2 The project (Document Reference 6.2) and essential mitigation in section 14.9 Design, mitigation and enhancement measures. Prior to the implementation of mitigation, the scheme has the potential to affect climate during construction and operation, both beneficially and adversely.

Impact of the scheme on climate (GHG emissions assessment)

14.8.2 The scheme would result in GHG emissions during construction as well as changes to emissions during operation.

14.8.3 Sources of potential GHG emissions during construction include:

- Embodied GHG emissions associated with the required raw materials, including raw material supply, transport and manufacture.
- GHG emissions associated with construction processes, including transport to/from works site and construction/installation processes.
- GHG emissions associated with land use change, for example those mobilised from vegetation or soil loss during construction.

14.8.4 Sources of potential GHG emissions during operation include:

- GHG emissions from vehicles using the highway infrastructure (road users).
- GHG emissions from the maintenance, repair and refurbishment of the scheme, for example emissions associated with raw materials and transport required to replace the road surface.
- GHG emissions associated with ongoing land use change/sequestration.

14.8.5 Opportunities identified for reduction of GHG emissions and mitigation measures incorporated in the design and construction of the scheme are set out in section 14.9 Design, mitigation and enhancement measures.

Vulnerability of the scheme to climate change (climate change resilience assessment)

14.8.6 Anticipated changing climate conditions and weather events have the potential to have significant adverse effects on the scheme, or on elements of the scheme during construction and operation.

14.8.7 During the construction process, receptors may be vulnerable to a range of short-term climate risks, including damage to construction materials, plant and equipment, unsuitable conditions for construction activities, delay, increased costs and health and safety impacts to the workforce during severe weather events.

14.8.8 Once operational, the scheme has the potential to be impacted upon by a changing climate and more frequent severe weather events in the medium to longer-term. Potential impacts include material and asset deterioration and damage giving rise to health and safety risks to users and increased maintenance requirements.

14.8.9 The potential risks are expected to be largely mitigated through the use of appropriate design standards, delivered through quality construction, as well as appropriate asset management procedures during operation.

14.8.10 The A417 provides an important transport link for Gloucester and is a part of the SRN in the region. The scheme is expected to increase the resilience of transport systems in the region to a range of hazards, including climatic hazards arising

from climate change, and hence provide benefit for the overall resilience of the region.

In-combination climate impacts

14.8.11 Potential effects could arise due to impacts from the scheme in combination with future projected climate conditions on all environmental factor receptors.

14.8.12 These are considered in ES Appendix 14.3 In-combination climate change impact assessment (Document Reference 6.4).

14.9 Design, mitigation and enhancement measures

14.9.1 The scheme has been designed, to avoid and prevent adverse environmental effects on climate through the process of design development and consideration of good design principles. Embedded mitigation measures for climate are reported as part of the scheme description in ES Chapter 2: The project (Document Reference 6.2).

Design and construction mitigation

Impact of the scheme on climate (GHG emissions assessment)

14.9.2 In accordance with DMRB *LA 114 Climate*, the third lifecycle stage for a project's GHG emissions (the first and second being construction and operation) comprises opportunities to reduce the production of GHG emissions.

14.9.3 In line with Highways England's *Sustainable Development Strategy* (2017)[57] and *Action Plan* (2018)[58], which set out Highways England's ambition to reduce carbon emissions, and the UK Government's carbon reduction plan targets, and with DMRB GG 103 Introduction and general requirements for sustainable development and design, the scheme has sought and would continue to seek to reduce GHG emissions as far as reasonably practicable to contribute to the UK's net reduction in carbon emissions and maximise its potential for reducing GHG emissions.

14.9.4 The following mitigation measures have been and would continue to be considered to reduce GHG emissions from the scheme. Key emissions impacts during construction would be from construction activities and embedded/embodied carbon of the materials. Mitigation measures identified in Table 14-14 are divided into the following hierarchy options:

- Avoid/prevent - maximise potential for re-using and/or refurbishing existing assets to reduce the extent of new construction required, and/or explore alternative lower carbon options to deliver the scheme objectives.
- Reduce - low carbon and/or reduced resource consumption solutions (including technologies, materials and products) to minimise resource consumption during the construction, operation, and at end of life.
- Remediate - measures to further reduce carbon through on or off-site offsetting or sequestration.

Table 14-14 GHG mitigation measures during design and construction

Mitigation measure	Delivery mechanism	Embedded/ Essential[59]	Method of reduction
The scheme has been designed to minimise the requirement for energy consuming operational equipment such as street lighting or intelligent	Scheme design	Embedded	Avoid/prevent Reduce

Mitigation measure	Delivery mechanism	Embedded/ Essential[59]	Method of reduction
transport systems wherever possible. Where lighting may be potentially required, for example at Grove Farm underpass, low lux demand sensitive lighting is proposed to reduce GHG emissions associated with operating the scheme.			
The crossings have been refined as part of the evolution of the scheme, which has resulted in a reduction in embodied GHG emissions due to fewer materials and associated construction works emissions.	Scheme design	Embedded	Avoid/prevent Reduce
The depth of cutting through the escarpment has reduced from 25 metres to 17 metres as the design has evolved. This has removed the requirement for a number of retaining walls and their associated embedded carbon emissions. This would also reduce the required earthworks and excess material, reducing the corresponding construction process emissions and emissions associated with waste management activities (transport, processing and final disposal).	Scheme design	Embedded	Avoid/prevent Reduce
The construction contractor would develop and implement a plan to reduce energy consumption and associated carbon emissions. This could include the consideration of renewable and/or low or zero carbon energy sources and recording the savings implemented. Highways England is committed to reducing carbon emissions and works closely with suppliers to reduce emissions from network related activity. Energy consumption and materials use would be recorded and reported on an ongoing basis during the construction phase of the scheme using the Highways England Carbon Reporting Tool.	Environmental management plan (EMP)	Essential	Reduce
Where practicable, measures would be implemented to manage material resource use during construction including: • Using materials with lower embedded GHG emissions and water consumption. • Using sustainably sourced materials. • Using recycled or secondary materials. • Employing low carbon construction techniques, e.g. warm asphalt.	EMP	Essential	Reduce
Material excavated during construction would be processed for use in the works wherever possible to reduce the amount of material disposed of off-site as well as imported from other sources, and associated GHG emissions. Possible uses include general fill and other graded materials. Processing of material would take place on-site.	EMP	Essential	Reduce
Existing pavements on the A417 would be retained wherever possible within the scheme to reduce the requirement for additional materials and construction.	EMP	Essential	Avoid/prevent
The scheme design has carefully considered the use of appropriate tree and shrub species and low	Scheme design	Essential	Reduce

Mitigation measure	Delivery mechanism	Embedded/ Essential[59]	Method of reduction
maintenance wildflower grassland (calcareous grassland) to reduce associated maintenance operations. Calcareous grassland, which has been used throughout the scheme, only requires cutting once a year (reducing maintenance-related emissions) and can be seeded directly on to subsoil, which would remove the requirement to import topsoil during construction.			

Vulnerability of the scheme to climate change (climate change resilience assessment)

14.9.5 The scheme has been designed to improve its resilience to climate change through a range of design and material specification measures including where practicable: the use of construction materials with superior properties (such as increased tolerance to fluctuating temperatures), incorporation of current road design standards and future climate change allowances. Embedded mitigation and adaption measures for all climate risks identified within the CCRA are set out in Table 14-20 within section 14.10 Assessment of likely significant effects. Additionally, the integral safety of the scheme has been considered against UKCP18 (and RCP8.5 models therein). A sensitivity test of the safety critical features against H++ scenarios is set out in Table 14-21 within section 14.10 Assessment of likely significant effects.

14.9.6 All weather and climate-related risks to construction activities are expected to be mitigated through best practice site management, including relevant specific measures which are set out in a register of environmental actions and commitments within ES Appendix 2.1 Environmental Management Plan (EMP) (Document Reference 6.4). The best practice site management measures and relevant specific measures would provide a level of resilience to the scheme throughout construction. Taking this mitigation into consideration, vulnerability of the scheme to impacts from climate change during construction has been scoped out of the assessment in line with PINS' Scoping Opinion on the scheme[60].

Operational mitigation

Impact of the scheme on climate (GHG emissions assessment)

14.9.7 In addition to the mitigation measures identified within Table 14-14, no essential operational mitigation measures have been proposed. It is not practical to monitor GHG emissions from road users during the operational phase of the scheme as Highways England does not have direct control over road user emissions.

14.9.8 As detailed in ES Chapter 2 The project (Document Ref 6.2), the scheme would include limited technology to support the maintenance and operation of the scheme. Renewable energy power sources for technology assets on the scheme would be considered at the detailed design stage.

14.9.9 As detailed in ES Chapter 2 The project (Document Ref 6.2), maintenance lay-bys have been located to provide safe access to maintain the structures and the drainage network, as well as undertake landscaping works. The opportunity for electric vehicle charging points would be considered at the detailed design stage.

Vulnerability of the scheme to climate change (climate change resilience assessment)

14.9.10 A number of general mitigation and adaptation measures to address the potential impacts associated with climate change events have been considered, many of which have been identified within the other aspect chapters of the ES and through the scheme design. The assessment identifies and takes into account existing resilience measures for each climate variable and associated impacts either already in place, or in development, for infrastructure and assets.

14.9.11 Most weather and climate-related resilience effects during operation are expected to be mitigated through measures embedded in the design of the scheme, providing a level of resilience throughout operation. Embedded mitigation and adaption measures for all climate risks identified within the CCRA are set out in Table 14-20 within section 14.10 Assessment of likely significant effects.

14.9.12 The CCR assessment results, which identify relevant mitigation measures and management practices are summarised in section 14.10 Assessment of likely significant effects, with detailed results presented in ES Appendix 14.2 Climate Change Resilience Assessment (Document Reference 6.4). Any further mitigation measures identified through the sensitivity test of the safety critical features against H++ scenarios are set out in Table 14-21 within section 14.10 Assessment of likely significant effects.

14.10 Assessment of likely significant effects

14.10.1 This section presents the assessment of likely significant effects on climate resulting from the construction and operation of the scheme. The assessment of effects takes into account the potential impacts to each receptor following the implementation of embedded and essential mitigation measures to determine the significance of the residual effects.

Impact of the scheme on climate (GHG emissions assessment)

14.10.2 This assessment presents a calculation of the emissions calculated for the 'Do-Something' scenario, a comparison against the 'Do-Minimum' baseline, and assessment against legislated UK Government carbon budgets.

14.10.3 Due to the embedded nature of the mitigation measures proposed, as outlined in section 14.9 Design, mitigation and enhancement measures, some of which have already been incorporated into the design and some of which are yet to be incorporated, it is not practicable to complete a quantitative assessment of 'before' and 'after' mitigation. Rather, the assessment shows a snapshot of the current design.

'Do-Something' scenario emissions

Construction

14.10.4 A high-level breakdown of construction phase emissions is displayed in Table 14-15. All assumptions used in the calculations are contained within ES Appendix 14.1 Greenhouse gas assessment assumptions, methodology and emissions factors (Document Reference 6.4) and section 14.5 Assessment assumptions and limitations. Emissions from the construction phase are predicted to total in the region of 74,144 tCO_2e.

Table 14-15 Construction stage emissions

Main stage of project life cycle	Sub-stage of life cycle		Emissions (tCO_2e)	% of total construction emissions*
Construction stage	**Product stage**; including raw material supply, transport and manufacture (A1-A3)		40,698	55%
	Construction process stage; including:	Transport to/from works site (A4)	2,668	4%
		Construction/installation processes (A5)	20,818	28%
	Land use change (D); future loss of ability to sequester carbon from habitats lost during construction (over the 60 year assessment period)		9,960	13%
	Construction stage total		**74,114**	**100%**

* Due to rounding, percentages may not always appear to add up to 100%

* Sub-stages of the construction life cycle and modules shown in this table align with PAS 2080 boundary stages and individual modules as shown in Table 14-7.

14.10.5 The largest magnitude of emissions during construction (55%) is likely to arise from the production of materials. Emissions associated with the future loss of ability to sequester carbon from habitats lost during construction equate to 13% over the 60-year assumed operational period. Emissions from on-site construction processes equate to 28% of the total, and transport of materials totals 4% of emissions.

Operation

14.10.6 As noted in the section 14.6 Study area, there are likely minimal direct emissions associated with operating the scheme since the scheme lighting is minimal. Power consumption has been assumed as negligible in the context of the scheme and therefore does not form part of the GHG emissions assessment.

14.10.7 Emissions associated with maintenance and refurbishment assume that the road surface would be replaced once every ten years for the duration of the assumed 60-year design life. Road user GHG emissions are expected to constitute the majority of the whole life GHG emissions of the scheme. Operational phase emissions for the modelled opening and design years[61] and total over the modelled 60-year operational period are shown in Table 14-16.

Table 14-16 Operation ('use stage') emissions for modelled opening year (2026), design year (2041) and total over the assumed 60-year operational period (2026 – 2085)

Main stage of project life cycle	Sub-stage of life cycle	Emissions (tCO_2e)		
		2026 annualised (modelled opening year)	2041 annualised design (future) modelled assessment year	Total (cumulative) over modelled 60-year operation (2026 – 2085)
Operation ('use-stage')	Use of the infrastructure by the end-user (road user emissions) (B9)	189,546	211,952	12,537,861
	Maintenance and refurbishment (B2-B5)	858	858	51,454
	Land use and forestry (D): future ability to sequester carbon from habitats gained (over the 60 year assessment period)	-180	-180	-10,793
	Operation ('use-stage') total	**190,224**	**212,630**	**12,578,522**

* Sub-stages of the Operation ('use-stage') life cycle and modules shown in this table align with PAS 2080 boundary stages and individual modules as shown in Table 14-7.

Comparing 'Do-Minimum' and 'Do-Something' scenarios

14.10.8 As GHG emissions associated with construction do not occur in the 'Do-Minimum' scenario, it can be considered that the construction stage of the scheme would have the effect of releasing in the region of an additional 74,144 tCO_2e into the atmosphere in the 'Do-Something' scenario.

14.10.9 The calculated annualised operation stage emissions for the modelled 2026 and 2041 'Do-Minimum' and 'Do-Something' scenarios and the cumulative operation stage emissions over the 60-year operation for the 'Do-Minimum' and 'Do-Something' scenarios are compared in Table 14-17.

Table 14-17 'Do-Something' and 'Do-Minimum' operation ('use stage') emissions comparison for modelled opening year (2026), design year (2041) and total over the assumed 60-year operational period (2026 – 2085)

Main stage of project life cycle	Emissions (tCO_{2e})								
	2026 (annualised) Do-Minimum	2026 (annualised) Do-Something	Difference	2041 (annualised) Do-Minimum	2041 (annualised) Do-Something	Difference	Total (cumulative) over 60-year operation (2026 – 2085) Do-Minimum	Total (cumulative) over 60-year operation (2026 – 2085) Do-Something	Difference
Total operational 'use stage' emissions (maintenance, road user and land use)	179,334	190,224	10,880	196,940	212,630	15,689	11,675,627	12,578,522	902,895

14.10.10 The scheme is estimated to lead to an increase of approximately 0.9 million tCO_2e during the modelled 60-year operational period (2026 – 2085), relative to the 'Do-Minimum' scenario.

Assessment against legislated UK carbon budgets

14.10.11 Table 14-18 shows the relevant carbon budget periods against which the scheme would contribute. This approximation assumes an even distribution of emissions across the assumed overall construction period.

14.10.12 If the DCO is granted, construction is expected to start in early 2023 and the scheme is expected to be open to traffic in 2026. Therefore, the construction period for the scheme falls wholly within the fourth carbon budget. Operation of the scheme would commence in 2026 and is assessed against the fourth and fifth carbon budgets, up to 2032. Operational and maintenance emissions between 2033 and 2037 (the period for the sixth carbon budget) are provided in Table 14-18, however emissions after 2032 are not assessed as this new target has yet to be legislated. The UK Government has indicated it intends to enshrine the sixth carbon budget in UK law by the end of June 2021.

Table 14-18 Assessment of scheme net emissions (up to 2032) against UK Government carbon budgets

Project stage	Estimated total (cumulative) GHG emissions over carbon budgets (tCO_2e) ('Do-Something' scenario)	Net (cumulative) GHG emissions over carbon budgets (tCO_{2e}) ('Do-Something'- 'Do-Minimum')	Net (cumulative) scheme GHG emissions per relevant carbon budget (tCO_2e)			
			Third (2018 - 2022)	Fourth (2023 - 2027)	Fifth (2028 - 2032)	Sixth[1] (2033 - 2037)
Construction (over a period of 42 months, assumed to commence in early 2023-2026)	74,114	74,114	n/a	74,114	n/a	n/a
Operation (modelled from 2026 through to 2037)	2,373,212	152,565	n/a	22,158	61,196	69,211
Total	**2,447,356**	**226,709**	**n/a**	**96,302**	**61,196**	**69,211**

Significant effects

14.10.13 The construction and operation phases of the scheme which fall within legislated carbon budget periods are expected to have an insignificant impact on the ability of the UK Government to meet its carbon budgets. Construction of the scheme is estimated to contribute approximately 0.00380% of the fourth carbon budget. Operation of the scheme is estimated to contribute approximately 0.00114% of the fourth carbon budget and 0.00355% of the fifth carbon budget. It is considered that this magnitude of emissions from the scheme in isolation would not have a material impact on the ability of the UK Government to meet its carbon budgets, and therefore is not anticipated to give rise to a significant effect on climate, in line with the position set out within Section 5.18 of the NPSNN.

Comparison with other schemes

14.10.14 Table 14-19 compares the estimated GHG emissions performance of the scheme against other comparable highway projects, normalised to take account of differences in size and scale.

[1] The sixth carbon budget has been committed to by government and is expected to become law by June 2021.

Table 14-19 Comparison of the scheme's carbon with other road infrastructure projects[62]

Carbon footprint life cycle modules	Project/length and width component								
	M4 corridor Around Newport	A14	A465	HA Project A	HA Project B	HA Project C	HA Project D	HA Project E	The scheme
	14.3 miles (23km) New relief road	23 miles (37km) improvement scheme	4.8 miles (7.8km) embankment section	16.5 miles (26.6km) widening of A road	4 miles (6.5km) single to 2 lane dual carriageway	2.5 miles (4km) upgrade of existing junction	0.4 miles (0.7km) Refurbished existing viaduct	13.7 miles (22.1km) Upgrade from dual to 3 lanes	3.4 miles (5.5km) widening of A road
Capital (embodied) CO_2e (tCO_2e)									
Material	436,600	740,100	44,300	74,500	77,300	36,100	5,800	213,700	40,698
Labour + plant	42,800	243,800	5,800	38,500	27,500	8,200	4,000	20,900	23,486
Earthworks	43,200	n/a	2,500	n/a	n/a	n/a	n/a	n/a	
Construction tCO_2e/km	*21,800*	*26,600*	*6,700*	*4,300*	*16,100*	*11,100*	*13,900*	*10,600*	*11,670*
Operational CO_2e (tCO_2e)									
Operation + Maintenance/ annum	1,600	2,400	2,600	n/a	n/a	n/a	n/a	n/a	858
Use Phase CO_2e (tCO_2e)									
Use/annum	2,268,700	4,386,400	882,000	n/a	n/a	n/a	n/a	n/a	209,642

Table Source: Welsh Government (2016). M4 Corridor around Newport, Environmental Statement: Volume 3, Appendix 2.4 Carbon Report

14.10.15 Construction related emissions are comparable with other projects on a per kilometre basis. Operational and maintenance carbon is expected to be significantly lower than other projects. This is likely due to minimal energy consuming assets within the design. On a per kilometre basis, estimated use phase emissions per annum are notably lower than comparable projects.

Vulnerability of the scheme to climate change (climate change resilience assessment)

Construction

14.10.16 Climate resilience impacts on the scheme during the construction phase are not expected to be significant due to the duration and nature of the construction activities. Therefore, these impacts have not been assessed any further.

Operation

14.10.17 Climate change risks to infrastructure assets designed and constructed as part of the scheme have been assessed during operation. The assessment finds all climate change risks to assets during the operation of the scheme to be 'not significant' because of mitigation measures already built into the design and

assumed management practices. Details of the mitigation measures identified to date and the significance assessment are contained in ES Appendix 14.2 Climate Change Resilience Assessment (Document Reference 6.4).

14.10.18 These non-significant climate resilience impacts, identified using criteria set out in the assessment methodology, are detailed in ES Appendix 14.2 Climate Change Resilience Assessment (Document Reference 6.4) and summarised in Table 14-20.

Table 14-20 Non-significant climate resilience impacts, embedded or essential mitigation measures and likelihood and consequence of hazard impact (extract from ES Appendix 14.2 Climate Change Resilience Assessment (Document Reference 6.4))

Risk ID	Climate hazard	Potential climate change risk to scheme	Embedded or essential mitigation measure	Likelihood of hazard impact	Consequence of hazard impact (should the impact occur)	Evaluation of significance
1	High temperatures	Increased heat stress for staff, particularly for outdoor construction and maintenance workers.	To be incorporated within proposed maintenance regimes. These can be reviewed regularly to ensure health and safety requirements within Highways England are met.	Low	Minor adverse	Not significant
2	High temperatures	Extended periods of hot, dry weather may lead to a risk of spontaneous grassland fires in vicinity of the route, leading to smoke from a fire to spread to the public highway and affect safety on the road network.	Risk to be sufficiently mitigated through standard emergency procedures. Additionally, the road would act as a firebreak, providing a gap in combustible material that would act as a barrier to slow or prevent the progress of a wildfire from one side to the other.	Low	Moderate adverse	Not significant
3	High temperatures	Asphalt surface may exhibit permanent deformation in long periods of hot, sunny conditions.	This risk would be managed through the selection of suitable road surface material as well as through the proposed maintenance regimes for road surface.	High	Minor adverse	Not significant
4	High temperatures	High temperatures increase the risk of surfacing rutting leading to water ponding in the ruts. Higher temperatures also increase the risk of reduced skid resistance due to fatting and chipping embedment. This would increase the risk of vehicle incidents.	This risk would be managed through the selection of suitable road surface material as well as through the proposed maintenance regimes for road surface.	Low	Moderate adverse	Not significant

Risk ID	Climate hazard	Potential climate change risk to scheme	Embedded or essential mitigation measure	Likelihood of hazard impact	Consequence of hazard impact (should the impact occur)	Evaluation of significance
5	High temperatures	Inability to flex under traffic loads. Increased risk of road surface cracking and fretting with age.	This risk would be managed through the proposed maintenance regimes.	Medium	Minor adverse	Not significant
6	High temperatures	Risk of being unable to lay road surface layers in hot weather.	Risk to be mitigated by following procedures to be detailed in the second iteration of the Environmental Management Plan (EMP), the EMP (Construction).	Low	Minor adverse	Not significant
7	High temperatures	Decreased viscosity in heat leads to greater spreading of diesel in a smaller timeframe. Higher temperatures and increased number of hot, dry days increase the likelihood of ignition of this diesel leading to road and forest fires.	Risk to be sufficiently mitigated through proposed maintenance procedures to be included in the EMP (End of construction).	Low	Moderate adverse	Not significant
8	High precipitation	Flooding of road surface.	Drainage basins designed for 1/100 year event +40% for climate change	Very low	Moderate adverse	Not significant
9	High precipitation	Flooding of access roads and/or road infrastructure.	Drainage basins designed for 1/100 year event +40% for climate change	Very low	Moderate adverse	Not significant
10	High precipitation	Increase risk of sewage overflow in floodwater causing damage and impacting health of maintenance workers.	Drainage basins designed for 1/100 year event +40% for climate change Climate change allowance in critical drainage areas increased to +40%.	Very low	Moderate adverse	Not significant
11	High precipitation	Increased risk of scouring of culverts.	Drainage basins designed for 1/100 year event +40% for climate change	Low	Minor adverse	Not significant

Risk ID	Climate hazard	Potential climate change risk to scheme	Embedded or essential mitigation measure	Likelihood of hazard impact	Consequence of hazard impact (should the impact occur)	Evaluation of significance
12	High precipitation	Flooding causing damage to fibre optic cables running near to site.	Drainage basins designed for 1/100 year event +40% for climate change	Very low	Negligible	Not significant
13	High precipitation	Increased pore water pressure in embankments/cuttings.	To be mitigated through drainage design. Risk likely to be absorbed by conservative assumptions made during design.	Very low	Large adverse	Not significant
14	High precipitation	Increased erosion at toe of embankment.	To be mitigated through drainage design. Risk likely to be absorbed by conservative assumptions made during design.	Low	Large adverse	Not significant
15	High precipitation	Water ingress to critical construction equipment.	Drainage on site to be suitably managed, to be specified within the EMP.	Very low	Minor adverse	Not significant
16	High precipitation	Water ingress to signalling, lighting and other operational electrical equipment.	Watertight cables housed in plastic ducts. No water ingress to underground cables.	Very low	Minor adverse	Not significant
17	High precipitation	Change in ground water level affecting earth pressures and foundation settlement causing possible large ground movement.	To be mitigated through drainage design. Risk likely to be absorbed by conservative assumptions made during design.	Very low	Large adverse	Not significant
18	High precipitation	Increased risk of debris deposit from water seeping up to the surface through the pavement e.g. calcium sulphate leading to reduced skid resistance.	Weather and weather effects on traffic considered within pavement design.	Low	Moderate adverse	Not significant
19	High precipitation	Construction site flooding during construction phase, excavations	Drainage on site to be suitably managed, to be specified within	Low	Moderate adverse	Not significant

Risk ID	Climate hazard	Potential climate change risk to scheme	Embedded or essential mitigation measure	Likelihood of hazard impact	Consequence of hazard impact (should the impact occur)	Evaluation of significance
		flooded and site roads impassable. Safety risk of slips, trips and falls to construction workers.	the EMP. Health and safety procedures to be further specified within the EMP.			
20	High precipitation	Increased ground water level in winter may lead to flooding of underpasses.	To be mitigated through drainage design.	Low	Minor adverse	Not significant
21	High precipitation	Increased risk of earthworks failure and landslides. Exacerbated by variance between high and low precipitation events and soil moisture levels.	To be mitigated through geotechnical and drainage design. Risk likely to be absorbed by conservative assumptions made during design. Any residual risk will be monitored in accordance with CS 641 Managing the maintenance of highway geotechnical assets[63].	Low	Large adverse	Not significant
22	High precipitation	Reduced capacity of attenuation ponds due to sediment build-up.	Risk to be mitigated through the monitoring and maintenance procedures specified for the relevant attenuation ponds, to be included in the EMP (End of construction).	Medium	Minor adverse	Not significant
23	High precipitation	Increased risk of debris washing into drainage gullies, blocking them. A blockage may result in flooding and resulting effects.	Mitigated through drainage design and monitoring and maintenance procedures proposed for drainage systems, to be included in the EMP (End of construction).	Low	Moderate adverse	Not significant
24	High precipitation	Increase stripping rate of the road surfaces.	This risk would be managed through the proposed maintenance regimes for road	Low	Minor adverse	Not significant

Risk ID	Climate hazard	Potential climate change risk to scheme	Embedded or essential mitigation measure	Likelihood of hazard impact	Consequence of hazard impact (should the impact occur)	Evaluation of significance
			surface, to be included in the EMP (End of construction).			
25	High precipitation	Wetter surface may lead to reduced skid resistance.	This risk would be managed through the selection of suitable road surface material as well as through the proposed maintenance regimes for road surface, to be included in the EMP (End of construction).	Low	Moderate adverse	Not significant
26	High precipitation	Increased likelihood of potholing, rutting and cracking from moisture entering and remaining in road surfaces.	This risk would be managed through the proposed maintenance regimes for road surface, to be included in the EMP (End of construction).	High	Minor adverse	Not significant
27	High precipitation	Increased flow of groundwater causing accelerated weathering effects, weakening the embankment.	Risk likely to be absorbed by conservative assumptions made during design. Any residual risk will be monitored in accordance with CS 641 Managing the maintenance of highway geotechnical assets.	Very low	Large adverse	Not significant
28	Low precipitation	Potential risk of soil shrinkage impacting foundations, including bridges and other structures. Possible ground movement (check differential settlement due to different types of foundations).	Risk to be absorbed by conservative assumptions made during design. Any residual risk will be monitored in accordance with CS 641 Managing the maintenance of highway geotechnical assets.	Very low	Large adverse	Not significant
29	Low precipitation	Reduced slope stability and potential earthworks failure during or immediately after	Risk likely to be absorbed by conservative assumptions made during design.	Low	Large adverse	Not significant

Risk ID	Climate hazard	Potential climate change risk to scheme	Embedded or essential mitigation measure	Likelihood of hazard impact	Consequence of hazard impact (should the impact occur)	Evaluation of significance
		summer storm events falling on desiccated soils.	Any residual risk will be monitored in accordance with CS 641 Managing the maintenance of highway geotechnical assets.			
30	Low precipitation	Anaerobic conditions may occur, risking die back of sediment collecting species, reducing attenuation basins functional capacity.	Risk to be mitigated through the monitoring and maintenance procedures specified for the relevant attenuation basins, to be included in the EMP (End of construction).	Medium	Minor adverse	Not significant

14.10.19 The A417 provides an important transport link for Gloucester and is a part of the SRN in the region. The scheme is expected to increase the resilience of transport systems in the region to a range of hazards, including climatic hazards and climate change, and hence provide benefit for the overall resilience of the region.

Sensitivity test of the scheme's vulnerable safety critical features against H++ climate scenarios

14.10.20 This section reports a sensitivity test of the vulnerable safety critical features of the scheme against the H++ climate scenarios[64] to assess the extent to which such features would be affected by more radical changes to the climate beyond that projected in UKCP18. Safety critical features that are vulnerable to climate change have been identified for the scheme to include:

- Drainage
- Earthworks

14.10.21 Other safety critical features of the scheme have been scoped out of the sensitivity test due to their limited vulnerability to climate change (e.g. road restraint systems), their embedded resilience due to the use of appropriate design standards such as specifications within relevant British Standards (e.g. bridges and structures) or risks being controlled through appropriate adaptive management and maintenance procedures already identified in the CCR assessment detailed in ES Appendix 14.2 Climate Change Resilience Assessment (Document Reference 6.4) and summarised in Table 14-20 (e.g. pavements).

14.10.22 The sensitivity testing has been informed by published research and guidance, including:

- Met Office, University of Reading and CEH for the Adaptation Sub-Committee (2015) Developing H++ climate change scenarios for heat waves, droughts, floods, windstorms and cold snaps[65].
- Highways England's Climate Adaptation Risk Assessment[66].

14.10.23 This high level appraisal is a sensitivity test for the worst plausible climate change scenario and so is additional to the CCR assessment detailed in ES Appendix 14.2 Climate Change Resilience Assessment (Document Reference 6.4) and summarised in Table 14-20.

14.10.24 The purpose of the appraisal is to identify any adaptive management measures potentially required over and above those already identified in the CCR assessment should any of the low likelihood extreme climate scenarios materialise over the assumed 60-year life of the scheme.

Table 14-21 Sensitivity test of the scheme's vulnerable safety critical features against the H++ climate scenarios

Hazard (and scenario)	H++ (or L--)[67] future climate scenario description	A417 vulnerable safety critical feature	
		Drainage	Earthworks
Heat waves (H++)	Annual average summer maximum temperatures exceeding 30°C over most of the UK and 34°C over much of central and southern England. Hottest days would exceed 40°C in some locations, with 48°C being reached in extreme cases.	**Risks/Consequences** N/A - No vulnerable features identified. **Adaptation measures** N/A	**Risks/Consequences** An increase in average summer maximum temperatures would result in an increased frequency of soils and sub soil desiccation, leading to surface erosion if followed by increases in extreme precipitation. **Adaptation measures** The increase in average maximum temperatures would need to be considered for soil slopes as part the detailed design.
Low rainfall (H++)	A 6 month duration summer drought with rainfall deficits of up to 60% below the long-term average (1900-1999). Longer dry periods spanning several years with rainfall deficits of up to 20% below the long-term average (1900-1999) across all of England and Wales, similar to the most severe and extensive long droughts in the historical record.	**Risks/Consequences** N/A - No vulnerable features identified. **Adaptation measures** N/A	**Risks/Consequences** Extensive drought conditions could impact on the growth of vegetation on soil slopes, which would otherwise provide erosion protection. This combined with soil and sub soil desiccation could lead to surface erosion over time. **Adaptation measures** Erosion management would need to be considered as part of the design and maintenance of the scheme.
Low river flows (H++)	A 40-70% reduction in 'low flows' (Q95) in England and Wales in a single summer. For multi-season droughts, including 2 summers, a 20 to 60% reduction in low flows in England and Wales.	**Risks** Highway assets: low Operation: low **Consequences** Pollution - With a reduction in mean precipitation, drainage dilution levels would be more concentrated due to receiving water courses carrying less water. However, this category and the projections apply to Main River basins and large catchments. This is not applicable to the scheme where there are none. **Adaptation measures** N/A	**Risks/Consequences** No vulnerable features identified. **Adaptation measures** N/A
High rainfall (H++)	A 70%-100% increase in winter rainfall (Dec to Feb) in a single winter (from a 1961-1990 baseline). An up to five-fold increase in frequency and 60% to 80% increase in heavy daily and sub-daily rainfall depths, for both summer and winter events (all year round).	**Risks affect:** • Maintenance, operation and management of existing assets • Design and Construction of new and replacement Highways England assets **Consequences** • Congestion and accidents - An increased risk of flooding within the highway would impact the performance of the network, including congestion and incidents (safety). • Third party flooding - There are risks associated with flooding of third party land from the network. • Cross asset deterioration - Flooding increases the rate of deterioration of other assets. In particular geotechnical assets and pavement assets. **Adaptation measures** • DMRB standards require the management of exceedance flows, so the drainage design considers events beyond the performance required by standards - this is done explicitly for events up to Q100+40%cc.	**Risks/Consequences** • An increase in winter precipitation could adversely impact the stability of any proposed earthworks, including cutting slopes and embankments, through increased groundwater levels and porewater pressures. • Increased rainfall would also impact the stability of existing engineered and natural slopes (e.g. slopes to the north and south of the alignment along Crickley Hill) that could impact the scheme. • Increased rainfall would also result in increased groundwater flows emerging from springs. This could result in internal erosion of earthwork embankments. **Adaptation measures** • Earthworks stability would need to be considered at the detailed design stage through incorporation of appropriate measures. • The stability of existing slopes, particularly where existing landslips have been identified, would need to be considered as part of the detailed design, with

Hazard (and scenario)	H++ (or L--)[67] future climate scenario description	A417 vulnerable safety critical feature	
		Drainage	Earthworks
		However adaptation measures for the H++ scenarios would not form part of the scheme design. • Carriageway collection systems and water levels in drainage systems are designed for synthetic design storms of Q5+20%cc – this is the designed level of service for operations. If the +70% cc factor is applied these interruptions would be more frequent than the specified level of service. The design already includes the facility to passively manage the exceedance events >Q5+20% so that the duration of closures is minimised. However, adaptation to attain the same level of service for operations would require a change to the design of the physical infrastructure – circa 15-20% larger channels, pipes, more outlets etc. This could be implemented at initial construction (precautionary) or retrofitted at a later time if required. • There will always be operational interruptions due to unplanned events such as blockages. Potential adaptations could involve enhanced maintenance and inspection regimes, enhanced response planning and monitoring (enabled by new technology), so that resultant closures are minimised. Adaptation might also include additional redundancies in the physical infrastructure, either at construction (precautionary) or retrofitted at a later time if required.	appropriate measures adopted taking into account any climate change aspects. • Internal erosion of earthwork embankments would need to be considered as part of the earthworks and drainage design at detailed design stage.
High river flows (H++)	A 60% to 120% increase in peak flows at the 'lower end' of the H++ scenarios for some regions in England and Wales. The upper limit for any region is a 290% increase in peak flows (1961-1990 baseline). *The scenarios are based on the average response of "Enhanced-high" catchments, which are particularly sensitive to increases in rainfall.*	**Risks** Watercourses affected by the scheme are serving relatively small catchments so direct rainfall allowances apply (see "High Rainfall"). **Consequences** Cross asset deterioration - Higher flows in watercourse may accelerate erosion/scour and impact on structures adjacent to watercourses. However, this category and the projections apply to Main River basins and large catchments. This is not applicable to the scheme as there are no Main Rivers. **Adaptation measures** N/A	**Risks/Consequences** The realigned tributary of Norman's Brook is positioned along the southern toe of the proposed earthworks embankment on Crickley Hill. Increased river flows, resulting in flooding, could lead to erosion of the earthworks embankment. **Adaptation measures** This would need to be considered as part of the detailed design.
Windstorms (H++)	A 50-80% increase in the number of days per year with strong winds over the UK (1975-2005 baseline). *A strong wind day is defined as one where the daily mean wind speed at 850 hPa, averaged over the UK (8W-2E, 50N-60N), is greater than the 99th percentile of the historical simulations.*	**Risks/Consequences** N/A - No vulnerable features identified. **Adaptation measures** N/A	**Risks/Consequences** No vulnerable features identified. **Adaptation measures** N/A
Cold snaps (L--)	In the 2020s, UK average winter temperatures (December, January and February) of 0.3°C and for the 2080s, UK average winter temperatures would be around -4°C. In the 2020s, UK average temperatures on the coldest day would be -7ºC in some locations. UK average temperature of the coldest day would be around -11°C.	**Risks** N/A - No vulnerable features identified. **Adaptation measures** N/A	**Risks/Consequences** The reduction in average winter temperatures could impact on the local stability of rock slopes through increased freeze-thaw action resulting in increased rock fall events. **Adaptation measures** This would need to be considered as part of the detailed design and maintenance of the scheme.

14.10.25 The sensitivity test of the vulnerable safety critical features against the H++ climate scenarios at this stage in the design indicate that such features would not be significantly affected by more radical changes to the climate beyond that projected in UKCP18. The extreme climate scenarios would continue to be taken in to account through detailed design and maintenance to ensure the scheme is designed with resilience to climate change as a key consideration.

In-combination climate change impacts (ICCI) assessment

14.10.26 The in-combination climate change impact assessment is presented in ES Appendix 14.3 In-combination climate change impacts assessment (Document Reference 6.4). The results of the assessment are provided as follows.

Air quality

14.10.27 While the impacts of climate change are likely to affect air quality in general terms, no significant in-combination effects with the scheme have been identified and no mitigation is proposed.

Cultural heritage

14.10.28 While the impacts of climate change are likely to affect the heritage resource in general terms, no significant in-combination effects with the scheme have been identified, and no mitigation is proposed.

Landscape and visual effects

14.10.29 While the impacts of climate change are likely to affect landscape character, views and visual resource in general terms, no significant in-combination effects with the scheme have been identified. However, a range of tree species that would be better adapted to climate change are included within the detailed mitigation design planting proposals. This is to provide a balance between the native species planting that would fit with the existing landscape character and non-native plant species that would better adapt to climate change over time.

Biodiversity

14.10.30 While the impacts of climate change are likely to affect habitats and consequently species in general terms, no significant in-combination effects with the scheme have been identified. However, a number of measures are included in the detailed mitigation design planting proposals to increase the resilience of the habitat to climate change. These are documented in Annex D Landscape and Ecological Management Plan of ES Appendix 2.1 EMP.

Geology and soils

14.10.31 While the impacts of climate change are likely to affect geology and soils in general terms, no significant in-combination effects with the scheme have been identified, and no mitigation is proposed.

Material assets and waste

14.10.32 While the impacts of climate change are likely to affect material assets and waste in general terms, no significant in-combination effects within the scheme have been identified and no mitigation is proposed.

Noise and vibration

14.10.33 No significant in-combination effects with the scheme have been identified, and no mitigation is proposed.

Population and human health

14.10.34 While the impacts of climate change are likely to affect population and human health receptors in general terms, no significant in-combination effects with the scheme have been identified and no mitigation is proposed.

Road drainage and the water environment

14.10.35 While the impacts of climate change are likely to affect the water environment, no significant in-combination effects are predicted as a result of the scheme with future climate conditions. The scheme design incorporates embedded mitigation such as climate change allowances in the drainage design, as identified within ES Appendix 13.3 Flood Risk Assessment (Document Reference 6.4).

14.11 Monitoring

Impact of the scheme on climate (GHG emissions assessment)

14.11.1 As no significant effects have been identified for the GHG emissions assessment, no monitoring of significant effects is required.

14.11.2 In line with the monitoring requirements set out in DMRB *LA 114 Climate*, and to be secured through ES Appendix 2.1 Environmental Management Plan (Document Reference 6.4), quarterly GHG emission returns during construction and operation shall be reported in accordance with Highways England's requirements. Data provided for the GHG returns shall be evaluated to inform any ongoing monitoring of GHG emissions and feed back into future assessment of projects during design development and planning approval.

14.11.3 Highways England is committed to reducing carbon emissions and working closely with suppliers to reduce emissions from network related activity. An EMP, has been prepared, as presented in ES Appendix 2.1 Environmental Management Plan (Document Reference 6.4), which would require energy consumption and materials use to be recorded and reported on an ongoing basis during the construction phase of the scheme using the Highways England Carbon Reporting Tool. It is not considered practical to monitor GHG emissions from road users during the operational phase of the scheme.

Vulnerability of the scheme to climate change (climate change resilience assessment)

14.11.4 As no likely significant effects have been identified within the climate change resilience assessment, no monitoring of significant effects is required.

14.11.5 ES Appendix 2.1 Environmental Management Plan (Document Reference 6.4) sets out monitoring to be undertaken during the construction stage to ensure that the mitigation measures embedded in the scheme design are appropriately implemented.

14.11.6 In line with the monitoring requirements set out in DMRB *LA 114 Climate*, and secured through the EMP, once operational, asset data would be managed, maintained and monitored to ensure the scheme design is operating as intended. Asset management measures would evolve once the scheme is operational and

to respond appropriately to climate impacts. Where a design issue is identified, an assessment shall be made to determine if corrective action is required.

14.12 Summary

14.12.1 The climate change chapter describes three separate assessments.

Impact of the scheme on climate (GHG emissions assessment)

14.12.2 The scheme would result in GHG emissions due to construction materials and activities during the construction phase; maintenance and refurbishment during the operation phase; vehicles using the road during the operation phase; and land use change over the assumed 60-year operational period.

Vulnerability of the scheme to climate change (climate change resilience assessment)

14.12.3 Assets and infrastructure designed as part of the scheme are likely to be affected by climate change. A number of potential risks have been identified and assessed; these would be mitigated by applying robust design standards or relevant mitigation measures or would be incorporated in the relevant asset management processes.

In-combination climate change impacts (ICCI) assessment

14.12.4 The ICCI assessment does not identify any new or different significant in-combination effects as a result of the scheme's effects combining with future climate conditions.

Significance

14.12.5 The assessment of scheme impacts is considered to be not significant based on evidence that in isolation the scheme would not have a material impact on the ability of UK Government to meet its carbon reduction targets. Therefore, the following conclusions can be made.

<u>Construction assessment</u>

- Impact of the scheme on climate: no significant effect.
- Vulnerability of the scheme to climate change: no significant effects.

<u>Operation assessment</u>

- Impact of the scheme on climate: no significant effect.
- Vulnerability of the scheme to climate change: no significant effects.

End Notes & References

[1] Highways England, Transport Scotland, Welsh Government, and Department for Infrastructure, "Design Manual for Roads and Bridges Sustainability and Environment Appraisal LA 114 Climate Revision 0," 2019

[2] GHG emissions are reported in this chapter in tonnes of carbon dioxide equivalents (tCO_2e). This measure considers the six Kyoto Protocol gases: Carbon dioxide (CO_2); Methane (CH_4); Nitrous oxide (N_2O); Sulphur hexafluoride (SF_6); Hydrofluorocarbons (HFCs); and Perfluorocarbons (PFCs).

[3] UK Government, Climate Change Act 2008. Statute Law Database, 2008

[4] UK Government, The Climate Change Act 2008 (2050 Target Amendment) Order 2019. Queen's Printer of Acts of Parliament, 2019

[5] Committee on Climate Change, "Net Zero - The UK's contribution to stopping global warming," 2019. [Online]. Available: https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/

[6] UK Government, The Carbon Budgets Order 2009. Queen's Printer of Acts of Parliament, 2009

[7] UK Government, The Carbon Budget Order 2011. Queen's Printer of Acts of Parliament, 2011

[8] UK Government, The Carbon Budget Order 2016. Queen's Printer of Acts of Parliament, 2016

[9] The Committee on Climate Change published its recommended Sixth UK Carbon Budget on 9 December 2020. The report 'The Sixth Carbon Budget: The UK's path to Net Zero' is available online at: https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf. The report notes that "the Government must set the Sixth Carbon Budget in law by the end of June 2021. This must be followed, as soon as is practicable, by a set of policies and proposals to meet the budget".

[10] UK Government, "UK Climate Change Risk Assessment 2017 (Policy Paper) Presented to Parliament pursuant to Section 56 of the Climate Change Act 2008," 2017

[11] The third UK Climate Change Risk Assessment is due in 2022

[12] Committee on Climate Change, "UK Climate Change Risk Assessment 2017. Synthesis Report," pp. 1–86, 2016

[13] *This chapter refers to 'carbon' as including all main greenhouse gases, as covered* by the Kyoto Protocol. GHG emissions are converted into tonnes of carbon dioxide equivalent (tCO_2e), a calculation which normalizes the global warming potential of the main GHG into one measure, based on the global warming potential of CO_2.

[14] The RCP8.5 global warming scenario represents a very high baseline emission scenario, representing the 90th percentile of no-policy baseline scenarios available at the time. '8.5' represents 8.5 watts per metre squared, which is a measure of the end-of-century radiative forcing increase relative to pre-industrial conditions. The four RCP scenarios include "one mitigation scenario leading to a very low forcing level (RCP2.6), two medium stabilisation scenarios (RCP4.5/RCP6.0) and one very high baseline emission scenarios (RCP8.5)". The high emissions baseline scenario is representative of the trajectory that global emissions have been on.

[15] H++ scenarios are a set of plausible 'high-end' climate change scenarios which are typically extreme climate change scenarios on the margins or outside of the 10th to 90th percentile range presented in the UK Climate Projections 2009 (UKCP09). They cover the following climate hazards: heat waves, cold snaps, low and high rainfall, droughts, floods and windstorms. Note: the UKCP18 project will not be producing an updated H++ scenario and so the H++ scenario developed from UKCP09 remains current and applicable. The H++ scenarios are available online: https://www.theccc.org.uk/publication/met-office-for-the-asc-developing-h-climate-change-scenarios/

[16] Department for Environment Food and Rural Affairs, "The National Adaptation Programme and the Third Strategy for Climate Adaptation Reporting Making the country resilient to a changing climate," 2018

[17] Highways England (2017), Climate Adaptation Risk Assessment Progress Update 2016. Available online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/596812/climate-adrep-highways-england.pdf

[18] UK Government, "The Clean Growth Strategy Leading the way to a low carbon future," 2017

[19] Department for Transport, “The Road to Zero Next steps towards cleaner road transport and delivering our Industrial Strategy,” 2018

[20] UK Government (2017) *Industrial Strategy: building a Britain fit for the future* (Policy paper). Available online: https://www.gov.uk/government/publications/industrial-strategy-building-a-britain-fit-for-the-future

[21] UK Government (2020) Decarbonising transport: setting the challenge (Policy paper). Available online: https://www.gov.uk/government/publications/creating-the-transport-decarbonisation-plan

[22] Gloucestershire County Council Local Flood Risk Management Strategy (LFRMS). Available online: https://www.gloucestershire.gov.uk/your-community/emergencies-and-your-safety/flooding-and-drainage/gloucestershire-county-councils-local-flood-risk-management-strategy-lfrms/

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[24] Gloucester, Cheltenham and Tewkesbury Joint Core Strategy (JCS) 2011-2031 (adopted December 2017). Available online: https://www.jointcorestrategy.org/

[25] Tewkesbury Borough Council (2019) Pre-submission Tewkesbury Borough Plan 2011-2031. Available online: https://www.tewkesbury.gov.uk/pre-submission-tewkesbury-borough-plan#the-pre-submission-plan

[26] Cotswolds Conservation Board, “Cotswolds Area of Outstanding Natural Beauty Management Plan 2018-2023” 2018

[27] Cotswolds Conservation Board (2012) *Climate Change Strategy for the Cotswolds Area of Outstanding Natural Beauty.* Available online at: https://www.cotswoldsaonb.org.uk/wp-content/uploads/2020/02/Climate-Change-Strategy-adopted-June-2012.pdf

[28] Highways England, Transport Scotland, Welsh Government, and Department for Infrastructure, “Design Manual for Roads and Bridges Sustainability and Environment Appraisal LA 114 Climate Revision 0” 2019

[29] Highways England, Transport Scotland, Welsh Government, and Department for Infrastructure, “Design Manual for Roads and Bridges LA 105 Air quality” 2019

[30] Highways England, Transport Scotland, Welsh Government, and Department for Infrastructure, “Design Manual for Roads and Bridges “GG 103 Introduction and general requirements for sustainable development and design”,2019

[31] British Standards Institution, “PAS 2080:2016 Carbon Management in Infrastructure,” 2016

[32] RICS (2017) *RICS professional standards and guidance, UK: Whole life carbon assessment for the built environment*. Available online: https://www.rics.org/globalassets/rics-website/media/upholding-professional-standards/sector-standards/building-surveying/whole-life-carbon-assessment-for-the-built-environment-1st-edition-rics.pdf

[33] UK Government, “TAG unit A3 environmental impact appraisal,” 2019. [Online]. Available online: https://www.gov.uk/government/publications/tag-unit-a3-environmental-impact-appraisal.

[34] Highways England, Transport Scotland, Welsh Government, and Department for Infrastructure, “Design Manual for Roads and Bridges Sustainability and Environment Appraisal LA 114 Climate Revision 0,” 2019

[35] The Institute of Environmental Management and Assessment (IEMA), “IEMA Environmental Impact Assessment Guide To: Climate Change Resilience And Adaptation,” 2020

[36] Publicly Available Specification (PAS) 2080 Carbon management in Infrastructure provides a common framework for all infrastructure sectors on how to manage and reduce whole life carbon when delivering infrastructure assets and programmes of work.

[37] Highways England (2015) *Carbon emissions calculation tool: Highways England*. Available online: https://www.gov.uk/government/publications/carbon-tool

[38] UK Government, “TAG unit A3 environmental impact appraisal,” 2019. [Online]. Available: https://www.gov.uk/government/publications/tag-unit-a3-environmental-impact-appraisal

[39] Available online at: https://infrastructure.planninginspectorate.gov.uk/projects/south-west/a417-missing-link/?ipcsection=docs

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[41] D. Collings (2006) *An environmental comparison of bridge forms,* Proceedings of the Institution of Civil Engineers - Bridge Engineering, Volume 159, Issue 4.

[42] Embodied carbon includes GHG emissions associated with energy consumption and chemical processes during the extraction, transport and/or manufacture of construction materials or products.

[43] The Met Office provides information on observed and future climate change relative to the baseline period of 1961-1990, based on the latest scientific understanding UKCP18. UKCP provides probabilistic projections for the whole of the UK, at regional level and at local level.

[44] H++ scenarios are a set of plausible 'high-end' climate change scenarios which are typically extreme climate change scenarios on the margins or outside of the 10th to 90th percentile range presented in the UK Climate Projections 2009 (UKCP09). They cover the following climate hazards: heat waves, cold snaps, low and high rainfall, droughts, floods and windstorms. Note: the UKCP18 project will not be producing an updated H++ scenario and so the H++ scenario developed from UKCP09 remains current and applicable. The H++ scenarios are available online: https://www.theccc.org.uk/publication/met-office-for-the-asc-developing-h-climate-change-scenarios/

[45] The RCP8.5 global warming scenario represents a very high baseline emission scenario, representing the 90th percentile of no-policy baseline scenarios available at the time. '8.5' represents 8.5 watts per metre squared, which is a measure of the end-of-century radiative forcing increase relative to pre-industrial conditions. The four RCP scenarios include *"one mitigation scenario leading to a very low forcing level (RCP2.6), two medium stabilisation scenarios (RCP4.5/RCP6.0) and one very high baseline emission scenarios (RCP8.5)".* The high emissions baseline scenario is representative of the trajectory that global emissions have been on.

[46] The Met Office generates climatologies based on standard areas (UK climate districts) of the UK. The scheme is within the Midlands district as shown on the UK climate districts map. Available online: https://www.metoffice.gov.uk/research/climate/maps-and-data/about/districts-map

[47] Wiltshire Council, "Local Climate Impacts Profile Summary Report," 2010.

[48] A. Cunningham *et al.*, "South West Local Climate Impacts Profile (LCLIP) Final Report," 2011

[49] The time periods for climate projections are selected based on the lifespan and stages of the scheme (60 years).

[50] For the ES, the traffic models are based on an opening year of 2026 and 2041 (15 years after opening).

[51] Met Office, "UK Climate Projections (UKCP) - Met Office," 2018. Available online: https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/index

[52] The Regional (12 kilometre) projections are downscaled versions of the Global (60 kilometre) projections providing information on local climate effects.

[53] Regional projections are only available up to 2079.

[54] 12 regional models are used in UKCP18 to project the variables for extreme weather events. The min. (minimum) and max. (maximum) values shown here are the minimum projection from the 12 models and maximum projection from the 12 models for the given parameter.

[55] There is no observational baseline available for wind, therefore values are presented without bias correction.

[56] Met Office, University of Reading and CEH for the Adaptation Sub-Committee (2015) Developing H++ climate change scenarios for heat waves, droughts, floods, windstorms and cold snaps. Available online: https://www.theccc.org.uk/publication/met-office-for-the-asc-developing-h-climate-change-scenarios/

[57] Highways England (2017) Sustainable development strategy – Our Approach. Available online at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/605079/Sustainable_Development_Strategy_6.pdf

[58] Highways England (2018) Sustainable Development and Environment Action Plan: Roads Period 1. Available online at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/763125/Sustainable_Development_and_Environment_Action_Plan_final.pdf

[59] As defined in DMRB LA 104 *Environmental assessment and monitoring*, Embedded mitigation comprises "Design measures which are integrated into a project for the purpose of minimising environmental effects". Essential mitigation comprises "Mitigation critical for the delivery of a project which can be acquired through statutory powers".

[60] The Planning Inspectorate (2019) Scoping Opinion for A417 Missing Link Case Reference: TR010056 (June 2019). Section 4.10 Climate. Available online: https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/TR010056/TR010056-000046-TR010056%20-%20Scoping%20Opinion.pdf

[61] 2026 represents the opening year (first year of operation) and 2041 represents the design (future) assessment year, 15 years after opening. For the ES, the traffic models are based on an opening year of 2026 and design (future) assessment year of 2041 (15 years after opening).

[62] Highways England (2019) M2 Junction 5 Improvements Environmental Statement Volume 1 – Main Report. Available online at: http://assets.highwaysengland.co.uk/roads/road-projects/M2+Junction+5/Environmental/Volume+1+Environmental+Statement+Main+Text.pdf

[63] Highways England, Transport Scotland, Welsh Government, and Department for Infrastructure, "Design Manual for Roads and Bridges CS 641 Managing the maintenance of highway geotechnical assets" 2020

[64] H++ scenarios are a set of plausible 'high-end' climate change scenarios which are typically extreme climate change scenarios on the margins or outside of the 10th to 90th percentile range presented in the UK Climate Projections 2009 (UKCP09). They cover the following climate hazards: heat waves, cold snaps, low and high rainfall, droughts, floods and windstorms. Note: the UKCP18 project will not be producing an updated H++ scenario and so the H++ scenario developed from UKCP09 remains current and applicable. The H++ scenarios are available online: https://www.theccc.org.uk/publication/met-office-for-the-asc-developing-h-climate-change-scenarios/

[65] Met Office, University of Reading and CEH for the Adaptation Sub-Committee (2015) Developing H++ climate change scenarios for heat waves, droughts, floods, windstorms and cold snaps. Available online: https://www.theccc.org.uk/publication/met-office-for-the-asc-developing-h-climate-change-scenarios/

[66] Highways England (2017), Climate Adaptation Risk Assessment Progress Update 2016. Available online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/596812/climate-adrep-highways-england.pdf

[67] Note the term L-- is used specifically for the 'cold snap' scenario to emphasise that it is at the opposite end of the scale to the extreme warm summer temperatures in H++ and linked to Low emissions.