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GREENGAUGE21

HIGH-SPEED RAIL

The carbon impacts of High Speed 2

09/2012

Since 2006, Greengauge 21 has been carrying out research and developing evidence on high-speed rail. Greengauge 21, a not-for-profit company limited by guarantee, seeks to act in the national and the public interest.

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The carbon impacts of High Speed 2

Greengauge 21

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This research has been sponsored by:

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Aims of the Research

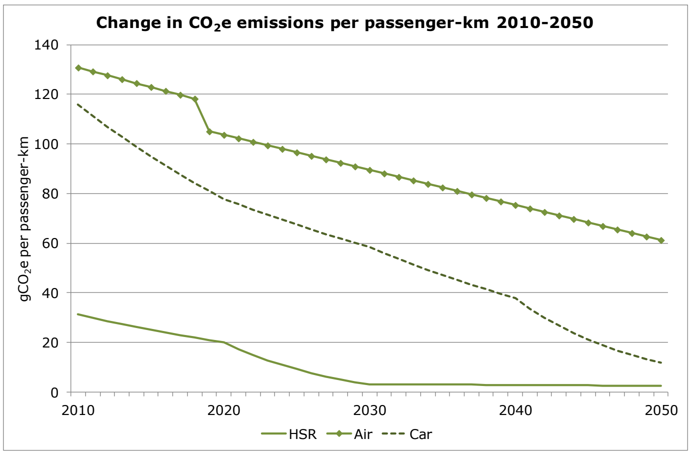
This research on the carbon impacts of High Speed 2 (HS2) was commissioned from Greengauge 21 by the Campaign to Protect Rural England (CPRE), the Campaign for Better Transport and the Royal Society for the Protection of Birds (RSPB). Its aim is to identify objectively the key factors that will determine HS2's contribution to reductions in the UK's carbon emissions and the steps that need to be taken to ensure that a consequence of HS2 is that carbon emissions are reduced. While carbon is not the only environmental issue related to HS2, it is an important element of the debate and is the focus of this research.

The evidence presented to date by HS2 Ltd appears to be equivocal on the carbon impact of HS2: we set out to establish if this is correct, or whether there could be a clear reduction in carbon, even though HS2 will inevitably attract and accommodate more travel.

Our work reviewed the evidence of HS2 Ltd and also drew on fresh analysis that we commissioned to look in detail into the crucial determinants of the level of carbon emissions, and in particular how these might change over time and/or in response to wider policy initiatives. Specifically, the research examined how net carbon emissions from HS2 will be influenced both by the railway's design, configuration and operation and by wider policy choices. The analysis focuses largely on the carbon impacts of phase 1 of HS2, between the West Midlands and London, although the implications of developing a more extensive high-speed rail network are discussed. While there are estimates available of the embedded carbon associated with HS2 infrastructure and rolling stock, it is difficult to establish reliable estimates of embedded carbon related to other transport modes, for example, the car fleet. We have therefore particularly examined the impacts of HS2 when it is in operation.

High-speed rail's carbon performance in comparison with other modes of transport

If HS2 was available for use today, the carbon emissions arising from making a trip by high-speed rail (HSR) would be 73% lower than making the equivalent journey by car and 76% lower than flying.



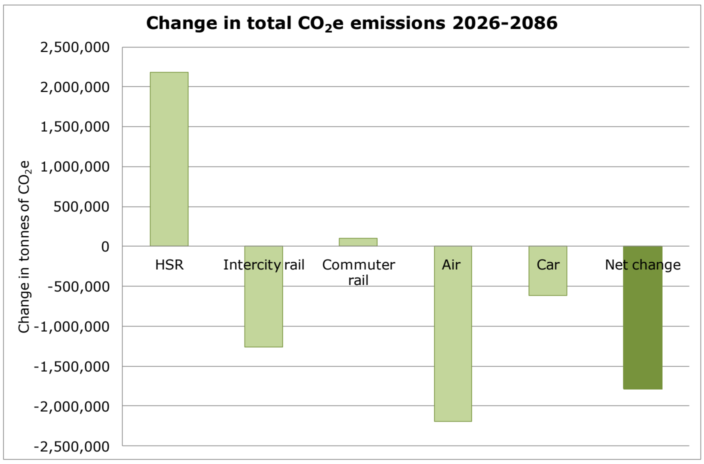
Over time, the carbon efficiency of different modes of transport will change. We expect the energy efficiency of all modes of transport to improve in response to the challenges of higher energy prices and the need to reduce carbon emissions. But the scope to achieve improvements varies across the different travel modes. High-speed rail is expected to benefit from much reduced carbon emissions as electrical power generation is decarbonised, and will therefore offer a major advantage over other modes, even if, as is assumed in the diagram, the private car fleet is also switched to low-carbon fuels, with a high proportion of electric vehicles.

The impact of HS2 on UK carbon emissions

We developed a base scenario, consistent with Government policies and forecasts, in which the operation of phase 1 of HS2 is estimated to reduce emissions by 1.8 million tonnes CO_2 equivalent

($MtCO_2e$) over 60 years.[1] This comfortably offsets the approximately 1.2MtCO2e embedded carbon that will result from construction of the line and confirms high-speed rail can reduce carbon emissions while increasing capacity and reducing journey times. This means that HSR can be part of a wider transport strategy that supports mode shift to sustainable modes and delivers reductions in carbon emissions.

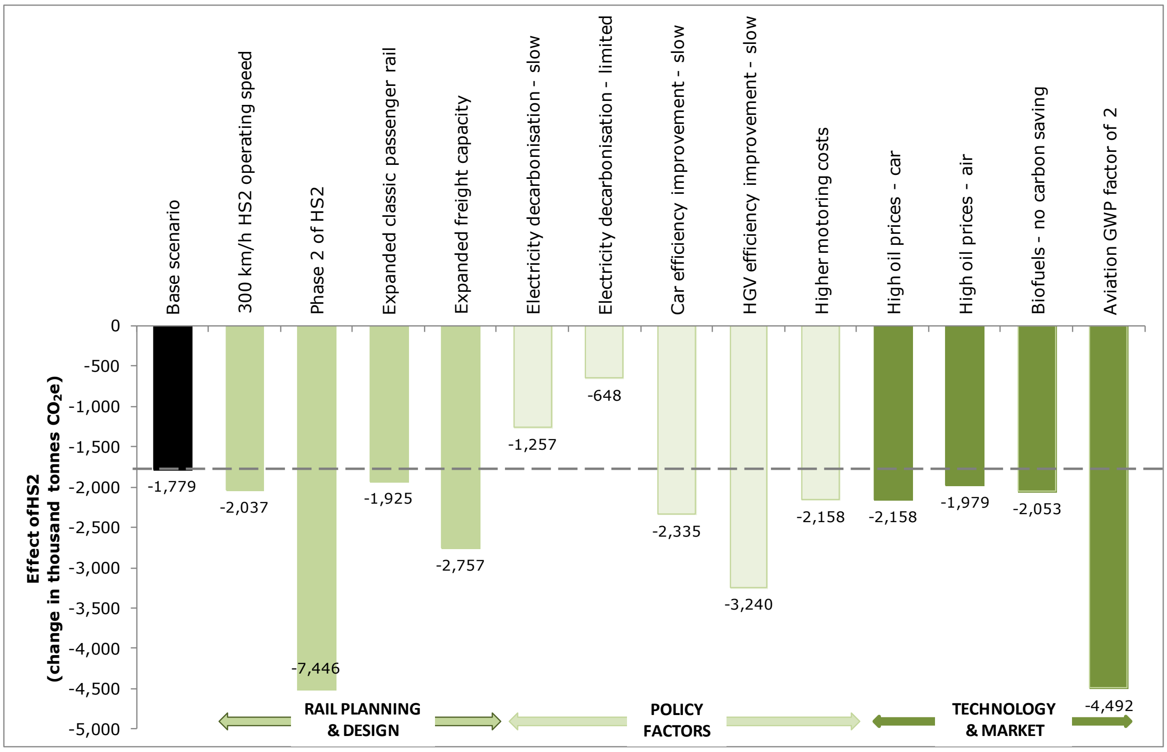
This forms the starting point of the main analysis, which is concerned with identifying the factors that influence the carbon benefits from HS2, and also the policies that need to be adopted to drive these environmental gains upwards and avoid the risk that the potential carbon benefits are not realised in practice.



Our work tested various plausible scenarios, looking at the effects on demand by mode, on energy consumption and on carbon emissions over each of the 60 years of the assumed project life. 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.

Scenarios

Under an environmentally-responsible scenario, the operational carbon savings could increase to 3.5$MtCO_2e$, increasing the net saving (taking into account embedded carbon) to 2.3$MtCO_2e$. But in contrast, under a laissez-faire scenario, without appropriate sustainability policies, it is possible that there will be no operational carbon savings available to offset the embedded carbon. The main areas that will influence the carbon case for HS2 are set out below.



[1] The 60-year period is consistent with standard appraisal guidance for major transport projects.

HSR design and operation

While the first phase of HS2 between London and the West Midlands is estimated to deliver a 1.8MtCO_2e reduction in carbon emissions, this would be increased four-fold to a saving of more than seven million tonnes CO_2e when the second phase of HS2 opens. The route extensions to Leeds, Manchester and Heathrow substantially increase the scope for mode shift from air and car travel.

Further, we conclude that, in the design for HS2 and for a wider HSR network, the following would maximise HS2's sustainability:

a) **Reducing the top speed of HS2 where justified, balancing energy consumption and mode shift**. Reducing the top speed of HS2 from 360km/h to 300km/h could reduce energy consumption by 19%. In the early years of HS2 operation, before the electricity supply is substantially decarbonised (say, before the 2030s), the carbon impacts of HS2 would be improved by adopting this lower top operating speed. Then, as electrical power generation is more fully decarbonised and the HSR network is extended, the journey time improvements on HS2 become even more important in delivering mode shift, and so a top speed of 360km/h is more likely to be needed and justified by the carbon savings from reduced air and private car travel;

b) **Construction of city centre stations rather than parkway stations where feasible**. City centre stations are estimated to be around 7% more efficient in carbon terms than parkway stations, even when only considering the direct impacts of HSR travel. The effect of local access trips to HSR stations, which can be made more readily by sustainable travel modes to city centre stations, will only increase this benefit. All HS2 stations need to be designed around high modal shares for sustainable access travel modes and supported by planning policies that deliver sustainable patterns of land use;

c) **Full use of capacity freed up on the existing rail network**. HS2 Ltd has adopted conservative assumptions on how much West Coast Main Line (WCML) capacity freed by HS2 is re-used for new and improved rail services. We estimate that the HS2 carbon savings could be increased by 8% by fully using spare WCML capacity for enhanced commuter or inter-regional passenger services. Even more benefits could be delivered with policies that ensure greater occupancy of these medium-distance trains. This highlights the value in ensuring that future rail franchises are set up so that they are able to unlock the spin-off benefits of HS2. However, the carbon savings from using the additional unclaimed capacity of three train paths per hour in each direction for freight are considerably larger still, adding 55% to the direct carbon savings from HS2. This is such a strong advantage that it will be worthwhile examining complementary measures to ensure that a major switch from HGV road haulage to railfreight is achieved as a consequence of HS2.

Public policy measures

As well as the extension of HS2 further north, wider policies that would have greatest effect in terms of maximising the potential of HS2 to reduce carbon emissions include:

a) **Ensuring the rate of electricity decarbonisation set out by the Committee on Climate Change is delivered.** The Committee on Climate Change (CCC) has recommended an ambitious decarbonisation trajectory for the UK's electricity sector which would result in the average HSR carbon emissions per passenger reducing by 92% by 2050. A slower but still relatively ambitious reduction in the carbon intensity of electricity could see the total HS2 carbon savings in the base scenario reduced by nearly one-third. A scenario in which there is a second 'dash for gas' and therefore slower decarbonisation would reduce the HS2 carbon benefits by two-thirds.

b) **Air capacity regulation and management.** HS2 will reduce the number of passengers making short-haul flights, and even the first stage of HS2 brings about a significant reduction in carbon from aviation, estimated at 2MtCO_2e over the life of the project. The question of how this result is affected by subsequent decisions on the numbers of runways and their levels of use at the congested South East England airports cannot be addressed at a national level because constraints on airport development in one country may simply move the location of airlines' hubs to other countries. Even if there is an uptake in longer-haul flights in place of displaced short-haul services at Heathrow, the aviation sector carbon reduction benefits of HS2 might therefore be achievable, particularly with appropriate regulation and management.

c) **Management and regulation of the motorway and trunk road network to reflect the external costs of driving.** Policies to manage the capacity and use of the strategic road network, including through pricing mechanisms, could increase the carbon savings of HS2 and would help ensure that the benefits of mode shift to HS2 are sustained. It is not possible to optimise the carbon savings by looking at individual travel modes in isolation; management of their use needs to be considered together.

d) **Transport and spatial planning policies to encourage sustainable travel choices.** Ensuring that HS2 serves locations of high demand density and locations where there is high capacity public transport should be a planning aim. The accessibility boost that HSR can provide to cities is a unique quality. It can be used to magnify the carbon benefits of HSR if complementary policies on spatial development seek to foster an intensification of development in urban areas so as to reduce trip distances and the need for private car use.

Uncertainties in technology and market developments

The key uncertainties that affect the carbon case for HS2, are:

a) **Improvements in the carbon efficiency of cars**. Large-scale decarbonisation of the transport sector requires substantial improvements in the fuel efficiency of cars and most likely a shift to a largely electric car fleet in the long term. If this does not take place as quickly as set out by the CCC, or if longer distance trips are harder to decarbonise than short trips (because of limitations of battery technology, for example), then the relative advantage of HSR travel becomes even greater and the HS2 carbon savings would be considerably higher.

b) **Future energy prices.** There are clearly considerable uncertainties over future energy prices, particularly for the road and air sectors where overall user costs are highly influenced by the price of oil. If oil prices rise in the long term above those assumed by the Department for Transport, then car and air demand would be depressed and the carbon savings from HS2 would be improved.

c) **Non-CO_2 impacts of aviation.** Our modelling has considered only the direct CO_2 impacts of HS2, given these typically account for 98% of greenhouse gas emissions from transport. The emissions from aviation are increased if account is taken of the effects of other non-CO_2 gases emitted at varying altitudes. Although there is high scientific confidence that the total climate warming effect of aviation is more than that from CO_2 emissions alone, there is considerable uncertainty as to the precise impact. If, as experts currently consider could be the case, non-CO_2 impacts double the direct CO_2 impacts, then the carbon savings from HS2 would increase sharply, with the base scenario resulting in a net saving of 3.3MtCO_2e.

d) **Sustainability of biofuels.** There is considerable concern that widespread adoption of biofuels in place of mineral-based fuels would not be sustainable because of direct and indirect land use effects as well as carbon accounting errors. If these effects are taken into account, the carbon intensity of car and air transport might be higher than current assumptions, increasing the attractiveness of HSR compared with other modes of transport.

In addition, there are a number of factors that we have not been able to quantify in this study but which are likely to increase the carbon emission savings from HS2.

Factor	Description	Likely impact
Direct HS2 services to continental Europe from the Midlands and the North	These have the potential to deliver a very valuable mode shift from short-haul international air services to HSR in the same way as Eurostar has delivered between London, Paris and Brussels	Positive
High-speed freight services on HS2	This could be achieved where/when there is spare HS2 capacity and with sufficiently high-performance high-speed electric freight trains. Freight carried by other transport modes has a significant carbon footprint and there are already trials in conveying high value freight by high speed rail on the continent.	Positive
Long-term demand growth beyond 2037	Rail demand continues to grow, with no evidence of market saturation, suggesting that the HS2 demand forecasts currently underplay the potential for even greater mode shift and carbon benefits in the long term.	Strongly positive
Land use changes	HS2 itself can be expected to have an effect on patterns of land use development around stations and urban centres, encouraging sustainable higher density development in cities. Compared with a more dispersed pattern of land use development, this brings major carbon benefits, and will be enhanced with improved rail services on the existing rail network. It would also be expected to boost the demand for HS2 and the transfer of passengers from other modes.[2]	Strongly positive

Conclusions and recommendations

Our analysis has demonstrated that HS2 is expected to deliver an increase in transport capacity while making a useful contribution to reducing the UK's carbon emissions from transport. It has also shown that there are several factors that exert a strong influence on the actual carbon outcome, and that many of these factors are subject to the influence of policies and measures that Government can apply. We recommend that a package of policy measures as a complement to HS2 should be adopted, to include:

1) **Commitment to developing a high-speed network**. Phase 1 of HS2 is the first step in creating a more extensive high-speed rail network. Published plans extend this network to Manchester, Leeds and Heathrow in phase 2, which would increase the carbon benefits by a factor of four as the mode shift impacts are substantially more beneficial with a larger network. A continuing investment programme, such as Greengauge 21 has suggested for the Great Western corridor to make it part of a high-speed rail network, would increase the benefits further.

2) **Rapid decarbonisation of the UK power grid**. One of the most important policy influences is the carbon intensity of power from the UK grid. If the trajectory of improvement falls behind that recommended by the CCC – which is an ambitious

[2] This analysis has considered certain land use factors, such as station location, but the wider effects of HS2 on land use, which will themselves have carbon impacts and which should be considered in the development of HS2 plans, have not been considered in this study.

government target requiring resolve and commitment if it is to be delivered – then there is a risk that the carbon savings from HS2 will fall short.

3) **Sustainable transport and planning policies to maximise mode shift from cars and planes**. Management of the national strategic road network and airport capacity regulation and management are necessary to ensure that the costs of different modes of transport reflect their environmental impacts. There should be sustainable spatial planning policies to encourage increased use of public transport and walking/cycling, and higher density development around stations, as a natural complement to the capacity offered on HS2.

4) **Configuration of HS2 to ensure efficient operation and high ridership**. City centre stations rather than parkway stations will attract more passengers to the high-speed rail network and the use of timetabling margins and efficient driving techniques will reduce energy consumption. In the early years of HS2 operation, before the electricity supply is decarbonised, the moderation of top speeds to 300km/h rather than 360km/h will manage HS2 energy usage, ensure carbon savings are delivered and have wider benefits in terms of noise reduction. This can be followed by a speed-up when the HSR network is extended and electrical power generation has been significantly decarbonised, as ultimately higher speeds will be needed to get the maximum benefit of diversion from other modes, especially as HS2 is extended.

5) **Full use of the additional capacity generated by HS2 on the existing network**. The ability to free up capacity on existing railway lines has always been recognised as being a key benefit of HS2. What this research shows is that the way the capacity is used on the classic lines – especially the WCML – has a dramatic effect on carbon. The central estimate of HS2's effect is increased by more than 50% if the three further train paths identified as being 'unclaimed' by HS2 Ltd's appraisal are set aside for and taken up by freight services. Coherent policies to exploit this opportunity would extend to the development of more and better rail freight access through terminals located in industrial areas.

Many of these measures are necessary regardless of HS2, to ensure that the trajectory to reduce carbon emissions set in the Climate Change Act 2008 can be achieved. Most of them will also help improve the business case for HS2 and bring wider benefits. Such a set of complementary policies for HS2 itself and on related matters could together ensure that the carbon legacy of HS2 is strongly beneficial. In other words, delivery of the carbon benefits of HS2 is in our own hands.

1. Introduction

1.1 High Speed 2

High Speed 2 (HS2) is a planned new high-speed railway line between London and the Midlands and the North of England, currently being progressed by Government. Its first phase, planned to open in 2026, will connect London and the West Midlands. The new HS2 trains operating over this 175 km railway will be up to 400 metres long, with over 1,000 seats. They will be able to operate at speeds up to 360 km/h, although the infrastructure is being designed for speeds up to 400 km/h, to allow for future technological development. In the first phase of HS2, there will be a connection to High Speed 1 and also to the West Coast Main Line (WCML) which will allow high-speed services from London to continue onwards to Manchester, Liverpool and Glasgow. In January 2012, the Secretary of State for Transport decided to progress with the first phase of HS2, planning for deposit of a hybrid bill in 2013 to secure the necessary legal powers.

Figure 1.1: High-Speed 2 - phases 1 and 2

Source: Department for Transport (January 2012), *High Speed Rail: Investing in Britain's Future*, Cm8247

The second phase of HS2 is currently under development and will see extensions to both Manchester and Leeds, together with a connection to Heathrow airport. The second phase is planned to open in the early 2030s.

Usage of the strategic road network, mainline railways and south east airports is currently high and demand is forecast by the Department for Transport (DfT) to continue to grow. While there are different views on whether or not road traffic levels will continue to grow, nevertheless, it is

Government policy that rail should provide increased capacity needed for the future. The prime rationale for HS2, therefore, is that it provides additional transport capacity using the most sustainable of the long distance travel modes. HS2 will allow many existing intercity rail services to be transferred to the new, faster route, freeing capacity on the existing railway for more commuter, local, regional and freight services. By offering a high-speed and highly reliable service it is forecast by Government that significant numbers of travellers will be attracted away from car or air travel with consequent benefits in terms of reductions in carbon emissions, congestion and other environmental impacts such as land use and noise.

1.2 Framework for greenhouse gas reduction

Rapid and significant reductions in global greenhouse gas (GHG) emissions is critical if we are to succeed in avoiding dangerous levels of climate change, and this is reflected in international, European and national targets. The European Union aims to reduce greenhouse gas emissions by 80-95% by 2050 compared to 1990 levels. In the UK, the ultimate 2050 target of a reduction of at least 80% has now been made legally binding through the Climate Change Act 2008, along with a system of five yearly carbon budgets.[3]

Domestic transport in the UK currently represents approximately 21% of total UK greenhouse gas emissions.[4] By 2050, on the basis of what can be achieved in all sectors of the economy, the Committee on Climate Change (CCC) estimates that an emissions reduction of more than 90% will be needed from surface transport in order to meet the economy-wide 80% reduction target. While greenhouse gas emissions from international aviation and shipping are not currently included within the carbon budgets set under the Act, the CCC has advised Government that they should be. Even if they are not, the Act still requires that these international emissions are taken account of when setting carbon budgets. By 2050, on the basis of what can be achieved in all sectors of the economy, the Committee on Climate Change (CCC) estimates that a reduction emissions from domestic sectors of more than 90% will be needed in order to meet the headline target of at least 80%.

Carbon dioxide (CO_2) is only one of six greenhouse gases covered by the Climate Change Act, although the vast majority (around 99%) of transport's direct greenhouse gas emissions are CO_2. Hence in relation to transport, CO_2 and GHG are sometimes used interchangeably. The main exception to this is in relation to aviation, where the effect of non-CO_2 emissions on climate change appears to be significant.

1.3 Purpose of Research

In summer 2011, the Campaign to Protect Rural England (CPRE), the Campaign for Better Transport and the Royal Society for the Protection of Birds (RSPB) commissioned Greengauge 21 to carry out research into the potential CO_2 impacts of HS2. Greengauge 21 has in turn commissioned various experts in the environmental and transport fields and coordinated the research programme.

The three commissioning organisations are all signatories of The Right Lines Charter, which has highlighted the need for high-speed rail 'to be planned and justified as a strategic element of a sustainable, near zero carbon transport system'.[5] Together with Greengauge 21, they believe that high-speed rail needs to contribute to reducing the UK's carbon emissions in line with the overall targets in and interim carbon budgets set by the Climate Change Act. Although climate change is a major threat to the protection of landscapes and biodiversity, some measures to reduce emissions may have negative impacts too. Ultimately, all such impacts have to be taken into account.

[3] See Climate Change Act 2008 at http://www.legislation.gov.uk/ukpga/2008/27/section/24
[4] See http://assets.dft.gov.uk/statistics/series/energy-and-environment/climatechangefactsheets.pdf
[5] The Right Lines Charter was launched in April 2011 and thirteen organisations have now signed up to it. It sets out four principles for 'doing High Speed Rail well'. See http://rightlines.org.uk/.

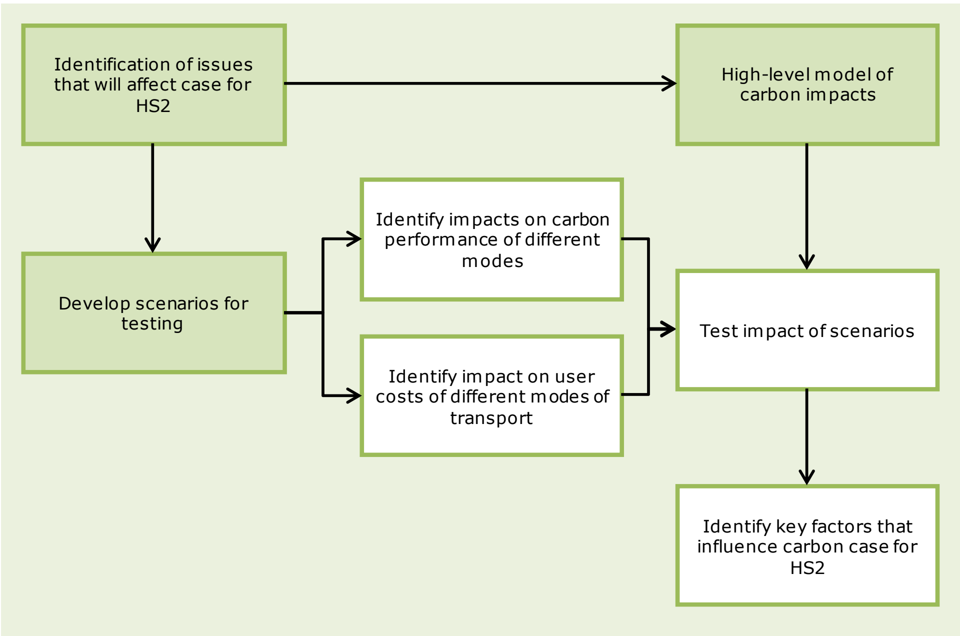
Some analysis on the potential range of carbon emissions from HS2 has been carried out for HS2 Ltd, the Government company responsible for planning the new line.[6] This found that HS2 would be broadly 'carbon neutral'. However, this analysis looked purely at impacts of the construction and operation of HS2, based on DfT and HS2 Ltd forecasts and assumptions, without considering many other factors. The intention of this new research is to take a broader view. Specifically, the research examines how net carbon emissions from HS2 will be influenced by both the railway's design, configuration and operation and by wider policy choices. The aim of the research was to identify objectively the key factors that will determine HS2's contribution to reductions in the UK's carbon emissions and to identify what steps need to be taken to ensure that a consequence of progressing with HS2 is that carbon emissions *are* reduced.

While the research and analysis is based primarily on the proposals for the first phase of HS2 (London – West Midlands, including the HS1 link), consideration has been given to the potential implications of developing a more extensive high-speed network in due course.

1.4 Study approach

The overall approach to the study is illustrated in Figure 1 below. Findings from phase 1 of the study (covering the tasks in the shaded boxes in Figure 1.2) were set out in an interim report published in December 2011. Phase 2 has now been completed and is the subject of this report.

Figure 1.2: Study Approach



This work has been informed by valuable supporting analyses from a panel of technical experts:

- Dr Ian Skinner of Transport and Environmental Policy Research (TEPR) provided an analysis of the environmental, transport, energy and other policy issues that will

[6] Booz & Co and Temple Group, (February 2011), *HS2 London to the West Midlands, Appraisal of Sustainability – Appendix 2 Greenhouse Gas Emissions*. Available at: http://highspeedrail.dft.gov.uk/library/documents/appraisal-sustainability

influence the carbon case for HS2, both directly and comparatively with respect to other competing modes of transport;[7]

- SYSTRA carried out an analysis of the energy consumption and carbon performance of high-speed trains and how this varies according to speed, rolling stock design, operating practices and infrastructure configuration;[8]
- The Association of Train Operating Companies (ATOC) updated their 2009 analysis of the carbon performance of high-speed rail[9] and developed the carbon modelling tools;
- Atkins provided analysis on the travel demand impacts of HS2.

Advice was also provided by the Rail Freight Group on the assessment of potential benefits from increasing capacity for rail freight.

1.5 Structure of report

The remainder of this report is structured as follows:

- Chapter 2 describes the development of 'base scenario' estimates of the carbon impacts of HS2;
- Chapter 3 assesses the influence of individual policy factors, future technological developments and HS2 configuration on the carbon case for HS2;
- Chapter 4 sets out potential future scenarios to illustrate the range of carbon impacts;
- Chapter 5 sets out our conclusions from this work.

A full analysis of the policy, high-speed rail and other issues that are likely to affect the carbon case for HS2 is set out in Appendix A, previously published as our interim report.

This research has been sponsored by Siemens and SYSTRA, who have provided funding and in-kind contribution of resources. Greengauge 21, CPRE, the Campaign for Better Transport and RSPB thank these sponsors for their generous support, as well as the Association of Train Operating Companies (ATOC) for their assistance and the Rail Freight Group for advice provided.

[7] See TEPR (November 2011), *Carbon impact of HS2: Overview of relevant policy issues and advice on modelling assumptions*. Available at: http://www.greengauge21.net/wp-content/uploads/TEPR-Overview-of-policy-issues.pdf
[8] SYSTRA (November 2011), *Carbon impacts of HS2: Factors affecting carbon impacts of HSR*. Available at: http://www.greengauge21.net/wp-content/uploads/SYSTRA-Factors-affecting-HSR-carbon-impacts.pdf
[9] ATOC (2009), *Energy consumption and CO2 impacts of High Speed Rail: ATOC analysis for Greengauge 21*. Available at: http://www.greengauge21.net/publications/fast-forward-a-high-speed-rail-strategy-for-britain/

2. The impacts of HS2 on carbon emissions: base scenario

2.1 Modelling approach

The carbon emissions of HS2 arise from two sources:

i) The embedded carbon associated with infrastructure construction and rolling stock manufacture; and

ii) The operational carbon emissions from operating the high-speed trains, plus the impacts on other transport modes.

While our new analysis has focused only on the operational carbon impacts of HS2, the embedded carbon associated with HS2's infrastructure construction and rolling stock manufacture has previously been assessed in the HS2 Appraisal of Sustainability[10] and we consider the combined impacts of operational and embedded carbon in Chapter 5.

In summary, the embedded carbon in HS2 infrastructure is expected to amount to approximately 1.2 million tonnes of CO_2 equivalent ($MtCO_2e$), although there is some uncertainty around this and it is affected by the nature of the route, in particular the amount of tunnels, viaducts and earthworks. Embedded carbon in HSR rolling stock is not expected to be significant. The HS2 Appraisal of Sustainability does not consider the likelihood that without HS2, there will be more intensive use of existing infrastructure, leading to more extensive renewals over the appraisal period and the probability that some other investments in transport infrastructure would be made. In particular, the embedded carbon impacts of road vehicle construction has not been assessed, nor the implications of higher vehicle use or ownership that might arise if insufficient rail capacity is provided. In such a without-HS2 scenario, there would be additional embedded carbon to account for, and the net embedded carbon effect of HS2 would therefore be lower than the $1.2MtCO_2e$ estimate.

The CO_2 impacts of HS2 operation are assessed over a 60-year period and take into account:

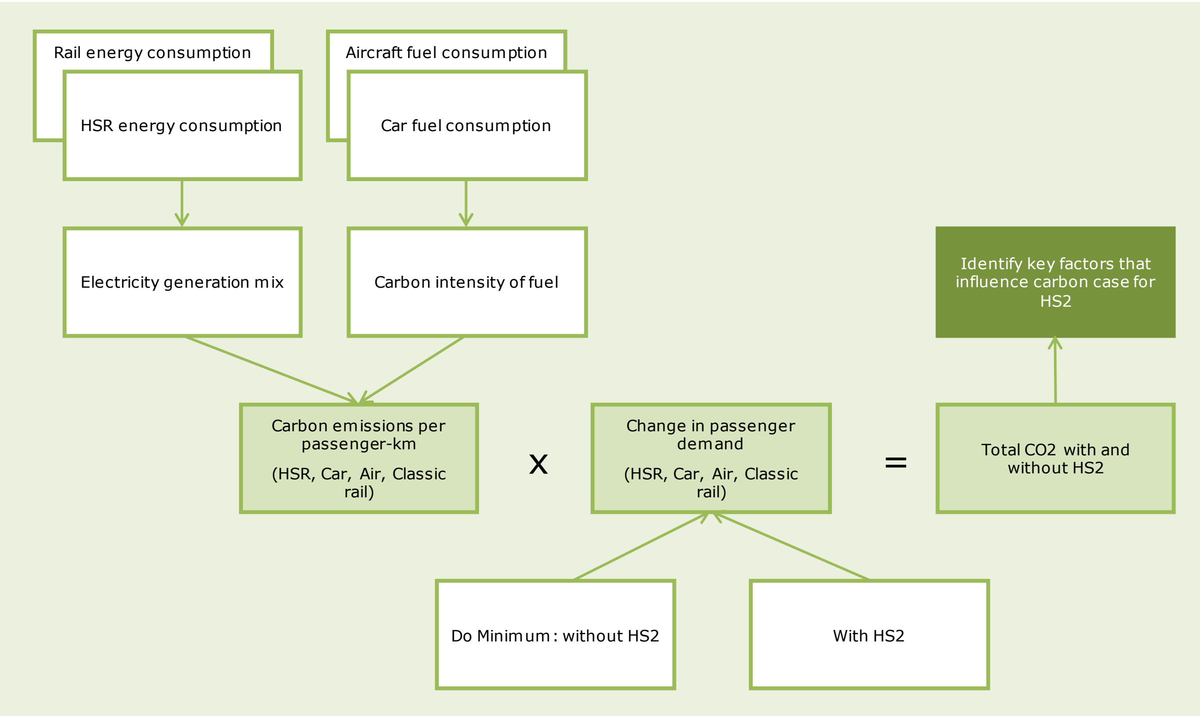
- The CO_2 emissions arising from HS2 operation, and how these change over time as the electricity used to power the HS2 trains becomes progressively decarbonised;
- The reduction in emissions associated with a shift from car travel, and how this changes over time as the car fleet becomes more efficient and eventually shifts, at least in part, to electric cars;
- The reduction in emissions associated with a shift from air travel, and how this changes over time as the aviation sector becomes more energy efficient;
- The change in emissions from conventional (or 'classic') rail services: rationalisation of intercity trains reduces emissions but emissions from expanded freight, local and commuter services using the freed-up capacity increases – and these too have consequential effects on other modes of transport.

The key inputs to the work were the assessments carried out by TEPR and SYSTRA on the current and likely future carbon efficiency of different modes of transport, together with the HS2 demand forecasts published by HS2 Ltd. As illustrated in Figure 2.1, the overall approach was to develop estimates of the carbon emissions per passenger-km travelled for each mode of transport for each year and to factor these by the forecast change in demand arising from HS2. A range of sensitivity tests was carried out in order to understand which of the underlying factors are most significant in

[10] Booz & Co and Temple Group, (February 2011), *HS2 London to the West Midlands, Appraisal of Sustainability – Appendix 2 Greenhouse Gas Emissions*. Available at: http://highspeedrail.dft.gov.uk/library/documents/appraisal-sustainability

influencing the carbon case for HS2. These were then combined into scenarios to understand the range of potential outcomes from HS2.

Figure 2.1: Carbon modelling approach



The 'base scenario' was constructed using the recommended central assumptions by TEPR and SYSTRA, together with the central HS2 demand forecasts. This was based on the first phase of HS2 only, although the impact of a more extensive network is assessed in Chapter 3.

2.2 Impact of HS2 on travel demand

HS2 changes carbon emissions because of the impact on the provision of transport services, as new passengers are attracted to HS2 services away from existing air and rail services and from private car travel. The HS2 Ltd passenger forecasts in Figure 2.2 show demand expressed in passenger-km (passenger trips multiplied by journey length) in the two forecast years 2026 and 2037.[11]

HS2 Ltd's published appraisals assume that demand does not grow beyond 2037 although it is understood that an amendment has since been made to cap demand growth in 2033, seven years after the first phase of HS2 opens. While we have not sought to test as a sensitivity the rather more likely assumption – based on all the relevant evidence – that long distance rail demand will not stop growing in an arbitrary year in the 2030s, the effect of a most likely case, with demand continuing to grow, even if at a lower level, would be to increase our estimates of operational carbon savings from HS2 will bring.

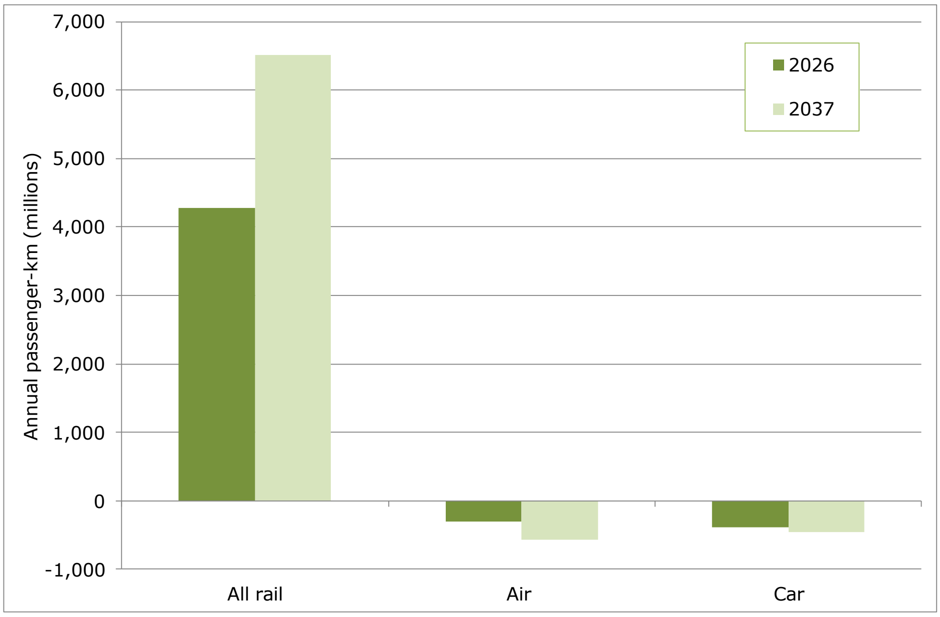
In 2037, the net increase in rail passenger demand on HS2 Phase 1 is forecast to total 6.5 billion passenger-km per year. The breakdown of impacts on each mode of transport is forecast to be:

- Demand for HS2 services of 13 billion passenger-km;

[11] The source data is extracted from the HS2 Ltd spreadsheets available at: http://www.hs2.org.uk/eco-consresp

- A reduction in demand for existing intercity rail services as long distance passengers switch to the HS2 services. Approximately two-thirds of HSR demand in the first phase of HS2 is forecast to transfer from existing rail services;
- An increase in demand for commuter or regional rail services, which will be expanded and improved to use some of the freed capacity on the existing railway network;
- A reduction in air passengers, who switch to HS2 services, comprising around 9% of the increase in total rail demand;
- A reduction in car travellers who switch to HS2 or to the improved commuter and regional rail services, comprising approximately 7% of the increase in total rail demand.

Figure 2.2: Forecast demand impacts of HS2 phase 1



The net effect of the changes shown in Figure 2.2 is an increase in demand, reflecting the additional capacity and rail services on offer. These forecasts of HS2 demand are the most up-to-date and comprehensive forecasts currently available and have been prepared according to Department for Transport WebTAG guidelines[12] for demand forecasting and economic appraisal and standard rail industry demand forecasting techniques.

Nevertheless, they are based on a set of assumptions which do not necessarily appear to be the most appropriate for such a long-term investment project as HS2, partly because of the arbitrary assumption of a demand cap soon after the line is open, as noted above. The organisations that commissioned this report have some reservations over the resulting forecasts, largely that because of unrealistically low DfT assumptions on the future costs of driving and flying they underplay the potential of high-speed rail to deliver mode shift from private to public transport. There have also been challenges to DfT's forecasts of background car growth, on the basis that road traffic may now be reaching saturation levels, although rail demand, which has more impact on this analysis, continues to grow strongly.

In addition, the current fares policy of above-inflation rail fare increases is assumed to continue into the future, albeit at a lower rate, RPI+1%, than currently planned for 2013. The effect of this is that over time the cost of using the rail networks will increase relative to other modes of transport, thereby suppressing rail and HSR demand.

The impact on the carbon case for HS2 of varying some of the key assumptions is discussed in Chapter 3.

[12] The full suite of guidance is available at: http://www.dft.gov.uk/webtag/

2.3 Carbon emissions by mode

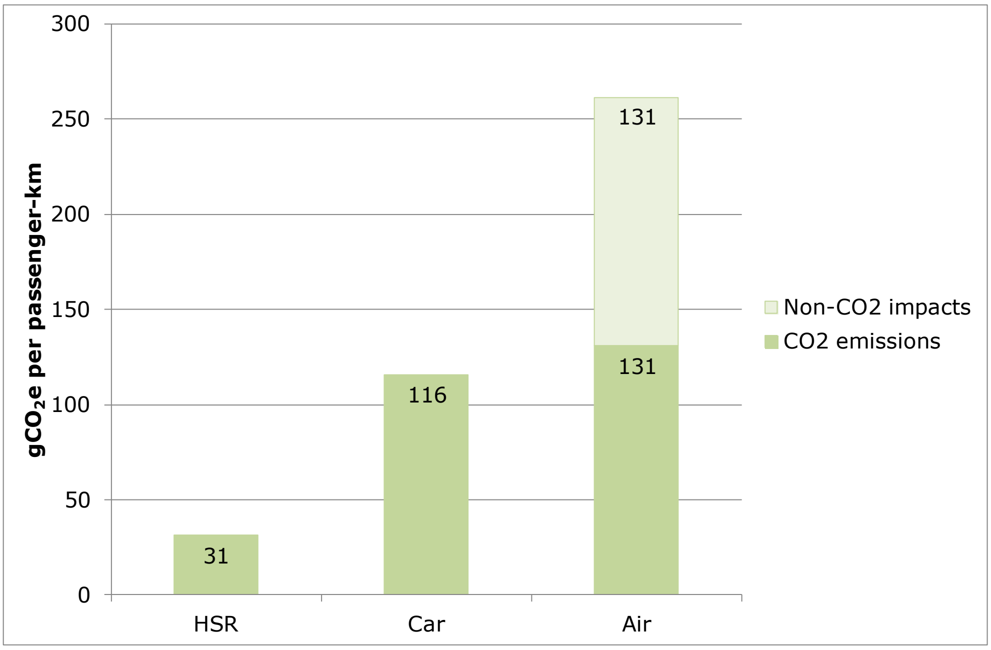
To assess the carbon implications of the demand shifts presented above, a model of carbon emissions for different modes of transport was constructed. The assumptions used in the carbon modelling are set out in Appendix B.

A comparison of current carbon emissions for HSR, car and air is set out in Figure 2.3. This updates the previous analysis carried out by ATOC in 2009: it draws on HSR energy consumption modelling carried out by Imperial College for HS2 Ltd,[13] takes into account SYSTRA's analysis of the impact of operating speeds, TEPR's analysis of energy efficiency of other modes and DEFRA's reporting guidelines on carbon intensity of different fuel sources.[14]

The emissions throughout this report are expressed in units of carbon dioxide equivalent (CO_2e), a measure that in principle includes all six greenhouse gases. Given that, for transport, CO_2 constitutes around 99% of CO_2e, we follow the recommended Department for Transport (DfT) approach of using CO_2 as a proxy for CO_2e.

As Figure 2.3 demonstrates, for a single trip, travel by HSR is considerably more carbon efficient than other modes of transport, producing only 27% of the emissions of travelling by car and 24% of the emissions of short-haul air travel.

Figure 2.3: Comparative CO_2e emissions by mode, 2010



A distinction is made in Figure 2.3 between CO_2 impacts and non-CO_2 impacts. While all the carbon modelling that follows is based solely on the CO_2 impacts, it is recognised that aviation also has a non-CO_2 impact on greenhouse gas emissions, which is very uncertain but is currently estimated to be approximately double the CO_2 impacts.[15] If a Global Warming Potential (GWP) factor of 2 is applied to the CO_2 impacts, air travel would have around eight times the greenhouse gas effect of HSR travel.

Estimates of carbon emissions for classic rail trains operating on the WCML have also been made. While not illustrated in Figure 2.3, they are similar to those for HSR, at approximately 37g CO_2e

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[13] Imperial College (2009), *HS2 Traction Energy Modelling.*
[14] 2012 Guidelines to Defra/DECC's GHG Conversion Factors for Company Reporting.
[15] Committee on Climate Change (December 2009), *Meeting the UK Aviation Target – options for reducing emissions to 2050.*

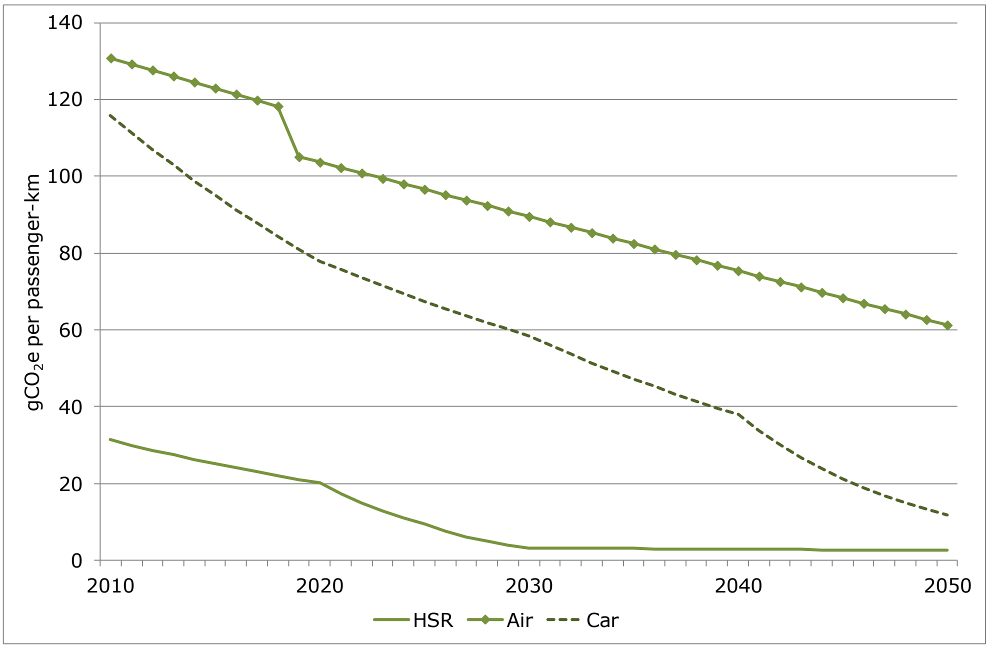
per passenger-km for electrically-powered intercity trains. The lower energy requirement of the classic trains that results from lower operating speeds is offset by the effect of shorter trains (constrained by infrastructure limitations), lower load factors and the effect of a greater proportion of the journey spent braking/accelerating.

The carbon assessment takes into account the expectation that the relative position of the different modes of transport will change over time:

- HSR will become more efficient as our electricity supply decarbonises. The Climate Change Commission's 'medium abatement' scenario, which is used for our base scenario forecasts, would see the UK-wide carbon intensity of electricity reduce by over 90% by the 2030s. While this CCC scenario is consistent with targets set out in the Climate Change Act, this scenario does not yet form Government policy;
- The carbon emissions of cars will reduce, in the short term as EU targets become tougher, and in the medium term with an anticipated shift towards an electric car fleet (which will benefit from decarbonisation of the electricity supply). This improvement is offset very slightly by DfT's forecast of continued small reductions in car passenger occupancy levels over time;
- Aviation becomes more efficient, with nearly 50% improvement in energy efficiency possible by the 2050s and some benefit from modest take-up of biofuels.

Figure 2.4 illustrates our forecasts of the impact of these changes. The timeline shows that while the absolute advantage of HSR over car or air travel is expected to reduce in the future, its proportionate advantage widens considerably by the 2040s as the electricity supply becomes decarbonised and remains so in future decades. By 2050, a progressive shift towards an electric car fleet would mean that carbon emissions from cars will be considerably reduced.

Figure 2.4: Change in CO_2e emissions per passenger-km 2010-2050



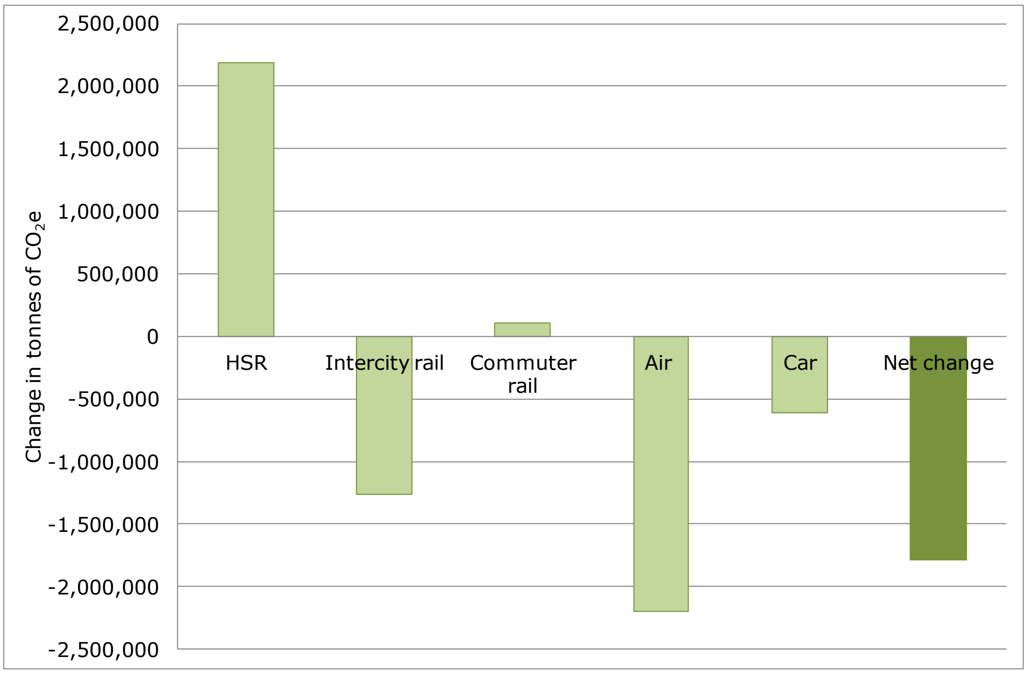
2.4 Change in carbon emissions

To estimate the impact of HS2 on carbon emissions, the changes in passenger demand are factored by the unit carbon emissions. The carbon impacts are assessed over a 60-year period, from the opening of HS2 in 2026 until 2086, although all the underlying parameters are assumed unchanged from 2050.

As a starting point, the modelling implicitly assumes that the provision of HSR, conventional rail and air services is directly related to the level of demand, so that as demand increases or reduces, the number of services operated is adjusted commensurately. When considering the first-order impacts, this is likely to be a reasonable assumption, but second-order impacts, including whether or not freed-up airport and road capacity gets re-used, are discussed further in Chapters 3 and 4.

Under the base scenario it is estimated that HS2 would reduce greenhouse gas emissions by 1.8 million tonnes CO_2e over 60 years. This is a small proportion of the total UK carbon emissions from transport, but is nevertheless significant when considering the increase in capacity and reduction in journey times provided by HS2. Figure 2.5 illustrates the change in emissions by mode: while the new HSR services are estimated to produce emissions of approximately 2.2 million tonnes CO_2e, this is more than offset by reductions in emissions from air travel of 2.2 million tonnes, from car travel of 0.6 million tonnes and intercity rail services of 1.3 million tonnes.

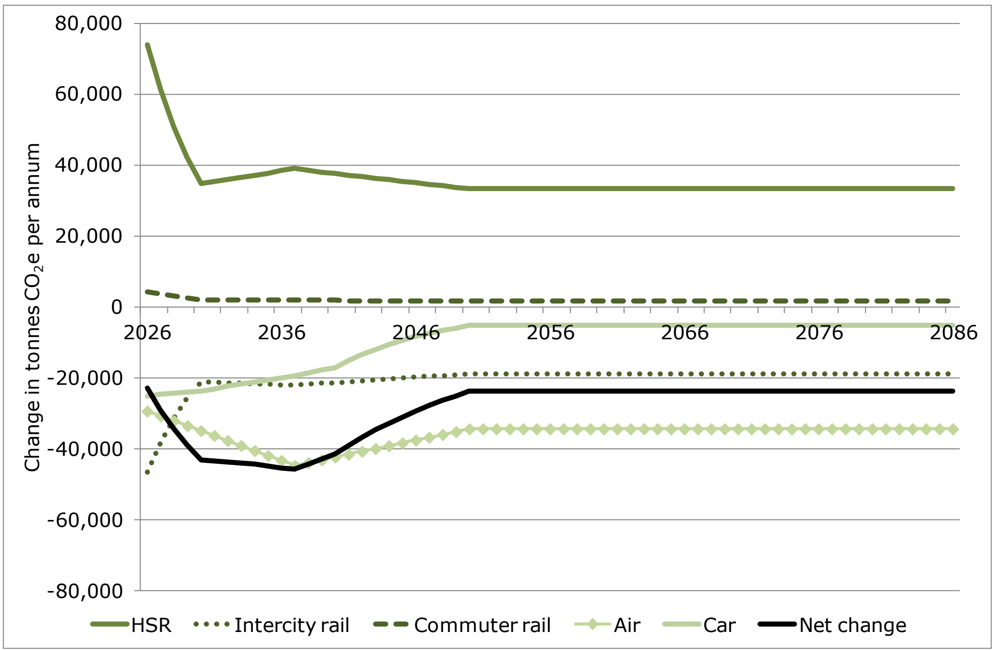
Figure 2.5: Change in total CO_2e emissions 2026-2086



The breakdown of the changes in carbon emissions by year is illustrated in Figure 2.6. Both the underlying demand forecasts and the estimates of unit emissions by mode change over time and so the figure shows the combined effects. In every year there is a net reduction in carbon emissions from HS2. While the net savings are largest in the 2030s and 2040s, there is still a substantial net saving in the long term, even after substantial improvements in the carbon efficiency of alternative modes have been delivered.

The importance of the assumptions on electricity decarbonisation can be seen: the first five years of HS2 operation coincide, under central policy assumptions, with a period of rapid electricity decarbonisation which reduces both the additional emissions associated with HS2 and the saving in emissions resulting from the rationalised classic intercity rail services.

Figure 2.6: Annual change in CO_2e emissions 2026-2086



For these base scenario estimates, only passenger demand effects are quantified, consistent with HS2 Ltd assumptions. The freed capacity on the existing railway could be used for expanded rail freight services too and the potential carbon benefits of this are discussed in Chapter 3.

2.5 Summary of findings

Under base scenario assumptions, the operational phase of HS2 makes a valuable contribution to reducing the UK's carbon emissions into the long-term. In every year HS2 brings about a net reduction in savings. The savings are highest in the 2030s and 2040s, once the UK's electricity supply is assumed to be largely decarbonised, but the benefits persist into the long-term, even when other modes have improved their performance. In Chapters 3 and 4 we explore the factors that will affect the scale of the carbon change that HS2 brings about.

What also needs to be considered, particularly in the long term, is the level of resource that is used for long-distance travel, even if shifts have been made to less carbon-intensive forms of energy. For example, using high-speed rail for a passenger trip between London and Birmingham would use approximately 12.4kWh in energy, 13% less than estimated for a trip by electric car, at 14.1kWh[16] (even if battery technology improved to enable such trips). Car trips over 25 miles are currently responsible for 36% of total CO_2 emissions from car travel. Moreover, a shift to an electric car fleet will have implications for total electricity consumption, which will need to be managed carefully. Net electricity consumption in the UK could potentially be increased by 20% if the entire car fleet were replaced with electric vehicles, depending on charging patterns, and could place a strain on the limited supply of renewable electricity.[17] HSR could allow better use to be made of limited resources and environmental capacity.

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[16] This is based on WebTAG assumptions on electric car energy consumption, which appears to be at the low end of the range of energy consumption of electric cars currently on the market, and average vehicle occupancy of 1.6. Source: Department for Transport (June 2012), *TAG Unit 3.5.6 Values of Time and Vehicle Operating Costs (draft)*.
[17] Aaron Holdway, Alex Williams, Oliver Inderwildi and Sir David King, Smith School of Enterprise and the Environment, (March 2010), *Indirect emissions from electric vehicles: emissions from electricity generation.* University of Oxford, March 2010. ISSN:2041-4897

3. Influence of HS2 configuration, policy factors and technical developments

3.1 Identification of key factors

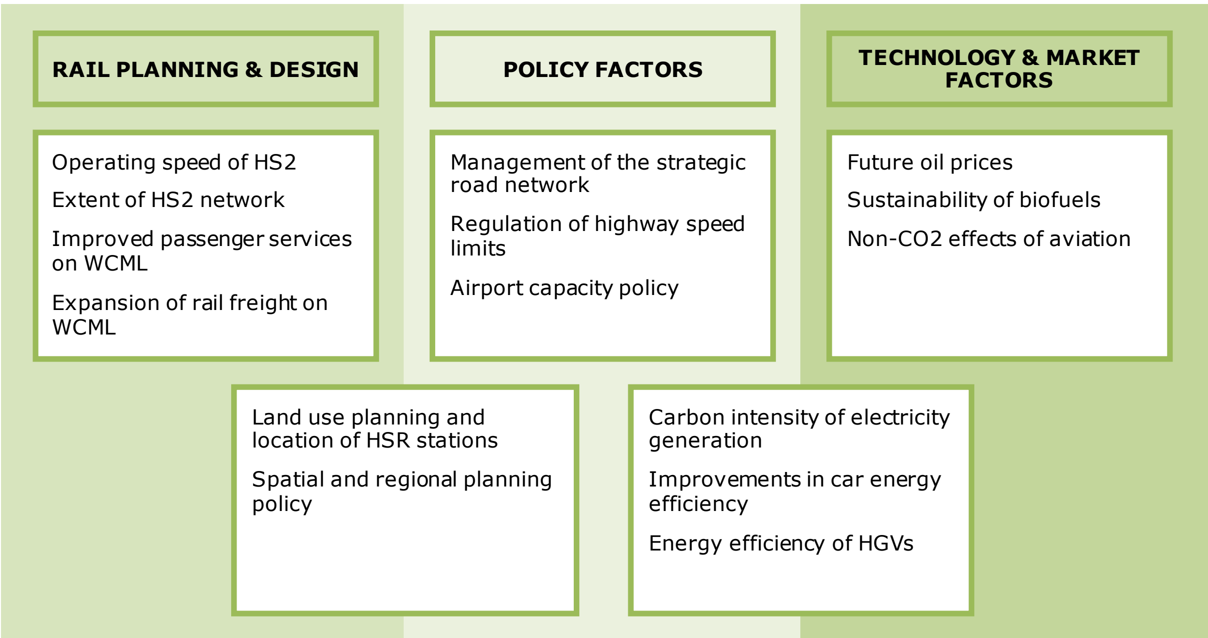
The early stages of this research project identified the critical factors likely to influence the carbon case for HS2. This analysis drew on the environmental review carried out for Greengauge 21 by TEPR and the review of HSR technology by SYSTRA, and is set out in Appendix A.

The key influences were identified as:

- **Rail planning and design**: the way HS2 is planned, designed and operated (including its integration with the existing railway);
- **Policy factors**: areas influenced by government, such as the pricing and capacity of other transport modes; and
- **Technology and markets**: external uncertainties such as oil prices and the way technology develops.

Some of the factors, such as car efficiency standards, are influenced both by technology development and by government policy on areas such as incentives for take-up of electric cars. Figure 3.1 sets out the factors identified in the first stage of the study.

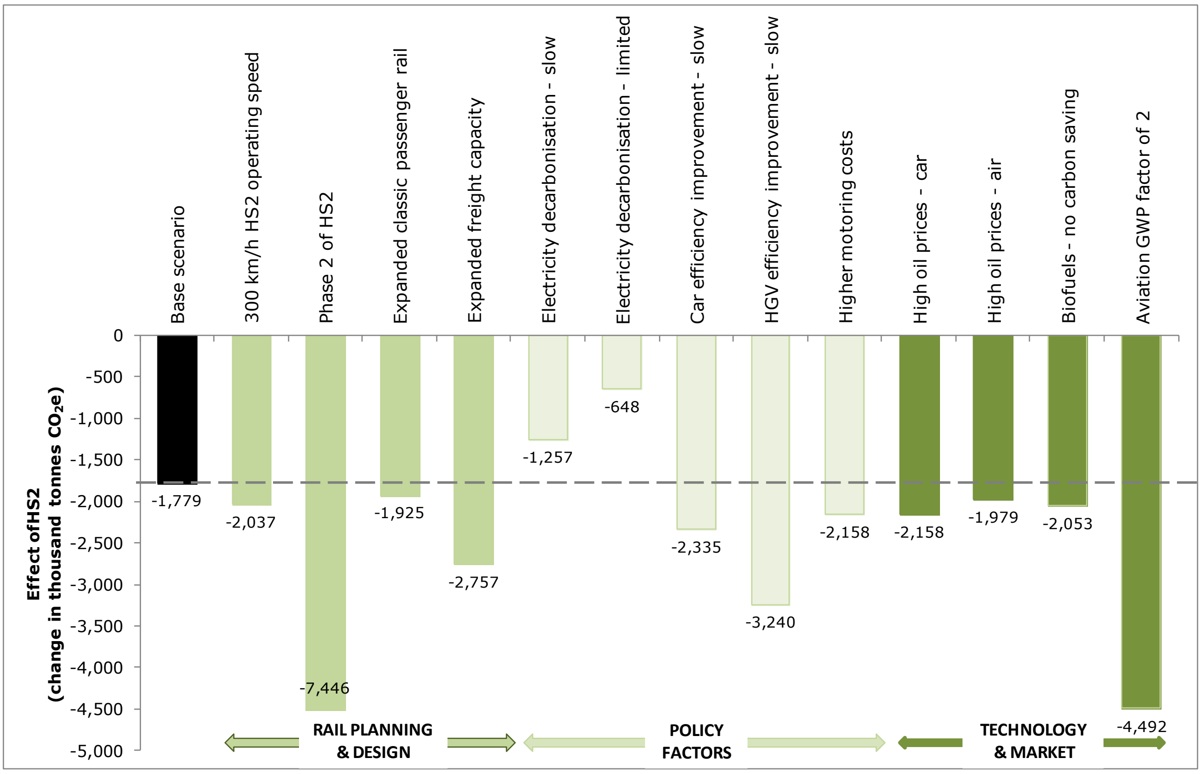
Figure 3.1: Factors likely to influence the HS2 carbon case



Where possible, we have sought to quantify through sensitivity tests the potential effect of these factors to understand which of them is likely to have most impact on the carbon savings from HS2. This sensitivity testing uses the base scenario analysis set out in Chapter 2 as a starting point and flexes the input assumptions on, for example, the carbon intensity of different fuels, or the level of demand for HSR and other modes. We have made use of available demand forecasts and sensitivity tests carried out for HS2 Ltd, which has in some cases placed limitations on the quantitative analysis we have been able to do.

A summary of the findings is presented in Figure 3.2 below, comparing each sensitivity test against the base scenario. This highlights the particular importance of the impact of aviation emissions, the pace of decarbonisation of the electricity supply, the scale of the HS2 network, the way in which the freed capacity on the existing railway is used and also of the effect of changes in the carbon efficiency of road transport.

Figure 3.2: Summary of sensitivity test results



The analysis underpinning these results is discussed below, together with some further analysis that is not included in Figure 3.2.

3.2 Operating speed of HS2

There has been considerable debate on the appropriate operating speed for HS2 and the business case and carbon implications of adopting different speeds. Operating HS2 at lower speeds would have two impacts:

1. It would reduce HSR demand, as the HSR services would be less competitive with other modes, thereby reducing the mode shift from car and air and hence reducing the emissions savings from these modes;
2. It would reduce the carbon emissions from HSR operation, particularly in the first few years of HS2 operation when decarbonisation of the electricity supply will not have taken full effect.

While the trains intended to operate over HS2 are expected to be capable of 360 km/h operation, in reality operating speeds would be lower, as we highlighted in our Interim Report. First, planned cruising speeds would normally be around 330 km/h, with the use of speeds above that level being necessary only as contingency. Second, there would be lower operating speeds near station stops and in some tunnels. These operational realities are taken into account in our carbon model.

The demand impacts of operating HS2 at a lower top design speed of 300 km/h have been forecast by HS2 Ltd and we have used the passenger forecast results in the carbon model. The same operating and infrastructure constraints are assumed to apply as described above for 360km/h operation, with the effect that a lower operating speed (probably around 270 km/h) brings a reduction in energy consumption of HS2 services of 19%.

As Table 3.1 shows, the overall effect is to reduce the carbon emissions of HS2 operation by 21% while the emissions savings from car and air mode shift are also reduced, by 7%. The overall impact of a reduction in the top operating speed is therefore a net improvement in carbon emissions over the base scenario of 15%.

Table 3.1: Potential impact of lower operating speed

	Change in CO_2e (thousand tonnes)						% change against base scenario
	HSR	Intercity rail	Commuter rail	Air	Road	Net change	
Base scenario	2,185	-1,263	107	-2,194	-612	-1,779	
Lower top speed (300 km/h)	1,722	-1,250	112	-2,051	-570	-2,037	+15%

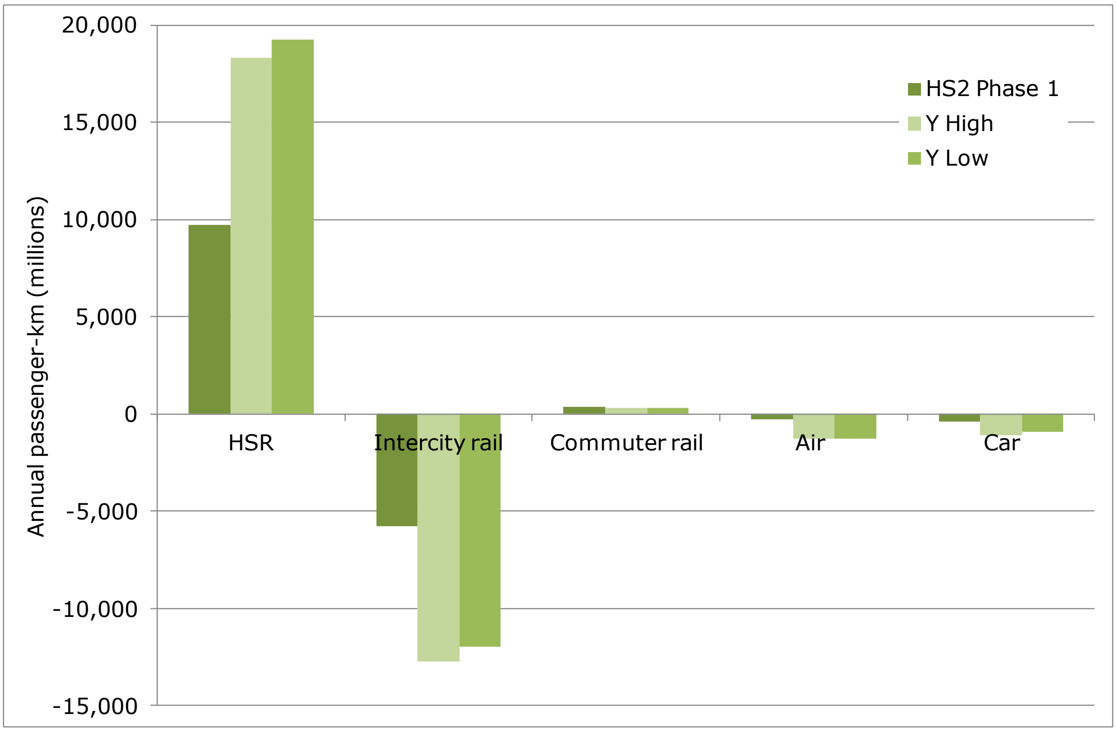
The savings from operating at a lower speed are concentrated in the early years of HS2 operation when the electricity supply is not fully decarbonised. In later years, the advantage is much diminished.

3.3 Length of HS2 network

The analysis so far has been based on the first phase of HS2: a new line from London to the West Midlands, connecting to the WCML. As Figure 2.2 showed, the mode shift impacts of the first phase of HS2 are relatively modest as the journey time savings of 35 minutes are not sufficient in themselves to capture a large part of the remaining air market in the West Coast corridor. However, the second stage of development is proposed to be a 'Y-shaped' network, with routes to Manchester and Leeds, connecting to the WCML and ECML respectively, and delivering a further 30 minute journey time saving. The second stage also brings a connection to Heathrow which, depending on service patterns, could have a further impact on air to rail demand transfer for interlining traffic – and also on car to rail transfer, although it would appear that the latter has not yet been fully examined by HS2 Ltd. Nevertheless, some indicative demand forecasts and economic appraisals have been carried out by HS2 Ltd and these have been used to assess the potential carbon impacts of extending HS2 beyond the first stage. These demand forecasts do not separate the impacts of the two extensions to Manchester and Leeds from the branch to Heathrow, so the carbon effects cannot at this stage be disaggregated between the elements of the Y network.

Two sets of forecasts have been made available: a high demand forecast and a low demand forecast. Figure 3.3 shows that the Y network is forecast to generate around twice the level of HSR passengers as the first phase of HS2. The mode shift impacts are even more marked, however, with the reduction in air travel being four times as great and the mode shift from car nearly three times as great.

Figure 3.3: Demand impacts of Y network, 2026 forecasts



The overall impact of phase 2 of HS2 would be an increase in the CO_2 savings from 1.8 million tonnes to over 7 million tonnes. The largest absolute change is in the savings from mode shift from air to HSR, which alone increases the potential CO_2 savings by over five million tonnes. Reducing the journey times between London and Scotland by as much as an hour clearly has a much larger impact on mode shift as it brings the rail journey times much closer to the journey times achievable by air travel; the direct connection into Heathrow Airport could help HS2 capture more interlining traffic, that is, passengers transferring between flights at Heathrow. Phase 2 of HS2 also allows a step-change reduction in the journey time between cities such as Birmingham and Manchester, which should allow the current low market share of rail to increase substantially.

Table 3.2: Potential impact of an extended HS2 network

	Change in CO_2e (thousand tonnes)						% change against base scenario
	HSR	Intercity rail	Commuter rail	Air	Road	Net change	
Base scenario	2,185	-1,263	107	-2,194	-612	-1,779	
1. Y network 'high'	4,022	-2,651	102	-7,616	-1,509	-7,653	+330%
2. Y network 'low'	4,224	-2,502	102	-7,604	-1,459	-7,239	+307%

Some simplifications have been made in our analysis with respect to the impact on the classic rail services by assuming that all intercity trains removed from the network produce the same emissions as the current intercity trains operating on the WCML. This is almost certainly conservative given that some of the East Coast and Cross Country trains are diesel-powered and hence have higher emissions. Therefore, the benefits of the Y network are likely to have been understated in Table 3.2. Intercity trains on the Midland Main Line (MML), while currently diesel-powered, will switch to electric traction before HS2 is built, following recently-announced Government plans to electrify the MML.

3.4 Land use planning and location of HSR stations

Land use planning issues and wider questions of spatial development and the distribution of expected population/employment growth at a regional level potentially have a significant impact on trip patterns and modal split. These effects would impact on the case for HSR by affecting the density of residential and employment development around HSR stations and their catchments. Of course, the pattern of development is itself also likely to be impacted by HS2 but no assessment of this effect is available. The HS2 Ltd appraisals all assume that land use is unchanged by the introduction of HS2 Ltd, so there is no dependable basis on which to assess the wider spatial planning and regional development scenarios that might arise. Nevertheless, some insight into the potential impact of location of HS2 stations can be provided.

The two sets of HS2 Ltd demand forecasts for the Y network presented in Figure 3.3 above are based on different assumptions on station location: the Y 'high' forecast models the stations on the Y route as city centre stations and the Y 'low' forecast models the stations as parkways with restricted accessibility. City centre stations tend to be more successful at generating public transport demand and shift from other modes than parkway stations. As expected, under the low forecasts, the mode shift from air and car is lower, although HS2 Ltd considers this to be a conservative view as it expects all stations, parkway or city centre, to have good public transport access in reality.

Comparison of the Y high and low forecasts therefore helps consider the issue of what impact station location has on the carbon impacts of HSR. In the case of the Y network, parkway stations reduce the carbon savings by approximately 7%. This is before the impact of station access trips is taken into account, which would increase this impact, passengers being more likely to drive to parkway stations than to city centre stations. There is clearly a carbon benefit from designing stations with very good public transport accessibility and low car modal share, and it is more likely that this can be achieved with city centre stations. By contrast, parkway stations are likely to increase pressure to add further road capacity, which is likely to increase mileage driven and so generate additional carbon emissions.

Moreover, HS2 could lead to more sustainable patterns of development, if its stations are integrated well with spatial development plans. Excellent public transport facilities – with HS2 integrated with local rail, bus and tram services, plus world class conditions and facilities for walking and cycling – can help encourage sustainable developments concentrated in urban areas.

3.5 Better use of WCML capacity: passenger services

One of the important benefits of HS2 is that it will free capacity on the existing rail network, primarily the West Coast Main Line, allowing new and expanded conventional passenger rail services to be operated and also increasing capacity for freight. Some of these benefits are taken into account in the HS2 Ltd forecasts, but these projections do not assume full utilisation of the WCML. Based on the post-HS2 timetabling study carried out by Greengauge 21 in 2011,[18] we estimate there to be an additional three paths per hour available on the WCML for additional passenger or freight trains over and above the assumptions used in the HS2 Ltd demand modelling.

An estimate has been developed of the potential carbon impacts of using this extra liberated capacity for more frequent commuter or inter-urban passenger trains, such as currently operated by London Midland. The spare capacity could be used in a number of ways: for example, to offer new services for destinations that are not currently served directly, to provide improved services between intermediate towns, or to improve frequencies of existing services. In the light of recent announcements on rail enhancements planned for the 2014-2019 period, there is also likely to be scope for enhanced WCML services to provide effective connection with other services, such as the

[18] Greengauge 21 (February 2011), *Capturing the benefits of HS2 on existing lines.*

future East West Rail services at Milton Keynes or at Coventry and Nuneaton following the Leamington-Coventry-Nuneaton upgrade.

The mode shift benefits of enhanced passenger rail services are potentially significant, for two reasons:

1. Enhancing conventional rail services over shorter distances between smaller towns and cities is effective in delivering mode shift from car to rail, with perhaps 40-60% of the increased rail demand coming from people who would otherwise have travelled by car;[19]

2. The potential for mode shift from car to rail is greater for non-London trips than for trips to/from London, in large part because rail does not yet have a large share of the non-London market. Freeing up capacity on the WCML allows a robust regular interval timetable to be developed, allowing reliable clockface connections between intermediate stations (and not just focused on journeys to/from London) tapping into travel markets poorly addressed by current services.

Table 3.3 presents a projection of the impacts of using the spare three paths per hour on the WCML for enhanced passenger services, on the basis that demand would build up over a 10-year period. This uses a mode shift model developed by Atkins to estimate the potential mode shift from car. Potentially, this could increase the HS2 carbon savings by 8%.

Table 3.3: Potential impact of enhanced conventional passenger rail services (three extra trains paths per hour)

	Change in CO_2e (thousand tonnes)						% change against base scenario
	HSR	Intercity rail	Commuter rail	Air	Road	Net change	
Base scenario	2,185	-1,263	107	-2,194	-612	-1,779	
Enhanced passenger rail services	2,185	-1,263	212	-2,213	-845	-1,925	+8%

The results are fairly dependent on the assumptions used to project demand. If, for example, one-third of the new classic rail demand is abstracted from other operators who suffer lower average loadings as a result, then the additional carbon savings might only be 6%. But if loadings on the enhanced conventional services increased by 10 percentage points, then the additional carbon savings would increase to 13%, and under the scenario of slower improvements in car efficiency, described earlier, the additional carbon savings might increase to 18%.

It is also the case that a change in the nature of WCML services could further enhance the potential land use planning benefits described in section 3.5 above. With appropriate complementary spatial planning policies, improved local and regional rail services could support higher density development near stations and further increase the carbon emission savings from HS2.

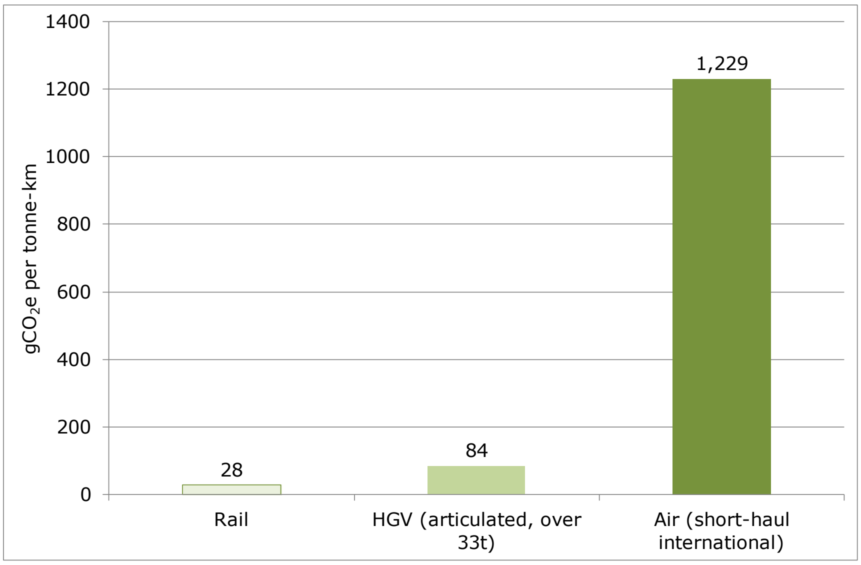
3.6 Better use of WCML capacity: freight services

A similar test was carried out to test the benefits of expanding freight capacity on the WCML rather than increasing passenger services. As is highlighted in Appendix A, the West Coast Main Line is the busiest long distance route for rail freight in the UK and providing additional capacity released via HS2 should be of considerable value as this reduces HGV traffic on the road network. Overall,

[19] Car to rail mode shift estimated from a simplified mode split calculator developed for this study, based on parameters consistent with the HS2 demand model.

per tonne-km, rail freight currently produces 77% less CO_2 than road freight. Even when taking into account the fact that longer distance rail freight on the WCML is more likely to be a substitute for the larger, more efficient, lorries, the carbon advantage is still 67%. The relative carbon advantage of rail freight over road freight is illustrated in Figure 3.4, with air freight also shown for comparison.

Figure 3.4: Carbon emissions for freight transport



Data source: 2012 Guidelines to Defra/DECC's GHG Conversion Factors for Company Reporting

We have assessed the potential freight impacts by assessing the mode shift benefits from up to three train paths per hour on the southern half of the WCML being made available for rail freight. The Rail Freight Group's 2011 forecasts for the WCML are that daily freight trains will increase from 65 in 2010/11 to 132 in 2030.[20] Around half of this increase could be delivered by the three train paths per hour freed up by HS2. While much of the growth forecast by the RFG is likely to be for north of Birmingham, for which the second phase of HS2 could free up WCML capacity, providing additional London-Birmingham freight capacity nevertheless appears likely to be valuable.

The results of this test show that in terms of carbon impacts the benefits of using any spare WCML capacity for freight are much greater than for passenger services. Under central assumptions, the carbon savings of expanded rail freight could increase the HS2 carbon benefits by over 50%.

Table 3.4: Potential impact of enhanced freight rail services

	Change in CO_2e (thousand tonnes)						% change against base scenario
	HSR	Intercity rail	Commuter rail & freight	Air	Road (car & HGV)	Net change	
Base scenario	2,185	-1,263	107	-2,194	-612	-1,779	
Expanded freight capacity	2,185	-1,263	1,724	-2,194	-3,207	-2,757	55%

[20] MDS Transmodal (October 2011), *Rail freight demand forecasts to 2030*, Produced for the Rail Freight Group and Rail Freight Operators Association.

This sensitivity test assumes that road feeder trips will be necessary to access WCML freight terminals, offsetting some of the carbon advantage of railfreight. The results are relatively sensitive to this assumption: for example, if the length of road feeder legs could be halved, the carbon savings would increase to 92% of base scenario emission savings. This highlights the benefit of locating sufficient rail freight terminals in industrial areas to allow for efficient access to the rail network.

The benefits of expanding rail freight is likely to be even higher than set out in Table 3.4 given the expected move towards more electric traction for freight, replacing the diesel traction that is predominantly used in the UK for rail freight today. With the planned electrification programme, which may well lead to electric traction used for freight trains between Southampton and the Midlands, for example, the carbon emissions of rail freight could fall substantially.

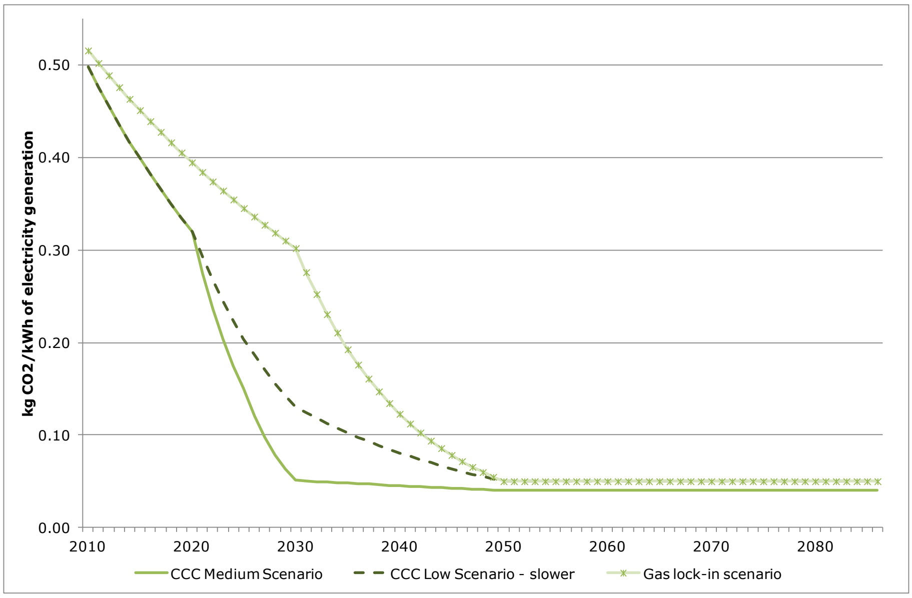
3.7 Carbon intensity of electricity supply

The carbon intensity of electricity supply is a major influence on the carbon emissions of HSR, given that HSR trains and many of those currently operating on the WCML all use electric traction.

The base scenario assumptions on decarbonisation of electricity supply are based on the Committee for Climate Change's medium abatement scenario; but this scenario clearly involves a radical decarbonisation. As with other inputs to the carbon model, there are assumed to be no changes from 2050 onwards.

We have developed two alternative scenarios, illustrated in Figure 3.5, to test the impact of slower decarbonisation. One scenario tests the impact of slower achievement of the CCC targets, but still resulting in significant decarbonisation by 2050. The other more pessimistic scenario is based on a second 'dash for gas', with new and expanded gas generation capacity deployed in coming years and only limited take-up of renewables, so that by 2030 there would be a less substantial reduction in carbon intensity.[21] Under this scenario we assume that post-2030, there is still a need to decarbonise the electricity supply and that this has to be met by costly retrofit of technologies such as Carbon Capture and Storage (CCS) to existing power stations.

Figure 3.5: Electricity decarbonisation scenarios



[21] See Green Alliance (June 2011), *Avoiding gas lock-in*. Available at: http://www.green-alliance.org.uk/uploadedFiles/Publications/reports/Avoiding_gas_lock-in_Jun11_Sgl.pdf

Slowing the rate of electricity decarbonisation has a substantial impact on carbon emissions from HS2 operations, increasing them relative to the base scenario by 51% in test 1 and by 112% in test 2. The savings from scaled-back intercity rail services are also greater, which offsets some of the additional HSR emissions. Overall, the carbon savings over the 60-year appraisal period would be 29% lower than in the base scenario for test 1 and 64% lower for test 2. This is clearly a key influence on the carbon impact of HS2.

Table 3.5: Potential impact of slower electricity decarbonisation

	Change in CO_2e (thousand tonnes)						% change against base scenario
	HSR	Intercity rail	Commuter rail	Air	Road	Net change	
Base scenario	2,185	-1,263	107	-2,194	-612	-1,779	
1. CCC Low abatement scenario	3,307	-1,921	164	-2,194	-612	-1,257	-29%
2. Gas lock-in scenario	4,642	-2,718	236	-2,194	-612	-648	-64%

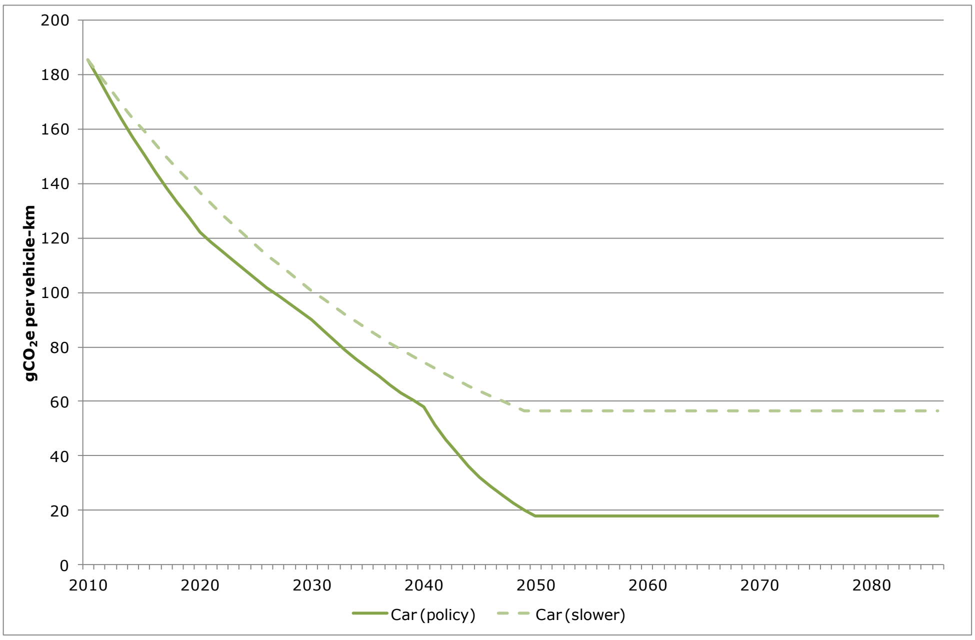
Some of the negative effects described in the sensitivity tests above would be offset by much higher carbon savings from car mode shift, as by the 2040s a large part of the car fleet is assumed to be electric-powered. This effect has not been quantified as the impact on electric car uptake in a situation where electrical power generation has not been de-carbonised is unclear, even if it is clear that for each electric vehicle used, the carbon effects would not be as benign as in our base scenario. The impacts shown in Table 3.5 must therefore be recognised as high-side impacts.

3.8 Improvements in car energy efficiency and emissions

The greenhouse gas savings from reduced car travel are influenced by the future rate of improvement of car energy efficiency and emissions.

Our base scenario assumes that car emissions progressively reduce, initially to meet EU targets for new cars and thereafter according to CCC scenario assumptions. The projected vehicle emissions are set out in Figure 3.6 for the average UK car and real-world operating conditions (rather than the more favourable test cycles normally reported). The base scenario implies that there would be a substantial take-up of electric cars beyond the 2030s. An alternative scenario with slower rates of improvement has been developed as a sensitivity test, illustrated in Figure 3.6. This may also be considered to be a proxy for the situation in which carbon efficiency improvements are more difficult to achieve on long-distance than on short-distance trips, at least where a shift to hybrid/electric car usage is concerned.

Figure 3.6: Change in car CO_2 emissions



We do not model any underlying demand impacts (which might arise from differences in operating costs) and so the only impact of this test is that car emissions are higher than under the base scenario. The effect would be to increase the carbon emissions from car travel, increasing the overall carbon savings by 31%. The carbon benefits of HS2 therefore would improve significantly if the automotive sector does *not* make the substantial improvements in carbon efficiency that we have assumed in the base scenario and/or if consumers do not choose to make the switch to electric and other low carbon vehicles.

Table 3.6: Potential impact of slower improvements in car efficiency

	Change in CO_2e (thousand tonnes)						% change against base scenario
	HSR	Intercity rail	Commuter rail	Air	Road	Net change	
Base scenario	2,185	-1,263	107	-2,194	-612	-1,779	
Slower car efficiency improvements	2,185	-1,263	107	-2,194	-1,169	-2,335	+31%

3.9 Management of the strategic road network

One of the policy factors that we identified as potentially significant was the way in which the strategic road network may be managed in the future, including the effects of changes in capacity of the network or the way in which charges are levied for its use. The potential range of future scenarios is wide and there are no existing established Government policies to draw on, beyond the 'managed motorway' programme, so we have not attempted to assess a specific policy.

However, to get a feel for the sensitivity of the carbon model results to motoring costs, the HS2 Ltd demand model test of a 50% increase in fuel duty is reproduced below. This may be taken to be rough proxy for a policy such as inter-urban demand management, which might increase the cost of inter-urban motoring relative to other modes of travel. The test implies that the impact of such a policy on HS2 could be significant in increasing the carbon benefits. In addition, any form of road charging based on congestion would be likely to increase peak loads on the rail network, further improving the case for HS2 and the mode shift benefits.

Table 3.7: Potential impact of higher motoring costs

	Change in CO_2e (thousand tonnes)						% change against base scenario
	HSR	Intercity rail	Commuter rail	Air	Road	Net change	
Base scenario	2,185	-1,263	107	-2,194	-612	-1,779	
Motoring costs (50% uplift in fuel duty)	2,409	-1,258	141	-2,414	-1,036	-2,158	+21%

A 50% increase in fuel duty rates can be argued to be a very reasonable sensitivity test, given the likely drop in exchequer receipts from fuel duty taxation that is likely to arise from future improvements in vehicle fuel efficiency as existing technologies are refined and new ones adopted in response to the Government's targets for greenhouse gas reduction. For example, the Institute for Fiscal Studies estimates that to preserve the current level of fuel duty revenue, even with a 44% forecast increase in traffic by 2035 (which is by no means certain), the rate of fuel duty would need to be raised by 50% to compensate for increased vehicle efficiency.[22]

3.10 Regulation of motorway speed limits

Motorway regulation could also affect carbon emissions if there were to be a change in speed limits, which affects both fuel consumption and journey times by road. In 2011, the Government announced that it would launch a consultation on the possibility of increasing the speed limits on motorways from 70 to 80mph. Our review of evidence from the European Environmental Agency suggests this might increase fuel consumption, and hence carbon emissions, by approximately 3%. This would widen the advantage of HSR over car travel in terms of carbon emissions per trip.

However, the other effect that would occur is that journey times by car would reduce, improving the relative attractiveness of car travel compared with rail, and this would be likely to reduce the mode shift from car to HSR. We have not been able to assess this impact quantitatively, although it is likely that relaxation of speed limits would have more impact on demand than the sensitivity test described in section 3.9 above. This would mean that the reduction in HSR demand, and consequent reduction in mode shift benefits, would probably outweigh the effect of increased fuel consumption for car travel. It suggests that the carbon savings from HS2 would be lower if average motoring speeds were increased.

On the other hand, some commentators have suggested there is a case to reduce motorway speed limits to reduce fuel consumption and carbon emissions. Under such a scenario, the journey time advantage of HS2 and classic rail services would be greater, and there could be a substantial shift of demand towards the rail network, with higher savings in carbon emissions.

3.11 Airport capacity policy

The first phase of HS2 attracts demand away from short-haul flights, and the high 'per passenger journey' carbon associated with air travel is an important part of the reason why high-speed rail reduces overall carbon – even while accommodating an increase in total travel. In this analysis, aviation sector carbon has been reduced pro rata with passenger numbers. Airlines have already

[22] Institute for Fiscal Studies and RAC Foundation (May 2012), Fuel for Thought – the what, why and how of motoring taxation.

indicated that, with good high-speed rail connections, they would seek to withdraw or at least reduce their short haul flights, for instance, between Manchester and Heathrow.

As a result, there will be a reduction in short haul flights at airports including in the South East. At Heathrow, where landing slots are at a premium, there is a need to consider what would (and what should) happen with any runway slots freed up. A market-led solution following the current slot-trading mechanism would probably see these slots replaced by more valuable long-haul flights. While these may bring economic benefits that have not been taken into account in the business case for HS2, this might be expected to have the effect of eroding the carbon reduction benefit at a national (UK) level.

The analysis here is conducted at a national level, and for consideration of other travel modes and consequential effects that is appropriate. But where there is a prospect of flight destination substitution between domestic and overseas destinations, it is inadequate. If there is a take-up of released runway slots to serve longer distance destinations, there will be an impact on the air travel market at a European level. Heathrow competes strongly with airports serving Paris, Amsterdam and Frankfurt; all are reliant to an extent on feeder short-haul flights from various locations including the UK. A stronger long-haul service offering from Heathrow with domestic access via high-speed rail could result in lower overall carbon since the likely alternative is UK-originating air journeys made through a continental European hub. These journeys would have a higher per passenger carbon impact because of the two flights involved. And the increase in long-haul flights from Heathrow may well be offset by fewer long-haul flights from competing European airports.

It is possible, therefore, that even if the runway slots are released for long-haul flights as a result of HS2, the carbon effect (which doesn't respect national boundaries) could be reduced as in our central estimates. And, if slot allocation arrangements were changed so that the freed-up runway slots were not used by long-haul flights but, say, used to create breather spaces in runway utilisation that can lead to less need for 'stacking' and on-airport aircraft taxiing, the carbon benefits of HS2 could be said to be greater still.

It is also the case that reduced short-haul air demand as a consequence of HS2 could reduce, at the margin, the perceived need for additional runway capacity in the South East. In summary, carbon accounting for HS2's effect on airport utilisation needs to be carried out at a European level and requires a much more detailed level of investigation to produce a meaningful improvement on the estimate given earlier in Figure 2.5 of the effects on aviation emissions.

3.12 Energy efficiency of HGVs

Under the rail freight scenario described in section 3.6, the efficiency of the HGV fleet is an important input. Unlike the private car fleet, there is less scope to decarbonise HGVs as there is unlikely to be a shift to electric HGVs because of the limits of battery technology. Nevertheless, in our modelling, we use a generous assumption that HGV efficiency improves by 29% by 2030, in line with the CCC's Medium Abatement scenario.

We tested the impact of only half this improvement being delivered, so that HGV efficiency improves by 15% by 2030. Under this test, the total carbon savings from HS2 increase to 3.2 million tonnes, a further 18% improvement.

Table 3.8: Potential impact of slower HGV efficiency improvements

	Change in CO_2e (thousand tonnes)						% change against freight test
	HSR	Intercity rail	Commuter rail	Air	Road	Net change	
Expanded freight capacity	2,185	-1,263	1,724	-2,194	-3,207	-2,757	
HGV efficiency improvement halved	2,185	-1,263	1,724	-2,194	-3,691	-3,240	+18%

3.13 Future oil prices

Clearly there is considerable uncertainty over future energy prices, in particular over the price of oil on which car and air travel is currently dependent. There is a risk that oil prices could rise substantially in the future as supplies become more costly to extract. With higher oil prices, the costs of air and car travel would increase and the relative attractiveness to travellers of these two modes would decline compared with high-speed rail. It is also possible that oil prices could fall, as they have done recently. The critical factor for our analysis is the extent to which potential future changes in oil prices are already factored into the HS2 demand forecasts.

The DfT's WebTAG guidelines for demand forecasting and economic appraisal include projections of increasing oil prices, based on Department of Energy and Climate Change (DECC) 2011 fossil fuel assumptions and these cost increases are reflected in the car travel cost assumptions behind the HS2 demand forecasts. Petrol prices, for example, are forecast to increase from 130.6 pence per litre in 2011 to 150.7 pence/litre in 2030 (2010 prices), a 16% increase in real terms. From 2030 onwards, prices are forecast to increase in line with inflation.

For air travel, the underlying air demand forecasts used for the HS2 forecasts also assume some increase in oil prices in future years, which feed through into air fares, although these future price rises look relatively low. DfT's 2011 aviation forecasts are based on DECC's 2009 fossil fuel price assumptions which were that oil prices would rise to $90 a barrel in 2030.[23] However, in its most recent projections, DECC revised its central oil price assumptions upwards to $118/barrel in 2020 and $128/barrel in 2030 (in 2011 prices).[24] Further, under a 'High Prices scenario, DECC suggests that oil prices could reach $168/barrel by 2030. The DfT air demand forecasts assume that future air fares are influenced not only by oil prices but also by the fuel efficiency of aircraft, by air passenger duty (assumed to remain constant) and the cost of EU Emissions Trading Scheme allowances. But they may be based on a now outdated optimism about aviation fuel prices and therefore passenger fares.

Clearly therefore, there is scope for oil prices and hence car operating costs and air fares to increase beyond the central assumptions in the HS2 demand forecasts. To assess the potential impact, two of the demand sensitivity tests carried out by HS2 Ltd were used as a rough proxy (a combined test of increased car and air prices was not available) of the impact of higher oil prices. These tests only represent one possible view of the future and we do not present this as a forecast of future oil prices, only as the sensitivity of carbon emissions to assumptions on fuel prices.

[23] DfT (2011) *UK aviation Forecasts*
[24] DECC (2011) *"Updated energy and emissions projections 2011*

Table 3.9: Potential impact of higher oil prices

	Change in CO_2e (thousand tonnes)						% change against base scenario
	HSR	Intercity rail	Commuter rail	Air	Road	Net change	
Base scenario	2,185	-1,263	107	-2,194	-612	-1,779	
1. Higher car costs (50% uplift in fuel duty)	2,409	-1,258	141	-2,414	-1,036	-2,158	+21%
2. Higher air fares (14% uplift in 2026, 19% uplift in 2037)	2,207	-1,262	107	-2,396	-634	-1,979	+11%

Under both tests, the increase in car costs or air fares depresses car and air demand but expands the rail market so that HS2 demand is higher. This brings a greater reduction in car and air emissions, improving the overall reduction in CO_2e emissions by 21% and 11% respectively. Higher oil prices would therefore be likely to increase the potential carbon savings from HS2. The effect would be even greater if the currently policy of above-inflation increases in rail fares was changed so that the costs of using the rail and HSR networks reduced relative to motoring and aviation costs.

3.14 Sustainability of biofuels

It is clear from the background environmental review in Appendix A that there are significant issues about the sustainability of biofuels, and many environmental analysts have raised concerns that the direct and indirect land use and other impacts of increased biofuel production may negate any carbon savings. The base scenario assumptions we have used assume a limited take-up of biofuels for car travel and aviation - 5% for car and 10% for aviation by 2020 – but it is implicitly assumed in the base scenario that the carbon emissions of biofuels are negligible.

Taking a different view of the sustainability of biofuels improves the carbon case for HS2. We have assessed this with a sensitivity test that assumes that biofuels have no carbon saving compared with mineral-based fuels, i.e. biofuels have the same CO_2 emissions factors as petrol, diesel and aviation fuel.

Table 3.10: Potential impact of biofuel sustainability assumptions

	Change in CO_2e (thousand tonnes)						% change against base scenario
	HSR	Intercity rail	Commuter rail	Air	Road	Net change	
Base scenario	2,185	-1,263	107	-2,194	-612	-1,779	
Biofuels: no carbon savings	2,185	-1,263	107	-2,437	-644	-2,053	+15%

The overall impact of this sensitivity test in which it is assumed that bio-fuels offer no carbon savings over conventional oil-based fuels, is that aviation emissions would be approximately 11% higher and car emissions 5% higher, which improves the total carbon savings from HS2 by 15%. These figures should be taken as indicative only as the emissions from biofuels are very uncertain but it highlights the fact that the carbon savings from HS2 will only improve if anything other than an optimistic view is taken of the sustainability of biofuels.

We have not estimated the potential impact of other unconventional fuels, such as tar sands, but it is clear from the available evidence that increased usage of such fuels could potentially increase the amount of greenhouse gases emitted in the production of transport fuels. This would also improve the net carbon savings from HS2.

3.15 Non-CO_2 effects of aviation

As highlighted in Figure 2.3, the impacts of emissions from aviation could be significantly higher than the direct CO_2 impacts modelled because of the atmospheric conditions in which they are emitted. Non-CO_2 emissions with climate impacts include water vapour and nitrogen oxides (NOx). If, as is suggested, these non-CO_2 climate effects are taken into account by applying a Global Warming Potential factor of 2 to the CO_2e emission rates (including biofuels), then the net saving in greenhouse gas emissions from HS2 would rise to 4.5 million tonnes CO_2e, highlighting the importance of reducing aviation emissions.

Table 3.11: Potential impact of non-CO_2 impacts of aviation

	Change in CO_2e (thousand tonnes)						% change against base scenario
	HSR	Intercity rail	Commuter rail	Air	Road	Net change	
Base scenario	2,185	-1,263	107	-2,194	-612	-1,779	
GWP factor of 2	2,185	-1,263	107	-4,876	-612	-4,492	+153%

3.16 Summary of findings

Under the set of individual sensitivity tests described in this chapter, the carbon savings from the first phase of HS2 range between 0.7 and 4.5 $MtCO_2$e. The most substantial improvements come when WCML freed capacity is used for freight services, when carbon efficiency improvements are not delivered in the road sector and if the potential non-CO_2 global warming effects of aviation are taken into account. The case for HS2 is worsened considerably if the necessary decarbonisation of the UK electricity supply is not delivered, although this scenario may be about timing, rather than absolute achievement: de-carbonisation may come slower, but it would seem likely to come eventually.

When HS2 is extended beyond the first phase, it is likely that the carbon savings will increase dramatically because of the increased mode shift from air and car. As HS2 infrastructure is extended beyond the West Midlands and to Heathrow, the journey time and increased connectivity benefits it delivers are even more valuable.

The following chapter considers the potential range of results that might occur by combining the sensitivities into plausible future scenarios.

4. Range of possible futures

4.1 Development of scenarios

Given the inherent uncertainties over a number of factors that will influence the future carbon case for HS2, including future government policies over the next fifty years, or long-term energy prices for example, we have developed scenarios to understand the potential range of outcomes for the HS2 carbon case. This is consistent with Principle 2 of the Right Lines Charter, on testing the options.

The base scenario uses current forecasts and policies as its basis, consistent with the estimates set out in Chapter 2. An environmentally-conscious scenario describes how the implementation of sustainable policies might influence the factors underlying the carbon case for HS2 and a 'laissez-faire' scenario describes how the absence of appropriate market intervention might take effect. These scenarios are summarised in Figure 4.1 and their potential impacts on the carbon case for HS2 are detailed below.

Figure 4.1: Potential future scenarios

LAISSEZ-FAIRE	BASE SCENARIO	ENVIRONMENTALLY-CONSCIOUS
Limited market intervention	*Continuation of current forecasts*	*Implementation of sustainable policies*
Market-led development and planning Limited regulation of standards No incentives for low-carbon electricity No environmental taxation or pricing	Continuation of current fuel taxation and pricing policies Some weak incentives on development of low-carbon technology Support for decarbonisation of electricity supply Regulation continues but not toughened	Environmental costs internalised through pricing Strong stimulus to radical decarbonisation of electricity Incentives on adoption of low-carbon technology Enforcement of tough standards on emissions Constraints on development of capacity for less sustainable modes

For this exercise, we have focused on the impacts on the first stage of HS2, although we also comment on any implications for subsequent development of the HSR network.

4.2 Base scenario: current forecasts, policies and plans

This base scenario uses HS2 Ltd's demand forecasts and is consistent with HS2 Ltd and DfT central assumptions on:

- Oil prices and hence fuel costs and air fares;
- Rail fares policy of RPI+1%;
- HS2 maximum operating speed of 360 km/h.

In addition, the following policies that affect carbon emission rates are assumed to apply:

- The Committee on Climate Change's 'medium abatement' scenario on electricity decarbonisation, which implies radical decarbonisation considered necessary to meet climate change targets;

- Car efficiency improvements according to existing short-term EU targets and the CCC's 'medium abatement' scenario in the longer term;
- Biofuels forming a small part of the overall fuel mix for car and air travel but only to levels that meet sustainability criteria (and it is assumed there are no other adverse indirect land use effects);
- Limited airport expansion in the UK, but expansion elsewhere in Europe. The implication is that a reduction in UK domestic demand will free capacity at UK airports for long-haul flights to be relocated from European airports to UK airports;
- Limited WCML freed capacity is used for improved passenger rail services.

Overall, under this base scenario, as we have seen, HS2 is estimated to accommodate additional demand and reduce carbon emissions by close to two million tonnes of CO_2e.

Table 4.1: Base scenario – overall change in CO_2e

Element	Change in CO_2e (thousand tonnes)
HS2 Ltd demand forecasts and underlying assumptions for 360 km/h operation High electricity decarbonisation High car efficiency improvements Airport expansion in Europe WCML capacity is not used beyond HS2 Ltd's current assumptions Biofuels are used according to sustainability limits	-1,779
Overall impact	**-1,779**

4.3 Environmentally responsible scenario: implementation of sustainable policies

The environmentally responsible scenario assumes that policies and plans are focused on improving the UK's long-term sustainability and maximising emission reductions in order to meet climate change targets. This includes policies that will improve the energy and carbon efficiency of all transport modes but that also, through pricing or other measures, seek to provide incentives towards use of the more sustainable forms of transport.

To assess the impact of this scenario, we have used HS2 Ltd's demand forecasts for a 300 km/h top speed rather than 360 km/h, on the basis that at least in the early years effort will be made to minimise HS2's carbon emissions, even at the cost of economic benefits; for simplicity we have assumed this arrangement continues into the long term.

In addition, a number of other policies are assumed to apply that will affect carbon emission rates of HSR and other forms of transport:

- The Committee on Climate Change's 'medium abatement' scenario on electricity decarbonisation, which implies radical decarbonisation, but which is considered necessary to meet climate change targets;
- Car efficiency improvements according to existing short-term EU targets and the CCC's 'medium abatement' scenario in the longer term;
- Biofuels forming a small part of the overall fuel mix for car and air travel but only to levels that meet sustainability criteria (and it is assumed there are no other adverse indirect land use effects);

- Strict control of aviation emissions so that any reduction in domestic air demand sees a commensurate decrease in aviation emissions that is 'locked in' with no re-use of released runway slots;
- High motoring costs and air fares, which may result from an increase in oil prices as extraction becomes more costly, or from some form of price regulation, or which may be taken as a proxy for other demand management measures;
- WCML freed capacity is used for expanded freight capacity on the basis that removing HGV traffic from the road network is the most environmentally valuable use of spare rail capacity.

Ideally we would also constrain the level of future rail fare increases in this scenario but we are unable to quantify the effect of this with the current data available.

Overall, under this environmentally responsible scenario, HS2 is estimated to reduce carbon emissions by nearly four million tonnes of CO_2e.

Table 4.2: Environmentally responsible scenario – overall change in CO_2e

Element	Change in CO_2e (thousand tonnes)
High electricity decarbonisation High car efficiency improvements Strict control of aviation emissions Biofuels are used according to sustainability limits	-1,779
HS2 Ltd demand forecasts for 300km/h operation	-258
High motoring costs*	-380
High air fares*	-200
WCML capacity used for freight expansion	-978
Overall impact	**-3,500**

* These effects are not necessarily additive so the overall impact has been rounded down.

4.4 Laissez-faire scenario: limited market intervention

In contrast to the environmentally-sustainable future, the 'laissez-faire' scenario considers what might arise with only limited intervention by government or other agencies in implementing sustainability policies. Essentially, markets would be left to determine the trajectory of change in transport efficiency, based only on short-term economic interests and with no regard to long-term environmental concerns.

This laissez-fare scenario uses HS2 Ltd's demand forecasts and is consistent with HS2 Ltd's central assumptions on:

- Oil prices and hence fuel costs and air fares;
- Rail fares policy of RPI+1%;
- HS2 maximum operating speed of 360 km/h.

In addition, the following policies that affect carbon emission rates are assumed to apply:

- A limited level of electricity decarbonisation, governed mainly by a switch from coal to gas on economic grounds with limited development of renewables, and hence not meeting climate change targets;
- Slower car efficiency improvements, albeit with significant improvements over the long term, but not meeting the necessary long-term targets;

- Biofuels, while still forming a small part of the overall fuel mix for car and air travel, not reducing carbon emissions because of adverse direct or indirect effects, due to a lack of sustainability standards;
- No control of aviation emissions, so that any reductions in domestic air demand do not lead to a reduction in aircraft movements overall;
- WCML freed capacity is not used beyond the HS2 Ltd assumptions of some improvements to passenger rail services.

Somewhat paradoxically, the assumptions on car efficiency and biofuels, while worsening the UK's carbon emissions overall, would actually improve the relative case for HS2 as the carbon advantage of high-speed rail over car and air travel would improve. Nevertheless, overall, under this laissez-faire scenario, HS2 is estimated to have a negative effect on carbon emissions, both because there are not assumed to be any benefits from air to HSR mode shift and because the electricity supply is decarbonised much slower than in other scenarios.

Table 4.3: Laissez-faire scenario – overall change in CO_2e

Element	Change in CO_2e (thousand tonnes)
HS2 Ltd demand forecasts and underlying assumptions for 360 km/h operation WCML capacity is not used beyond HS2 Ltd's current assumptions	-1,779
Limited electricity decarbonisation	+1,131
Slower car efficiency improvements	-557
Unsustainable biofuels are used	-275
No control of aviation emissions	+2,194
Overall impact	**+714**

4.5 Summary of findings

The carbon savings from HS2 under the three scenarios ranges from 3.5 million tonnes CO_2e under the environmentally responsible scenario to 1.8 $MtCO_2$e under current forecasts and policies to an increase of 0.7 $MtCO_2$e under the laissez-faire scenario. The benefit of adopting sustainable policies on transport and planning is clear.

Under the laissez-faire scenario, there is a risk that carbon emissions from the operation of HS2 will actually increase and will not therefore counterbalance the embedded emissions arising from the construction of the HS2 infrastructure. But a combination of policy measures on sustainability could double the carbon savings achieved in the base scenario which follows current HS2 Ltd assumptions and Government policies. And the benefits of such policies would extend well beyond consideration of the impacts of HS2.

Moreover, this analysis has focused on the first stage of HS2. The potential carbon savings would be over four times as large when HS2 is extended to the north of England, and the relative benefit of complementary sustainable policies would in this circumstance be all the greater.

5. Conclusions

5.1 Introduction

The analysis we have carried out has demonstrated that HS2 can be part of a low carbon transport system in the UK that will allow us to meet the climate change targets established in the Climate Change Act. If delivered along with a package of policies that sees high-speed rail services operated across the country, shifts passengers and freight out of planes and roads and on to rail, and ensures that the electricity supply is decarbonised, then HS2 will deliver significant emission reductions.

Failure to achieve this will, however, mean that HS2 emission reductions are modest, or, at worst, marginally negative.

Under the base scenario we developed, consistent with Government policies and forecasts, operation of phase 1 of HS2 is estimated to reduce carbon emissions by 1.8MtCO_2e over 60 years. This comfortably offsets the approximately 1.2MtCO2e embedded carbon that will result from construction and confirms that high-speed rail can reduce carbon emissions while increasing capacity and reducing journey times. This means that HSR can be a key part of a sustainable transport strategy that supports mode shift to sustainable modes and delivers reductions in carbon emissions.

The scale of carbon reduction will vary depending on the design of the HSR network, on wider government policies and on external risks and uncertainties. Under an environmentally-responsible scenario, the operational carbon savings could increase to 3.5MtCO_2e, increasing the net saving (embedded and operational carbon) to 2.3MtCO_2e. But in contrast, under a laissez-faire scenario, without appropriate sustainability policies, it is possible that there will be no operational carbon savings available to offset the embedded carbon.

The main areas that will influence the carbon case for HS2, and which we recommend be considered carefully by Government, are set out below. As we make clear, a perfectly achievable set of complementary policies for HS2 itself and on related matters can together ensure that the carbon legacy of HS2 is strongly beneficial.

5.2 HSR design and operation

Under current HS2 plans and forecasts, operation of the first phase of HS2 between London and the West Midlands is estimated to deliver a 1.8MtCO_2e reduction in carbon emissions. It is clear, however, that these operational savings would expand four-fold when the second phase of HS2 opens, with the route extensions to Leeds, Manchester and Heathrow substantially increasing the scope for mode shift from air and car travel.

Further, we conclude that, in the design for HS2 and for a more extensive HSR network, the following features would maximise HS2's sustainability:

a) **Reducing the top speed of HS2 where justified, balancing energy consumption and mode shift**. Reducing the top speed of HS2 from 360km/h to 300km/h could reduce energy consumption by 19% and further improve the carbon savings from HS2 phase 1, in the early years while the UK's electricity supply is still being decarbonised, perhaps through to 2030. This may also have other environmental benefits, such as allowing time for planting along the line of route to mature before higher speed operation commences. In later years as electrical power generation is more fully decarbonised and the HSR network is extended, the journey time improvements are likely to be important in delivering mode shift, particularly from air, and so a top speed of 360km/h is more likely to be needed and may be justified by the carbon savings from reduced air travel. In certain markets, there may be a case to make a longer-term trade-off between speed and carbon where (such as on the eastern route of the Y) HSR services could connect a number of intermediate cities much better than currently.

b) **Construction of city centre stations rather than parkway stations where feasible**. City centre stations are estimated to be around 7% more efficient in carbon terms than parkway stations, even when only considering the direct impacts of HSR travel. The effect of local access trips to HSR stations, which can be made more readily on public transport to city centre stations, and public transport-oriented 'smart growth' around stations will only increase this benefit. All HS2 stations need to be planned to have high modal share for sustainable modes, both through careful siting and excellent connections for sustainable travel modes.

c) **Full use of capacity freed up on the existing rail network**. HS2 Ltd has adopted conservative assumptions on how much WCML capacity freed by HS2 is re-used for new and improved rail services. We estimate that the HS2 carbon savings could be increased by 8% by using spare WCML capacity for enhanced commuter or inter-regional passenger services and by even more with greater occupancy of these medium-distance trains. This highlights the value in ensuring that future rail franchises will be set up so that they are able to unlock the spin-off benefits of HS2. However, the carbon savings from reserving capacity for freight are considerably larger, potentially adding 55% to the direct carbon savings from HS2, and this is such a strong advantage that it will be worthwhile examining complementary measures to ensure that a major switch from HGV road haulage to railfreight is achieved.

d) **Use of timetabling margins and efficient driving techniques to reduce energy consumption**. Operating trains with a standard 8% timetabling margin reduces average speeds and requires 13-15% less energy. Eco-driving techniques or adjustment of driving speed according to gradients could result in 11-13% reductions in energy consumption.

5.3 Public policies

It is evident from our analysis that public policies beyond the rail sector, and even beyond the transport sector, will have a significant impact on the carbon case for HS2. The wider policies that will have most effect are:

a) **Ensuring the rate of electricity decarbonisation set out by the Committee on Climate Change is delivered.** The CCC has set out an ambitious trajectory of improvement for the UK's electricity sector which would result in the average HSR carbon emissions per passenger reducing by 92% by 2050. This is key to delivering carbon savings from HS2. A slower but still relatively ambitious reduction in the carbon intensity of electricity could see the total HS2 carbon savings fall short of the base scenario by 29% and a scenario in which there is a second 'dash for gas' and therefore slower decarbonisation would reduce the HS2 carbon benefits by two-thirds.

b) **Air capacity regulation and management.** HS2 will reduce the number of passengers making short-haul flights, and even the first stage of HS2 brings about a significant reduction in carbon from aviation, estimated at 2MtCO_2e over the life of the project. The question of how this result is affected by decisions on the use of runways at the congested South East England airports cannot be addressed in the same way as other policy choices related to HS2, at a national level. Rather, it is necessary to consider carbon at least at a European level, in which case it seems possible, as shown here, that even if there is an uptake in longer-haul flights in place of displaced short-haul services at Heathrow, the carbon reduction benefits of HS2 could be maintained. In addition, European airlines are now subject to the Emissions Trading Scheme which controls and prices carbon emissions. Although its effectiveness has been criticised due to the low cost of carbon permits and the amount of free allocations, by the time HS2 opens this may change. A tighter emissions cap for aviation and a higher cost of carbon permits could provide a means of managing the effects of take-up of released runway capacity. Much more work is needed on the related question of flight management to get a definitive answer, and the upcoming aviation policy review may prove to be a suitable opportunity. In earlier work, Greengauge 21 pointed to the opportunity that HS2 could create to create 'breather slots' at Heathrow with the aim of reducing the carbon levels at and around the airport arising from the need for aircraft to queue both for take-off and landing.[25]

c) **Management and regulation of the strategic road network to reflect the external costs of driving.** Increasing motorway speeds above current limits would increase the fuel consumption of cars, increase carbon emissions from driving and reduce the mode shift from car to HS2. Overall, these effects are likely to worsen the carbon case for HS2 and they should be taken into account before any change in policy. In contrast, policies to manage the use of the strategic road network, such as through pricing mechanisms, could increase the carbon savings of HS2 and would help ensure that the benefits of mode shift to HS2 are sustained.

d) **Sustainable land use and spatial planning policies to encourage use of public transport.** Particularly around HSR stations, encouraging sufficient density and type of development will help ensure that the HS2 demand meets, and indeed exceeds, current forecasts. Put another way, ensuring that HS2 serves locations of high demand density and locations where there is high capacity, low carbon access transport should be a planning aim. The accessibility boost that HSR can provide to cities is a unique quality. It can be used to magnify the carbon benefits of HSR if complementary policies on spatial development seek to foster an intensification of development in areas served by public transport in urban areas. The alternative, without the new dynamic that high-speed rail brings, is a continuation of the trends of previous decades with incremental improvements to the highway network being used as the basis for decentralised low density development patterns. The effects of improved classic rail services only help to enhance the benefits of HS2. These are big differences that will lead over time to huge swings in carbon consequences for the nation: the greater the level of urbanisation, the lower the carbon. But it is beyond the scope of this work to seek to quantify the effect.

5.4 Uncertainties

Our carbon analysis has also highlighted a number of areas where there are risks to the long-term achievement of carbon targets because of uncertainties and risks ahead, for example in long-term energy prices. The key uncertainties that we have identified that affect the case for HS2 are:

a) **Improvements in the carbon efficiency of cars**. Large-scale decarbonisation of the transport sector requires substantial improvements in the fuel efficiency of cars and most likely a shift to a largely electric car fleet in the long term. If this does not take place as quickly as set out by the CCC, or if longer distance trips are harder to decarbonise than short trips (because of limitations of battery technology, for example), then the relative advantage of HSR travel becomes even greater and HS2 carbon savings would be considerably higher. Electric car technology (whether hybrid or otherwise) would be a good complement to HSR, with electric cars being suited to short-medium distance trips and HSR being a good solution for longer distance journeys.

b) **The pace of change in the carbon efficiency of heavy goods vehicles.** A similar argument applies in the HGV sector, which is arguably even harder to decarbonise than cars and vans. If the freed WCML capacity is used to expand freight services, then slower decarbonisation of the HGV sector will increase the carbon case for HS2.

[25] Greengauge 21 (February 2010), *The Heathrow Opportunity*.

c) **Future energy prices.** There are clearly considerable uncertainties over future energy prices, particularly for the road and air sectors that are directly influenced by the price of oil. If oil prices rise in the long term above those assumed by HS2 Ltd – which is one possible scenario – then car and air demand would be depressed and the carbon savings from HS2 would be improved.

d) **Non-CO_2 impacts of aviation.** Our modelling has considered only the direct CO_2 impacts of HS2, given these typically account for 98% of greenhouse gases from transport. The one exception is aviation which potentially has a substantially increased impact because of the effects of operation at altitude. There is considerable uncertainty over this impact but if, as experts currently consider, non-CO_2 impacts effectively double the direct CO_2 impacts, then the carbon savings from HS2 would be more than double the levels we have presented here.

e) **Sustainability of biofuels.** There is considerable concern that widespread adoption of biofuels in place of mineral-based fuels would not be sustainable because of direct and indirect land use effects as well as carbon accounting errors. If these effects are taken into account, the carbon intensity of car and air transport might be higher than current assumptions, increasing the attractiveness of HSR compared with other modes of transport. Alternatively, regulation of biofuels might be necessary to ensure they are only used where sustainable, which may result in limits on biofuel take-up.

In addition, there are a number of factors that we have not been able to quantify in this study but which are likely to increase the carbon emission savings from HS2.

Table 5.1: Factors not quantified in this study

Factor	Description	Likely impact
Direct HS2 services to continental Europe from the Midlands and the North	These have the potential to deliver a very valuable mode shift from short-haul international air services to HSR in the same way as Eurostar has delivered between London, Paris and Brussels	Positive
High-speed freight services on HS2	This could be achieved where/when there is spare HS2 capacity and with sufficiently high-performance high-speed electric freight trains. Freight carried by other transport modes has a significant carbon footprint and there are already trials in conveying high value freight by high speed rail on the continent.	Positive
Long-term demand growth beyond 2037	Rail demand continues to grow, with no evidence of market saturation, suggesting that the HS2 demand forecasts currently underplay the potential for even greater mode shift and carbon benefits in the long term.	Strongly positive
Land use changes	HS2 itself can be expected to have an effect on patterns of land use development around stations and urban centres, encouraging sustainable higher density development in cities. Compared with a more dispersed pattern of land use development, this brings major carbon benefits, and will be enhanced with improved rail services on the existing rail network. It would also be expected to boost the demand for HS2 and the transfer of passengers from other modes.	Strongly positive

5.5 Conclusion

Our analysis has demonstrated that not only will HS2 deliver a substantial increase in transport capacity for long-distance travel, for commuters and for freight, but it will do so while reducing the UK's carbon emissions. It is only under our most pessimistic scenario that phase 1 of HS2 fails to deliver net carbon savings.

If the effects of the non-CO_2 effects of aircraft emissions are taken into account, phase 1 of HS2 will on our central case lead to a reduction of more than 4MtCO_2e; phase 2 will increase this value to 15MtCO_2e. These operational benefits, developed over the lifetime of the project are much greater than the carbon cost embedded in its construction.

The extent of the carbon benefits in practice will be affected considerably by wider public policies as well as by the way HS2 is configured and operated. This report has highlighted the key influences on the carbon case for HS2 and pointed out some ways forward for Government to ensure that it is as sustainable as possible.

High-speed rail particularly targets medium and long-distance surface travel and short-haul air travel and this is where other modes will almost certainly suffer capacity constraints or be subject to technology limitations in the future. If there continue to be limits on airport capacity, as there are now, then it may make sense to ensure that the available capacity is used for services such as long-haul flights where there is no practical alternative, shifting as much domestic and short-haul international travel to HSR as possible.

What has also emerged is that a key background influence is the pace of change in electrical power production towards a low carbon future as is going to be necessary to meet Government targets. There is a risk that in the early years (which, for the type of change envisaged from today's largely fossil fuel-based production platform can be taken to extend to 2030, some four years after stage one of HS2 is opened) the rate of decarbonisation will lag behind the required trajectory set out by the CCC. If this proves to be the case, there is a remedy that can restore the reduced carbon effect of HS2: operating services at a lower top speed such as 300km/h rather than 360 km/h. The higher speeds would come into play subsequently as electrical power generation *is* decarbonised. Higher speeds will be needed to get the maximum benefit of diversion from other modes, especially as HS2 is extended in phase 2 and after that.

The ability to free up capacity on existing railway lines has always been recognised as being a key benefit of HS2. What this research shows is that the *way* the capacity on the classic lines – especially the WCML – is used has a dramatic effect on the carbon case. The central estimate of HS2's effect is increased by no less than 50% if the three further train paths identified in this report as being 'unclaimed' by HS2 Ltd's appraisal are set aside for and taken up by freight services. Coherent policies to exploit this opportunity would extend to the development of more and better rail freight access to industrial areas.

Alongside this opportunity is scope for much improved rail passenger services; this has been documented by Greengauge 21 in an earlier report.[26] But there is more than just the narrow transport impacts with the associated carbon measures to consider. As argued here, the policy choices that HS2 opens up are at their greatest when consideration is given to alternative trajectories that become possible in the pattern of national and regional spatial development. It is not necessary to seek to accommodate the expected substantial growth in population in the congested South East if there is good reason to look to the Midlands and the North as better prospects for development. The carbon effect of these choices is clearly profound, given the huge differences in the carbon emissions from urban and rural residents and businesses, but it is beyond the level of analysis reported here to attempt a quantification.

[26] Greengauge 21 (February 2011), op. cit.

Appendix A: Factors likely to affect the carbon impacts of HS2

(Previously published in December 2011 as chapters 2-4 of Interim Report)

A1. Why the carbon impacts of HS2 depend on key policy decisions

Framework for greenhouse gas reduction

Reducing global greenhouse gas (GHG) emissions is critical in addressing the causes and consequences of climate change, and this is reflected in international, European and national targets. The European Union aims to reduce greenhouse gas emissions by 80-95% by 2050 compared to 1990 levels. In the UK, the ultimate 2050 target of a reduction of at least 80% is now included in the Climate Change Act 2008[27] and the Committee on Climate Change (CCC) advises the UK Government on achieving the target and on setting interim five-year budgets.

Domestic transport in the UK currently represents approximately 21% of total UK greenhouse gas emissions.[28] By 2050, on the basis of what can be achieved in all sectors of the economy, the CCC estimates that an emissions reduction of more than 90% will be needed from surface transport in order to meet the economy-wide 80% reduction target. While greenhouse gas emissions from international aviation are not currently included within the carbon budgets, the CCC has advised Government that it should include these and will advise the Government how this might be done.

Carbon dioxide (CO_2) is only one of six greenhouse gases covered by the Climate Change Act, although the vast majority (over 98%) of transport's direct greenhouse gas emissions are CO_2. Hence in relation to transport, CO_2 and GHG are sometimes used interchangeably. The main exception to this is in relation to aviation, where the effect of non-CO_2 emissions on climate change appears to be significant (see section 2a below).

In order to examine the policies that might have an impact on the CO_2 emissions associated with HS2, Dr Ian Skinner was commissioned to carry out an independent review.[29] As well as providing advice on modelling assumptions that will be used in phase 2 of the study, the report provides a comprehensive review of policies that affect the:

a) **Carbon intensity** of energy used in the transport sector;

b) **Energy efficiency** of transport vehicles;

c) **Use of vehicles**, including policies that focus on improving the utilisation of vehicles; and

d) **Capacity and location** of transport infrastructure.

From this review, the factors that are considered most likely to influence the carbon impact of HS2 have been identified and are discussed below. These factors will be the subject of the phase 2 analysis which will be described in our final report. The HS2 carbon case will be influenced directly by factors that affect the efficiency of HS2 operations but also less directly by policies that affect the usage or efficiency of other modes of transport, (as these will influence demand levels and the amount of mode shift from car and air to rail) and on wider policies related to land use (which affects the pattern of demand for travel).

[27] See Climate Change Act 2008 at http://www.legislation.gov.uk/ukpga/2008/27/section/24.
[28] See http://assets.dft.gov.uk/statistics/series/energy-and-environment/climatechangefactsheets.pdf
[29] Transport and Environmental Policy Research (November 2011), *Carbon impact of HS2: Overview of relevant policy issues and advice on modelling assumptions*.

(a) Factors that affect the carbon intensity of energy used in the transport sector

The vast majority of transport fuel used in the UK is derived from oil, i.e. petrol and diesel in road transport, and kerosene in aviation. The main exception is rail transport, which uses electricity as well as diesel. There is also a small amount of biofuels used by road transport (approximately 3%). In the future, it is likely that the use of fuel derived from sources other than oil will increase in the transport sector. In the short to medium term, this is likely to mean increases in the use of biofuels and electricity, while hydrogen is a potential medium to long term option. However, in order for this to contribute to reducing transport's GHG emissions, biofuels need to be environmentally 'sustainable' and electricity and hydrogen needs to be produced from low/very low carbon sources.

Electricity generation

High-speed rail trains will be powered by electric traction and so the carbon intensity of HSR operation will be heavily dependent on the carbon intensity of electricity generation and how this changes over time. Under the CCC's medium abatement scenario (effectively their 'central case') shown in Table A1, the carbon intensity of power generation would reduce from 544 to just 50gCO_2/KWh between 2008 and 2030. This would have a substantial impact on HSR emissions, reducing unit carbon emissions by a factor of 10. This would also improve the carbon performance of private car travel if there is a widespread adoption of electric cars (see section A1b below).

Table A1: Key CCC assumptions for the power sector in economy-wide medium abatement scenario

	2008	2020	2025	2030
Demand (TWh)	319	325	355	425
gCO2/kWh	544	320	150	50
Low carbon capacity (GW)	16	26	33	58

Source: CCC (2010), Table 3.5

However, the CCC notes that its medium abatement scenario 'reflects significantly increased penetration of low-carbon technologies across the economy, which would require technology innovation, cost reduction and policy effort.'[30] In order to reflect this potential risk to achievement of this scenario, in our phase 2 modelling we will also assess the impact of a slower decarbonisation of electricity generation, based on the CCC's low abatement scenario. Given the degree of ambition implicit in the CCC's medium abatement scenario, we will not explicitly assess the impacts of a faster rate of decarbonisation of electricity generation.

Biofuels

The UK and EU are proposing to decarbonise fossil fuels used in car and air transport by relying on an increase in the proportion of biofuels that is blended with such fuels. Under the EU's 2009 Renewable Energy Directive (RED), each Member State has a minimum target of 10% for the proportion of final energy consumption used by transport that should come from renewable resources by 2020. The UK's National Renewable Energy Action Plan[31] illustrates how the transport target could be met: largely through increasing the use of biofuels in transport. However, the more recent Renewable Energy Roadmap takes a more cautious approach to biofuels – noting that the existing RED sustainability criteria do not address some important sustainability concerns, such as carbon and other negative impacts arising from indirect land use change.[32]

[30] CCC (2010) *The Fourth Carbon Budget: Reducing emissions through the 2020s*
[31] The UK NREAP can be found at: http://ec.europa.eu/energy/renewables/transparency_platform/doc/national_renewable_energy_action_plan_uk_en.pdf
[32] DECC (2011) *UK Renewable Energy Roadmap*; see http://www.decc.gov.uk/assets/decc/11/meeting-energy-demand/renewable-energy/2167-uk-renewable-energy-roadmap.pdf

While the CCC in its scenarios assumes that biofuels are zero carbon, there are concerns about the potential of biofuels to deliver GHG reductions. Current EU law only requires greenhouse gas savings for biofuels of 35% compared to fossil fuels. In addition, one of the main concerns regarding climate impacts is over indirect land use change (ILUC) effects. First generation biofuels compete directly with land used for food and can therefore drive deforestation directly or indirectly; biofuel crops that can be grown on marginal land may also compromise future food supplies; and technologies to produce other future biofuels (such as those produced from algae) are as yet embryonic and extremely expensive. The European Commission intends to report on a review of ILUC and to make a proposal to amend the Renewable Energy Directive as appropriate, although a proposal has not yet been forthcoming. Another significant concern is a carbon accounting error highlighted by the European Environment Agency earlier this year. The EEA opinion is that burning biomass increases the amount of carbon in the air (in the same way as does burning fossil fuels) 'if harvesting the biomass decreases the amount of carbon stored in plants and soils, or reduces ongoing carbon sequestration'.

One further factor to take into account is that the increased use of oil from 'unconventional' sources (such as tar sands) has the potential to increase the amount of GHG emitted in the course of the production of fossil fuels.

Reflecting concerns over the sustainability of both biofuels and unconventional fuels, we will assess the potential impact of these on the case for HSR, taking into account the negative land use impacts of biofuels on carbon emissions that would result from increased usage in the car and aviation sectors.

Aviation and non-CO_2 emissions

The effects on non-CO_2 emissions from aviation appears to be significant. A 'comprehensive updated assessment' of the impact of aviation on climate change has suggested that the inclusion of these non-CO_2 elements could double the effect of aviation's impact on climate change.[33] This results from the warming effects of nitrogen oxides at high altitude, water vapour and soot and also contrails produced in certain atmospheric conditions. While there is still some scientific uncertainty over the scale of the effects, we consider it prudent to include this factor in our phase 2 modelling.

Key findings so far: carbon intensity of fuels and energy sources

- Emissions from HSR operations will be heavily influenced by the carbon intensity of electricity generation and it is assumed that this is reduced by 90% by 2030 in order to meet climate change targets, in line with CCC projections. However, it is possible that the rate of improvement may be slower than planned and so the impacts of an alternative scenario will be examined in our HS2 carbon modelling.
- Some improvements in the decarbonisation of fuel for the road and air sectors have been forecast to come from the increased take-up of biofuels. While international convention currently assesses biofuels as zero carbon, there are widespread concerns over the greenhouse gas emissions arising from direct and indirect land use effects as well as carbon accounting errors associated with biofuels. Examination will therefore be made of whether taking these effects into account significantly changes the carbon performance of road or air transport. In addition, unconventional sources of oil such as tar sands has the potential to increase the greenhouse gas emissions arising from the extraction of fossil fuels.
- The non-CO_2 effects of aviation are widely held to be significant, likely to double the CO_2 impacts, and so this will be reflected in our modelling of the effects of domestic air travel.

[33] See Box 3.2 in DfT (2011), *UK Aviation Forecasts.*

(b) Energy efficiency of transport vehicles

There are expected to be considerable improvements in the energy efficiency of the road fleet in the future, particularly for cars and vans, which is of interest because of the potential for mode shift from HSR to road. The carbon benefits of any mode shift will depend on the relative carbon emissions of the two modes of transport. The fuel efficiency requirements for new passenger cars and new vans are set in EU regulations. In the UK, the average CO_2 emissions for new cars in 2010 were 144gCO_2/km. EU targets require an average of 130gCO_2/km to be achieved by manufacturers by 2015 and 95gCO_2/km by 2020. There are similar (but somewhat higher) targets for new vans.

Looking further ahead beyond the EU targets, the CCC in its medium abatement scenario for 2030 assumes that the efficiency of conventional cars improves to 80gCO_2/km (although the CCC argues that the UK Government should push for EU targets to be set for 2030 at around 50gCO_2/km).[34] Under the medium abatement scenario, the CCC anticipates that 60% of new cars would need to be electric (accounting for 31% of the total fleet), with 30% being battery electric and the remainder plug-in hybrid. Between 2030 and 2050, the take up of alternatively-fuelled vehicles will depend on the path that has been taken to 2030.

These emissions per kilometre figures are all based on standard industry test cycles which do not reflect real world emissions as well as might be expected: evidence suggests that real world CO_2 emissions are on average 16-18% higher than as measured on the test cycle. Moreover, a further allowance of approximately 10% needs to be made to reflect the higher emissions from the average car fleet in operation at any time rather than new car emissions.

Given the dependence of the CCC scenarios on the take-up of electric cars which has not yet started to any significant degree – partly no doubt because of their high up-front costs – we consider it will be useful to assess the impact of a slower take-up of low-carbon cars than assumed in the CCC medium abatement scenario. This will illustrate the implications for HS2 of a more energy-intensive car fleet.

As yet, there is no EU-level GHG reduction target for HGVs, although standards have been developed and implemented elsewhere, including in Japan and the USA. The CCC believes that the potential for widespread use of electric HGVs is limited and therefore notes that biofuels might be considered appropriate to decarbonise HGVs (but note the issues discussed in section 2a above). However, the CCC's medium abatement scenario assumes a 15-30% efficiency improvement for conventional trucks between 2020 and 2030. This reduces CO_2 emissions from the average new conventional HGV from 799gCO_2/km in 2008 to 750gCO_2/km in 2020, to 600gCO_2/km in 2025 and 580gCO_2/km in 2030.[35] In the long run, it is considered possible that HGVs could run on low carbon hydrogen, with any residual need for liquid fuels (e.g. for plug-in cars, non hydrogen HGVs) coming from biofuels.[36]

Key findings so far: energy efficiency of transport vehicles

- Considerable improvements in the energy efficiency of cars are required in the future in order to achieve the targets for reductions in greenhouse gas emissions and this may improve the relative performance of car travel compared with rail or HSR travel.
- Achievement of these car efficiency targets is heavily dependent on the take-up of electric cars and so two scenarios will be assessed in our modelling: one based on achievement of the CCC targets and another based on a slower rate of improvement more in line with current trends.

[34] By 'conventional' cars and vans, the CCC means those using internal combustion engines, i.e. not electric vehicles. The EU targets that it proposes do include electric vehicles, which is the reason for the difference.
[35] CCC (2010), Table 3.5.
[36] CCC (2010)

- Changes in the energy efficiency of HGVs may also be important if HS2 releases any classic rail capacity which is used to provide for more rail freight services, potentially shifting freight from road to rail. The scope for a decarbonised HGV sector is much lower than in the car sector and so modal shift from freight to rail will be important to meet carbon reduction targets.

(c) Use of vehicles

Policies or factors that affect the ways in which vehicles are used will influence the carbon impact of HSR through influencing the shift of passengers from road- or air-based transport to rail. There are a number of potential policy options that could influence the way in which vehicles are used and hence could change transport's CO_2 emissions. These might include:

- Congestion charging, local road pricing schemes and parking charges;
- Investment in public transport and cycling infrastructure;
- Smarter choices and other means of promoting the use of public transport, cycling and walking;
- Car clubs and car sharing;
- Information and training on eco-driving;
- Fuel and vehicle taxation;
- The regulation of speeds.

It has generally been found that policies based on pricing and taxation have much greater scope to influence greenhouse gas emissions than other types of policy and so we will consider explicitly the impacts of oil prices and road pricing, and also the effects of different speed limits for inter-urban travel. However, there are considerable carbon benefits from the other policies highlighted above: while they may be less relevant when considering the direct carbon impacts of HS2, they are significant if we consider the entire door-to-door journey which will include the modes of transport people use to access the HS2 services.

Oil prices

Perhaps the most significant factor that has the potential to influence road and air travel substantially is that of oil prices (or fuel prices for road use), given that there is a general expectation of continued increases in prices over time as available supplies become more difficult to extract. For example, the Department of Energy and Climate Change (DECC) assumes in its central scenario that oil prices will rise from $81/barrel in 2010 to $118/barrel in 2020 and $128/barrel in 2030 (in 2011 prices).[37] DECC's high price scenario sees oil prices rising to $168/barrel in 2030. These prices appear to be higher than those assumed by the Department for Transport (DfT), which were based on earlier DECC forecasts. There are other projections available internationally, which tend to be more in line with the recent DECC projections. However, there is clearly a great deal of uncertainty over future oil prices and their impacts on the costs faced by car and air users. Higher oil prices could reduce the demand for car and air travel and hence would have an impact on the mode shift and consequential carbon benefits of HSR travel. We will therefore examine how a wide range of oil prices influences the carbon impacts of HSR.

Road pricing

While the current UK Coalition Government is not considering a national road pricing scheme for cars on existing roads, or even making any preparations for such as scheme in the lifetime of the current Parliament, road pricing could have a substantial impact on the cost of motoring and on the balance of supply and demand on the strategic highway network. This would influence how

[37] DECC (2011) *'Updated energy and emissions projections 2011'*; see http://www.decc.gov.uk/assets/decc/11/about-us/economics-social-research/3134-updated-energy-and-emissions-projections-october.pdf

well HSR services can compete with road travel and so we consider it would be informative to understand the potential impacts of road pricing. There is an analytical challenge in that there is no accepted national road pricing scheme to evaluate and the effects will vary depending on the precise mechanisms of any scheme, but we will draw on existing work to consider the possible impacts. The CCC notes that road pricing, if introduced in addition to existing fuel duty, could result in significant greenhouse gas emissions reductions, mainly from a reduction in distances travelled, but others have suggested the need for tax-offsets to address distributional impacts.

Motorway speed limits

The other policy that we will examine is speed limits on trunk roads, which affects fuel consumption and journey times by road. Tests carried out for the European Environment Agency have estimated that a reduction in speed limits from 75mph to 68mph could theoretically deliver fuel savings for car travel of between 12% and 18%, although only 2-3% under more realistic assumptions. While reducing speed limits would improve the carbon case of car travel relative to rail travel, it would also increase journey times for car trips and make HSR relatively more attractive. Conversely, if speed limits were raised, car journey times would decrease and the relative journey time advantage of HSR would be reduced. The Government has announced that it intends to launch a consultation on the possibility of increasing the speed limits on motorways to 80mph.[38]

Key findings so far: use of vehicles

- Future oil prices may have a substantial impact on the cost and competitiveness of car and air travel compared with travel by rail and there is a wide range of uncertainty around the future level and volatility of fuel prices. We will examine in our phase 2 modelling the impact of a plausible range of prices.
- A national road pricing scheme for inter-urban roads could potentially alter the competitive balance of road travel vs rail. While there are no plans to develop any schemes at this stage, this may change by the time HS2 is completed and so the potential impact on the case for HSR will be examined.
- Journey times for inter-urban travel will also be affected by the regulation of speed limits. The Government is currently considering raising the motorway speed limit to 80mph, while research has demonstrated the carbon benefits of lower speed limits.

(d) Capacity and location of transport infrastructure

Land use planning policy

The importance of integrated land use planning and transport policy in contributing to reduced CO_2 emissions from transport has been highlighted by the CCC, recommending the development of integrated land use and transport planning strategies. Experts consider that land use policy would be most favourable to reducing CO_2 emissions if it favoured higher densities, active and attractive local communities, with amenities within walking distance, and which were well served by public transport. Additionally, urban brown field development would be favoured over ex-urban green field development.[39] This applies to new high-speed rail stations, which have the potential to promote sustainable land use patterns if they are located where they can stimulate brownfield regeneration and be accessed by public transport, walking and cycling, thereby avoiding new sprawling development and the generation of new car trips.

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[38] See http://www.dft.gov.uk/news/press-releases/dft-press-2011100

[39] Goodwin, P (2009) Report of CCC Expert Workshop *Land Use Aspects of Transport's Contribution to Climate Change*; see http://downloads.theccc.org.uk/CCC_land_use_transport_report.pdf
Green Balance (2011) *Building in a small island? Why we still need a brownfield first approach*, produced for CPRE; see http://www.cpre.org.uk/resources/housing-and-planning/planning/item/download/1503

Research on international high-speed rail experience[40] has highlighted the importance of planning for good linkages between HSR and local transport systems, particularly public transport networks, and for high-speed rail stations to provide for effective access to HSR services. This will help to ensure that the whole 'door-to-door' journey takes place on sustainable modes of transport. Integrated land use and transport planning can therefore be used to maximise high-speed rail demand, the consequential economic development benefits and the carbon savings arising from mode shift.

In response to the Government's 2011 consultation on its draft National Planning Policy Framework (NPPF), a number of transport organisations have called for the reduction of GHG emissions and the promotion of a low carbon economy to be one of the core principles and objectives for the framework.[41] CPRE has called for 'smart growth' to be promoted in the NPPF, in order to focus development where there are the highest levels of accessibility by sustainable modes of transport, and also for the better integration of land use and transport planning.[42] The draft framework contains a presumption in favour of development (with some protections) and weakens the town centre first policy contained in previous planning guidance. If followed through, this is likely to impact on the demand for public transport, including HSR demand, by reducing the proportion of development built in places well served by public transport, and could increase the demand for car travel. In phase 2 of this study we will therefore examine the differences between a land-use planning approach based on NPPF principles compared with an approach based on retention of brownfield-first approach to land release with a prioritisation around public transport nodes and industrial areas well served by rail and water transport.

Airport capacity

The other key transport infrastructure factor that will affect net HSR carbon emissions is that of airport capacity. The main UK airports in the South East are at or near capacity and given that the Coalition Government has no plans to allow for additional runways at Heathrow, Gatwick or Stansted airports, it appears that there will be no immediate expansion of airport capacity in South East England. While HSR has the scope – particularly when HS2 is connected direct to Heathrow and also expanded northwards beyond the West Midlands – to reduce domestic air travel, it has been pointed out that this would result in carbon savings only if any airport slots freed up by reduced domestic flights remain unused.[43]

With the capacity constraints currently being experienced at the South East airports, there is clearly a risk that any airport slots freed by HS2 would instead be used for international flights. However, it is to be noted that airport capacity is far from constrained across Europe and airports such as Paris Charles de Gaulle and Amsterdam Schiphol are already handling increasing numbers of feeder flights from UK airports, with UK passengers transferring onto long-haul flights outside the UK. To consider global carbon emissions we should therefore consider whether there is a net increase or decrease in the total emissions from aviation if HS2 frees up capacity at Heathrow, allowing an increase in long-haul flights but also the replacement of short haul feeder flights to Europe by high-speed rail access to Heathrow.

Key findings so far: capacity and location of transport infrastructure

- Land use planning issues can have a significant impact on modal split and trip patterns and could impact on the case for HSR both by affecting the density of residential and employment

[40] For example, see Reg Harman for Greengauge 21 (2006), *High Speed Trains and the Development and Regeneration of Cities*.

[41] Chartered Institution of Highways and Transportation et al (2011) *Consultation on National Planning Policy Framework (NPPF) Summary of key responses – Joint submission*

[42] CPRE (October 2011), *Draft National Planning Policy Framework: A response by the Campaign to Protect Rural England (CPRE) to the Department for Communities and Local Government consultation.* Available at: http://www.cpre.org.uk/resources/housing-and-planning/planning/item/download/1449

[43] Booz & Co and Temple Group (2011).

development around HSR stations and by influencing the location of the HSR stations themselves. While these effects are difficult to quantify, it is clearly important that they be considered alongside the other impacts that we are modelling.

- The carbon impacts of HSR will be affected by the impacts on the aviation sector. While HS2 (and future extensions to an even greater extent) will undoubtedly reduce the demand for domestic flights within the UK, the carbon benefits will be affected by the degree to which any airport capacity freed up is used for new long-haul flights, and by the extent to which there is transfer from feeder flights, including via hub airports in NW Europe. We will consider the issue at an international level to understand the potential impact on global emissions.

A2. How the design and operation of high-speed rail affects carbon emissions

Overview

High-speed rail produces carbon emissions in three main ways:

1. Embedded carbon arising from the construction of infrastructure for the track, stations and depots;
2. Embedded carbon arising from the manufacture of rolling stock;
3. Operational carbon from train operations.

In most case, the majority of emissions over its lifetime arise from train operations, so while we consider embedded emissions below, the review we commissioned from SYSTRA[44] focused on identifying and quantifying the key factors that influence operational emissions from high-speed rail, and we cover that aspect at greater length. In particular, the review by SYSTRA considers the relationship between carbon emissions and HSR speeds. In phase 2 of this study, we will use the SYSTRA analysis as inputs into our modelling of the operational carbon emissions from HS2. This will also incorporate the impacts of passengers shifting from other modes of transport and the different scenarios which will influence the extent to which this occurs, reflecting the issues discussed in Chapter 2.

Embedded carbon

A comprehensive assessment of the embedded carbon of HS2 was carried out by Booz & Co and Temple Group for HS2 Ltd,[45] taking into account 'the carbon emissions associated with construction operations such as constructing the rail infrastructure and trains, as well as the embedded energy within the bulk construction materials'. This assessment reached the following conclusions:

- Total embedded carbon emissions for HS2 were assessed at 1.2 million tonnes CO_2 in total;
- There is some uncertainty around this estimate, with a reported range of 0.29 to 2.12 $MtCO_2e$;
- Within this 1.2 $MtCO_2e$, only 0.1 $MtCO_2e$ results from the manufacture of high-speed trains, with the bulk of the emissions being associated with infrastructure construction.

It is noted by SYSTRA that the level of embedded emissions for the line of route can vary considerably, by up to a factor of 20, depending on:

[44] Systra (28 November 2011), *Factors affecting carbon impacts of HS2*.
[45] Booz & Co and Temple Group (2011).

- The nature of the route, with tunnels, viaducts or major earthworks being particularly carbon intensive;
- The construction methods used, for example, the use of quicklime to treat soil in earthworks can increase carbon emissions considerably.

The HS2 Ltd assessment found that two-thirds of embedded carbon from HS2 arises from materials, particularly steel and concrete. Transporting the bulk materials produces another 19% of the embedded carbon, although this was assessed on the basis that materials were transported predominantly by HGV. Given that it will be possible to transport at least some of the materials to site by rail, it should be possible to reduce this source of emissions significantly.

Operational carbon

High-speed rail trains operate under electric traction and so carbon emissions from HSR operation are influenced significantly by the electricity generation mix. This was discussed separately in Chapter 2 and so this chapter focuses solely on how the design and operation of HSR affects energy consumption, expressed as kilowatt hours (kWh). Our phase 2 modelling will bring together the two factors of electricity generation mix and HSR characteristics.

The modelling will also need to be able to compare between modes and to assess the impacts of passengers shifting, for example, from air to HSR. For this reason, we assess energy consumption per seat-km, taking into account seating capacity.

The factors that influence the energy consumption of HSR operations can be grouped into three categories: rolling stock design, operational strategy and infrastructure design. The key factors are highlighted below in Table A2. The relationship between speed and energy consumption is discussed separately in the next section.

Table A2: Factors that influence the energy consumption (per seat or per passenger) from HSR operations

Factor	Explanation	Effect
Rolling stock design		
Aerodynamics	High-speed rolling stock offers less air resistance than conventional trains by appropriate design that shapes the front and rear of the train, ensures doors, windows etc are flush with walls, provides rounded outer surfaces and streamlined protection on equipment.[46] Aerodynamic design can also mitigate the air resistance impacts of double-deck trains.	TGV trains in France offer 35% less air resistance than a conventional train.[1] TGV Duplex (double deck) only offers 5% more air resistance than TGV-R (single deck).[2]
Seating capacity	The larger the seating capacity, the lower the energy consumption per seat-km. Seating capacity is influenced by the factors below:	
	i. Train width – making best use of the available loading gauge available on new infrastructure.	HS2 'captive' trains will be able to make use of the European gauge infrastructure.
	ii. Train length – air resistance increases less than proportionally with train length.	When two 200m-long trainsets are combined, energy per seat reduces by 3-4% compared with one 200m-long trainset.[3]
	iii. Distributed traction – with motors under each car rather than in separate power cars, passenger seating can be provided in the end cars that would otherwise be dedicated power cars.	Trains with distributed traction offer the best seating ratios.[4]

[46] This cannot generally be achieved with conventional speed trains, as it would require nosecones to be fitted; it would be uneconomic to do this on a system as in the UK where there are generic constraints on platform length.

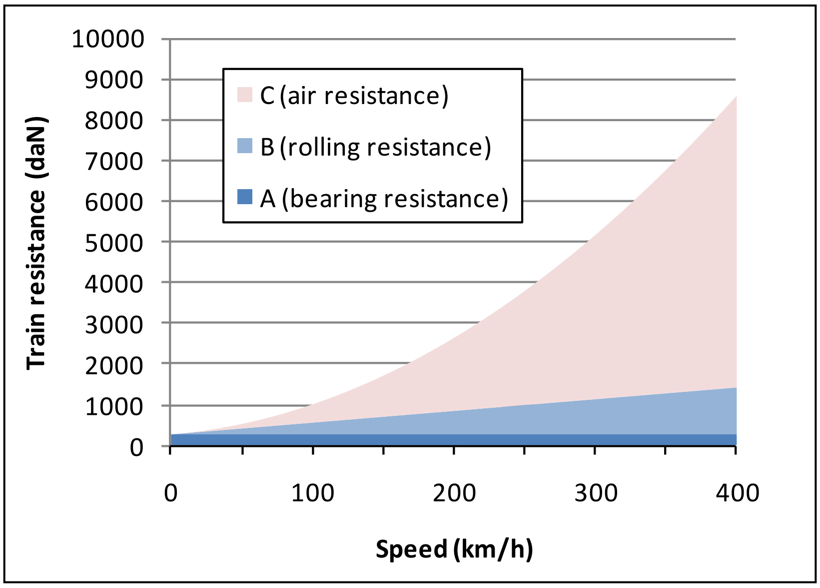
Factor	Explanation	Effect
Operational strategy		
Timetabling margins	It is recommended operational practice to apply timetabling margins to HSR services and the most energy-efficient way to apply these margins is to reduce cruising speed (but maintain maximum acceleration). HS2 Ltd assume an 8% margin is applied in this way, so that with a maximum line speed of 360 km/h, the actual average cruising speed of trains will be no higher than 330 km/h.	13-15% less energy is needed to maintain velocity for a given distance if trains run at 92% of maximum speed as is assumed for HS2.[5]
Eco-driving	Adjustment of driving speed according to gradients can reduce energy consumption.	Optimised operating speeds could result in 11-13% reductions in energy consumption on HS2.[6]
Stopping patterns	Intermediate stops increase overall energy consumption and so point-to-point services are more efficient.	An intermediate stop (say, midway between London and Birmingham) can result in additional energy consumption of 2-4%.[7]
Booking reservation strategy	Higher occupancy rates reduce average energy consumption per passenger and this can be encouraged by reservation-only booking strategies. This is still compatible with turn-up-and-go systems as long as the booking system allows last minute reservations.	Bookings are compulsory on Eurostar and on French TGV services which achieve 70% load factors. Contrast with German ICE services which do not require advance booking and which only achieve 50% loadings on average.[8]
Infrastructure design		
Horizontal and vertical alignment	The configuration of high-speed rail infrastructure impacts on energy consumption, principally by the factors below:	
	i. Gradients – uphill gradients increase resistance proportional to train mass and the gradient. This can be relieved by eco-driving (see above).	
	ii. Curves – increase mechanical resistance (and hence energy consumption), so large curve radii minimise the impacts.	
	iii. Tunnels – increase energy consumption compared with open line because of greater air resistance, although the effects are reduced for tunnels with wider diameters.	At 320 km/h a (notional) 10km tunnel could increase energy consumption by 65-157 kWh depending on tunnel diameter.[9]
Route length	High-speed railways will tend to be shorter than conventional railways because of the avoidance of intermediate stations, large curve radii and higher gradients.	The Paris-Lyon high-speed line is 16% shorter than the conventional line.[10]
Integration of green energy sources	Rail-specific green energy sources can be built into infrastructure projects, delivering renewable energy.	A Belgian high-speed rail tunnel is topped with 16,000 solar panels, sufficient to power Belgium's trains for one day/year.[11]

Sources:
1, 2, 4, 5, 10, 11 SYSTRA (2011).
3, 6, 7, 9 Imperial College (2009), *HS2 Traction Energy Modelling.*
8 Nash, Chris (2009), *High Speed Rail Investment; an overview of the literature*.

Energy consumption and speeds

The energy needed to operate a train at any given speed is determined by the degree of train resistance that it has to overcome, which is affected by air resistance, bearing resistance (caused by friction within a vehicle's wheel bearings), rolling friction and other factors such as flange friction and the effects of sway. These elements vary according to train weight and operating speed. As Figure A2 shows, at high speeds, air resistance provides the majority of resistance and this element is proportional to the square of speed.

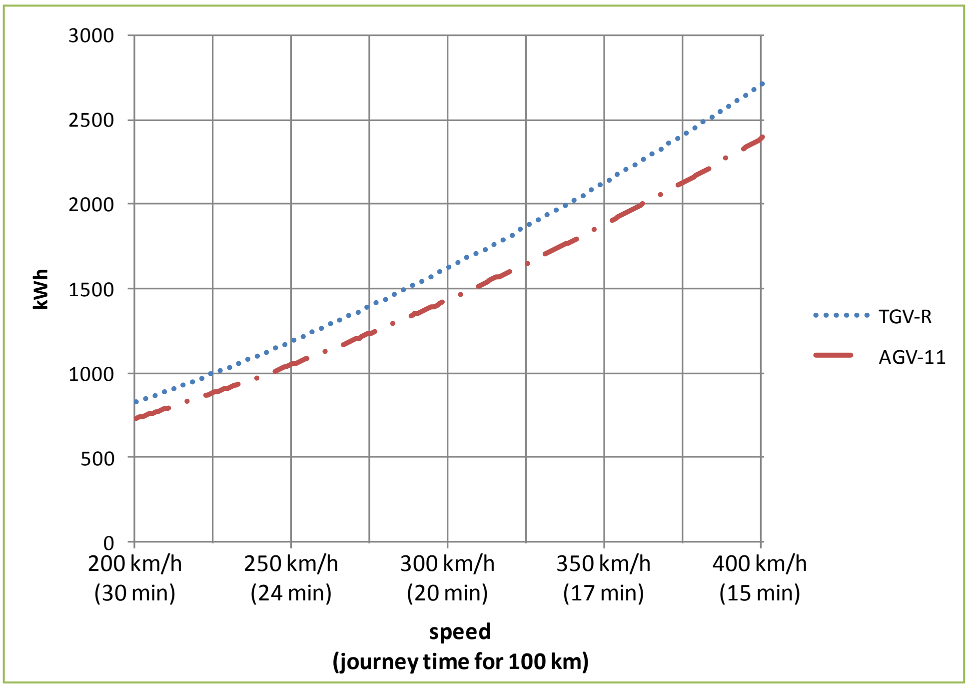
Figure A2: Contribution of bearing, rolling and air resistance to overall resistance of an AGV-11 at different speeds



Source: SYSTRA (2011), *Factors affecting carbon impacts of HSR*

Figure A3 shows the energy needed to operate two existing types of high-speed train over 100km at different constant speeds. As can be seen, the newer AGV train is 12% more efficient than the TGV-R train (the primary difference being that the AGV has distributed traction). For both trains, continuous operation at 360 km/h uses 38% more energy than at 300 km/h.

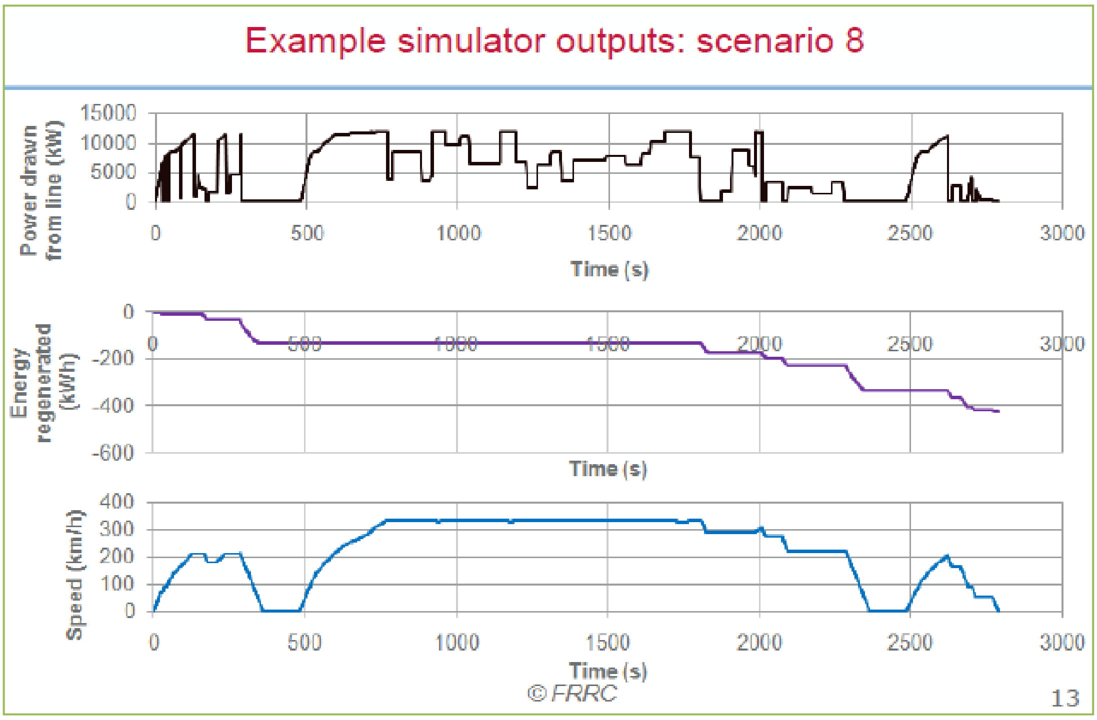
Figure A3: Energy to overcome resistance for a 100-km journey for different speeds/journey times



Source: SYSTRA (2011), *Factors affecting carbon impacts of HSR*

The estimates in Figure A3 show the theoretical effects of operation over 100km at a constant speed, but they do not take into account the effects of acceleration, regenerative braking, hotel power[47] and the impact of line speed limitations. In reality, these impacts also affect energy consumption. For example, Figure 4 shows the results of traction modelling carried out by Imperial College for HS2 Ltd of high-speed services on the London Euston to Birmingham Curzon Street HS2 route. The effect of station calls at both Old Oak Common Interchange and Birmingham Interchange stations, together with the sections of route with line speeds below the maximum (and in this example, 'optimised' operating speeds) means that an HS2 train would be operating at top speed for less than half of its overall journey time. As the top graph of Figure A4 shows, there are sections of the journey with very low power draw.

Figure A4: London – Birmingham traction energy simulation
(Two intermediate stops, 200m-long train, 70% load factor, optimised line speeds)



Source: Imperial College (2009), *HS2 Traction Energy Modelling*

The Imperial College modelling of this and other cases on the HS2 alignment suggests that in practice a London – Birmingham journey on HS2 would consume only 23% more energy when the maximum speed capability is increased by 20% (from 300 km/h to 360 km/h). In other words, energy consumption in practice increases less than the square of the speed increase.

Key findings so far: HSR design and operation

- The embedded carbon in HS2 infrastructure is expected to amount to approximately 1.2 $MtCO_2e$, although there is some uncertainty around this and it is affected by the nature of the route, in particular the amount of tunnels, viaducts and earthworks. Embedded carbon in HSR rolling stock is not expected to be significant.
- The energy consumption of HSR operations is affected by aerodynamic design and the seating capacity of rolling stock; by the application of timetabling margins, driving techniques, stopping patterns and reservation strategy; and by the horizontal and vertical alignment of the infrastructure, and route length.

[47] Hotel power is the energy needed to support the equipment in passenger saloons and catering vehicles: lighting, heating, air conditioning , kitchen equipment, etc. It does not vary as a function of operating speed.

- Operating speed is a critical determinant of energy consumption. Operating HS2 at a maximum capability 360 km/h rather than 300 km/h (a 20% increase) would consume 23% more energy in actual operation on the London – Birmingham HS2 route, once the impacts of the need to provide a continuous power supply for passenger accommodation (hotel power), acceleration, braking and line speed limitations are taken into account. This is less than a theoretical constant-speed model would predict, which is close to a power square difference.
- The application of an 8% timetabling margin to high-speed services for traction during operations at high speed, as assumed for HS2, would reduce energy consumption by 13-15%.

A3. How HS2 can drive wider carbon benefits from the existing rail network

Overview

One of the principal advantages of HS2 is that it will free capacity on the existing railway through the rationalisation of the current fast intercity services (which very largely switch to HS2), allowing improved local and commuter passenger services and expanded numbers of freight trains. The carbon impacts of these improved conventional rail services has not been examined before, but potentially, there is substantial scope for the transfer of passengers and freight from the road network (and higher carbon forms of transport) to an already electrified rail network.

Greengauge 21 previously published a proposition for 'Capturing the benefits of HS2 on existing lines',[48] which set out a potential post-HS2 WCML timetable. This exercise focused on the potential for improved regular interval passenger services between London and the West Midlands, while providing capacity for some growth in freight. Network Rail and Passenger Focus have since been asked by DfT to develop a post-HS2 timetable, but this work is not due to be complete until Spring 2012.

In phase 2 of this research, we will assess the potential carbon impacts of an expansion of passenger rail services, based on the Greengauge 21 service proposition. We will also develop and assess an alternative scenario based on providing greater capacity for an expansion of rail freight. The issues that will need to be considered in these two scenarios are outlined in this chapter.

The benefits of expanded passenger rail services

The post-HS2 WCML timetable previously developed by Greengauge 21 established a set of new passenger services that better served the intermediate towns and cities on the West Coast Main Line. Watford, Milton Keynes, Rugby, Nuneaton, Tamworth and Lichfield were provided with frequent regular interval services that would allow them to act as major public transport interchanges and Birmingham and London were both provided with substantially expanded commuter services. These service enhancements will be made possible because of the capacity liberated by HS2, allowing fast intercity services to transfer to HS2. The net change in carbon emissions from conventional rail services that would result from these timetable changes would need to be assessed.

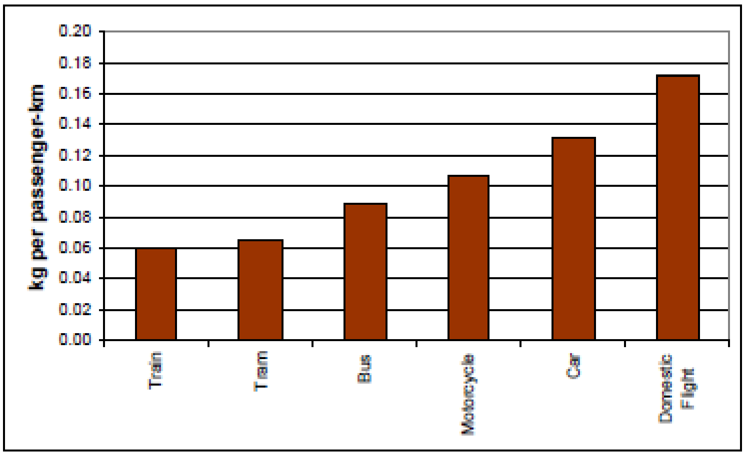
Moreover, a set of wider network opportunities can be opened up by freeing up WCML capacity – to improve the feasibility of the East West Rail link, or new services to re-opened stations, such as Kenilworth.

[48] Greengauge 21 (February 2011), *Capturing the benefits of HS2 on existing lines.*

The significance of these new services in carbon terms is that they are likely to trigger a significant mode shift from car to rail, possibly greater than is forecast to switch from car to HSR. This indirect effect is therefore particularly important. It cannot be realised without the release of capacity that HS2 brings, and it is therefore properly attributable to HS2. HS2 Ltd's forecasts suggest that 7% of HSR demand will be passengers who would previously have travelled by car – although this is based in part on assumptions of relatively low future petrol costs.

It is clear that there will be carbon benefits from any shift of passengers from car travel to rail travel. Figure 5 sets out some indicative figures for carbon emissions for different modes of transport. This will be updated for the phase 2 modelling, projected forward over 50 years and will reflect the specific type of electric rolling stock used on the WCML. What is already evident from Figure 5 is the clear carbon advantages of rail travel over car travel. On a passenger-km basis, rail travel currently produces less than half the CO_2 emissions of car travel and even less in relation to air travel (even when the effects of radiative forcing are excluded as they are in Figure A5).

Figure A5: CO_2 emissions by transport mode, 2008

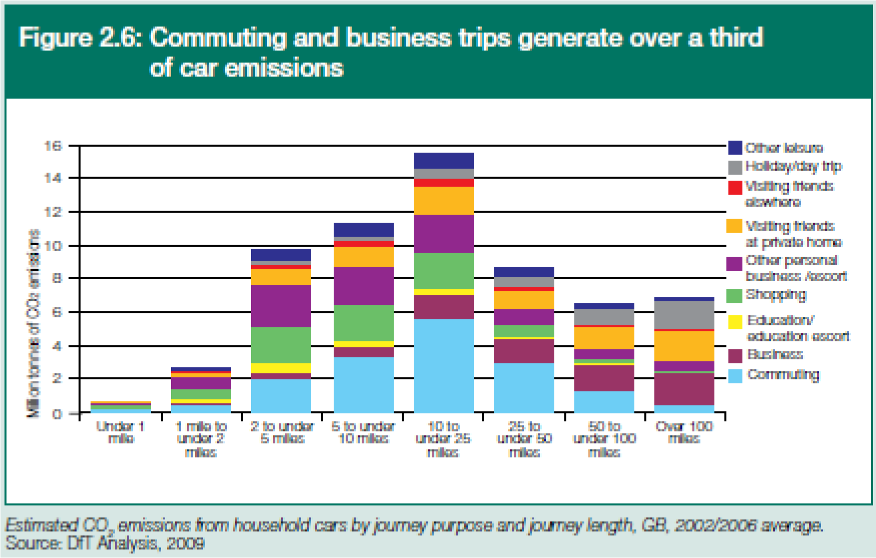


Source: Steer Davies Gleave (December 2008) for Campaign for Better Transport, *Transport costs and carbon emissions*.

The potential for mode shift arising from expanded conventional rail passenger services will be particularly valuable considering the types of journeys that improved WCML services could be targeting. Figure A6, extracted from DfT's 2009 Low Carbon Transport strategy[49], illustrates that 25% of car emissions arise from trips of 10-25 miles and another 14% from trips of 25 to 50 miles. Many of these trips are for commuting or business. These types of trips are those that can readily be targeted by improved local, commuter and regional rail services on the WCML, once capacity has been freed by HS2.

[49] Department for Transport (2009), *Low Carbon Transport: A Greener Future*.

Figure A6: Car emissions by journey length and purpose, 2002/2006



Any mode shift from road transport to rail services (or indeed to high-speed rail services) potentially frees up road capacity. This has the potential to reduce road congestion although, as with airport capacity, it may be that such freed road capacity stimulates some new road trips. This extent of this impact can be influenced by complementary measures to reallocate road space or 'smarter choices' policies.

Rail freight

The West Coast Main Line is the busiest long distance route for rail freight in the UK and providing additional capacity released via HS2 will be of considerable value. Forecasts recently produced for the Rail Freight Group indicate that rail freight in terms of tonne-km lifted will increase by between 90% and 105% by 2030, depending on future increases in productivity.[50] This suggests that train-km per weekday will increase by 93-121% over the same period. A major contributor will be the 'gateway' flows in the South East through the major deep sea ports and to a lesser extent the Channel Tunnel. The forecasts do not include any explicit changes in road costs such as lorry road user charging.

The impacts of this traffic growth on the West Coast Main Line will be substantial. At the southern end, the RFG estimates that the number of weekday trains will double from 65 to 132 per day, with even higher growth at the northern end of the route. By 2030, the RFG estimate that freight will need six paths an hour in each direction on the WCML, more than double today's provision. If this freight does not travel by rail it is estimated that 200 trucks per hour would be added to the road network (the M40, M1 and parallel A roads), increasing CO_2 emissions by 500,000 tonnes annually.[51] The correspondence between the freight that can be carried by train and the equivalent number of HGVs is shown in Table A3.

Table A3: Potential for a fully loaded freight train to remove lorries

Commodity	Fully loaded train potential	Equivalent number of heavy goods vehicles[1]
Coal	1,500 tonnes	52
Metals and ore	1,000 to 2,500 tonnes	60

[50] MDS Transmodal (October 2011), *Rail freight demand forecasts to 2030*, Produced for the Rail Freight Group and Rail Freight Operators Association.
[51] Letter from Tony Berkeley, Rail Freight Group Chairman, to Philip Hammond, Secretary of State for Transport, 28 September 2011.

Commodity	Fully loaded train potential	Equivalent number of heavy goods vehicles[1]
Construction materials	1,500 to 3,000 tonnes	77
Oil and petroleum	2,000 tonnes	69
Consumer goods	600 to 1,100 tonnes	43
Other traffic	1,000 to 1,500 tonnes	43

1. Where a range has been given, the mid-point of the range has been used to estimate the number of HGVs.
Source: Network Rail (July 2010), *Value and Importance of Rail Freight*.

Network Rail's analysis of the value of rail freight highlights that per tonne of cargo conveyed, rail freight currently produces 76% less CO_2 than road freight. This is based on DEFRA estimates that on average HGV road freight emits 118.6g CO_2 per tonne-km of freight carried compared with 28.5g CO_2 per tonne-km for rail freight. These factors will be taken into account in our phase 2 modelling.

Key findings so far: HS2 and the existing rail network

- HS2 will free capacity on the existing rail network, primarily the West Coast Main Line, allowing new and expanded conventional passenger rail services to be operated and increasing capacity for freight.
- Improved passenger services open up the potential for greater mode shift from car to rail, with consequential carbon savings: on a passenger-km basis, rail currently has less than half the CO_2 emissions of car travel.
- There are forecast to be substantial increases in rail freight in the WCML corridor and if this can be accommodated on the railway post-HS2 it will allow significant reductions in HGV traffic and CO_2 emissions. Rail freight currently emits 76% less carbon than HGV road freight.

Appendix B: Carbon Modelling Assumptions

Table B1: Assumptions on unit carbon emissions

Factor	Assumption
General	
HS2 scheme	First phase only, i.e. new line London to West Midlands with connection to WCML to allow services to Manchester, Liverpool, Glasgow. Y network is tested as a sensitivity.
Appraisal period	60 years from 2026 (HS2 opening year). Y network is assumed to open in 2033, after 7 years of HS2 phase 1.
Carbon intensity of electricity generation	As projections from Committee for Climate Change, i.e. medium scenario based on 2010 projections. Capped from 2050 onwards
High speed rail	
Average all-day load factor	70%
Top operating speed	360 km/h (central scenario), but assumed 'optimised line speed' in practice, approx 330 km/h.
Energy consumption per seat-km	0.049 kWh/seat km (360kmh), 0.040 kWh/seat km (300kmh). (Source: Imperial College simulation for HS2 Ltd.) Factored down by 8% to allow for lower speed running on WCML for some services.
Train length	200m for 70% of services, 400m for 30% of services (Lon-Bhm). Energy efficiency saving per seat from 400m-long trains: 4%.
Number of seats per train	510 per 200m unit.
Change in energy consumption over time	No efficiency improvement. Unit emission rates held constant from 2050 onwards
Car	
Load factor (no. passengers)	32% (i.e. 1.6 passengers per 5 seat vehicle). Annual reduction in passenger occupancy of 0.5% to 2036 (source: WebTAG).
Carbon emissions per veh-km	As EU targets and TEPR recommendations: 2010 144g CO_2e, 95g 2020, 70g 2030, 45g 2040, 14g 2050. No change from 2050 onwards. With 10% uplift for average car performance and 17% uplift for real world emissions compared with test cycle.
Air	
Average all-day load factor	80%
Carbon emissions per veh-km	Assumed 0.038 litres/seat km in 2010 (baseline) declining as per below. Based on 156 seat A319 Airbus (Easyjet configuration).
Rate of improvement	1.2% per annum improvement in fuel efficiency, based on DfT 2011 assumptions (as reported in 2012 CCC).
Fuel mix	10% biofuels in fuel mix from 2020, based on DfT assumptions.
Carbon intensity of aviation fuel	Aviation fuel 2.526kgCO2 per litre (source: DEFRA) Biofuel: 0.5% of CO2 emissions of aviation fuel (sensitivity test of 100% CO2 impact).
Indirect routes adjustment	9% increase in fuel consumption (to allow for impact of 'great circle' routeings on km flown, plus circling, etc.) (source: DEFRA)
Non-CO_2 impact	Not incorporated in modelling of carbon emissions but shown separately for information. Assumed to double the CO_2 impact.
Classic rail: intercity	
Energy consumption per seat-km	0.037 kWh/seat km
Rate of improvement	Reduction of 10% in energy consumption by 2026
Average all-day load factor	50% (whole route, total operating day)

Factor	Assumption
Top operating speed	200 km/h
Classic rail: commuter	
Energy consumption per seat-km	0.032 kWh/seat km
Rate of improvement	Reduction of 10% energy consumption by 2036
Load factor	30% (whole route, total operating day)
Top operating speed	180 km/h

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