Natural England Commissioned Report NECR085

A strategic analysis of the sustainability case for High Speed 2

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. Therefore, the views in this report are those of the authors and do not necessarily represent those of Natural England. It should be noted that this study was undertaken by TRL before the publication of the high speed rail consultation documents by HS2 Ltd in February 2011. The analysis is therefore based on older documentation published in 2010 and does not reflect the most recent work on the Appraisal of Sustainability nor amendments to the proposed route alignment.

Background

In March 2010 the Department for Transport (DfT) published the High Speed Rail Command Paper setting out plans for the development of an initial core high speed rail (HSR) network. In the first phase this would link London to Birmingham. Natural England commissioned TRL to undertake an independent strategic analysis of the sustainability case for High Speed 2 (HS2), focusing mainly on the environmental impacts of the proposals. The study objectives were to:

- Summarise the evidence regarding comparative emissions from rail, road, air and HSR and the assumptions underlying the main figures.
- Discuss the evidence regarding the carbon emissions for HS2, discuss the issues relating to energy generation for HS2, and identify the best and worst case scenarios for emissions.
- Discuss the contribution that HS2 could make to UK carbon budgets and targets.
- Examine the evidence for the potential for modal shift from road and air to HS2 (including impacts on freight movements) and identify the measures required to maximise modal shift.
- Review the literature and establish the lessons that can be learned regarding the impacts on the natural environment of other HSR routes and the approaches, and mitigation, that have been employed.
- Assess the valuation of environmental impacts of HSR in the supporting documentation.
- Prepare an analysis of the sustainability of HSR, supported/informed by research relating to the above objectives.

This study involved reviewing the HSR documents produced by the DfT and HS2 Ltd and a review of approximately 100 other papers related to HSR in the UK and overseas. The research concluded before the release of the February 2011 consultation documents and does not therefore include these in its analysis.

The findings published in this report are being used to inform Natural England's views about the proposal for HS2 including its formal response to the public consultation on the proposed route for a high speed rail link between London and Birmingham. This report is also available for others to use in developing their response to the consultation on HS2.

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Further information
This report can be downloaded from the Natural England website: **www.naturalengland.org.uk**. For information on Natural England publications contact the Natural England Enquiry Service on 0845 600 3078 or e-mail **enquiries@naturalengland.org.uk**.

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Summary

Study Objectives and Methodology

In March 2010 the Department for Transport (DfT) published the High Speed Rail Command Paper setting out plans for the development of an initial core high speed rail (HSR) network. In the first phase this would link London to Birmingham. Natural England commissioned TRL to undertake an independent strategic analysis of the sustainability case for High Speed 2 (HS2), focusing mainly on the environmental impacts of the proposals as per Natural England's remit. The study objectives were to:

1) Summarise the evidence regarding comparative emissions from rail, road, air and HSR and the assumptions underlying the main figures.

2) Discuss the evidence regarding the carbon emissions for HS2, discuss the issues relating to energy generation for HS2, and identify the best and worst case scenarios for emissions.

3) Discuss the contribution that HS2 could make to UK carbon budgets and targets.

4) Examine the evidence for the potential for modal shift from road and air to HS2 (including impacts on freight movements) and identify the measures required to maximise modal shift.

5) Review the literature and establish the lessons that can be learned regarding the impacts on the natural environment of other HSR routes and the approaches, and mitigation, that have been employed (for example, for HS1 or for other HSR routes).

6) Assess the valuation of environmental impacts of HSR in the supporting documentation.

7) Prepare a SWOT analysis of the sustainability of HSR, supported/informed by research relating to the above objectives.

The approach to this study involved reviewing the HSR documents produced by the DfT and HS2 Ltd to assess the extent to which the key issues of interest to Natural England were considered. This was followed by a review of approximately 100 other papers related to HSR which discussed both research and practice in the UK and overseas. The research concluded before the release of the February 2011 consultation documents and does not therefore include these in its analysis.

Main Findings

Research indicates that impacts on the natural environment from High Speed Rail are comparatively fewer than those from new roads schemes but still present significant challenges due to:

- Landscape impacts caused by land-take, fragmentation and severance, visual intrusion from infrastructure, loss of tranquillity; and

- Biodiversity impacts caused by land-take, habitat degradation and fragmentation caused by vibration, pollution, noise and the barrier effects of infrastructure, wildlife collisions.

Lessons learnt from the Channel Tunnel Rail Link indicate that substantial mitigation measures involving design, alignment, planting, habitat creation and species relocation along the length of the route were developed to address some of the most significant landscape and biodiversity impacts, though there is little data available as to the effectiveness of these measures.

At the time of this research, little available information about the predicted environmental effects of HS2 exists, except that provided within the Non-Technical Summary of the Appraisal of Sustainability for the first phase of HS2 (March 2010) which acknowledges that the main landscape impact of the scheme will occur in the Chilterns Hills. It is likely that the construction and operation of HS2 will have numerous and varied impacts on the natural environment, which must be avoided, mitigated or compensated through sensitive choice of routing, design, construction methods, train operation and maintenance practices. Some of these impacts will occur regardless of the route, while others will be dependent on the specific route chosen.

The publication of the full Appraisal of Sustainability for the revised HS2 route will provide more detail about the predicted effects of constructing and operating HS2. However, until the Environmental Statement is prepared prior to the Hybrid Bill, the full effects of the scheme will be unknown and cannot therefore be taken into account in these early stages of planning and decision-making. In identifying a possible route for HSR between London and the Midlands, it is apparent there are a number of compromises: between impacts on the natural environment versus impacts on populated areas; between speed and energy use; and speed and the ability to deviate around sensitive locations, which impacts on journey time and potential modal shift. It is evident that the revised route announced in December 2010 has explored some of these compromises, although further analysis by HS2 Ltd would be needed to identify whether a lower design speed would reduce the impact of HS2 on the natural environment and what the resulting impacts on modal shift and energy use might be.

In relation to carbon the study found that the carbon savings forecast for HS2 are very small in comparison with the UK's total transport emissions, so by themselves make very little contribution to overall carbon reduction targets. The majority of forecast carbon savings arise from modal shift from air travel to rail, with the modal shift from road contributing much smaller savings. However, there is a significant range in the estimated values for these savings, which arise chiefly from uncertainties in the extent to which the UK's electricity supply will be decarbonised, and uncertainties about potential 'rebound effects' arising in relation to how aviation and road capacity freed-up by modal shift to rail will be utilised.

To maximise the carbon benefits of HS2, significantly greater decarbonisation of the electricity supply will be required than that assumed (conservatively) by HS2 Ltd. The forecast savings will be nearly five times greater if the carbon intensity projections used by the Climate Change Commission are achieved.

The funds for HS2 could, of course, be spent on other investments, including but not exclusively, in transport. The study considered whether the other transport options in the HS2 London-Birmingham corridor offer a feasible and realistic alternative to HS2. It was found that none appear to deliver the same level of benefits, for example in terms of capacity and journey times, as HS2 on the proposed alignment, although the rail-based 'Package 2' option delivers extra capacity for lower cost and less environmental impact (Atkins, 2010).

In order to help maximise the benefits of HS2 other supporting measures and interventions would be required to lock in these benefits and encourage the maximum use of the new line and the capacity that would be released by its construction. The study identified a number of these measures, including improving sustainable access to rail stations, providing integrated ticketing for all HS2 journeys, taxation of air travel and road user charging.

Acknowledgements

This independent strategic analysis of the sustainability case for High Speed 2 has been undertaken by the Transport Research Laboratory (TRL). The key authors were Clare Harmer, Marcus Jones and Derek Palmer. The authors are grateful to Rob Gardner who carried out a technical review of this work.

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1 Introduction

HS2 – a short summary

1.1 In March 2010 the Department for Transport (DfT) published the High Speed Rail Command Paper setting out plans for the development of an initial core high speed rail (HSR) network. This would link London to Birmingham in the first phase, with later extensions to Manchester, the East Midlands, Sheffield and Leeds. From the outset, high speed trains (HSTs) will run from the new high speed line (HSL) onto the existing network, through to the North West and Scotland; then to Newcastle and Edinburgh when the second phase is built. The route preferred by the Coalition government is the "Y" route with separate branches to Manchester and to Leeds via the East Midlands.

1.2 The project is being developed by High Speed Two (HS2) Ltd, a company established by Government in January 2009. If approved, HS2 Ltd believes construction of the first phase could begin by 2018 with the first trains running by 2025 (HS2 Ltd, 2010a).

1.3 HS2 is intended to:

1) Provide necessary additional capacity, relieving the already congested West Coast Main Line (WCML) south of Birmingham, including additional capacity for freight on freed-up existing lines;

2) Create significant journey time savings, both to Birmingham and destinations to the North West and Scotland;

3) Support housing development in the WCML corridor, and economic regeneration in the West Midlands through overcoming existing limitations on connectivity;

4) Integrate with the existing national and international networks[1];

5) Provide a sustainable alternative to additional motorway or air capacity; and

6) Have a high benefit-cost ratio despite its price tag of over £30bn (Adonis, 2010; HS2 Ltd, 2009b).

1.4 Reports produced by HS2 Ltd since March 2010 and submitted to the DfT have investigated refinements to the original recommended route considering options for linking HS2 with Heathrow Airport and HS1 (the Channel Tunnel Rail Link). An announcement by the Coalition Government on their preferred route was made in December 2010, prior to the planned public consultation from February to July 2011. In the revised proposal the Government favours direct links between HS2 and both the HS1 line (St Pancras to Brussels/Paris, via the Channel Tunnel) and to Heathrow Airport. The link to HS1 will allow trains to run directly from the Midlands and the North to the Channel Tunnel; Heathrow will be linked by a spur to the main HS2 line. Alterations to the original route alignment and design have also been made, with around 50% of the route modified either through horizontal or vertical changes and the inclusion of further tunnelling.

1.5 HS2 Ltd has submitted detailed route proposals for the first phase to Birmingham and a connection onto the West Coast Main Line (WCML) near Lichfield. It is now developing route proposals for two separate legs, from Birmingham to Manchester and from Birmingham to Leeds, with options for serving the East Midlands and South Yorkshire.

[1] See para 1.4 below.

1.6 The project is undergoing continual refinement in order to address issues of concern that have been raised by scheme opponents. The forthcoming public consultation will help to decide the future of the scheme and could also lead to further route and design changes.

Aims of this project

1.7 Natural England is the Government's advisor on the natural environment. They have been charged with the responsibility to ensure that England's unique natural environment including its flora and fauna, land and seascapes, geology and soils are protected and improved. Natural England's purpose is to ensure that the natural environment is conserved, enhanced, and managed for the benefit of present and future generations, thereby contributing to sustainable development.

1.8 Natural England were part of the HS2 Ltd Reference Group that advised on the scope of the Appraisal of Sustainability and were consulted on the findings of the early drafts of the Habitats Regulation Assessment Screening Report.

1.9 Natural England have commissioned TRL to undertake an independent strategic analysis of the sustainability case for HS2, focusing mainly on the environmental impacts of the proposals as per their remit. The analysis includes consideration of carbon emissions, modal shift, impacts on land use and travel patterns, and impacts on the natural environment from other HSR schemes, and will provide an evidence base for Natural England's response to the formal consultation on HS2.

1.10 The study objectives are as follows:

1) Summarise the evidence regarding comparative emissions from rail, road, air and HSR and the assumptions underlying the main figures.

2) Discuss the evidence regarding the carbon emissions for HS2, discuss the issues relating to energy generation for HS2 and identify the best and worst case scenarios for emissions.

3) Discuss the contribution that HS2 could make to UK carbon budgets and targets.

4) Examine the evidence for the potential for modal shift from road and air to HS2 (including impacts on freight movements), and identify the measures required to maximise modal shift.

5) Review the literature and establish the lessons that can be learned regarding the impacts on the natural environment of other HSR routes and the approaches, and mitigation, that have been employed (for example, for HS1 or for other HSR routes).

6) Assess the valuation of environmental impacts of HSR in the supporting documentation.

7) Prepare a SWOT analysis of the sustainability of HSR, supported/informed by research relating to the above objectives.

Coverage of the study

1.11 This study has focussed on the proposed route from London to Birmingham. The Y-route option is expected to form part of the public consultation and is referred to in this study where it is relevant for a better understanding of the impacts of the London to Birmingham route.

Methodology

1.12 Our approach has been to assess the extent to which the key issues of interest to Natural England have been considered in the various documents produced by the DfT, HS2 Ltd and supporting studies, using additional sources to identify detailed questions that need to be asked and where available to fill information gaps. The tasks can be summarised as:

- Literature review. In addition to documents published by HS2 Ltd and the DfT, TRL has reviewed in the region of 100 other papers, including many from academic journals covering experience from both the UK and overseas;

- Gap analysis. TRL has identified matters on which there is little available evidence on which to form conclusions;

- Review scenarios in transport, and energy supply;

- Assess the valuation of environmental impacts; and

- Prepare a SWOT analysis of modal shift, energy savings and environmental impacts.

1.13 In addition to using Internet searches the literature review has been undertaken broadly following the Systematic Review (SR) process, developed by TRL. Information for the review comes from the TRL Knowledge Base, including the ITRD (International Transport Research Documentation) database - a multi-lingual database that delivers high quality information on global developments in transport and transport research. To supplement this, academics have been approached to gather further contributions. The literature review has generated information that has been stored in a Microsoft Access 2007 database for easy reference and viewing.

1.14 This study has not involved reviewing the transport models adopted by HS2 Ltd in its evaluation of the impacts of the line. Neither has it involved an assessment of the route at a detailed level.

2 The role of rail in a sustainable transport system

Introduction

2.1 Rail is often promoted by virtue of its perceived environmental benefits, at least by comparison with road transport and aviation. In 1995 the environmental damage from transport within Europe was estimated to be €530billion with 92% of this damage coming from cars, 6% from air and only 1.9% from rail (Ellwanger, 2002). Along with walking and cycling, public transport (including rail) is seen as a sustainable mode of transport. By comparison with road transport the environmental effects of rail are perceived to be beneficial, generating: better air quality; less noise; minimal visual intrusion; and lower carbon emissions (per passenger or tonne kilometre). Furthermore, rail travel is considered to be safer, avoids travel on congested roads and also offers the potential for social and economic benefits, by providing greater choice, especially for those without access to a car although this potential is greatly affected by price.

2.2 Similarly, high speed rail is considered to have fewer environmental impacts than other transport modes, particularly aviation. However the construction and operation of high speed lines does lead to negative environmental impacts, including carbon emissions, noise pollution, visual intrusion, severance and land take. Transport system scenarios including high speed lines may therefore result in greater environmental impacts than for transport system scenarios without HSR (Institution of Engineering and Technology, 2010).

2.3 It is helpful to highlight the main ways in which HSR can contribute to sustainability, against which its environmental impacts can be considered. This section therefore considers the role of rail and, in particular, HSR in a sustainable transport system.

2.4 In addition to discussing the environmental performance of HSR in general, this chapter also identifies the different environmental impacts of HS2 that are known, along with potential measures which could be used to mitigate these effects. Where possible, lessons learnt regarding the effects on the natural environment of other HSR routes are provided, along with the different approaches to mitigation that have been employed. For this report the focus is on environmental impacts relevant to Natural England's remit.

2.5 At the time of this research, little available information about the predicted environmental effects of HS2 exists, except that provided within the Non-Technical Summary (NTS) of the Appraisal of Sustainability for the first phase of HS2 (March 2010) which acknowledges that the main landscape impact of the scheme will occur in the Chilterns Hills. It is likely that the construction and operation of HS2 will have numerous and varied impacts on the natural environment, which must be avoided, mitigated or compensated through sensitive choice of routing, design, construction methods, train operation and maintenance practices. Some of these impacts will occur regardless of the route, while others will be dependent on the specific route chosen.

2.6 Since the Non-Technical Summary of the Appraisal of Sustainability for the first phase of HS2 was released (March 2010), the (then) Secretary of State tasked HS2 Ltd with further work, particularly in addressing noise impacts, and the current Secretary of State has commissioned additional work to address effects on local people and to further the development of a connection to Heathrow and HS1. The preferred route announced in December 2010 includes alterations to the original route alignment and design, with around 50% of the route modified either through horizontal or vertical changes and the inclusion of further tunnelling.

2.7 The full Appraisal of Sustainability for the revised HS2 route will need to reflect this further work, and its publication will provide more detail about the predicted effects of constructing and operating HS2. However, until the Environmental Statement is prepared prior to the Hybrid Bill, the full environmental effects of the scheme will be unknown and cannot therefore be taken into account in these early stages of planning and decision-making.

2.8 It is important to note that the NTS of the AoS provides information relating to the effects of the previous proposed route and not the route announced in December 2010 which will be the topic of the formal consultation. Therefore where information from the NTS of AoS has been provided within this report, this relates to the previous proposed route.

Priorities for sustainable transport

2.9 The sustainability of HSR can be assessed against its ability to deliver against the four sustainable development priorities set out in the UK Sustainable Development Strategy[2]. The HS2 Appraisal of Sustainability Non-Technical Summary used these priorities to form the basis of its study and assessed the extent to which HS2 would:

1) Reduce greenhouse gas emissions and combat climate change;

2) Protect natural and cultural resources and enhance the environment;

3) Create sustainable communities; and

4) Achieve sustainable consumption and production (Booz & Co and Temple, 2010).

2.10 The contributions that rail, including HSR, could make to support these priorities include:

- Environmental benefits arising from modal shift from car and aviation (i.e. carbon reduction, lower noise, air quality improvements; also wider benefits such as reduced accidents);
- Greater accessibility, especially for those without access to a car;
- Economic regeneration providing more jobs and services in deprived areas served by the HSR network by encouraging inward investment;
- Enabling growth in low-carbon travel in the future; and
- Synergy with other sustainability policy measures. A HSR network helps to support and improve public acceptance for wider policy measures to develop a low-carbon transport system.

2.11 To set against these potential benefits are the negative impacts through which HSR could undermine sustainability:

- The environmental impacts of construction;
- The impacts of CO_2 generation and other emissions to air;
- The long-term impacts of the line on habitats and the countryside;
- The impacts of the line on local communities, including noise, visual intrusion and severance;

[2] Defined in “UK Sustainable Development Strategy: Securing the Future”.

- Further encouraging the trend towards increased journey lengths, additional journeys and dispersed travel patterns: 'hypermobility' (CBT, 2010)[3];
- The risk of exacerbating regional economic differences, and transport inequalities between rich and poor; and
- Using financial resources that are not then available for funding more sustainable activities.

2.12 The following sections discuss how rail, in general terms, and HSR can help to deliver the four priorities of sustainable development, although in keeping with Natural England's remit the first two priorities are dealt with in greater depth.

The role of rail in reducing greenhouse gas emissions from transport

2.13 Greenhouse gas emissions (GHG) from the transport sector are a cause of particular concern in Europe because, unlike those from other energy-using sectors, they continue to grow. This is because the underlying demand for transport continues to grow, the energy efficiency of transport technology has not yet improved sufficiently, and because transport remains highly dependent on oil, in particular road, but also aviation and shipping. Recent scenario studies (for example Skinner and others, 2010) suggest that if emissions from transport are not reduced significantly then total emissions from transport alone will prevent Europe from achieving its targets for reducing carbon emissions.

2.14 The factors that determine carbon emissions are complex and can be influenced at different levels, including: the underlying demand for travel; the modes employed (a brief discussion on factors affecting modal choice is given in a text box below); and the fuels and technologies that power them. These factors combine to determine the carbon efficiency (gCO_2[4] / passenger km) of HSR. Factors specifically affecting modal choice are discussed below.

Factors affecting modal choice

As the environmental benefits offered by HSR are largely achieved through attracting passengers from other modes and ensuring high utilisation levels, it is important to understand the factors that affect the choice of mode. In the literature these factors are categorised in a number of different ways, but six are commonly discussed:

- Time;
- Cost;
- Reliability;
- Convenience;
- Comfort; and
- Security (or safety) (McDonald and others, 2003).

[3] The ability to travel much greater distances within the same time span that, for example, allows longer distance commuting.
[4] Grams of carbon dioxide.

Within ‘time’, account is taken of not only absolute journey times, but also other factors that affect how transport users perceive, and value, time, in particular reliability and time spent between modes. Studies (Jones, 2010) have found that people value time spent waiting for connecting services or connecting modes to have a greater value than time spent actually travelling on the train, showing that train reliability, and the need to use another mode to access rail, have disproportionate effects on people’s willingness to travel by rail. For example, figures from Network Rail (Network Rail, 2009) show that while rail currently has 80% of the market share for travel between central London and central Manchester, this falls to less than 15% for journeys between north London and central Manchester. As a consequence, improvements in reliability and connections can make a bigger difference to modal choice than absolute reductions in journey time. HS2 is expected to provide reliability improvements as well as journey time reductions, which accounts for some of the predicted modal shift, but there may be potential for greater modal shift through improvements to access modes at the connecting stations. Improving the quality and reliability of rail encourages travellers to switch from other modes (DfT, 2009).

The demand for rail is sensitive to price changes in other modes; so modal shift from road is affected by the price of car travel relative to that of rail. Shifting 10% of passenger trips from private cars onto the railways could double rail traffic (CPRE, 2010). Evidence from Spain indicates that significant modal shift to HSR is possible: the AVE high speed service generated both induced journeys and substitution; a fall of 50% in air traffic, a 30% reduction in car use and an 11% drop in coach journeys (Carrera-Gomez and others, 2006). However it has also been argued that HSR tends to attract traffic from rail rather than road (Scott Wilson, 2008).

2.15 Influencing carbon efficiency in transport requires three strategic levels of policy measures, known as the ASI approach:

- ‘Avoid’; measures that reduce the overall demand for travel, for example by reducing the distance people have to travel to access jobs and services, or by using telecommunications as a substitute for travel;
- ‘Shift’; measures that shift journeys onto more sustainable, lower emission modes, such as from private car use towards rail travel; and
- ‘Improve’; measures, usually technological, that reduce the carbon intensity of travel through improved vehicle efficiency or finding alternative, low-carbon, sources of energy.

2.16 The main role of rail in such a hierarchy is at the ‘Shift’ level, for which it usually provides a lower carbon alternative than other modes, especially car travel. Table 1 maps out where rail fits into the ‘ASI’ hierarchy.

Table 1 Rail and the ASI categories

ASI	How rail helps	How rail hinders
'Avoid'	Providing an alternative to car (or second car) ownership; availability of a car is a strong driver of the demand for travel.	Encouraging dispersed settlement patterns and hypermobility.
'Shift'	Rail travel is generally more energy efficient per passenger km than car use and aviation.	Services need to maintain high occupancy rates to retain energy efficiency benefits.
'Improve'	Rail is inherently energy efficient for many reasons, including low rolling resistance. Rail can use electrical propulsion much more easily than road transport; making it easier to use renewable energy sources, this also permits energy efficient measures such as regenerative braking.	Rail vehicles are very heavy with a high tare weight[5] per passenger. Replacement cycle of rolling stock is very long. Carbon benefits of electrical propulsion are limited by that of electricity supply.

2.17 Recent scenario studies, including those undertaken by the EU and the European Environment Agency (EEA) (EEA, 2009), have concluded that technology changes alone ('Improve') will not be sufficient to meet the desired CO_2 savings in transport; and that further savings will have to be achieved through 'Shift' and 'Avoid' measures as part of a policy packages. This is partly because little progress has been made in finding low carbon energy sources to power transport and partly because the gains from predicted efficiency achievements (see Appendix 1) are likely to be countered by increased vehicle use, due to rebound effects and the ongoing growth in transport demand.

2.18 The role of rail in reducing CO_2 emissions therefore needs to be seen in this wider context, where it is used as part of a package of policy instruments that also addresses the underlying demand for transport and the carbon efficiency of all modes of transport. It is also important to understand the potential for rebound effects, are discussed below.

Understanding 'rebound' effects

One of the limiting factors in the success of carbon reduction measures is the 'rebound effect'. This is where an efficiency improvement reduces costs to the user, thereby stimulating increased demand. In transport this affects both 'Improve' measures, for example improved fuel efficiency reducing the cost of motoring; and 'Shift' measures, where road and aviation capacity freed up by modal shift can be filled by previously suppressed demand. As the rebound effect lies outside influence of the scheme or the policy measure that has been affected by it, there is a debate as to whether these impacts can reasonably be attributed to that measure. Nonetheless rebound effects will reduce the benefits unless other policy instruments are applied to 'lock in' the benefits by restraining suppressed demand. This is one of the reasons why a package of policy measures working together is needed to deliver the greatest CO_2 savings in transport. As will be seen later, the modal shift and CO_2 reduction benefits of HS2 are very heavily influenced by rebound effects, so it is important to understand their role.

2.19 In comparison with the private car and aeroplanes, HSR is a much less polluting transport mode (Campos and others, 2009). According to INFRAS/IWW 2000, the primary energy consumed by HSR in litres of petrol per 100 passenger km was 2.5, compared to six and seven litres respectively for cars and planes (Campos and others, 2009).

[5] Tare weight is the unladen weight, i.e. the weight of an empty vehicle or container.

2.20 A study analysing the comparative environmental burdens of HSR and short haul air travel found that short haul air journeys have higher CO_2 emissions, per passenger km; domestic aircraft have emissions of 200-300g CO_2 per passenger km compared to approximately 40g CO_2 per passenger km for HSR (Campos and others, 2009).

2.21 Studies comparing the difference in energy consumption between conventional trains and high speed trains indicate that high speed trains require anything from 9 to 150% more energy per seat km (Kageson, 2010). According to Kageson (2010), as running resistance at speeds above 200 km/h is dominated by drag, (which increases approximately with the square of the speed), it is reasonable to assume that increasing train speeds from 200 to 300 km/h would raise electricity consumption by 85%, with all other factors remaining the same.

2.22 A Network Rail study (undated) compared the relative energy consumption and GHG emissions of conventional and high speed (electric) rail services[6]. The study found that:

- Because the power required to overcome air resistance increases with speed, conventional rail uses less energy and produces fewer GHG emissions than HSR per seat km. HSR is expected to result in 9.3% more GHG emissions on average (at 12.8g CO_2eq/seat-km[7]) than conventional rail (at 11.7g CO_2eq/seat-km) in 2025. This difference drops to 4.4% over the lifetime of the trains due to the forecast decarbonisation of electricity generation.

- However, per passenger km (pkm) HSR was found to produce significantly lower GHG emissions than conventional rail, due to the higher average occupancy levels that are normally achieved on HSR. On average, HSR (at 30.3g CO_2eq/pkm[8]) is expected to result in around 15% less GHG emissions than conventional rail (at 35.7g CO_2eq/pkm) in 2025. The GHG emissions for HSR reduce further to 18.8% less when considered over the 30-year lifetime of the trains. When both modal shift and demand creation are factored in, the differential increases further to 17.4% less in 2025 and 23.5% over the 30-year lifetime.

2.23 This study clearly demonstrates that there can be significant net benefits of HSR over conventional rail services in terms of energy consumption and GHG per passenger-km. HSR is able to offer attractive journey times in comparison with other modes, so it attracts more passengers, enabling vehicles to be well utilised, and to attract passengers from less energy efficient modes. Clearly there is a compromise between the greater power requirements as speed increases and the greater potential to attract passengers through reduced journey times. As more people choose to use rail over other modes, and trains are utilised closer to capacity, rail becomes even more energy efficient (Dalkmann and others, 2010).

2.24 While to date most studies concerning carbon issues for rail transport have focused on point of use emissions, more recently there have been growing concerns about the life cycle costs of rail and the need to consider emissions from vehicle production, infrastructure provision and fuel production. It has been estimated that total life cycle energy inputs and GHG emissions contribute an additional 63% for road, 155% for rail and 31% for air over point of use emissions (Chester and Horvathm, 2009 in Preston, 2009).

2.25 In terms of HSR in the UK, two recent studies have explored some of the potential life cycle costs. Firstly, Booz and Allen (2007b in Preston 2009) estimate that taking into account construction when calculating emissions adds approximately 35% to the CO_2 that will result from operation. Secondly, Network Rail (2009) estimates that when assuming current grid electricity emissions factors, GHG emissions can be attributed as follows: over 80% to train operations, 18% to infrastructure and 1% to train production. However, as a result of the proposed rapid

[6] For the purposes of the Network Rail study HSR services were defined as those typically over 250 km/hour and up to 350 km/hour.
[7] Estimated net greenhouse gas emissions per seat-km.
[8] Estimated net greenhouse gas emissions per passenger-km.

decarbonisation of UK electricity generation, and assuming the use of new trains over 30 years from 2025, the direct operation component falls to around 20%, with emissions from new infrastructure accounting for around 70% of the total. In order to reduce overall emissions from the new infrastructure there will be a need to focus for example on sourcing low carbon materials and the recyclability of end of life components.

Carbon emissions and HS2

2.26 The impact of HS2 on carbon emissions has been identified by HS2 Ltd as 'complex and highly uncertain'. There are effects from the operation and use of HS2 and also from its construction (i.e. embedded carbon). Table 2 shows how carbon emissions are forecast to change as a result of HS2 and the modal shift described above. Overall, the total contribution to carbon savings is expected to be very small. The figures show a very wide range, which is a consequence of variation in the underlying assumptions used in the calculations, most of which are outside the influence of HS2 Ltd. Of particular note is the increase in carbon emissions as a result of HS2 and the small benefits of the reduction in modal shift away from the car, especially when compared to aviation.

Table 2 Impact on operational carbon emissions following the introduction of HS2 (HS2 Ltd, 2010)

	Change in CO_2 over 60 years ($MtCO_2$)[9]	(Range)
HS2 emissions	+19.7	(0 to +26.1)
Other rail impacts	-0.9	(-1.3 to +0.5)
Car mode shift	-0.2	(-0.5 to 0)
Air mode shift	-23.2	(-23.2 to 0)
Total from transport changes	-4.6	(-25.0 to + 26.6)
Embedded carbon in construction	+ 1.2	(+0.29 to +2.12)

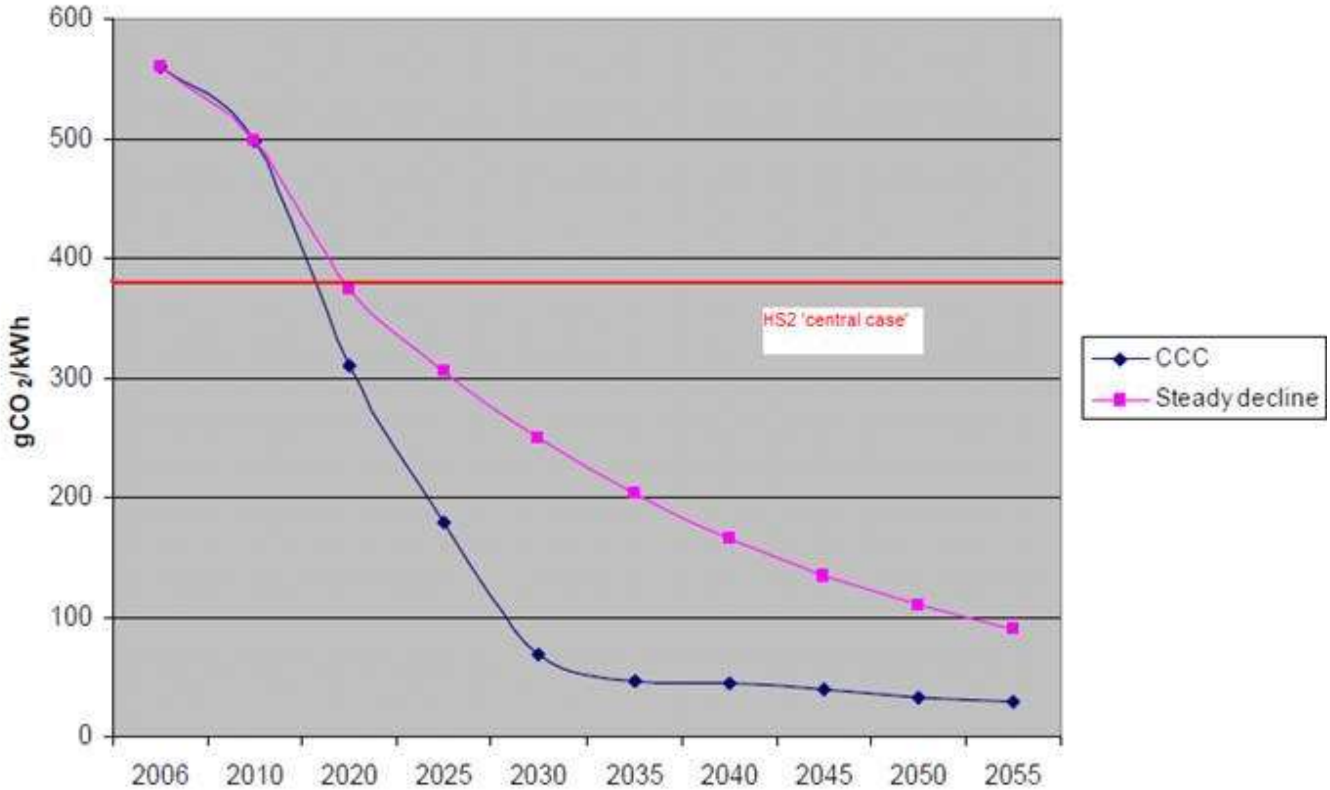
2.27 Once Phase 1 (the London-Birmingham HSR) is in operation it could reduce or increase carbon emissions from the transport sector by 0.3%, a total of about 0.5$MtCO_2$ per annum, either way an impact of less than 0.1% of domestic emissions (HS2 Ltd, 2010). This is a fraction of the 25$MtCO_2$ reduction in transport emissions that the Committee on Climate Change say is needed by 2020 in order to stay within legal limits. It also compares poorly to the 2.5$MtCO_2$ per annum that doubling the proportion of freight carried by rail could lead to, particularly as greater electrification of the rail network would increase that figure further (CPRE, 2010). HS2 is targeted at longer car trips (of over 50 miles) which currently only account for 2.3% of trips made, but produce about 23% of CO_2 emissions from household cars (DfT, 2008). Commuting and business trips are associated with low car occupancy resulting in relatively high CO_2 emissions per passenger. Electric trains emit 20-35% less carbon per seat kilometre than diesel equivalents (based on the current electricity generation mix) (DfT, 2009a).

2.28 The key areas of uncertainty regarding the carbon impact of HS2 identified are discussed below:

- **The extent to which the electricity grid will be decarbonised**. HS2 Ltd has taken a conservative estimate of 0.385$kgCO_2$ per MWh for the duration of the 60 year appraisal period; however this is only slightly lower than the Government's projection of 0.4$kgCO_2$/kwh for 2025. The Committee on Climate Change (CCC) conclude that if the UK is to meet its climate change targets then the carbon intensity of electricity will need to fall to less than

[9] Million tonnes of carbon dioxide.

0.1kgCO_2/kwh by 2050. At that level the emissions from HS2 would be around a quarter of those in the HS2 central case, leading to significantly greater overall savings. If the CCC's trajectory is followed, then the carbon intensity of the electricity supply by the time HS2 is opened will be lower than HS2 Ltd's central forecast, and will continue to decline after that (CCC, 2010). To achieve decarbonisation on this scale requires very significant changes in the electricity market in the UK, involving a range of technologies, including renewable energy, nuclear, and carbon-capture and storage. Nonetheless the CCC considers this to be 'feasible, cost-effective, and desirable'. While there are major implications arising from a move to these technologies, including environmental impacts, decarbonisation of the electricity supply is essential if the UK is to meet its targets at a time of rising energy demand, irrespective of whether HS2 is built or not. Below (Figure 1) is an Association of Train Operating Companies (ATOC) chart based on CCC's scenarios, showing the carbon intensity of UK electricity supply on two scenarios: the CCC trajectory and a scenario assuming a 'steady decline' at a lower rate (ATOC, 2009). In both cases it can be seen that the expected carbon intensity is significantly lower than HS2's central case throughout the period considered.



(Source: ATOC, 2009)

Figure 1 Projected carbon intensity of UK generation

- **The carbon emissions arising from construction of HS2**, which varies between 0.29 and 2.12 MtCO_2. A mid range value of 1.2 MtCO_2 is used.

- **The carbon efficiency of other modes:**

  - **Aviation:** is entirely dependent upon liquid aviation fuels, so there is very little scope for the introduction of low carbon alternatives and the rate at which energy efficiency improvements are introduced is relatively slow, not least because of the long replacement cycle for aircraft. DfT's Carbon Pathways Analysis (DfT, 2008) assumes only a 1% per year improvement in the efficiency of the UK aircraft fleet to 2030.

- **Cars:** the potential improvements in the carbon efficiency of the car fleet are much greater, both because of the potential for greater energy efficiency and because of the possibility of eventual electrification of the car fleet. However, there is very considerable uncertainty over how these trends will develop over future decades. The HS2 Ltd CO_2 calculations use the standard DfT WebTAG[10] assumptions on CO_2 emissions from cars, which are arguably greater than those that will be the case in the future if current carbon reduction targets are met. This would mean that the forecast CO_2 reductions from modal shift from cars will be lower than those calculated; however if cars of the future are being powered by low carbon electricity this will also further reduce the future emissions from HSR (see Appendix 1). Fuel efficient cars could offset rises in fuel prices and lead to a large, 5%, increase in motoring as well as falls in both rail and coach travel (Independent Transport Commission, 2010).

- **What happens to freed up capacity:** this is a rebound effect, as discussed earlier. A key uncertainty identified is the longer term aviation policy, as the extent to which airlines will be able to re-use released capacity and compete with rail could be greatly affected by future policies on airport expansion and the treatment of aviation in climate change targets. The top end of the HS2 Ltd CO_2 savings for aviation assume that flights are reduced in proportion to the modal shift to rail; the lowest end (zero) would be the case if all freed up capacity were used for other services, such as increased long haul aviation. It is a matter of debate whether it is reasonable for such rebound increases in emissions elsewhere to be attributed to the HS2, nonetheless it is clear that if the savings made by HS2 are not to be lost through increased consumption elsewhere, then they will need to be 'locked in' through supportive policies to restrain the demand for aviation. (These matters are discussed further in section 3 below.) Nevertheless HSR is unlikely to replace all UK domestic flights, especially east-west links between regions and flights to Northern Ireland and the Scottish Highlands (House of Commons Transport Committee, 2009). Rail is also unlikely to be an option for short haul passengers transferring to onward flights. Views diverge over the extent to which improved rail services or HSR would reduce the number of short haul flights and free up capacity at the busiest airports in the south east, particularly Heathrow.

2.29 As noted earlier, the modelling for rail demand on the southern and West Midlands sections of the WCML that benefit from freed-up capacity was for rail only, so the modal shift implications have not been considered in detail. It is therefore possible that the additional capacity will mean that some journeys that would otherwise have been undertaken by road, would now be made by rail, delivering additional CO_2 savings on top of those calculated for long distance travel. Clearly a better understanding of CO_2 implications of the 'do minimum' scenario is needed for a robust conclusion to be drawn.

2.30 A further consideration that affects the carbon impacts of HS2, though not reflected in the above figures, is the design speed of the trains themselves. HS2 Ltd's modelling is based on the assumed design speed of 400km/h; however if the trains ran at lower speeds then the power requirement would be lower. Because power consumption increases non-linearly with speed, relatively small changes in maximum speed can make a disproportionate difference to the power required. Modelling for HS2 Ltd by Imperial College (HS2 Ltd, 2009c) comparing different maximum line speed scenarios shows that the energy per seat km (at a passenger loading of 70%) at 360km/h is 23% higher than that required for 300 km/h (the maximum speed of Eurostar), but only reduces the journey time by 3.5 minutes from London to Birmingham. However, their modelling also shows the per seat-km energy consumption to be comparable to that of Eurostar. The trains that would be used would be expected to benefit from the latest technology, which would reduce the penalty of high speed; nonetheless, all things being equal,

[10] **http://www.dft.gov.uk/webtag/**

running the trains at the lower end of the range of HSR speeds would clearly make a significant saving in the energy required.

2.31 However, against this must be set the journey time savings and the model shift they bring. As discussed earlier, comparisons between conventional rail and HSR have shown that, on a per passenger km basis, higher speeds can lead to lower overall energy consumption because the reduced journey times attracts more passengers, leading to better utilised vehicles and more modal shift from less efficient modes. HS2 is expected to achieve a high level of passenger loading- 70%; however this may be reduced if journey times are less attractive. Clearly there is a compromise between optimal journey times and energy consumption, an issue that also arises with other impacts of HSR, so this is an area where further analysis by HS2 Ltd would be helpful. It should also be noted that the carbon penalty of higher speed will fall, as the electricity supply network is decarbonised.

2.32 The carbon savings forecast for HS2 are very small in comparison with the UK's total transport emissions, so by themselves make very little contribution to overall climate reduction targets. The majority of forecast carbon savings arise from modal shift from air travel to rail; modal shift from road contributes much smaller savings. Furthermore there is a significant range in the estimated values, which arise chiefly from uncertainties in the extent to which the UK's electricity supply will be decarbonised, and uncertainties about potential 'rebound effects' arising from how aviation (and road) capacity freed-up by modal shift to rail will be used. Clearly, to maximise the carbon benefits of HS2 significantly greater decarbonisation will be required than the fairly conservative assumptions used by HS2 Ltd. The forecast savings would be nearly five times greater if the carbon intensity projections used by the Climate Change Commission were used[11].

2.33 It is important to note that even with only the first phase of HS2 built, so that trains to Scotland will mostly still be running at 'conventional' speeds north of Birmingham, the time savings are sufficient to deliver significant modal shift from aviation. However, if the displaced journeys are simply replaced with new journeys stimulated by the release of new capacity, the full benefit will not be realised. This will require supporting policies to restrain demand for air travel and so 'lock in' the benefits.

2.34 The potential for modal shift from aviation will be greater if the proposed northern extensions to HS2 are also built; and also if improved links are made between HS2 and HS1 so that rail can compete better with air travel for journeys to Europe from outside London.

2.35 Modal shift from car travel only provides a small amount of the forecast CO_2 savings, so the total is less sensitive to the uncertainties in this estimate. Modal shift could be greater if the cost of motoring is significantly increased in the future; however rail travel is relatively 'inelastic' with respect to the cost of driving, so such increases have to be very large for this to significantly affect total CO_2 savings. In addition there may be CO_2 savings arising from modal shift to rail facilitated by capacity freed-up on the conventional lines between Birmingham, the Trent Valley and London, which are not fully modelled in the HS2 Ltd proposals. Very high levels of demand and overcrowding are forecast for the conventional network in the absence of new capacity, but it is not clear whether this demand would realistically be carried under those circumstances, or whether it would lead to some shift to road traffic instead. A particular problem will arise with some of the existing lines reaching capacity before HS2 is operational (House of Commons Transport Committee, 2009). A better, multi-modal, understanding of the 'do minimum' case for conventional rail, is needed.

2.36 HS2 Ltd's analysis of carbon impacts is based on an assumed speed of 400 km/h, although this significantly increases power consumption in comparison with lower speeds. Further analysis

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[11] "Applying projections from the Committee on Climate Change in its first progress report on carbon budgets would suggest HS2 emissions would be less than 3 MtCO2 over 60 years" see **www.theccc.org.uk/reports/building-a-low-carbon-economy**

would clarify the balance between energy consumption and the greater levels of patronage and modal shift that higher speeds can deliver.

Impacts of rail on the natural environment

Land take

2.37 The amount of land taken for transport infrastructure determines the impact of the scheme on biodiversity and natural habitats (UIC, 2011). Land-take for transport can result in habitat fragmentation, and habitat loss, whilst also affecting community severance (AEA, 2001).

2.38 Land take efficiency, the ratio between land used and the infrastructure's carrying capacity, varies between transport modes. Railways are said to have a lower requirement of land take per unit (i.e. per passenger km), as rail tracks allow for a higher throughput of passengers per hour than a road with the same width (UIC, 2011). Past experience shows that a HSR line can carry 12,000 passengers per hour per track, compared to the maximum capacity of a single lane highway of 2,250 passenger cars per hour (UIC, 2011). With regard to land take per passenger, rail infrastructure is considered to require two to three times less land than other modes of transport (UIC, 2011). However, fragmentation and severance remain an issue.

2.39 The actual strip of land required for new railways lines is relatively modest, whereas the area of the slopes created by embankments and cuttings is sometimes large (AEA, 2001). Table 3 shows that, on flat land, the average area of land required for rail, even for high speeds, is relatively low, when compared with roads. However it does show that the land take required for HSR is greater than that for conventional rail.

Table 3 Comparison of land take for different types of transport infrastructure (Berthoud, 2003)

Means of transport	Type	Average width	Surface area occupied in ha/km
Railway	Conventional 2 tracks	26m	2.6ha
	Upgraded TGV line	32m	3.2ha
	New TGV line	35m	3.5ha
Road	Motorway 2x2 lanes	54m	5.4ha
	Motorway 2x3 lanes	60m	6ha
	Motorway 2x4 lanes	72m	7.2ha

2.40 It is important to note that compared with conventional rail the width of the transport corridor for high speed lines needs to allow greater distances between the tracks (1-2 metres) due to the pressure caused when two trains pass each other at high speeds (i.e. 250-350 kph) (Network Rail, undated). High speed trains also require track layouts with large radius curves, for example to accommodate speeds of 300 km/h the horizontal curve radius must be at least 5.5 km and ideally should not be less than 7 km; comparatively these figures would be 2.5 km and 3.5 km for speeds of 200km/h (UIC, 2010).

2.41 As part of a comparative study looking at the environmental burdens of HSR and short haul air travel an initial analysis showed that aviation requires less land than rail transport (AEA, 2001). However, due to the difficulty in separating out the land attributable to regional journeys and the background of overall transport activity for both modes, it was not considered possible to compare the relative land-take for HSR and aviation.

Landscape

2.42 The construction and operation of railway infrastructure can have significant effects on landscapes and their character, through for example physical encroachment and also disruption to natural patterns and relationships found in the landscape as a result of the introduction of rails, overhead lines, cutting and embankments. Railway infrastructure can also cause visual intrusion, while increased levels of noise and vibration can also impact upon people's enjoyment of the countryside and reduce tranquillity thereby potentially reducing recreational use of areas affected by the line. As a subjective quality, tranquillity is hard to define; the 1995 tranquillity maps produced by CPRE and partners defined tranquil areas as "places which are sufficiently far away from the visual or noise intrusion of development or traffic to be considered unspoilt by urban influences." DEFRA's Rural Strategy 2004 identified tranquillity as one of the key elements that people value about the countryside, and tranquillity is often used in Landscape Character Assessments (LCAs) to describe the special quality of a landscape.

2.43 Despite occupying less surface area than comparable road infrastructure, railway infrastructure nevertheless:

- Occupies large areas of land with high-visibility equipment and infrastructure which are difficult to merge into the landscape; and
- Becomes a component of the landscape which plays a significant role in the natural environment of the regions they cross, due to the required cuttings, embankments, bridges and viaducts (Berthoud, 2003).

2.44 The general characteristics of railway lines make it very difficult to avoid every topographical (or biological) obstacle in their path (Berthoud, 2003). The shallow gradients needed for railways (as compared to roads) can require long embankments and bridges, which can be both visually intrusive and obstruct the view from nearby locations. The pylons and overhead catenary associated with electrified railways are also a cause of visual intrusion[12]. In addition, in the vicinity of railway lines operators are required, for safety reasons, to periodically cut back vegetation to limit any risk. For lower speed stretches of track (for example, less than 160km/h) a small clearance is sufficient to avoid the risk of contact in instances of fallen power lines. However for higher speed stretches (for example, more than 160km/h) wider clearances are needed to prevent trees from blocking tracks or touching power lines (Berthoud, 2003). Zones are often marked out within which trees may not reach more than a certain height, depending on the lie of the land and the vegetation. In addition to impacting on the landscape, these safety measures will also have consequences for biodiversity (Berthoud, 2003) that will need to be addressed through suitable mitigation and/or compensation that maximises the potential for the route to act as a 'green corridor'.

2.45 On the other hand, as railway corridors are narrower than major roads, and track beds are constructed with aggregate rather than with hard surfaces, they are less noticeable to the eye. Furthermore, the ability to route lines through tunnels and cuttings can help reduce the impact on the most sensitive locations. It is however worthwhile noting that use of tunnels may result in an increase in energy consumption, for instance if tunnels make up 10% of the distance of a high speed line they may increase overall air drag by around 8% and overall energy consumption by 5% (Kageson, 2010).

2.46 In terms of high speed trains, these can cope with much steeper gradients than conventional trains (3% incline as compared to 1% incline) and therefore it is considered that high speed lines can 'hug' the natural contours of landscapes much more closely (Lacôte, 1998; HS2 Ltd,

[12] Railways using diesel or electricity from a third rail do not use catenaries and so have less visual intrusion. However it is likely that HS2 will be designed and developed to meet European Standards for Interoperability which means third rail power is not an option

undated). However, to maintain their top speeds high speed lines must be built with the fewest possible curves (HS2 Ltd, undated) therefore limiting the extent of this integration with natural contours.

2.47 Fencing along railway lines to prevent people, farm animals or wildlife straying onto the track can also cause visual intrusion. Generally only high speed tracks, urban railways and those in livestock farming areas are systematically fenced off (Berthoud, 2003). Where fences are in place, tracks need to be equipped with wildlife crossings (i.e. underpasses and bridges) to allow wildlife movement.

2.48 Visual intrusion can be mitigated through good design, including landscaping techniques such as cuttings and embankments to make the route blend in to its surroundings, and sensitive architecture so that unavoidable man-made constructions, in particular bridges, look attractive and in keeping with their location. One of the most visually intrusive aspects of HS1 is considered to be the standard white concrete bridges (CPRE, 2010).

2.49 Landscape fragmentation can arise from new infrastructure when it affects an increase in residual, marginal and unused areas, that are hardly accessible and so can become degraded (these are also called “infraspaces”) (UIC, 2011). Landscape designs should aim to provide a continuity of land-use beyond the fenced railway. Various compensatory measures can be implemented. Among these, regeneration and planting of trees and shrubs, maintenance and management operations for different types of vegetation (for example, grasslands, scrub and woodland) and other landscaping/ re-naturalisation works can be effective.

2.50 Clearly the detailed choice of route is a key determinant of its visual impact, and the straighter paths required for higher speeds means that there is less flexibility in mitigating the impact through changing the alignment than for conventional rail. Mitigation measures will depend largely on the local characteristics of the route and will therefore vary along its length. As with many of the impacts of HSR, a compromise between design speed and environmental impacts will need to be achieved.

HS2 land take and landscape impacts

2.51 Away from junctions, stations, bridges and tunnels, where land take will be much more significant, the land-take for HS2 comprises the 14m wide strip of ballast that carries the track, and a fenced-off space on either side of the track, providing a margin for safety and access for track work, creating a total ‘fence to fence’ width of 25m (HS2 Ltd, 2009a). This can be reduced to 15m for short sections where space is constrained, though access for maintenance is still needed. Furthermore, a zone 25m on either side of the fenced area must be kept free of tall vegetation, but still available for other purposes. So, while the trackbed itself is comparatively narrow, and similar in scale to a conventional rail line, the clearance margin on either side greatly increases the impact on wooded areas. There may be scope to review the necessity for such a wide clearance zone along the full route, clearly if localised exemptions can be permitted in sensitive areas then the visual impact can be greatly reduced.

2.52 The main landscape impact of HS2 is predicted to occur in the Chiltern Hills, which extend for 75km between Hitchin in the north and the River Thames in the south (Booz & Co and Temple, 2010). Nationally designated areas, including Areas of Outstanding Natural Beauty (AONBs), are afforded the highest level of protection in relation to landscape and scenic beauty, with national planning policy precluding major developments in designated areas, except in exceptional circumstances (ODPM, 2004). Policy advises that major development proposals should be demonstrated to be in the public interest before being allowed to proceed, and that consideration of such applications should therefore include an assessment of:

- the need for the development, including in terms of any national considerations, and the impact of permitting it, or refusing it, upon the local economy;

- the cost of, and scope for, developing elsewhere outside the designated area, or meeting the need for it in some other way; and

- any detrimental effect on the environment, the landscape and recreational opportunities, and the extent to which that could be moderated.

2.53 The policy also states that applications for any such developments should be subject to the most rigorous examination.

2.54 It will be difficult for HS2 to avoid the Chilterns AONB without significantly adding to its length, thereby increasing journey times and resulting in greater overall land take. It will therefore be essential that the assessment of HS2 fulfils the above requirements as set out in national planning policy, considers the potential detrimental effect on the environment, landscape and recreational opportunities, and that any development is carried out to high environmental standards.

2.55 It is stated by HS2 Ltd that, to date, considerable work has been undertaken to mitigate the potential adverse effects on this nationally protected landscape (Booz & Co and Temple, 2010). This includes (as stated in the NTS of the AoS) putting at least 6.5km of the route within a tunnel[13], over 5km within the same corridor as the A413 and over 9km in a cutting which is felt would reduce some views of the scheme (Booz & Co and Temple, 2010). The announcement of the revised route in December 2010 included additional measures such as the creation of a 'green bridge' and longer 'green tunnel' between Amersham and Wendover, to reduce its visual impact and avoid severance of public rights of way. The NTS of the AoS also stated that as the design detail is taken forward further opportunities to reduce the impacts would be sought, for example by using natural screening, earthworks, false cuttings and landscape planting (Booz & Co and Temple, 2010). However, given that as yet there is no information available in relation to any landscape and visual impact assessments that have been undertaken in relation to the AONB, it is not possible to make a judgement as to whether the potential impacts have been thoroughly assessed, or whether the proposed mitigation measures are compatible with the landscapes found in the Chilterns AONB.

2.56 It is important to consider that along the length of the route it is also likely that the development of HS2 will have implications on landscape character, as a result of physical encroachment and disruption to natural landscape patterns. The introduction of rails, overhead lines, embankments and cuttings, as well as other equipment and structures will undoubtedly alter landscapes along the route and cause visual intrusion thereby impacting upon people's enjoyment of the countryside. Reduced tranquillity along the length of the route but particularly in rural areas, as a result of noise pollution, lighting and visual distraction from the passing trains, would also occur as a result of the scheme.

2.57 The development of HS1 experienced similar issues in relation to landscape with the route crossing the Kent Downs AONB and numerous other attractive rural landscapes, including areas designated for their regional landscape importance. In order to harmonise the railway and associated infrastructure with the character and scales of the different landscapes it is acknowledged that great care was taken through the planning, design and implementation stages of the project (Armour, 2003). In contrast to the plans for HS2, from the inception of the project the line of the first 74km of the route (in Kent) was designed to mainly follow the existing transport corridors of the A2/M2 and M20 in order to reduce the landscape impacts (Armour, 2003).

[13] Although tunnelling can result in significant benefits to the landscape it must be noted that there are many environmental effects generated by construction, use and eventually decommissioning (Temporal, 1997). These need to be considered as part of the assessment process for HS2.

2.58 Other landscape mitigation measures included:

- Much of the route was depressed into the landscape or placed within false cuttings;
- In the vicinity of the AONB, a 3km tunnel was driven under the North Downs, to conceal the railway as it crosses between the M2 and M20 corridors;
- Steep embankments, which can be visually intrusive, were graded out to gentle profiles. This so called 'integration' method was employed at many bridges to improve the setting of these structures;
- New slopes were designed using contours which complemented the local land forms;
- Steep cuttings were rounded back to avoid abrupt cut edges; and
- Noise barriers were replaced with earth bunds (where appropriate) and where possible the back slopes were graded to mask their function (Johnson, 2003; Armour, 2003).

2.59 Substantial areas of new planting were also implemented to help to integrate the railway with its surrounding landscape and to create screening were appropriate. This included (for the first 74km of the route built in Kent):

- 255 ha of new woodland;
- 40 km of new native hedgerow;
- 1.2 million trees and shrubs;
- 200 ha of new permanent grassland;
- 45 ha of grass and wildflower seeding;
- 3 ha of new wetland; and
- 3 land-bridges (Armour, 2003).

2.60 The plant species mix and arrangements were designed to address their functional requirements, including screening, harmonisation with existing planting, creating new wildlife habitats, and where appropriate installing new landmarks, such as tree avenue circles.

2.61 When designing HS2 there is a particular need to consider the design of structures, including the numerous viaducts and the road and footbridges, as these may be the most visible features in the landscape. They should be designed so as to fit in with the surrounding landscapes and traditional local vernacular. It is noted that one of the most visually intrusive aspects of HS1 is the standard white concrete bridges that carry roads and rights of way across it (CPRE, 2010) and this should not be replicated for HS2.

2.62 No information is provided in the NTS of the AoS relating to the effects likely on landscape as a result of the construction process, effects which could be significant in the short term. It is essential that the effects of construction on landscape are effectively mitigated. An Environmental Management System, similar to that used for HS1, should be implemented to help to minimise effects on landscape during construction.

Biodiversity

2.63 The main impact of transport on wildlife and biodiversity is considered to be the fragmentation and degradation of habitats due to the barrier effects of the infrastructure, as well as from wildlife collisions (UIC, 2011). Biodiversity is affected by both the infrastructure and the traffic which uses it (Berthoud, 2003). In England Network Rail owns and manages 146 designated Sites of Special Scientific Interest (SSSIs).

2.64 There are numerous potential effects on biodiversity resulting from rail infrastructure and traffic, as outlined below. It should be noted that although the effects on natural habitats are well documented for roads, far less consideration has been given to these in relation to railways. Nevertheless the key issues identified in relation to biodiversity are:

- The loss of natural habitats caused by land being occupied by railways and associated installations;
- Deterioration of the quality of habitats caused by vibration, noise and pollution;
- Changes in habitats caused by earthworks and the presence of ballast;
- The loss of communication between different sections of habitat, caused by continuous physical barriers such as fences or ballast;
- Collisions between trains and animals attempting to cross the track; and
- The creation of new habitats for flora and fauna. For example, in London almost 200km of land bordering London Underground lines provides refuges and corridors for wildlife. Its embankments are inhabited by numerous types of fauna, including deer, badgers, foxes, hedgehogs, squirrels, butterflies, frogs, toads, lizards and snakes etc, and over 350 plant species (Berthoud, 2003).

2.65 It is reported that the construction of railway lines creates “vast mosaics of wastelands” stretching along either side of the track (Berthoud, 2003). Following completion of construction works species can begin to recolonise the site, with bare or grassy banks being repopulated by the surrounding vegetation and wildlife. The success of this natural process is largely dependent on the sensitivity and frequency of maintenance work, i.e. the extent to which these environments are treated with herbicides, mowing, clearing or the addition of gravel (Berthoud, 2003).

2.66 These so called ‘railway ecosystems’ can serve as a refuge biotope[14] for many plant and animal species which thrive in pioneer environments and provide a major corridor for the spread of these species (Berthoud, 2003). Typically these species include small vertebrates, such as reptiles, frogs/toads and small mammals and many invertebrates (Berthoud, 2003).

2.67 In general, wildlife seems to adapt well to the frequent passing of trains, with heavy rail traffic not appearing to have significantly more negative impacts (on large animals) (Berthoud, 2003). However, the barrier effect is well documented, with studies in Denmark and the Netherlands having shown that railways are barriers which prevent the propagation of some small animals such as arthropods, snails, amphibians and small mammals (Table 4).

[14] A biotope is an area of uniform environmental conditions providing a living place for a specific assemblage of plants and animals.

Table 4 Significance of the barrier effect caused by railways in the Netherlands

Barrier Effect	Species Group
Absolute	Grasshoppers and carabids
Significant	Mice, shrews, spiders, ants
Small	Stone martens, hedgehogs, squirrels, reptiles, frogs/toads
None	Roe deer, hares, birds
Unknown	Bats

(Source: Berger in (Berthoud, 2003))

2.68 Wildlife mortality due to collisions, although smaller than for road traffic, can be significant (Berthoud, 2003), with mammals and birds being particularly vulnerable (Table 5). In fact, collisions are thought to be the main cause of death for wildlife living near railways. The animals (i.e. birds) generally collide with trains, but can also collide with electric power cables. The main factors in animal mortality are train speed, the topography of the line and the type of environment through which the line passes.

Table 5 Mortality by species group caused by railways in the Netherlands

Mortality	Species Group
High	Owls, amphibians, reptiles
Average	Mammals, some bird species
None	Most birds, spiders, carabids, grasshoppers
Unknown	Bats, butterflies

(Source: Berger in (Berthoud, 2003))

2.69 In France, it has been estimated that the number of bird collisions with trains is between 480,000 and 2.4 million (Berthoud, 2003). A study conducted during the summer months on the TGV North found that 3.4 birds were killed per kilometre per month (Berthoud, 2003). The risk of collision with cables can be dependent on whether vegetation is the same height or higher than the cables, as when this is the case birds can cross them without a problem. Railway lines without vegetation are considered a much more significant risk to birds (Berthoud, 2003). Clearance of vegetation close to cables is needed for safety and operational reasons however impacts on biodiversity could be reduced by minimising vegetation clearance to branches in proximity of the cables. This would help to reduce bird collisions with cables with trees acting as a barrier to bird flights (English Nature, 2002).

2.70 Secondary effects on biodiversity may also result from any impacts on geomorphology and or contamination of water courses. Effects on biodiversity are particularly of concern during construction when land drainage and water courses may be severely disrupted resulting in a lowering of the water table (TEST, 1991). Depending on the local geology, adverse effects of lowering a water table can disrupt habitats which are a considerable distance from the development. More permanent effects may also be felt as groundwater movement can be restricted by embankments and infrastructure (TEST, 1991). Chemical pollution and contaminated run-off resulting from the regular use of herbicides to keep the tracks and surrounding areas clear of vegetation, metal dust produced by wear and tear on the tracks and rolling stock and lubricant leakage from rolling stock could also result in localised secondary effects on biodiversity (Berthoud, 2003).

2.71 The most effective way to protect biodiversity is through good design and ecologically sensitive maintenance of HSR routes. For example, during route layout, adjustments can be made to avoid natural areas by building tunnels and viaducts and re-routing around some areas. In addition, fencing can be designed into the scheme to help to avoid collisions with wildlife, and animal crossings can be built (UIC, 2011). In addition, phased construction could be used to minimise disturbance to fauna, for example, seasonal breeding cycles.

HS2 and biodiversity

2.72 The AoS NTS states that no international sites would be adversely affected and that impacts on nationally protected sites would be restricted to a few locations, these being the Long Itchington and Ufton Wood SSSI near Leamington Spa, and SSSIs near the river crossings at the Colne Valley in Denham, near Uxbridge and the River Blythe, near Coleshill. The revised preferred route (as of December 2010) is also identified as having an effect on the Helmdon Disused Railway SSSI, near Brackley. Some impacts on local and regional sites were also identified, including the loss of ancient woodland in the Chilterns. More detailed information is required on the effects that are predicted for these sites and the specific measures that are proposed to avoid or mitigate these effects.

2.73 The NTS of the AoS provides no indication of whether any assessment has been made of the effect of the scheme on wildlife and biodiversity outside designated sites. Given the evidence reported in the previous chapter of the numerous effects of rail infrastructure on biodiversity, it is likely that effects will be felt along the length of the route and not just within designated sites. For example, issues of fragmentation, deterioration of habitat quality due to noise, and wildlife collisions need to be considered and mitigation measures designed along the length of the route.

2.74 To reduce the impact of overhead lines on bird fatalities through collision mitigation measures could consist of ensuring the presence of tall trees that act as barriers to flight paths crossing overhead lines (English Nature, 2002).

2.75 The potential for secondary effects on biodiversity, such as those resulting from changes to geomorphology and contamination to water courses, also needs to be thoroughly assessed and reported.

2.76 No information is provided in the NTS of the AoS related to the effects likely on biodiversity as a result of the construction process, such as effects of habitat fragmentation, habitat loss and disturbance, effects which could be significant in the short term. It is essential that the effects of construction on biodiversity are effectively mitigated. For example, phasing of construction activities should be implemented to minimise disturbance to fauna during their seasonal breeding cycles. An Environmental Management System, similar to that used for HS1, should be implemented to help to minimise effects on biodiversity during the construction process.

2.77 The evidence reviewed in the previous chapter suggests that the provision of rail infrastructure allows for the creation of new habitats for flora and fauna either side of the tracks, but the success of these sites is largely dependent on the sensitivity and frequency of maintenance work, i.e. the use of herbicides and vegetation clearing. For HS2, wider clearances are needed which could reduce the potential for these positive effects. Further work is needed to assess the potential positive effects that these sites could achieve and also consideration should be given to trackside maintenance programmes which would have implications on any potential positive effects that could be felt.

2.78 Mitigation measures, such as providing green bridges across the track and tunnels under the track and creating new habitats, could help to compensate for the potential impacts of the scheme on wildlife and biodiversity. For HS1 various measures were implemented to mitigate effects on wildlife, including:

- Displacing water voles to adjacent habitats using techniques such as spreading predator odour and vegetation management;

- Encouraging the movement of hazel dormice from affected woodland to nearby undisturbed areas by vegetation management and providing extra breeding boxes;
- When badger setts were encountered in the working area, new artificial setts were constructed in appropriate safe habitats, a safe distance from disturbance and the badgers were gradually encouraged to move to their new homes;
- Translocation of certain species, under licence, including: a hundred hazel dormice which were trapped and released into ancient woodland in the East Midlands to colonise new areas as part of a national species re-introduction programme; and reptiles, such as grass snakes and slow worms, and amphibians, such as smooth and great crested newts, which were trapped and released either at suitable existing sites in Kent, or in newly prepared ponds with appropriate surrounding habitat near the route;
- Providing new roosting boxes and hibernacula for bats and nest boxes for breeding birds, a protected reserve, including a translocation site for the very rare grey mouse-ear plant and a new brackish pond habitat for the protected tentacled lagoon worm;
- Habitat replacement, on an at least one to one basis, for reed beds, chalk grassland, wild flower meadows, floodplain forest, small ponds and deciduous woodland; and
- Monitoring of the success of the nature conservation programme at translocation sites, watercourses, newly created habitat, and on habitat adjacent to the new rail corridor (Johnson, 2003).

2.79 National Planning Policy[15] states that where a planning decision would result in significant harm to biodiversity and geological interests which cannot be prevented or adequately mitigated against, appropriate compensation measures should be sought and that if that significant harm cannot be prevented, adequately mitigated against, or compensated for, then planning permission should be refused. Planning Policy also states that where a proposed development on land within or outside a SSSI is likely to have an adverse effect on an SSSI (either individually or in combination with other developments), planning permission should not normally be granted.

2.80 For HS2 there is a need to ensure that any effects on designated sites are where possible avoided and if they cannot be avoided are satisfactorily mitigated or compensated. It is also essential that impacts on the wider wildlife and biodiversity found along the route are also avoided, mitigated or compensated. Importantly, the success of the mitigation or compensation measures needs to be monitored to ensure that, should the measures be found to be failing, action can be taken as soon as possible to remedy the problem.

Geology and soils

2.81 Construction of new railways can have both positive and negative effects on geology. Although, on one hand it provides opportunities for geological exposures it can also result in the loss or concealment of these new exposures. Furthermore due to the vertical and horizontal alignment restrictions, when compared to road, rail may have less of an ability to avoid sensitive sites which may result in more frequent occurrence of impacts on geological features.

2.82 In order to mitigate the effects during construction it is necessary to undertake early consultation on the potential for geological interest and provide for geological recording and sampling. In addition, the engineering of rail embankments and cuttings should be avoided in relation to

[15] Planning Policy Statement 9: Biodiversity and Geological Conservation (2005) **www.communities.gov.uk/documents/planningandbuilding/pdf/147408.pdf**

geological sections (particularly SSSIs and sites of local geological importance - RIGS[16]). Netting and concrete cover would permanently damage geological sections. During operation it will be necessary to have agreed access protocols for geological research and provide visual access for geological exposures.

2.83 The effect of rail on soils consists of changes in hydrogeological conditions, pollution effects, erosion, subsidence, loss and compaction. During construction considerable amounts of waste soil are produced (Berthoud, 2003) and large amounts of material, including soil, will need to be moved. Best practice soil handling methods should be used to minimise damage to soils and any surplus soil should be used sustainably, for example in the construction of earth bunds to reduce noise pollution and visual intrusion.

2.84 It is also worth noting that although rail transport is generally considered to be the most environmentally friendly mode of transport; several studies have shown that it is not completely pollution free. For example a study in Switzerland, which presented an overview of soil contamination by heavy metals produced by rail traffic showed large quantities of metal dust are deposited at the entrances to towns (i.e. in the braking area) and that dispersion may reach several dozen metres, although the study concluded that generally standard toxicity values are not commonly exceeded at a distance of more than 10m (Berthoud, 2003).

HS2 and geology and soils

2.85 The NTS of the AoS provides no information related to potential impacts of the scheme on geology. It is important that this issue is specifically considered as construction of the scheme could have both positive and negative effects on geology as outlined previously in this report.

2.86 The NTS of the AoS also provides no information related to soils and therefore it is unclear whether an assessment has been undertaken in relation to the impact of HS2 on soils. During construction there is potential for significant negative effects on soil, for instance due to soil compaction and due to the amount of fill that generated during the process (i.e. for creating cuttings and embankments and through tunnelling). It is worthwhile noting that the construction of the first 74km of HS1 resulted in the generation of 15 million m^3 of fill which had to be dealt with, i.e. stored and used in the scheme design (Armour, 2003). For HS2 it will be important that 'best practice' soil handling techniques are used to minimise damage to soils and that any surplus soil is used sustainably, ideally within the scheme, i.e. as earth bunds to mitigate noise and visual effects.

2.87 For both geology and soils it is important that any work completed to date assessing the potential impacts is made available or if such work has not been undertaken it is completed with some urgency.

Air quality

2.88 In relation to air quality, the quantity of polluting gases generated to power a high speed train for a given trip depends on the amount of energy consumed and the air pollutant emissions from the electricity generating plant. Due to the high diversity of primary energy sources used within different countries, it is difficult to make comparisons between the air pollution emissions of different HSR systems (Campos and others, 2009). However, generally the most harmful air emissions related to the operation of HSR are sulphur dioxide (SO_2) and nitrogen oxides (NO_X) which are emitted from fossil fuel burning power stations generating the required electricity.

2.89 SO_2 and $NO_{x,}$ through acidification and deposition, can be harmful to biodiversity. Sulphur dioxide for example is toxic to a variety of plant life and may produce visible signs of injury and/or reduce

[16] Regionally Important Geological and Geomorphological Sites (RIGS) are non-statutorily protected sites of regional and local importance for geodiversity (geology and geomorphology).

yields of certain crops (Environment Agency, 2010a). High levels of NO_2 and NO can hinder growth and stress plant life making vegetation more susceptible to other effects, such as disease and frost damage (Environment Agency, 2010b). Importantly when found together nitrogen dioxide and sulphur dioxide have a synergistic effect increasing the damage done to plant life that is greater than the sum of individual effects of the pollutants alone (Environment Agency, 2010b). In addition, they both contribute towards acid rain which also causes damage to vegetation (Environment Agency, 2010a; 2010b).

2.90 Across Europe approximately 80% of rail traffic is powered by electricity, with the result that the vast majority of trains emit no local air pollutants where they operate. The remaining 20% are diesel-powered, producing approximately 1-2% of Europe's particulate (PM_{10})[17] emissions, and 1-3% of transport-related nitrogen oxides (NOx) (UIC and CER, 2009).

2.91 HSR lines are 100% electric operated and therefore no direct local air pollution related to energy generation is produced. Remote source of air pollution is, however caused when producing energy for the railway system. The emissions performance of HSR is therefore strongly linked to the source of energy supply and in particular the share of coal used to generate the electricity (Button 1993 in Givoni 2006). There could be environmental advantages of emissions only occurring at the source of the electricity generation, as at power stations emissions control and filtering can be much more efficient than in mobile machines (CER, 2008).

2.92 Unlike road and air transport, electric rail can make use of renewable energy without requiring any changes in vehicle technology. However, clearly there are environmental implications from all sources of electrical power, including renewable ones. Wind and tidal energy require very significant new infrastructure to be constructed, often in sensitive locations, with embodied carbon in construction materials.

2.93 Regardless of the energy mix however, HSR emits less air pollutant emissions than other transport modes and is considered to play an important role in reducing local air pollution, for example in urban areas (UIC, 2011). An example, from Germany, comparing the emissions on a given route shows the benefits of HSR in relation to air pollution. For PM_{10}s, HSR was found to be 14 times less polluting than car and air travel; for NO_x HSR was found to be 13 times less polluting; and for non-methane hydrocarbons HSR was found to be 19 times less polluting (UIC, 2011).

2.94 A study for Commission for Integrated Transport (CfIT) study analysing the comparative environmental burdens of HSR and short haul air travel found that:

- HSR has higher emissions of SO_2, per passenger km, than short haul air journeys. This is as a result of the high SO_2 emissions from the UK electricity mix. It is thought that SO_2 emissions from HSR will fall significantly in the future due to changes in the future electricity generating mix, and in the medium term (by 2020) HSR and domestic aviation will have similar emissions per passenger km.

- Domestic aircraft have higher emissions of ground level carbon monoxide (CO), NO_x and volatile organic compounds (VOCs), per passenger km, than HSR and in the future emissions from HSR are likely to be even lower, as changes in the electricity generation mix lead to greater emissions reductions.

- Electric HSR trains have slightly lower emissions of PM_{10}, per passenger km than aircraft (AEA, 2001).

[17] Particulate matter less than 10 microns in size.

2.95 The CfIT study also investigated emissions from surface access trips to airports and railway stations, finding that the choice of surface access mode is extremely important in the comparison of HSR and domestic aviation in relation to emissions. It was shown that the reduction in car use for surface access was a priority in reducing the overall environmental burdens from both transport modes (AEA, 2001). Thus in order to maximise the environmental benefits of HSR it is essential that access by sustainable travel modes is encouraged.

HS2 and local air quality

2.96 Currently little data exists in relation to the potential effects of the scheme on air quality although it is accepted, as stated by the NTS of the AoS, that HS2 will be powered by electricity and will therefore not directly result in localised air pollution.

2.97 There is however a need to assess the potential effects on local air quality during construction of the scheme, for example the use of heavy machinery and vehicles and the shifting of soils will create temporary air and dust pollution along the route. In order to minimise construction effects it will be important to implement an environmental management system, similar to the one considered to be successful for HS1 (Johnson, 2003). Mitigation measures, such as dust control strategies, will also need to be introduced to help to minimise any effects.

2.98 The NTS of the AoS recognises that there is some potential for increased traffic around HS2 stations which could cause some air pollution, although it does not consider these effects as likely to be significant, as the proposed stations would have good public transport links. However, there is potential that there will be very significant levels of car use at the Birmingham Interchange and the effect of this should be assessed in relation to local air quality. Mitigation measures to minimise access by car to stations along the line should be implemented as part of the scheme to ensure that local air quality is not adversely affected. These could include reducing the amount of car parking provided, improving public transport access to the new HS2 station and ensuring high quality and convenient interchange is provided with conventional rail services at nearby Birmingham International. Lessons from the Association of Train Operating Companies (ATOC) and the Road Safety and Standards Board (RSSB) pilot programme of Station Travel Plans[18] might be applicable to reduce traffic impacts while providing good passenger access to HS2 services.

Construction

2.99 Construction of new rail lines, including those for HSR, can have major environmental impacts. Of particular concern is the visual impact of construction machinery and spoil from workings, noise, especially if night-time construction is undertaken, vibration from the use of machinery, local air quality degradation as a result of dust and increased traffic on local roads. Remote impacts, such as aggregate extraction, can also result in environmental effects.

2.100 Nevertheless there are beneficial effects too. For example there would be opportunities for geological investigations as a result of exposures during the construction allowing scientists to investigate the sites.

2.101 Many of the construction impacts are short-term, arising only during the building of the HSR. Of greater importance is the longer-term impact of the route upon the environment.

[18] See **www.stationtravelplans.com**

Impacts of rail on sustainable communities

Noise

2.102 Locally, along high speed lines, noise nuisance from train services can be considered to be the main environmental impact of HSR (Givoni, 2006). The level of noise generated depends mainly on the speed of the train (Givoni, 2006). As the speed of trains increase, so too does the intensity of noise produced (Krylov, 2001). At speeds between 50 and 300 km/h, rolling noise is the most significant noise source (Bron and others, 2003 in Givoni, 2006) and is dependent on the smoothness of the wheels and the railhead. Generally the high standards of HSR infrastructure (i.e. the trains used and the construction and maintenance standards) means that their operation generally generates less noise than conventional trains running at the same speeds (Givoni, 2006). At speeds above 200 km/ aerodynamic noise, due to turbulence, starts to contribute to noise levels (Mellet and others, 2006 in Preston, 2009) and this then becomes the main source of noise at speeds over 300 km/h (Givoni, 2006; Thompson 2001). It is worthwhile noting that tunnelling can result in 'tunnel booms' as train enter and exit, although the impacts of this can be reduced by aerodynamic design of trains and the use of air shafts (Ricco and others, 2007 in Preston, 2009).

2.103 Measurements of different high speed technologies indicate that the noise levels vary, ranging from 80 to 90 dB(A), levels which are considered disturbing, particularly in urban areas (Campos and others, 2009). It is reported that on a number of occasions during the construction of HSLs insufficient attention has been paid to the potential for noise pollution. For example, in France complaints about the noise of TGVs passing near towns and villages have since led to the building of acoustic fencing along large sections of the track to reduce the level of disturbance to residents (Campos and others, 2009).

2.104 Current thinking is that noise from HSR is acceptable at speeds of up to 300km/h, especially where there is a separation from the infrastructure of at least 150m (Gourvish, 2010). Above 300km/h the higher speeds produce more intrusive level of noise as a result of the aerodynamic effects (Gourvish, 2010). On other HSLs, noise barriers, cuttings and tunnels have been used to mitigate these adverse environmental effects, although such features add to the costs of construction (Gourvish, 2010).

2.105 It is difficult to make direct comparisons of the noise impacts of rail, road and aviation, for a number of reasons. Noise from aviation is largely confined to the area around airports, although this can be a very wide area, whereas rail and road noise exists along a much narrower corridor, but affecting the whole route. The type of noise is also different: rail and aviation noise comes in loud, intermittent bursts from each individual train or plane, whereas road traffic noise is more continuous, at least during daytime. Noise also varies with track quality and can be created at points and junctions. For electric trains there is no engine noise; however noise created at the wheels and by air turbulence increases significantly with speed.

2.106 However when comparing the noise created per transported unit between different modes, rail is seen to be advantageous as trains can seat several hundreds of passengers and therefore create less noise (per passenger) than cars or aircraft (UIC, 2011).

2.107 A study for CfIT (AEA, 2001) concluded that the noise burden for HSR could be slightly worse than from short haul aviation, for comparable journeys, although it was thought that this could be overcome through the use of noise barriers and other mitigation measures. It should also be noted that noise from rail is considered easier to mitigate than noise from aviation (Givoni, 2006).

HS2 and noise

2.108 The effects on noise pollution of HS2 will depend not only on the train carriage characteristics, speed levels and rail traffic intensities, but also on the local characteristics of the infrastructure and its surroundings along the route, i.e. vegetation and topography (DOM, 1994).

2.109 Noise impacts from HS2 are identified by the NTS of the AoS (Booz & Co and Temple, 2010) as affecting many people living along the route, with approximately 350 dwellings predicted to experience high noise levels (≥ 73dB LAeq[19]) and approximately 21,300 predicted to experience a noticeable increase in rail noise (≥3dB LAeq compared with the existing rail noise levels and >50dB LAeq) were no mitigation put in place. In addition, some 200 non-residential receptors (including community; education; healthcare; and recreational/social facilities) within 300m of the route have the potential to experience significant noise impacts. The NTS of the AoS however states that a significant number of these potential impacts could be mitigated, with an initial appraisal of additional mitigation indicating that the number of dwellings subject to high levels of noise could be reduced to less than 50 and with those subject to a noticeable increase reduced to about 9,700. The NTS of the AoS does not provide any detail on what this mitigation will involve.

2.110 Disappointingly no consideration is given within the NTS of the AoS to the effect of noise levels on wildlife or tranquillity, both of which could be significantly affected by the noise likely to result from HS2, at the proposed speed of 360 km/h. One possible effect on wildlife would be its impact on the reproductive ability of birds. For example, studies show that the singing behaviour of birds changes in the presence of traffic noise and perhaps noise from railways as well (Parris and Schneider, 2008). Although as stated previously in the report there is some evidence to suggest that wildlife seem to adapt to the frequent passing of trains, further work needs to be undertaken to fully understand the potential effects of the noise from HS2 on wildlife.

2.111 The issue of loss of tranquillity, due to the noise of the trains, is also a concern, particularly within the Chilterns AONB but will also affect other rural/countryside areas through which the route runs. Further assessment work is needed to investigate the potential effects on tranquillity as a result of HS2 and mitigation measures should be put forward to minimise the potential effects.

2.112 Mitigation measures, including the use of noise barriers, cuttings and tunnels have been widely used on HSR across Europe to reduce the recognised impacts of noise pollution. Although as recognised previously in this report tunnelling can result in ‘tunnel booms’ (Ricco and other in Preston, 2009) and therefore require careful design.

2.113 For HS1, noise was considered to be one of the most significant environmental risks of the project (Johnson, 2003). Noise bunds were used, utilising surplus spoil in a carefully designed landscape form to control the effects of noise. In addition, two main types of innovative noise barrier were also developed:

- Wayside timber barriers up to 5m high, which in places were enhanced by attaching an absorbent lining to improve the reflective barriers acoustic performance; and

- Low level barriers (1.4m high) installed close to the wheel rail interface (a significant noise source) on structures, including bridges and viaducts, made of galvanised steel panels with absorbent linings. The benefits of these low level barriers, which were found to be as effective as the 2m high concrete outer parapets originally planned, were large allowing for the design of structures to be lighter, more sustainable and less visually intrusive (see Figure 2) (Johnson, 2003).

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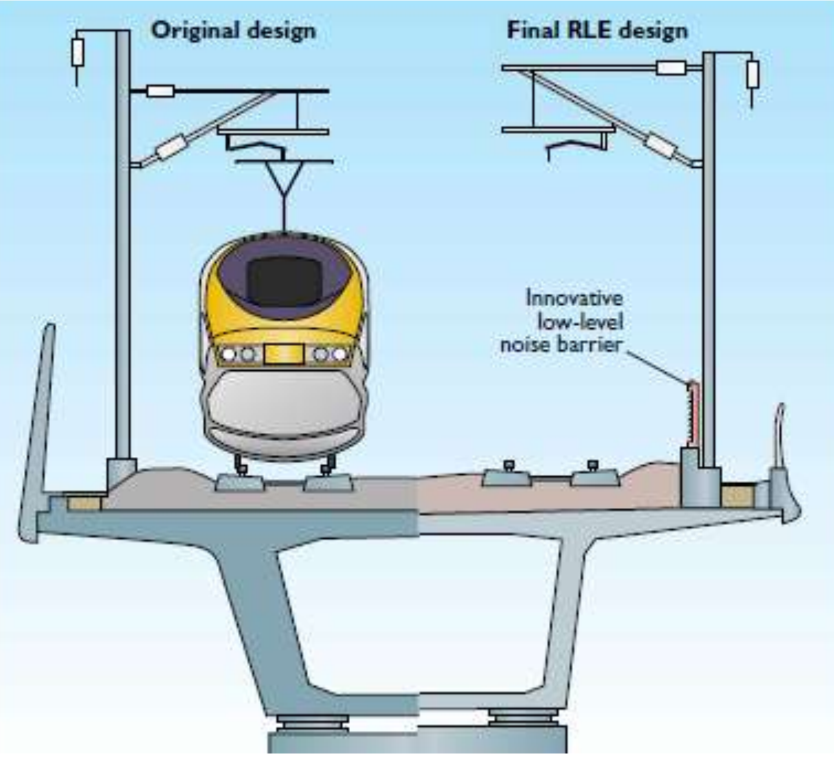
[19] The equivalent continuous A-weighted noise level, in decibels, i.e. the equivalent continuous noise level of a steady sound that has, over a given time period, the same energy as the fluctuating sound. It is a time-weighted average level.

2.114 In addition to these designs earthwork bunds were used as much as possible in rural areas where there was excess spoil from the works.



(Source: Johnson, 2003)

Figure 2 Innovative low level noise barriers used for HS1

2.115 It is also important to consider short term noise pollution during construction which could also result in significant adverse effects. For HS1 a Code of Construction Practice was developed with key policy commitments on noise and vibration. This included the need to seek prior consent for construction methods and noise and vibration control measures from local authorities, to provide noise insulation and even temporary housing where noise levels could not be reduced below defined trigger levels by reasonable and practicable measures on site and a framework for working hours (Allett and others, 2002).

2.116 In addition to these measures directly related to the scheme, low noise surfaces could be installed on local roads, to reduce overall noise levels and improve tranquillity along the route.

Accessibility

2.117 Rail networks provide access to jobs and services for people who don't have access to a car, and new services can attract employers and other developers to locations served by rail.

2.118 Railway lines can sever existing access routes to recreation and the countryside. However creating new lines provides an opportunity to review and improve rights of way along the route, bringing potential recreation and economic benefits. Railway lines can also provide increased opportunities for sustainable leisure travel and tourism and access to the natural environment thereby improving quality of life.

2.119 It should be noted however that rail travel increases with income, with the highest earners using rail nearly four times as much as those on the lowest incomes (DfT, 2009b). Long-distance trips (i.e. over 50 miles) vary significantly with income, with rail use rates in the top fifth of people in terms of income around three times higher than those in the bottom fifth (Scott Wilson, 2008). Caution must therefore be applied in assumptions about the role of HSR in improving travel choices for the least well off. However it has been suggested by scheme backers that HSR would be affordable for all. In today's prices, it is claimed that the average fare paid for a single journey could be £40-45. Lower fares, perhaps £20-25 one-way, are expected to be available (Greengauge, 2010). Fare changes seem to have a moderate effect on business and commuting, but a major effect on other journeys (Independent Transport Commission , 2010).

HS2 and accessibility

2.120 The NTS of the AoS states that the preferred route will sever a number of rights of way and cycleways, however it anticipates that permanent effects will be minimal as most should be reinstated. Temporary effects, during construction however are likely to cause severance (Booz & Co and Temple, 2010). The NTS of the AoS is unclear as to whether any of the routes that will be severed are national trails or promoted routes. This should be clarified.

2.121 More consideration needs to be given to the effects of the scheme on the enjoyment of the existing rights of way and cycleways in relation to tranquillity. In addition to ensuring that severed rights of way are reinstated, construction of HS2 could provide an opportunity to review the existing rights of way and adjust them to maximise the accessibility to the countryside for walkers and cyclists. HS2 Ltd could work with landowners and the local highways authority to identify opportunities for improved rights of way and access along or near the route as this could improve access to outdoor opportunities and have a positive effect on health and well-being by encouraging more active lifestyles. Given the likely noise and visual effects resulting from the new line and their impact on tranquillity, it will be important that mitigation measures are designed and implemented to ensure that these new rights of way can be enjoyed.

Impacts of rail on sustainable consumption and production

2.122 The construction and operation of railway infrastructure will lead to the generation of waste. It is likely that most waste will be generated during the construction phase of the project, for example large quantities of spoil will arise from tunnelling and the creation of cuttings, although this could be reused on site for embankments, landscape and earth bunds.

2.123 Ballast, consisting of crushed rock, forms the rail bed. The depth of ballast used varies from a minimum of 50cm to around 70cm. At regular intervals during railway maintenance ballast must be screened to remove dirt, rounded stones and dust. In order to maintain track geometry and ride comfort at high speeds it is necessary to improve the upper portion of the road bed by introducing an additional structural layer called the sub-ballast (Dalla Chiara, 2007).

2.124 The aggregate required for railway ballast will need to be extracted, processed and transported. Efficient operation of the quarry processes will help to minimise the amount of quarry fines and waste produced and maximise the amount of useful product generated[20]. Additionally, in 2005 Network Rail reused or recycled 91% of ballast removed from the network thereby minimising the amount of waste ballast generated and reducing the need for new aggregate extraction (Network Rail, 2010c).

2.125 For information related to the effect of rail on land resources please see sections 0 to 0 on land take.

HS2 resources

2.126 The NTS of the AoS provides little detail in relation to the waste that will be generated through the construction and operation of HS2. It simply notes that 2 million cubic metres of spoil will be arise from tunnel excavation and that any opportunity to re-use this material either on parts of the HS2 construction, such as landscaping or noise bunds, or for other uses of site would be sought due

[20] Goodquarry.com **http://goodquarry.com/article.aspx?id=152&navid=19**

to the potential cost of landfill. It will be important that all waste generated through construction and operation is reduced, re-used or recycled, with disposal only being considered as a last resort. It is not yet clear as to the amount, source and transportation requirements of ballast needed in construction of the scheme and during its life for track maintenance. This data should be made available, along with information on the level of predicted re-use and recycling of this material.

The impact of speed on environmental performance

2.127 As has been discussed above, there are a number of impacts that increase with speed, in particular energy consumption and noise, or are made harder to mitigate because higher speeds require a straighter route, so sensitive locations cannot readily be avoided. The minimum turning radius at 400 km/h is 7.2km, in comparison with 1.8km at 200km/h[21]. Clearly a lower design speed would in principle offer greater flexibility in making localised changes to the route to avoid sensitive locations and make it easier to follow the natural contours of the landscape with fewer visually intrusive structures. However, against this must be set the greater journey time that will result from lower speeds, which reduces the attractiveness of rail in comparison with other modes, and the increased energy consumption that will result if a route is curved to the extent that significant changes in speed are required throughout the route. HS2 Ltd's proposals do not provide an assessment of how different speed options would affect its local impacts, so further detailed analysis of the route would be needed to determine whether a lower-speed option would in practice offer significant sustainability benefits overall. Such an analysis would have to take account of future proposals to extend HS2 further to the North, because changes in design speed would have a greater impact on journey times, and hence the potential for modal shift, for longer distance travel.

Summary

2.128 The requirements that HS2 must fulfil if it is to support the sustainability priorities outlined previously in this chapter are summarised in Table 6.

[21] **http://www.hs2.org.uk/about-hsr**

Table 6 The sustainability requirements of HS2

Priority	Where rail is advantageous	Limitations of rail
Reduce greenhouse gas emissions	Lower levels of emission per passenger km. Modal shift from car or air. Supports other carbon reduction policy measures by providing a potentially low carbon alternative.	New rail services need to have high occupancy rates if modal shift is to lead to overall carbon reductions. Carbon intensity of electric traction limited by that of electricity sources. There is a conflict between greater rail occupancy and modal shift achieved by reduced journey times, and the increased power required for greater speeds. 'Rebound effects' can undermine modal shift benefits of rail unless 'locked in' with supporting measures. Only a relatively small proportion of total travel is readily transferable to rail. Significant carbon emissions result from construction of the infrastructure.
Protect natural and cultural resources and enhance the environment	Enabling future road building or runway construction to be avoided. Rail generally considered less intrusive than major roads. Rail uses less land than road for comparable passenger carrying capacity. Rail can more easily be tunnelled than road to minimise impacts. Rail can result in the creation of new habitats for flora and fauna. (Electric) rail results in minimal direct local air pollution along the route.	New rail infrastructure will need to be built, resulting in landtake. HSR noise can be intrusive and has different characteristics from road. Straight path required for HSR reduces ability to avoid sensitive locations (both biological and geological). Railway routes can isolate sections of land and fragment habitats having adverse effects on landscape character, biodiversity and local communities. Overhead electrification increases visual intrusion.
Create sustainable communities	By improving access to jobs and services for those without cars. By improving access to the natural environment and providing opportunities for sustainable leisure travel.	Rail travel generally used by higher income groups.
Achieve sustainable consumption and production	Supporting low carbon economic growth, encouraging regional development.	Results in waste generation, particularly during construction. High costs and infrastructure requirements.

2.129 The construction and operation of HS2 will have numerous and varied impacts on the natural environment, which must be avoided, mitigated or compensated. Some of these impacts will occur regardless of the route, while others will be dependent on the specific route chosen. A short summary of key environmental impacts is provided Table 7 below.

Table 7 Summary of key environmental impacts

Environmental issue	Summary of key impacts of HS2
Carbon emissions	The carbon savings forecast for HS2 are very small, so by themselves make very little contribution to climate reduction targets. To maximise the carbon benefits of HS2 greater decarbonisation of its energy source will be required, combined with effective management of rebound effect on freed up road and air capacity.
Landtake and landscape	Landtake for HS2 will consist of a 14m wide strip that carries the track and an additional fenced off area on either side of the track creating a 25m wide fence to fence width. A further 25m zone either side of the fenced area also needs to be kept free of tall vegetation. Landtake however will be greater for junctions, stations, bridges, and tunnels. The main impact on landscape is predicted to occur in the Chilterns AONB, through which the route passes. However, along the length of the route physical encroachment and disruption to natural landscape patterns would also result in adverse effects on landscape character. Reduced levels of tranquillity are also expected along the length of the route.
Biodiversity	Adverse effects on four SSSIs and also the wider biodiversity and wildlife found along the length of the route are likely due to habitat fragmentation, deterioration of habitat quality and wildlife collisions.
Geology and soils	There is potential for both positive and negative effects on geology as although construction may allow for the exposure and therefore study of geological sites of interest, they could then be damaged or destroyed. During construction there is potential for significant adverse effects on soil mainly as a result of fill that is likely to be generated through the development of cuttings, embankments and tunnels.
Climate Change Adaptation	The scheme has been designed to adapt to the impacts of climate change, mainly through the use of viaducts in areas prone to flooding. However these measures would introduce potential new effects on landscape character and noise.
Local air quality	Although HS2 will be powered by electricity and therefore not result in any local air quality issues along the route (apart from during construction), emissions as a result of the generation of the electricity will have implications on air quality.
Noise	Approximately 350 dwellings are predicted to experience high noise levels and approximately 21,300 predicted to experience a noticeable increase in rail noise were no mitigation put in place. There is also likely to be loss of tranquillity along the length of the route, particularly affecting the countryside/rural areas through which the line runs. Potential impacts of noise on wildlife need to be considered.
Accessibility	A number of rights of way and cycleways will be severed during the construction process; however most of the routes should be reinstated.
Resource use	The scheme will result in waste generation, particularly during construction, and will require the use of materials, including aggregate for the rail bed.

2.130 At the time of this research, little available information about the predicted environmental effects of HS2 exists, except that provided with the NTS of the AoS for the previous scheme. Lessons regarding some of the impacts and the mitigation that may be required to address them can be learnt from HS1.

2.131 In identifying the most appropriate route it is apparent there are compromises between impacts on countryside versus impacts on populated areas; between speed and energy use; and between the ability to deviate around sensitive locations and speed, which impacts on journey time and potential modal shift. Further analysis by HS2 Ltd would in practice be needed to identify whether a lower design speed would reduce the environmental impact of HS2 and what the resulting impacts on modal shift and energy use might be.

3 Review of other HS2 sustainability issues

Introduction

3.1 This chapter discusses some of the other issues relevant to determining the sustainability of HS2. It looks at the perceived benefits of HS2, in particular the modal shift and new capacity it could provide, and the measures that could help to maximise these benefits. It examines the advantages and disadvantages of some of the possible alternatives to HS2. It concludes with a SWOT analysis of HS2, based on the literature review and evidence base gathered in the previous chapters.

Transport benefits of HS2

3.2 The transport benefits of HS2 identified in the HS2 Ltd documentation are summarised as follows:

- Providing capacity to meet future long distance rail demand, forecast to be twice as great in 2033 as in 2009, the base year for the HS2 Ltd proposals. HSR has higher capacity utilisation (load factor) than conventional rail and would release capacity at airports.

- Releasing capacity on the congested southern section of the WCML permitting improved local and regional services.

- Reducing journey times and improving reliability on long distance services (even from 'Day 1'), leading to modal shift from road and aviation (see Table 8).

Table 8 Journey time savings

Destination	Current Journey Time	HS2 Phase 1 'Day 1'	Time saving	% reduction
Birmingham	1 hr 25	49 mins	35 mins	41%
Manchester	2 hrs 09 mins	1 hr 40 mins	29 mins	22%
Liverpool	2 hrs 10 mins	1 hr 50 mins	20 mins	15%
Glasgow	4 hrs 30 mins	4 hrs	30 mins	11%

3.3 These journey time savings are significant and would enhance the competitiveness of rail compared to other modes, even for longer distance journeys to Scotland.

3.4 The HS2 Demand Model Analysis provides the following breakdown (Table 9) of where the trips forecast to be undertaken on HS2 will come from.

Table 9 Source of trips of passengers using HS2

	Passengers using HS2
Switch from conventional rail	57%
New trips	27%
Modal shift from air	8%
Modal shift from car	8%

3.5 This table shows that under the assumptions used by HS2 Ltd, the modal shift from air and road will only comprise a relatively small part of the total usage. More than half (57%) of passengers will have transferred from the existing 'conventional' service, another 27% will come from completely new trips that would not otherwise have been made in the 'do minimum' scenario. On the face of it, little modal shift would be achieved. However there is significant variation with trip length; from Scotland almost one third of trips using HS2 would have switched from air, as rail journey times become more competitive with air services. This is significant, as this modal shift would have been achieved solely from time savings in phase 1, the majority of the journey to Scotland being undertaken on the conventional line north of Birmingham. This is consistent with international observations of the share of long distance travel that rail takes for journeys of that duration, with quite rapid increases in modal share with journey time reductions for rail journeys of around 4 hours – see Figure 3. The more recently constructed HSR lines have a much higher modal shift, including over shorter journey times. A modal share of 50% could be expected for the 127 mile long HS2, all else being equal. HSR could be a viable substitute for trips of up to 1,000 km (Patterson and Perl, 1999).

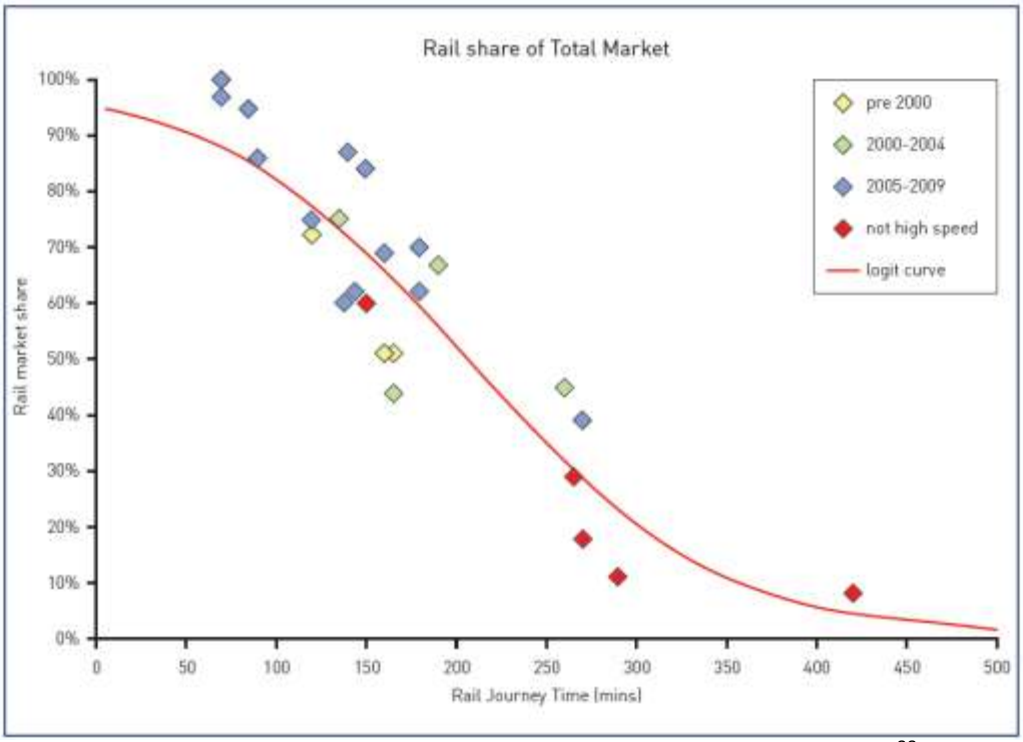


Figure 3 Relationship between Rail Journey Time and Market Share[22]

3.6 There is a risk that by capturing travellers from other modes, the released capacity becomes filled so that the benefits of modal shift are not secured i.e. the 'rebound effects' outlined in Chapter 2 overwhelm the benefits realised.

[22] HS2 Demand Model Analysis

3.7 In order to maximise the benefits of modal shift to HS2 and to avoid the rebound effect, other measures would be required to lock in the benefits and encourage the maximum use of the new line and the capacity that would be released by its construction[23]. Measures to maximise the benefits would include:

a) Competitive fares. In the modelling used by HS2 Ltd the fares for HS2 are assumed to be 'normal' fares, i.e. comparable to the conventional London-Birmingham route, rather than a premium service. This is consistent with the proposal for existing long distance services to be transferred to HS2 from the conventional speed lines, thereby releasing capacity, rather than continuing to operate in competition with HS2. A HSR line has a capacity of 15 trains per hour and per track. Assuming 800 passengers per train, 12,000 passengers could be transported per hour and per track (UIC, 2011). In order to fill this level of seating capacity competitive fares would need to be set. Premium fares would reduce patronage, reduce social inclusion and also undermine the concept of HS2 as an integral part of the national rail network: if reasonably fast direct services on the conventional line have to be maintained then the capacity benefits from HS2 would be lost.

b) Improved sustainable access to rail stations. Although HS2 will have few stations these will provide facilities for interchange with other modes. It will therefore be essential for excellent access to be provided for travellers on foot, cycle, by bus/ coach, rail (Decourriere, 1998) and by private car/ taxi. To minimise car dependency, public transport access will need to be improved and excellent interchange provided with rail services so that HS2 users can make use of local rail services. Lessons from the RSSB and ATOC Station Travel Plans pilot programme will be useful in developing non-car alternatives to the new stations[24].

c) Real-time information (RTI) for HS2 journeys, and for onward travel, must be provided for potential customers.

d) Integrated ticketing for all HS2 journeys through from origin to destination would be needed to provide for more efficient door-to-door travel (seamless journeys). This could be assisted by ensuring that HS2 tickets are purchasable not only on the Internet but also via mobile phones etc. By ensuring that through ticketing is provided the HS2 travel offer would become more competitive with the private car.

e) Land use and planning policies can also help realise the agglomeration benefits – economies of scale and network effects that arise where people and firms are close together – of HS2. These benefits fade where places are more than 30-40 minutes apart (CPRE, 2010). Agglomeration economies do exist, but the extent to which they explain why cities have higher productivity is not fully established[25]. HSR tends to strengthen dynamic, bigger cities that it serves to the cost of cities off the network and smaller settlements along it (Albalate & Bel, 2010). HSR in other European countries has not always resulted in transformational change in the areas served by the lines while there exists a potential for competitive disadvantage for those places not served by the line (House of Commons Transport Committee, 2010). Application of a more rigorous planning regime, based on PPG13[26], to favour locating new movement generating developments in close proximity to the stations, will generate continued passenger demand and revenue generation.

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[23] Making High Speed Rail Part of the UK's Low Carbon Future, Campaign for Better Transport, February 2010
[24] See ATOC Station Travel Plan website, **www.stationtravelplans.com**
[25] Representing International Business Impacts in Transport Appraisal, Literature Review, NERA for DfT, April 2010
[26] **www.communities.gov.uk/documents/planningandbuilding/pdf/155634.pdf**

f) Carbon savings will depend upon the use made of the released capacity. Measures designed to deter the released capacity in aviation and motorways from being reused must therefore be adopted. Some are discussed below which might require being set within the context of a new national transport plan or framework:

- One key benefit of HS2 will be the transfer of short-haul aviation passengers from the north and Scotland onto HSR. To be truly effective the taxation of air travel might need to be increased. There always exist penalties for travel by air – the time delays due to security checks for example – which HSR does not currently face. Faced with a new competitor the aviation industry will respond; air may still offer a competitive service to rail. The travel market is differentiated geographically and not all air passengers will view HSR as a realistic alternative. Higher taxation of air flights would shift the financial advantages towards HSR. Journeys from outside of London to Europe are significant; maximising connection opportunities from Euston to St Pancras, and linking HS2 to HS1 would be particularly beneficial to these passengers.

- Another competitor on the London-Birmingham HSR route is the motorway network (the M1/ M6 and M40 corridors). Use of these motorways could also be discouraged by the introduction of motorway tolling. Road-user charging, of which motorway tolling is a specific form, is controversial, and any new tolling might need to be applied within an overhaul of the charging regime for road-space. HS2 may have difficulty in attracting car users when trying to compete with the free alternative motorways.

- A major problem will be the power generation used for the construction and operation of HS2. The carbon impacts of the proposal are expected to be carbon-neutral, i.e. no significant improvements or adverse impacts. This could change however if the nation's power generation were to be structured so as to include a much higher proportion of carbon-free sources, for example, wind and wave power and nuclear generation. As such a trend emerges the carbon reduction benefits of HS2 will grow.

- Continued funding for the upgrade and maintenance of conventional rail services so as to ensure proper, efficient connected services are provided for all the regions, i.e. not just those served by the new HS2 line. It is important to ensure that the construction of HS2 would not penalise other services.

3.8 Whether such supporting measures would lock in the benefits of HS2 would depend upon the intensity with which they are pursued.

Alternatives to HS2

3.9 A relevant issue for this study is whether the other transport options in the HS2 London-Birmingham corridor offer a feasible and realistic alternative to HS2 that also deliver the benefits discussed above. The Treasury's Green Book is designed to promote efficient policy development and resource allocation across government and recommends the need to identify other possible approaches which may achieve similar results. Likewise the NATA appraisal process requires the consideration of alternatives for solving the problems and meeting the objectives of the project being appraised. PPS7 also requires an assessment of the cost of, and scope for, developing elsewhere outside the designated area, or meeting the need for the proposed scheme in some other way.

3.10 In their analysis HS2 Ltd have compared their proposals to a 'do minimum' scenario, and also considered alternative transport schemes that would meet at least some of its objectives. 'Do minimum' assumes transport demand increases in line with current forecasts, based on a projection of current trends and assumptions about economic growth and travel behaviour, but that no additional transport capacity is provided beyond already expected upgrades. As alternative transport schemes, HS2 Ltd considered the following:

- A new railway serving a similar route to HS2, but running at conventional speed;
- A package of railway improvements[27]; and
- A package of highway improvements.

3.11 It is important to note that none of these different options are true alternatives to each other, not least because they involve growth in different modes, so comparison is difficult. Furthermore, within the Highway and Rail 'packages', the individual options considered are not alternative schemes that provide similar benefits, but rather consist of a series of progressively more intensive and expensive schemes that build on each other to provide greater capacity improvements.

3.12 The Highway packages lead to increased traffic growth and emissions, so are not discussed further in this report.

3.13 The rail alternatives involve different combinations of improvements to the existing WCML and Chiltern lines, ranging from relatively small enhancements to signals and stations in the least intensive package through to 4-tracking and electrification of the Chiltern line. Although some of the smaller scale enhancements show better BCRs than is expected for HS2, none of the options considered provide comparable capacity benefits to building a new line, and through not offering high speed journeys cannot deliver the same potential for modal shift.

3.14 Comparison with a new 'conventional' speed line showed that while the capacity improvements are comparable, the lower speed results in fewer passengers and far less potential for modal shift. Clearly, a decision to build a conventional line would effectively preclude high speed running in the future, even if the network is extended to the north, making it impossible to create a rail network that can compete significantly with aviation on journey times.

3.15 A number of route alternatives were considered by HS2 Ltd before the preferred route was selected. This route is one of the most direct, minimising journey times as well as the length of route miles of construction, and hence land-take needed. Routes further to the east would be longer and require more tunnelling on the approaches to London, so as to minimise disturbance to the most populated areas.

3.16 An alternative route, to the west of the proposed alignment, has been suggested by Arup. This would use the Chilterns railway and the M40 corridor. It is expected that such a route would increase journey times from London to Birmingham by 3-4 minutes compared to the HS2 Ltd proposal. Other alignments might also be feasible.

3.17 The model used by HS2 Ltd for long distance transport, 'PLANET Long Distance', was multi modal, whereas the models used for the shorter distance travel, 'PLANET South and Midlands', focuses on rail demand only. Therefore the multi-modal implications of the different options have not been considered in as much detail for the released capacity on the conventional line as they have for the longer distance high speed travel. This means that the additional services provided on the existing WCML using released capacity may also deliver additional modal shift to that reported for HS2, but this has not been modelled explicitly. It is possible that the levels of overcrowding forecast in the 'do minimum' case would, in practice, constrain the potential for passenger growth to below the forecast level, potentially encouraging a switch to car use, which could be avoided with increased capacity such as that which would be provided by HS2 or the rail

[27] Based on those considered in the High Speed 2 Strategic Alternatives Study: Baseline Report, Atkins, March 2010.

alternatives. Applying a multi-modal model to demand for the South and Midlands corridors would provide a better understanding of the impacts of the 'do minimum' case.

3.18 As noted earlier, it is clear that there are compromises between environmental impacts and the need to provide high speeds to minimise journey times in comparison with other modes. Concerns have been raised that the proposed speed for HS2, at 400 km/h, is significantly higher than HS1 and most current high speed systems, making it much harder to modify the route to avoid the most sensitive locations and to reduce its visual impact. It has therefore been proposed[28], that HS2 should consider the option of a lower design speed, but still higher than 'conventional'. As different design speed options, other than conventional, have not been assessed in HS2 Ltd's proposals it is not possible to offer a definitive view on where the optimal balance lies between reducing journey times and reducing the environmental impact through lower speeds. This would require an assessment of the route at a detailed level to assess the extent to which a lower speed would permit significantly lower environmental impacts in practice, given that even at a lower speed of 300 km/h a very straight route is still needed, and also to model the demand and level of modal shift using the different speeds.

3.19 Table 10 summarises the advantages and disadvantages of the main alternatives to HS2. It is clear from this analysis that none of the alternatives seem to offer the same level of benefits that HS2 is expected to generate. Some of the WCML enhancement options considered, in particular HS2's "Package 2" of upgrades[29] demonstrate a higher BCR than HS2, albeit for fewer benefits at much lower cost.

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[28] For example, by CPRE (2010).
[29] Based on those considered in the High Speed 2 Strategic Alternatives Study: Baseline Report, Atkins, March 2010.

Table 10 A comparison of HS2 against the rail alternatives

Alternative schemes	Do nothing	Proposed HS2 Route	Alternative HS2 Route	Minor improvements to existing route	Widening existing WCML and Chilterns Line	Construction within existing WCML corridor	Alternative new conventional rail route
Advantages	No costs incurred: funding available for other policy measures No new adverse environmental impacts from construction of new schemes.	Faster journey times and improved reliability, including to major destinations north of Birmingham via compatible conventional services. Enables modal shift from air. Capacity made available for passenger & freight trains on existing routes. Interchange with other rail lines. Possible economic gains in West Midlands. Preferred route avoids largest population centres. Few stations allow for fast journey times. Little construction disruption in heavily populated areas, other than in London.	Alternative routes could reduce impacts on communities and environment A lower design speed could allow greater ability to avoid sensitive locations within the existing corridor.	Lower cost than HS2. No new adverse environmental impacts. Some potential reduction in congestion on WCML.	Lower cost than HS2. Limited additional environmental adverse impacts. Greater potential reduction in congestion on WCML than minor improvements.	Limited additional environmental adverse impacts. Capacity made available for passenger & freight trains on existing routes. Fewer stations would allow for fast journey times.	Lower cost than HS2. Capacity made available for passenger & freight trains on existing routes. Fewer stations would allow for fast journey times.

Table continued...

Alternative schemes	Do nothing	Proposed HS2 Route	Alternative HS2 Route	Minor improvements to existing route	Widening existing WCML and Chilterns Line	Construction within existing WCML corridor	Alternative new conventional rail route
Disadvantages	Congestion on existing WCML will worsen considerably leading to unreliability and delays, and overcrowding. If demand and overcrowding were left to grow to the forecast levels a potential shift back to the car and air might arise.	Adverse environmental impacts. Few stations so catchment areas limited to those with large populations. Needs full route to be operational before full benefits of modal shift would be derived.	All potential routes will have some adverse impacts somewhere. A longer or slower route will increase journey time, reducing the modal shift potential and time saving benefits	Fails to deliver time savings or capacity release. Construction disruption to existing route.	Fails to deliver comparable time savings or capacity release. No significant modal shift from aviation. Construction disruption in populated areas. Even upgraded Chiltern line does not connect as effectively to the North, new links in the Birmingham area would be necessary.	Possibly slower line speeds than HS2. Fewer economic gains than HS2. Significant construction disruption. No significant modal shift from aviation. Higher cost than HS2 due to construction through densely populated areas.	Cost savings only about 10% lower than building to high speed standards Slower line speeds than HS2, time savings insufficient to seriously compete with aviation. Largely precludes the future option of building a high speed network. Depending on the route additional environmental adverse impacts. Fewer economic gains than HS2. Comparable construction disruption to high speed.

3.20 SWOT analysisTable 11a/11b provides a SWOT analysis of the scheme as proposed and under the stated assumptions, i.e. the March 2010 route. Undoubtedly HS2 has many strengths and future opportunities for enhancing its contribution to the economy and to providing transport opportunities. However it also has weaknesses, of which its potential impact upon the natural environment is significant. The table highlights the main issues involved.

3.21 Opportunities identified are those to improve the scheme within the current proposals as well as external prospects that would support HS2 and deliver greater benefits. The main threats are those risks to the benefits of the scheme as proposed as well as external risks that would undermine it and lead to negative impacts if they came to fruition.

Table 11a SWOT Analysis – Strengths and Weaknesses

Strengths	Weaknesses
By running long distance 'conventional compatible' through trains to the NW and Scotland from Day 1, the scheme delivers journey time reductions that encourage modal shift from aviation, even with only phase 1 to Birmingham constructed.	Modal shift from road transport only accounts for a small percentage of forecast journeys.
Frees up capacity on existing lines so that future demand can be carried by rail rather than being forced back to road by overcrowding. It also provides more rail freight capacity.	Environmental damage to countryside .Route goes through Chilterns AONB[30], affects SSSIs[31] and other sensitive environments. There are 11 internationally protected sites within 10km of the preferred route.
Provides a low carbon alternative for long distance travel, supporting other policy measures to restrain car and aviation (see Opportunities).	Noise impacts on communities along route, which increase with speed.
Selected route avoids most densely populated areas, while following existing road and rail corridors.	Visual intrusion in countryside, made worse by width of area that is to be kept free of vegetation outside the fenced off railway itself.
Proposed termini are in city centres, all new stations are well-connected to public transport networks.	Community severance.
In comparison with highway alternatives, rail requires less land take.	High carbon impact in constructing HS2.
Tunnelling is used to minimise impact on most sensitive locations.	Few stations on route limit transport benefits to communities directly along route.
	Very small CO_2 reductions overall within current modelling assumptions, largely because of limited decarbonisation of electricity supply.
	Car use encouraged for access to high speed stations, especially at Birmingham Interchange.
	There is a compromise between speed and directness, which significantly affects journey time and modal shift potential; and the need for the route to curve to avoid sensitive locations and centres of population.

[30] Area of Outstanding Natural Beauty
[31] Site of Special Scientific Interest

Table 11b SWOT Analysis – Opportunities and Threats

Opportunities	**Threats**
Opportunities to improve the sustainability of the proposed scheme (within the HS2 scheme)	
Potential to review design speed to optimise environmental impacts versus modal shift. Further use of tunnelling, earthworks and other mitigation measures to reduce noise and impact.	Rebound-effects undo modal shift benefits: freed-up aviation capacity is used for further growth; freed-up road-space taken by additional traffic.
Review requirement for clearance zone 25 metres on either side of fenced off track in sensitive locations, which would reduce need to clear trees and would make it possible to use plantings to help reduce visual impact. Modifications to route to avoid sensitive locations (though constrained by compromise with journey time savings).	New travel opportunities encourage more dispersed settlement patterns, with longer distance commuting and an overall increase in demand for travel.
Use of sustainable construction techniques to minimise resource implications and embedded CO_2.	Electricity supply is not decarbonised, for example, future energy shortages lead to a return to coal generation.
Use of wildlife bridges and tunnels to minimise disruption to animal movements and territories.	Carbon advantage of rail over air and road could be eroded if low carbon technologies are introduced more rapidly in those modes.
Maximising integration and interchange with other modes at new stations.	Opportunity costs - resources used for HS2 might deliver greater benefits if used for other schemes. In particular there could be a "crowding out"[32] of private sector investment.
Minimise additional car parking at new HS2 stations. Energy supply contracts with renewable energy suppliers to stimulate progress towards decarbonisation of grid.	
Through running onto HS1 to encourage greater potential for modal shift from air travel to Europe.	
Opportunities to extend benefits with supporting policies and initiatives (external to HS2 scheme)	
Extension to north and Scotland via Y-route would deliver significantly greater time savings to Scotland and the North, maximising future modal shift benefits, especially from air.	

Table continued...

[32] "Crowding out" is any reduction in private consumption or investment that occurs because of an increase in government spending. If the increase in government spending is financed by a tax increase, the tax increase would tend to reduce private consumption. If instead the increase in government spending is not accompanied by a tax increase, government borrowing to finance the increased government spending would increase interest rates, leading to a reduction in private investment.

Opportunities	Threats
Potential for connection to HS1 permits greater modal shift from aviation to Europe.	
If the electricity supply is decarbonised in the future then CO_2 saving benefits of HSR will increase.	
If future carbon reduction policies require measures to restrain demand for aviation then HSR will be there as a low carbon alternative, potentially making those policies more acceptable.	
Road user charging, carbon pricing and other demand management measures would lock in benefits and encourage greater modal shift in the future.	
Redevelopment opportunities in areas near HS2 stations should be designed to minimise car-use, with new housing and office developments placed as close as possible to provide journey opportunities that are not car dependent.	

Summary

3.22 The main transport benefits expected from HS2 are capacity to meet future rail demand, freed up capacity allowing improved regional and local services on the WCML, freed up capacity at airports, and reduced journey times enabling modal shift from road and air to rail.

3.23 One of the key Green Book and other national policy challenges is whether there are better ways to achieve the objectives and benefits of HS2. None of the alternative rail schemes considered in this chapter appears to deliver the same level of benefits as HS2 on the proposed route alignment although the rail-based ‘Package 2’ of options delivers extra rail capacity for lower cost and less environmental impact.

3.24 When considering different options it is also necessary to understand the implications of the ‘do minimum’ alternative. Forecasts of future demand for rail show that the existing West Coast Mainline will be running significantly above capacity, the predicted occupancy levels implying very high levels of over-crowding. What is not clear from the available data is what the consequences of that are likely to be in practice. Applying a multi-modal transport demand model to the Midlands and South sections of the existing WCML might provide a better understanding of the wider implications of the forecast demand for rail, and what will happen if new capacity is provided or not.

3.25 Consideration should also be given to a non-infrastructural option: the ‘demand management’ option, in which instead of predicting future demand, and looking at how to provide additional infrastructure to meet that demand, the use of pricing and other demand management tools is applied to restrain that demand and so encourage the far greater use of planning measures to avoid the need for travel in the first place. Clearly such an approach would have to be multi-modal, as if demand restraint is only applied to rail demand, then modal shift to road and aviation is likely occur.

4 Conclusions

Impacts of HS2

4.1 The construction and operation of a high speed railway will have numerous and varied impacts on the natural environment. Some of these impacts will occur regardless of the route, while others will be dependent on the specific route chosen. All of these impacts will need to be avoided, mitigated or compensated through sensitive choice of routing, design, construction methods, train operation and maintenance practices, for example through the use of tunnels and cuttings to minimise the impact on sensitive landscapes, in particular the Chilterns AONB, and the use of wildlife bridges and underpasses to reduce the effects of habitat fragmentation.

4.2 While there is scope to reduce these impacts through changes to the route, there are compromises that might need to be made between impacts on communities and impacts on the natural environment; between speed and energy use; and also between the potential for deviations to the route and journey time savings, which affects the potential modal shift benefits. Further detailed route analysis would be needed to assess whether a reduced maximum speed would in practice provide sufficiently greater flexibility in routing to justify the reduced benefits.

4.3 It should be noted that there are some potential opportunities for benefitting the natural environment, such as the exposure of geological formations or through compensation and enhancement packages. There is also the potential for an extremely carbon efficient mode of transport if the UK's energy sector succeeds in reducing its dependence on fossil fuels.

Benefits and impacts by environmental topic

4.4 Table 12 summarises the main environmental benefits and impacts of higher speed rail lines.

Table 12 Environmental benefits and impacts of higher speeds

Environmental impacts	Impacts of higher speed	Benefits of higher speed
Landtake and landscape	Straighter alignment needed, less ability to avoid sensitive locations. Wider vegetation free clearance zone. Need for fencing along the length of the route. Greater impact on tranquillity due to higher noise levels. Greater noise levels require increased numbers of noise barriers.	Takes less land than a motorway for equivalent numbers of passenger km. Encourages greater modal shift from road, so providing landscape benefits if further road building can be avoided.
Biodiversity	Straighter alignment needed, less ability to avoid sensitive sites. Wider vegetation free clearance zone. Greater noise disturbance to wildlife.	Takes less land than a motorway for equivalent numbers of passenger km thereby reducing habitat loss. Encourages greater modal shift from road, so providing biodiversity benefits if further road building can be avoided.

Table continued...

Environmental impacts	Impacts of higher speed	Benefits of higher speed
Geology and soils	Straighter alignment needed, less ability to avoid sensitive sites.	Takes less land than a motorway for equivalent numbers of passenger km thereby reducing impacts on soils.
Air quality	Powering high speed trains requires more electricity than conventional trains thereby resulting in greater remote source air pollution from electricity generating plants.	Lines are 100% electric therefore resulting in no direct local air pollution.
Noise	Rail noise levels increase significantly with speed.	Modal shift from road reduces traffic noise impacts, especially if new construction is avoided. Air travel has very serious noise impacts in area around airports, so modal shift from air could offer significant noise benefits if flights can be avoided.
Carbon emissions	Increased power consumption of trains: power required to overcome air resistance increases with the square of speed.	Reduced journey times improve attractiveness of rail in comparison with other modes, hence better occupancy levels and modal shift from air with associated reductions in greenhouse gas emission.
Accessibility	Access to the natural environment along HSLs reduced due to severance of roads and public rights of way and reduced tranquillity.	Reduced journey times improving accessibility to jobs, services, leisure and recreation.
Economics	Greater costs arising from longer viaducts and longer, wider tunnels needed for straighter path. Increased mitigation costs.	Reduced journey times attract greater numbers of passengers, improving business case. Greater investment in connected locations.

Study objectives and key findings

4.5 The following section summarises the key findings and how these objectives have been met:

1) Summarise the evidence regarding comparative emissions from rail, road, air and HSR and the assumptions underlying the main figures.

   Our review has shown that in comparison with car, planes and conventional trains high speed trains use much less energy per passenger km, although different studies have shown this to differing degrees. Emissions are dependent on the source of energy used to power HSR.

2) Discuss the evidence regarding the carbon emissions for HS2, discuss the issues relating to energy generation for HS2, identify the best and worst case scenarios for emissions.

   On the basis of our research the carbon emissions of HS2 would, if there is no improvement in the current electricity generation network, be likely to result in a marginal increase in carbon emissions. This is because of the dominance of UK power generation by carbon emitting electricity generating plants i.e. coal and oil-fired power stations. However, work by the Committee on Climate Change shows that significant decarbonisation is achievable, and if their trajectory for decarbonisation is followed then emissions from HS2 will be significantly *lower than the central case assumed by HS2 Ltd, and HS2 could then deliver net carbon savings.*

3) Discuss the contribution that HS2 could make to UK carbon budgets and targets.

   HS2 will have a fairly small contribution to overall UK carbon budgets and targets.

4) Examine the evidence for the potential for modal shift from road and air (including impacts on freight movements) to HS2, and identify the measures required to maximise modal shift.

   Modal shift from the car is likely to be relatively small while that from aviation, especially when the whole route from London to Scotland is completed, could be significant. A range of measures could maximise modal shift, such as improving sustainable access to rail stations, providing integrated ticketing for all HS2 journeys, taxation of air travel and road user charging but their success would depend on the intensity with which they are pursued.

5) Review the literature and establish the lessons that can be learned regarding impacts on the natural environment of other HSR routes and the approaches, and mitigation, that have been employed (for example, for HS1 or for other HSR routes).

   The available literature shows that many types of mitigation measures are available and being used to reduce the effects of HSR on the environment, such as earth noise bunds, and wildlife tunnels. It also shows that standards of design are improving, with mitigation measures now being built in at the earliest opportunity.

6) Assess the valuation of environmental impacts of HSR in the supporting documentation.

   Section three provides some commentary on the assessment of environmental impacts of HS2 that has been undertaken to date, but highlights the current lack of detailed information available on environment impacts. Within the extensive literature review no valuations were found of the environmental impacts of other high speed lines.

7) Prepare a SWOT analysis of the sustainability of HSR supported/informed by research into the above objectives.

   The SWOT analysis highlights the various strengths and weaknesses of HS2, in addition to the potential opportunities that will need to be maximised and the threats from HS2 that need to be addressed.

Overall conclusions

4.6 It is concluded that:

1) Research indicates that impacts on the natural environment from High Speed Rail are comparatively fewer than those from new roads schemes but still present significant challenges due to:

   - Landscape impacts caused by land-take, fragmentation and severance, visual intrusion from infrastructure and lighting, loss of tranquillity;
   - Biodiversity impacts caused by land-take, habitat degradation and fragmentation caused by vibration, pollution, noise and the barrier effects of infrastructure, wildlife collisions.

2) Lessons learnt from HS1 indicate that substantial mitigation measures involving design, alignment, planting, habitat creation and species relocation along the length of the route were developed to address some of the most significant landscape and biodiversity impacts.

3) At the time of this research, little available information about the predicted environmental effects of HS2 exists, except that provided within the Non-Technical Summary of the

Appraisal of Sustainability for the first phase of HS2 (March 2010) which acknowledges that the main landscape impact of the scheme will occur in the Chilterns Hills. It is likely that the construction and operation of HS2 will have numerous and varied impacts on the natural environment, which must be avoided, mitigated or compensated through sensitive choice of routing, design, construction methods, train operation and maintenance practices. Some of these impacts will occur regardless of the route, while others will be dependent on the specific route chosen.

4) When the full Appraisal of Sustainability for the revised HS2 route is published, and the Environmental Statement is prepared prior to the Hybrid Bill, more detail will be known about the predicted effects of constructing and operating HS2, but at this stage the full effects of the revised scheme are unknown and cannot be taken into account in the planning and decision-making processes.

5) In identifying a possible route for HSR between London and the Midlands, it is apparent there are a number of compromises: between impacts on the natural environment versus impacts on populated areas; between speed and energy use; and speed and the ability to deviate around sensitive locations, which impacts on journey time and potential modal shift. It is evident that the revised route announced in December 2010 has explored some of these compromises, although further analysis by HS2 Ltd would be needed to identify whether a lower design speed would reduce the impact of HS2 on the natural environment and what the resulting impacts on modal shift and energy use might be.

6) In relation to carbon the study found that the carbon savings forecast for HS2 are very small in comparison with the UK's total transport emissions, so by themselves make very little contribution to overall carbon reduction targets. The majority of forecast carbon savings arise from modal shift from air travel to rail, with the modal shift from road contributing much smaller savings. However, there is a significant range in the estimated values for these savings, which arise chiefly from uncertainties in the extent to which the UK's electricity supply will be decarbonised, and uncertainties about potential 'rebound effects' arising in relation to how aviation and road capacity freed-up by modal shift to rail will be utilised.

7) To maximise the carbon benefits of HS2, significantly greater decarbonisation of the electricity supply will be required than that assumed (conservatively) by HS2 Ltd. The forecast savings will be nearly five times greater if the carbon intensity projections used by the Climate Change Commission are achieved.

8) The funds for HS2 could, of course, be spent on other investments, including but not exclusively, in transport. The study considered whether the other transport options in the HS2 London-Birmingham corridor offer a feasible and realistic alternative to HS2. It was found that none appear to deliver the same level of benefits, for example in terms of capacity and journey times, as HS2 on the proposed alignment. Although the rail-based 'Package 2' option[33] delivers extra capacity for lower cost and less environmental impact.

9) In order to help maximise the benefits of HS2 other supporting measures and interventions would be required to lock in these benefits and encourage the maximum use of the new line and the capacity that would be released by its construction. The study identified a number of these measures, including improving sustainable access to rail stations, providing integrated ticketing for all HS2 journeys, taxation of air travel and road user charging.

[33] Based on those considered in the High Speed 2 Strategic Alternatives Study: Baseline Report, Atkins, March 2010.

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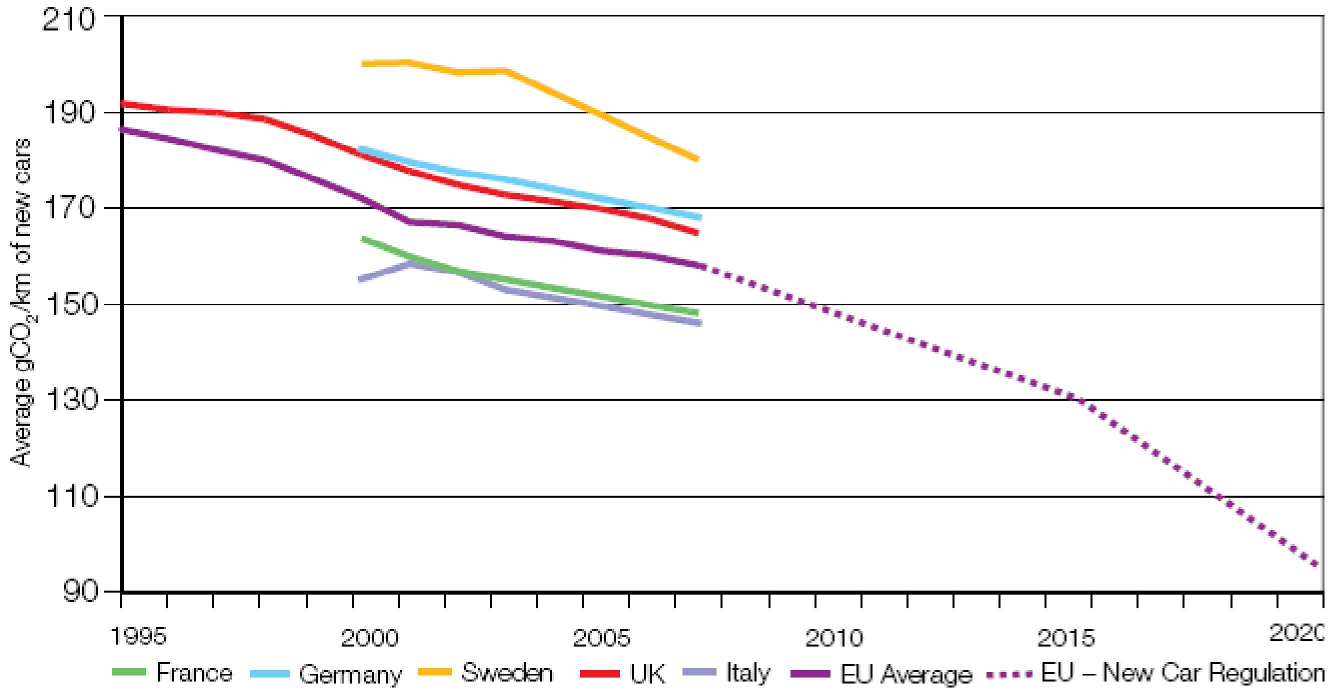
Appendix 1 Vehicle efficiency

Vehicle efficiency in the UK has been improving, with the average CO_2 emissions of new cars declining, as shown in the following graph.



(Source: DfT, 2009a)

Figure A Vehicle efficiency in the UK