The Carbon Impacts of HS2

Interim Report

December 2011

Sponsored by:

Executive Summary

Previous work on the proposed new high-speed railway line High Speed 2 (HS2), has suggested that it would be broadly carbon neutral. This however was based purely on looking at the HS2 project in isolation, and many have suggested that it is important to look at the possible carbon impacts in full. A research study into the potential full carbon impacts of HS2 has therefore been commissioned from Greengauge 21 by the Campaign to Protect Rural England (CPRE), the Campaign for Better Transport (CBT) and the Royal Society for the Protection of Birds (RSPB), and this report sets out the interim findings.

Below we highlight the issues that we have identified as likely to be significant in the carbon case for HS2. In the second phase of the research study, we will model the effects of HS2 on carbon emissions, taking into account knock-on impacts on other modes of transport, and testing the scenarios identified in this report. The final research report, to be published in 2012, will report on this analysis to quantify the key factors that will determine HS2's contribution to reductions in the UK's carbon emissions.

Carbon intensity of fuels and energy sources

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

Energy efficiency of transport vehicles

- Considerable improvements in the energy efficiency of cars are required in the future in order to achieve the targets for reductions in greenhouse gas emissions and this may improve the relative performance of car travel compared with rail or HSR travel.
- Achievement of these car efficiency targets is heavily dependent on the take-up of electric cars and so two scenarios will be assessed in our modelling: one based on achievement of the CCC targets and another based on a slower rate of improvement more in line with current trends.
- Changes in the energy efficiency of HGVs may also be important if HS2 releases any classic rail capacity which is used to provide for more rail freight services, potentially shifting freight from road to rail. The scope for a decarbonised HGV sector is much lower than in the car sector and so modal shift from freight from road to rail will be important to meet carbon reduction targets.

Use of vehicles

- Future oil prices may have a substantial impact on the cost and competitiveness of car and air travel compared with travel by rail and there is a wide range of uncertainty around the future level and volatility of fuel prices. We will examine in our phase 2 modelling the impact of a plausible range of prices.

- A national road pricing scheme for inter-urban roads could potentially alter the competitive balance of road travel vs rail. While there are no plans to develop any schemes at this stage, this may change by the time HS2 is completed and so the potential impact on the case for HSR will be examined.
- Journey times for inter-urban travel will also be affected by the regulation of speed limits. The Government is currently considering raising the motorway speed limit to 80mph, while research has demonstrated the carbon benefits of lower speed limits.

Capacity and location of transport infrastructure

- Land use planning issues potentially have a significant impact on modal split and trip patterns and could impact on the case for HSR both by affecting the density of residential and employment development around HSR stations and by influencing the location of the HSR stations themselves. While these effects are difficult to quantify, it is clearly important that they be considered alongside the other impacts that we are modelling.
- The carbon impacts of HSR will be affected by the impacts on the aviation sector. While HS2 (and future extensions to an even greater extent) will undoubtedly reduce the demand for domestic flights within the UK, the carbon benefits will be affected by the degree to which any airport capacity freed up is used for new long-haul flights, and by the extent to which there is transfer from feeder flights, including via hub airports in NW Europe. We will consider the issue at an international level to understand the potential impact on global emissions.

HSR design and operation

- The embedded carbon in HS2 infrastructure is expected to amount to approximately 1.2 $MtCO_2e$, although there is some uncertainty around this and it is affected by the nature of the route, in particular the amount of tunnels, viaducts and earthworks. Embedded carbon in HSR rolling stock is not expected to be significant.
- The energy consumption of HSR operations is affected by aerodynamic design and the seating capacity of rolling stock; by the application of timetabling margins, driving techniques, stopping patterns and reservation strategy; and by the horizontal and vertical alignment of the infrastructure, and route length.
- Operating speed is a critical determinant of energy consumption. Operating HS2 at a maximum capability 360 km/h rather than 300 km/h (a 20% increase) would consume 23% more energy in actual operation on the London – Birmingham HS2 route, once the impacts of the need to provide a continuous power supply for passenger accommodation (hotel power), acceleration, braking and line speed limitations are taken into account. This is less than a theoretical constant-speed model would predict, which is close to a power square difference.
- The application of an 8% timetabling margin to high-speed services for traction during operations at high speed, as assumed for HS2, would reduce energy consumption by 13-15%.

HS2 and the existing rail network

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

1. Introduction

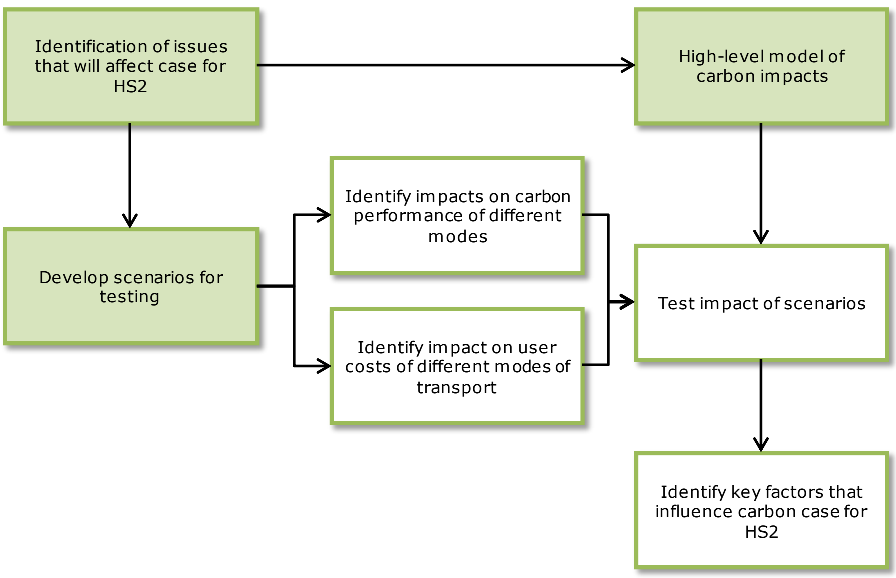
In summer 2011, the Campaign to Protect Rural England (CPRE), the Campaign for Better Transport (CBT) and the Royal Society for the Protection of Birds (RSPB) commissioned Greengauge 21 to carry out research into the potential carbon impacts of the proposed new high-speed railway line High Speed 2 (HS2), the first phase of which will be between London and the West Midlands. Greengauge 21 has in turn commissioned various experts in the environmental and transport fields and coordinated the research programme.

The three sponsoring organisations are all signatories of The Right Lines Charter, which has highlighted the need for high-speed rail "to be planned and justified as a strategic element of a sustainable, near zero carbon transport system'.[1] Together with Greengauge 21, they believe that high-speed rail needs to contribute to reducing the UK's carbon emissions in line with the overall targets in and interim carbon budgets set by the Climate Change Act 2008. Although climate change is a major threat to the protection of landscapes and biodiversity, some measures to reduce emissions may have negative impacts too. Ultimately, all such impacts have to be taken into account.

Some analysis on the potential range of carbon emissions from HS2 has been carried out for HS2 Ltd (the Government company responsible for planning the new line).[2] This found that HS2 would be broadly 'carbon neutral'. However, this analysis looked purely at the building and operation of HS2 itself, without considering other factors. The intention of this new research is to take a broader view.' Specifically, the research examines how net carbon emissions from HS2 will be influenced by both the railway's design, configuration and operation and by the wider policy context. The aim is to identify objectively the key factors that will determine HS2's contribution to reductions in the UK's carbon emissions. While the research and analysis is based primarily on the proposals for HS2 as currently developed by HS2 Ltd (London – West Midlands, including the HS1 link), qualitative consideration is being given to the potential implications of developing a more extensive high-speed network in due course.

The overall approach to the study is illustrated in Figure 1 below.

Figure 1: Study Approach



[1] The Right Lines Charter was launched in April 2011 and thirteen organisations have now signed up to it. It sets out four principles for 'doing High Speed Rail well'. See http://rightlines.org.uk/.

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

To date, phase 1, encompassing the three highlighted stages, has been carried out: the identification of key issues, the development of a model to analyse the impacts of HS2 and the development of scenarios for testing in phase 2 of the study.

This report sets out the interim findings from phase 1 of the research study and highlights issues likely to be significant in the carbon case for HS2. It draws heavily on two reports commissioned so far for the research study and published alongside this report:

- An analysis of the environmental, transport, energy and other policy issues that will influence the carbon case for HS2, both directly and comparatively with respect to other competing modes of transport. This analysis was commissioned from Dr Ian Skinner of Transport and Environmental Policy Research (TEPR) and the key issues highlighted are discussed in Chapter 2;
- An analysis of the energy consumption and carbon performance of high-speed trains and how this varies according to speed, rolling stock design, operating practices and infrastructure configuration. This analysis was carried out by SYSTRA and is discussed in Chapter 3.

One further aspect that has been discussed but, as far as we are aware, not analysed in any great depth, is the carbon impact of capacity released on the existing rail network. This secondary benefit from HS2 would allow additional passenger services or freight services to be operated on existing lines, with consequential benefits in terms of mode shift from cars or lorries. This is particularly important in the UK context given the West Coast Main Line, which will be relieved by HS2, is one of the busiest mixed use railway lines in Europe. The issue is discussed further in Chapter 4. The next steps for the research study are set out in Chapter 5.

The intention is to complete this research and publish the overall findings in 2012. Feedback on this interim report will be welcomed, and in particular on whether there are any significant issues not covered in this report that we should be considering. Responses should be emailed to co-ordinator@greengauge21.net.

This research is being sponsored by Siemens, the Association of Train Operating Companies (ATOC) and SYSTRA, who have provided either funding or an in-kind contribution of resources. Greengauge 21, CPRE, CBT and RSPB thank these sponsors for their generous support.

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

Framework for greenhouse gas reduction

Reducing global greenhouse gas (GHG) emissions is critical in addressing the causes and consequences of climate change, and this is reflected in international, European and national targets. The European Union aims to reduce greenhouse gas emissions by 80-95% by 2050 compared to 1990 levels. In the UK, the ultimate 2050 target of a reduction of at least 80% is now included in the Climate Change Act 2008[3] and the Committee on Climate Change (CCC) advises the UK Government on achieving the target and on setting interim five-year budgets.

Domestic transport in the UK currently represents approximately 21% of total UK greenhouse gas emissions.[4] By 2050, on the basis of what can be achieved in all sectors of the economy, the CCC estimates that an emissions reduction of more than 90% will be needed from surface transport in order to meet the economy-wide 80% reduction target. While greenhouse gas emissions from international aviation are not currently included within the carbon budgets, the CCC has advised Government that it should include these and will advise the Government how this might be done.

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

In order to examine the policies that might have an impact on the CO_2 emissions associated with HS2, Dr Ian Skinner was commissioned to carry out an independent review.[5] As well as providing advice on modelling assumptions that will be used in phase 2 of the study, the report provides a comprehensive review of policies that affect the:

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

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

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

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

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

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

The vast majority of transport fuel used in the UK is derived from oil, i.e. petrol and diesel in road transport, and kerosene in aviation. The main exception is rail transport, which uses electricity as well as diesel. There is also a small amount of biofuels used by road transport (approximately 3%). In the future, it is likely that the use of fuel derived from sources other than oil will increase in the transport sector. In the short to medium term, this is likely to mean increases in the use of

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

biofuels and electricity, while hydrogen is a potential medium to long term option. However, in order for this to contribute to reducing transport's GHG emissions, biofuels need to be environmentally 'sustainable' and electricity and hydrogen needs to be produced from low/very low carbon sources.

Electricity generation

High-speed rail trains will be powered by electric traction and so the carbon intensity of HSR operation will be heavily dependent on the carbon intensity of electricity generation and how this changes over time. Under the CCC's medium abatement scenario (effectively their 'central case') shown in Table 1, the carbon intensity of power generation would reduce from 544 to just 50gCO_2/KWh between 2008 and 2030. This would have a substantial impact on HSR emissions, reducing unit carbon emissions by a factor of 10. This would also improve the carbon performance of private car travel if there is a widespread adoption of electric cars (see section 2b below).

Table 1: Key CCC assumptions for the power sector in economy-wide medium abatement scenario

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

Source: CCC (2010), Table 3.5

However, the CCC notes that its medium abatement scenario 'reflects significantly increased penetration of low-carbon technologies across the economy, which would require technology innovation, cost reduction and policy effort.'[6] In order to reflect this potential risk to achievement of this scenario, in our phase 2 modelling we will also assess the impact of a slower decarbonisation of electricity generation, based on the CCC's low abatement scenario. Given the degree of ambition implicit in the CCC's medium abatement scenario, we will not explicitly assess the impacts of a faster rate of decarbonisation of electricity generation.

Biofuels

The UK and EU are proposing to decarbonise fossil fuels used in car and air transport by relying on an increase in the proportion of biofuels that is blended with such fuels. Under the EU's 2009 Renewable Energy Directive (RED), each Member State has a minimum target of 10% for the proportion of final energy consumption used by transport that should come from renewable resources by 2020. The UK's National Renewable Energy Action Plan[7] illustrates how the transport target could be met: largely through increasing the use of biofuels in transport. However, the more recent Renewable Energy Roadmap takes a more cautious approach to biofuels – noting that the existing RED sustainability criteria do not address some important sustainability concerns, such as carbon and other negative impacts arising from indirect land use change.[8]

While the CCC in its scenarios assumes that biofuels are zero carbon, there are concerns about the potential of biofuels to deliver GHG reductions. Current EU law only requires greenhouse gas savings for biofuels of 35% compared to fossil fuels. In addition, one of the main concerns regarding climate impacts is over indirect land use change (ILUC) effects. First generation biofuels compete directly with land used for food and can therefore drive deforestation directly or indirectly; biofuel crops that can be grown on marginal land may also compromise future food supplies; and technologies to produce other future biofuels (such as those produced from algae) are as yet embryonic and extremely expensive. The European Commission intends to report on a

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

review of ILUC and to make a proposal to amend the Renewable Energy Directive as appropriate, although a proposal has not yet been forthcoming. Another significant concern is a carbon accounting error highlighted by the European Environment Agency earlier this year. The EEA opinion is that burning biomass increases the amount of carbon in the air (in the same way as does burning fossil fuels) 'if harvesting the biomass decreases the amount of carbon stored in plants and soils, or reduces ongoing carbon sequestration'.

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

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

Aviation and non-CO_2 emissions

The effects on non-CO_2 emissions from aviation appears to be significant. A 'comprehensive updated assessment' of the impact of aviation on climate change has suggested that the inclusion of these non-CO_2 elements could double the effect of aviation's impact on climate change.[9] This results from the warming effects of nitrogen oxides at high altitude, water vapour and soot and also contrails produced in certain atmospheric conditions. While there is still some scientific uncertainty over the scale of the effects, we consider it prudent to include this factor in our phase 2 modelling.

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

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

(b) Energy efficiency of transport vehicles

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

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

manufacturers by 2015 and 95gCO_2/km by 2020. There are similar (but somewhat higher) targets for new vans.

Looking further ahead beyond the EU targets, the CCC in its medium abatement scenario for 2030 assumes that the efficiency of conventional cars improves to 80gCO_2/km (although the CCC argues that the UK Government should push for EU targets to be set for 2030 at around 50gCO_2/km).[10] Under the medium abatement scenario, the CCC anticipates that 60% of new cars would need to be electric (accounting for 31% of the total fleet), with 30% being battery electric and the remainder plug-in hybrid. Between 2030 and 2050, the take up of alternatively-fuelled vehicles will depend on the path that has been taken to 2030.

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

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

As yet, there is no EU-level GHG reduction target for HGVs, although standards have been developed and implemented elsewhere, including in Japan and the USA. The CCC believes that the potential for widespread use of electric HGVs is limited and therefore notes that biofuels might be considered appropriate to decarbonise HGVs (but note the issues discussed in section 2a above). However, the CCC's medium abatement scenario assumes a 15-30% efficiency improvement for conventional trucks between 2020 and 2030. This reduces CO_2 emissions from the average new conventional HGV from 799gCO_2/km in 2008 to 750gCO_2/km in 2020, to 600gCO_2/km in 2025 and 580gCO_2/km in 2030.[11] In the long run, it is considered possible that HGVs could run on low carbon hydrogen, with any residual need for liquid fuels (e.g. for plug-in cars, non hydrogen HGVs) coming from biofuels.[12]

Key findings so far: energy efficiency of transport vehicles

- Considerable improvements in the energy efficiency of cars are required in the future in order to achieve the targets for reductions in greenhouse gas emissions and this may improve the relative performance of car travel compared with rail or HSR travel.
- Achievement of these car efficiency targets is heavily dependent on the take-up of electric cars and so two scenarios will be assessed in our modelling: one based on achievement of the CCC targets and another based on a slower rate of improvement more in line with current trends.
- Changes in the energy efficiency of HGVs may also be important if HS2 releases any classic rail capacity which is used to provide for more rail freight services, potentially shifting freight from road to rail. The scope for a decarbonised HGV sector is much lower than in the car sector and so modal shift from freight to rail will be important to meet carbon reduction targets.

(c) Use of vehicles

Policies or factors that affect the ways in which vehicles are used will influence the carbon impact of HSR through influencing the shift of passengers from road- or air-based transport to rail. There

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

are a number of potential policy options that could influence the way in which vehicles are used and hence could change transport's CO_2 emissions. These might include:

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

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

Oil prices

Perhaps the most significant factor that has the potential to influence road and air travel substantially is that of oil prices (or fuel prices for road use), given that there is a general expectation of continued increases in prices over time as available supplies become more difficult to extract. For example, the Department of Energy and Climate Change (DECC) assumes in its central scenario that oil prices will rise from \$81/barrel in 2010 to \$118/barrel in 2020 and \$128/barrel in 2030 (in 2011 prices).[13] DECC's high price scenario sees oil prices rising to \$168/barrel in 2030. These prices appear to be higher than those assumed by the Department for Transport (DfT), which were based on earlier DECC forecasts. There are other projections available internationally, which tend to be more in line with the recent DECC projections. However, there is clearly a great deal of uncertainty over future oil prices and their impacts on the costs faced by car and air users. Higher oil prices could reduce the demand for car and air travel and hence would have an impact on the mode shift and consequential carbon benefits of HSR travel. We will therefore examine how a wide range of oil prices influences the carbon impacts of HSR.

Road pricing

While the current UK Coalition Government is not considering a national road pricing scheme for cars on existing roads, or even making any preparations for such as scheme in the lifetime of the current Parliament, road pricing could have a substantial impact on the cost of motoring and on the balance of supply and demand on the strategic highway network. This would influence how well HSR services can compete with road travel and so we consider it would be informative to understand the potential impacts of road pricing. There is an analytical challenge in that there is no accepted national road pricing scheme to evaluate and the effects will vary depending on the precise mechanisms of any scheme, but we will draw on existing work to consider the possible impacts. The CCC notes that road pricing, if introduced in addition to existing fuel duty, could result in significant greenhouse gas emissions reductions, mainly from a reduction in distances travelled, but others have suggested the need for tax-offsets to address distributional impacts.

Motorway speed limits

The other policy that we will examine is speed limits on trunk roads, which affects fuel consumption and journey times by road. Tests carried out for the European Environment Agency

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

have estimated that a reduction in speed limits from 75mph to 68mph could theoretically deliver fuel savings for car travel of between 12% and 18%, although only 2-3% under more realistic assumptions. While reducing speed limits would improve the carbon case of car travel relative to rail travel, it would also increase journey times for car trips and make HSR relatively more attractive. Conversely, if speed limits were raised, car journey times would decrease and the relative journey time advantage of HSR would be reduced. The Government has announced that it intends to launch a consultation on the possibility of increasing the speed limits on motorways to 80mph.[14]

Key findings so far: use of vehicles

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

(d) Capacity and location of transport infrastructure

Land use planning policy

The importance of integrated land use planning and transport policy in contributing to reduced CO_2 emissions from transport has been highlighted by the CCC, recommending the development of integrated land use and transport planning strategies. Experts consider that land use policy would be most favourable to reducing CO_2 emissions if it favoured higher densities, active and attractive local communities, with amenities within walking distance, and which were well served by public transport. Additionally, urban brown field development would be favoured over ex-urban green field development.[15] This applies to new high-speed rail stations, which have the potential to promote sustainable land use patterns if they are located where they can stimulate brownfield regeneration and be accessed by public transport, walking and cycling, thereby avoiding new sprawling development and the generation of new car trips.

Research on international high-speed rail experience[16] has highlighted the importance of planning for good linkages between HSR and local transport systems, particularly public transport networks, and for high-speed rail stations to provide for effective access to HSR services. This will help to ensure that the whole 'door-to-door' journey takes place on sustainable modes of transport. Integrated land use and transport planning can therefore be used to maximise high-speed rail demand, the consequential economic development benefits and the carbon savings arising from mode shift.

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

[15] Goodwin, P (2009) Report of CCC Expert Workshop *Land Use Aspects of Transport's Contribution to Climate Change*; see http://downloads.theccc.org.uk/CCC_land_use_transport_report.pdf

Green Balance (2011) *Building in a small island? Why we still need a brownfield first approach*, produced for CPRE; see http://www.cpre.org.uk/resources/housing-and-planning/planning/item/download/1503

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

In response to the Government's 2011 consultation on its draft National Planning Policy Framework (NPPF), a number of transport organisations have called for the reduction of GHG emissions and the promotion of a low carbon economy to be one of the core principles and objectives for the framework.[17] CPRE has called for 'smart growth' to be promoted in the NPPF, in order to focus development where there are the highest levels of accessibility by sustainable modes of transport, and also for the better integration of land use and transport planning.[18] The draft framework contains a presumption in favour of development (with some protections) and weakens the town centre first policy contained in previous planning guidance. If followed through, this is likely to impact on the demand for public transport, including HSR demand, by reducing the proportion of development built in places well served by public transport, and could increase the demand for car travel. In phase 2 of this study we will therefore examine the differences between a land-use planning approach based on NPPF principles compared with an approach based on retention of brownfield-first approach to land release with a prioritisation around public transport nodes and industrial areas well served by rail and water transport.

Airport capacity

The other key transport infrastructure factor that will affect net HSR carbon emissions is that of airport capacity. The main UK airports in the South East are at or near capacity and given that the Coalition Government has no plans to allow for additional runways at Heathrow, Gatwick or Stansted airports, it appears that there will be no immediate expansion of airport capacity in South East England. While HSR has the scope – particularly when HS2 is connected direct to Heathrow and also expanded northwards beyond the West Midlands – to reduce domestic air travel, it has been pointed out that this would result in carbon savings only if any airport slots freed up by reduced domestic flights remain unused.[19]

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

Key findings so far: capacity and location of transport infrastructure

- Land use planning issues can have a significant impact on modal split and trip patterns and could impact on the case for HSR both by affecting the density of residential and employment development around HSR stations and by influencing the location of the HSR stations themselves. While these effects are difficult to quantify, it is clearly important that they be considered alongside the other impacts that we are modelling.
- The carbon impacts of HSR will be affected by the impacts on the aviation sector. While HS2 (and future extensions to an even greater extent) will undoubtedly reduce the demand for domestic flights within the UK, the carbon benefits will be affected by the degree to which any airport capacity freed up is used for new long-haul flights, and by the extent to which there is transfer from feeder flights, including via hub airports in NW Europe. We will consider the issue at an international level to understand the potential impact on global emissions.

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

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

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

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

Overview

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

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

The majority of emissions over its lifetime arise from train operations, so while we consider embedded emissions below, the review we commissioned from SYSTRA[20] focused on identifying and quantifying the key factors that influence operational emissions from high-speed rail, and we cover that aspect at greater length. In particular, the review by SYSTRA considers the relationship between carbon emissions and HSR speeds. In phase 2 of this study, we will use the SYSTRA analysis as inputs into our modelling of the operational carbon emissions from HS2. This will also incorporate the impacts of passengers shifting from other modes of transport and the different scenarios which will influence the extent to which this occurs, reflecting the issues discussed in Chapter 2.

Embedded carbon

A comprehensive assessment of the embedded carbon of HS2 was carried out by Booz & Co and Temple Group for HS2 Ltd,[21] taking into account 'the carbon emissions associated with construction operations such as constructing the rail infrastructure and trains, as well as the embedded energy within the bulk construction materials'. This assessment reached the following conclusions:

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

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

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

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

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

Operational carbon

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

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

The factors that influence the energy consumption of HSR operations can be grouped into three categories: rolling stock design, operational strategy and infrastructure design. The key factors are highlighted below in Table 2. The relationship between speed and energy consumption is discussed separately in the next section.

Table 2: Factors that influence the energy consumption (per seat or per passenger) from HSR operations

Factor	Explanation	Effect
Rolling stock design		
Aerodynamics	High-speed rolling stock offers less air resistance than conventional trains by appropriate design that shapes the front and rear of the train, ensures doors, windows etc are flush with walls, provides rounded outer surfaces and streamlined protection on equipment.[22] Aerodynamic design can also mitigate the air resistance impacts of double-deck trains.	TGV trains in France offer 35% less air resistance than a conventional train.[1] TGV Duplex (double deck) only offers 5% more air resistance than TGV-R (single deck).[2]
Seating capacity	The larger the seating capacity, the lower the energy consumption per seat-km. Seating capacity is influenced by the factors below:	
	i. Train width – making best use of the available loading gauge available on new infrastructure.	HS2 'captive' trains will be able to make use of the European gauge infrastructure.
	ii. Train length – air resistance increases less than proportionally with train length.	When two 200m-long trainsets are combined, energy per seat reduces by 3-4% compared with one 200m-long trainset.[3]
	iii. Distributed traction – with motors under each car rather than in separate power cars, passenger seating can be provided in the end cars that would otherwise be dedicated power cars.	ICE3 trains with distributed traction offer the best seating ratios.[4]
Operational strategy		
Timetabling margins	It is recommended operational practice to apply timetabling margins to HSR services and the most energy-efficient way to apply these margins is to reduce cruising speed (but maintain maximum acceleration). HS2 Ltd assume an 8% margin is applied in this way, so that with a maximum line speed of 360 km/h, the actual average cruising speed of trains will be no higher than 330 km/h.	13-15% less energy is needed to maintain velocity for a given distance if trains run at 92% of maximum speed as is assumed for HS2.[5]
Eco-driving	Adjustment of driving speed according to gradients can reduce energy consumption.	Optimised operating speeds could result in 11-13% reductions in energy consumption on HS2.[6]

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

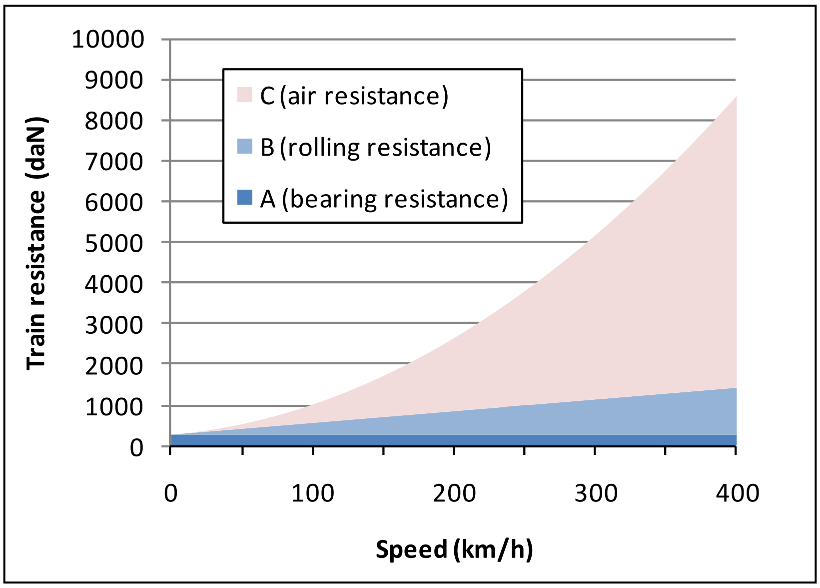
Factor	Explanation	Effect
Stopping patterns	Intermediate stops increase overall energy consumption and so point-to-point services are more efficient.	An intermediate stop (say, midway between London and Birmingham) can result in additional energy consumption of 2-4%.[7]
Booking reservation strategy	Higher occupancy rates reduce average energy consumption per passenger and this can be encouraged by reservation-only booking strategies. This is still compatible with turn-up-and-go systems as long as the booking system allows last minute reservations.	Bookings are compulsory on Eurostar and on French TGV services which achieve 70% load factors. Contrast with German ICE services which do not require advance booking and which only achieve 50% loadings on average.[8]
Infrastructure design		
Horizontal and vertical alignment	The configuration of high-speed rail infrastructure impacts on energy consumption, principally by the factors below:	
	i. Gradients – uphill gradients increase resistance proportional to train mass and the gradient. This can be relieved by eco-driving (see above).	
	ii. Curves – increase mechanical resistance (and hence energy consumption), so large curve radii minimise the impacts.	
	iii. Tunnels – increase energy consumption compared with open line because of greater air resistance, although the effects are reduced for tunnels with wider diameters.	At 320 km/h a (notional) 10km tunnel could increase energy consumption by 65-157 kWh depending on tunnel diameter.[9]
Route length	High-speed railways will tend to be shorter than conventional railways because of the avoidance of intermediate stations, large curve radii and higher gradients.	The Paris-Lyon high-speed line is 16% shorter than the conventional line.[10]
Integration of green energy sources	Rail-specific green energy sources can be built into infrastructure projects, delivering renewable energy.	A Belgian high-speed rail tunnel is topped with 16,000 solar panels, sufficient to power Belgium's trains for one day/year.[11]

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

Energy consumption and speeds

The energy needed to operate a train at any given speed is determined by the degree of train resistance that it has to overcome, which is affected by air resistance, bearing resistance (caused by friction within a vehicle's wheel bearings), rolling friction and other factors such as flange friction and the effects of sway. These elements vary according to train weight and operating speed. As Figure 2 shows, at high speeds, air resistance provides the majority of resistance and this element is proportional to the square of speed.

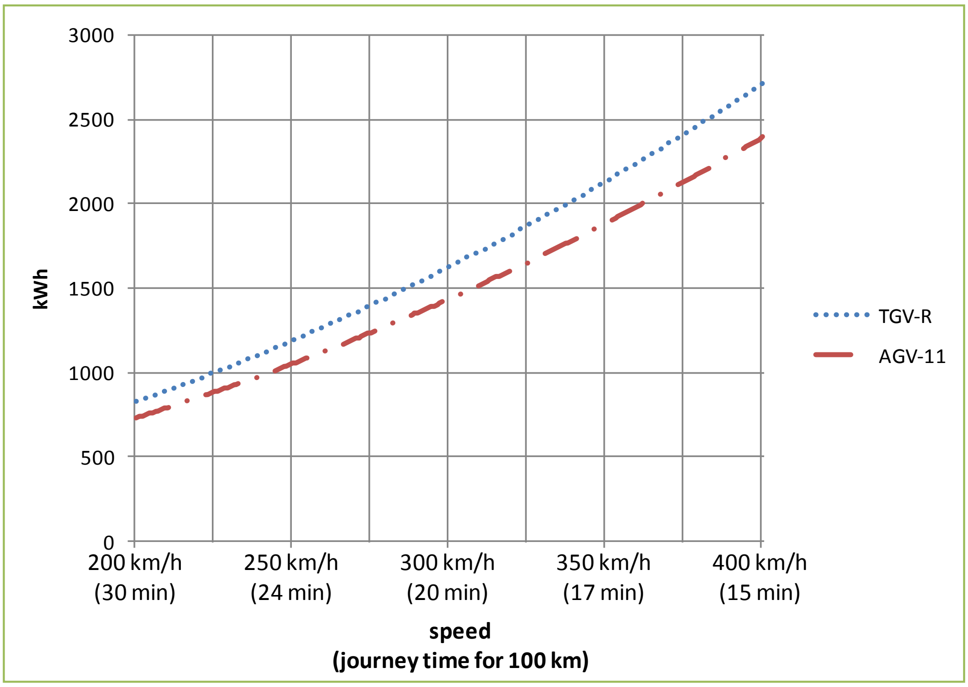
Figure 2: Contribution of bearing, rolling and air resistance to overall resistance of an AGV-11 at different speeds



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

Figure 3 shows the energy needed to operate two existing types of high-speed train over 100km at different constant speeds. As can be seen, the newer AGV train is 12% more efficient than the TGV-R train (the primary difference being that the AGV has distributed traction). For both trains, continuous operation at 360 km/h uses 38% more energy than at 300 km/h.

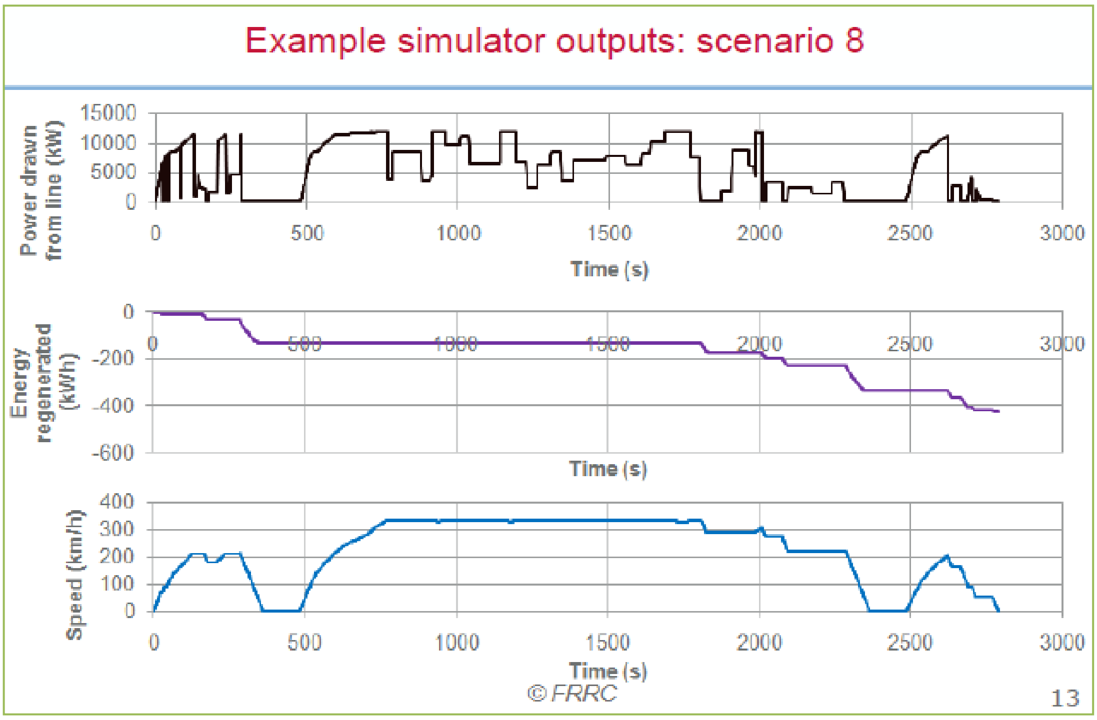
Figure 3: Energy to overcome resistance for a 100-km journey for different speeds/journey times



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

The estimates in Figure 3 show the theoretical effects of operation over 100km at a constant speed, but they do not take into account the effects of acceleration, regenerative braking, hotel power[23] and the impact of line speed limitations. In reality, these impacts also affect energy consumption. For example, Figure 4 shows the results of traction modelling carried out by Imperial College for HS2 Ltd of high-speed services on the London Euston to Birmingham Curzon Street HS2 route. The effect of station calls at both Old Oak Common Interchange and Birmingham Interchange stations, together with the sections of route with line speeds below the maximum (and in this example, 'optimised' operating speeds) means that an HS2 train would be operating at top speed for less than half of its overall journey time. As the top graph of Figure 4 shows, there are sections of the journey with very low power draw.

Figure 4: London – Birmingham traction energy simulation
(Two intermediate stops, 200m-long train, 70% load factor, optimised line speeds)



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

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

Key findings so far: HSR design and operation

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

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

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

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

Overview

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

Greengauge 21 previously published a proposition for 'Capturing the benefits of HS2 on existing lines',[24] which set out a potential post-HS2 WCML timetable. This exercise focused on the potential for improved regular interval passenger services between London and the West Midlands, while providing capacity for some growth in freight. Network Rail and Passenger Focus have since been asked by DfT to develop a post-HS2 timetable, but this work is not due to be complete until Spring 2012.

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

The benefits of expanded passenger rail services

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

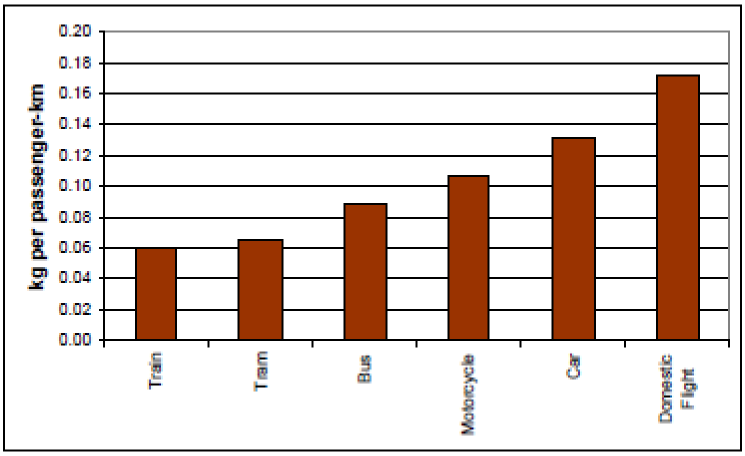
Moreover, a set of wider network opportunities can be opened up by freeing up WCML capacity – to improve the feasibility of the East West Rail link, or new services to re-opened stations, such as Kenilworth.

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

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

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

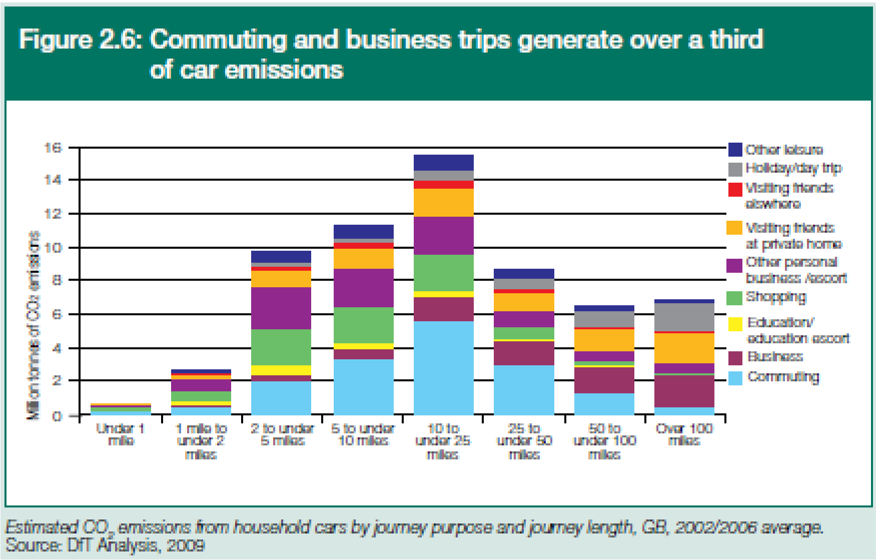
Figure 5: CO_2 emissions by transport mode, 2008



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

The potential for mode shift arising from expanded conventional rail passenger services will be particularly valuable considering the types of journeys that improved WCML services could be targeting. Figure 6, extracted from DfT's 2009 Low Carbon Transport strategy[25], illustrates that 25% of car emissions arise from trips of 10-25 miles and another 14% from trips of 25 to 50 miles. Many of these trips are for commuting or business. These types of trips are those that can readily be targeted by improved local, commuter and regional rail services on the WCML, once capacity has been freed by HS2.

Figure 6: Car emissions by journey length and purpose, 2002/2006



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

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

Rail freight

The West Coast Main Line is the busiest long distance route for rail freight in the UK and providing additional capacity released via HS2 will be of considerable value. Forecasts recently produced for the Rail Freight Group indicate that rail freight in terms of tonne-km lifted will increase by between 90% and 105% by 2030, depending on future increases in productivity.[26] This suggests that train-km per weekday will increase by 93-121% over the same period. A major contributor will be the 'gateway' flows in the South East through the major deep sea ports and to a lesser extent the Channel Tunnel. The forecasts do not include any explicit changes in road costs such as lorry road user charging.

The impacts of this traffic growth on the West Coast Main Line will be substantial. At the southern end, the RFG estimates that the number of weekday trains will double from 65 to 132 per day, with even higher growth at the northern end of the route. By 2030, the RFG estimate that freight will need six paths an hour in each direction on the WCML, more than double today's provision. If this freight does not travel by rail it is estimated that 200 trucks per hour would be added to the road network (the M40, M1 and parallel A roads), increasing CO_2 emissions by 500,000 tonnes annually.[27] The correspondence between the freight that can be carried by train and the equivalent number of HGVs is shown in Table 3.

Table 3: Potential for a fully loaded freight train to remove lorries

Commodity	Fully loaded train potential	Equivalent number of heavy goods vehicles[1]
Coal	1,500 tonnes	52
Metals and ore	1,000 to 2,500 tonnes	60
Construction materials	1,500 to 3,000 tonnes	77
Oil and petroleum	2,000 tonnes	69
Consumer goods	600 to 1,100 tonnes	43
Other traffic	1,000 to 1,500 tonnes	43

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

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

Key findings so far: HS2 and the existing rail network

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

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

5. Next steps

Scenarios for analysis

The review of policy issues, HSR performance and impacts on the classic rail network carried out so far has highlighted a number of factors that we wish to examine further, in order to understand their impact on the carbon impacts of HSR:

- **Policy issues:**
    - The decarbonisation of electricity generation
    - The carbon impact of biofuels and unconventional sources of oil
    - The energy efficiency of road vehicles
    - A wider range of oil prices
    - The likely effects of a national road pricing scheme
    - Changes to motorway speed limits
    - The influence of land use planning policy
    - Airport capacity
- **HSR performance**
    - The impact of different operating speeds
- **Impacts on the conventional rail network**
    - Re-use of liberated capacity for passenger rail services
    - Re-use of liberated capacity for freight services.

Analysis of carbon impacts

In phase 2 of the study we will use the advice provided by Dr Ian Skinner and by SYSTRA to populate our model of the carbon impacts of HSR. This incorporates not only the carbon emissions from HSR operations but also the carbon savings arising from passengers shifting from other modes of transport. It also needs to take into account secondary mode shift effects that will arise when conventional rail services are reconfigured in order to provide more effective local passenger services or expanded freight capacity.

The model will then be used to test the impact of the scenarios described above, where possible. We may not be able to quantify each of these, but the likely carbon impacts on HSR will be identified and described. The modelling and analysis will allow us to identify the policy measures that will have the most impact on the carbon emissions for HSR.

This analysis will be reported in our final report to be published in 2012.