In Parliament – Session 2021 - 2022

HS2

High Speed Rail (Crewe – Manchester) Environmental Statement

Volume 5: Appendix CL-004-00000

Climate change

Greenhouse gas calculation methodology

M74

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Department for Transport

High Speed Two (HS2) Limited has been tasked by the Department for Transport (DfT) with managing the delivery of a new national high speed rail network. It is a non-departmental public body wholly owned by the DfT.

High Speed Two (HS2) Limited
Two Snowhill
Snow Hill Queensway
Birmingham B4 6GA

Telephone: 08081 434 434

General email enquiries: HS2enquiries@hs2.org.uk

Website: www.hs2.org.uk

A report prepared for High Speed Two (HS2) Limited:

ARUP+ ERM | FOSTER + PARTNERS | JACOBS
RAMBOLL | TYPSA | COSTAIN

MWJV
Mott MacDonald | WSP

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1 Introduction

1.1.1 This appendix presents the methodology for the quantification, assessment, interpretation and reporting of the greenhouse gas (GHG) emissions associated with the construction and operation of the Phase 2b Proposed Scheme. GHG emissions are typically converted into tonnes of carbon dioxide equivalent (tCO_2e) which standardises the global warming potential of the main GHG into one index based on the global warming potential of carbon dioxide (CO_2). Hereafter both terms (carbon and GHG) are used interchangeably referring to the combined GHG emissions.

1.1.2 This appendix identifies the GHG study system boundary (both physical and in life cycle stages) that reflects the systems under study for the quantification of the GHG impact of the Proposed Scheme.

1.1.3 The definition of the system boundary follows the principles set out in PAS 2080[1].

1.1.4 The carbon assessment comprises several distinct but linked sub-assessments:

- construction and maintenance of civil assets and construction waste management associate with these assets;
- construction plant energy use;
- demolition waste management during construction of the Proposed Scheme and waste arising from construction worker accommodation;
- Tunnel Boring Machines (TBM) manufacture and use in construction of the Proposed Scheme;
- mass haul transportation during construction;
- ground remediation / treatment during construction;
- land use, land use change and forestry during construction and operation of the Proposed Scheme;
- modal shift arising from the Proposed Scheme; and
- rolling stock traction energy during operation of the Proposed Scheme.

1.1.5 The assessment relies on key assumptions around external factors, principally the expected rate of decarbonisation of the UK electrical grid prior to construction and during operational phase.

1.2 General principles

1.2.1 Table 1 summarises the principles underpinning the GHG assessment.

[1] British Standards Institute (2016), *PAS 2080: 2016: Carbon management in infrastructure*. BSI, London, UK.

Table 1: General principles underpinning the GHG assessment (adapted from PAS 2080)

Principles	Description
Relevance	Data collection and GHG assessment methods used will be relevant to the Proposed Scheme.
Completeness	All carbon emissions providing a material contribution to the Proposed Scheme's carbon footprint will be included.
Consistency	Consistent data and assessment methodologies will be used. Any changes in data, methodology or assumptions will be transparently documented.
Accuracy	Carbon emissions will be assessed, and uncertainties reduced as far as reasonably practicable. The level of accuracy should be such that decision makers have a reasonable level of assurance as to the integrity of the carbon emissions reported.
Transparency	Information on the methodology, data sources used, and relevant assumptions will be made available.

1.3 Goal

1.3.1 The goal of the GHG assessment is to quantify and report – in the form of a 'carbon footprint' – the reasonable worst case scenario carbon emissions associated with the construction and operation of the Proposed Scheme. The GHG assessment will identify carbon hotspots associated with the Proposed Scheme and help focus mitigation efforts in areas with the most potential for carbon reduction.

1.4 Scope

1.4.1 High Speed Two (HS2) is a new high speed railway proposed by the Government to connect major cities in Britain. It will transform intercity and long distance passenger rail travel in the UK, providing the first major increase in intercity rail capacity for over a century and freeing up substantial capacity for rail travel and freight on the conventional rail network. London, Birmingham, Leeds, Manchester and cities in the Midlands, the North and Scotland will be served by high-speed trains running at speeds of up to 360 kilometres per hour (kph) (225 miles per hour (mph)) on HS2 lines and on the existing conventional rail network. As part of the Proposed Scheme, new stations will be built at Manchester Piccadilly and Manchester Airport in addition to the stations in London and the West Midlands included in HS2 Phase One.

1.4.2 The Proposed Scheme comprises:

- the Western Leg from Crewe to Manchester, including:
  - new stations at Manchester Airport and Manchester Piccadilly;
  - a depot north of Crewe;
  - maintenance facilities north of Crewe and at Ashley; and
  - a connection onto the West Coast Main Line (WCML) near Bamfurlong;

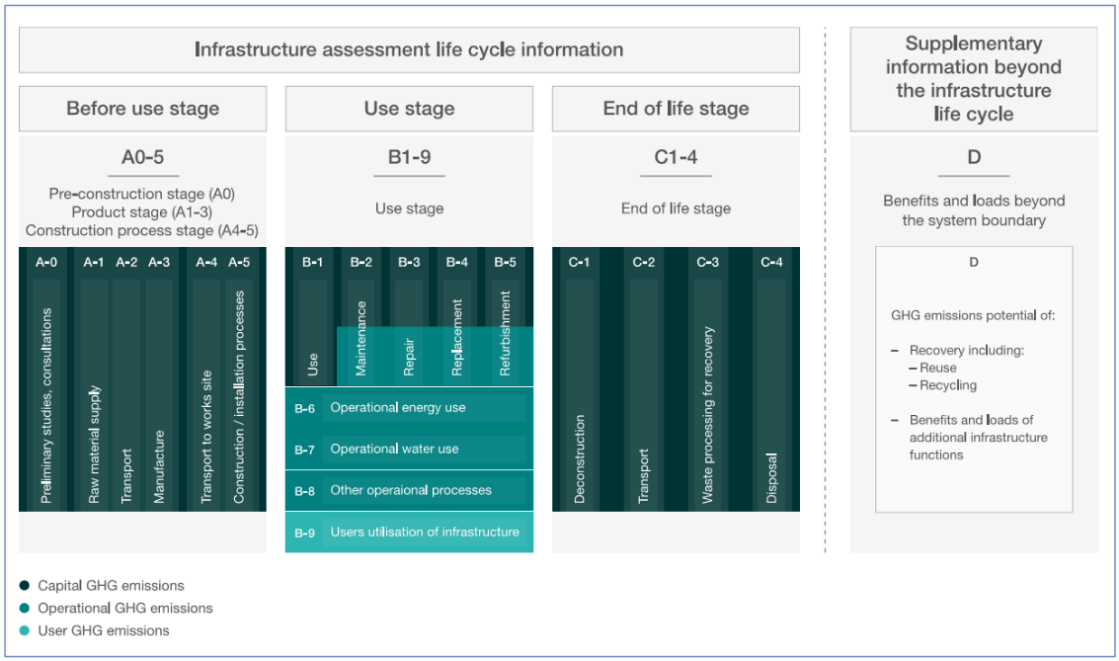
- the Crewe Northern Connection, connecting the route of the Proposed Scheme with the WCML and enabling future Northern Powerhouse Rail (NPR) services to connect with HS2;
- provision for the NPR London to Liverpool, Manchester to Liverpool, and Manchester to Leeds junctions, to enable these future NPR routes to connect with HS2; and
- a number of works at locations beyond the Western Leg route corridor, referred to as 'off-route works' which include:
  - works to enable HS2 trains to call at existing stations further north on the WCML; and
  - construction of depots to provide overnight stabling for HS2 trains serving the north of England and Scotland.

2 Study boundaries

2.1 Defining study boundaries and the application of cut-off rules

2.1.1 Study boundaries define the scope of the GHG emissions quantification study and with this the processes and physical aspects included or excluded. Figure 1, reproduced from PAS 2080, identifies the GHG life cycle stages and modules to be considered when identifying potential sources of GHG emissions to include in the study. Detailed guidance describing the boundaries associated with each module are documented in BS EN 15804[2].

Figure 1: Modular approach showing the life cycle stages and individual modules for infrastructure GHG emissions quantification



Source: PAS 2080: 2016: Carbon management in infrastructure. BSI, London, UK

2.2 Study boundary

2.2.1 The GHG assessment adopted a life cycle assessment (LCA) approach.

2.2.2 Table 2 presents each of the life cycle stages (modules) and representative activities associated with the Proposed Scheme[3].

[2] British Standards Institution (2012), *BS EN 15804:2012 Sustainability of construction works – environmental product declarations – core rules for the product category of construction products (+A2:2019)*. BSI, London, UK.

[3] The precise boundary, emissions sources and data included in the assessment are derived from this in line with methodological principles discussed later in this document.

Table 2: Scope of the GHG assessment broken down by life cycle stages, consistent with the principles set out in BS EN 15978:2011 and PAS 2080:2016

Life cycle stage	Activities incorporated
Pre-construction stage (module A0)	Represents preliminary desk-based studies and works such as: • strategy and brief development; • architecture; • design efforts; • EIA; and • cost planning. Includes emissions associated with office energy use and consultants' travel.
Product stage (modules A1 – A3)	Represents the embedded carbon emissions associated with the extraction, processing and manufacturing of the Proposed Scheme's construction materials for permanent assets. This includes all energy and carbon emissions from manufacturing plants, primary and secondary manufacturing stages as well as any transport emission between these stages. For example, concrete manufacturing includes energy and carbon emissions linked to all key stages: quarrying, aggregate crushing, transport of aggregates to ready-mix concrete plants and asphalt plants. This final stage includes emissions associated with the adding of water and cement mixes.
Construction process stage – transport to site (module A4)	Represents transport related carbon emissions associated with the delivery of construction material, such as concrete and steel, and construction equipment to construction sites along the Proposed Scheme from the point of production (or point of storage in the case of plant and machinery).
Construction process stage – construction and installation (module A5)	Represents carbon emissions from construction site works activities including: • temporary work, ground works and landscaping; • materials storage and any energy or otherwise need to maintain necessary environmental conditions; • transport of materials and equipment on site; • installation of materials and products into the infrastructure asset; • emissions associated with site water demand; • waste management activities (transport, processing, final disposal) associated with waste arising from the construction site; and • production, transportation, and waste management of materials/products lost during works. This module also includes carbon emissions from land use change during construction.
Use stage – installed products and materials (module B1)	Represents the carbon emissions emitted directly from the fabric of products and materials once they have been installed, as well as the sequestration of emissions from trees planted as part of the Proposed Scheme.
Use stage – maintenance (module B2)	Represents the production, transportation (to and from the site) and end of life processing of all materials required. This module includes the electricity, fuel and water for regular preventative maintenance of the Proposed Scheme.
Use stage – repair (module B3)	Represents the production, transportation (to and from the site) and end of life processing of all materials required for responsive or reactive treatment to an acceptable condition. This module includes the electricity, fuel and water used for responsive or reactive treatment to an acceptable condition.
Use stage – replacement (module B4)	Represents the production, transportation (to and from the site) and end of life processing of all materials required to replace any assets or any components within assets that have a design life of less than 120 years.

Life cycle stage	Activities incorporated
Use stage – refurbishment (module B5)	Represents the production, transportation (to and from the site), and end of life processing of all materials required for any anticipated refurbishment of the Proposed Scheme. This module includes the electricity, fuel and water used for any refurbishment of the Proposed Scheme.
Use stage – operational energy (module B6)	Represents the carbon emissions resulting from the energy used by the Proposed Scheme to operate infrastructure-integrated systems necessary for the technical and functional performance of the Proposed Scheme (e.g. lighting, ventilation, drainage, heating and cooling) minus any electricity generated through on site low carbon energy sources not exported to the grid.
Use stage – operational water (module B7)	Represents water required by the Proposed Scheme to enable it to operate and deliver its service. It will include all water used and its treatment (pre- and post-use) during the normal operation of the Proposed Scheme.
Use stage – other operational processes (module B8)	Represents other process carbon emissions arising from the Proposed Scheme to enable it to operate and deliver its service including management of operational waste.
Use stage – users utilisation (module B9)	Represents the carbon emissions associated with the operation of the rolling stock and un-regulated energy consumption not required for the technical and functional performance of the infrastructure (e.g. plug-in appliances, such as computers, refrigerators, audio, TV and production or process-related energy use).
End of life stage – deconstruction (module C1)	Represents the carbon emissions resulting from activities of deconstructing, demolishing and decommissioning the Proposed Scheme. Essentially these are on-site carbon emissions from plant equipment.
End of life stage – transport (module C2 – C4)	Represents the activities associated with transport, waste management and final disposal of materials associated with the site and materials of the Proposed Scheme.
Benefits / loads beyond the project boundary (module D)	Includes emissions sources outside the project boundary: • avoided carbon emission impacts associated with the Proposed Scheme including potential for reuse, recovery and recycling of materials and/or energy beyond the system boundary; • savings in carbon emissions from modal shift of passenger and freight journeys associated with the Proposed Scheme; and • electricity and fuel use for surface access journeys to depots.

2.3 Cut-off rules

2.3.1 PAS 2080 states that activities may be excluded from the quantification process in the GHG emissions study when they do not significantly change the result of the assessment. However, there are several rules that shape the application of this. PAS 2080 states the following criteria for the exclusion of inputs and outputs (cut-off rules):

- include in the system boundary all the activities leading to GHG emissions relevant to the system being assessed;
- exclude only activities that do not significantly change the result of the quantification, using sensitivity analysis to demonstrate that such exclusions are not significant;
- apply the following provisions to any exclusion of input or outputs to the study system:
  - All inputs and outputs to any process for which data are available are always included;
  - data gaps may be filled by conservative assumptions using generic data (subject to data quality requirements); and
  - the total excluded input or output flows per module[4] shall be a maximum of 5% of energy usage and mass.
- expert judgement by the practitioner shall be used to determine compliance with these criteria[5]; and
- justify and document any exclusions applied to the study system including any assumptions and criteria used to decide them.

2.3.2 The use of cut-off rules is intended to support an efficient calculation procedure. They shall not be applied in order to hide data. Any application of the criteria for the exclusion of input and outputs from the quantification must be documented.

2.4 Study period

2.4.1 The GHG assessment reports carbon emissions from construction and 120 years of operation to align with the assumed design life of the Proposed Scheme.

[4] i.e. A1 – A3, A4 – A5, B1 – B5, B6 – B7, C1 – 4 and module D.

[5] In practice this requires the practitioner to have experience in the field of where they are undertaking the study and apply logical reasoning to their exclusion choice. This can also be achieved by seeking expert advice from others.

3 Data

3.1 Data required for the assessment

3.1.1 Two types of data have been collected for the GHG assessment: activity data and GHG emissions factors. A set of data quality principles will be applied to ensure results from the GHG assessment are as accurate and representative as possible.

- **activity data** represents the available design information for the design stage reached at the time of assessment. This represents early stage design information and as such includes a range of assumptions appropriate to the design stage; and
- **GHG emissions factors** are drawn from the most up-to-date information sources to provide the most accurate assessment of GHG emissions for each activity.

3.2 Assumptions and limitations to data

3.2.1 With large scale projects such as HS2 there are inherent limitations to the assessment of GHG emissions. A key limitation reflects the long timescales associated with the Proposed Scheme. With a design life of 120 years there are no published GHG emissions factors which project that far into the future. The most forward-looking projections do not exceed 2050, aligning with the UK's carbon reduction target of Net Zero by 2050. There is a level of uncertainty with all projects' GHG emissions factors linked but not limited to: technology development and deployment, economic uncertainty, political drive, and future energy demands.

3.2.2 Assumptions relating to grid decarbonisation are presented in Volume 3, Route-wide effects.

3.2.3 The GHG assessment is based on early design information. The nature of this stage of design is that it incorporates assumptions across all design and construction aspects, and these carry through into estimates of material quantities and energy consumption. The GHG assessment has adopted a 'reasonable worst case scenario' assessment whereby conservative assumptions are adopted to minimise the risk of underestimating the scale of GHG emissions impact. A series of sensitivity assessments were carried out to illustrate how external trends and factors may influence the scale of the Proposed Scheme's carbon footprint, and to inform the development of the reasonable worst case scenario.

3.2.4 Subsequent sections provide details on assumptions within each sub-assessment.

4 Methodology

4.1 Calculation methodology

4.1.1 Carbon emissions have been assessed using a calculation-based methodology as per the below equation:

'activity' data x GHG emissions factor = GHG emissions value

4.2 Use of LCA software

4.2.1 Modelling of the Life Cycle Assessment (LCA) impacts of the Proposed Scheme has been developed in part using a proprietary LCA assessment platform. The platform draws on international databases of Environmental Product Declarations (EPD) and other sources of GHG/environmental impact from materials and processes in order to quantify the net GHG impact of each asset of the relevant study period. Assets are defined in terms of their physical scale, material quantities, and constituent materials prior to using the LCA platform to calculate life cycle GHG emissions.

4.2.2 For other aspects of the GHG assessment the calculation of GHG emissions values has been carried out manually by obtaining material and energy quanta, and multiplying by an industry standard GHG emissions factor.

4.3 Assumptions by life cycle stage

4.3.1 The key assumptions relating to individual sub-assessments are set out in Table 3.

Table 3: Assumptions by life cycle stage and Proposed Scheme element

Aspect	Assumption
Modules A1 – 5 Construction embodied emissions for civils assets	• The quantities of materials used for construction of the Proposed Scheme are assumed to be representative of the likely final construction and are taken from data developed by the wider project design team. Aggregated material quantities from design information are presented in Annex A. • Civils assets are assumed to be consistent in the relative proportions of their constituent material quantities and representative of generic instances of that specific civil asset type. • Benchmark information on generic asset constituent materials was obtained via interviews with relevant design professionals within the design team and comparison to as-built data from earlier HS2 phases. • In some asset types a potential under-reporting of material quantities from the source documents used for the GHG assessment was identified through benchmarking. Material quantities have been uplifted to account for any apparent under-representation of specific materials due to the early design stage of the assessment in order to avoid under-estimation of the carbon footprint. Details of these uplifts are provided in Annex A.

Aspect	Assumption
	The following civil asset types were modelled in the LCA platform: • balancing pond; • overbridge; • underbridge; • viaduct; • aqueduct; • culvert; • cutting; • depot; • electricity distribution systems; • embankment; • highway; • retaining wall; • signalling and communications systems; • stations; • temporary compounds; • tunnel; • tunnel portal; and • ventilation shaft.
Modules A1 – 5 Construction embodied emissions for rail systems and track	The track has been assumed to be a mix of ballast track and slab track. The assessment of life cycle impacts for track is based on a validated life cycle unit model developed for HS2 Phase One which has been scaled to the Proposed Scheme based on design data for the length of each track type. Details of the assessment of rail system is provided in Annex B.
Modules A1 – 5 Ground treatment	The primary data source for the assessment was the Ground Improvement Schedule. Representative estimates of GHG emissions per linear metre of rail track were developed and applied to the applicable route length to determine GHG emissions. Further information is provided in Annex C.
Module A5 Construction plant	Construction plant usage estimates are derived from the construction programme information providing an estimate of hours of usage by type throughout construction. Further information on plant types and usage levels is provided in Annex D. Embodied carbon and energy use for Tunnel Boring Machines (TBM) is based on benchmark data as set out in Annex D.
Module A5 Construction water use	Construction water usage estimates are derived from the construction programme information contained in the Project design and construction information. Further information on water use is provided in Annex E.
Module A5 Construction compound waste and demolition waste	Estimates on construction compound waste and demolition waste quantities are taken from design information. This information has been developed in accordance with the HS2 Phase 2b Technical Note – Construction and Demolition Waste Forecasting Methodology. All demolition waste is assumed to achieve recycling performance target of 90%, with remaining 10% disposed to landfill. All construction compound waste is assumed to be combusted. Further information in set out in Annex F.
Module A5 Construction area – land use change during construction and operation	The extent of the land to be used for construction and operation equates to a total of 1,327 hectares. Emissions from land use during construction assume all vegetation and soil is removed across this area. Areas of future land use within the land to be used for construction and operation once the Proposed Scheme is operational have been mapped and the sequestration potential has been calculated using standard sequestration factors.

Aspect	Assumption
	More information on the assessment of impacts from Land Use is presented in Annex G.
Module A5 Mass haul road movements	The mass haul assessment has been based on Project design and construction information. More information on the assessment of impacts from mass haul is presented in Annex H.
Module B1 Carbon sequestration	The Woodland Carbon Code (WCC) Carbon Calculation Spreadsheet[6] has been used to estimate carbon sequestration associated with tree planting within the land to be used for construction and operation over the design life of the scheme. It is assumed all land uses proposed within the extent of the Proposed Scheme are newly planted, and that carbon sequestration potential will not vary over time or with land maturity.
Modules B2 – 5 Maintenance, repair, replacement and refurbishment of civil assets	Allowance for maintenance has been made within each material type for each civil asset based on use of new material (for maintenance purposes) at a rate of 2% of the asset construction material quantity, within the assumed lifetime for that material. The repair of any fixed infrastructure assets is excluded as it is assumed they would be maintained to prevent failure. Any non-preventable failures are not included within scope as it cannot be anticipated and therefore cannot be assessed. Several assets within the Proposed Scheme will require replacement over the assumed 120 year design life. The assumed replacement period for each asset material is presented in Annex A. Refurbishment of assets has been excluded from the assessment in line with cut-off rules set out in Section 2.3 as it is only considered relevant only to buildings and it is expected these would be less than 1% of the total carbon emissions for the relevant Module. This is based on professional judgement.
Module B6 Operational energy consumption	Operational energy consumption has been included for the operation of buildings (stations and depots) and for the traction energy for rolling stock. Other operational emissions are not expected to be significant in comparison to rolling stock energy consumption and it is expected that these would be less than 1% of the total carbon emissions for the Proposed Scheme. This is based on professional judgment. Information on energy use for stations and depots and rolling stock is provided in Annex I.
Module B7 Operational water consumption	Operational water consumption has been included for the operation of buildings (stations and depots). Other operational water use is not expected to be significant and it is expected these would be less than 1% of the total carbon emissions for the Proposed Scheme. This is based on professional judgement. Information on operational water use for stations and depots is provided in Annex I.
Module B8 Other operational processes	These are excluded as operational waste is expected to contribute less than 1% of the total carbon emissions based on professional judgement due to low annual quantities and high rates of diversion from landfill.
Module C End of life stage	Deconstruction and the end-of-life impacts are excluded as the fixed infrastructure assets are assumed to be extended into operation beyond the 120 year design lifetime with regular maintenance and replacement where necessary.
Module D Modal shift	The modal shift modelling is based on the Planet Framework Model (PFM). The PFM is a strategic transport model developed by HS2 Ltd. and covers all long-distance rail, car

[6] Woodland Carbon Code (2018), *Standard Project Carbon Calculation Spreadsheet*, (Version 2.0 March 2018). Available online at: https://www.woodlandcarboncode.org.uk/standard-and-guidance/3-carbon-sequestration/3-3-project-carbon-sequestration.

Aspect	Assumption
	and air movements across England, Scotland and Wales. Further information on the Modal Shift assessment is provided in Annex J.

4.3.2 Table 4 provides detail on the main exclusions from the assessment after application of the cut-off rules set out in Section 2.3.

Table 4: Exclusions by life cycle stage

Aspect	Assumption
(A0) Pre-construction	This is excluded as no sources of carbon emissions more than 1% of the total emissions for the Proposed Scheme can be identified from this module based on professional judgment.
(A4 – A5) Construction transport	Worker commute to compounds has been excluded as these are not required to be reported with PAS 2080 and BS 15978 standards. Carbon emissions have been estimated to be less than 1% and are not through to be a major contributor to the footprint of the Proposed Scheme. This also includes the transport of equipment to and from site, which is expected to be less than 1% of the total footprint of the Proposed Scheme.
(C1 – C4) End-of-life	Deconstruction and the end-of-life impacts are excluded as the fixed infrastructure assets are assumed to be extended into operation beyond the 120 year design lifetime with regular maintenance and replacement where necessary.

4.4 Reporting

4.4.1 The results of the GHG assessment are reported in Volume 3, Route-wide effects. The reporting of GHG emissions is provided in tonnes of carbon dioxide equivalent (tCO_2e) and is aligned with the life cycle stages presented in Table 2. The following carbon footprints are reported:

- construction (A0 – A5);
- operation (B1 – B9);
- end of life (C1 – C4); and
- benefits and loads beyond the system boundary (D).

4.4.2 A residual carbon footprint (i.e. carbon emissions minus carbon benefits) has also been reported.

4.5 Interpretation

4.5.1 There currently are no agreed significance criteria with respect to carbon emissions for the purpose of Environmental Impact Assessment. The Proposed Scheme's carbon emissions will therefore be assessed in the context of:

- UK national GHG emissions;
- the UK construction sector; and
- the UK transport sector.

4.5.2 In addition, the operational efficiency ($kgCO_2e$/passenger-km) of the Proposed Scheme will be compared against other modes of transport.

Annex A: Construction and maintenance of civil assets

Table A 1: Civil asset aggregated material quantities

Material	Unit	Balancing pond	Bridge (aqueduct)	Bridge (overbridge)	Bridge (underbridge)	Bridge (viaduct)	Culvert	Cutting	Depot
Concrete (ready mix / batch on site)	m^3	480	1,990	51,027	9,457	423,778	10,221	-	160,838
Reinforcement bar	t	-	377	8,363	1,730	78,078	1,529	-	26,063
Formwork	m^2	-	3,457	72,401	16,483	421,246	25,863	-	69,510
Precast concrete beams	Number	-	-	333	-	2,164	-	-	-
Precast concrete parapets	m	-	292	3,505	258	22,606	317	-	-
Pipe (drainage)	m	1,799	-	753	727	3,904	-	-	-
Drainage stone	m^3	7,555	-	745	53	422	-	-	-
Sub ballast	m^3	-	-	-	-	13,533	-	-	-
Granular fill	m^3	-	375	75,533	4,980	60,081	880	-	960,874
Excavation material for disposal	m^3	234,976	1,439	74,492	10,633	393,490	14,325	-	520,245
Hot rolled asphalt	t	-	-	87,825	6,449	393	593	-	62,330
Temporary haul road / platforms granular fill	t	-	-	-	-	-	-	-	-
Temporary steel structures	t	-	-	-	-	-	-	-	-
Precast concrete tunnel rings	No	-	-	-	-	-	-	-	-
Grout	m^3	-	-	-	-	-	-	-	-
Sprayed concrete	m^3	-	-	545	-	-	-	-	-
Other precast concrete elements	m^3	1,212	-	-	-	238	-	-	-
Precast concrete culverts	m	-	-	-	-	4,039	-	-	-

Material	Unit	Balancing pond	Bridge (aqueduct)	Bridge (overbridge)	Bridge (underbridge)	Bridge (viaduct)	Culvert	Cutting	Depot
Permanent steel structures	t	-	-	4,633	-	5,023	-	-	15,232
Precast concrete kerbs	m	-	-	27,229	1,216	36	-	-	22,186
Drainage precast concrete hollow blocks	m	-	-	761	247	1,981	-	-	154
Steel fabric reinforcement	m^2	-	-	29,063	1,838	254,025	-	-	1,127
Edgings	m	-	-	-	-	-	-	-	-
Precast L wall	m^3	-	-	-	1,345	-	-	-	-
Twin track box girder viaduct	m	-	-	-	77	7,633	-	-	48
Precast concrete slab	m^3	-	-	-	-	4,124	1,613	-	-
Blockwork/ brickwork	m^2	-	-	-	-	-	-	-	-
Precast stairs	No	-	-	2	-	18	-	-	3,845
Waterproofing; sheet materials	m^2	-	-	21,549	1,936	145,864	-	-	53,330
Dense concrete blocks	m^3	-	-	-	1,751	-	-	-	50
Painting; coat emulsion	m^2	-	-	-	10,131	75,585	-	-	8,666
Precast concrete box girder viaduct	m	-	-	-	-	972	-	-	-
Cladding	m^2	-	-	-	-	256	-	-	-
Screed	m^3	-	-	-	-	-	-	-	-
M&E fitout	m^2	-	-	-	-	792	-	-	-
Landscaping	m^2	-	-	-	-	-	-	-	-
Steel fabric reinforcement	m^2	480	1,990	51,027	9,457	423,778	10,221	-	160,838

Material	Unit	Electricity distribution	Embankment	Highway work	Retaining wall	Signalling and communication	Station	Temporary compound	Tunnel
Concrete (ready mix / batch on site)	m^3	28,038	10,966	7,454	341,976	11,001	278,899	-	175,690
Reinforcement bar	t	-	1,550	290	55,559	-	50,939	-	22,016
Formwork	m^2	3,074	2,191	4,038	193,271	2,470	163,746	-	144,905
Precast concrete beams	Number	-	-	12	-	-	-	-	-
Precast concrete parapets	m	-	-	145	-	-	195	-	1,070
Pipe (drainage)	m	-	-	53,448	-	-	4,831	-	170,883
Drainage stone	m^3	-	-	17	-	-	-	-	-
Sub ballast	m^3	-	-	-	-	-	-	-	-
Granular fill	m^3	-	451	42,578	28,555	-	199,913	-	176,362
Excavation material for disposal	m^3	30,583	7,573	217,067	231,817	11,590	726,752	-	3,374,166
Hot rolled asphalt	t	-	-	324,805	-	-	69,245	2,405,332	129
Temporary haul road / platforms granular fill	t	-	3,762	1,358	53,547	-	-	3,772,290	-
Temporary steel structures	t	-	-	-	1,778	-	-	-	-
Precast concrete tunnel rings	No	-	-	-	-	-	-	-	29,664
Grout	m^3	-	-	-	-	-	-	-	205,145
Sprayed concrete	m^3	-	-	-	-	-	1,281	-	11,091
Other precast concrete elements	m^3	-	-	-	-	-	19,692	-	-
Precast concrete culverts	m	-	-	-	-	-	-	-	-
Permanent steel structures	t	6,090	-	671	611	4,876	18,666	-	-

Material	Unit	Electricity distribution	Embankment	Highway work	Retaining wall	Signalling and communication	Station	Temporary compound	Tunnel
Precast concrete kerbs	m	-	-	68,477	-	-	10,736	-	30
Drainage precast concrete hollow blocks	m	-	-	25	-	-	-	-	-
Steel fabric reinforcement	m^2	122,329	-	1,744	-	46,322	12,809	-	3,218
Edgings	m	-	-	180	-	-	9,039	-	-
Precast L wall	m^3	-	-	-	-	-	-	-	-
Twin track box girder viaduct	m	-	-	-	-	-	2,327	-	-
Precast concrete slab	m^3	-	-	-	-	-	18,507	-	-
Blockwork/ brickwork	m^2	-	-	-	-	-	17,669	-	-
Precast stairs	No	-	-	-	-	-	358	-	-
Waterproofing; sheet materials	m^2	61,164	-	909	-	23,161	15,234	-	8,453
Dense concrete blocks	m^3	-	-	-	484	-	-	-	14,110
Painting; coat emulsion	m^2	-	971	-	66,964	-	-	-	23,420
Precast concrete Box Girder Viaduct	m	-	-	-	-	-	-	-	-
Cladding	m^2	-	-	-	-	-	220,716	-	1,394
Screed	m^3	-	-	-	-	-	64,385	-	-
M&E fitout	m^2	-	-	-	-	-	459,454	-	-
Landscaping	m^2	-	-	-	-	-	14,532	-	-
Steel fabric reinforcement	m^2	28,038	10,966	7,454	341,976	11,001	278,899	-	175,690

Source: Project design and construction information

Table A 2: Uplift factor applied to asset types to reflect estimated shortfall in design material quantities

Asset type	Uplift applied to design team material quantities
Balancing pond	No uplift applied
Bridges	15% uplift applied to steel
Culvert	0.2% uplift to aggregate 5% uplift to plastics 1.8% uplift to steel
Cutting	3% uplift to plastics
Depot	No uplift applied
Electricity distribution	No uplift applied
Embankment	No uplift applied
Highways	5% uplift to asphalt 1% uplift to aggregates 15% uplift to steel
Rail track	No uplift applied
Signalling and communication	No uplift applied
Tunnels	26% uplift for steel 8% uplift for plastics
Tunnel portal	3% uplift for plastics
Ventilation shaft	1.3% uplift for plastics 18% uplift for steel
Temporary compound	No uplift applied

Table A 3: Carbon factors used in the assessment of civil assets

Activity	Type	Unit	GHG emissions factor ($kgCO_2e$/unit)	Source
Materials used for construction of civil assets	All	All carbon factors for the assessment of civils assets are derived from the proprietary life cycle assessment (LCA) platform used for the assessment. These are derived from several life cycle inventory data sources including IMPACT EN15804, AusLCI, and EcoInvent.		

Table A 4: Assumptions associated with material use in construction

Material	Description	Density (kg/m^3)[7]	Assumed recycled content	Construction waste factor	Assumed transport mode to construction site	Assumed transport distance to construction site (km)
Aggregate	Bulk aggregates sands and soils/aggregate (compacted)/unspecified	2,240	-	1%	Articulated truck	175
Asphalt	Asphalt and bitumen/asphalt - 4.6% bitumen	2,000	-	1%	Articulated truck	50
Brick	Bricks, blocks and pavers/clay bricks and pavers/unspecified	2,000	-	1%	Articulated truck	50
Cement grout	Cements and limes/mortars and renders/1 lime: 3 sand	1,650	-	1%	Articulated truck	50
Concrete – Cast for in-situ applications	Concrete/unreinforced/blast furnace slag blends/40 mpa/20% bfs	2,384	-	1%	Articulated truck	50
Concrete – hollow lightweight	Concrete/light weight/autoclaved aerated concrete block	2,240	-	1%	Articulated truck	50
Concrete – precast	Concrete/unreinforced/blast furnace slag blends/50 mpa/20% bfs	2,423	-	1%	Articulated truck	50
Concrete – sprayed	Concrete/unreinforced/portland cement blends/40 mpa	2,384	-	1%	Articulated truck	50
Elevator Car, Passenger (no counter weight)	An LCA platform in-built standard profile was used for this element					

[7] ICE Database v3.0. Available online at: https://circularecology.com/embodied-carbon-footprint-database.html.

Material	Description	Density (kg/m³)[7]	Assumed recycled content	Construction waste factor	Assumed transport mode to construction site	Assumed transport distance to construction site (km)
Formwork	Timber/plywood/unspecified	650	-	1%	Articulated truck	50
General plastic	Plastics/general/unspecified	1,380	-	1%	Articulated truck	500
M&E fit out	An LCA platform in-built standard profile was used for this element					
Paint	Paints and finishes/unspecified/2 coats (5mm thickness)	1,200	-	1%	Articulated truck	50
PVC plastic	Plastics/polyvinyl chloride (PVC)/PVC Pipe	1,380	5% Closed loop secondary material	1%	Articulated truck	500
Reused material off site	Generic/reused product or material / unspecified	1,000	-	1%	Articulated truck	100
Soil - compacted	Bulk aggregates sands and soils/soil (compacted)/unspecified	2,000	-	1%	Articulated truck	50
Steel reinforcement bars and cages	Ferrous metals/steel/reinforcement bar/unspecified	7,900	97% Closed loop secondary material	1%	Articulated truck	500
Steel reinforcement fibres	Ferrous metals/steel/wire/unspecified	7,900	10% Closed loop secondary material	1%	Articulated truck	500
Structural steel sections	Ferrous metals/steel/galvanised structural/unspecified	7,900	10% Closed loop secondary material	1%	Articulated truck	500
Temporary aggregate	Bulk aggregates sands and soils/aggregate (compacted)/unspecified	2,240	-	1%	Articulated truck	175

Material	Description	Density (kg/m³)[7]	Assumed recycled content	Construction waste factor	Assumed transport mode to construction site	Assumed transport distance to construction site (km)
Temporary structural steel sections	Ferrous metals/steel/galvanised structural/unspecified	7,900	10% Closed loop secondary material	1%	Articulated truck	500

Table A 5: Material assumed repair interval, maintenance load and maintenance disposal for civil asset LCA assessment

Material	Replacement interval (years)	Proportion replaced after full replacement interval	Proportion replaced during maintenance over full replacement interval
Aggregate	120	100%	2%
Asphalt	25	100%	2%
Brick	120	100%	2%
Cement grout	120	100%	2%
Concrete – Cast for in-situ applications	120	100%	2%
Concrete – hollow lightweight	120	100%	2%
Concrete – precast	120	100%	2%
Concrete – sprayed	120	100%	2%
Elevator car, passenger (no counter weight)	-	100%	2%
Formwork	120	100%	2%
General plastic	40	100%	2%
M&E fit out	-	100%	2%
Paint	20	100%	2%
PVC plastic	40	100%	2%
Reused material off site	120	100%	2%
Soil - compacted	120	100%	2%

Material	Replacement interval (years)	Proportion replaced after full replacement interval	Proportion replaced during maintenance over full replacement interval
Steel reinforcement cars and cages	120	100%	2%
Steel reinforcement fibres	120	100%	2%
Structural steel sections	40	100%	2%
Temporary aggregate	120	100%	2%
Temporary structural steel sections	120	100%	2%

Annex B: Construction and maintenance of rail systems and track

Table B 1: OCS deployment by type and length of route (main route)

Overhead Catenary System (OCS) location	Deployed length on route (km)
Open route	54.5 km
Tunnels	20.2 km
On civils assets	9.7 km

Source: Data provided directly by HS2 Phase 2b Rail Systems Design Team.

Table B 2: Track type (main route) by length of route

Overhead catenary system (OCS) location	Deployed length on route (km)
Pre-cast slab track	Main route pre-cast slab track = 44.2 km Crew Depot = 15.1 km Total pre-cast slab track = 59.2 km
Non-standard slab track	Main route cast in situ slab track (tunnel) = 16.7 km Total in-site slab track (non-standard) = 16.7 km
Ballast track	Main route ballast track = 122.0 km Crewe Depot ballast track = 39.4 km Ashley IMB-R ballast Track = 1.2 km Total ballast Track = 162.6 km

Source: Data provided directly by HS2 Phase 2b Rail Systems Design Team.

Table B 3: Off-route works rail systems by length of route

Location	OCS Open-route	Ballast track
Preston Station	3.10 km	3.10 km
Carlisle Station	1.90 km	1.90 km
Gretna Stabling Facility	23.40 km	23.40 km
Gretna Stabling Facility connections to Network Rail	2.26 km	2.26 km

Source: Data provided directly by HS2 Phase 2b Rail Systems Design Team.

Annex C: Ground treatment

Table C 1: Ground treatment length of deployment of treatment options

Ground treatment profile	Linear metre deployment (m)	Assumptions
2 x Basetex + 275mm square precast reinforced piles at 2.5m centres 10m long. 1x1x0.5 pile caps	1,030	All embankment footprints are 2 x assume average width of 22m at track level
2 x Basetex + 350mm circular unreinforced piles at 2.5m centres 10m long. 1x1x0.5 pile caps	8,540	
Geosynthetic Reinforcement Mattress (GRM) comprising two layers of geogrid and one layer HDPE membrane	24,150	Assumed average width of 22m at track level
Formation of cement stabilised layer for Base Slab to Earthwork Transition	540	Cross sectional area assumed at 11m^2
Track Bed Geotextile	3,210	Assume typical geotextile

Source: Ground Improvement Schedule data

Table C 2: Material carbon factors for Ground Improvement carbon factors

Material	GHG emissions factor[7]	Unit
Reinforced concrete	309	$kgCO_2e/m^3$
Unreinforced concrete	246	$kgCO_2e/m^3$
Geogrid material (HDPE)	1.93	$kgCO_2e/kg$
Fill material / cement stabilised soil	0.084	$kgCO_2e/kg$

Annex D: Construction plant and use of TBM

Table D 1: Assumptions associated with plant equipment fuel use during infrastructure construction and installation

Plant equipment type	Fuel	Total fuel consumption (litres)	Fuel consumption rate (litres/hr)	Source
Generator 200KVA	Diesel	83,350,925.46	15	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Compressor above 34m3/min	Diesel	20,986,966.96	16	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
HIAB	Diesel	19,575,710.20	39	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Lorry delivery (rigid / tipper)	Diesel	16,576,240.75	14	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Dozer 14 – 41T	Diesel	13,089,489.05	53	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
360 excavator 45t	Diesel	12,615,328.85	54	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
360 excavator 20 – 25t	Diesel	10,932,851.58	21	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Articulated dump truck 25t	Diesel	10,651,577.93	25	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
30T 360 degree excavator tracked, 170kW, 30T	Diesel	8,195,040.00	21	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
General delivery HGV	Diesel	7,159,508.66	14	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Fork lift 10t	Diesel	6,729,519.46	9	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Water pump 6in	Diesel	5,433,370.74	3	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant

Plant equipment type	Fuel	Total fuel consumption (litres)	Fuel consumption rate (litres/hr)	Source
28 – 35T Dumper HGV	Diesel	4,560,487.54	30	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Telehandler 4t	Diesel	3,846,485.63	9	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Generator 150KVA	Diesel	3,646,829.67	11	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Flat bed (segment delivery / haulage, plant delivery) HGV	Diesel	3,391,591.32	14	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Poker vibrator	Diesel	3,246,521.07	20	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Dozer 20t	Diesel	3,051,232.00	25	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Mobile Crane 22 - 100T	Diesel	2,770,759.89	8	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Large roller 22t	Diesel	2,683,689.36	25	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
General Site Loader	Diesel	2,438,994.62	15	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Cherry picker lifting platform 35kW, 8t	Diesel	2,276,400.00	7	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
360 excavator 15t	Diesel	2,076,594.60	30	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Diesel powered power-float diesel	Diesel	2,072,736.00	14	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
25T gantry	Diesel	1,902,592.00	8	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Grader 168kW	Diesel	1,803,759.61	16	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant

Plant equipment type	Fuel	Total fuel consumption (litres)	Fuel consumption rate (litres/hr)	Source
Vibratory compactor (asphalt) 60kg	Diesel	1,780,165.31	20	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Fuel tanker 11t	Diesel	1,771,567.20	14	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
4-wheel platform cherry picker	Diesel	1,749,480.69	7	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Chipping concrete pneumatic hammer	Diesel	1,712,005.33	20	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Tracked mobile 55 – 150T	Diesel	1,583,030.01	8	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
20T 360 deg excavator 20t	Diesel	1,496,167.68	21	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Cement mixer truck	Diesel	1,431,716.77	4	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Scissor lift lifting platform 35kW, 8t	Diesel	1,365,840.00	7	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Tracked mobile 600T	Diesel	1,177,741.40	33	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
44t Excavator with pulverizer 44t	Diesel	978,229.44	54	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Crawler crane tracked mobile crane 240kW, 105T	Diesel	936,576.00	8	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Dozer 11 – 14t	Diesel	916,918.39	15	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Scabbling concrete pneumatic chipper	Diesel	861,863.47	16	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Compaction of concrete	Diesel	842,251.73	20	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant

Plant equipment type	Fuel	Total fuel consumption (litres)	Fuel consumption rate (litres/hr)	Source
Generator	Diesel	701,831.23	14	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Concrete pump 8t / 350 bar / 150mm diameter	Diesel	679,174.80	3	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
D-Wall rig crane-mounted hydraulically operated	Diesel	670,911.23	46	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Pile boring rig	Diesel	655,727.27	13	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
4 wheel platform scissor lift	Diesel	609,766.08	7	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Generator 75kVA	Diesel	586,338.89	6	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
360 Excavator with Breaker 29t	Diesel	576,830.72	32	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Compressor 10m3/min to 34m3/min unsilenced	Diesel	498,773.33	16	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Articulated dump truck 40t	Diesel	480,184.41	30	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Vibrating roller (medium)	Diesel	415,037.50	25	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Wheeled mobile crane 275kW 35t	Diesel	390,240.00	8	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Long reach tracked excavator 21m arm / 39t	Diesel	323,320.32	32	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Front end loader 11t	Diesel	322,396.80	9	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Dumper 3 - 6t	Diesel	309,635.17	5	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant

Plant equipment type	Fuel	Total fuel consumption (litres)	Fuel consumption rate (litres/hr)	Source
Back-hoe excavator 8t	Diesel	294,956.48	21	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Medium roller vibratory, 12t	Diesel	281,898.83	5	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Vibrating Roller Medium	Diesel	254,496.00	20	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Concrete delivery bullet	Diesel	229,397.13	14	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Tracked excavator 40t	Diesel	221,184.00	54	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Wheeled loader 25t	Diesel	199,872.12	15	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Pneumatic chipping hammer	Diesel	147,667.73	20	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Breaker mounted on excavator 15t	Diesel	144,000.00	32	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Generator (power for site cabins) 150KVA	Diesel	136,006.72	11	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Large generator	Diesel	120,037.88	23	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Mobile 200 – 250T	Diesel	116,578.80	13	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
De-watering pump diesel	Diesel	105,297.92	3	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
25T dumper 6t	Diesel	104,006.67	25	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Tracked excavator	Diesel	102,196.80	30	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant

Plant equipment type	Fuel	Total fuel consumption (litres)	Fuel consumption rate (litres/hr)	Source
6T excavator mounted breaker 15t	Diesel	71,265.60	21	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
20t Excavator with pulverizer	Diesel	69,316.80	21	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Cherry picker	Diesel	60,659.20	7	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Small roller vibratory, 4t	Diesel	56,583.99	3	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Scabbling concrete	Diesel	54,816.00	20	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
29t Excavator with Hammer	Diesel	39,628.80	32	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Vibratory piling rig	Diesel	34,637.90	13	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
MEWP scissor lift	Diesel	33,381.60	7	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Excavator Terex	Diesel	31,105.20	21	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
29t Excavator with pulverizer	Diesel	26,419.20	32	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
D-wall Hydrofraise	Diesel	20,736.80	46	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Compressor l-245-s2	Diesel	19,136.00	16	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Vibrating roller (medium)	Diesel	17,908.53	5	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
CFA piling rig Soilmec CM45	Diesel	12,201.14	13	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant

Plant equipment type	Fuel	Total fuel consumption (litres)	Fuel consumption rate (litres/hr)	Source
22t Excavator with Hammer	Diesel	11,491.20	21	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
15T 360 deg Excavator	Diesel	10,008.00	30	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Crane-mounted auger (Bored / Kelly Bar) 120kw	Diesel	9,813.05	11	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Vibrating roller (small)	Diesel	9,244.80	3	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
30T Tracked excavator with pneumatic breaker	Diesel	8,755.20	32	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Crawler crane 80t	Diesel	6,092.80	8	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
15T 360 deg excavator	Diesel	5,577.60	21	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
30T Gantry 30t, 25m span	Diesel	4,569.60	8	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Well drilling rig	Diesel	3,048.55	24	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant
Diaphragm wall rig	Diesel	2,082.86	24	Institute Civil Engineering Surveyors (1998) The Reference Manual for Construction Plant

Source: Project construction and acoustics data.

Table D 2: Assumptions informing assessment of TBM

Parameter	Assumption
Operating profile	• 7 days / week • 24 hour operation • Utilisation of 80%
Installed power	• 6,500 kW per TBM

Parameter	Assumption
Number of TBM required	• 2 for Crewe tunnels (1 per tunnel) • 4 for Manchester tunnels (2 per tunnel from both ends)
Progress rate	• 80 – 95m per week
Tunnel lengths	• Crewe: 13,570m (2 tunnels 6,785m each) • Manchester (North): 7,846m • Manchester (South): 4,808m
Embodied emissions	• 1,087 tCO_2e per TBM[8]

[8] Chris Chau, Kenichi Soga, Nick O'Riordan and Duncan Nicholson (2012), *Embodied energy evaluation for sections of the UK Channel Tunnel Rail Link,* Institute of Civil Engineers, Volume 165, Issue GE2.

Annex E: Construction water use

Table E 1: Total construction compound water use.

Community area	Water consumption (l)	GHG emissions (tCO_2e)
MA01	916,663,359	315
MA02	1,985,223,541	683
MA03	674,898,297	232
MA04	678,406,219	233
MA05	687,172,219	236
MA06	1,745,925,438	601
MA07	945,913,797	325
MA08	543,050,656	187
Carlisle	7,951,797	3
Preston	7,830,047	3
Annandale	58,455,219	20
Total	8,251,490,588	2,839

Source: Project construction and logistics data

Table E 2: Construction water use GHG emissions factor[9]

Activity	GHG Emissions factor ($kgCO_2e$ / million litres)
Construction water use	344

[9] Department for Business, Energy and Industrial Strategy (2020), *Greenhouse gas reporting: conversion factors 2020*. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020.

Annex F: Construction compound waste and demolition waste management

Table F 1: Waste quantities (tonnes) from construction worker compound by community area

Community Area	Waste from construction worker site accommodation (tonnes)[10]
MA01/04	125
MA02/01a	87
MA02/05	140
MA02/11	80
MA03/06	188
MA04/10	133
Total	**754**

Source: Project construction and logistics data.

Table F 2: Total waste quantities (tonnes) of demolition waste

Demolition waste	
Total quantity landfilled (tonnes)	**Total quantity recovered (tonnes)**
54,586	491,280

Source: Project construction and logistics data.

[10] Assumed 100% combusted.

Table F 3: Construction worker compound waste and demolition waste disposal carbon factors ($kgCO_2e$/tonne)

Waste type	Disposal method	GHG emissions factor ($kgCO_2e$/ tonne)
Waste disposal, construction	Open-loop	1.009
	Landfill	3.879
Waste disposal, refuse	Municipal waste	21.317

Source: BEIS[9].

Annex G: Land Use

Table G 1: Areas (hectares) of different land uses disturbed during the construction phase

Land use category	Area (hectares)
Arable & horticulture	948
Urban	325
Broad leaf, mixed & yew woodland	44
Neutral grassland	9
Fen, marsh and swamp	1
Total	**1,327**

Source: Project design data.

Table G 2: Areas (hectares) of different land uses to be established as part of the scheme

Land use category	Area (hectares)
Maintained grassland - grazed	139
Terrestrial - Wetland, reed, shrub	148
UK woodlands, average	371
Urban	669
Total	**1,327**

Source: Project design data.

Table G 3: Tree planting assessment assumptions for input into the Woodland Carbon Code (WCC) tool

Tree planting assessment input	Assumption
Tree planting area (m^2)[11]	3,515,110
Tree spacing (m) [11]	1.5
Tree species[11]	Oak, Aspen, Birch, Scots Pine, Limes, Mountain Ash
Establishment conditions	Tree shelters and herbicide used, no fencing
Yield classes[12]	Oak – 6 Aspen – 12 Birch – 6 Ash – 8 Scots Pine – 10 Limes – 8 Mountain Ash – 8

Source: WCC tool[13].

[11] As advised by the HS2 Phase 2b EOC Landscape and Visual team. The closest spacing available has been used where the exact spacing was unavailable for a particular species in the Biomass Carbon Lookup Table within the WCC spreadsheet.

[12] Yield classes for each tree species have been determined using Forest Research's ESC-DSS. Available online at: http://www.forestdss.org.uk/geoforestdss. Three locations along the route of the Proposed Scheme have been chosen to represent average yield classes. Where the correct yield class has not been available for selection in the WCC spreadsheet, the closest available yield class for each of the tree species has been chosen.

[13] The assessment is based on the 'Example 3 Mix native wdld' worksheet of the WCC Carbon Calculation Spreadsheet, used in conjunction with the WCC Carbon Lookup Tables.

Table G 4: Land use carbon factors used for assessment of the construction phase

LULUCF category[14]	Source	GHG emissions factor	Unit	Converted to CO_2e	Unit
Arable & horticulture	Natural England Research Report (2012)[15]	44	tC/ha	161	tCO_2e/ha
Broad leaf, mixed & yew woodland	Natural England Research Report (2012)	137	tC/ha	502	tCO_2e/ha
Coniferous woodland	Natural England Research Report (2012)	140	tC/ha	513	tCO_2e/ha
Fen, marsh and swamp	Natural England Research Report (2012)	76	tC/ha	279	tCO_2e/ha
Neutral grassland	Natural England Research Report (2012)	61	tC/Ha	224	tCO_2e/ha
Urban	Ostle et al. (2009)[16]	0	tC/ha	0	tCO_2e/ha

Table G 5: Land use GHG factors used for assessment of the operational phase

LULUCF category[14]	Source	GHG emissions factor	Unit
Terrestrial - wetland, reed, shrub	Boerema et al. (2016)[17]	25	tCO_2e/ha/yr
Maintained grassland - grazed	De Deyn et al. (2011)[18]	2.2	tCO_2e/ha/yr

[14] LULUCF carbon factors have been sourced from available literature. UK specific carbon factors have been used where possible and more recent sources have been selected over older sources.

[15] Natural England (2012), *Carbon storage by habitat: Review of the evidence of the impacts of management decisions and condition of carbon stores and sources.* Available online at: http://publications.naturalengland.org.uk/publication/1412347.

[16] Ostle, N. J., Levy, P .E., Evans, C. D. and Smith, P. (2009*), UK land use and soil carbon sequestration*. Elsevier: Land Use Policy.

[17] Boerema, A., Van der Biest, K. and Miere, P. (2016), *Presentation - Ecosystem services: towards integrated marine infrastructure project assessment.* Available online at: https://www.researchgate.net/publication/310465854_Ecosystem_services_towards_integrated_marine_infrastructure_project_assessment.

[18] De Deyne, G. B., Shiel, R. S., Ostle, N. J., McNamara, N. P., Oakley, S., Young, I., Freeman, C., Fenner, N., Quirk, H. and Bardgett, R. D. (2011*), Additional carbon sequestration benefits of grassland diversity restoration,* Journal of Applied Ecology, 48.

Annex H: Mass haul transportation

Table H 1: Mass haul material quantities and haul journey numbers by type from Mass Haul Movement Plan

Haul type	Total volume of material (m^3)	Total no. of haul journeys
Site haul	10,825,474	1,237,197
Road haul (internal)	3,314,004	779,766
Road haul (external)	534,370	125,734
Rail haul	1,667,757	5,559

Source: Project mass haul data

Table H 2: Site haul assumptions

Site haul (assumed as dump truck)	
Total number of Heavy Goods Vehicles (HGV)	1,237,197
Average distance (km)	1.06
Total distance travelled (km)	1,311,671

Table H 3: Road haul assumptions (internal)

Road haul (assumed as road wagon)	
Total number of HGV	779,766
Average distance (km)	18
Total distance travelled (km)	13,733,625

Table H 4: Road haul assumptions (external)

Road haul (assumed as road wagon)	
Total number of HGV	125,734
Average distance (km)	50
Total distance travelled (km)	6,286,706

Table H 5: Rail haul assumptions

Rail haul	
Density of excavated material (kg/m^3)	1,950[19]
Total volume of material (tonnes)	3,252,126
Average distance (km)	75
Total tonnes.km	243,909,461

Table H 6: Mass haul carbon factors

Vehicle	GHG emissions factor	Unit	Notes
Articulated diesel HGV (>33 tonnes), 100% laden	1.08	$kgCO_2e$/km	Assumed for road and site haul movements. No improvement in HGV and rail freight has been assumed between the 2020 carbon emissions factor up to the end of the construction phase.
Well-to-tank (WTT), articulated diesel HGV (>33 tonnes), 100% laden	0.26		
Rail, freight train	0.03	$kgCO_2e$/tonne.km	Assumed for rail haul movements.
WTT, rail, freight train	0.01		

Source: BEIS[9]

[19] Assumed to be sand and gravel for the purposes of the assessment.

Annex I: Rolling stock, stations and depots

Table I 1: Assessment of rolling stock manufacture and operation assumptions

Aspect	Assessment parameter(s)
Type	"Very high speed" train[20]
Length	200m (single unit)
Maximum speed	330 / 360km/h
Maximum numbers of passengers:	548 (number of seats)
Power supply:	Electric
Lifespan:	35 years
Product groups assessed	• Car body; • Interior, windows and doors; • Bogies and running gears; • Propulsion and electric equipment; and • Comfort systems.
First year of assessment	2038
Load factor	80%
Number of rolling stock units	113
Total unit-km per annum[21]	HS2 network: 29,968,027 Conventional network: 12,730,046
Energy consumption rate[22]	HS2 network: 24.97 kWh/unit-km Conventional network: 15.27 kWh/unit-km

[20] Enviodec (2021), *Product Category Rules - Rolling Stock*, Version 3.01.

[21] Annual unit-km of rolling stock on the HS2 network and the conventional rail network based on the most recent issue of the Phase 2B Operation Plan

[22] Energy consumption rates per unit-km on the HS2 network and the conventional rail network as advised by the HS2 Ltd ID Rolling Stock team and reflects that assumed in HS2 business case.

Table I 2: Assessment of rolling stock manufacture and operation data sources, boundary in time and geography for upstream, core and downstream modules

Module	Activity	Representative source	Boundary in time	Geography	Notes
Upstream	Extraction of raw materials and production of base materials	ETR1000, Environmental Product Declaration, Hitachi Rail Italy (August 2013). Available at: https://www.environdec.com/Detail/?Epd=9267	2012	Unknown	In accordance with PCR for Rolling Stock 2009:05 version 3.01, ISO 14040 and ISO 14044 The Ecoinvent database has been used for all processes, for base materials production, for waste treatment processes and for electronic parts production Independent verification of the declaration and data, according to ISO 14025 *Assembled (Pistoia) and used (Naples) in Italy, transported by rail
	Production of auxiliary materials for rail vehicle assembly/manufacturing				
	Transportation of products from suppliers' manufacturing facilities to train manufacturer assembly plants				
Core	Electricity, heat, steam, fuels and auxiliary materials produced and used for rail vehicle assembly/manufacturing	ETR1000, Environmental Product Declaration, Hitachi Rail Italy (August 2013). Available at: https://www.environdec.com/Detail/?Epd=9267	2012	Hitachi Rail Italy Pistoia site plant.	
	Production and use of auxiliary materials for vehicle assembly				
	Transportation of the rail vehicle from assembly facility to the location of its use*				
	Waste generation and treatment of waste from the assembly processes on the rolling stock manufacturer site				
Downstream	Electricity consumption for rail vehicle operation	• **Network use:** 77% of unit-km on HS2 network; 23% on classic rail network • **End of life** is insignificant and its exclusion from the assessment will not materially affect the outcome of the assessment[23]			
	Production of maintenance materials and spare parts				
	Waste from maintenance materials and spare part				

[23] EPD data for regional and intercity trains (non 'very high speed') identifies that the end of life impact accounts for less than 1% of the total lifecycle carbon impact and therefore is not considered likely to materially affect the outcome of this assessment.

Module	Activity	Representative source	Boundary in time	Geography	Notes
	Direct disposal of materials				
	Incineration of materials with no energy recovery				

Table I 3: Operational energy and water use associated with Annandale Gretna depot, Ashley IMB-R, Crewe Depot and Manchester stations and depots

Station/depot	Area (m2)	Energy consumption (kWh/annum)	Water consumption (m^3/m^2/annum)
Annandale Gretna[24]	13,137	1,664,922	7,882
Ashley IMB-R[25]	250	29,700	150
Crewe[26]	57,034	19,507,124	34,220
Manchester Station[27]	227,360	23,698,401	136,416

[24] Information sourced from Gretna RSD – Maintenance shed, Depot Accommodation Building design information.

[25] Information sourced from HS2 Maintenance Strategy report.

[26] HS2 Phase 2B Crewe Rolling Stock Depot (RSD) CP3.0 Design Stage Report, and as advised by HS2 Phase 2b BREEAM team.

[27] Information sourced from Manchester Piccadilly Station, Appendix 4: Accommodation Schedule, and as advised by HS2 Phase 2b BREEAM team.

Annex J: Modal shift

Table J 1: Modal shift - effects modelled within PLANET framework model (PFM)

Reference	Modal shift effect
VK2	Change to classic rail network to HS2 – not reported within the PLANET model and instead provided by HS2's Economic Analysis Team[29]
VK3	Induced car travel to access HS2 stations
VK4	Shift from car travel to HS2 (long distance travel – cross country trips)
VK7	Shift from car travel to HS2 (short distance travel – local trips)
PK5	Shift from car travel to HS2 to access domestic airports
Freight	Shift from road freight to rail freight due to released capacity on the classic rail network

Planet framework model (PFM)[28]

Table J 2: Modal shift baseline and sensitivity analysis assumptions and data sources

Road	Assumption
VK2: Change to conventional rail network as a result of HS2	• Annual change to classic rail network train-km and the associated change to electricity and diesel consumption as a result of HS2 provided by the HS2 Economic Analysis team[29]; • Fleet mix projections for conventional rail (shift from diesel to electric trains) as advised by Network Rail Traction Decarbonisation Network Strategy (TDNS) team and endorsed by DfT[30]; and

[28] The Planet Framework Model (PFM) is a strategic transport model developed by HS2 Ltd. and covers all long-distance rail, car and air movements across England, Scotland and Wales. The PFM has been run for a future baseline, Phase One, Phase 2a and the Proposed Scheme. The impacts of introducing the Proposed Scheme are isolated from impacts associated with Phases One and 2a. PFM assumes changes in the provision of future rail services in line with industry expectations and changes to macroeconomic indicators based on DfT and Office of Budgetary Responsibility (OBR) assumptions.

[29] Change to Classic Rail Network Annual Train-km is based on the Train GHG Emissions Estimation for the Economic Case: 'Diesel Model FBC Masterfile v6'.

[30] Traction Decarbonisation Network Strategy Pathway 6 diesel and electric fuel consumption forecasts have been applied as advised by Network Rail Traction Decarbonisation Network Strategy (TDNS) team and endorsed by DfT.

Road	Assumption
	• WebTAG Data Book rail diesel carbon factors[31].
VK3, VK4, VK5, VK7: Impact on car travel	• PFM vehicle-km for VK3, VK4, VK5 and VK7[32]; • DfT fleet fuel efficiency projections (adjusted for biofuels)[33]; • WebTAG fleet mix projections[31] (Base case); and • DfT fleet mix projections[33] (Sensitivity analysis).
PK5: Shift from domestic aviation to HS2	• PFM annual air passenger-km[32]; and • Domestic aviation efficiency factors, including the rate of biofuel uptake, provided by the DfT[33].
Freight: Shift from road freight to rail freight	• Potential freight paths released due to HS2 as advised by DfT[34]; • Fleet mix projections for rail freight as advised by Network Rail Traction Decarbonisation Network Strategy (TDNS) team and endorsed by DfT[30]; • Diesel and electric HGV efficiency provided by DfT[33]; • Diesel rail freight efficiency improvements derived from the ORR Freight rail usage and annual performance source historical figures[35]; and • Electric rail freight energy consumption as per Network Rail CP6 Traction electricity modelled consumption rates[36].

[31] Department for Transport (2021), *TAG Data Book*. Available online at: https://www.gov.uk/government/publications/tag-data-book.

[32] PFM v9.6 developed by HS2 Ltd (PFMv9.6 Carbon Data – Absolute Numbers).

[33] DfT EEP consistent outputs reflecting a net zero transport sector consistent with BEIS' Ten Point Plan prior to the publication of the DfT's Transport Decarbonisation Plan in July 2021 (prepared by DfT for HS2).

[34] Potential freight paths released due to HS2 provided by DfT's Rail Technical Advisory team.

[35] Office of Rail and Road, *Table 6100 - Estimates of normalised passenger and freight carbon dioxide equivalent (CO2e) emissions*. Available online at: https://dataportal.orr.gov.uk/statistics/infrastructure-and-emissions/rail-emissions/table-6100-estimates-of-normalised-passenger-and-freight-carbon-dioxide-equivalent-co2e-emissions/.

[36] Network Rail, *CP6 Traction Electricity Modelled Consumption rates*. Available online at: https://www.networkrail.co.uk/industry-and-commercial/information-for-operators/cp6-access-charges-2/.

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High Speed Two (HS2) Limited
Two Snowhill
Snow Hill Queensway
Birmingham B4 6GA
Freephone: 08081 434 434
Minicom: 08081 456 472
Email: HS2enquiries@hs2.org.uk