High Speed Rail: Consultation on the route from the West Midlands to Manchester, Leeds and beyond

Sustainability Statement

Appendix F – HS2 and Carbon

Assessment of carbon emissions for Phase One and Two

A report by Temple-ERM for HS2 Ltd

October 2013

TEMPLE ERM

Contents

Executive Summary

HS2 has the potential to provide a key part of the UK's future low-carbon transport system and to support the Government's overall carbon objectives. High speed rail offers some of the lowest carbon emissions per passenger kilometre when compared with other transport modes. But the potential carbon benefits of HS2 that occur from high speed rail's attraction of passengers from these other modes will depend on a number of factors. Some of these are outside HS2's control, but still have an important bearing on the carbon emissions of the scheme; for example the decarbonisation rate of the electricity sector from which HS2 will draw its power, or of the transport sector in general, against which HS2's carbon emissions would be compared. These potential carbon benefits need to be considered alongside carbon emissions resulting from the operation of the trains and infrastructure and from the scheme's construction.

Understanding the overall carbon impact of HS2 is therefore complex, requiring consideration of numerous factors over a long time period and often with uncertain outcomes. Estimates of HS2's carbon impacts depend as much upon the definition of these futures as they do on the innate carbon characteristics of the scheme itself.

To explore all of these issues so as to better understand the source and extent of any potential carbon emissions and savings, the HS2 proposals (both Phase One and Phase Two) were subject to a carbon assessment as part of the wider Appraisal of Sustainability (AoS) for Phase Two. This has helped improve understanding of how HS2 could support UK and wider European objectives for carbon reduction. It also enables HS2 Ltd to identify the principal types of carbon emissions and so help shape emerging initiatives for carbon reduction, in line with its *Sustainability Policy* and other emerging policy documents. The assessment has not included any monetary valuation of carbon, which is addressed within the Economic Case for HS2.

Rail and carbon

In 2011, the transport sector contributed around 25% of the UK's greenhouse gas (GHG) emissions[1]. These emissions were predominantly from road vehicles (around 22%), with trains contributing around 0.8% (4.4 Mtonnes CO_2e/year[2]). National and international studies[3] confirm that rail transport, and high speed rail in particular, is consistently amongst the most carbon efficient mass transport modes. Even though more power is needed for high speed rail travel in comparison with standard inter-city services, high levels of passenger usage mean that, per passenger-km, carbon emissions remain comparatively low. Emissions from high speed rail are particularly favourable when compared to roads and aviation, which would have equivalent carbon intensities six times and twenty times as high as HS2 when the high speed services commence.

HS2 and CO_2 emissions

The construction and operation of HS2 will give rise - directly and indirectly - to CO_2 emissions. These emissions will arise principally from elements such as the fabrication of construction materials, the transport of construction and excavated materials to and from sites, and, once operating, the generation of electricity used to power the trains.

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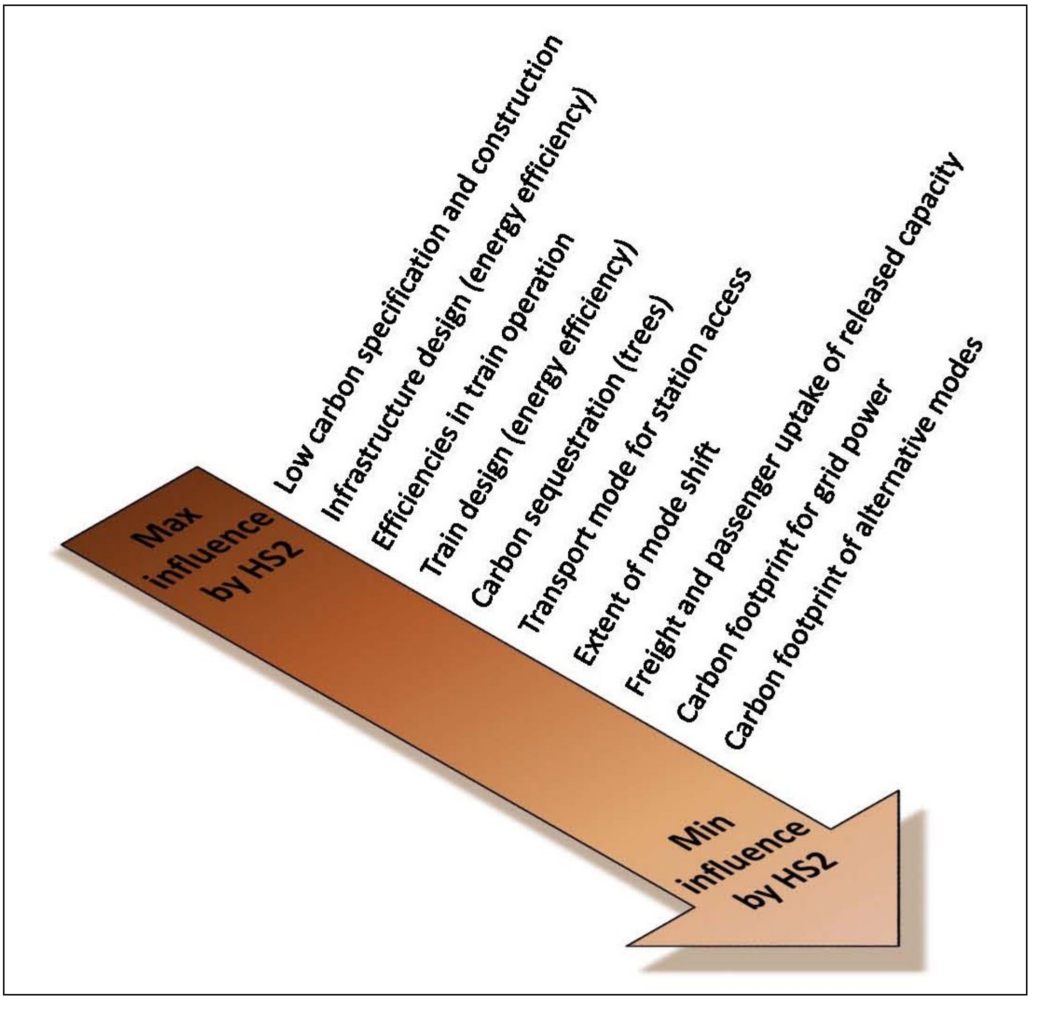
[1] 2011 final UK figures: data tables. https://www.gov.uk/government/publications/final-uk-emissions-estimates.

[2] There are a range of gases that contribute to climate change, each with a greater or lesser impact compared with CO_2. As a result, measures of emissions tend to be equalised to a CO_2 equivalent (or CO_2e).

[3] 'Carbon Footprint of High Speed Rail', Systra for the UIC (2011) ; 'Comparing environmental impact of conventional and high speed rail', Network Rail (2009); 'Relative carbon performance of rail compared to other modes', Department for Transport (2007); 'T618 – Traction Energy Metrics', Rail Safety and Standards Board (2007).

There are a number of factors affecting the carbon emissions from or associated with HS2. Some of these would be determined in part by the way the scheme is designed, built and operated. Adoption of a range of carbon saving measures would lead to carbon efficiencies in construction and operation, in line with HS2's *Sustainability Policy*, which seeks, amongst other things, to minimise the carbon footprint of HS2 as far as reasonably practicable. However, a great many of the scheme's carbon emissions will depend on other factors either entirely outside the control of HS2 Ltd or only partly within its influence. This is illustrated below.

HS2 Ltd's influence and control over carbon emissions will vary for different factors



There is therefore, considerable uncertainty in the precise carbon impact of HS2, dependent as it is on so many different influences with many possible futures, and the timescale over which the impacts are assessed.

The carbon assessment

To try and address this uncertainty the carbon assessment has used two scenarios to illustrate two possible futures, with each accommodating a number of different assumptions about the way carbon emissions may change over time. Scenario A draws on many of the same assumptions that are used by, and reflected in, the Economic Case for HS2. Scenario B uses assumptions contained within advice to Government from the Committee on Climate Change in relation to the Fourth Carbon Budget[4]. This tends to be more ambitious in its portrayal of future reductions in carbon with, for example, a greater proportion of power generated from renewables and higher uptake of cleaner road vehicles.

[4] 'The Fourth Carbon Budget: Reducing Emissions through the 2020s', Committee on Climate Change (December 2010)

The assessment involved calculating the potential CO_2 emissions resulting from HS2's construction and operation, and potential reductions in CO_2 emissions over the first 60 years of operation of the full (Phase One and Two) scheme. These reductions would result from people switching to high speed rail services in preference to other transport modes with higher carbon emissions or as a result of freight switching from road to rail to make use of space vacated on existing lines by previous inter-city passenger services. Calculation of these quantities has used different factors and assumptions for each of the two scenarios.

The carbon assessment adopted a 60 year assessment period from the opening of Phase Two, in line with the Economic Case for HS2. This assessment period accords with standard methodology used by the Department for Transport (DfT) to assess transport schemes (the 'WebTAG' carbon assessment assumptions[5]). In practice, the HS2 design life will be twice as long as this, so the assessment has also reflected how this longer 120 year period may affect overall carbon emissions.

In addition, the figure for estimated carbon emissions attempted to reflect a future with HS2 when compared to one without. In practice, were HS2 not to proceed, there would be a set of other transport initiatives that would be implemented to address (albeit less effectively) the increasing challenges for satisfying transport demand in the UK. Each of these non high speed rail alternatives would have its own carbon impact. In the absence of detail on how strategic alternatives might be developed, the assessment is not able to take into account this more representative future carbon baseline. To provide some context, based on estimates from the Phase One Environmental Impact Assessment (EIA) carbon report[6], a motorway alternative to the Phase One proposals could result in operational emissions some 10 times those of HS2.

It is clear, however, that strategic scale transport solutions such as HS2 are likely to require significant infrastructure investment, which inevitably carries short-term carbon consequences.

The emissions (in millions of tonnes of carbon dioxide equivalent, $MtCO_2e$) estimated to arise during the first 60 years of operation of HS2 under the two scenarios are summarised in the table below.

Carbon emissions for HS2 over the 60 year operational assessment period

Emission Source	Scenario A ($MtCO_2e$)	Scenario B ($MtCO_2e$)
Operational emissions	+ 5.27	+ 2.15
Modal shift emissions	- 10.49	- 8.21
Freight uptake of released capacity[7]	-3.25	-3.25
Carbon sequestration from tree planting[8]	-1.00	-1.00

This table shows that over the first 60 years of operation HS2 would result in an overall decrease of about 9.5$MtCO_2e$ under Scenario A and about 10.3$MtCO_2e$ under Scenario B.

[5] http://www.dft.gov.uk/webtag/

[6] Section 5 of Volume 3 (Route-wide effects) of the Phase One Environmental Statement

[7] See Section 4.5.

[8] A figure has been calculated for the Phase One Environmental Impact Assessment based upon an estimate of 2,000,000 trees that will be planted as part of the Phase One scheme only. The Phase One estimate is doubled to reflect a further commitment to planting 2,000,000 trees within Phase Two.

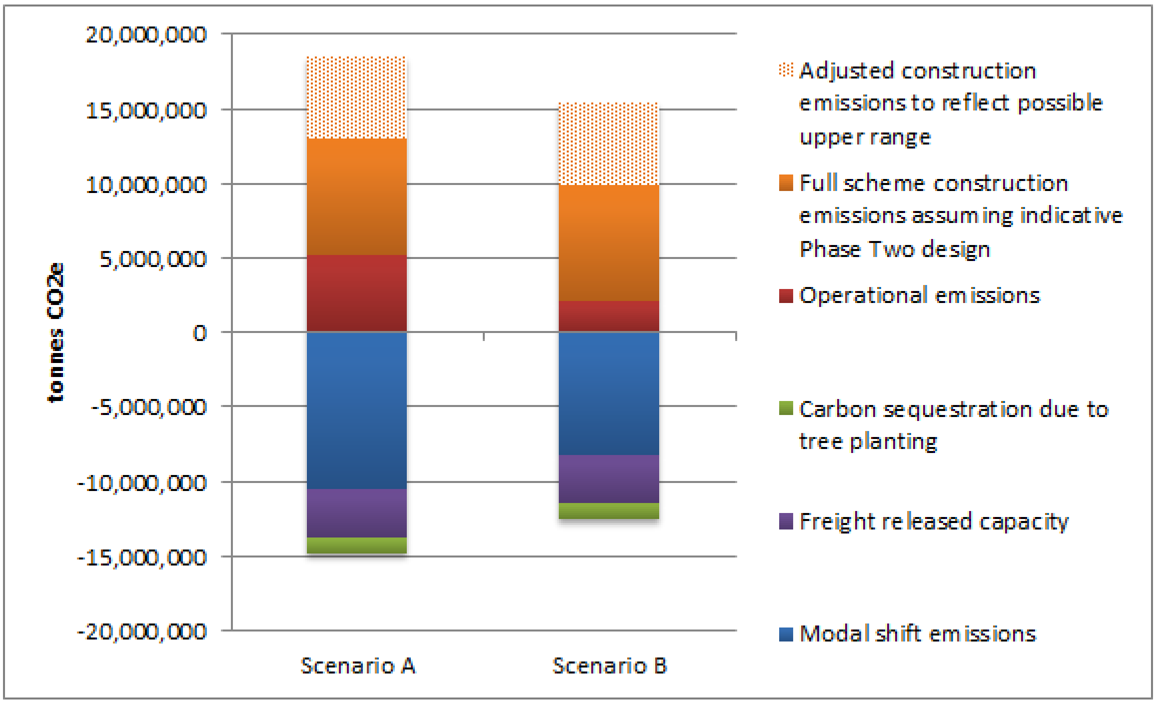
These potential carbon reductions during operation over 60 years need to be seen in the context of potential carbon emissions during the construction of HS2. For the construction phases of both Phase One and Phase Two, construction emissions are estimated to be between 7.8 and 13.3MtCO_2e. The smaller figure uses construction data for Phase Two that is based on the indicative design available at the current time. In practice, the Phase Two construction emissions are expected to be greater than this; the larger figure for construction emissions therefore accommodates an adjustment to account for a more developed Phase Two design based on the current, more detailed Phase One assessment of construction emissions.

Taking both the construction and operational phases together, and assuming the value of construction emissions based on the Phase Two indicative design, there would be an estimated net decrease of about 1.7MtCO_2e under Scenario A and about 2.5MtCO_2e under Scenario B. However, accepting that the construction emissions for Phase Two may be larger in practice, a net increase in emissions is also possible, with estimated increases of 3.8 MtCO_2e and 3.0 MtCO_2e, for scenarios A and B respectively.

An important qualification for these results is that they reflect only the first 60 years of operation. Over its full 120 year design life, HS2 would continue to give rise to ongoing carbon reductions due to the net effect of its operations, and to carbon increases due to the natural cycle of maintenance, repair and replacement of the infrastructure. Assuming that these reductions and increases continue in line with trends for years 0-60, then over years 61-120, net reductions of around 7MtCO_2e could result, ensuring that HS2 over its design life would be carbon beneficial.

The bar chart below illustrates the relative contributions from the different sources of carbon emissions and carbon reductions. The chart identifies (for construction and the first 60 years of operation) the most significant areas of carbon emission. HS2 will use this information to identify where carbon can be minimised in relation to those elements within its control. This is reflected in HS2 Ltd's *Sustainability Policy* commitment to "minimise the carbon footprint of HS2 as far as practicable and deliver low carbon long distance journeys that are supported by low carbon energy".

Carbon emissions for HS2 over the assessment period



Assuming an overall carbon increase during the 60 year assessment period, the estimated quantities of carbon are very small compared with emissions from the UK as a whole. If the

HS2 overall emissions are divided into annual amounts, they would represent 0.06% of the UK's yearly GHG emissions and about 0.25% of the UK's transport GHG emissions.

Carbon benefits from HS2

High speed rail offers some of the lowest carbon emissions per passenger kilometre when compared with other transport modes, such as road, conventional rail and aviation. In addition, key carbon benefits will derive from the shift of passengers from these other modes onto HS2.

There are also potential secondary carbon benefits that arise from the construction of a wholly new rail transport scheme such as HS2. Because the HS2 scheme would increase the total carrying capacity of the rail transport system, it would provide a means to free up capacity on existing rail networks. If this 'released capacity' can then be used to transfer freight or passenger traffic from higher-carbon modes such as road or aviation to the existing rail network, a further carbon benefit arises. This benefit is unlikely to arise from alternative transport schemes that add no significant new strategic capacity.

Most of the carbon emissions due to the construction and operation of HS2 would arise from activities that fall within the EU's Emissions Trading System (EU ETS). This scheme operates across the European Union and sets a steadily decreasing cap on carbon emissions from a specified range of activities. Emissions from the majority of HS2 activities will therefore effectively be absorbed by the EU ETS and will not result in overall carbon increases. Emissions from activities outside this scheme, while covered in the UK by legally binding targets, are not subject to a fixed cap. Emissions from diesel trains and road vehicles are currently outside the EU ETS, whereas those from power generation are inside it. Through modal shift, HS2 would therefore also draw more emissions into this scheme. In addition, HS2 will make further contributions to a reduction in carbon through its *Sustainability Policy*.

Achieving these carbon benefits relies partly on commitments that the HS2 project can make. But it also relies on a supportive and consistent wider policy framework, to ensure that transport is organised around long-term carbon goals as implied by the UK's commitment to decarbonisation of the economy[9].

Conclusions

The carbon assessment has been undertaken to understand the potential carbon impacts of HS2. This is a complex process that relies on numerous factors, some under the direct influence of HS2, some not, and all with various degrees of uncertainty given the long period over which the scheme will operate and the difficulty in knowing how the transport and power sectors will perform over this time.

Over the construction and the first 60 years of operation of HS2, it is likely that carbon savings - that come about as people switch from other transport modes with higher carbon emissions, and as released capacity on existing railways is taken up by new passenger and freight services at the expense of road vehicles – will be less than the carbon emissions, resulting largely from the construction phase. This will depend on the final design for the scheme which for Phase Two is currently at a preliminary level of detail in advance of the first round of public consultation. However, these carbon emissions would be negligible in comparison with emissions from the UK transport sector as a whole (around a quarter of one per cent).

Over the full lifetime of the scheme, assumed to be 120 years, HS2 would continue to give rise to net carbon reductions from its operations, as well as to carbon increases due to ongoing maintenance, repair and replacement of infrastructure. As a result, the overall

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[9] The Carbon Plan – Delivering our Low Carbon Future', HM Government (December 2011).

carbon trend for HS2 could be a net carbon reduction over its design life, even if the higher value of construction emissions is assumed.

In practice, if HS2 did not proceed, other strategic transport alternatives would be required to seek to address the current and emerging transport challenges, each with their own carbon impacts. These alternatives have not been considered as part of this study. However, in comparison with most other transport modes, high speed rail offers some of the lowest carbon emissions per passenger-kilometre, and significantly less than cars and planes. Furthermore, most of the carbon emissions due to HS2 would arise from activities that fall within the EU ETS and would therefore be limited and gradually reduced.

In addition to these overarching conclusions, the assessment has identified the relative carbon impacts of different aspects of the scheme. This is being used by HS2 Ltd to better understand how carbon can be reduced through the life of the project. HS2 Ltd has adopted a *Sustainability Policy*, which seeks to minimise the carbon footprint of HS2 and deliver low carbon long distance journeys that are supported by low carbon energy.

1. Introduction

1.1. Context

1.1.1. HS2 is the Government's proposed high speed railway linking London with Birmingham, Manchester and Leeds. Proposals for Phase One, between London and the West Midlands, are currently the subject of an environmental impact assessment (EIA). Phase Two, extending Phase One up to Manchester and Leeds and including connections with the existing rail network, is at an earlier stage of development. Phase Two proposals have been the subject of an appraisal of sustainability (AoS), the findings of which were published in a *Sustainability Statement* in July 2013.

1.1.2. *HS2 and Carbon* supplements the *Sustainability Statement,* by describing the approach and findings of the carbon assessment for the proposed HS2 scheme. The publication of *HS2 and Carbon* after the *Sustainability Statement* is due to its reliance on data from the Economic Case for HS2, which was still being completed in July 2013, when consultation on the Phase Two proposals commenced. *HS2 and Carbon* now joins a number of other documents that have been produced to support the consultation process, including the main consultation document, *High Speed Rail: Investing in Britain's Future - Consultation on the route from the West Midlands to Manchester, Leeds and beyond*. Further information is available at www.hs2.org.uk/developing-hs2/consultations.

1.1.3. *HS2 and Carbon* considers how HS2 could support UK and wider European objectives for carbon reduction. It has focused on the HS2 proposals as a whole – both Phase One and Phase Two. Phase One proposals on their own are being addressed by the EIA and reported within the Phase One Environmental Statement, although the two studies have been undertaken in parallel and with close working between the respective teams. Included in *HS2 and Carbon* is an assessment of the scheme's potential emissions of carbon dioxide (CO_2). These encompass the following elements:

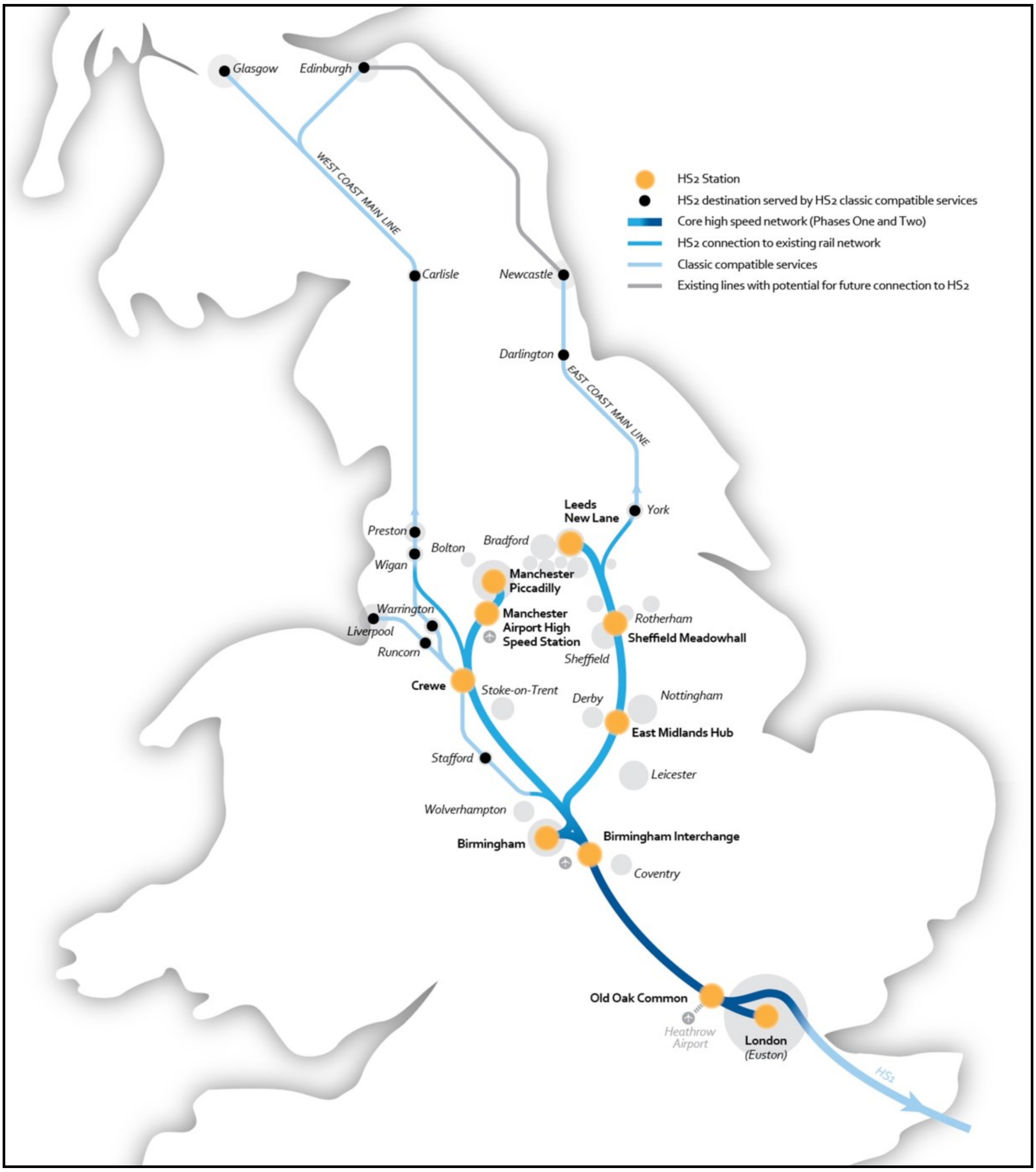
- emissions from construction of the scheme (the so-called Y network – Phase One and Phase Two), including manufacture of rolling stock;
- operational emissions from the power used to operate the Y network, covering anticipated HS2 timetabling and speed profiles; and
- modal shift impacts arising from people switching to HS2 from other forms of transport including secondary modal shift arising from road journeys (principally for freight) switching to the existing rail network to make use of the released capacity due to HS2.

1.1.4. The report supersedes an earlier study undertaken in support of the AoS for Phase One of HS2 between London and the West Midlands (March 2011). Since that was prepared the proposals for HS2 have advanced considerably.

1.2. The HS2 proposals

1.2.1. HS2 comprises new high speed lines from London to Manchester and Leeds (via the West Midlands), along with connections to existing 'classic' lines that would carry trains to further destinations up to Scotland. The HS2 scheme is illustrated in **Figure 1**.

Figure 1 The HS2 proposals



1.2.2. Phase One will comprise a new line starting in Euston and passing in tunnel to a new station at Old Oak Common. It will continue north-westwards passing through the Chilterns, substantially in tunnel, and then on to a new interchange station next to Birmingham Airport and the National Exhibition Centre. The route continues northwards, with a spur providing a connection to a new station in Birmingham city centre. Until Phase Two is complete, trains continuing north on the Phase One scheme will connect with the West Coast Main Line (WCML) to the north-west of Lichfield.

1.2.3. Phase Two will comprise northward extensions of the Phase One route along separate western and eastern legs via Manchester and Leeds respectively. The western leg of the proposed scheme would connect with the WCML at Crewe as well as near Golborne; it would include a station in Manchester city centre, and an interchange station adjacent to Manchester Airport. The eastern leg would connect with the East Coast Main Line (ECML) south-west of York; as well as a station in Leeds city centre, it would include intermediate stations near Nottingham (the East Midlands Hub) and at Meadowhall, Sheffield.

1.3. The emerging UK carbon agenda

1.3.1. The Government's strategy for meeting climate change objectives has evolved since the earlier HS2 carbon report. In 2011, the government set the level of the Fourth Carbon Budget, covering the period 2023-2027, following advice from the Committee on Climate Change (CCC)[10]. In December 2011, the government published the Carbon Plan to set out its strategic approach to the achievement of the UK's statutory carbon-reduction targets. The Carbon Plan provides a range of scenarios through which the UK can deliver its legally-binding objective of cutting greenhouse gas emissions by 80% of 1990 levels by 2050.

1.3.2. The CCC, in its consideration of transport and aviation issues set out advice to government in its Fourth Carbon Budget[11], views HS2 as an important part of the climate agenda in the UK through its potential to replace domestic and short-haul aviation. The CCC states "*we assessed a maximum potential emissions reduction of 2MtCO_2 annually through switching from aviation to high-speed rail, with two caveats that this would require a low-carbon electricity system, and would also need complementary levers …*". The CCC also states that "*we estimate that the effects of the high-speed rail proposals on surface transport emissions (i.e. the combined effect of the increase in emissions from electricity generation and any reduction in car emissions through modal shift) would be negligible*".

1.3.3. The Carbon Plan (2011)[12] sets out the Government's plans for achieving the GHG emissions reductions committed to in the Climate Change Act and the first four carbon budgets. Low carbon transport is an essential part of the Carbon Plan. The Plan states that rail travel will become substantially decarbonised through increasing electrification and the use of more efficient trains and lower carbon fuels. The Plan also mentions that the high speed rail network being developed by HS2 "will transform rail capacity and connectivity to promote long term and sustainable economic growth". Furthermore, the Plan notes that further electrification of the rail network will support low carbon modal shift in the future. In addition the freight sector will have found lower carbon ways of working, such as modal shift to rail and water.

1.3.4. In addition, the context provided by the EU's New Car CO_2 Regulation[13] establishes a long-term framework for industry to develop lower emitting vehicles.

1.3.5. With respect to aviation, in 2013, the Government issued updated future aviation projections[14]. It has also issued an Aviation Policy Framework[15], setting out the principles that will inform and drive UK aviation policy into the future. Most notably, these principles include maintaining and developing the UK's air connectivity and ensuring that the UK aviation sector makes a significant and cost-effective contribution towards reducing global emissions.

1.3.6. There is a variety of international, European and UK greenhouse gas (GHG) policies and targets that are of relevance to HS2's carbon assessment. These are described in more detail within Annex A.

1.3.7. Foremost amongst these are the Climate Change Act [16], which sets a legally binding target of emissions reductions for 2050, and a series of carbon budgets to achieve this.

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[10] 'The Fourth Carbon Budget: Reducing Emissions through the 2020s', Committee on Climate Change (December 2010)

[11] Committee on Climate Change (Dec 2010) The Fourth Carbon Budget. Reducing emissions through the 2020s

[12] The Carbon Plan (2011) https://www.gov.uk/government/publications/the-carbon-plan-reducing-greenhouse-gas-emissions--2 ; Accessed 11 September 2011

[13] http://ec.europa.eu/clima/policies/transport/vehicles/cars/index_en.htm

[14] 'UK Aviation Forecasts', Department for Transport (January 2013)

[15] 'UK Aviation Policy Framework', March 2013 https://www.gov.uk/government/publications/aviation-policy-framework

[16] 'Climate Change Act 2008', http://www.legislation.gov.uk/ukpga/2008/27/contents

2. Previous high-speed rail carbon studies

2.1.1. Previous estimations of the carbon impact of a new UK high speed rail project undertaken by Booz Allen Hamilton and Temple Group for the Department for Transport[17] demonstrated that a key determining variable for carbon efficiency of high speed rail was the geographical scale of such an initiative (city to city routes). The construction carbon element was expected to be substantial, and only where significant modal shift (largely from air to rail) was possible, would a carbon reduction be achieved.

2.1.2. The first carbon assessment of HS2, for Phase One[18], sought to understand the constituent elements of the HS2 carbon emissions in detail. The assessment indicated that the operational carbon elements of Phase One were more significant than for construction carbon and that – as for the Booz-Temple study – mode shift issues were of fundamental importance to HS2's carbon emissions.

2.1.3. Other assessments undertaken by third parties provide a useful context for these conclusions. Analysis by ATOC for Greengauge 21[19] found significant carbon benefits associated with high speed rail. The ATOC report argued that the carbon advantage of high speed rail over other methods of travel is likely to improve over time as power generation becomes increasingly carbon efficient, and therefore concerns about the energy demands of rail at higher speeds needs to be put into context. In particular, its carbon advantage per passenger-km over new cars would remain at least three times greater. In addition, it was argued that higher quality journey time is enjoyed on high speed rail compared to air travel, with significantly less disruption associated with security checks, boarding, etc, as well as greater potential for wireless communications and use of IT equipment. Such 'quality time' was thought to be more likely to drive modal shift from air to high speed rail rather than simply elapsed journey time.

2.1.4. Greengauge 21 has undertaken further work on the carbon implications of HS2. Its interim report[20] sets out the issues that the full study aimed to address, including using different scenarios for estimating carbon benefits, and attention to other issues such as uptake of released capacity on the existing rail network.

2.1.5. More recently, Greengauge 21 issued a report on the carbon implications of HS2[21]. The report looks in detail at the potential carbon implications of HS2 and seeks to identify the main issues on which alternative carbon outcomes depend. The report states that '*We found that there is huge scope to influence the carbon outcome of HS2, and specifically, to ensure that it brings about a useful reduction in emissions*'.

2.1.6. The Greengauge 21 report identifies three principal categories of measures that would help to ensure that HS2 has a positive carbon outcome, these being:

- rail planning and design;
- policy factors; and
- technology and market factors.

2.1.7. The report suggests that the scheme is capable of delivering a carbon saving of more than 7MtCO_2e over the assumed 60 year appraisal lifetime of the project[22], in which '*The route*

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[17] DfT (2007) Estimated Carbon Impact of a New North-South Line. Report by Booz Allen Hamilton and Temple Group

[18] 'HS2 London to West Midlands Appraisal of Sustainability – *ibid*

[19] Greengauge 21 (2009) Energy consumption and CO_2 impacts of High Speed Rail: ATOC analysis for Greengauge 21

[20] 'The Carbon Impacts of HS2' – Interim Report (Dec 2011). http://www.greengauge21.net/publications/carbon-impacts-of-hs2-interim-report/

[21] 'The Carbon Impacts of HS2' (September 2012), Greengauge 21. http://www.greengauge21.net/publications/the-carbon-impacts-of-hs2/

[22] See Table 3,2. P22

extensions to Leeds, Manchester and Heathrow substantially increase the scope for mode shift from air and car travel'. This outcome suggests that the operational carbon emissions from the scheme (ca. 4MtCO_2e), are exceeded by reductions from modal shift carbon emissions from classic rail (ca. -2.5MtCO_2e), aviation (ca. -7.6MtCO_2e) and road passenger vehicles (ca. -1.5MtCO_2e). Construction emissions for Phase One were estimated to be 1.2MtCO_2e.

2.1.8. There is also precedent arising from the overseas experience of high speed rail and assessments of its carbon characteristics. A carbon footprint assessment of the Rhin-Rhône LGV[23] ('High Speed Line') undertook a close examination of the operational and construction carbon issues associated with this new line (constructed 2006 -2011) and established that:

- the contribution of traction energy and construction to the project's carbon footprint are the most significant elements of carbon generation over a 30 year lifetime;
- the carbon benefits arising from modal shift of road and air transport to the new high speed rail system is anticipated to enable a significant reduction in carbon emissions; and
- the achievement of further carbon savings through the use of carbon efficiency measures within design, construction and operation have been built into the project.

2.1.9. The planned California High Speed Rail (CHSR) project[24] envisages a high-speed train system that would eventually stretch from San Diego to Sacramento (by way of the Los Angeles basin and San Francisco), with trains running at more than 200 miles per hour. It is estimated that – over a 40 year period – the system would result in 320 billion fewer vehicle miles and lead to significant CO_2 emissions reductions.

[23] 'Bilan Carbone of Rhin-Rhône LGV', ADEME – RFF – SNCF (Nov 2009)

[24] http://www.hsr.ca.gov/docs/newsroom/fact%20sheets/High-Speed%20Rail%20Big%20Picture.pdf

3. Scope and methodology for the carbon assessment

3.1. Purpose and scope of the assessment

3.1.1. The purpose of this study is to identify the key elements contributing to HS2's carbon emissions and to determine how these contributions could vary depending on assumptions about other factors both inside and outside the control of HS2.

3.1.2. As stated earlier, the carbon assessment of the scheme consists of three principal elements, construction emissions, operational emissions and mode shift emissions. The assessment has been carried out for emissions arising over the construction period and a 60 year operational period from Phase Two opening[25], the latter assumed to cover the period 2033 – 2092, with services on Phase One commencing in 2026, and services on Phase Two commencing in 2033.

3.1.3. ***Construction emissions*** are mostly associated with the railway's construction and include, amongst other things, emissions arising from:

- use of bulk materials within construction, namely steel, concrete and aggregate;
- highly carbon-intensive elements within the electrification system, namely copper and aluminium;
- use of high-energy tunnel-boring machines during construction;
- transport of construction materials to construction sites;
- movement of excavated material within and between sites for re-use and if necessary to landfill destinations; and
- manufacture of rolling stock.

3.1.4. ***Operational emissions*** are principally those arising from the grid-supplied electricity used to power HS2 trains. Indirectly they would also include emissions from new road journeys due to people driving to HS2 stations.

3.1.5. ***Modal shift emissions*** arise from changes in travel patterns on other transport modes, due to the existence of the scheme. They include:

- the change in emissions arising from HS2's overall effect on conventional[26] train services on the wider rail network (which is a combination of displaced services and new services);
- the change in emissions arising from HS2's displacement of road journeys; and
- the change in emissions arising from HS2's displacement of aviation.

[25] The actual HS2 lifespan will be 120 years; the reasons for using the 60 year operational period are addressed in Section 4.1

[26] Also referred to within this report as 'classic' train services

3.1.6. In addition to these direct effects of modal shift, an additional category of indirect ***modal shift emissions*** has been considered, arising from the effect of HS2 on the ability of the classic rail network to accommodate more rail freight. This is described more fully in Section 4 and Annex B.

3.1.7. Emissions from each of these elements of the scheme are calculated using a combination of ***activity data*** and ***emissions factors***. The results are presented in million tonnes of carbon dioxide equivalent ($MtCO_2e$).

3.1.8. ***Activity data*** are the estimated quantities of factors affecting carbon emissions, such as kilometres travelled, passengers displaced or tonnes of materials that go to make up the scheme. For the assessment, activity data have been generated in two main ways.

- For the construction carbon calculations, aspects such as quantities of construction materials and excavated material, or distances for transporting materials, have been estimated directly from preliminary engineering design details for the scheme, utilising the data for the Phase Two proposed scheme for consultation as well as more detailed design data from Phase One. This approach is discussed further in Section 4.2.

- For the operational carbon calculations, annual travel distances for HS2 trains and speed profiles have been provided by HS2 Ltd. For mode shift emissions, data have been provided from HS2's demand modelling assessments (see Annex B). The assessments have calculated annual changes in quantities such as road passenger vehicle miles due to the operation of the scheme.

3.1.9. ***Emissions factors*** show the relationship between the quantity of GHGs emitted and an emission-generating activity; for example the number of grammes of CO_2 emitted for each kilometre travelled on an electric train. Emission factors have also been estimated in two main ways.

- For construction carbon, values have been taken from the literature[27] relating to the manufacture or transport of materials required during the construction phase. In addition, building upon future projections developed as part of the Phase One EIA process, estimated improvements over time in the construction carbon content of concrete and steel have been utilised for these bulk materials.

- For operational carbon, the values of key emissions factors (for example for electricity generation) have been projected forward at 5-year intervals over the time period to the 2090s, through the use of future carbon scenarios described further in Annex B. These carbon scenarios are defined in line with UK carbon policy which envisages that the UK will substantially 'decarbonise' over the period to 2050 and beyond. These carbon scenarios have adopted either the factors set out in DfT documentation [28] used to provide a framework for UK Government appraisal of transport schemes, or views of the future encapsulated within the CCC's work on future UK carbon trajectories.

[27] For example, ' 2012 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting', (May 2012); 'Embodied Carbon – The Inventory of Carbon & Energy (ICE)', BSRIA / University of Bath (2010)

[28] http://www.dft.gov.uk/webtag/

3.2. Methodology overview

3.2.1. The overall approach has been informed by the previous assessment used for the Phase One AoS, continuing to use methods and techniques consistent with the UK GHG Emissions Inventory[29]. The assessment of construction carbon has been informed by a parallel – and more detailed - carbon assessment undertaken in support of the EIA process for Phase One. In addition, a number of assumptions have been made (as detailed below), many of which may have an important influence on HS2 carbon emissions.

3.2.2. One of the approaches adopted in order to help frame assumptions – particularly in respect of UK emissions – has been the definition of scenarios for possible carbon futures. These have been used to help place the carbon performance of HS2 within the wider UK context, and to show how it may be influenced by policies and measures outside of HS2's own operational and construction activities. This approach is discussed in Annex B and summarised in **Box 1** below.

Box 1 – Outline of carbon scenarios

Scenario A

The Economic Case for HS2 involves the valuation of carbon emission consequences. These methods require the application of emissions factors to changes in classic rail and road passenger vehicle distances, and also future projections of the mix of vehicle types for these sectors. The factors are set out in DfT documentation[30], which reflect variations over a timeline up to 2050.

Scenario B

In its supporting evidence for the Fourth Carbon Budget submission[31], the CCC sets out a series of trajectories for future emissions factors associated with different sectors of the UK economy, such as the electricity generation sector and the road transport sector. These trajectories have been used to define a Scenario B.

3.2.3. The operational, construction and modal shift carbon impacts of the scheme are reported in $MtCO_2e$, aggregated over a 60 year assessment period. For operational and modal shift carbon, the impacts are heavily influenced over HS2's operational lifetime by the ongoing decarbonisation of the UK economy. This is represented within our method through carbon emission factors that reduce over time, as described in Annex B. HS2's construction carbon emissions are less influenced by these scenario assumptions. Overall emissions are then determined as the sum of construction, operational and modal shift carbon emissions.

3.2.4. Annex B describes in detail the carbon estimation methods for construction, operation and mode shift, the approach to scenarios and sensitivity assessments, the use of demand modelling data, and the definition of scenarios for UK carbon futures. Annex C itemises individual approaches and assumptions for each element of the calculations adopted within the Phase Two assessment.

[29] http://www.ghgi.org.uk/index.html

[30] http://www.dft.gov.uk/webtag/

[31] Committee on Climate Change (Dec 2010) The Fourth Carbon Budget. Reducing emissions through the 2020s

4. Results

4.1. Overall carbon emissions

4.1.1. **Table 1** and **Figure 2** summarise emissions for the HS2 scheme over its construction period and an assumed operational lifetime of 60 years under both of the UK future carbon scenarios[32]. Construction of the HS2 scheme has been assumed to take place between 2017 and 2031. Phase One operations are assumed to commence in 2026, with full scheme operations commencing in 2033. The operational assessment presented here is the sum of Phase One (2026-2032) and a further 60 year operational period (2033 – 2092) for the full HS2 scheme. The 60 year period accords with standard methodology used by the Department for Transport (DfT) to assess transport schemes[33], although in practice, HS2 will be designed to operate twice as long as this.

Table 1 - Carbon emissions for HS2 over the 60 year operational assessment period[34]

Emission Source	Scenario A ($MtCO_2e$)	Scenario B ($MtCO_2e$)
Operational emissions	+ 5.27	+ 2.15
Modal shift emissions	- 10.49	- 8.21
Freight uptake of released capacity[35]	-3.25	-3.25
Carbon sequestration from tree planting[36]	-1.00	-1.00

4.1.2. This table shows that over the first 60 years of operation, HS2 would result in an overall decrease of about 9.5$MtCO_2e$ under Scenario A and about 10.3$MtCO_2e$ under Scenario B. However, these potential carbon reductions during operation need to be seen in the context of potential carbon increases during the construction phases of both Phase One and Phase Two, which together are estimated to be between 7.8 and 13.3MtCO2e. The smaller figure uses construction data for Phase Two that is based on the indicative design available at the current time. In practice, the Phase Two construction emissions are expected to be greater than this; the larger figure for construction emissions therefore accommodates an adjustment to account for a more developed Phase Two design based on the current, more detailed Phase One assessment of construction emissions (see Section 4.2 and Annex B).

4.1.3. Taking both the construction and operational phases together, and assuming the value of construction emissions based on the Phase Two indicative design, there would be an estimated net decrease of about 1.7MtCO2e under Scenario A and about 2.5MtCO2e under Scenario B. However, accepting that the construction emissions for Phase Two may be larger in practice, a net increase in emissions is also possible, with estimated increases of 3.8 $MtCO_2e$ and 3.0 $MtCO_2e$, for scenarios A and B respectively.

[32] See Annex B.

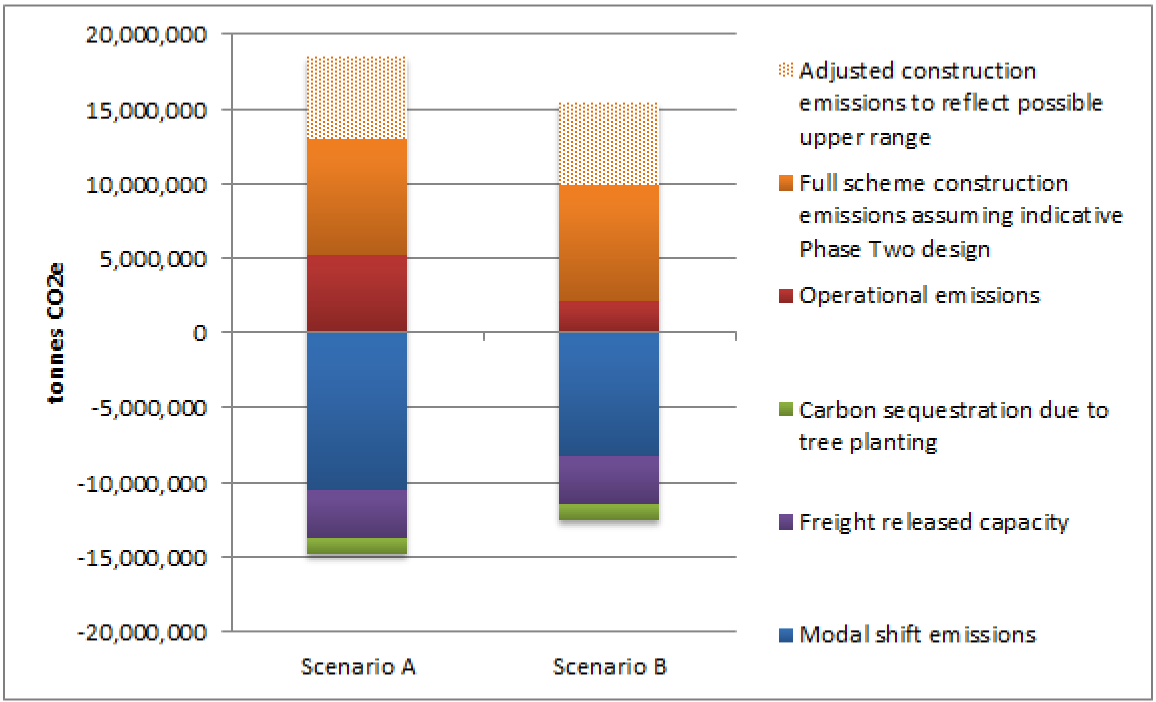
[33] http://www.dft.gov.uk/webtag/

[34] All data in $MtCO_2e$. Positive values represent additional emissions, -ve values represent emissions reductions. Totals may differ slightly due to rounding.

[35] See Section 4.5.

[36] A figure has been calculated for the Phase One Environmental Impact Assessment based upon an estimate of 2,000,000 trees that will be planted as part of the Phase One scheme only. The Phase One estimate is doubled to reflect a further commitment to planting 2,000,000 trees within Phase Two.

Figure 2 Carbon emissions for HS2 over the assessment period[37]



4.1.4. An important qualification for these results is that they reflect only the first 60 years of operation. Over its full 120 year design life, HS2 would continue to give rise to ongoing carbon reductions due to the net effect of its operations, as well as to carbon increases due to the natural cycle of maintenance, repair and replacement of the infrastructure. Assuming that these reductions and increases continue in line with trends for years 0-60, then over years 61-120, net reductions of around 7MtCO2e, could result, ensuring that HS2 over its design life would be carbon beneficial.

4.1.5. These results demonstrate the strong influence of the UK future carbon scenarios on the carbon emissions of the HS2 scheme. Under either set of alternative assumptions for the 60 year assessment period, the emissions of the HS2 scheme are positive (ie the scheme emits more carbon than it displaces). Further analysis is illustrated in subsequent sections.

4.2. Construction carbon

4.2.1. Construction carbon emissions are largely due to the use of high energy bulk materials such as steel and concrete (often referred to as embedded emissions), and highly energy-intensive construction processes such as tunnel boring. Estimates of embedded carbon associated with concrete and steel have been calculated using projected future emission factors for these materials, pertaining at the time of construction. These projected future factors have been derived in discussion with representatives of the industries concerned.

4.2.2. The results of estimating construction carbon emissions for the scheme are summarised in **Table 2**.

[37] Carbon emissions **above** the zero line represent additional emissions, whereas those **below** the zero line are reductions

Table 2 Estimated construction carbon emissions

Source of emissions	ktCO2e
TOTAL PHASE ONE	**5,590**
TOTAL PHASE TWO	**2,180**
ADJUSTED PHASE TWO	**7,700**
OVERALL TOTAL	**7,770 to 13,290**

4.2.3. Based on the assessment methods used, the Phase One construction carbon was found to be relatively larger than the equivalent measure for Phase Two, despite having a shorter track length. There are certain design factors which would result in larger construction carbon emissions on Phase One, notably the greater extent of tunnel. However, this discrepancy has highlighted some limitations in the construction carbon assessment method for Phase Two due to its less refined and detailed design proposals and associated construction information. In particular, the Phase One assessment has been able to include:

- a more comprehensive range of materials, including glass, plastics, and other non-bulk materials;
- specified construction activities, for which required plant are defined;
- additional factors based on the defined scheme footprint, including changes in land use; and
- a refined estimation of bulk material requirements which includes better defined infrastructure requirements.

4.2.4. As a result, the estimated construction carbon emissions have been adjusted for Phase Two using representative factors such as tunnel distances and track lengths to give the adjusted construction carbon figure presented in the table. Taken together these construction carbon emissions for the scheme are estimated to be about 13.3MtCO_2e.

4.2.5. An understanding of the relative contribution to the construction carbon of the different scheme elements for Phase One, and the different materials for Phase Two will nevertheless help HS2 Ltd to focus attention on where emphasis should be placed in seeking carbon efficiencies as the scheme progresses. The large proportion of construction emissions embedded through the use of steel and concrete, and the logistics involved in the transportation of bulk construction material and excavation material suggest that there remain opportunities for reducing carbon emissions during the construction process. Some examples of these opportunities are shown in **Box 2**.

Box 2 Carbon efficiency opportunities in HS2 construction

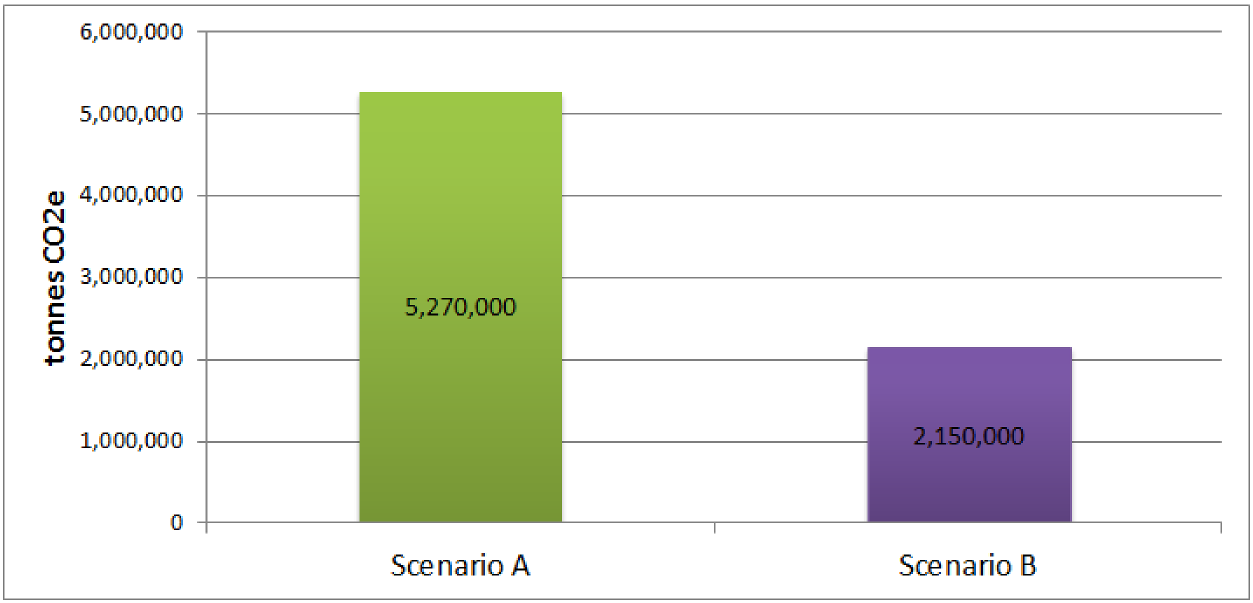
- Increased use of recycled materials (particularly steel).
- Use of less carbon-intensive concrete blends.
- Improved design and construction of rolling stock to reduce weight where possible.
- Maximum management and re-use of excavated material in the construction process, for landscaping and other mitigation measures.
- Adoption of efficient logistics management for transport of construction materials and excavated material.
- Adoption of construction workers travel plans to encourage use of sustainable modes of transport to construction sites.
- Maximisation of materials transport via rail rather than road.
- Energy efficiency in site management and transport.
- Adoption of resource efficiency measures to tackle inefficiencies across supply chains, overuse of resources (e.g. materials, energy and water) and waste generation.

4.2.6. It is clear that the construction carbon within HS2 is a key factor in the scheme's overall performance. However, the carbon figures reported in this study are set against a background of nil construction carbon in the absence of HS2. This is not a fair reflection of the status quo. Were HS2 not to proceed, other transport initiatives would be necessary to seek to address (albeit less effectively) the current and emerging transport challenges upon which HS2 is predicated. These other schemes would have their own carbon implications. Against this context, the relative construction carbon impacts of HS2 would be significantly less.

4.3. Operational carbon

4.3.1. The operation of HS2 trains would result in carbon emissions through demand for electricity. The scale of these emissions varies greatly according to the UK future carbon scenario assumed, with Scenario A predicted to give rise to 5.27MtCO_2e and scenario B to 2.15MtCO_2e. This is illustrated in **Figure 3**.

Figure 3 Operational emissions of HS2



4.3.2. As the carbon efficiency of UK grid electricity increases, contributions from HS2 operational carbon emissions decrease. There is likely to be scope for innovations in design and energy management in the operation of HS2 trains leading to reductions in operational carbon emissions, as shown in **Box 3**.

Box 3 Carbon efficiency opportunities in HS2 operation

- Improved aerodynamic design of HS2 rolling stock
- Reduction of rolling stock weight
- Drive style management and/or automatic train operation (consistent, optimal use of energy throughout journey)
- Better management and control of infrastructure and rolling stock auxiliary (non-traction) power usage
- Changes to speed profiling / improved fleet operation control and timetabling
- Opportunities for local renewable energy generation associated with stations and depots

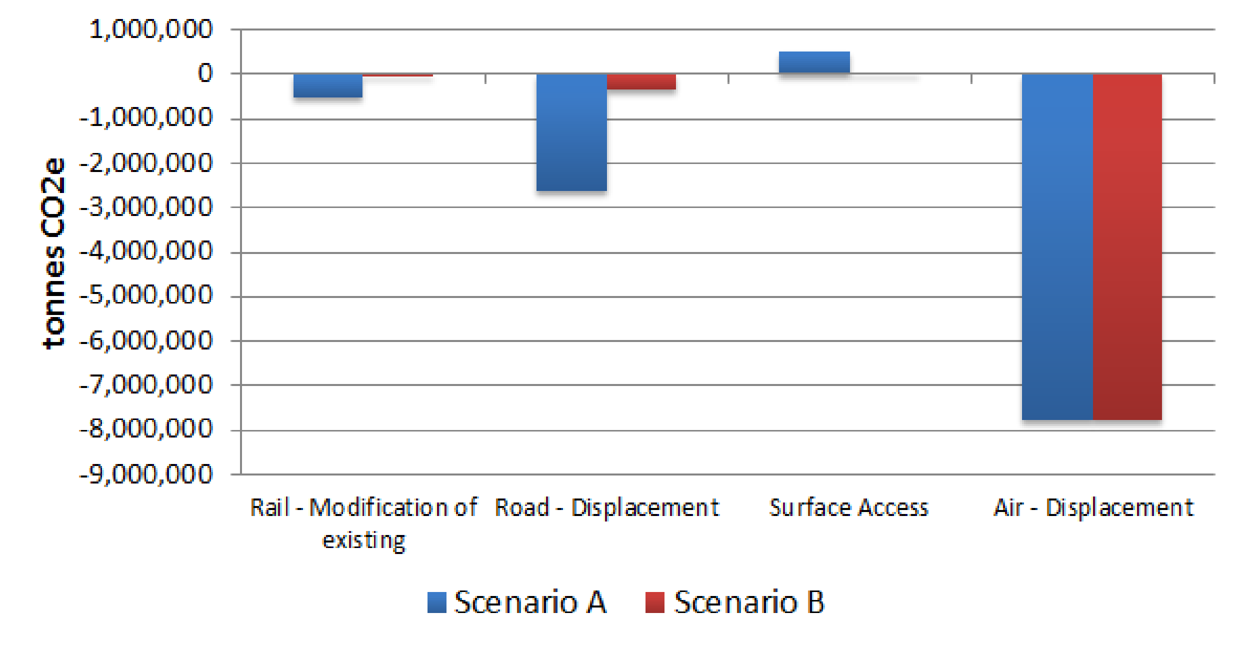
4.4. Modal shift carbon

4.4.1. The operation of HS2 would lead to modal shift changes in carbon emissions associated with the displacement of journeys on alternative transport modes. These changes have been assessed using the methods described in Annexes B & C. The results of these assessments under each of the UK future carbon scenarios are shown in **Table 4** and **Figure 4**.

Table 4 Modal shift carbon emissions for HS2 ($MtCO_2e$)

Mode Type	Scenario	
	A	B
Domestic aviation[38]	- 7.80	- 7.80
Classic rail services	- 0.53	- 0.07
Long distance road	- 2.63	- 0.38
Road access journeys	+ 0.48	+ 0.04
TOTAL	**- 10.49**	**- 8.21**

Figure 4 Contribution of modal shift emissions



4.4.2. A complex picture emerges from these modal shift results. Firstly, it can be seen that – under each UK future carbon scenario – modal shifts would lead to a substantial reduction in net carbon emissions from the scheme. The only potential additional emissions would be from road journeys to access HS2 stations, but these are small in comparison to the anticipated emissions reductions arising from the anticipated shift away from long distance road journeys due to HS2.

4.4.3. The results for each of the three modes - classic rail, passenger road transport and aviation - are considered in turn.

[38] The aviation modal shift carbon values presented in **Table 4** takes account of emissions of carbon dioxide, methane and nitrous oxide from aviation at altitude, and the additional climatic change factors that arise from factors such as water vapour and contrails.

Classic rail

4.4.4. There is a small difference between the anticipated carbon emissions reductions arising from classic rail modal shift under the two UK future carbon scenarios. The assumed future composition (diesel / electric split) of the classic rail fleet is the same under each scenario and the differences observed here arise due to alternative assumptions on the long-term (post-2050) carbon intensity of the UK electricity grid.

Long-distance passenger road transport

4.4.5. There are significant differences between the two UK future carbon scenarios for this mode. These arise from assumptions over the rate of uptake of ULEV (electric vehicles) and over the long-term carbon intensity of the UK electricity grid. For Scenario B, a much higher uptake of ULEV over time and a lower long-term grid electricity factor results in HS2 displacing significantly lower emissions from this mode than under Scenario A.

Aviation

4.4.6. Both of the UK future carbon scenarios use DfT data arising from the most recent aviation projections publication[39] to establish appropriate time-varying emissions factors, and so generate identical results. The central DfT projections have been used to derive these estimates.

4.4.7. The aviation modal shift carbon values presented in **Table 4** takes account of emissions of CO_2, methane and nitrous oxide from aviation at altitude, and the additional climatic change factors that arise from factors such as water vapour and contrails. Such additional and accentuated effects can be accommodated through the use of a multiplier applied to the standard emission estimates.

4.4.8. The appropriate value to apply as a multiplier is subject to uncertainty, but has been previously estimated by the Intergovernmental Panel on Climate Change (IPCC) to be within the range 2 – 4. Current best evidence and Defra guidelines suggest the application of a factor of 1.9[40], which is the multiplier used within this assessment.

4.4.9. Although there has been some concern voiced about how HS2 could, by liberating airport slots used for domestic flights, bring about an increase in long-haul (more carbon emitting) flights, it is important to recognise that the reallocation of slots is a commercial matter, primarily for the airlines. Factors that might influence the future use of slots could include passenger demand, airport capacity issues, agreements with airport operators and other local commercial considerations at the time.

4.5. Released capacity

Concept and calculation approach

4.5.1. This assessment has considered the secondary freight 'released capacity' carbon impacts from HS2[41]. Released capacity arises where the transfer of journeys to high speed rail frees up space on the existing network of roads and railways. It concerns the way that this space is then used by people and the train and freight operating companies, and what the carbon effect of this would be, based upon freight service changes on the existing rail network.

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[39] 'UK Aviation Forecasts', Department for Transport (January 2013)

[40] 2012 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting', (May 2012); derived from Sausen R et al, (2005) http://elib.dlr.de/19906/1/s13.pdf

[41] 'Released capacity' could arise on existing rail lines, principally the West Coast Main Line (WCML), because of changes in train services as passengers shift to the high speed alternative. This 'released capacity' may lead to a carbon benefit if road freight traffic switches to conventional rail, since the latter typically has substantially lower carbon emission factors than road freight transport.

4.5.2. Released capacity would arise – particularly on the WCML - because of reductions in passenger services as people opt to use the high speed alternative. Accordingly, it has been assumed that, to maintain a level of connectivity between places along the route that are not serviced by HS2, freed paths on the classic network will be prioritised for passenger services. However, even after the passenger service level is maintained, capacity remains available for freight services.

4.5.3. In order to estimate potential carbon benefits, a set of assumptions has been used to define a future scenario for the freight released capacity on the WCML as a result of the HS2 network.

4.5.4. Calculation of the freight released capacity benefits has relied upon a variety of assumptions (see Annex B), each of which may effect a large range of values. Combining conservative assumptions, for freed rail space and for future emission factors for road and rail freight, suggests that carbon benefits would be in the order of 3.25MtCO_2e.

4.5.5. Further freight paths over this assumed number may become available during the course of timetable development or due to market demands. Less conservative assumptions, supposing twice as many additional freight paths, estimate potential carbon benefits for released capacity of up to 6.5MtCO_2e.

Other estimates of released capacity benefits

4.5.6. Other reports and statements[42,43,44] have highlighted the potential that released capacity may hold for benefitting HS2 carbon emissions, particularly in respect of freight operations. In addition, further work on the carbon implications of HS2 – including released capacity - has been undertaken by Greengauge 21[45].

4.5.7. Network Rail and Passenger Focus issued a joint report in 2012[46] that considered the future potential priorities for the WCML in the event that Phase One came to fruition. Although much of the report was concerned with the implications for the provision of future passenger services, the report did identify that prospective growth in freight demand across the WCML could conditionally be accommodated with Phase One in place.

4.5.8. This scale of potential benefits can be compared with those suggested by the latest Greengauge 21 report[46]. This suggests that Phase One of the scheme would lead to a 50% increase in carbon benefit relative to Greengauge's 'central case', arising from utilisation of released train paths on the WCML.

European experience

4.5.9. The UK is not alone in considering the potential carbon and other benefits of released capacity. France implemented its first high speed rail (HSR) services 30 years ago, as a way to increase the competitiveness of rail against air travel. The first HSR line was developed between Paris and Lyon, leading to a significant reduction in air travel between those destinations. More recently, analysis of the case for the continuing extension of French high speed rail services are looking at benefits related to the potential increase in freight services that could be provided on the existing network. For example a proposed

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[42]Eg 'Rail Freight Needs HS2 as much as Passengers', letter from Tony Berkeley, RFG Chairman to SoS Philip Hammond, 28th September 2011.

[43]The Carbon Impacts of HS2' – Interim Report (Dec 2011). http://www.greengauge21.net/publications/carbon-impacts-of-hs2-interim-report/ '

[44] 'HS2 and Freight – A Hidden Benefit?', WSP (Nov 2012)

[45]' 'The Carbon Impacts of HS2' (September 2012), Greengauge 21

[46] 'Future priorities for the West Coast Main Line: Released capacity from a potential high speed line', Network Rail / Passenger Focus (Jan 2012)

extension of high speed services from Tours to Poitiers is anticipated to lead to a 150% increase in freight services[47] between these cities over the period 2005 to 2025.

[47] LGV Sud Europe Atlantique – Tours-Angouleme: Utilite Publique (2007)

5. HS2 carbon emissions in context

5.1. Benchmarking HS2 carbon emissions

5.1.1. There is no officially recognised methodology or precedent for assessing the significance of GHG impacts of a large infrastructure project. For example, there are no accepted general standards for emissions from transport projects, or HSR projects in particular. A more general GHG emissions context is set by the UK's Climate Change Act and the EU ETS, as described within Annex A.

5.1.2. Nevertheless, it is still useful to benchmark HS2's performance against other significant transport infrastructure and other construction schemes[48], and within the context of the UK's GHG emissions.

5.1.3. Benchmarks of HS2's performance have been developed for emissions per passenger kilometre (p-km) and for the contribution of HS2 to UK national emissions, as described further in Annex D.

5.1.4. These benchmarking exercises show that:

- HS2's anticipated carbon emissions per p-km at 2030 would be lower than other transport modes;
- projected HS2 carbon emissions per p-km over longer timescales will continue to be more favourable than most alternative modes (illustrated in **Figure 5**), assuming that the UK meets its electricity decarbonisation trajectory; and
- the HS2 scheme carbon direct emissions - for annualised construction and operation (not taking account of any modal shift reductions) compared to projected annual UK emissions shows that annualised GHG emissions arising from HS2 represent 0.06% of the UK's annual GHG emissions and also about 0.25% of the UK's transport emissions (see **Figure 6**).

[48] A recent carbon assessment for the Thames Tideway Tunnel ('Energy and Carbon Footprint Report, Jan 2013) is an example of the increasing emphasis placed on this issue within major infrastructure projects.

Figure 5 - Carbon emissions per passenger kilometre at 2030[49]

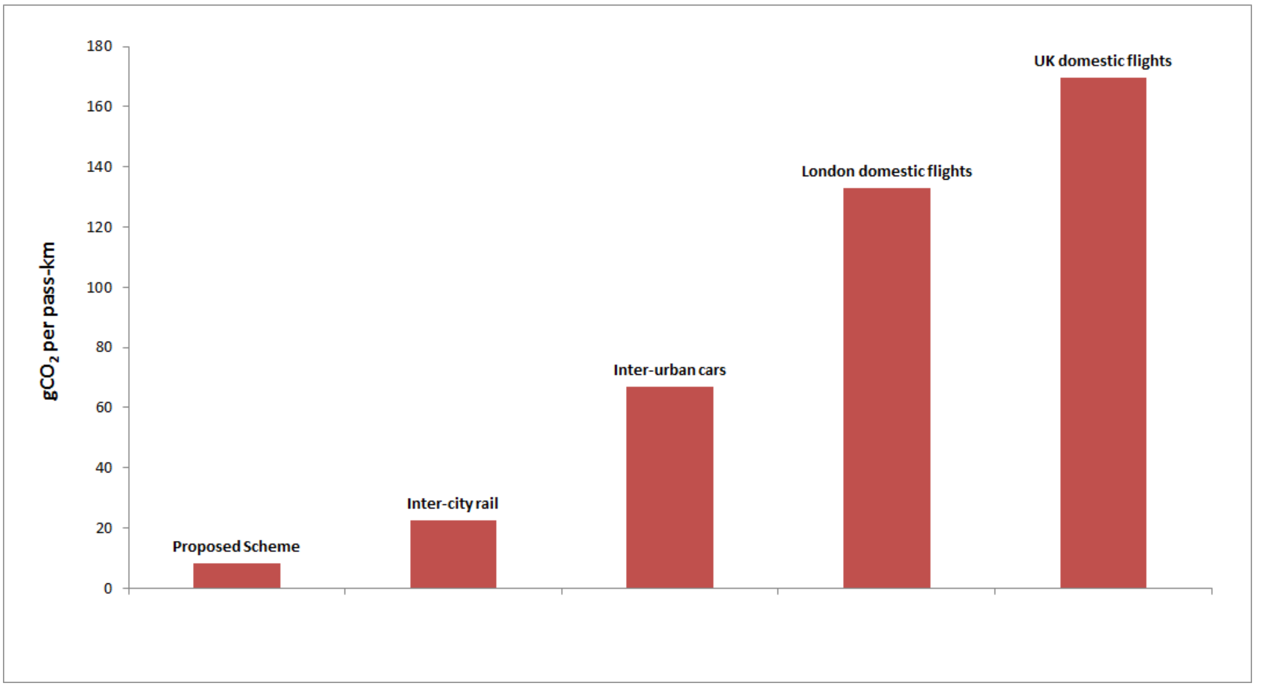
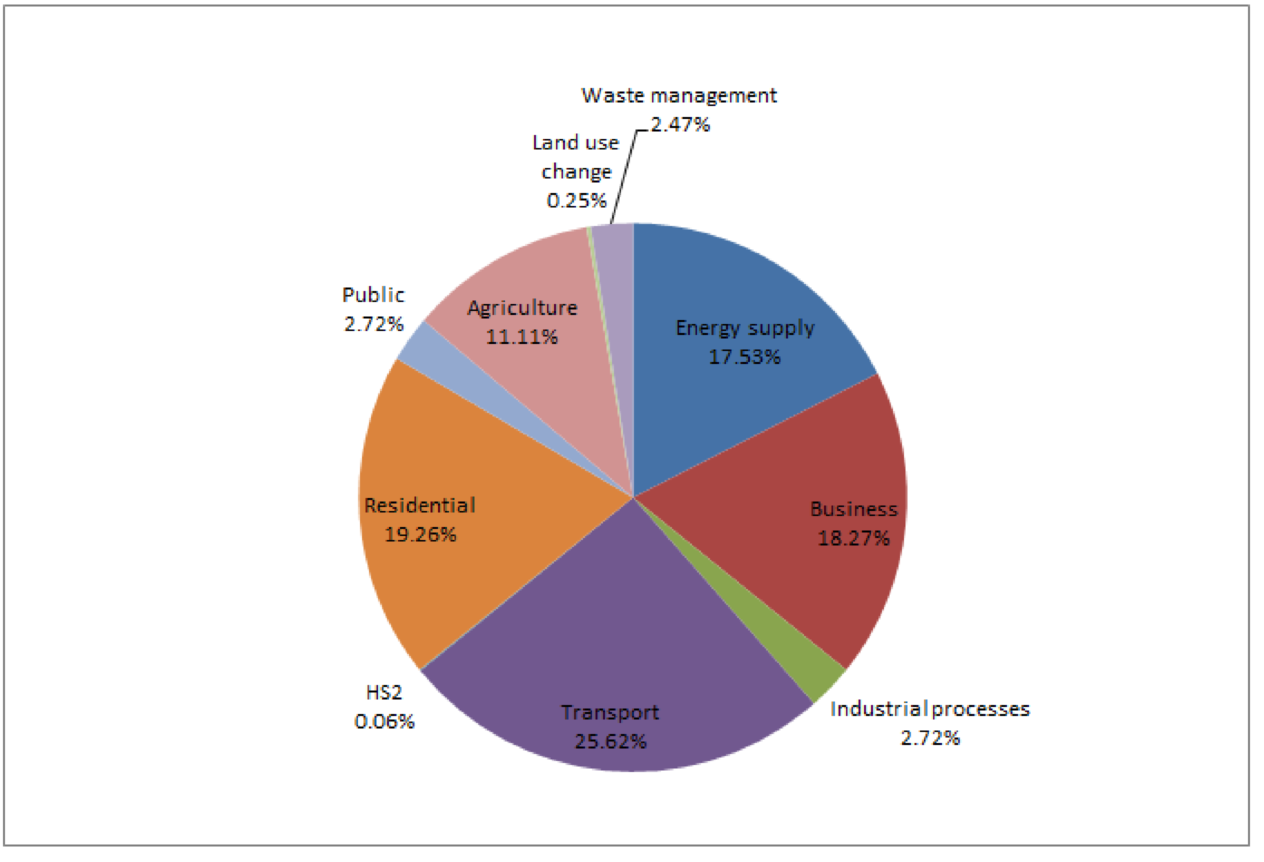


Figure 6 - HS2 annualised emissions compared to UK projected emissions in 2030[50]



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[49] 2030 is the nearest date to Phase Two scheme opening where forecast data has been assessed, during which time Phase One will be operational. In addition, it should be noted that the intercity rail forecast is for the entire classic network, including the predicted mix of both diesel and electric trains in 2030, data provided by DfT.

[50] 'Updated Energy and Emissions Projections 2012', DECC (October 2012) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65717/6660-updated-emissions-projections-october-2012.pdf - Data from Table 3.1. 2030 is the nearest date to Phase Two scheme opening where forecast data has been assessed, during which time Phase One will be operational.

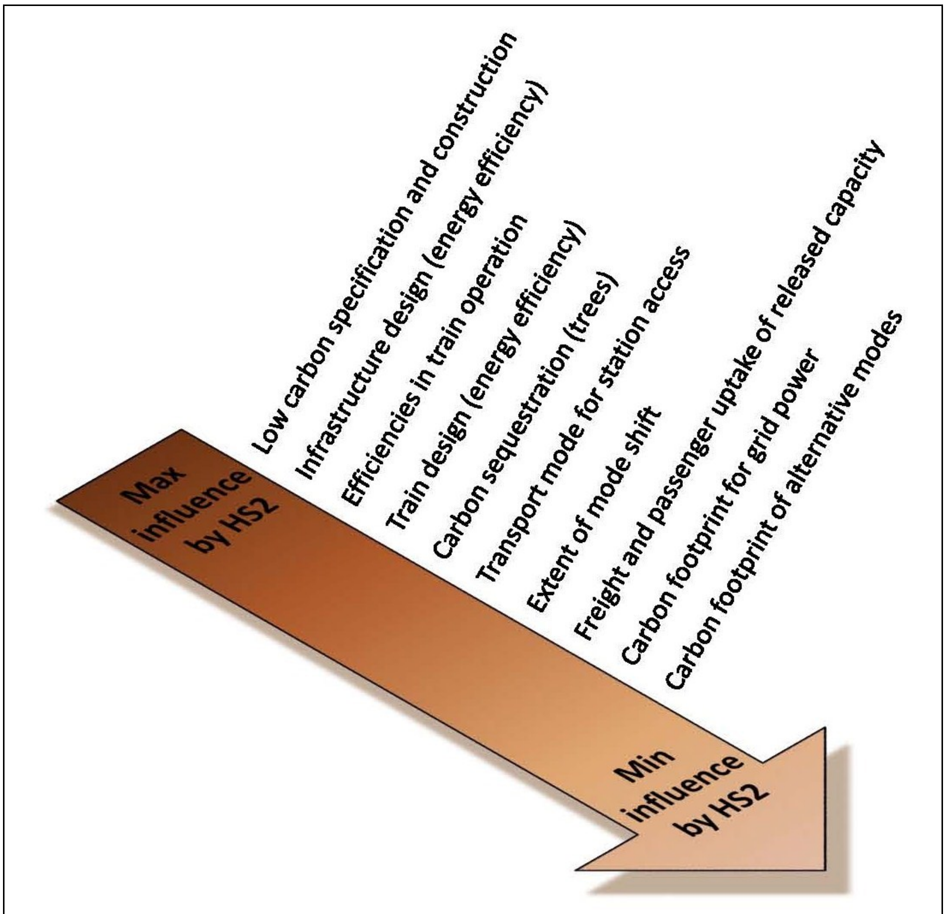
5.2. Carbon – traded vs. non-traded

5.2.1. Most of the carbon emissions arising from HS2 would arise from activities that fall within the EU's Emissions Trading System (EU ETS[51]). This scheme operates at an EU-wide level and sets a steadily decreasing cap on total carbon emissions within the traded sector, thereby ensuring that emissions are reduced overall through measures such as efficiency improvements and adoption of new carbon-efficient technologies. The consequence of this is that the majority of HS2 emissions (along with other emissions covered by the EU ETS) are subject to an overall Europe-wide carbon emissions cap which cannot be exceeded. Moreover, by drawing in activities covered by the EU-ETS (e.g. shifting emissions to electrically-powered rail transport), it allows for a more effective control of emissions at an EU level.

5.3. Influences on HS2's carbon assessment

5.3.1. There are a number of factors affecting the carbon emissions from or associated with HS2. The varying influence that HS2 has on these is illustrated in **Figure 7**.

Figure 7 - HS2 Ltd's influence and control over carbon emissions will vary for different factors



[51] The main exception to this being combustion of liquid fuels within road and classic rail transport.

5.3.2. Each factor has the potential to affect the scheme's carbon emissions. These factors will be dependent on HS2 Ltd internal policies (over which it has direct influence) and external policies over which HS2 Ltd has less influence. For example, the extent of modal shift is dependent on the attractiveness both of HS2 and of the alternative modes of travel.

5.3.3. HS2 Ltd will use the ambition set out in the Sustainability Policy, across the factors within its influence, to influence carbon performance, for example the controls set out in the Code of Construction Practice (CoCP).

6. Conclusion

6.1.1. The carbon assessment has been undertaken to understand the potential carbon impacts of HS2. This is a complex process that relies on numerous factors, some under the direct influence of HS2, some not, and all with various degrees of uncertainty given the long period over which the scheme will operate and the difficulty in knowing how the transport and power sectors will perform over this time.

6.1.2. Over the construction and the first 60 years of operation of HS2, it is likely that carbon savings - that come about as people switch from other transport modes with higher carbon emissions, and as released capacity on existing railways is taken up by new passenger and freight services at the expense of road vehicles – will be less than the carbon emissions, resulting largely from the construction phase. This will depend on the final design for the scheme which for Phase Two is currently at a preliminary level of detail in advance of the first round of public consultation. However, these carbon emissions would be negligible in comparison with emissions from the UK transport sector as a whole (around a quarter of one per cent).

6.1.3. Over the full lifetime of the scheme, assumed to be 120 years, HS2 would continue to give rise to net carbon reductions from its operations, as well as to carbon increases due to ongoing maintenance, repair and replacement of infrastructure. As a result, the overall carbon trend for HS2 could be a net carbon reduction over its design life, even if the higher value of construction emissions is assumed.

6.1.4. In practice, if HS2 did not proceed, other strategic transport alternatives would be required to seek to address the current and emerging transport challenges, each with their own carbon impacts. These alternatives have not been considered as part of this study. However, in comparison with most other transport modes, high speed rail offers some of the lowest carbon emissions per passenger-kilometre, and significantly less than cars and planes. Furthermore, most of the carbon emissions due to HS2 would arise from activities that fall within the EU ETS and would therefore be limited and gradually reduced.

6.1.5. In addition to these overarching conclusions, the assessment has identified the relative carbon impacts of different aspects of the scheme. This is being used by HS2 Ltd to better understand how carbon can be reduced through the life of the project. HS2 Ltd has adopted a *Sustainability Policy*, which seeks to minimise the carbon footprint of HS2 and deliver low carbon long distance journeys that are supported by low carbon energy.

Glossary

Carbon Model	A series of linked spreadsheets used to assess the carbon implications of the 'Y' network
CCC	Committee on Climate Change
DECC	Department of Energy and Climate Change
Design Life	The period of time for which elements of the scheme will last before requiring significant or complete replacement
DfT	Department for Transport
ECML	East Coast Main Line
EIA	Environmental Impact Assessment (of HS2 Phase One)
EU ETS	European Union (carbon) Emissions Trading System
GHGs	Greenhouse Gas (emissions)
HS1	The existing High Speed rail link from London to the Continent
HS2	The complete HS2 scheme, from London to Manchester & Leeds and beyond
HS2 Phase One	The London to West Midlands section of the HS2 scheme
HS2 Phase Two	The West Midlands to Manchester and Leeds sections of the HS2 scheme
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land use, land use change and forestry
MML	Midland Main Line
$MtCO_2e$	Millions of tonnes of CO_2 equivalent
Mode shift	Changes in travel patterns on other transport modes, due to the existence of the HS2 scheme
NAEI	National Atmospheric Emissions Inventory
p-km	Passenger – kilometre
Released Capacity	The space provided for new services on the classic rail network (or for cars on the road network) arising from the implementation of the HS2 scheme. Transfer of road freight to this freed capacity is likely to lead to carbon benefits
TBM	Tunnel Boring Machines
ULEV	Ultra-Low Emission Vehicles
WCML	West Coast Main Line
WebTAG	A suite of documents and methods that together represent the UK Department for Transport's guidance on appraising transport projects and proposals

Annex A

Summary of Climate and Greenhouse Gas Emissions Policy Context

A1.1.1 The latest Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR5) was published on the 27th September 2013. The IPCC strengthened its statement on human induced climate change from being 90% certain in the last assessment report in 2007 to 95% certain in AR5. The IPCC now also states that it is extremely likely that humans have been the dominant cause of observed warming since the mid-20th century. The IPCC states in AR5 that atmospheric CO_2 has increased by 40% to 391ppm (2011) since preindustrial times.[1]

A1.1.2 The United Nations Framework Convention on Climate Change (UNFCCC) (1992) established an overall framework for intergovernmental efforts to address global climate change.

A1.1.3 The Kyoto Protocol to the UNFCCC, adopted in 1997, provided legally binding limits on GHG emissions for 37 Annex 1 countries[2] originally up until 2012. Recent negotiations at the 18th Conference of the Parties (Cop) of the UNFCCC in Doha on the future of international cooperation on climate change have resulted in the European Union (EU), Australia, Switzerland, and Norway agreeing to a second commitment period of the Kyoto Protocol from January 2013 to the end of 2020. The EU's current pledge of a 20% cut in emissions from 1990 levels by 2020 under the Protocol may be extended to 30% if other parties show an appropriate level of ambition[3]. It was agreed at Cop 17 (Durban, 2011) that a new international treaty[4] will come into force after 2020.

A1.1.4 The EU Emission Trading System (EU ETS) is an EU-wide cap-and-trade mechanism whereby a total amount of allowable annual GHG emissions for electricity generation, large energy-intensive industries (such as steel and aluminium production) and commercial flights to and from the EU and the three EEA-EFTA states (Norway, Lichtenstein and Iceland) has been agreed at the EU level. This will also include Croatia from January 2014[5]. Those companies within the industries covered by the cap are allowed to trade emission allowances[6] with one another. Owners of the affected installations can also buy limited amounts of international credits from emission-saving projects around the world though a scheme known as the Clean Development Mechanism (CDM).

[1] IPPC Working Group 1 (2013) Summary for Policy Makers. http://www.climatechange2013.org/images/uploads/WGIAR5-SPM_Approved 27Sep2013.pdf ; Accessed 30 September 2013

[2]Annex I Parties include the industrialised countries that were members of the Organisation for Economic Co-operation and Development in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States. http://unfccc.int/parties_and_observers/items/2704.php; Accessed March 2013.

[3] UNFCCC *Appendix I - Quantified economy-wide emissions targets for 2020.* http://unfccc.int/meetings/copenhagen_dec_2009/items/5264.php;Accessed December 2012

[4] This new comprehensive international treaty is to be negotiated no later than 2015. https://www.gov.uk/government/policies/taking-international-action-to-mitigate-climate-change/supporting-pages/negotiating-for-a-comprehensive-global-climate-change-agreement;Accessed: 16 April 2013

[5] International flights to and from countries outside the EU (are) included in the scheme, but as a "goodwill gesture" the application of the scheme to international flights has been deferred as long as certain conditions are met, to enable a global agreement on aviation to be reached by October 2013. http://ec.europa.eu/clima/policies/transport/aviation/index_en.htm accessed 11 September 2013

[6] One allowance equals one tonne of CO_2e. Allowances can either be allocated freely or auctioned by governments

A1.1.5 The emissions cap for 2013 from power stations and other activities covered by the EU ETS (excluding aviation) is set provisionally at 2,039,152,882 allowances[7] (tonnes of CO_2e). In each subsequent year after 2013, the total number of allowances issued will decrease by 1.74% of the average number of allowances issued between 2008 and 2012. This will mean that each year there will be an absolute reduction of 37,435,387 allowances. This will result in there being 21% less emissions (within the cap) in 2020 than in 2005. The annual reduction in the cap is set to continue after 2020, but will be revised before the end of 2025.

A1.1.6 The current price of allowances is very low due to slower economic growth in the EU leading to lower demand combined with member states largely allocating allowances at zero cost rather than auctioning them. In order to address the exceptionally low price of allowances the European Parliament's Environment Committee has adopted a position called 'backloading' which involves postponing the auctioning of new allowances by one year (2014-2015). This should reduce some of the supply and thus slightly increase the price. This proposal was approved by the European Parliament in July 2013. Talks with the European Council have now been opened to progress the implementation of the backloading proposal[8].

A1.1.7 The European Commission has issued pilot guidance on *Integrating Climate Change and Biodiversity into Environmental Impact Assessment*[9] to improve the systematic integration of both biodiversity and climate change within EIA. It states that the direct GHG emissions from construction, operation and perhaps decommissioning should be considered as well as from land use, land use change and forestry. Indirect impacts might include increased energy demand, supporting infrastructure/activities and personal travel and freight transport.

A1.1.8 The 2011 White Paper *Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system*[10], states that transport policy must be resource and energy efficient. The White Paper's goal is "to help establish a system that underpins European economic progress, enhances competitiveness and offers high quality mobility services while using resources more efficiently". The White Paper states that curbing mobility is not an option. For high speed rail, the objective by 2050 is to "complete a European high-speed rail network, triple the length of the existing high-speed rail network by 2030 and maintain a dense railway network in all Member States. By 2050 the majority of medium-distance passenger transport should go by rail".

A1.1.9 The Climate Change Act (2008) establishes a framework for the UK to achieve its long-term goals of reducing GHG emissions by at least 80% from 1990 levels by 2050 and to ensure that steps are taken towards adapting to the impact of climate change. An interim target of 34% reduction from 1990 by 2020 has also been agreed.

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[7] http://ec.europa.eu/clima/policies/ets/cap/index_en.htm; Accessed April 2013.

[8] Online http://ec.europa.eu/clima/policies/ets/reform/index_en.htm; Accessed 11 September 2013

[9] Integrating Climate Change and Biodiversity into Environmental Impact Assessment (2013) http://ec.europa.eu/environment/eia/pdf/EIA%20Guidance.pdf ; Accessed on; 11 September 2013

[10] 2011 White Paper Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system [online] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52011DC0144:EN:NOT. Accessed August 2013.

A1.1.10 *The Carbon Plan* (2011)[11] sets out the Government's plans for achieving the GHG emissions reductions committed to in the Climate Change Act and the first four carbon budgets. Low carbon transport is an essential part of the *Carbon Plan*. The Plan states that rail travel will become substantially decarbonised through increasing electrification and the use of more efficient trains and lower carbon fuels. The Plan also mentions that the high speed rail network being developed by HS2 "will transform rail capacity and connectivity to promote long term and sustainable economic growth". Furthermore, the Plan notes that further electrification of the rail network will support low carbon modal shift in the future. In addition the freight sector will have found lower carbon ways of working, such as modal shift to rail and water.

A1.1.11 In 2011 (the latest figures available), the UK's progress against its Climate Change Act targets was a reduction of 29.1% (i.e. 549,200,000 tCO_2e) from 1990 levels excluding the effects of emissions trading[12]. In terms of overall UK emissions, transport accounted for 134,800,000 tCO_2e (25%) and rail for 4,400,000 tCO_2e (less than 1%).

A1.1.12 Carbon budgets were introduced as part of the Climate Change Act 2008. The first four 5-year budgets have been set in law from 2008-2027. The budgets are split into traded and non-traded carbon. A limit on UK carbon emissions is imposed for each five-year period. The budgets are prepared by the Committee on Climate Change who were set up under the Climate Change Act as an independent evidenced advisory body to the UK Government and parliament. The Fourth Carbon Budget (2010) [13] was accepted by parliament and covers the period 2023-2027, which includes the Proposed Scheme's opening year (2026). The key recommendations for this budget include:

- The need for the UK to be on a pathway to at least an 80% cut in greenhouse gases below 1990 levels by 2050, with maximum 2050 emissions of 160,000,000 tCO_2e;
- By 2025 annual UK emissions should be reduced to around 390,000,000 tCO_2e (a 50% reduction relative to baseline levels);
- Although domestic aviation and shipping emissions are included in the budget, international aviation and shipping are currently not.

A1.1.13 The Government legislated for the fourth budget in June 2011 with a budget for 2023-27 of 1,950,000,000 tCO_2e.

[11] The Carbon Plan (2011) https://www.gov.uk/government/publications/the-carbon-plan-reducing-greenhouse-gas-emissions--2 ; Accessed 11September 2011

[12]2011 final UK figures: data tables. https://www.gov.uk/government/publications/final-uk-emissions-estimates, Accessed April 2013.

[13] Committee on Climate Change (Dec 2010) The Fourth Carbon Budget. Reducing emissions through the 2020s http://www.theccc.org.uk/publication/the-fourth-carbon-budget-reducing-emissions-through-the-2020s-2/; Accessed 01 October 2013

A1.1.14 In its supporting evidence for the Fourth Carbon Budget submission[14], the Committee on Climate Change views HS2 as being an important part of the UKs low carbon transport strategy as it has the potential to replace domestic and short-haul aviation. The Committee on Climate Change states "we assessed a maximum potential emissions reduction of 2 $MtCO_2$ annually through switching from aviation to high-speed rail, with two caveats that this would require a low-carbon electricity system, and would also need complementary levers ".

A1.1.15 *The Industrial Strategy*[15] sets out a partnership approach between government and the construction industry to “become dramatically more sustainable through its efficient approach to delivering low carbon assets more quickly and at a lower cost, underpinned by strong, integrated supply chains”. By 2025, the construction industry and government aspire to achieve a 50% reduction in GHG emissions in the built environment[16]. This will be achieved through resource efficiency and adapting the built environment to deal with the effects of climate change; in particular, by developing plans to drive carbon out of the built environment, led by the Green Construction Board. In terms of infrastructure, the Strategy recognises that less capital carbon can equate directly to less capital cost.

[14] Ibid

[15] Construction 2025 (2013) Industrial Strategy: government and industry in partnership. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/210099/bis-13-955-construction-2025-industrial-strategy.pdf; Accessed August 2013.

[16] Versus a 1990 baseline. This is set out in the Green Construction Board’s Low Carbon Route map for the Built Environment.

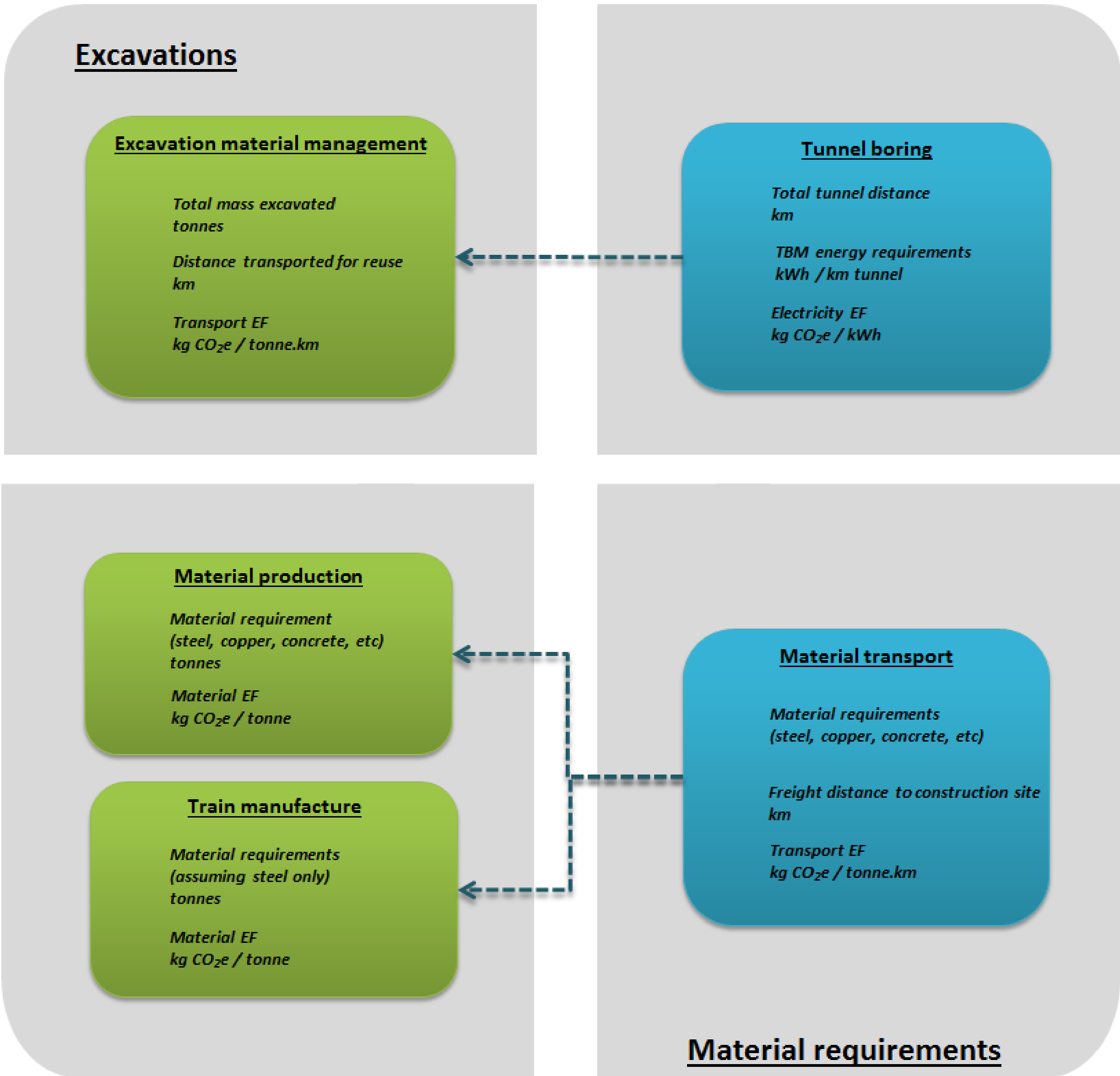
Annex B

Carbon Estimation Methods, Scenarios, Assumptions & Limitations

B.1. Summary method

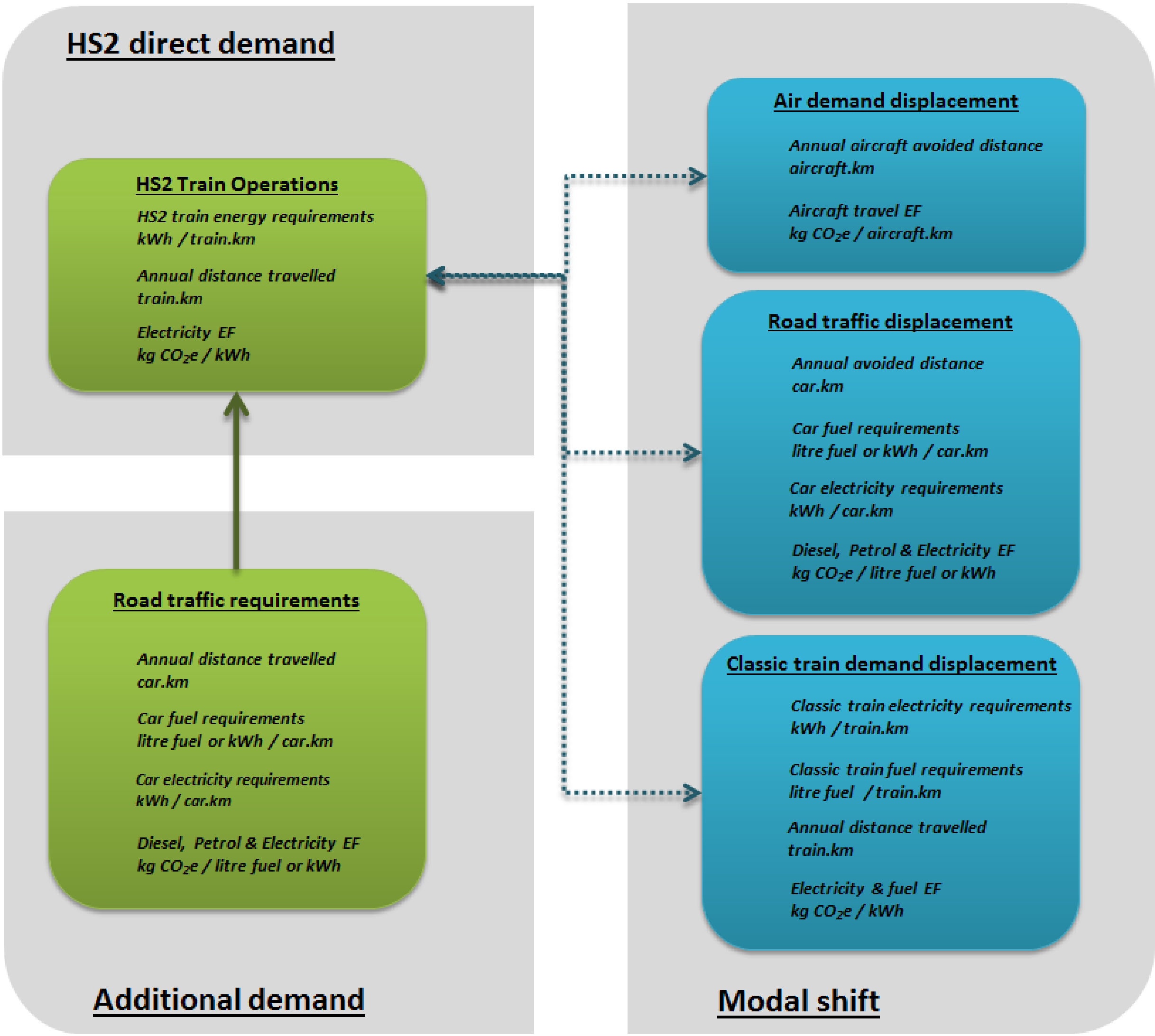
B1.1.1. Figure 1 and Figure 2 illustrate the methods adopted respectively for estimating carbon emissions from the construction and operation of the indicative Phase Two design. Detail on the assessment of construction carbon for Phase One followed a different method since it was able to use a more detailed design and set of construction assumptions. This is reported within the Phase One EIA carbon report[17] although the key differences are described in Annex B5.

Figure 1 – Methodology for estimation of construction carbon



[17] Section 5 of Volume 3 (Route-wide effects) of the Phase One Environmental Statement

Figure 2- Methodology for estimation of operational carbon



B.2. Scenarios and sensitivity assessments

B2.1.1. To try and address uncertainty, the carbon assessment has used scenarios to illustrate two possible futures, with each accommodating a number of different assumptions about the way carbon emissions may change over time. The first scenario (Scenario A) uses many of the same assumptions that are used by - and reflected in the Economic Case for HS2. The second scenario (Scenario B) uses assumptions contained within the Fourth Carbon Budget produced by the Committee on Climate Change. This tends to be more ambitious in its portrayal of future carbon reductions with, for example, a greater proportion of power generated from renewables and higher uptake of cleaner road vehicles.

B2.1.2. In addition to these future carbon scenarios, a number of sensitivities have been defined to explore the effect of alternative assumptions on the carbon assessment.

B.3. HS2 demand modelling

B3.1.1. Activity data used for estimating modal shift emissions are an important aspect of this assessment. These rely on an integrated modelling tool - the Planet Framework Model (PFM)[18] - used by HS2 Ltd (as well as on major transport schemes generally) to gauge the extent to which people opt to use HS2 services, and how this affects people's use of other transport modes.

B3.1.2. The PFM forecasts demand across rail, road and air, taking into account a range of factors that impact travel behaviour such as journey time, train service frequency, interchange (both between modes and within modes), crowding, and station access/egress times.

B3.1.3. Travel mode choices included in the PFM passenger demand modelling assessments are not considered to be dependent on carbon emissions (i.e. people do not generally tend to select their mode of transport on the basis of its carbon footprint). Therefore, key drivers for reducing HS2 operational carbon emissions are assessed independently of travel choices, based upon future policies and measures arising from the UK future carbon scenarios. This analysis can shed light on the policies and measures that may be most relevant to maximising the carbon benefit of HS2.

B.4. UK future carbon scenarios

B4.1.1. The UK has put in place a long-term strategy to decarbonise its economy. There is a clear policy and target-driven framework for this journey out to 2050[19] which, in the context of the assumed HS2 lifetime, provides a basis for one or more carbon scenarios that provide a backdrop to and direct influence on HS2's own carbon performance.

[18] Model documentation available at http://www.hs2.org.uk/news-resources/publications/economic-documents

[19] The principal targets and commitments framing this carbon-reduction journey are the Climate Change Act commitment requiring the UK to reduce its emissions of GHGs in 2050 by at least 80% relative to 1990, and the four UK carbon budgets that cover the period 2008 – 2027.

B4.1.2. Publications such as the UK's Carbon Plan[20], and the CCC's supporting evidence for the Fourth Carbon Budget[21], set out possible routes for the UK to achieve its carbon targets. They outline the relative carbon contributions from different sectors of the economy and the nature of the changes that are likely to be required in the carbon performance of these sectors.

B4.1.3. The carbon performance of the full HS2 scheme is determined by these possible carbon futures. This study has defined two scenarios, both of which are compatible with the Carbon Plan, to explore the effect of future assumptions. These scenarios and assumptions are defined in outline below, and more fully in Table 1 and *Error! Reference source not found.*.

B4.1.4. **Scenario A:** The determination of the economic case for HS2 involves, inter alia, the valuation of carbon emission consequences. These methods require the application of emissions factors to changes in classic rail and road passenger vehicle distances, and also future projections of the mix of vehicle types for these sectors. The factors are set out in DfT documentation[22], which reflect variations over a timeline up to 2050. These assumptions have been used within Scenario A.

B4.1.5. **Scenario B:** In its supporting evidence for the Fourth Carbon Budget submission[23], the CCC sets out a series of trajectories for future emissions factors associated with different sectors of the UK economy, such as the electricity generation sector and the road transport sector. These trajectories have been used to define Scenario B.

B4.1.6. It is also conceivable that the UK may over- or under-perform against its 2050 carbon targets. We do not represent these cases within this analysis, on the grounds that HS2 itself is unlikely to be the deciding factor in determining whether the UK meets its wider carbon targets.

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[20] 'The Carbon Plan: Delivering our Low Carbon Future', HM Government (December 2011)

[21] 'The Fourth Carbon Budget: Reducing Emissions through the 2020s', Committee on Climate Change (December 2010)

[22] http://www.dft.gov.uk/webtag/documents/expert/pdf/U3_3_5-ghg-120723.pdf

[23] Committee on Climate Change (Dec 2010) The Fourth Carbon Budget. Reducing emissions through the 2020s

Table 1 Comparison of the two scenarios used for the assessment

	Scenario A	Scenario B
UK grid electricity	UK grid electricity carbon efficiency improves by around 90% over the period 2025 to 2050 and thereafter stays the same	UK grid electricity carbon efficiency improves somewhat more rapidly than Scenario A and reaches a lower baseline figure
Uptake of electric vehicles	The proportion of electric passenger cars within the UK fleet increases to 5% by 2030 and thereafter stays the same	The proportion of electric passenger cars within the UK fleet increases rapidly to 100% by 2050
Conventional road passenger transport	The carbon efficiency of petrol and diesel passenger vehicles improves respectively by around 10% and 5% over the period 2010 to 2020 and thereafter stays the same	The carbon efficiency of petrol, diesel and electric passenger vehicles improves in line with CCC future assumptions
Electric passenger vehicles	The carbon efficiency of electric vehicles stays the same from 2010 to 2025, and then improves by around 95% by 2050 (reflecting the significant decarbonisation of UK grid electricity)	
'Classic' electric rail	The carbon efficiency of electric classic rail services improves in line with WebTAG projections	The carbon efficiency of electric classic rail services improves in line with CCC projections
'Classic' diesel rail	The emissions factors associated with classic rail diesel services do not change over time	
Composition of UK 'classic' rail fleet	The proportion of electric and diesel units within the UK classic rail fleet changes in line with assumptions prepared within the Economic Case for HS2	Not addressed by CCC, so Scenario A assumptions adopted
UK domestic aviation	Domestic aviation emission factors follow a time trajectory developed by DfT in support of the 2013 Aviation Forecasts, overlaid by sensitivities that illustrate the effect of varying aviation carbon efficiency	

B4.1.7. We assume that – under both scenarios – there is widespread and significant market intervention in pursuit of transport and carbon-related policy aims, although these interventions vary; for example through their respective reliance on taxation regimes, incentive mechanisms, and direct government investment and regulation. Our assumptions are that:

- The UK Carbon Budgets – and the UK's Climate Change Act commitment - are achieved;
- A very strong emphasis is placed upon modal shift to rail and to local low-carbon road transport. Short haul air traffic reduces due to the pressures of the EU ETS and there is a strong presumption in favour of long-haul rail freight.

B4.1.8. Illustrative policy measures considered likely to accompany these outcomes include:

- A taxation framework rewarding low-carbon travel choices, travel planning and travel minimisation;
- Maintenance of incentives for development and deployment of low carbon vehicles and associated infrastructure;

- Investment in transport hubs to facilitate low-carbon transport mode inter-connectivity;
- Support for land use planning systems that facilitate various low carbon objectives; and
- Support for integrated transport solutions.

B.5. Methodology for construction carbon

B5.1.1. Construction carbon represents the carbon emissions associated with construction of the rail infrastructure, the embedded carbon[24] within the bulk construction materials, the carbon emitted during transportation of construction materials to construction sites and the transportation of excavated material within and between sites for re-use and if necessary to landfill destinations. It also includes the embedded carbon from the construction of the rolling stock and the carbon arising from the use of high-energy consuming TBM.

B5.1.2. The appraisal of construction carbon has included the carbon impact of the construction phase of the HS2 scheme as described in the Sustainability Statement for Phase Two and the carbon assessment undertaken within the Phase One EIA[25].

B5.1.3. The approach used entails the following steps:

- Definition of emissions sources;
- Collation of activity data and appropriate emissions factors; and
- Estimation of the carbon impact.

B5.1.4. Details of the construction carbon for the Phase One elements of the scheme were taken directly from the parallel assessment undertaken for the EIA. The two workstreams involved frequent and regular consultation to ensure that working methods and assumptions were broadly in line, but accepting that the level of design detail was more advanced for Phase One and thus enabled greater definition and certainty of the material quantities, working methods and construction details.

B5.1.5. This highlighted a number of clear distinctions between the construction carbon figures for Phase One and Phase Two. In particular, the Phase One assessment has been able to include:

- a more comprehensive range of materials, including glass, cement, timber, glass fibre reinforced plastics, etc;
- specified construction activities, for which required plant are defined;
- additional factors based on the defined scheme footprint, including changes in land use and soil lime stabilisation requirements; and

[24] Embedded carbon is all carbon expended in the extraction and processing of materials up to the factory gate: Cradle to Gate. This definition applies to all the bulk construction materials.

[25] Section 5 of Volume 3 (Route-wide effects) of the Phase One Environmental Statement

- a refined estimation of bulk material requirements which includes better defined infrastructure requirements.

B5.1.6. To allow for the fact that the Phase Two construction carbon could not be undertaken at the same level of detail and coverage as that for Phase One, an adjustment has been applied to estimate the range of construction carbon that might arise from the Phase Two section, if assessed in the same way as Phase One. This involved using the detail of the Phase One EIA construction carbon estimates to establish carbon intensity for different types of route alignment. These were then applied to the corresponding alignment types for Phase Two using known dimensions for each type.

B5.1.7. Details of each emission source and calculation method are presented in Annex C.

B5.1.8. In defining the construction emissions boundaries, a number of data limitations were identified and necessary assumptions were made, which have also been set out in Annex C.

B5.1.9. Uncertainties in estimating construction carbon emissions also arise from the activity data used to estimate quantities or the values of emission factors. We have considered the uncertainties in each of these elements for the Phase Two data, as described in Annex C.

B.6. Methodology for operational carbon

B6.1.1. Operational carbon refers to the carbon emissions associated with the proposed operation of HS2 (principally from the power generated to operate trains).

B6.1.2. For operational carbon, annual distances travelled by HS2 trains were obtained from the PFM. Distance information was coupled with data on the average energy performance of HS2 trainsets for journey profiles representative of the expected HS2 timetable, and alternative trajectories for UK grid electricity emissions factors, in order to derive estimates of operational carbon. The approach and assumptions for operational carbon are summarised in Annex C.

B.7. Methodologies for modal shift carbon

B7.1.1. Modal shift carbon represents the changes in carbon emissions associated with the displacement of journeys on alternative transport modes, due to the operation of the full HS2 service.

B7.1.2. The appraisal has determined modal shift carbon emissions in a two-stage process. The passenger demand outputs from the PFM are calculated first, followed by an assessment of the carbon consequences of these demands over time. This is an important step as significant changes in carbon emissions over time are expected across different commercial sectors in the economy (and hence, from different transport modes) as a result of government intervention.

B7.1.3. The approach used relies on the following steps:

- Definition of emissions sources;
- Identification of PFM outputs that provide activity data[26] for each emission source;
- Identification of appropriate emissions factors[27]; and
- Estimation of the carbon impact.

B7.1.4. Details of each emission source and calculation method are presented in Annex C.

B7.1.5. There is obviously uncertainty in estimating operational carbon emissions, which arise from a number of sources, reliant as it is on the accuracy of the activity data[28] used to estimate quantities or the values of emissions factors[29]. Demand forecasts used to generate the activity data are dependent upon many factors such as the level of economic growth, behavioural responses and the point at which long distance rail demand will saturate. These factors have been explored in the risk and uncertainty analysis of the Economic Case for HS2. The levels of uncertainty associated with the assessment of operational carbon emissions are also highly dependent upon the extent to which future UK emissions follow the alternative ‘carbon compliance’ trajectories defined in Annex B.4, and, most specifically, the assumptions regarding displacement of aviation emissions. However, on the basis that the results can only ever be estimated, the analysis is considered to provide good approximation. The assumptions made and the limitations of these and of the assessment method are set out in Annex C.

B.8. Assumptions underlying freight released capacity estimate

B8.1.1. The rail movements assumptions underlying estimates of carbon benefit associated with released capacity are shown in **Box 1** below.

B8.1.2. Assumptions regarding the emissions factors used to estimate released capacity carbon benefits are shown in **Box 2** below.

[26] Activity data refers to the estimates of quantities such as kilometres travelled, or passengers displaced, that underlie the operational carbon assessment

[27] Including the effect of changes in emission factors over time, due to UK decarbonisation proceeding in parallel with the construction and operation of HS2.

[28] Activity data refers to the estimates of quantities such as kilometres travelled, or passengers displaced, that underlie the operational carbon assessment.

[29] Emission factors show the relationship between the quantity of GHGs emitted and an emission-generating activity, for example the number of grammes of CO_2 emitted for each kilometre travelled on an electric train.

Box 1 Released capacity freight path assumptions for the conventional rail network

- Released capacity is only assumed to be available for the WCML. No significant released capacity is assumed for either the MML or the ECML. - The hours during which released capacity could be attributed to HS2 are assumed to be 06:00 – 22:00, 16 hours per day. - No released capacity is assumed during peak hours, which are 07:00–10:00 (3 hours) and 16:00–19:00 (3 hours). - Therefore, net released capacity attributable to HS2 is only available for 10 hours of the day. - Network Rail freight forecasts will form the basis of a scaled introduction of freight services between London and Lichfield over the first ten years of Phase One. - From day one of Phase Two opening, 50% of the Phase One paths are assumed to extend to Crewe. From 2033 one freight path every other hour (during the 10 off-peak hours) would be available from London to Lichfield in both directions, and one freight path every other hour (during the 10 off-peak hours) would be available from London to Crewe in both directions.

Box 2 – Released capacity carbon assumptions

- Freight displacement capacity is assumed to arise on the basis of 36 twenty-tonne containers per freight train - A range of fuel efficiencies is assumed for HGVs, as follows: (1) Current national average figures (4mpg, Defra)[30]; (2) Forecast future HGV fuel efficiencies (8 - 10mpg, Road Haulage Association)[31]. - This range of estimates for HGV fuel efficiencies is used to calculate a range of carbon benefits arising from freight switch from road to rail over the assumed operational lifetime of HS2.

B.9. The influence of mode shift on HS2 carbon emissions

B9.1.1. The displacement of road passenger transport, classic rail services, and domestic and short-haul aviation - arising from the full HS2 scheme - is a significant influence on carbon emissions. The scale of potential carbon reductions from each of these elements of mode shift is dependent upon assumptions regarding the evolution of the UK's long-term carbon future.

[30] 2013 Guidelines to Defra / DECC's Conversion Factors for Company Reporting

[31] Road Haulage Assocation, personal communications

B.10. Aviation

B10.1.1. The scope for displacement of aviation emissions is particularly dependent upon future policy assumptions. In particular, if landing and take-off slots at an airport are no longer required for certain domestic flights owing to passengers' preference for using HS2 over flying, the question arises as to how the vacated slots would subsequently be used. If they are taken up by genuinely new flights (i.e. not simply displaced from other existing or new airports or runway capacity), then there is no overall carbon reduction. Indeed, there could well be a significant carbon increase, depending on the length of any new journey introduced and the definition of the boundary for emission accounting purposes. This issue led to a wide degree of variation in the estimation of aviation emissions benefits (or disbenefits) within the previous 2011 Phase One AoS Report[32].

B10.1.2. The UK Aviation Policy Framework was issued in March 2013. Key principles included within the framework are to maintain and develop the UK's air connectivity, and to ensure that the UK aviation sector makes a significant and cost-effective contribution towards reducing global emissions. Within the framework, the Government continues to support the principle of integrating HS2 with the UK's airports, and believes that the development of HS2 will '…ease pressure on our hub airport … into the medium and long term…'.

B10.1.3. The Aviation Policy Framework also states that '…beyond 2020, we recognise that even with HS2 in place, using current operating techniques, there will be a capacity challenge at the biggest airports in the South East of England. The five London airports were at 78% capacity in 2010 and they are forecast to be 91% full in 2020 and totally full by around 2030'.

B10.1.4. Given the identified aviation capacity constraints and the timetable for development of the full HS2 scheme, it can be seen that HS2's effect on demand for aviation services is not a fundamental driver of UK aviation carbon emissions into the future. If HS2 leads to freed landing and take-off slots at UK airports due to changed passenger choices, the reallocation of slots would be a commercial matter, primarily for the airlines. Factors that might influence the future use of slots could include passenger demand, airport capacity issues, agreements with airport operators and other local commercial considerations at the time. This conclusion is supported by analysis undertaken on behalf of Greengauge 21[33].

[32] 'HS2 London to the West Midlands Main Report Volume 1 and Appendix 2 Greenhouse Gas Emissions' (February 2011)

[33] 'The Carbon Impacts of HS2' (September 2012), Greengauge 21

B.11. Road transport

B11.1.1. The full HS2 scheme's ability to displace road passenger vehicle emissions depends significantly on the evolving mix of vehicle types into the long-term future and the rate at which these vehicle types improve their carbon efficiency. Conventional passenger (petrol and diesel) vehicles are anticipated to improve their carbon efficiency in line with European Directives[34]. However, the emerging market for ULEV (electric vehicles) within the UK may also lead to decarbonisation over time. The rate at which electric vehicles are adopted within the UK, and the rates of decarbonisation for all vehicle types, is explored within the UK future carbon scenarios adopted for this assessment.

B.12. Classic rail

B12.1.1. Estimates of displaced classic rail emissions have been derived using assumptions about the future mix of the UK classic rail fleet, and the relative proportions of electric and diesel units. Emissions benefits from displaced classic rail services are dependent upon future assumptions about the carbon intensity of UK grid electricity.

B.13. The rate of UK decarbonisation

B13.1.1. The lengthy construction and operational timetable of HS2 (assumed for the purposes of this assessment to cover the period from 2017 to 2092) means that its carbon emissions are very strongly influenced by the speed at which the UK decarbonises across other sectors (particularly road transport, air transport and power generation) and whether this decarbonisation takes place at comparable rates across different sectors of the economy.

B13.1.2. Overall, there are potential UK-wide carbon reduction outcomes under which HS2 might make a greater relative contribution than others. Such outcomes are, mostly, not within the direct influence of HS2 but, nevertheless, are important influences on HS2 carbon emissions.

B13.1.3. The Climate Change Act 2008 set legally binding targets to reduce the UK's emissions of CO_2 by at least 34% by 2020 and 80% by 2050, compared with a 1990 baseline. The UK Carbon Plan[35] builds on earlier CCC reports to develop indicative approaches to how the UK will achieve this level of GHG emissions reductions. These projections would reduce operational emissions from HS2 directly through the source of power utilised for traction energy. In addition, the projections influence the scope for HS2 to displace emissions from other transport sources.

[34] Regulation EC 443/2009 - Emission performance standards for new passenger cars

[35] 'The Carbon Plan – Delivering our Low Carbon Future', ibid

B.14. Principal limitations and information gaps

B14.1.1. Were HS2 not to progress, there would be a set of other transport initiatives that would be implemented to address the increasing challenges for satisfying transport demand in the UK. Each of these alternative non-HS2 schemes would have its own carbon implications which has not been reflected in the figure assessed here. .

B14.1.2. This assessment uses the 'Proposed Scheme for Consultation' for the Phase Two design defined within the *Sustainability Statement*[36] and the proposed scheme subject to EIA for the Phase One design. If other route options were to be considered following consultation, this may influence carbon outcomes; a subsequent Phase Two EIA would also consider this issue further.

B14.1.3. The carbon assessment uses PFM forecasts of travel patterns which underpin those used in the Economic Case for HS2. These are results from a single scenario and therefore we have been unable to test the impact of different activity data.

B14.1.4. Train kilometres and car kilometres used as activity data are assumed to remain constant from 2036 onwards, where demand is assumed to saturate in PFM.

B14.1.5. The approach has allowed the use of two UK future carbon scenarios, both of which are compatible with the UK's long-term carbon reduction objectives. It is possible to conceive of other scenarios which could greatly influence HS2 carbon emissions.

B14.1.6. A simplified approach to uncertainty within the construction carbon calculation has been adopted, in which the individual input parameters of quantities and emission factors have been individually reviewed for their potential variability.

B14.1.7. Given the relatively early stage of design for Phase Two, this study has been carried out in the absence, necessarily, of detailed information for Phase Two of the Proposed Scheme regarding scheme construction and specific design. Illustrative quantities of materials have been developed route-wide, making reference to other external sources where available. Only the main bulk construction materials were estimated, and included within this appraisal, these being concrete, steel, copper, aluminium and aggregate. The emissions for construction materials relate to the quantity of materials required for tunnels, at grade sections, viaducts, track, stations and platforms. They use standard conversion factors pertinent to current materials and techniques. In addition, they accommodate potential low carbon innovations in respect of the manufacture of steel and concrete that are likely to have taken place by the time construction commences.

B14.1.8. This approach has provided an estimated figure for construction carbon that, in all likelihood, under-estimates the actual construction carbon emissions, based on the relatively larger construction figure that has been described for the Phase One proposals. As a result, the estimated Phase Two construction carbon figure has been adjusted, as described earlier in B5.

[36] 'High Speed Rail: Consultation on the route from the West Midlands to Manchester, Leeds and beyond : Sustainability Statement' (July 2013)

B.15. Assumptions for extrapolating results to 120 years

B15.1.1. The Phase Two AoS carbon model undertakes a calculation over the WebTAG assessment period (a total period of 76 years, starting with the construction of Phase One and ending with 60 years operation of Phase Two from 2033 – 2092).

B15.1.2. The design life of HS2 is 120 years. Therefore an additional assessment of carbon has been undertaken for a further 60 year operational period, from 2093 to 2152 inclusive. For this additional period of 60 years, the following assumptions are made:

1 There are no changes to the year-on-year carbon benefits or dis-benefits arising from:

- HS2 operations;
- modal shift from or to other transport modes;
- released capacity benefits;
- carbon benefits from sequestration.

2 The year-on-year net operational benefits arising from the categories above in 2092 (the last year of the 60-year assessment period) are kept constant, extrapolated forward and totalled over a further 60 years;

3 For rolling stock, and for replacement, repair and maintenance of the track, the amount of construction carbon arising in the first 60 year period is assumed to arise again during the second 60 year period, due to the natural replacement cycle of these elements;

4 Other infrastructure (such as bridges, viaducts etc) requires no further upgrade and so no further carbon investment over the period.

B15.1.3. For both Scenario A and B, the carbon arising over the period from Year 61 – 120 is calculated as the sum of elements 2 – 4 above.

Annex C – Calculation Methods & Assumptions

Table 2 Construction Carbon Emissions Sources and Appraisal Approach (Phase Two Data)

Emission classification	Emissions source	Determination	Variables	Assumptions / limitations	Sensitivity and scope for reduction
Direct at source (on-site emissions)	Emissions from construction plant equipment used on site (excl tunnel boring machines – see below)	For each plant type: carbon emissions = distance travelled by plant type x relevant emissions factor (kg CO_2/km)	Number and type of plant equipment, distance travelled (km)	This source contribution has been set at zero as reasonable estimates of the number and type of plant equipment used on site are not available at this time. The estimation of construction costs is expected to include a schedule of construction plant equipment e.g. dump trucks, bulldozers, diggers, etc. The carbon implications arising from land use changes due to construction activity have not been included within the Phase Two assessment.	This source is subject to uncertainty but with considerable scope for reducing emissions through selection of efficient plant equipment, use of efficient techniques, etc. No sensitivity analysis has been undertaken at this time
Direct remote (off-site emissions)	Emissions from the carriage of bulk construction materials to site	For each bulk material: carbon emissions = total volume of material (tonnes) x % carried by road, rail x distance from point of manufacture to site (km) x relevant emissions factor (kg CO_2/km)	Volume of each bulk material (tonnes), % carried by mode of transport (road, rail), distance from point of manufacture to site (km)	Given the preliminary stage of the design only the emissions from the transport of bulk construction materials (steel, concrete and aggregate) have been estimated. For purposes of illustration, the generic assumptions are made that all materials are transported for a distance of 50km, unless specific detailed data are available, and that all materials are transported by road (HGV). Return journeys have been assumed.	This source is subject to uncertainty but with considerable scope for reducing emissions through reducing the volume of materials required e.g. recycling on site, use of rail rather than road, etc.
	Emissions from the carriage of excavated material from site	Carbon emissions = total volume of excavated material (tonnes) x % carried by road, rail x distance travelled to landfill site(s) (km) x relevant emissions factor (Kg CO_2/km)	Volume of excavated material (tonnes), distance landfill site(s) (km), % by mode of transport (road, rail)	It is assumed that excavated material is dominated by tunnel excavations, with a balance achieved between cuttings and land raising elsewhere and demolition waste being a small contributor. Excavated material is assumed to be transported within and between sites for re-use and if necessary to landfill destinations. Return journeys and 100% road transport of excavated material have both been assumed. Tunnel excavated material was estimated as $\pi r^2 L$, where L = length of tunnel and r = 0.5 x tunnel diameter. There is a mixture of single bore and twin bore tunnels along the proposed route, with tunnel diameters varying between 7.5 and 16m.	This source is subject to uncertainty with extensive scope for reducing the carriage of excavated material through re-use on sites along the route.

Emission classification	Emissions source	Determination	Variables	Assumptions / limitations	Sensitivity and scope for reduction
	Emissions from construction personnel travel to and from the site	Mode of transport characteristics i.e. private transport or public transport	Mode of transport specification/ efficiency	This source contribution has been set at zero as reasonable estimates of the number and type of vehicles used by personnel are not available at this stage of Phase Two design.	This source is subject to large uncertainty with extensive scope for reducing emissions through use of Green Travel Plans, etc. No sensitivity analysis has been undertaken at this time
	Generation emissions from construction plant power use (e.g. Tunnel Boring Machines (TBM))	Carbon emissions = electrical demand of TBM (MWh/km) x tunnel length (km) x relevant emissions factor (kg CO_2/kWh)	Electrical demand of TBM (MWh/km), number of TBM, tunnel length (km), tunnel diameter	All tunnels are assumed to be constructed through boring. TBM are energy intensive and typically represent one of the primary sources of carbon emissions from a construction project of this nature. Mains electricity consumption data are available from TBM suppliers in terms of MWh/km of tunnel bored. Operating hours is principally a function of tunnel length but also geology (hardness of rock). Electrical consumption data are provided as 12,125MWh/tunnel km. Tunnels assumed to be a maximum external diameter of 12m diameter, twin bore, with two earth pressure balance TBM operating at 90% capacity. To allow for differing tunnel diameters, the electrical consumption of TBM has been pro-rated by tunnel diameter.	This source is subject to uncertainties in: tunnel length; geology (hardness of rock).
Indirect	Emissions from the manufacture (cradle to gate) of bulk construction materials (embedded carbon), for each type of track feature (i.e. rail, rail driveway, viaducts, tunnels, stations, OHLE structures and wires). The bulk construction materials included were concrete, steel, aluminium, copper and	Carbon emissions = tonnes of steel x relevant emissions factor (kg CO_2/tonne)	Tonnes of steel	Standard multipliers for steel requirements per unit length of rail, rail driveway, OHLE, tunnels, viaducts and stations, were derived from previous studies. (Rail - assumed two tracks, two rails per track; Rail Driveway - sleepers, ballast; OHLE - overhead line electrification; tunnels - tunnel structure, assumed twin bore duplex lining). Due to design limitations, concrete and steel requirements for stations and viaducts were estimated using standard factors for major structures, i.e. 2,000m^3 / 4,800 tonnes concrete required for stations and factors of 23,000 m^3 concrete / 1650 tonnes steel per km of viaduct[37]. It was assumed that 25kg reinforced steel is used per m^3 concrete for tunnels and stations. For the OHLE, embedded carbon from copper and aluminium	Future reduction in steel production emissions factors was included, based upon discussions with industry representatives. Carbon emissions from this source could be further reduced with increasing proportion of recycled steel used.

[37] UIC (2011), Carbon Footprint of High Speed Rail, SystraConseil

Emission classification	Emissions source	Determination	Variables	Assumptions / limitations	Sensitivity and scope for reduction
	aggregate.			was also estimated.	
		Carbon emissions = tonnes of concrete x relevant emissions factor (kg CO_2/tonne)	Quantity (tonnes) and grade (% of cement) of concrete used	Standard multipliers for concrete requirements per unit length of rail, rail driveway, OHLE, tunnels, viaducts and stations, were derived from previous studies. (Rail - assumed two tracks, two rails per track; Rail Driveway - sleepers, ballast; OHLE - overhead line electrification; tunnels - tunnel structure, assumed twin bore duplex lining). Due to design limitations, concrete and steel requirements for stations and viaducts were estimated using standard factors for major structures, i.e. 2,000m^3 / 4,800 tonnes concrete required for stations and factors of 23,000 m^3 concrete / 1650 tonnes steel per km of viaduct. It was assumed that 25kg reinforced steel is used per m^3 concrete for tunnels and stations. For the OHLE, embedded carbon from copper and aluminium was also estimated.	Future reduction in concrete production emissions factors was included, based upon discussions with industry representatives. In addition, lighter weight designs and a proportion of recycled content for appropriate structures could be considered at the detailed design stages.
		Carbon emissions = tonnes of ballast (aggregate) x relevant emissions factor (kgCO_2/tonne)	Quantity (tonnes) of aggregate required	Due to safety concerns only virgin aggregate has been considered although a potential for recycled ballast remains. Standard multipliers for aggregate requirements per unit length of rail, rail driveway, tunnels, viaducts and stations were derived from previous studies	No sensitivity in the emissions factor was considered. Existing research and demonstrations for Network Rail approved standard polypropylene geogrid to reduce the amount of ballast required by around 1/3, and also reducing subsequent maintenance requirements and related emissions.
	Emissions from the manufacture (cradle to gate) of trains (embedded energy)	Carbon emissions = number of vehicles x tonnes of steel per vehicle x relevant emissions factor for steel (kgCO_2/tonne)	Number of vehicles	All of the embedded carbon in train manufacture is assumed to be represented by steel production at this design stage.	No sensitivity in the emissions factor was considered. There are opportunities to pursue options for low carbon components and materials that could be considered.

Emission classification	Emissions source	Determination	Variables	Assumptions / limitations	Sensitivity and scope for reduction
	Emissions from the manufacture of road vehicles and associated infrastructure	Carbon emissions = number of vehicles x tonnes of bulk material per vehicle x relevant emissions factor ($kgCO_2$/tonne of bulk material)	Number of vehicles	This source contribution has been set at zero as reasonable estimates of the number and type of vehicle are not available at this time	This source is subject to uncertainty. No sensitivity analysis has been undertaken at this time
	Emissions from the manufacture of airplanes and associated infrastructure	Carbon emissions = number of airplanes x tonnes of bulk material per vehicle x relevant emissions factor ($kgCO_2$/tonne of bulk material)	Number of airplanes	This source contribution has been set at zero as reasonable estimates of the number and type of airplanes are not available at this time	This source is subject to uncertainty. No sensitivity analysis has been undertaken at this time
Secondary	Emissions from construction of secondary development induced around HS2 stations and along existing lines (through released capacity)	Not applicable	Not applicable	Excluded as the Economic Case for HS2 assumes no over development	Not applicable

Table 3 Operational Carbon Emissions Sources and Appraisal Approach

Emission classification	Emissions source	Determination	Variables	Assumptions / limitations	Sensitivity and scope for reduction
Direct at source (on-site emissions)	Electricity demand from HS2 train operations	Carbon emissions = annual mean electricity demand (kWh)[38] x relevant emissions factors (kg CO_2/kWh)[39]	Annualised electricity demand, projected carbon emission factors	The definition of future emissions factors has been based either on WebTAG future assumptions or derived from CCC future projections of UK grid electricity carbon intensity. No direct consideration is given to variations in the carbon intensity associated with marginal increases in electricity demand although the WebTAG data is based upon marginal factors. Other operational carbon, associated with issues such as train maintenance spare parts, electricity for stations, depots, operation of auxiliary equipment and tunnel fans, has not been included in the Phase Two assessment.	There is scope to reduce the HS2 electricity demand through a variety of train design and operation measures. This source is very sensitive to policy delivery of reductions in the carbon intensity of the electricity supply industry.

[38] Provided as a direct output of the PFM passenger demand model and checked with reference to a study by Imperial College (Watson R *et al* (2009) Final Outputs of Traction Energy Modelling, Imperial College, London).

[39] Current carbon emission factors are taken from the latest version of the 2012 Guidelines to Defra / DECC's Conversion Factors for Company Reporting (May 2012); future projected emission factors have been developed in line with the scenario assumptions set out in Annex B4.

Table 4 Modal Shift Carbon Emissions Sources and Appraisal Approach

Emission classification	Emissions source	Determination	Variables	Assumptions / limitations	Sensitivity and scope for reduction
Direct remote (off-site emissions)	Net changes in demand from existing electric train operations, based upon existing stock types	Carbon emissions = change in existing train distance travelled (train-km) x relevant emissions factor (kg CO_2/train-km)[40]	Annualised electricity demand, projected carbon emission factors	The definition of future emissions factors has been based either on WebTAG future assumptions or derived from CCC future projections of UK grid electricity carbon intensity. No direct consideration is given to variations in the carbon intensity associated with marginal increases in electricity demand although the WebTAG data is based upon marginal factors.	This source is sensitive to policy delivery of reductions in the carbon intensity of grid electricity.
	Net changes in demand from existing diesel train operations, based upon existing stock types	Carbon emissions = change in existing train distance travelled (train-km) x relevant emissions factor (kg CO_2/train-km)[41]	Annualised diesel usage, projected carbon emission factors	It is assumed that there is no change over time to the emissions factor for classic diesel rail sets. This assumption may lead to a small over-estimate of carbon benefits.	This source is sensitive to the future carbon intensity of classic diesel rail trains.
	Net changes in road transport emissions from long distance journeys	For each vehicle type: carbon emissions = change in total vehicle kilometres travelled in each year[42] x emission factor (year, petrol/diesel/electric split/vehicle speed)[43]	Total vehicle kilometres travelled, year, proportion of petrol, diesel and electric vehicles, vehicle speed, projected carbon emission factors	The alternative carbon scenarios define widely varying outcomes for the long-term future split of passenger road vehicle types	This source is very sensitive to the carbon scenario assumptions and the associated policy delivery of reductions in the carbon intensity and vehicle type splits for road passenger transport
	Net changes in road transport emissions from journeys to gain	For each vehicle type: carbon emissions = change in total vehicle	Total vehicle kilometres travelled, year, proportion of	The alternative carbon scenarios define widely varying outcomes for the long-term future split of passenger road vehicle types	This source is very sensitive to the carbon scenario assumptions and

[40]Calculated within the Carbon Model as a time-varying emission factor (kg CO_2eq / train-km) for current and projected future classic electric rail rolling stock

[41]Calculated within the Carbon Model as an emission factor (kg CO_2eq / train-km) for current and projected future classic diesel rail rolling stock

[42]Provided as a direct output of the PFM passenger demand model.

[43]Annualised vehicle emission factors and split in petrol, diesel and electric vehicles estimated from DfT data, DfT and CCC projections.

Emission classification	Emissions source	Determination	Variables	Assumptions / limitations	Sensitivity and scope for reduction
	access to HS2 services ('surface access')	kilometres travelled in each year[44]x emission factor (year, petrol/diesel/electric split/vehicle speed)[45]	petrol, diesel and electric vehicles, vehicle speed, projected carbon emission factors		the associated policy delivery of reductions in the carbon intensity and vehicle type splits for road passenger transport
	Net changes in air travel	For domestic flights: carbon emissions [across all aviation routes within the UK] = total daily aviation passengers displaced[46] x average UK domestic per passenger emission factor[47].	Total aviation passengers displaced, projected carbon emission factors	Assumptions are made that reductions in the number of daily aviation passengers are a good proxy for displaced flights across the UK as a whole	This source is sensitive to the assumptions listed. It is also dependent upon projections regarding future carbon efficiency within UK aviation.
Secondary	Emissions from secondary development induced around HS2 stations and along existing lines (through released capacity)	Not applicable	Not applicable	Excluded as the Economic Case for HS2assumes no over development	Not applicable
	Emissions changes from 'released capacity' (where freed conventional rail	Estimates have been developed of (1) potential new rail freight movements[48] and (2)	Available freight paths & lengths, current and projected emissions factors for rail freight	Assumptions are made regarding the potential scale of future freight paths, which in turn depends on future usage of the rail network. Future demand for rail freight services will determine actual uptake of potential rail	The scope for emissions changes from 'released capacity' is sensitive to the assumptions adopted in

[44]Provided as a direct output of the PFM passenger demand model.

[45] Annualised vehicle emission factors and split in petrol, diesel and electric vehicles estimated from DfT data, DfT and CCC projections.

[46] A direct output from the PFM passenger demand model

[47] Information obtained from direct discussions with DfT

[48] Assumptions as summarised in Annex B8.

Emission classification	Emissions source	Determination	Variables	Assumptions / limitations	Sensitivity and scope for reduction
	capacity leads to switches from road to rail freight)	current and future emissions factors for rail freight and HGVs[49]	and HGVs	capacity. Carbon efficiencies of rail and road freight may change differently to the efficiencies assumed.	the assessment.

[49] Alternative data for these future HGV fuel efficiencies have been derived from WebTAG, Defra and the Road Haulage Association, summarised in Annex B8.

Annex D – HS2 Benchmarks

D1.1.1. In terms of emissions per passenger Table 5 sets out the Phase One carbon emissions per passenger km figures for HS2 at the key assessment times used for the Phase One EIA. This is based on HS2 power supply modelling outputs for the rolling stock, combined with projected grid decarbonisation figures from Scenario A.

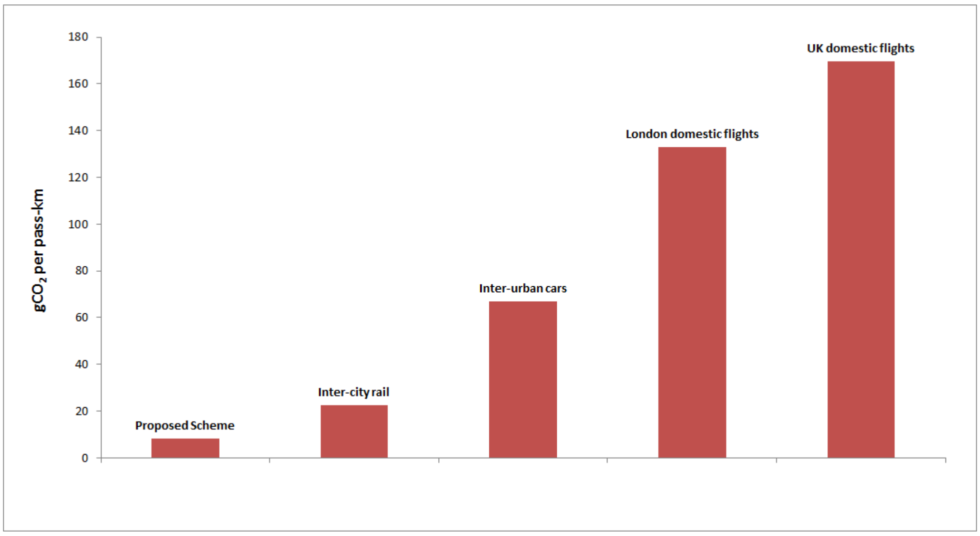
Table 5 HS2 projected carbon emissions per passenger-kilometre (gCO_2e/pkm)

Year	2026	2041	2050	2086
HS2	15.33	2.88	1.57	1.57

D1.1.2. Figure 3 presents average passenger km figures for road, rail and air emissions per passenger km for 2030. The figures are provided specifically by DfT upon request[50].

D1.1.3. Figure 3 shows that HS2 offers a significant benefit in terms of gCO_2e/p-km compared with air and road transport. As well as the increasingly low carbon traction system the large capacity of each train and the whole new line gives HS2 a significant advantage as a high volume low carbon form of transport.

Figure 3 Carbon emissions per passenger kilometre by mode at 2030[51]



While there are very few comparable projects to HS2, published data for the carbon footprint for Crossrail, a £14.5billion[52] new 118km railway between the east and west of London, reveals that its emissions are estimated to be between 9,600,000 tCO_2 and 14,900,000 tCO_2 during its lifetime for construction and 120 years of operation.[53] Approximately 85% of the

[50] DfT (2013) Personal communication

[51] 2030 is the nearest date to Phase Two scheme opening where forecast data has been assessed, during which time Phase One will be operational. In addition, it should be noted that the intercity rail forecast is for the entire classic network, including the predicted mix of both diesel and electric trains in 2030, data provided by DfT.

[52] Available online: https://www.gov.uk/government/speeches/annual-update-on-crossrail. Accessed August 2013.

[53] Available online: http://www.tfl.gov.uk/assets/downloads/Item08-SHEAC-9-March-2011-Sustainability-Crossrail.pdf. Accessed August 2013.

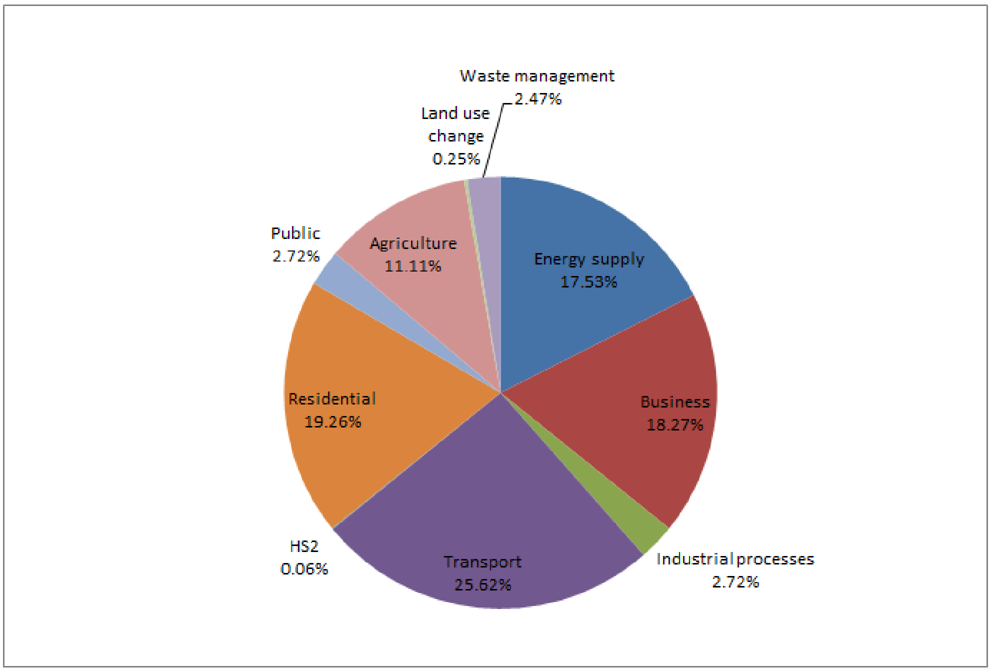
emissions are from operation with the construction emissions estimated to contribute approximately 1.5 $MtCO_2$. This scheme also requires a significant element of tunnelling, in common with HS2. Modal shift is estimated to save 1,300 tCO_2 per year.[54]

D1.1.4. To provide some context to the assessment of HS2's carbon emissions it is helpful to present it in relation to the UK's total GHG emissions, as well as specific elements of the total, such as construction emissions.

D1.1.5. In terms of construction emissions a report by the Green Construction Board[55] reported that all UK construction emissions in 2010 were 34.2 $MtCO_2e$. In comparison the annualised construction emissions of the full scheme represent less than 1% of this figure.

D1.1.6. Figure 4 presents the HS2 carbon emissions for construction and operation (annualised), compared to projected total UK annual emissions in 2030. The carbon emissions for HS2 in this figure do not include the benefits of modal shift and tree planting as they are not part of the scheme's direct emissions.

Figure 4 HS2 annualised emissions compared to UK projected emissions in 2030[56]



[54] Available online: http://www.sonasrecruitment.com/sonas-news/17-crossrail-europes-biggest-civil-engineering-project. Accessed August 2013

[55] Green Construction Board (2013) Low carbon route map for the UK built environment Online:[http://www.greenconstructionboard.org/otherdocs/Routemap%20final%20report%2005032013.pdf]

[56] 'Updated Energy and Emissions Projections 2012', DECC (October 2012) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65717/6660-updated-emissions-projections-october-2012.pdf - Data from Table 3.1. 2030 is the nearest date to Phase Two scheme opening where forecast data has been assessed, during which time Phase One will be operational.