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High Speed Rail: Implications for carbon emissions and biodiversity

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Abstract

Rail has traditionally been seen as 'good' for the environment, as it is fast and efficient with a low carbon footprint. With respect to HS2 in the UK, new environmental debates have arisen over the competing global objectives of reducing the carbon footprint of HSR and the need to maintain and enhance local biodiversity and habitat. This paper identifies, measures and comments on the longer term environmental consequences of major infrastructure decisions that have to be made today. Short term pragmatism is seen as the means by which these decisions are made, and this results in issues relating to the complexity and uncertainty in assessing future impacts being relegated to a secondary level of importance. Mitigation measures (and not alternative routes) are discussed, and the legacy value of HSR to future generations is based on notions of short term mobility and economic growth, and not on the lower levels of carbon emissions and biodiversity loss.

Keywords: high-speed rail; transport; assessment; biodiversity;carbon

1. Introduction

High-Speed 2 (HS2) is a £55 Billion (2017 prices) high speed rail (HSR) project designed to connect London to Birmingham in the West Midlands, with further extensions to Manchester, Sheffield and Leeds in the North of the United Kingdom. It is the result of a long and debated strategic process of revitalising the rail network in the UK (Table 1). The Eddington Report of 2006 provides a good starting point, as it was about this time that a serious debate began to take place over the construction of a new HSR in the UK and the long term links between economic growth and wider development goals. It concluded that in the UK context of a compact economic geography, competing transport demands and an overloaded transport system, "ambitions and dreams of extensive new networks" should be put on hold (Paras I51 and I76-7 [1]). The Report also showed concern for the environmental consequences of "excessive provision" in meeting unconstrained demand (Para I.3). Referring explicitly to the Stern report for the role of transport in emissions of greenhouse gases, and with regard to HSR more specifically, the Report openly questioned the "assumption that more and faster are always better" (Paras I.3 and I.50).

However, in 2008 the House of Commons Transport Committee concluded that ruling out HSR restricted future options, given the relatively low marginal costs of higher speeds, and the expected potential for HSR to improve capacity and reliability of the existing network. Because the planning process would likely take decades, there was a need to act to avoid "years of avoidable misery and overcrowding on the network" (paras 28 and 27 [2]). Since that time, there has been a slow build-up of political support for HS2, even though there has been substantial criticism over the appraisal process and the failure to consider all benefits and costs, with many reassessments. Cost-Benefit Analysis has been heavily criticised, both with the cost analysis and the benefit estimation, initially in terms of time savings, then in terms of additional capacity, and finally the connectivity of the rail system. The Wider Economic Impacts (WEIs) were seen as being central to the debate, as were the high levels of business travel and the assumption that time spent travelling on HSR would have no value [3]. In addition to the economic analysis, there has been much debate over environmental issues, with the promoters of the HS2 proposal producing one of the largest environmental assessments ever carried out on a transport project, extending to about 50,000 pages.

Two environmental issues form the central part of this paper, namely the carbon footprint created by HSR and the local environmental issues concerning the loss of biodiversity and habitat. The complex dependencies between these two issues illustrate the difficulties of seeing a clear pathway through the different controversies in the debates about HS2. The paper has a short review section and an outline of the approach taken. It then focuses on two case studies, before presenting the results as a series of choices that have to weigh local environmental benefits from increasing tunnelling and remediation against the additional costs and carbon that this would produce. The final section attempts to bring together an overall perspective on the sustainability of HS2. Even within the environmental debate, it will be shown that there are difficult and conflicting decisions to be taken with respect to global (carbon dioxide) and local issues (habitat protection).

2. Background to HS2

The London to Birmingham line is 221 km in length, with further extensions from Birmingham to Manchester (150 km), and from Birmingham to Leeds (185 km). Construction on Phase 1 will start in 2017, and it will run between London and Birmingham, opening in 2026; and Phase 2: links Birmingham to Manchester and Leeds will open in 2033. The total length of HS2 would be about 530 km.

More than half the Phase 1 route will be in cuttings or tunnels; this means that about 90 km of Phase 1 will be partially or totally hidden in cuttings to reduce visual effects and noise. For example, in the Chilterns Area of Outstanding Natural Beauty (AONB) over 18 km of the Phase 1 route will be in tunnels, green tunnels or cuttings, with just over 2 km of the line on the surface.

Figure 1: Existing (HS1) and planned (HS2) alignments of High Speed Rail in the UK. Sources: Butcher [4], DfT [5], DfT [6] and other sources

Legislation has now completed its passage through Parliament as a Hybrid Bill – submitted in November 2013 and completed in February 2017. The project will be publicly funded and the total cost of Phase 1 will be £15.6B, with a contingency of £5.8B and a total budget of £21.4B – Phase 2 will cost £12.5B, with a contingency of £8.76B and a total budget of £21.2B. There will also be £7.5B spent on new rolling stock. This overall figure has now risen from £50.1B (2013) to £55.7B (2017), and the Benefit Cost Ratios are given in Table 1.

Table 1: BC Ratios of the HS2 proposals.

Benefit Cost Ratio - Phase 1 (with WEIs)	1.4 (1.7)	
Benefit Cost Ratio - Phase 1+2 (with WEIs)	1.8 (2.3)	
Breakdown of the benefits of the proposed HS2 scheme	Phase 1	Phase 1+2
Time savings	17,334	45,679
Crowding benefits	4,068	7,514
Improved reliability	2,624	5,496
Car user benefits	568	1,162
Total transport user benefits	**24,594**	**59,852**
Wider economic impacts (WEIs)	4,341	13,293
Other impacts	407	788
Loss to Government of indirect tax	-1,208	-2,912
TOTAL – all prices in £M present values (2011)	**28,134**	**71,020**

Notes: The BCR ratios used are the latest ones from DfT [6], and the ones used in the text come from Castles and Parish [3], and are based on DfT [5] and other reports available at that time.

3. Review and Approach

Traditionally, rail has been seen as being ‘good’ for the environment, as it provides an efficient and fast form of transport, with high load factors [7], [8]. It has normally had the support of environmental groups for these reasons, but this unanimity among the different environmental groups has substantially weakened with respect to the HSR debate, as the energy requirements increase with speed, and consequentially the CO2 emissions factors also increase, given the high carbon content of the energy mix in the UK. But not all environmental groups are concerned about the global issues of greenhouse gas emissions, and many are more concerned about the local issues of protecting their environment. Included here is the impact of HSR on the natural environment (e.g. landscape, cultural heritage, biodiversity, water resources and flooding), as well as on their own communities (e.g. air quality, noise and vibration, health and wellbeing) and the use of resources more generally (e.g. land resources, waste and the use of materials).The construction of new rail infrastructure (tunnelling and track) has high carbon costs that may affect the global climate for future generations, but equally the destruction of local environment (woods, habitat and biodiversity) may affect the quality and diversity of their local environment. The purpose of this paper is to highlight the longer-term consequences of some of these choices on future generations. Climate change and biosphere integrity are core planetary boundaries[9], [10]. Significantly altering either of these core boundaries could shift the Earth System to a new state with potentially considerable consequences for humans [11]. Therefore climate change and biosphere integrity are taken here to illustrate the environmental choices that need to be made with respect to HS2. The question addressed here is whether the investment decision has effectively considered these two planetary boundaries.

3.1. Sustainable Transport Assessment

Ever since the growth of environmental awareness in the 1960s, there has been a long tradition for relatively comprehensive transport assessment procedures in the UK. A first milestone is the Buchanan Report (1963) which prescribed a new and more environmentally sensitive approach to traffic planning and, together with the Beeching Report of the same year, introduced the concept of minimum environmental standards [12], [13]. Concerned with the maintenance of good environmental conditions despite expected traffic volumes, Buchanan introduced methods for estimating environmental capacity and the idea of satisfying environmental norms as an absolute requirement. Fast forward to 1997, a transport white paper set a ‘new deal’ for “safe, efficient, clean and fair” transportation, based on supporting sustainable development goals [14]. The white paper also introduced multi-criteria decision analysis (MCDA) framework in its New Approach to Appraisal (NATA). This was to become the basis for today’s web-based Transport Appraisal Guidance (WebTAG) that is central to all evaluation in the UK.

Climate change and biosphere integrity are two long-term threats that are more difficult to include in short-term impact assessment (IA). Recent research has highlighted how ambitious high level climate goals in the UK are largely symbolic when looking at their implementation in the transport sector. This limitation is said to be due to the lack of clear targets and accountability at departmental and local level [15]. Similar conclusions are echoed in the environmental assessment literature: “most impact assessment has sustainable development as the stated goal, but it doesn’t deliver sustainable outcomes”[16]. Others have attributed this to the very technical-rationalist model of environmental impact assessments (EIA), calling for strategic environmental assessments (SEA) that would take an advocacy role for sustainability, rather than the narrow concept of SEA usually found in EIA-based approaches [17].

This raises questions about the effectiveness of the UK transport appraisal framework presented above, which will be shortly discussed in the final part of this paper, after the two cases of carbon and biodiversity impacts for HS2 have been presented.

3.2. Data and timeline

One characteristic of the UK appraisal process for HS2 is the vast amount of readily available material: official appraisal guidance, environmental assessments, reports from parliamentary committees, the Government responses to these reports, transcripts of oral and written evidence presented during the consultations, petitions, official correspondence and speeches, etc. are available online and easily searchable, all from one single site (GOV.uk). As per the Aarhus convention, stakeholder involvement in the form of public consultations (and later petitioning) were carried out at various stages, with a number of parliamentary committees mandated to examine HSR strategy or HS2 plans at various points in time (Table 2).

Therefore the analysis carried in this research focuses more specifically on these (rather voluminous) proceedings and the assessment material produced by HS2 Limited (the entity created by the Department for Transport to manage the HS2 project), and does not rely on primary data such as interviews. Complementing this, a large number of reports from various governmental, non-governmental, academic, and corporate entities were also collected and studied. For example, the Chilterns material draws from a variety of external sources, ranging from institutions mandated by parliament such as Natural England and The Chilterns Conservation Board, as well as non-governmental organisations and charities such as the Campaign to Protect Rural England.

Table 2: HS2 phase I main appraisal documents and timeline

Type of documents	Release date	References used in this paper
HS2 Phase I official appraisal documentation		
Appraisal of Sustainability (AoS)	February 2011	[18]–[21]
Environmental Statement (ES)	November 2013	[22]–[33]
- Chilterns data		[34]–[39]
HS2 Phase I parliamentary committees and evidence from consultations		
House of Commons Transport Committee (HC 1185)	November 2011	[40], [41]
House of Commons Environmental Audit Committee (HC 1076)	April 2014	[42], [43]
House of Lords Economic Affairs Committee (HL 134)	March 2015	[44]
House of Commons High Speed Rail Bill Select Committee (HC 338)	July 2015 (preliminary)	[45]–[47]

4. HS2 and Carbon

The UK Government is committed to making an 80 percent reduction in net UK carbon emissions, covering all six Kyoto greenhouse gases[1] by 2050 (on 1990 levels), meaning that the total levels of emissions will have to fall from 809.4 Mt CO2e (1990) to 161.9 Mt CO2e (2050). Good progress has been made, as the current level is 520.5 Mt CO2e (2014), a reduction of 36 percent over 24 years, but the next steps are crucial, and all major energy intensive decisions, including large scale infrastructure projects, need to contribute to this carbon reduction target (Table 3 [48]). Transport is the one sector where CO2 emissions dominate and it has proved difficult and costly to reduce emissions levels – these have remained almost unchanged over the 24 years (Transport CO2 emissions are 116.9 Mt CO2e in 2014).

The carbon issue with respect to HS2 has not featured prominently in the debate, and HS2 Ltd as the main promoter of the project has remained rather ambivalent on the issue [49], as their Sustainability Policy states the aim is to "minimize the carbon footprint of HS2 as far as practicable and deliver low carbon long distance journeys that are supported by low carbon energy". Part of the case is strong, as rail overall is a relatively small contributor to carbon emissions in terms of the operation of transport systems (4.4 Mt CO2e per annum, or about 0.8 percent of all emissions), and even within the transport sector, this figure amounts to 3.26 percent. Rail is also (rightly) seen as being more efficient than travelling by car and air over the same distances, and over time the carbon profile of rail will improve as power generation is decarbonized. If HS2 was available today, it is estimated that carbon emissions from a trip by HSR would be 73% lower than making the equivalent journey by car [50].

HS2 has carried out a considerable amount of research into the measurement of carbon and their key conclusions are summarised in Table 3, where two Scenarios were used to frame the calculations over the 60 year operating assessment period. As can be seen from this Table, a substantial saving in CO2 will be made through the decarbonisation of the energy sector, as shown in Scenario B where there is substantial new investment in 'clean' energy. The benefits result from the switching of car users and air passengers to the HSR, but there are a series of important, yet unresolved issues here, including the assumptions around the nature and scale of the modal shift, the time over which the assumed benefits will accrue, and the embedded carbon in the construction of the HSR.

Table 3: Based on Table 1 in Temple-ERM [51] and other information.
Note: Tree planting includes 4 million trees split equally between the two Phases

Emissions Source	**Scenario A** (Mt CO_2e)	**Scenario B** (Mt CO2e)
Operational emissions	+5.27	+2.15
Modal shift emissions	-10.49	-8.21
Freight uptake of released capacity	-3.25	-3.25
Carbon sequestration from tree planting	-1.00	-1.00
Scenario A: This is based on the Economic Case for HS2, using the emissions factors for the different modes of travel, distance and mix.	**Scenario B**: This uses the assumptions in the 4th Carbon Budget [52] – this is more ambitious in the future reductions in carbon from the decarbonisation of the power sector and greater take-up of clean vehicle technology.	

[1] The six greenhouse gases (GHG) are carbon dioxide, methane, nitrous oxide, hydro-fluorocarbons, perfluorocarbons and sulphur hexafluoride. Note that in the UK most reductions have taken place in the 5 GHGs (excluding CO2) – a reduction of 55 percent (1990-2014). CO2 has reduced by 30 percent (1990-2014).

4.1. Modal Shift

Firstly, almost all the air passengers will switch only when the full system is opened (2033), and that the CO_2 savings for air travel from Phase 1 are negligible, as no one flies from Birmingham to London [50]. So the full carbon savings (Table 3) from the modal shift will only materialise if and when the whole system is completed. These modal shift 'benefits' seem to account for about two thirds of all the carbon 'savings'. Secondly, there is the issue about how the released capacity will be used (the air slots and the take-up of the released road capacity by both cars and freight), but this is not addressed, and HS2's response has been that this is a commercial decision of private companies (para 6.10 [49]) and not the responsibility of HS2. So HS2 have only looked at potential carbon savings from rail, and not the wider net contribution to UK targets.

Related to this is a third issue, namely that accessibility to HS2 deteriorates with the limited number of access points and as a consequence overall journey distances (and carbon emissions) are likely to be longer (higher). For example, Martínez Sánchez-Mateos and Givoni [53] used travel time to London as the main benchmark to measure accessibility of a station on the current (conventional) and future (high-speed) rail networks, and they examined the likely winners and losers from the construction of the HSR. They concluded that the accessibility benefits from the HSR are relatively limited in terms of geographic spread, and that many cities close to the line would not see any travel time reductions on journeys to London. It is the door-to-door journey time that is important to travellers, and not only the high speed part of that journey. This has implications in terms of use of the HSR and the overall carbon emissions for the total journey. More generally, there are issues such as the potential contribution of HS2 to longer distance commuting and the impact that it might have on the location of businesses and residences. The numbers estimated to be switching from car and air to HSR are quite small, as the main beneficiaries will be existing rail travellers (65 percent) and new trips (22 percent) (para 7.3 [54]).

Finally, there is the speed issue, as higher speeds are usually associated with more energy use and more carbon. Simulation studies carried out for HS2 show that a London to Birmingham journey on HS2 would consume 23 percent more energy at a maximum speed of 360 km/h as compared with a 300 km/h maximum [55]. This difference is reduced when the unit of measurement is carbon emissions per passenger km, as the increased HSR energy consumption (and carbon emissions) as compared with conventional rail, as the trains carry more passengers and there is less stopping and starting, where most of the energy is used. These similar figures are used in other HSR systems. These range from 0.023 kWh/seat km (Japanese - Shinkansen) to 0.065 kWh/seat km (German – ICE3), and the differences relate to operating speed, the number of stops, drag factors, and the number of passengers. The Eurostar travelling at 300 km/h has an energy use of 0.055 kWh/seat km, and if the carbon intensity is 200 g CO2/kWh, this translates to 11g CO2/seat km (para 7.6 – figure for 2030 [54]). A central assumption here is the high occupancy factors assumed for HS2 (70 percent), when those for Eurostar are lower (about 60 percent) and those for the UK InterCity network are even lower (40 percent) (paras 7.7-7.10 [54]).

Speed and carbon, together with longer distances, have often been seen as working in opposite directions, as greater speed leads to increased CO2 emissions. However, the figures given here suggest that this dilemma may not be as great as thought, as the higher energy figures are offset by other mitigating factors listed above. More generally, the debate has not really focussed upon these factors, instead concentrating more on the levels of decarbonisation of the energy supply sector. These lower levels of embedded carbon are central to the two Scenarios listed above (Table 3). The case for higher speeds is seen by HS2 Ltd to be very important as it is the time savings compared with other modes (car and air) that makes HSR the best option, with the carbon issues not being central to the case for investment.

There is always considerable uncertainty, when looking at longer term futures, hence the use of scenarios (Table 3). Yet the assumptions used in the HS2 case do seem to be rather cautious in terms of the potential for reduction in carbon emissions from cars. Since 2010 there has been some reduction in the CO2 emissions figures for new cars in the UK, with the 2014 figure of 124.6 g CO2/km, down from the 2000 figure of 181.0 g CO2/km (a 31 percent reduction over 14 years, equivalent to about 2.5% yearly reduction on average) [56]. This will be reflected in the overall car stock carbon profile in about 5-6 years, when the 2014 new car CO2 profile will become the total stock average (in about 2020). There is also the EU requirement for all new cars to have an average of 95 g CO2/km by 2020.

In conclusion, the potential reductions in CO2 emissions resulting from modal shift from air and car to HSR is rather limited in Phase 1 (2026), and it will only become more substantial when Phase 2 is completed (2033). There are CO2 emissions implications over the alternative use of the air slots and the road capacity that might be released as a result of modal shift to HSR, as this may mean more capacity and more carbon use (but not in the rail sector). The carbon savings from HSR rely mainly on the energy mix, and this is expected to undergo decarbonisation over the next 30 years, but other modes of transport may also become less carbon intensive over that period.

4.2. Time for Change

The timing of the changes is also important, as not all carbon savings will take place immediately. Certainly, there will be no carbon savings until HS2 is open (2026 and 2033), but even then questions must be raised over the phasing of the modal transfers, the freight (and passenger) uptake of released capacity, the carbon sequestration from tree planting (Table 3), and the decarbonisation of the energy system. For example, if the planting of the trees takes place between 2026 and 2033, as is likely as it is one of the last activities to take place in the construction process, then how long will it be that the benefits of carbon fixing becomes effective? This depends on the type of tree planted, the rate of growth, and when maturity is reached, and this is in addition to the numbers of trees (estimated to be 2 million trees for each Phase of construction). Typically, a tree takes 20-30 years to reach maturity, and it then increases its carbon fixing for the next 50-70 years before reaching a plateau [57]. If this is the case, and the time also depends on whether the trees are actively managed or not, the earliest that substantial carbon sequestration takes place will be about 2050 when the UK carbon emissions target of an 80 percent reduction has to be reached. There is also some doubt about the net effect of sequestration with forest planting [58], where it has been concluded that although carbon sequestration has been very effective, the benefits of unharvested forests is far less clear.

Perhaps the time element should be presented in periods of 10 years to determine when carbon savings accrue rather than averaged over a sixty year period, as this gives the impression that these savings are immediate rather than cumulative. For example, for all the 10 Mt CO2e savings over the 60 year period (Table 3 – average), a linear increase might suggest that about 5 percent of carbon savings occur in the first ten years, 9.5 percent in years 10-20, and so on until about 28.6 percent on savings are realised in years 50-60. This thinking is particularly important where there is carbon accounting and budget periods over which clearly specified targets need to be met, as in the UK [52].

4.3. Construction and Carbon

However, when considering the carbon footprint for a mega project such as HS2, the carbon embedded in the construction of the railway has the greatest impact, as most of this is produced before the infrastructure is in use (see Table 4). It is effectively another huge upfront cost for the project. This is a carbon penalty that is imposed as a result of the decision to construct the HSR, and it is a cost that will not be ’repaid’ over the 60 years of use of the line. There will still be a deficit that may only be balanced over 120 years, but even here there must be a high level of uncertainty. There will be additional carbon costs resulting from maintenance and upgrading the HSR over time, as well as the replacement of rolling stock, even though these carbon costs may be mitigated through the continued decarbonisation of the electricity supply.

As part of the London to West Midlands Environmental Statement (ES) [22], a detailed analysis has been carried out on the carbon created over the construction process. This extremely useful assembling of data from a wide range of sources demonstrates the seriousness with which this issue has been addressed by HS2 Ltd. Three different cases have been calculated for Phase 1 of HS2 (Worst, Central and Stretch) to cover the scope elements (embedded, transport, labor and plant) and the design elements (viaducts, roads, tunnels). Here the Central case is presented in Table 4 with commentary that looks at the other two variants. The main differences in the Worst and Stretch cases were higher (or lower) costs for bridges and viaducts (+25 percent and – 9 percent respectively) and for tunnels (+21 percent and -9 percent respectively), together with smaller adjustments in some of the other categories.

Table 4: HS2 Phase 1 Construction Carbon Footprint for the Central Case. Source HS2 Ltd. [31]

Element	**Embedded (t CO_2e)**	**Transport (t CO_2e)**	**Labour and Plant (t CO_2e)**	**Total (t CO_2e)**
Earthworks	0	390,000	200,000	590,000
Construction and demolition waste	0	40,000	0	40,000
Land use – change and forestry	100,000	0	0	100,000
Bridges and viaducts	520,000	30,000	180,000	730,000
Roads	100,000	10,000	10,000	120,000
Retaining walls, cuttings and embankments	140,000	10,000	90,000	240,000
Tunnels, portals and dive-unders	1,170,000	80,000	10,000	1,260,000
Tunnel boring machine	30,000	500	250,000	280,000
Stations and depots	520,000	10,000	120,000	650,000
Track	970,000	30,000	160,000	1,160,000
Rolling stock	230,000	0	0	230,000
Other	140,000	20,000	30,000	190,000
Total	3,920,000	620,000	1,050,000	5,590,000

It is surprising that the largest single transport infrastructure intervention in the UK this century will be making no contribution to reducing the UK’s CO2 emissions, and that this this conclusion has not been of much greater importance in the debate over HSR. These carbon construction costs can be set against the operational costs as they relate to the two scenarios (Table 3). In summary it can be seen that the carbon associated with construction amounts to about 5.6 Mt CO2e (Table 4), and these are all incurred before HS2 opens over the 10 year construction period (2017-2026), whilst the net carbon savings (about 3 Mt CO2e) will all occur over the next 60 years. Even after 70 years (2086), there will still be ‘residual carbon’ deficit of about 2.6 Mt CO2e, only balanced out over the next 60 years (2146). It should also be noted that the carbon costs associated with Phase 2 have also been calculated, but only a range can be given as the time horizon is obviously much longer and uncertain, and as the route has not been finalised. The figures are between 2.18 Mt CO2e and 7.7 Mt CO2e (Table 2 in Temple-ERM [51]). The carbon costs of construction are high, while those associated with the operation of the railway are low, yet both aspects require consideration.

Another aspect of this is that most of the embedded emissions and operational emissions would be covered by either the European emission trading system (ETS) or other policy frameworks, such as the binding UK Climate Change Act (paras 5.1.17-19 [26]). As noted above, direct emission reductions from modal shift can be challenged in a number of ways (e.g. more transport capacity tends to generate more transport in the long run). However, building a new motorway would multiply operational emissions by a factor of 10 over the 60 years of the appraisal period (para 5.1.15 [26]).

In the case of the HS2 route, one of the major costs is the tunnelling that will take place, principally for environmental reasons and to maintain areas of outstanding natural beauty, including ancient woodlands and unique habitats. For Phase 1, some 39.1 km will be in twin bore tunnels and a further 8.2 km in twin cut and cover tunnels. The total of 47.3 km accounts for about 21 percent of the total route [59]. Tunnelling has considerable costs associated with it, both in financial and in carbon terms (some 28 percent of the total carbon embedded in the construction of the HSR). The question here is that while more tunnelling helps allay the concerns of communities and the natural environment that would be affected by the railway, at the same time it raises the costs. The global environmental costs (carbon) are being raised and the local environmental costs (biodiversity) are being reduced, but there seems to be no discussion over the appropriate balance between the two concerns.

5. HS2 and Biosphere Integrity

The UK Government ambition regarding biodiversity is to move to a ‘net gain’ in the value of nature, and this includes a halt to the loss of habitats and species and the degradation of landscapes, and (perhaps ambitiously) to restore biodiversity by creating a resilient ecological network [60], [61]. However, the UK, just as the rest of Europe, has so far failed to meet its commitment to halt biodiversity loss by 2010 [62]. For the UK, this goal has now been set for 2020 [61].

Unlike carbon, there isn’t one simple measure for biosphere integrity, and quantification of impacts for biodiversity is difficult. While there is clearly some economic benefit to be gained through the use of natural resources, maintaining biodiversity is crucial to biosphere integrity [63]. Recent work on biodiversity indicators shows progress in terms of volunteer time spent in conservation activities, the total protected or sustainably managed areas, the availability of biodiversity data, and public expenditure on UK biodiversity. But the long-term downward trends for species group indicators - including the UK priority species - remain to be reversed [64].

The impact of transport infrastructure on long term biodiversity and habitats is complex. Within the Chilterns alone, the National Biodiversity Network Gateway reports more than 7000 species, of which 219 are listed on the UK Biodiversity Action Plan (BAP)[65]. The latter comprises a wide variety of small insects (moths, butterflies and beetles), various types of lichen, moss and fungus, reptiles, amphibians, birds, flowering plants, and small mammals such as bats and mice, and biodiversity relates to species, genetic diversity, and to the interactions between all aspects over time. Official appraisal guidance is based on a natural capital approach, requiring a consideration for both designated and non-designated areas, and establishing an assessment of the magnitude of the impact together with the relevance of key features based on their substitution possibilities – for example, whether a habitat is technically replaceable, or whether species can be relocated (para 9.2.4 [66]).

HS2 Ltd endorsed early on the ambition of demonstrating ‘no net loss’ with regard to biodiversity, both in the Appraisal of Sustainability (AoS [18]) and later in the Environmental Statement (ES) (para 4.8 [33], para 9.8.6 [24]). Its Sustainability Policy commits to “minimise impacts where they occur and deliver enhancements as far as practicable to ensure there is no net loss to the natural environment.” [67]. This commitment to no net loss has not dominated the debate, but the goal has been called anything from ‘incredibly ambitious’ by the Department for Transport to ‘window-dressing’ by some opponents [44]. HS2 Ltd pointed out that building HS2 will inevitably cause effects on the natural environment, but committed themselves to looking for “environmental enhancements and benefits” [67].

With regard to ecology, the ES reports on effects arising from both construction and operation, such as habitat loss, fragmentation of ecological sites and corridors, noise, lighting, or mortality as a result of collisions with trains (para 8.5.1 [24]). Ecological effects for each of the 26 community forum areas (CFAs) along the route are reported in volume 2 of the ES (chap.7 [25]); volume 5 provides ecological baselines for designated sites, flora and fauna [32], and a summary of cumulative effects is laid out in the ecology chapter of volume 3 on route-wide effects [26]. Of particular interest are the avoidance, mitigation and compensation measures for each CFA, as well as the expected residual effects. Habitat loss within statutory and non-statutory sites will both see compensatory habitats created elsewhere. For example, the ES reports a loss of 330 ha of habitats of principal importance (BAP), including 280ha of lowland mixed deciduous woodland and 165ha of lowland meadow. As compensation, approximately 520ha of habitats of principal importance will be created (chap.8 [26]). Eleven of the 26 CFAs report some level of ancient woodland to be lost, totalling 32ha (see Table 5). While ancient woodlands are categorized as irreplaceable, the Chilterns ES (CFA9) mentions the planting of (over) 40ha of new semi-natural broad-leaved woodlands which will be a benefit when mature.

Table 5: HS2 Phase I impacts on ecology (sites and habitats only) (chap.8 [26], [25])

Element	**Description**
Designated sites	
Statutory sites	Habitat loss and fragmentation of 2 Sites of Special Scientific Interest (SSSI, of national value for nature conservation, CFA7)
Non-statutory sites	Habitat loss or fragmentation at 89 Local Wildlife Sites (LWS), 61 of which result in significant adversity on the integrity of the site

Habitats	
Ancient woodlands	Loss of 32ha, 19 woodlands will be directly affected. 10.2ha in the Chilterns Area of Outstanding Natural Beauty (AONB)
Broadleaved woodland	Loss of 310ha, of which 195ha is semi-natural woodland
Grassland	Loss of 170ha, including 11ha of species rich grassland (CFA25)
Fen, marsh and swamps	Loss of 19ha
Hedgerows	Loss of up to 490km

Effects on species are numerous and also complex. For example, sixteen of the 26 CFA reports highlight the loss of barn owl territory from the construction, and the risk of collision with barn owls from the operation of HS2 (barn owls are low-flying birds). Twenty of the 26 CFA reports mention the risk of impacts to bats (bats account almost for a quarter of all mammal species in the UK). Some rare species such as the Bechstein's bat (a European protected species on the list of UK species of principal importance) depend on ancient woodlands for both roosting and foraging. The loss of hedgerows affects the ability of bats to move between roost sites and foraging areas. A number of measures are proposed to reduce the impacts, including replanting. But the ES recognizes the time lag required for these new habitats to become established and it concludes that there will be inevitable but temporary adverse effects on bat populations.

Overall, with exception of the loss of ancient woodlands and the risk of adverse effects on the conservation status of barn owls, the ES concludes that with all mitigation, compensation and enhancement measures, cumulative effects on designated sites, habitats and species will be reduced to a level that is not significant.

5.1. No net loss

Key to the conclusions from the extensive assessment of ecological impacts in the ES is the HS2 Ltd mitigation hierarchy.

On one hand, not net loss is a traditional conservationist position, which can also be justified from ecological economists' logic of strong sustainability where human and natural capital are not substitutable [68]. This approach implies development should contribute positively to all three dimensions of sustainability, including the environmental dimension. On the other hand, no net loss allows for substitution *within* the environmental dimension. First introduced in the Lawton report [62], the UK Government has been keen to test and further develop biodiversity offsetting [60], [61]. With this approach, genuinely unavoidable biodiversity losses are to be offset, "not by replacing the rare and threatened by the commonplace, but by ensuring the natural environment remains diverse and continues to provide essential services" (para. 3.10 [61]). In light of this, HS2 Ltd adopted the Lawton report's recommendation to avoid impacts first, to mitigate impacts second, and to compensate for inevitable damage (Figure 2). The latter puts responsibility on developers to secure compensatory habitat expansion or restoration elsewhere as a last resort, once reasonable efforts have been made to consider the mitigation strategy at an earlier stage.

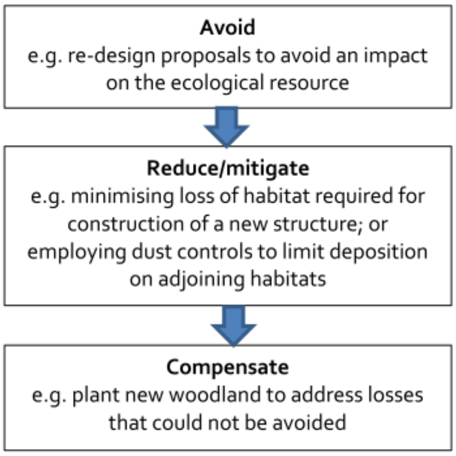

Figure 2: Mitigation hierarchy for HS2 (Annex D Ecology – Technical note #4 'Methodology for demonstrating no net loss in biodiversity' [28])

Essential to this approach is the metrication of biodiversity. According to the technical note for demonstrating no net loss in biodiversity [28], the ES explains the use of so-called biodiversity units to determine the extent of required compensation for loss of habitat. This is based on scores given for distinctiveness, current habitat condition, and coverage. There is the issue of how to account for environmental limits and irreplaceable natural capital, for which HS2 Ltd used a new, 'very high' score for habitat distinctiveness. This received considerable attention, as the House of Commons Environmental Audit Committee recommended in its final report that the Government aim higher than 'no net loss', due to the expected damages to sites of high ecological value such as Sites of Special Scientific Interest (SSSIs), Local Wildlife Sites (LWSs) and ancient woodlands. For ancient woodlands, the Committee recommended that they be treated separately from the 'no net loss' accounts, or at minimum, that they be given 'very high' for all three scores to "recognize their irreplaceability" [42].

A number of ancient woodlands are on the path of the current alignment for HS2. Avoiding them would require an alternative alignment, or tunnelling.

5.2. Alignment

The choice for the route proposed for HS2 Phase I has been the subject of dispute (see for e.g. Q345 [40]). The current route was settled in the Appraisal of Sustainability and has remained largely unchanged since. Assembling a full length route was done via a weighting process of biodiversity impacts similar to the one conducted in the ES. But instead of using (time-consuming) absolute biodiversity units, the approach used qualitative expert assessments to compare route segments (Para 5.3.2 [21]). This stage of option generation was criticized for imposing from the start a 400km/hr maximum operating speed and a connection to Heathrow via Old Oak Common, which was said to ultimately favor the current alignment (see High Speed UK written evidence para 10 [44], also [69]).

A number of opponents proposed alternatives, particularly to avoid the crossing of the Chilterns Area of Outstanding Natural Beauty, some of which were considered in more detail by HS2 Ltd [30], [70], [71] (Figure 3). The first, preferred by proponents such as High Speed UK (HSUK), suggested that any high-speed rail development should follow existing transport corridors. This is expected to have lower biodiversity impacts, particularly on SSSIs, LWSs, ancient woodlands, and BAP habitats (para 3.3.1 [71]). However a route following the M1 motorway would also encounter more populated areas, which would require (possibly costly) mitigation measures and was likely to be more controversial (see written evidence from Lord Adonis para 222 [44]). A 10 percent additional cost premium was estimated for this route (£2.2bn)[71]. Another issue is speed. Following the motorway curvature would only allow speeds up to 186mph (similar to HS1, between the Channel Tunnel and London) and would likely create a number of unusable islands of land, essentially cutting off communities or biodiversity between a highway and a high-speed rail line.

A second alternative, preferred by proponents such as 51m (a group of authorities opposing HS2), is the upgrade of existing lines, which consists of an array of measures including platform and train lengthening, expansion of capacity and electrification of the network. The claim is that incremental improvements to the West Coast Main Line (WCML) would meet growing capacity requirements at much lower costs and environmental impacts, but without the benefit of speed (which could only be realistically increased from 125mph to 140mph) and with the risks of continuous disruption to the rail network during construction.

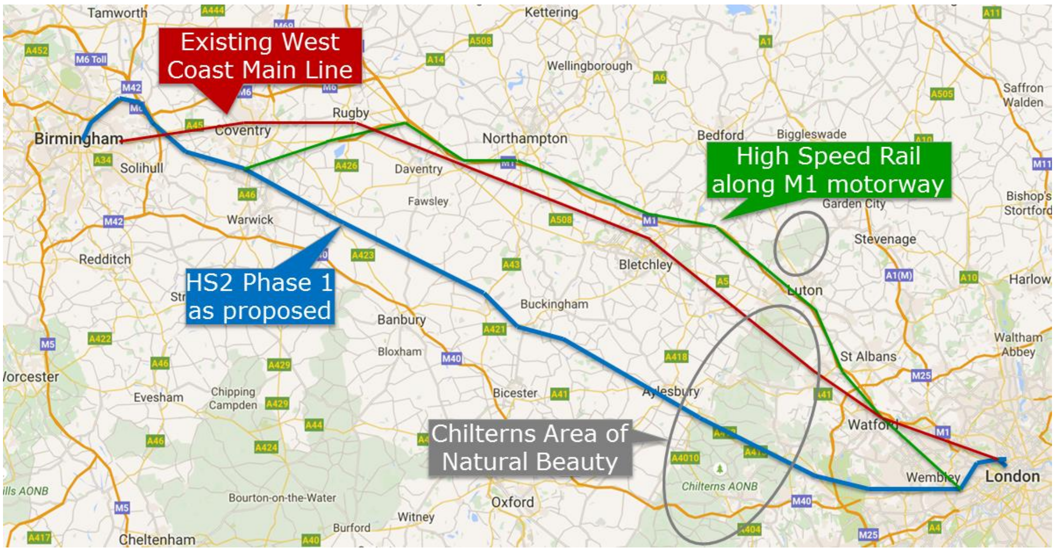

Figure 3: Alternatives along existing transport corridors considered for HS2 Phase I:
Slower route along the M1 motorway (green); Upgrade of the existing West Coast Main Line (red).

The HS2 route is an example of the potential outcome from the principles implemented by HS2 Ltd, which originate from the Lawton report . While LWSs, BAP habitats, and ancient woodlands are designated for their high biodiversity value, avoiding them altogether is not a statutory requirement. Qualifying them as irreplaceable does not provide them with a veto right. While their intrinsic value is recognised extensively throughout the ES and in the debate, the environmental audit committee rightly points out that, in order to avoid further eroding of natural capital, the Government would need to go beyond ‘no net loss’. HS2 Ltd’s other option is to consider tunneling under these areas – an expensive endeavour both in terms of upfront monetary and carbon costs.

How the application of these guidelines plays out is best demonstrated by the case of the Chilterns and its ancient woodlands.

5.3. The Chilterns Ancient woodlands

The Chiltern Hills, or the Chilterns, cover a large area of valleys and countryside situated in the north-western outskirts of London. The Chilterns are a designated Area of Outstanding Natural Beauty (AONB), which means they enjoy protection from development except under exceptional circumstances. The HS2 route is the largest infrastructure project crossing the Chilterns since the construction of the M40 in the late 1960s. The selected route also crosses the AONB at its widest point (around 20 km).

Effects on the Chilterns were first identified in the 2011 appraisal of sustainability (AoS), which was to serve as basis for the environmental statement (ES): “Although a significant proportion of the route through the Chilterns is in bored tunnel there would be localised loss of woodland habitat, notably north of Amersham at (..) Sibley Coppice, Mantles Wood and Farthings Wood (ancient woodlands)” (para 8.6.6 [19], p14 [20]). The report concluded potential land take of up to 19 ancient woodlands along the full route, but that fragmentation and habitat loss in the Chilterns is “limited and considered not significant” and that “impacts on BAP habitats is less severe than other route options in much of the route” (p14 [20]). The Chilterns Mantle’s Wood, Farthings Wood and Sibley’s Coppice are to be directly crossed by the route (Figure 4), leading to the permanent loss of 6.2ha (31%), 0.5ha (15%), and 2.5ha (31%) respectively ([23] and para 2.5.14 [26]).

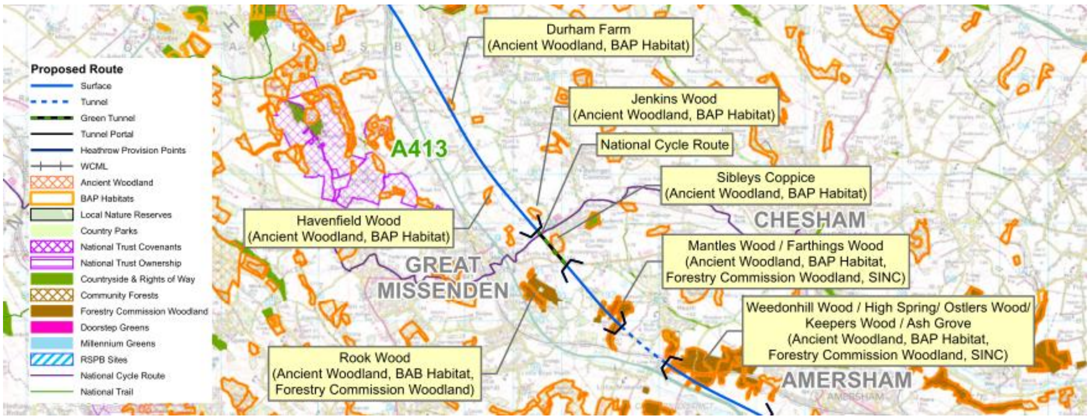

Figure 4: Ancient woodlands and BAP habitats impacted in the Chilterns AONB.

All three woodlands are designated as LWS and consist of replanted lowland mixed deciduous woodland managed for forestry during the past 100 years, parts of which qualify as habitat of principal importance (local BAP habitat [34]). The Forestry Commission categorises the three woods as ‘managed plantations on ancient woodland sites’(PAWS) [72]. Mantle’s Wood is connected to adjacent Farthings Wood via hedgerows and lines of trees, and is part of the wider landscape of woodland and agricultural land that is dominant in the area (Figure 5).

Figure 5: Farthings Wood ancient beech trees, with some oak and hazel. Intensively managed. Moss is indicative of old forest (left). Agricultural land between Mantle's and Farthings Wood (top-right). Mantle's wood, with many grass species and birch trees (bottom right).

The AoS and ES have been systematic in following transport appraisal guidance, and to a remarkable level of detail in the ES, even though access was not always granted for surveying onsite (para 4.4.41 [34]). The length and breadth of the ES is also a test of the complexity required to report such impacts (Table 6). Both the guidance and the ES acknowledge explicitly that ancient woodlands are irreplaceable. Thus the various organisations overseeing the Chilterns had little to add to the impact coverage, but all parties concluded that permanent fragmentation of habitat and loss of irreplaceable ancient woodlands habitat was inevitable [73]–[75].

Table 6: Reported biodiversity in the ES for The Chilterns Mantle's Wood

Impact	Description	Ref.
Ancient woodland	Mature beech maidens (80-100 years old) with occasional cherry and oak, hornbeam, large mature field maples and locally some mature large ash. The understorey has holly, maple and regenerating hornbeam and cherry.	[34]
Ground flora	Bluebell and wood millet	[34]
Birds	33 species recorded: Marsh tit, Song thrush (red list) and Dunnock, Green woodpecker, Mistle thrush (Amber list). Red kite is listed. Barn owl was recorded in farmland habitat nearby.	[35]
Bats	Strips of woodland and hedgerow that provide suitable bat commuting habitat, 6 species were recorded (low levels): common pipistrelles, soprano pipistrelle, noctule and Myotis species.	[36], [39]
Invertebrates	Bark and sapwood decay, grassland and scrub matrix serve as habitats for Scaphidema metallicum, Stenus fuscicornis, Anaglyptus mysticus, Dryodromya testacea (nationally scarce or notable).	[37]
Amphibians	Small population of great crested newt in nearby pond.	[35], [38]

A number of organisations and residents opposed the route via the Chilterns area from early on, and they are protected by various layers of legislation: “The line is planned to cross the widest point of the Chilterns, an AONB. What is the point of establishing protected areas if they are ruined?” (written evidence from a resident of the Chilterns [41]). This is in contrast with the rest of the HS2 route which traverses large areas of rural areas and intensive farmland, considered of ‘relatively low ecological value’ (p14 [20]). The general consensus was that the current route would be devastating for the Chilterns. Following the publication of the AoS in February 2011, organisations such as Campaign to Protect Rural England, the Chilterns Conservation Board, and the National Trust requested the government to consider other routes which follow existing transport corridors (as was done with HS1), instead of running through 'virgin countryside' (see for example Q321/Q340 in the House of Commons Transport Committee evidence [40]). HS2 and the route though the Chilterns was nevertheless approved for a full environmental statement by the then Secretary of State for Transport in January 2012 – albeit with the promise for further consideration and mitigation for the Chilterns [76].

The ES was published in November 2013. It committed to the translocation of all displaced ancient woodland soils and associated seedbank to form the basis for 40 ha of new woodland planting ([23] and Para 2.9.1 [29]). It concluded "The loss of woodland and the loss and severance of agricultural land will have an effect, although this will reduce over time as planting matures. By year 60 of operation, planting will have further matured and integrated the project into the AONB so that the effect will not be significant" [23].

5.4. Tunnelling

Following public consultations, the Chilterns as a geographical area as a whole received the largest volume of responses, warranting a section by itself in the independent assessor's report [77]. Much of the feedback was organised around the demand for full tunnelling under the Chilterns. The House of Commons Environmental Audit Committee report of April 2014 was critical about the ES with regard to ancient woodlands: "The Woodland Trust told us that the destruction of ancient woodlands raised questions about the application of the mitigation hierarchy, and illustrated it argued by a lack of explanation about why a Chilterns Tunnel ("that would save one third of the ancient woodland threatened along the route") would not be taken forward. Environment Bank, similarly, said it was necessary to use tunnels rather than cuttings to minimise damage to ancient woodlands." (Para 13 [42]).

Following the report, in a series of correspondence between DfT, HS2 and the newly formed HS2 Bill Committee, the Audit Committee raised a number of concerns about fully addressing environmental impacts, particularly with the offsetting regime, "for HS2 puts even the modest Government aim of delivering 'no net biodiversity loss' in doubt" [43]. The Government refused to raise the ambition for no net loss, judging it adequate, and in effect relegating any environmental concerns to the petitioning process of the HS2 Bill Select Committee .

In a final round of consultations regarding the HS2 Bill, local environmental groups petitioned independently to contest the loss of ancient woodlands and the policy of offsetting, with different shades of "green". These include the Chilterns Conservation Board (petition 415): "As ancient woodland is irreplaceable there is no mitigation possible for this loss, and the destruction of it is of national significance"; the Royal Society of Wildlife Trusts (petition 1293): "Your Petitioners share the concerns raised by the Environmental Audit Select Committee of your honourable House in their recent report on HS2 and the Environment relating to biodiversity offsetting"; the Chiltern Countryside Group (petition 1288): "Planting should be carried out as early as possible as the scheme progresses through the AONB. Monitoring at the expense of the Promoter should extend over a 60 year period during which replacement trees should be planted, should the original planting fail"; and the Woodland Trust (petition 1508): "Your Petitioners would humbly ask that opportunities to realign the track should be taken to avoid the destruction and damage of irreplaceable habitats such as ancient woodland. Your Petitioners have calculated that 33% of the ancient woodland to be lost to the line falls within the Chilterns AONB. However, this loss is being caused by less than 4.5% of the line. Bored tunnelling throughout the Chilterns AONB could significantly reduce the environmental impact of the scheme" (petitions 415, 1293 [45]). Other petitioners included the National Trust, the Buckinghamshire Wildlife Trust, The Chiltern Ridges Action Group, the Chiltern Society, Conserve the Chilterns and Countryside, the Berkshire, Buckinghamshire and Oxfordshire Wildlife Trusts etc.

The turnaround came following a visit by the Bill Select Committee to Little Missenden in June 2015 [46]. By July, the committee reported that the case for tunnelling under the ancient woodlands had been made [47]. A 2.6 km extension of the Chiltern tunnel was confirmed in a letter by the Government in late August [78].

6. Comment

Both carbon and biosphere integrity were found to be comprehensively addressed by HS2 Ltd. But environmental choices remain complex. The decision related to the tunnelling under the Chilterns ancient woodlands well illustrates this, in that it took more than 5 years (much of the appraisal period) to build the case, even though it raises the construction costs and contributes to global carbon costs.

6.1. Global versus local

At the time of the AoS publication, economic reviews by the Department for Transport recognised the high cost of tunnelling to avoid the Chilterns: "although tunnels would make up 13% of the total route length, they would contribute to some 23% of the construction cost" (para 4.6.6 [79]). Since much of the route through the AONB would be either in tunnel, in cutting, or alongside transport corridors, it was argued the line would be hidden from many views (para 8.5.5 [19]). This argument that only a small portion of the line through the Chilterns would be at or above surface was repeated in official speeches by all three Secretaries of State for Transport [80]–[82]. Despite such reassurances, concerns about the visual effects on the landscape and the AONB designation prompted HS2 Ltd to just about double the length of the Chiltern tunnel by the time of the ES (from 6.7km to 13.5km) (para 12.3.4 [27]). But the area passing through the three ancient woodlands of Little Missenden were still planned as deep cuttings. Some noted the extra costs in tunnelling along the full line had already surpassed the extra costs of mitigation for populations on the M1 route.

The desire for more tunnelling along the route came again as a primary concern in the ES independent assessor’s report [77]. Top concerns for the Central Chilterns area (CFA9) were very local in nature, namely the impacts of construction on transport and traffic, the impacts on community and tranquility, the landscape and visual impacts, and the noise and vibration effects (in this order) [77]. Related to disruption from construction is the issue of spoil. Deep cuttings (typically 65-90m wide at the top and 15m deep) within the AONB generate more spoil than tunnels, thus increasing both local HGV traffic and emissions from earthworks (e.g. see written evidence from the Chiltern Countryside Group para 6.2.9 [41]) (Figure 6). In the report, ecology came 8th, and sustainability (a proxy for climate change and carbon emissions) came 14th. Forestry and agriculture were of higher concern than ancient forests, biodiversity or carbon emissions.

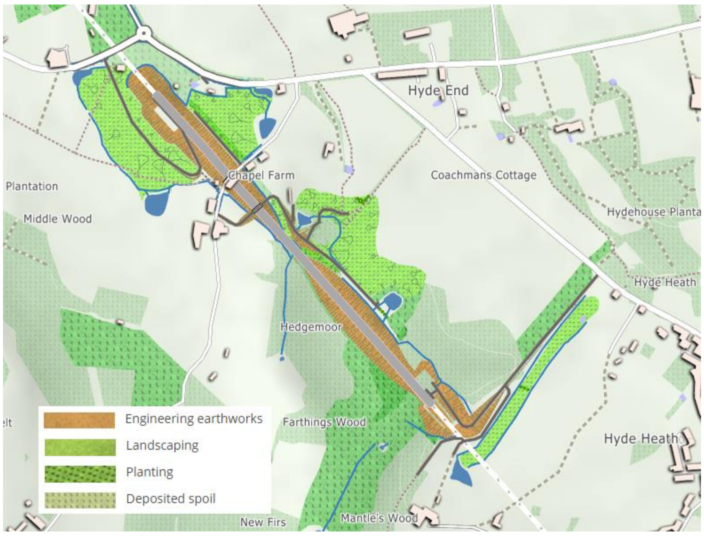

Figure 6: Landscape impacts and deep cuttings through Farthings Wood and Mantle's Wood [83].

Aside from the general critique that HS2 was not delivering carbon reductions overall, petitioners and environmental groups in consultations did not mention carbon emissions in relation to the Chilterns.

6.2. Reconciling carbon and biodiversity integrity

The connection between increased tunnelling and costs was clear. The fact that high speeds both prevented the scheme from contributing to carbon emission reductions and dictated a more direct route was also understood. For example, the HS2 Action Alliance submitted evidence in support of the WCML upgrade to the first Transport Committee: “upgrades are environmentally preferable, the lower speeds give rise to lower carbon emissions, they follow existing rail corridors and so do not require the sacrifice of an AONB or tranquil countryside.” [40]; or in this evidence from the first Transport Committee “Slower speeds permit greater track curvatures and reduced tunnelling and associated costs, as well as significantly reduced embedded carbon impacts.” [41]. This conclusion was repeated by the Environmental Audit Committee, which suggested trains should operate at slower speeds in the first years, to allow for the UK to decarbonise its electricity production. But slower speeds also impacted the business case based on journey times, and it was argued that it would likely result in less mode shift, which in turn would lead to an increase in emissions [76]. The House of Lords also requested the Government to review opportunities to reduce costs by lowering speeds, which was rejected based on HS2 commitment to deliver “a world class railway that stands the test of time” [84].

Interconnectivity between costs, carbon and biodiversity loss received much less attention, although it is possible to estimate cost and carbon impacts from the material provided (Table 7).

Table 7: Estimates of costs and carbon emissions for the Chilterns South Heath tunnel extension. Costs vary depending on length, radius, topography, number of shafts, and type of boring machine. HS2 estimate: £33m per single tunnel km [85]. Peter Brett Associates: £25m per single tunnel km [86]. Carbon emissions estimates: 37ktons CO2e per km (bored), 30ktons CO2 per km (cut-and-cover) (central case data from Table 4).
Carbon content for old-growth forest: 420 tons C /ha [57] (weight factor C to CO2 = 3.67) [57].
Carbon sequestration rate of northern hemisphere temperate old-growth forest: 2.4 tons C /ha /year (data for up to 800 years) [87].

South Heath tunnel extension	**Values**
Length	2.6km
Gross construction costs (twin bore tunnel)	£130m - £172m
Net cost increase compared to ES baseline	*see text*
Gross construction (embedded) emissions	95,000 tons CO2e
Net emissions increase (compared to ES baseline with 950m green tunnel and 1.65km deep cuttings)	approx. 60,000 tons CO2e
Ancient woodlands saved	9.2ha
Carbon content of woodlands saved (old-growth)	14,200 tons CO2
Carbon sequestration of woodlands over 60 years	4,900 tons CO2
Carbon sequestration of woodlands over 800 years	Up to 65,000 tons CO2 - *see text*

Although the appraisal process in the UK does not attempt to monetise impacts on biodiversity, the net avoidance costs can provide an implicit value to those forests. Cost calculations above only provide an average per kilometre, which is likely higher than the marginal cost of extending the existing tunnel. It must also be said that lifetime maintenance costs of a tunnelled route are also considerably less than an overground route. Additionally, savings from the green tunnel and deep cuttings that will no longer be needed should also be deducted. These costs are not available, however evidence from Buckinghamshire County submitted to the House of Lords expects the extra tunnelling to be cost neutral (para 24 [44]), and an earlier independent feasibility study for full tunnelling of the Chilterns concluded the scheme would actually save money to HS2 Ltd [73].

A deep-bore tunnel comes at a 25% premium to a green (cut-and-cover) tunnel in terms of embedded carbon. The bulk of the emissions come from the use of carbon-intensive materials such as concrete and steel. On paper, the increased cost of ‘saving’ the ancient forests in terms of carbon emissions is approximately three times the carbon sink potential of the forest over 60 years. Carbon sequestration processes from old-growth forests remain somewhat unclear, but recent studies report that mature deciduous trees absorb more carbon than fast-growth forests, and that both trees and top soils in ancient woodlands continue to accumulate carbon over centuries [87]–[89]. If this is the case, the carbon footprint of the extra tunnelling would be offset in about 800 years. These findings could call for the protection of ancient woodlands, not only because they harbour a wider range of species, but also for their role as carbon sinks in the long term.

In conclusion, the immediate carbon emissions from the loss of woodlands are relatively low, contributing less than 2% of the total embedded emissions (using HS2 methodology and central case from Table 4, assuming mature forests are carbon neutral). Reducing embedded carbon emissions would hence require minimising the total amount of tunnels, viaducts and earthworks construction. In this context, if the priority was to contribute to reducing net transport-related carbon emissions, modal shift from air or road to rail should be a top priority. But that also means that the released capacity is not taken up by more road or air travel (this is true for both passenger and freight). Therefore revising the route alignment to not only follow an existing motorway, but to replace a number of lanes on an existing motorway would likely deliver far higher carbon emissions reductions, as well as offering reduced impacts on biodiversity from habitat fragmentation or degradation. The physical footprint of HSR is not fundamentally different to that of motorways (approximately 23 metres of land take, as opposed to 33 metres). The tracks themselves take 5 metres in each direction, leaving much of the remaining area suitable for some wildlife. Unlike Germany or Sweden, fencing is mandatory in the UK, and this acts as a barrier to larger animals. But HSR can be more easily elevated (to allow for dedicated animal underpasses), and it is likely to produce significantly less chemical runoffs, and the transport corridor would be free of pesticides or fertilizers, otherwise common in the intensive farmlands it crosses. Whether HSR is a ‘Berlin wall for wildlife’ or a type of ‘Green corridor’ remains to be more precisely assessed and understood (Q463 [40]).

The potential for mode shift serves to illustrate how the environmental assessment of HS2 from a planetary boundaries perspective raises important questions about the UK transport system planning as a whole. Reducing carbon or biodiversity impacts are very sensitive to the delivery of policy measures supporting these goals.

6.3. Systems planning

HS2 serves to meet wider community objectives (e.g. economic competitiveness, accessibility, environmental protection) than just increasing mobility and rail capacity. The issues presented here only highlighted to a small extent the complexities involved in assessing large scale transport projects for their contribution towards sustainable development.

As shown above, carbon and biodiversity impacts are complex in their details. They require a certain level of precision to be dealt with, while at the same time this very precision is no guarantee of ‘getting things right’ at the systems level (e.g. mode shift from air reduces carbon emissions, but also depends on the use of freed-up capacity at airports). Impacts are complex in the way they unfold over time, making long-term forecasting based on patterns of causal chains is difficult, and small differences may reveal problems over time (e.g. time of planting of new forest leading to permanent loss of biodiversity or not). The assessment process and accompanying consultations also showed potential for much discordance between various stakeholders in addressing the challenge. Hence impacts are complex as they relate to the interests underpinning them (e.g. there is more support for impacts that can be made tangible in the here-and-now, such as the permanent loss of a forest).

This raises the issue of delineation of the system itself [90]. As required by the European Commission directive on the assessment of projects on the environment, the ES sets its boundary to the project itself (HS2 Phase I)[91]. But addressing these complexities requires an integrated, multi-modal, transport network perspective on the goals and the possible means to achieve them [92]. This is something that could be covered by Strategic Environmental Assessments (SEA), which by definition provide a broader perspective to environmental assessments than EIAs. The environmental audit committee identified the absence of a formal SEA process for HS2 [42], and this was also raised as a potential breach to EU regulation in consultations for both the AoS and the ES ([93], [77]).

HS2 Ltd defended the level of detail in the AoS as adequate and compliant with SEA requirements (para 8.1.3 [21], para 3.1.1 [93]). But the key issue here may be related to the understanding of a 'programme'. While it is correct that for strategic purposes, the level of detail required in a EIA is not required in a SEA, as SEAs require identifying, describing and evaluating "reasonable alternatives taking into account the objectives and the geographical scope of the plan or programme" (article 5 para 1 [94]). The understanding of SEA in transportation is that it serves as the means to judge investments on their network-wide, cumulative effects. A SEA intends to provide a robust analysis of alternatives to competing goals of transportation, economic growth, environmental protection, equity and costs. Therefore a SEA applies to the transport system as a whole, across all modes, and in relation to other national plans [92]. This goes quite beyond the scope of HS2's AoS, which in comparison served as a type of early EIA. But even a comprehensive SEA may not have the answers to all the questions being raised.

Such approach was demonstrated by the New Economic Foundation (an independent think-tank), who undertook to evaluate a series of multi-modal, national-level alternatives to meeting the wider goals set by HS2 [95]. But this wider perspective appears to have been lacking in the current official appraisal process, thus relegating the wider considerations to a more uncertain consultation and petitioning process later in the process. The public has not been given a chance to evaluate alternatives to HS2 itself and to its route as agreed in the Aarhus convention. But the current trend in the UK for devolution, localization of powers, the various spatial scales involved with a project like HS2, and the lack of integrated, multi-modal, transport plan at national level, all contribute to make such high-level assessment difficult, and this has been compounded here with the use of a Parliamentary procedure (Hybrid Bill) rather than a full Public Inquiry.

At the other end of the planning spectrum, the National Planning Policy Framework (NPPF) was also criticised for having a presumption in favour of development. The guidance, intended to support better bottom-up planning by local authorities, mixes strong language for sustainable development – including limits - but at the same time allows for a lot of margin in the implementation. In short, the NPPF serves as a pragmatic tool to relativise and reduce the initial ambitions set in, for example, "The Natural Choice" guidance by DEFRA [60]. This may give an impression in the UK of high ambition over the scale of new infrastructure projects, but it really allows for business as usual to proceed.

Thus from a planning perspective, the UK framework could be said to lack both top-down, integrated guidance, as well as bottom-up planning guidance that provide effective solutions. In the case of the Chilterns ancient forests, this was compensated by a strong tradition for democratic involvement.

7. HS2 and Defining a Legacy

The case of HS2 illustrates the inherent difficulties that arise from an essentially pragmatic style of decision making in defining an environmental legacy for future generations. In reality, once the initial decision was made to go ahead with the line, then such issues as the carbon emissions impacts on long-term climate change, and trade-offs with local biodiversity systems, become secondary to the official necessity to carry the project through the policy making process. This tendency towards short-term pragmatism with regard to environmental planning is exacerbated by the complexity of many of these issues, and uncertainties in terms of assessing future impacts. For example, as we discussed, these complexities are particularly well illustrated by the difficulties in assessing the carbon impacts of the construction of HS2, against the long-term carbon savings made by new tree planting. Similarly, as we discussed in Section 4, the impact of transport infrastructure on species, habitats and ecosystems is complex. Under these conditions of complexity and uncertainty, then it becomes more likely that important decisions such as the percentage of the line that will run through tunnels is made more on the grounds of responding to political pressures, than considerations of long-term integrated environmental planning.

There is nevertheless significant irony in the fact that there is no shortage of expert assessments of the environmental impacts of HS2. For example, HS2 Ltd has been particularly thorough in its assessments of the carbon impacts of construction of the line. As this study has illustrated, therefore, the appraisal process is transparent and voluminous. In addition, stakeholder involvement was also extensive. Consultations (and later petitioning) were carried out at each step, and transparency and openness served as a type of virtuous circle, where matters of concern were shared and explored. At the same time, it could also be said that there was too much information [96], as illustrated by the 50,000 page Environmental Statement. Thus in practical terms it would be virtually impossible for any individual or group to absorb this information, and so again encourages decisions to be made on a pragmatic and piecemeal basis.

In reality, the initial decision to build the line, and that the maximum speed should be 400 km/hr, was made prior to any consultation process. In turn, these basic decisions largely dictated that the line would run through an AONB in the form of the Chilterns, rather than take a less environmentally intrusive route, and so would inevitably have a significant impact on the complex biodiversity of that area. Consequently, the subsequent decision making process has involved mitigating the impacts of this high speed line, rather than any significant consideration of alternative routes. Considerations of speed and cost have therefore taken priority over carbon and biodiversity impacts. In terms of neutralizing the carbon impacts, much will depend on the speed with which UK electricity generation will be de-carbonised over the next thirty years, and this is a subject that HS2 Ltd would claim is beyond its control. This is therefore an area where environmental planning requires an integration of transport and energy policy, but these considerations have apparently played little part in the HS2 decision making process.

The direct environmental impacts of HS2 have been given a relatively low political salience, when compared with the mobility and economic impacts. It could be said that underlying these considerations is an assumption that high speed rail is inherently more environmentally friendly than other transport modes such as roads or air. Once this assumption is made, then the actual environmental costs of a project such as HS2 become of secondary significance to its apparent virtues in offering an efficient alternative travel mode. In this context, the legacy for future generations will be perceived chiefly in the virtues it offers for ease of mobility and economic growth. This question of officially defining an HS2 legacy is illustrated best in a 2014 Report by HS2 Ltd Chairman Sir David Higgins. He argues that, if done right, HS2 can provide an answer that does stand the test of time, and addresses the issues of congestion in the South, and lack of connectivity in the North. He adds that the cost and impact have to be recognized, but so too do the cost and impact of doing nothing, and without HS2 the people of Britain will continue to face the failures of the transport system on a daily basis. With it, they will begin to see a strategic answer that can deliver real benefits within the foreseeable future. Consequently, he concludes that HS2, despite the issues it raises, is a project in the national interest [97].

When HS2 is defined in these terms, then it becomes inevitable that wider environmental questions are given a subsidiary role, and handled in terms of pragmatic mitigation, rather than giving primacy to such issues as biodiversity and carbon impacts. Essentially, therefore, in environmental terms the mandate handed to future generations is to deal with these latter issues as best they can.

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Acronyms

AONB	Area of Outstanding Natural Beauty
AoS	Appraisal of Sustainability
ASNW	Ancient and Semi-Natural Woodland
BAP	Biodiversity Action Plan
BCR	Benefit-Cost Ratio
CBA	Cost-Benefit Analysis
CFA	Community Forum Area
DEFRA	Department for Environment, Food & Rural Affairs
CfIT	Commission for Integrated Transport
DfT	Department for Transport
EMR	Environmental Minimum Requirements
EIA	Environmental Impact Assessment
ES	Environmental Statement
ETS	(European) Emission Trading System
HoC	House of Commons
HoL	House of Lords
HS1	High Speed Rail 1 (cross-channel scheme)
HS2	High Speed Rail 2 (current scheme)
HSR	High Speed Rail (also HSL and HST for High Speed Line or Train respectively)
LWS	Local Wildlife Site
MCDA	Multi-Criteria Decision Analysis
NATA	New Approach to Appraisal
NEF	New Economic Foundation
NPPF	National Planning Policy Framework
PAWS	Plantations on Ancient Woodland Sites
SEA	Strategic Environmental Assessment
SES	Supplementary Environmental Statement
WCML	West Coast Main Line
WEI	Wider Economic Impacts
WebTAG	Web-based Transport Appraisal Guidance

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