Carbon Implications of Alternative Operational Scenarios

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Executive Summary

In November 2013 HS2 Ltd submitted an Environmental Statement (ES) alongside the hybrid Bill for Phase One of HS2. The ES included an assessment of the carbon emission implications of the construction and operation of Phase One of HS2. The ES concluded that Phase One of HS2 would be one of the most effective low carbon transport solutions for travel between London and the West Midlands. In terms of emissions per passenger kilometre, Phase One generates 8 grams of carbon dioxide equivalent per passenger kilometre (gCO_2e/pkm) as compared to inter-urban cars (67 gCO_2e/pkm), intercity rail (22 gCO_2e/pkm) and UK domestic flights (170 gCO_2e/pkm), based on projected carbon emissions in 2030.

Benchmarking illustrated that operational emissions of HS2 in 2030 will be 0.06% of projected total UK transport emissions in 2030[1]. The emissions of the UK's electricity generation sector used to power HS2 are regulated by the European Union Emissions Trading System (EU ETS); a cap and trade system with a decreasing cap over time. As a result the carbon emissions associated with the operation of HS2 rolling stock will be regulated through the EU ETS and will not contribute to an increase in Europe-wide carbon emissions.

In January 2014 the Environmental Audit Committee (EAC) launched an inquiry into 'HS2 and the environment'. The inquiry intended to inform the House of Commons about route-wide environmental aspects of the project ahead of the second reading of the HS2 hybrid Bill and the forming of a Select Committee.

In April 2014 the EAC reported their findings. In respect of carbon emissions the EAC recommended that 'Government should examine the scope for requiring a reduced maximum speed for the trains until electricity generation has been sufficiently decarbonised'. This report presents and discusses the results of work to further examine the possible carbon emission implications of alternative operational scenarios.

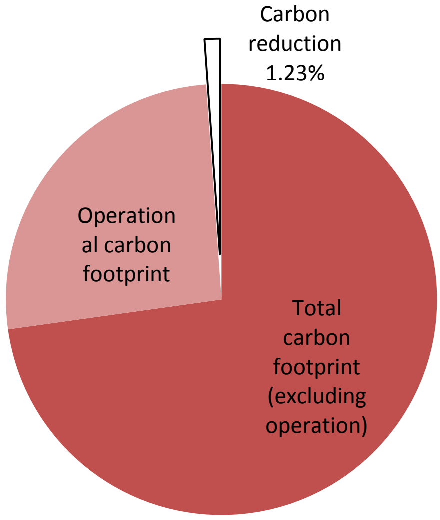
Operational energy for rolling stock and resulting carbon emissions of three operating scenarios has been calculated over a 60 year assessment period. In addition, manufacture and maintenance of rolling stock, and resulting carbon emissions, has been included in the calculation to account for the increase to the rolling stock fleet size; required to provide the same train service pattern at reduced train speeds. The assessment considered two different projections of the rate and extent of the replacement of fossil fuel based electricity generation with low carbon generation (otherwise known as grid decarbonisation). For the purpose of this report grid electricity is considered 'sufficiently decarbonised' when the carbon emissions associated with the generation of one kilowatt hour (kWh) of electricity is less than or equal to 50 grams of carbon dioxide equivalent (gCO_2e).

Compared to the current planned operating scenario (360kph maximum speed with normal timetable operation at circa 330kph), limiting maximum line speed to 300kph until electricity generation has been sufficiently decarbonised results in a reduction of 0.07-4.56% in carbon emissions associated with the manufacture, operation and maintenance of rolling stock (over 60 years). This represents a reduction of up to 1.23% in the context of Phase One of HS2's total carbon emissions (construction and 60 years of operation), as seen in Figure 1[2].

[1] The figure of 0.06% is based upon the DECC/IAG figure which is more conservative than CCC with respect to the rate of grid decarbonisation.
[2] Figure 1 is based on the most favourable scenario, which uses DECC emission factors and assumes a maximum line speed of 300 kph until sufficient grid decarbonisation. The full version of this Figure and associated commentary can be seen in Section 3, Figure 3.

This does not represent the total net change in carbon emissions, as the potential consequences that a change in line speed may have on other aspects of the footprint, such as reduced carbon benefit associated with modal shift or the additional carbon emission implications of constructing additional infrastructure (e.g., additional station platforms and stabling to accommodate more rolling stock at depots) have not been quantified[3].

Figure 1: The carbon reduction achieved under the most favourable line speed reduction scenario

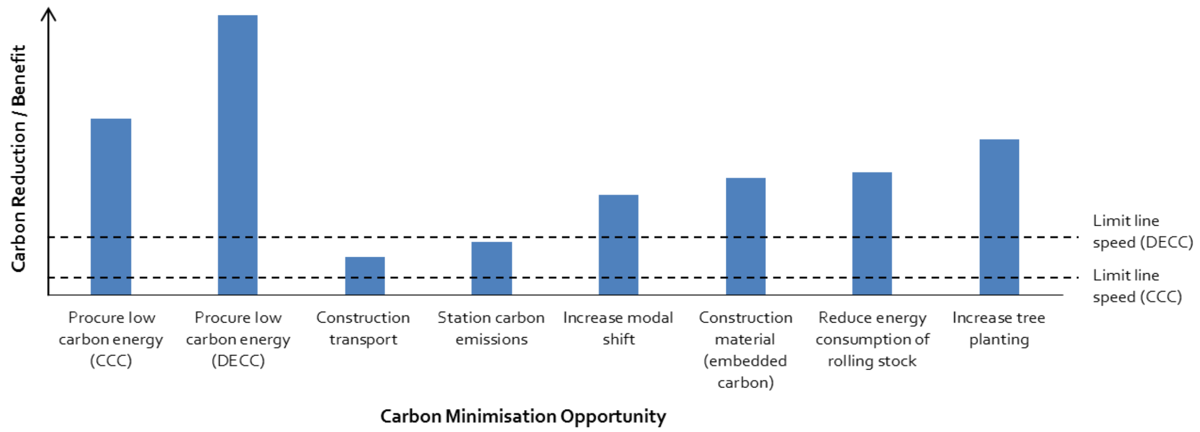


The results presented are based on current technology. Expected improvements in rolling stock energy efficiency or other options to optimise energy efficiency, such as timetable refinements, have not been considered. These considerations can be expected to further reduce carbon emissions from operation of rolling stock. The net change would therefore represent an even smaller proportion of total carbon emissions and analysis of the impact on modal shift (and associated carbon implications) would be required to determine whether the net carbon emissions impact is positive or negative.

This assessment demonstrates that limiting line speed offers minimal carbon reduction. Opportunities offering more certain and significant carbon emission benefits exist across the design, construction and operation of Phase One of HS2. Examples of these are presented in Figure 2[4]. HS2 Ltd is committed to minimising carbon emissions, as articulated in its Sustainability Policy, Carbon Minimisation Policy and as demonstrated by the endorsement of the Infrastructure Carbon Review.

[3] This report focuses on the carbon implications only and does not consider other factors such as changes in capital cost or land-take as a result of reduced line speeds.
[4] The full version of this Figure and associated commentary can be seen in Section 4, Figure 4.

Figure 2: Carbon minimisation opportunities relative to limiting line speed



HS2 Ltd is currently developing a Carbon Management Strategy to deliver its carbon minimisation objectives and will continue to consider lower carbon solutions across the design, construction and operation phases.

2 Introduction

2.1.1 The UK is required, through the Climate Change Act (2008)[5], to reduce greenhouse gas emissions by, as a minimum, 80% from 1990 levels by 2050. An interim target of 34% reduction from 1990 by 2020 has also been agreed.

2.1.2 The Carbon Plan (2011)[6] sets out the Government's plans for achieving the greenhouse gas emissions reductions committed to in the Climate Change Act and the first four carbon budgets. Low carbon electricity and low carbon transport are essential parts of the Carbon Plan.

2.1.3 In November 2013 HS2 Ltd deposited a hybrid Bill with Parliament to seek powers for the construction and operation of Phase One of HS2. An Environmental Statement (ES) was submitted alongside the Bill which included an assessment of the carbon emission implications of the construction and operation of Phase One of HS2[7].

2.1.4 The assessment concluded that the construction and operation of Phase One of HS2 will inevitably result in carbon emissions, but it will also result in carbon benefits from modal shift, planting of two million trees and potential utilisation of released capacity by rail freight. Furthermore, in operation Phase One of HS2 would be one of the most effective low carbon transport solutions for travel between London and the West Midlands. In terms of emissions per passenger kilometre, Phase One generates 8 gCO_2e/pkm as compared to inter-urban cars (67 gCO_2e/pkm), intercity rail (22 gCO_2e/pkm) and UK domestic flights (170 gCO_2e/pkm), based on projected carbon emissions in 2030.

2.1.5 The assessment identified that the operational carbon footprint is highly sensitive to the rate and extent at which fossil fuel electricity generation is replaced with renewable and low carbon energy (otherwise known as grid decarbonisation). This is an influencing factor on HS2's carbon footprint over which HS2 Ltd has no direct control and which is instead driven by market forces influenced by Government policy.

2.1.6 Sensitivity analysis using grid decarbonisation projections from Government, Department of Energy and Climate Change/Interdepartmental Analysts' Group (DECC/IAG) and the Committee on Climate Change (CCC) identified a significant difference in the operational carbon footprint (approximately 1,000,000 tCO_2e). Nevertheless, benchmarking illustrated that operational emissions in 2030 will be 0.06% of the projected total UK transport emissions in 2030[8]. Moreover, the emissions of the UK's electricity generation sector used to power HS2 are regulated by the European Union Emissions Trading System (EU ETS)[9], a cap and trade system with a decreasing cap over time. The carbon emissions associated with the operation

[5] Her Majesty's Stationery Office, (2008), Climate Change Act 2008, London.
[6] HM Government, (2011), The Carbon Plan: Delivering our Low Carbon Future, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47613/3702-the-carbon-plan-delivering-our-low-carbon-future.pdf; Accessed: 11 February 2015
[7] HS2 Phase One Environmental Statement, https://www.gov.uk/government/collections/hs2-phase-one-environmental-statement-documents Accessed: 31 March 2015
[8] The figure of 0.06% is based upon the DECC/IAG figure which is more conservative than CCC with respect to the rate of grid decarbonisation.
[9] European Commission, the EU Emissions Trading Scheme, http://ec.europa.eu/clima/policies/ets/index_en.htm Accessed 30 March 2015

of HS2 rolling stock will therefore be regulated through the EU ETS and thus will not contribute to an increase in Europe-wide carbon emissions.

2.1.7 Regardless, HS2 Ltd is committed to minimising carbon emissions by implementation of its Sustainability Policy[10], Carbon Minimisation Policy[11] and through its commitments as a signatory of the Infrastructure Carbon Review[12].

2.1.8 In January 2014 the Environmental Audit Committee (EAC)[13] launched an inquiry into 'HS2 and the environment'. The inquiry intended to inform the House of Commons about route-wide environmental aspects of the project ahead of the second reading of the HS2 hybrid Bill and the forming of a Select Committee. In April 2014 the EAC reported their findings. In relation to carbon emissions the EAC reported that:

2.1.9 'While the impact of lower maximum train speed on reducing emissions is currently not seen as substantial, the legally binding commitment to reduce emissions makes even a small reduction desirable. HS2 Ltd and the Department should therefore examine the scope for requiring a reduced maximum speed for the trains until electricity generation has been sufficiently decarbonised to make that a marginal issue, and publish the calculations that would underpin such a calculation.'

2.1.10 In response, the Government stated:

2.1.11 'HS2 Ltd will undertake further examination of the possible emissions benefits of changing the operational specification. However, HS2 Ltd is clear that operating at lower speed would reduce carbon emissions from the operation of rolling stock by only a relatively small degree, and would increase journey times, making HS2 a less attractive option to customers on roads and using flights. This is likely to result in less mode shift and potentially less carbon benefit associated with the operation of HS2, which could lead to an overall increase in UK carbon emissions compared to the existing proposed operating speed.'

2.1.12 This report presents and discusses the results of work to further examine the possible carbon emission implications of changing the operational specification. The report builds on the results of simulations and further desktop timetable analyses undertaken by Parsons Brinckerhoff[14]. The executive summary to Parsons Brinckerhoff's report is provided in Appendix A. Appendix B summarises the key results from Parsons Brinckerhoff's study that are of relevance to this report.

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[10] HS2 Sustainability Policy, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/370480/HS2_Sustainability_Policy.pdf Accessed 30 March 2015
[11] HS2 Information Paper E10: Carbon, http://assets.hs2.org.uk/sites/default/files/hb_pdf/E10%20-%20Carbon%20v1.1.pdf
[12] Infrastructure Carbon Review, HM Treasury, 2013
[13] The Environmental Audit Committee is appointed by the House of Commons to consider to what extent the policies and programmes of government departments and non-departmental public bodies (such as HS2 Ltd) contribute to environmental protection and sustainable development; to audit their performance against such targets as may be set for them by Her Majesty's Ministers; and to report thereon to the House.
[14] HS2 Carbon Implications Study Report, Parsons Brinckerhoff, C240-PBR-OP-REP-000-000017 (P03).

3 Methodology

3.1 Overview

3.1.1 Six scenarios have been investigated (Table 1) to assess the impact of limiting the maximum line speed until the grid is sufficiently decarbonised[15]. Calculations have been modelled over sixty years of operation.

3.1.2 All speed scenarios in this assessment apply the same assumptions from HS2's Phase One timetable. However, in reality, slower speeds would require a modified timetable to avoid conflicts. Under HS2's Phase One timetable, 51 train units (excluding operational and maintenance spare trains) would be required for Scenario 3 and 6 (330/360 kph), 54 train units would be required for Scenario 2 and 5 (300/330 kph), and 55 train units would be required for Scenario 1 and 4 (270/330 kph). The modelling on which this assessment is based has been refined since the production of the ES. The results presented here are therefore not directly comparable with the line speed sensitivity presented in the ES; hence this report should be viewed as a stand-alone assessment.

Table 1: Summary of line speed scenarios investigated

	Decarbonisation Electricity dataset	Line speed prior to decarbonisation year	Line speed post decarbonisation year
Scenario 1	CCC	300 (90% 270kph, 10% 300kph)	360 (90% 330kph, 10% 360kph)
Scenario 2		330 (90% 300kph, 10% 330kph)	360 (90% 330kph, 10% 360kph)
Scenario 3		360 (90% 330kph, 10% 360kph)	360 (90% 330kph, 10% 360kph)
Scenario 4	DECC	300 (90% 270kph, 10% 300kph)	360 (90% 330kph, 10% 360kph)
Scenario 5		330 (90% 300kph, 10% 330kph)	360 (90% 330kph, 10% 360kph)
Scenario 6		360 (90% 330kph, 10% 360kph)	360 (90% 330kph, 10% 360kph)

3.1.3 Energy consumption per train kilometre, running on high speed rail tracks and the classic network, has been modelled for the different maximum speeds (300 kph, 330 kph and 360 kph). For each scenario, the maximum speed was assumed to be required on 10% of journeys (to allow trains to catch-up on timetable following minor disruptions). For the remaining 90% of journeys, it is assumed that trains would operate up to the lower speed bracket (Table 1).

[15] For the purpose of this report grid electricity is considered 'sufficiently decarbonised' when the carbon emissions associated with the generation of one kilowatt hour (kWh) of electricity is less than or equal to 50 grams of carbon dioxide equivalent (gCO_2e).

The energy consumption per train kilometre of these average speed scenarios were multiplied by the total train kilometres travelled to provide the total energy consumption per scenario.

3.1.4 For the purpose of this assessment, two different projections of the rate and extent of grid decarbonisation have been adopted:

- CCC projections[16]; and,
- DECC/IAG projections[17].

3.1.5 The projections assume that decarbonisation occurs at different rates and therefore provide different projected carbon emission factors for UK grid electricity for future years. The energy consumption figures for each operational scenario have been multiplied by the carbon emission factors for each year. This has been completed for both grid decarbonisation projections and the results are therefore presented as a range. The carbon emissions from each scenario have been analysed and compared to give a relative change in carbon impact against the current planned operating scenario (trains running at 330 kph on 90% of journeys and 360 kph on the remaining 10% of journeys) and have been considered in the context of the overall carbon footprint.

3.2 Assumptions and Exclusions

This assessment has only considered the carbon emission implications associated with the manufacture, operation and maintenance of rolling stock for the different operating scenarios, as presented in Section 2.1.

3.2.1 Key exclusions include:

- Expected improvements in rolling stock system efficiency and management;
- Quantification of the impact that operating at slower speeds would have on modal shift and the associated carbon implication;
- Quantification of the impact that a larger rolling stock fleet size would have on the infrastructure design and the associated carbon implication;
- Consideration of carbon implications for Phase Two of HS2; and,
- Consideration of other impacts (e.g., noise, economics).

3.2.2 A full list of exclusions is contained in Appendix C.

3.2.3 Key assumptions in the scenarios above include:

- Grid electricity is considered 'sufficiently decarbonised' when the carbon emissions

[16] Factors derived from the Committee on Climate Change showing a projection of how the carbon intensity of the grid will reduce in the future in order to achieve the 2050 target set in the Climate Change Act.
[17] Factors derived from DECC / Interdepartmental Analysis Group (IAG) by the Department for Transport, WebTAG 2013 Emission factors - Long-run marginal - rail specific. These are a projection of how fast fossil fuel based electricity generation capacity will be replaced before 2050.

associated with the generation of one kilowatt hour (kWh) of electricity is less than or equal to 50 grams of carbon dioxide equivalent (gCO_2e);

- Once the carbon intensity of grid electricity reaches 50 gCO_2e/kWh, HS2 would operate as per the current planned operating scenario (330kph on 90% of journeys and 360kph catch up 10% of journeys for the purpose of this study); and,
- Limiting line speed would be a temporary measure (i.e., up until sufficient decarbonisation) and as such the need to design the infrastructure for a maximum speed of 360 kph with a passive provision, where appropriate, of 400 kph for future proofing remains.

3.2.4 A full list of assumptions is contained in Appendix C.

4 Results

4.1.1 The change in carbon emissions from manufacture, operation and maintenance (over 60 years) of the rolling stock under the scenarios assessed (Table 1) ranges between -1,000 tCO_2e and -27,000 tCO_2e (equivalent to a change of -0.07% to -1.97% in carbon emissions) assuming the CCC decarbonisation projection (Table 2). If sufficient decarbonisation according to DECC is assumed, the carbon emission reduction ranges from -34,000 tCO_2e to -101,000 tCO_2e (equivalent to a -1.53 to -4.56% reduction in carbon emissions, Table 2).

4.1.2 In the context of the total carbon footprint[18] of Phase One of HS2 (construction and 60 years of operation), limiting line speed to 300kph results in a carbon reduction of between -0.38% and -1.23% (see Table 2 and Figure 3). Limiting line speed to 330kph results in a change in carbon of between -0.03 and -0.42% (Table 2).

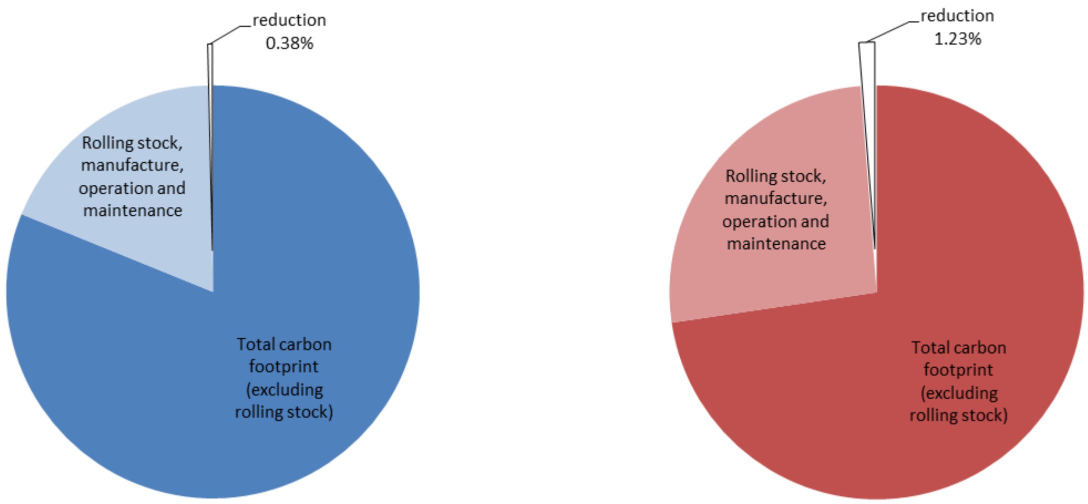
Table 2: Change in rolling stock manufacture, operation and maintenance (over 60 years) carbon emissions from the baseline for each speed and emission scenario

Line speed scenario	Change from manufacture, operation and maintenance of rolling stock from the baseline (tCO2e)	Carbon reduction in context of total carbon footprint
Scenario 1, 2030, CCC, 300 (90% 270kph, 10% 300kph)	-27,000 (-1.97%)	-0.38%
Scenario 2, 2030, CCC, 330 (90% 300kph, 10% 330kph)	-1,000 (-0.07%)	-0.03%
Scenario 4, 2040, DECC, 300 (90% 270kph, 10% 300kph)	-101,000 (-4.56%)	-1.23%
Scenario 5, 2040, DECC, 330 (90% 300kph, 10% 330kph)	-34,000 (-1.53%)	-0.42%

[18] Note that this does not include carbon benefits (i.e. modal shift, freight uptake of released capacity and carbon sequestration from tree planting).

4.1.3 Appendix D displays the absolute carbon emissions broken down by rolling stock manufacture, operation and maintenance alongside the emission reductions displayed in Table 2 and Figure 3.

Figure 3: Relative carbon reduction achieved in the context of the total carbon footprint (construction and 60 years of operation). The total carbon footprint and operational carbon footprint segments represent the baseline scenarios (line speed of 330/360kph) for both CCC and DECC, while the carbon reduction segment represents the reduction resulting from lowering the operating speed in line with the 270/300kph scenario.



5 Discussion

5.1 Estimated Carbon Reductions

5.1.1 The results presented in Section **Error! Reference source not found.** demonstrate that in the context of the overall carbon emissions arising from Phase One of HS2, the carbon reduction achieved by limiting line speed until the grid is sufficiently decarbonised is minimal (the change ranges from -0.03% to -1.23%). This value, however, does not represent the total net change in carbon emissions because the consequences that a change in line speed will have on other aspects of the footprint, such as modal shift and construction, have not been quantified as part of this assessment.

5.1.2 Limiting line speed has the potential to negatively impact other areas of the carbon footprint. For example, a slower train service could reasonably be expected to reduce the carbon benefits achieved by modal shift as, by increasing journey times, it could be expected that customers may be less likely to travel on HS2 over other modes of transport.

5.1.3 Additionally, the results presented are based on current technology. Expected improvements in rolling stock energy efficiency or other options to optimise energy efficiency, such as timetable refinements, have not been considered. It should therefore be acknowledged that opportunities to minimise carbon emissions and maximise carbon benefits exist across design, construction and operation. Furthermore, strategic actions for example procuring low carbon energy for rolling stock operation before the grid is sufficiently decarbonised could play a key role in reducing the operational carbon footprint.

5.2 Opportunities to Minimise Carbon Emissions

5.2.1 HS2 Ltd is committed to minimising carbon emissions and as such has defined a series of ambitions that reflect best practice within the sector and stakeholder expectations. For instance:

- HS2 Ltd's Sustainability Policy identifies its ambition to be an exemplar project;
- HS2 Ltd has developed a specific Carbon Minimisation Policy which commits HS2 to minimising the carbon impact of the Scheme and defines how this could be achieved, e.g., through low carbon options, material choices, energy efficiency and sequestration; and,
- HS2 Ltd has endorsed the Infrastructure Carbon Review which commits it to pursue lower carbon solutions that also cost less.

5.2.2 HS2 Ltd is developing a Carbon Management Strategy which forms an essential part of realising the carbon objectives of HS2. The Carbon Management Strategy uses the total carbon footprint published by HS2 as a tool to guide carbon management.

5.2.3 The following paragraphs explore the opportunities to drive positive carbon change across the operation and construction of the Scheme.

Operation

5.2.4 Due to the early stages in the development of the Scheme, HS2 Ltd has the opportunity to engage with the suppliers to drive rolling stock innovation. In addition, there are still potential opportunities to optimise the energy efficiency of the network. Such opportunities include:

- improved aerodynamic design of HS2 rolling stock;
- reduction of rolling stock weight;
- improved traction system efficiency (to reduce energy losses during motoring and braking);
- 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; and,
- opportunities for local renewable energy generation associated with stations and depots.

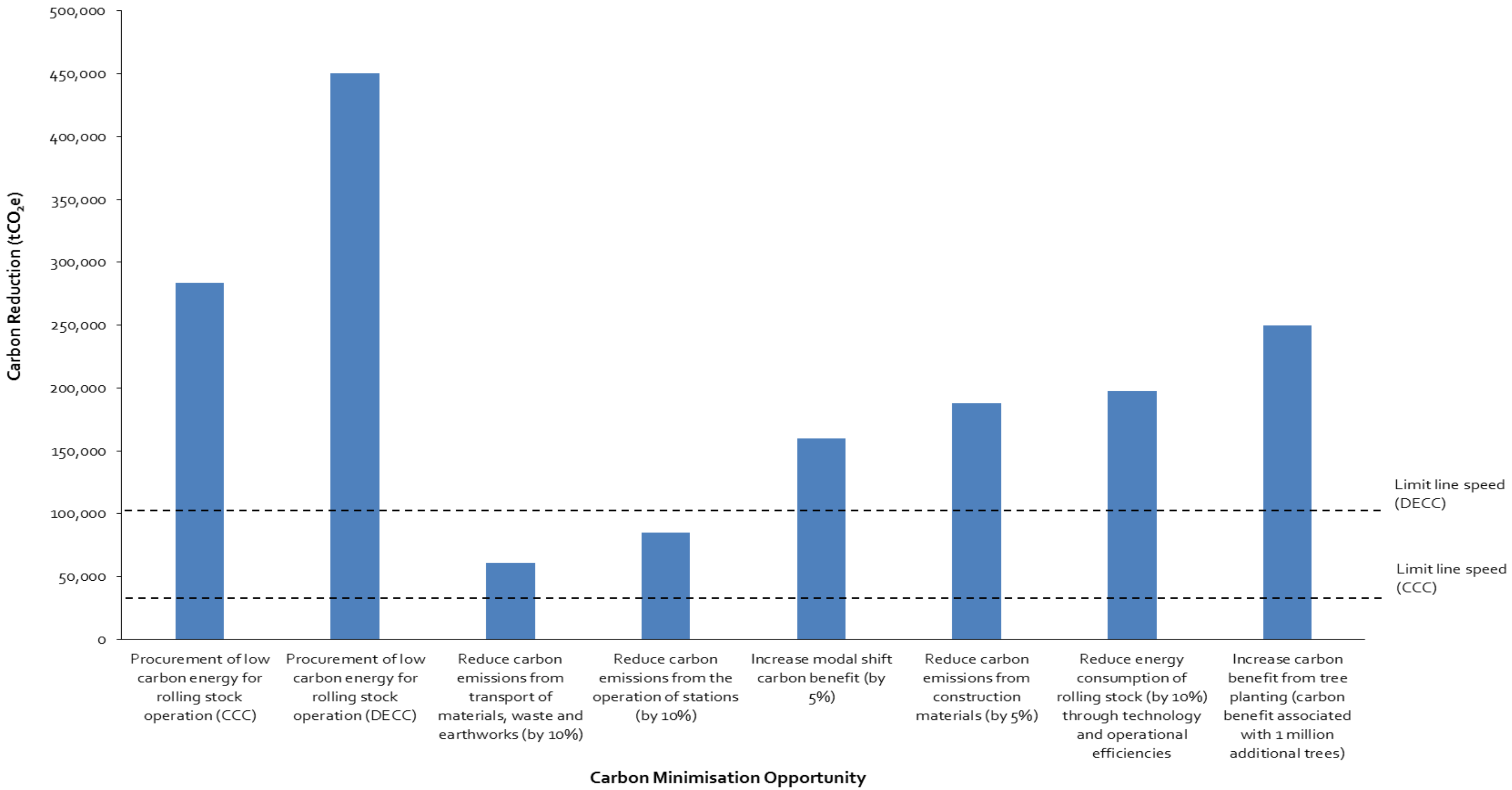
Construction

5.2.5 HS2 Ltd has identified a number of potential opportunities to minimise carbon emissions arising from the construction phase of the Scheme. These include:

- increased use of recycled materials (e.g., steel);
- use of less carbon-intensive concrete blends;
- improved design and construction of rolling stock to reduce weight where possible;
- maximum management and reuse 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 workforce travel to reduce travel impact;
- maximisation of materials transport via rail rather than road;
- energy efficiency in site management and transport; and,
- adoption of resource efficiency measures to tackle inefficiencies across supply chains, overuse of resources (e.g. materials, energy and water) and waste generation.

5.2.6 **Error! Reference source not found.Error! Reference source not found.** provides an illustration of potential carbon minimisation opportunities compared to the potential reductions that could be realised through limiting maximum line speed.

Figure 4: Potential carbon minimisation opportunities in the context of the reductions achieved through limiting line speed



6 Conclusions

6.1.1 This assessment demonstrates that limiting line speed offers minimal carbon reduction. Carbon emission changes range between -1,000 and -101,000 tCO_2e over 60 years, equivalent to a -0.03% to -1.23% change to Phase One of HS2's total carbon emissions (construction and 60 years of operation).

6.1.2 The results do not represent the total net change in carbon emissions as the potential consequences that a change in line speed may have on other aspects of the footprint, such as the carbon benefit associated with modal shift or the carbon emission implications of constructing additional infrastructure (e.g., additional station platforms and stabling to accommodate more rolling stock at depots) have not been quantified. Analysis of the impact on modal shift and associated carbon implications would be required to determine whether the net carbon emissions impact is positive or negative.

6.1.3 Regardless, in operation Phase One of HS2 would continue to be one of the most effective low carbon transport solutions for travel between London and the West Midlands. In terms of emissions per passenger kilometre, Phase One generates 8 gCO_2e/pkm as compared to inter-urban cars (67 gCO_2e/pkm), intercity rail (22 gCO_2e/pkm) and UK domestic flights (170 gCO_2e/pkm), based on projected carbon emissions in 2030.

6.1.4 Opportunities offering more certain and significant carbon emission benefits exist across the design, construction and operation of Phase One of HS2. Strategic actions, for example procuring low carbon energy for rolling stock operation before the grid is sufficiently decarbonised, could play a key role in reducing the operational carbon footprint.

6.1.5 Moreover, HS2 Ltd is committed to minimising carbon emissions, as articulated in its Sustainability Policy and Carbon Minimisation Policy and as demonstrated by the endorsement of the Infrastructure Carbon Review. HS2 Ltd is currently developing a Carbon Management Strategy to deliver its carbon minimisation objectives.

Appendix A: Executive summary to Parsons Brinckerhoff's report

1 Executive summary

1.1.1 The purpose of this study is to support the determination by the Environmental Overview Consultants (EOC) of carbon emissions and the implications on HS2 Ltd's carbon footprint of operating trains at lower limiting speeds of 360-270kph in 30kph steps. This study has considered both single train journeys and full-day timetables for both Phases One and Two as defined in the HS2 Train Service Specification.

1.1.2 This report provides the results of simulations and further desktop timetable analyses to demonstrate timetable impacts, journey times, energy demand, train set sizing, and effects of delay for the Phase One & Two routes to/from London and Birmingham, Manchester, Leeds, Newcastle, Glasgow and Edinburgh, using the HS2 routes, dedicated West Coast Main Line and East Coast Main Line.

1.1.3 In order to ensure HS2 can function as a robust, operational railway, the design and modelling carried out to date has adopted internationally recognised best practice timetable planning methodology. As such, while the maximum operating speed on HS2 is 360km/h, trains are able to achieve normal timetabled operation (i.e. required journey times) while operating up to between 320 and 340km/h. This allows for a margin which, put simply, enables trains to "catch-up" on the planned schedule following delays. Such a margin is critical to the reliable operation of a railway.

1.1.4 As a result of this, operation at 330km/h is shown in this report to have no impact on achievement of the required journey times. However, were the train speed to be limited to 330km/h, the timetable would need to be changed to recreate the necessary margin which allows for reliable operation. A timetable designed for 330km/h maximum speed (or lower) would need to be based on longer journey times than are currently required for HS2 and under such a timetable, trains would normally operate at a lower speed, expected to be around 300km/h. Unless otherwise stated, the increases in journey time reported in this document therefore reflect the increased timetabled journey time (including margins derived at 360km/h) rather than the minimum achievable journey times. It is ultimately these timetabled journey times which will be published to the travelling public.

1.1.5 The results as expected demonstrate that the energy demands reduce and journey times increase as a result of each stepped reduction in speed limit within the timetable runs carried out. Table ES1 below indicates the journey time increases for Phase One of stepped speed reductions:-

Table ES1: Change in timetabled journey time (and % increase) in Phase One for varying maximum railway operating speed scenarios (minutes) compared with Final ES

From	To	Final ES	330 kph	300 kph	270 kph
Euston	Handsacre	0 (0%)	2 (4.6%)	4 ½ (11.0%)	8 (19.8%)
Euston	Curzon St	0 (0%)	1 ½ (3.5%)	3 ½ (8.5%)	6 ½ (15.4%)
Handsacre	Euston	0 (0%)	2 (4.4%)	4 ½ (11.1%)	8 ½ (20.4%)
Curzon St	Euston	0 (0%)	1 ½ (3.2%)	3 ½ (8.3%)	6 ½ (15.4%)

1.1.6 Where extended running time leads to inadequate turnround time at termini, this results in trains "stepping down" at termini, introducing additional units into the rolling stock circulation, and thus adding to the fleet size. The change in fleet sizes following timetable review for Phases One and Two is listed below in Table ES2:-

Table ES2 – Additional 200m units needed in service for each maximum railway operating speed scenario compared with Final ES - Summary

Route	330 kph	300 kph	270 kph
Total (Phase One)	+2 CP, +1 CL	+2 CP, +2 CL	+2 CP, +2 CL
Total (Phase Two)	+2 CP, +5 CL	+4 CP, +5 CL	+8 CP, +8 CL

CP = Captive HS2 Stock, CL = Classic compatible for Network Rail operation

1.1.7 This "stepping down" at termini also adds to the platform occupation, as at the point at which an extra unit is introduced, what was a minimum turnround become well above minimum. Availability of additional platforms is forecast to be required:

- Phase 1:
  - Manchester Piccadilly, in the 300 kph and 270 kph scenarios, HS2 services would need to use three platforms, reducing platform capacity available to other services.
- Phase 2:
  - Curzon St: Regular use of an additional platform is necessary in the 330kph, 300kph & 270kph speed scenarios, but this is already provided in the Final ES infrastructure
  - Manchester Piccadilly: For the 270 kph scenario, a fifth platform is essential
  - Leeds: A sixth platform is required in the 300 kph scenario, and then a seventh in the 270 kph scenario
  - Liverpool: in the 270 kph scenarios, availability of a third platform for HS2 trains is required, reducing capacity for other services
  - Glasgow: use of an additional platform is required in the 330kph, 300kph & 270kph scenarios, reducing capacity for other services
  - York: use of an additional platform is required in the 330kph, 300kph & 270kph scenarios, reducing capacity for other services
  - Newcastle: use of two additional platforms is required in the 330kph, 300kph & 270kph scenarios, reducing capacity for other services

1.1.8 It is possible that these requirements could be mitigated by redesign of the timetable and measures such as shunting trains out of a station after arrival and back again before departure, but it is not possible to confirm this without extensive detailed analysis.

1.1.9 Table ES3 below indicates the 'HS2-infrastructure only' train energy reductions (known colloquially as Captive trains) observed as an indicative sample of of all trains, where other trains on routes beyond HS2 infrastructure are detailed further in this report:-

Table ES3 – Mechanical Energy consumption for Captive HS2 trains

Scenario and train make-up	Max (all out) speed (km/h)	All-out service energy (kWh/km)	% energy of all-out 360km/h scenario	Max attained speed (timetabled run with margin) (km/h)	Timetabled service energy (kWh/km)	% Timetabled Energy to all-out energy
1 - 11 car	360	23.78	100%	317.9 for 330 limit	20.50	86%
2 - 11 car	330	21.89	92%	300 for 300 limit	19.90	91%
3 - 11 car	300	19.71	83%	270 for 270 limit	17.60	89%
4 - 22 car	360	45.33	100%	317.3 for 330 limit	38.81	86%
5 - 22 car	330	41.57	92%	300 for 300 limit	37.85	91%
6 - 22 car	300	37.32	82%	270 for 270 limit	33.63	90%

1.1.10 From a journey time and energy reporting perspective the results align with expectations for longer journey times and lower energy overall. Journey times for services that operate on the classic network as discussed later in this report observe lower overall impact since the classic network operates <270kph in any case. Where all energy demand is quoted in mechanical energy terms (excluding regen braking since receptivity is not known within this study), we would recommend based on other work for HS2 in this area that an approximate 11% uplift for electrical demand (including regen braking) is appropriate.

Appendix B: Summary of key results from Parsons Brinckerhoff's report[19]

Scenario	Train type	Energy consumption for 200m units (kWh/km)[20]	Change (%)[21]	Change in fleet size (number of 200m units)	Change in journey time (minutes)	
					Euston - Curzon St	Euston - Handsacre
270/300kph	Captive trains	17.80	- 14%	+2	3.5	4.5
	Journeys with a component on the classic network	15.81	- 24%	+1		
300/330kph	Captive trains	20.08	- 3%	+2	1.5	2
	Journeys with a component on the classic network	18.03	- 13%	+2		

[19] All results are for Phase One only.
[20] The energy consumption figures are for HS2 trains on Phase One infrastructure only (i.e. modelled only for Phase One and excludes classic rail network operations).
[21] Changes are in comparison to the current operating scenario (360kph maximum speed with normal timetable operation at circa 330kph).

Appendix C: Assumptions and Exclusions

The assumptions and exclusions applied in this assessment are detailed in Table 3 and 4.

Table 3: Assumptions applied to the line speed assessment

Assumption
Grid electricity is considered 'sufficiently decarbonised' when the carbon emissions associated with the generation of one kilowatt hour (kWh) of electricity are less than or equal to 50 grams of carbon dioxide equivalent (gCO_2e).
Once the carbon intensity of grid electricity reaches 50 gCO_2e/kWh, HS2 will operate as per the current planned operating scenario (330kph 90% of the time with 360kph catch up 10% of the time for the purpose of this study).
There is a continuing need for the infrastructure to be designed to accommodate faster train speeds as this is likely to increase after substantial decarbonisation of grid electricity.
No advancement in rolling stock technology has been assumed throughout the 60 assessment years.
It has been assumed that track design will remain the same as part of this assessment and infrastructure construction emissions reported in the ES will not change.
A simplified approach to energy calculation has been undertaken which does not take into account factors such as energy regeneration in braking or electrical losses in the train systems or the railway power supply network. To account for these omissions, a net uplift[22] of 11% has been applied to the energy figures. This uplift is based on the results of previous more detailed analysis of these factors.
Energy consumption figures for journeys on the classic network were not recalculated for the purposes of this assessment, therefore original data used in the Environmental Statement was used here.
The line speed modelling was based on HS2's Phase One timetable for all speeds, fully acknowledging that in reality, slower speeds would require a modified timetable to avoid conflicts. Under this assumption 51 train units would be required for Scenario 3 and 6 (330/360 kph) and 54 train units would be required for Scenario 2 and 5 (300/330 kph) and 55 trains for Scenario 1 and 4 (270/330 kph).
Limiting line speed would be a temporary measure (i.e., up until substantial decarbonisation)

Table 4: Exclusions applied to the line speed assessment

Exclusion
Quantification of the impact that a larger rolling stock fleet size would have on the infrastructure design and the associated carbon implication.
Consideration of carbon implications for Phase Two of HS2.
Aspects that could be influenced by changes in line speed such as different modal shift and longer journeys have been excluded from this assessment.

[22] Depending on the sensitivity of the output that uses this mark-up, it would be prudent to undertake 'high & low' calculations of demand or cost based on this figure with +/- 2% tolerance given the limited sample size (18 trains) that was used, to include the range of costs expected.

Considerations of emerging rolling stock technology have been excluded from this assessment.
Consideration of improvements in system efficiency and management has been excluded from this assessment.
Surface Access to stations and implication associated with changes in passenger numbers as a result of changes in line speed has not been accounted for in the calculation as it is negligible.
Emissions from empty coach stock have been excluded from the assessment in line with the footprint reported in the Environmental Statement due to their minimal impact.
Consideration of other impacts (e.g. noise, economics).

Appendix D: Tabulated Results

Table 5: Carbon emissions and reduction from manufacture, operation and maintenance of rolling stock (tCO2e) under each line speed scenario in the context of the rolling stock and total carbon footprint

Line speed scenario	Emissions from rolling stock operation (tCO_2)	Emissions from rolling stock manufacture and maintenance (tCO_2e)	Emissions from manufacture, operation and maintenance of rolling stock (tCO_2e)	Change in emissions from manufacture, operation and maintenance of rolling stock from the baseline (tCO_2e)	Emissions reduction in rolling stock footprint	Emissions reduction in context of total footprint presented in the ES
Scenario 1, 2030, CCC, 300 (90% 270kph, 10% 300kph)	880,000	462,000	1,342,000	-27,000	-1.97%	-0.38%
Scenario 2, 2030, CCC, 330 (90% 300kph, 10% 330kph)	914,000	454,000	1,368,000	-1,000	-0.07%	-0.03%
Scenario 3, 2030, CCC, 360 (90% 330kph, 10% 360kph)	941,000	428,000	1,369,000	0	0.00%	0.00%
Scenario 4, 2040, DECC, 300 (90% 270kph, 10% 300kph)	1,645,000	471,000	2,116,000	-101,000	-4.56%	-1.23%
Scenario 5, 2040, DECC, 330 (90% 300kph, 10% 330kph)	1,720,000	463,000	2,183,000	-34,000	-1.53%	-0.42%
Scenario 6, 2040, DECC, 360 (90% 330kph, 10% 360kph)	1,780,000	437,000	2,217,000	0	0.00%	0.00%

References

The data sources used to calculate the rolling stock footprint are presented here:

Title	Reference
Energy consumption per train kilometre for captive and hybrid trains running on the HS2 network	C240-PBR-OP-REP-000-000017 'HS2 Carbon Implications Study Report' - Modelled data from Parsons Brinkerhoff.
Energy consumption per train kilometre for hybrid trains running on the classic network	Original ES data used
Emission factors - Climate Change Commitment (Scenarios 1-3)	The Committee on Climate Change showing a projection of how the carbon intensity of the grid will reduce in the future in order to achieve the 2050 target set in the Climate Change Act
Emission factors - DECC (Scenarios 4-6)	From DECC/Interdepartmental Analysis Group (IAG) by the Department for Transport, WebTAG 2013 Emission factors