HS2—towards a zero carbon future

An independent review of the carbon case for HS2

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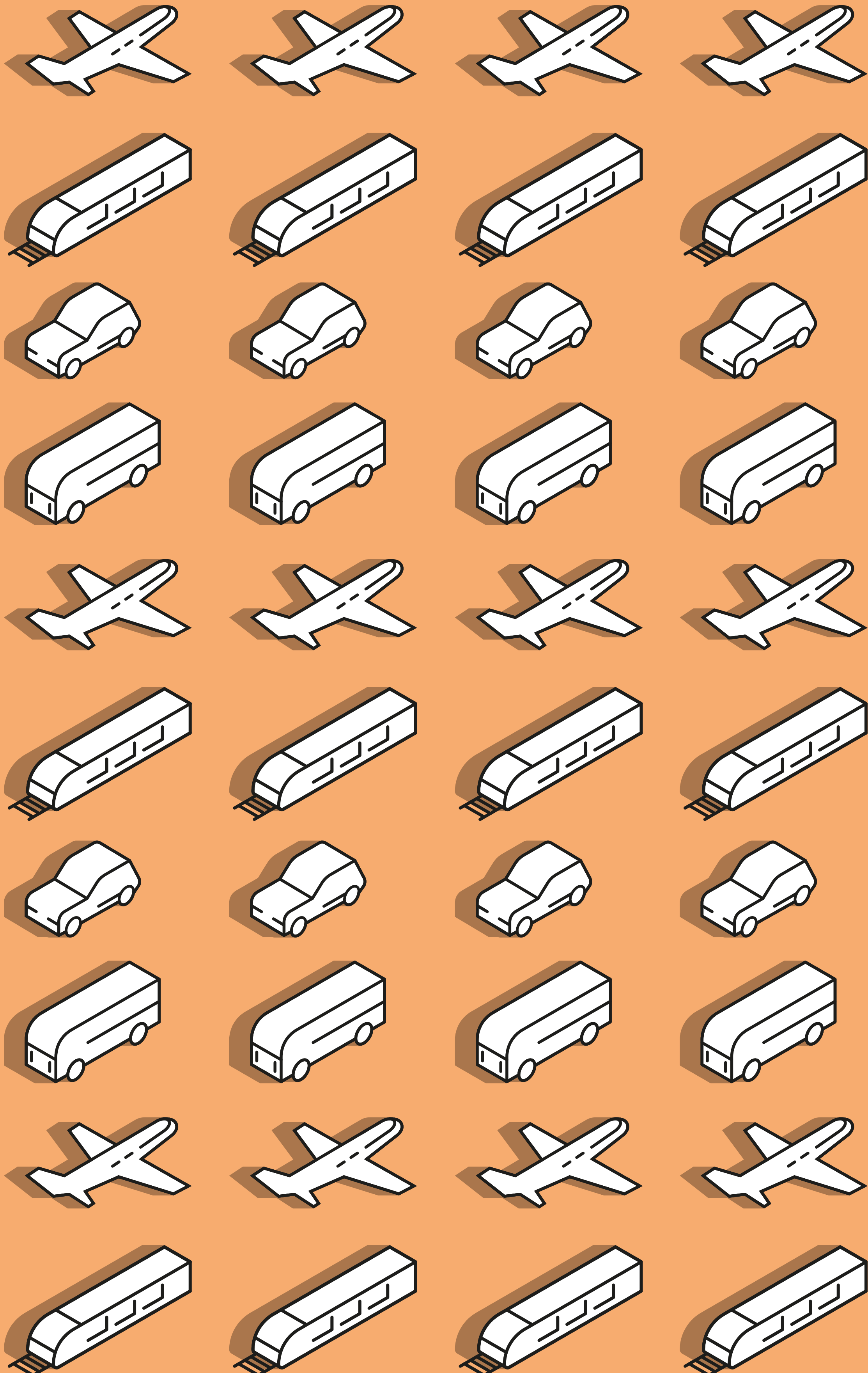

Foreword

High Speed Rail Industry Leaders is pleased to have commissioned and published this independent review of the carbon case for HS2, an important subject which is largely being overlooked in the current debate on HS2. We are particularly pleased that Ralph Smyth accepted our request to write it. He is the former Head of Infrastructure and Legal for CPRE, the countryside charity, and was in fact the only person to be allowed to petition against HS2 legislation in relation to its climate change impact.

The report offers a detailed, thorough and balanced assessment of a set of complex issues. It considers the design, construction and operation of HS2 as well as the wider policy shifts required to achieve the government's net zero target. As such, this is a report "to" HSRIL, rather than one "from" the organisation.

HSRIL is made up of a wide range of companies, all with an interest in the successful delivery of high-speed rail in the UK. Our members are acutely aware of the challenges to industry that the net zero carbon target brings. However the scale of the HS2 project, and the transformational benefits that it can bring, provides industry with real impetus to step up the pace of change. Companies contracted to deliver HS2, and the wider high-speed rail supply chain are already making significant achievements in driving down design and construction carbon as the report shows.

The passing of legislation this year to commit the UK to a legally binding target of net zero carbon emissions by 2050 is going to be transformational, and the Committee on Climate Change's recent analysis demonstrates why policy shifts are essential to achieve that goal. It is in this context that the carbon impact of HS2 needs to be considered, as the scale of a new high-speed network could facilitate achieving these policies. By contrast the lack of capacity on our busiest existing railways or the disruption from trying to upgrade them incrementally would hinder achieving net zero.

From the report, we draw five significant conclusions about carbon reduction and HS2:

1. **HS2 is essential to net zero**. The HS2 project will—in fact, must—form a crucial part of the transition to net zero. The UK's answer to the emission reduction challenge in the transport sector must be an irreversible shift to low-emission mobility, and HS2, as a high-capacity fully electrified railway, is key to making this happen.

2. **HS2 is already out-performing carbon targets**. Initial estimates of the carbon impact of HS2's construction phase may have been substantially over-estimated. The Align Joint Venture for example, has already found carbon savings of 13% against projection on preparatory works it is carrying out. Outperformance of initial forecasts of embodied carbon in the construction phase by 20–30% seems now likely.

3. **HS2 is a vital investment to the de-carbonisation of the UK's transport sector**. In order to maximise the modal shift effect of HS2, we should be looking at 'sweating' the significant benefits that the project brings by looking at how it can do more in terms of to use the released capacity that HS2 creates for better commuter services on existing lines, to get more lorries off long-haul routes and their loads switched to rail, and modal shift increased by further reducing journey times from London to Newcastle, Glasgow and Edinburgh. HS2 should be viewed through the lens of the forthcoming Transport Decarbonisation Strategy, in which HS2 investment should be recognised as a key sector-wide catalyst.

4. **HS2 can play a key strategic role in climate change adaptation**. With extreme weather events becoming more frequent, our existing transport networks are increasingly revealing an ill-preparedness in the face of high winds, intense rainfall and increased frequency of major storms. HS2 will be the most reliable transport infrastructure available in the more extreme weather conditions ahead and so plays a key role in adapting to climate change—an under-recognised aspect of the current environmental case.

5. **Any moves to curtail HS2 will weaken its carbon case**. It is clear from this report that any moves to curtail the scope of HS2 would weaken, not improve, its carbon case by reducing the wider benefits that the project unlocks from the released capacity carbon benefits and the transformational effects of sustainable developments facilitated by the project, including housing.

UK carbon emissions from transport are still increasing and have recently become the country's single largest source of carbon emissions. Only a new electrified railway has the capacity to attract substantial travel volumes from road and air and enable rail to become the longer distance mode of choice. In light of these facts and the challenge of the new 2050 target, it is plain that investing in HS2 should be a central plank of the Government's forthcoming Transport Decarbonisation Strategy. HS2 services will launch with largely de-carbonised electrical power generation with a rapid path to zero emissions ahead. HS2 has an unassailable case to be part of Britain's net zero future.

Our view is that by looking at this polarised debate in such a balanced way, Mr Smyth's work, makes an important new contribution to that discussion. In doing so, it reinforces our view that HS2 is a vital investment to the de-carbonisation of the UK's transport sector. As such, high speed rail is an essential and irreplaceable part of the UK net zero strategy. We commend Mr Smyth's report, and hope it will be reviewed and considered by policy-makers as we move forward with the construction of the most important infrastructure project the UK has delivered for generations.

The Board, High Speed Rail Industry Leaders

Biography, Ralph Smyth

Ralph Smyth is an independent consultant, who was formerly head of infrastructure and legal at CPRE, the countryside charity. He led CPRE's engagement with HS2 and, through the Right Lines Charter on doing High Speed Rail well, brought together twelve national environmental and transport NGOs to challenge supportively HS2's development.

His extensive experience of major infrastructure projects ranges from appearing as a barrister at public inquiries to advising Highways England on its Strategic Design Panel and helping communities understand HS2's impacts better by delivering interactive mapping from HS2 open data. A champion for and expert on sustainable mobility, he proposed the creation of the Cycling and Walking Investment Strategy, described as the biggest legal change for cycling since 1888, and advised ministers on its implementation by local authorities. He has chaired a leading Business Improvement District's travel workstream, overseeing successful bids to TfL's Future Streets Incubator and Business Low Emission Neighbourhood funds. He holds law degrees from Oxford University and an MBA from Warwick Business School.

Executive summary

Achieving net zero carbon emissions is a particular challenge for surface transport and aviation. Technology alone will be insufficient so a transport transition is required that includes measures to manage demand and shift it to sustainable modes. The importance of making rail the long distance mode of choice, including through investing in high speed rail, as part of this transition is increasingly recognised internationally.

Understanding HS2's potential carbon impacts means considering emissions from its construction, operation and wider impacts beyond the project's boundary, typically modal shift. Those impacts beyond HS2's direct control are where its greatest carbon benefits exist. Earlier environmental assessment was legally required to assess the reasonable worst case for HS2's overall impact. The scale of the project is now catalysing new techniques to reduce construction emissions, while the Committee on Climate Change believes wider transport policies will be needed, such as to rebalance the cost of rail versus road and air travel. HS2 is likely to play a far more important role in reducing carbon emissions than officially estimated.

To understand HS2's impact in an increasingly uncertain future, this report considers the potential impact of three contrasting scenarios, the recently legislated net zero by 2050, net zero by 2030 that some political parties and NGOs are calling for, and a reduction in ambition where the necessary policies are not put in place. Three investment strategies are compared, besides delivering the full HS2 all the way to the north, a descoped HS2 is considered as well as alternatives. Finally wider interactions are touched upon, in particular unlocking sustainable housing growth, as this is increasingly a focus of transport investment.

Key recommendations

Aligning vision and benefits with net zero ambition

1. HS2 's environmental narrative should be reset and relaunched in time for its 10th anniversary, so that it aligns as well with the ambition of net zero as it did with the Climate Change Act 2008 when first launched. This should include a commitment in the forthcoming Transport Decarbonisation Strategy to make rail the longer distance mode of choice, with HS2 being the backbone..

2. In line with the call for new methodologies in the Allan Cook HS2 stocktake, there should be an examination how transformational schemes like HS2 can deliver and unlock wider changes in the economy to facilitate the achievement of a net zero trajectory.

Construction

3. Stretch targets to reduce construction carbon should continue and learnings should be shared with other construction projects and the supply chain. HS2 provides a major opportunity for the UK to position itself as a global leader on lower carbon construction, on the back of its record of infrastructure innovation around Building Information Modelling (BIM) and offsite construction. This could help attract young people into a greener construction sector.

4. Tree planting should not where possible be delayed by the retiming of HS2's commencement of operation. Planting sooner will help offset inevitable emissions from the chemical reactions occurring when using concrete, for instance.

Operation

5. As a new, wholly electrified, transport network, HS2 is of such a scale it should secure genuinely additional renewable electricity capacity, both from integrating it within the project boundary, such as solar on stations, and by contracting directly with providers. Through this, HS2 could commit to using zero carbon electricity from its opening year, if not for construction and through its supply chain.

6. The track access charge regime should be optimised to maximise carbon benefits, with a lower rate close to marginal cost for otherwise less economically viable services with potential for high modal shift from air. HS2's potential use for high value/low volume time sensitive freight should be considered, such as designing in dedicated freight consolidation hubs at interchanges.

7. Stations able to use capacity released by HS2 as well as stations directly served by it should become beacons of sustainable travel, building on proposals for enhanced local public transport networks that HS2 has already catalysed, with ambitious targets for modal share.

Integration beyond the project boundary

8. HS2's carbon benefits can be magnified through integrating it better with wider rail schemes, such as Midlands Rail Engine and Northern Powerhouse Rail and with upgrades of existing Anglo-Scottish main lines.

9. The review of HS2 should be aligned with government decisions to implement transport policies that will ensure complying with the fifth carbon budget (2028-2033). Updated modal shift and emission factor scenario modelling is urgently required, including assessing national policies for charges for road use and parallel short-haul flights.

10. More detail and commitments to minimum service uplifts are needed urgently to catalyse higher density development around stations freed up by HS2.

Introduction

In June 2019 the Government accepted the Committee on Climate Change's (CCC) advice and legislated for net zero UK greenhouse gas emissions by 2050, referred to here simply as 'net zero'. The CCC calculated "reaching net-zero emissions requires an annual rate of emissions reduction (15 $MtCO_2e$ per year, 3% of 2018 emissions) that is 50% higher than under the UK's previous 2050 target"[1]. This challenge is especially acute for surface transport as its emissions have not fallen since 1990, making it the single largest contributor. The challenge for aviation is even greater, with the sector due to make up the majority of all UK emissions by 2050.

Achieving the necessary trajectory to meet net zero will require new technologies, pricing and regulation, all of which will interact within and between different sectors of the economy. The challenge of the net zero commitment, in particular its impact on forecasts of road and air travel and on HS2 are very relevant at this time of the Oakervee Review ('the Review') and should be taken into account by Government in responding to its findings.

This report considers HS2 and the Review through a net zero lens. This is not simply about revisiting HS2's environmental baseline and modal shift forecasts but about assessing how the net zero target fundamentally changes the strategic context that HS2 needs to fit within. The implications of changing the scope of HS2, with the risks this brings to delivery of carbon benefits are also considered.

1. Committee on Climate Change (2019). **Net Zero—The UK's contribution to stopping global warming**. Available at https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/

Some argue HS2 simply has no environmental case, others that as rail can rely on low carbon electricity, it is green by default. A previous study, 'The Carbon Impacts of HS2'[2] took a position in between. It argued there is huge scope to influence HS2's net impact, not just in terms of its design, construction and operation but also on wider policies to shift travel away from road and air and electricity generation from fossil fuels. The Committee on Climate Change's recent analysis demonstrates why such wider policies are now essential to achieve net zero. The scale of a new high-speed network could in turn facilitate achieving these policies[3]. By contrast the lack of capacity on our busiest existing railways or the disruption from trying to upgrade them incrementally would hinder getting them in place.

Rail and the climate emergency abroad

In September 2019 Germany announced its Climate Package which includes a 10% rail fare cut **and** investment in an expanded high-speed rail train fleet alongside a tax on domestic air travel and the introduction of a carbon trading scheme with built-in annual carbon price increases. But the German Green Party is calling for far more radical action. The party asserts the climate cannot be protected without a transport transition and that rail should be the backbone of this transition. It is calling for decisive action to make domestic flights obsolete by 2035, including through a kerosene tax, further reductions in rail fares and €3 billion extra invested in the network each year to enable expansion with new lines. This is needed it says, to provide adequate capacity and reduce rail journeys to below four hours between German cities and those in neighbouring countries[4].

In the Netherlands plans to ban combustion from some cities by 2030 are now accompanied by Parliamentary proposals to prohibit short distance flights to neighbouring countries. This has led to national airline KLM launching a campaign named "Fly Responsibly", calling on customers to fly less often. Meanwhile in Sweden, where the concept of 'flygskam' or flight shaming originated, rail traffic has grown by 10% in the last year, bringing increasing capacity challenges[5] and in the medium term a new high-speed line is planned.

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2. Greengauge 21 (2012). **The Carbon Impacts of HS2**. Available at **http://www.greengauge21.net/the-carbon-impacts-of-hs2/**

3. Åkerman, J. (2011) 'The Role of High-Speed Rail in Mitigating Climate Change—The Swedish Case Europabanan from a Life Cycle Perspective'. **Transportation Research Part D: Transport and Environment** 16 (3), 208–217.

4. Bündis 90 Die Grünen Bundestagsfraktion (2019). **Kurzstreckenflüge Zug um Zug Auf die Schiene verlagern**. Available at **https://www.N.de/fileadmin/media/gruenebundestag_de/themen_az/mobilitaet/pdf/2019-07_Autorenpapier_Zug_umZug_mLogo.pdf**

5. Various 2019 articles from **https://www.railjournal.com/tag/sweden/**

HS2 and the transport hierarchy

When thinking about waste or energy and the need for sustainability, there is a familiar slogan available: to "reduce, reuse, recycle". Far less well known is the transport hierarchy[6] shown below. But, with transport now the largest contributor to climate change, it is at least as important.

Sustainability			
+	**Priority 1**	**Minimise Demand**	Reduce the need for motorised travel, such as by planning for new developments to be mixed use and higher density.
	Priority 2	**Enable Modal Shift**	Increase the attractiveness of transport modes with the lowest environmental impacts, by improving their relative cost, reliability and journey times compared to driving. Improve integration between modes.
	Priority 3	**Optimise System Efficiency**	Increase average occupancy and energy efficiency of all modes, to reduce gCO_2e/km per passenger and freight tonne.
–	**Priority 4**	**Increase Capacity**	Any capacity increases required after taking the first three steps should be prioritised to the most efficient and sustainable modes.

6. e.g. Institution of Mechanical Engineers (2013) **Policy Statement: Transport Hierarchy**. Available from https://www.imeche.org/policy-and-press/reports/detail/transport-hierarchy

Minimise Demand

The urgency of net zero challenges this first step, as measures to minimise travel **demand**, such as land use planning, while valuable in the longer term, are insufficient to meet emissions reduction trajectories in the short term. So they will need to be supplemented by pricing and policy levers to reduce **travel**. A recent study suggests that to have a 66% chance of achieving the Paris 1.5˚C target, a reduction of car traffic of 40% by 2030 will be needed, even if there is substantial electrification of the fleet[7].

The vast majority of travel is by private motor vehicles, so measures aimed to reduce traffic, such as road user charging, could be expected to have a significant impact on the rail network even if accompanied by increased active travel, car sharing and bus use. Shifting 10% of passenger miles from private motor vehicles to rail would mean an increase in distance travelled on the rail network of over 80%[8]. With road traffic concentrated on the Strategic Road Network between and around our biggest cities, as shown in Figure 1 opposite, this growth would be concentrated on railways (and urban transit systems) that have experienced high growth over the last two decades in part because of high (and increasing) levels of road congestion. The railway lines concerned are typically at or close to capacity and can mostly only offer marginal increases in capacity although removing non-stopping services onto a new line would be an effective solution.

Modal Shift

Enabling a shift to transport modes with the least environmental impact comes next in the hierarchy of measures. Here it is relatively clear which modes are the most benign.

A key challenge is that dense, mixed, development requires improved rail as the backbone of sustainable travel[9]. But existing rail capacity in many growth areas like the South East Midlands is allocated primarily for longer distance travel.

Discouraging flights will not stop people taking holidays. Instead they are more likely to holiday nearer to home[10], adding to the pressure on congested surface transport corridors.

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7. Hopkinson L. and Sloman L. (2019). **Planning for less car use**. Available at https://policy.friendsoftheearth.uk/insight/more-electric-cars

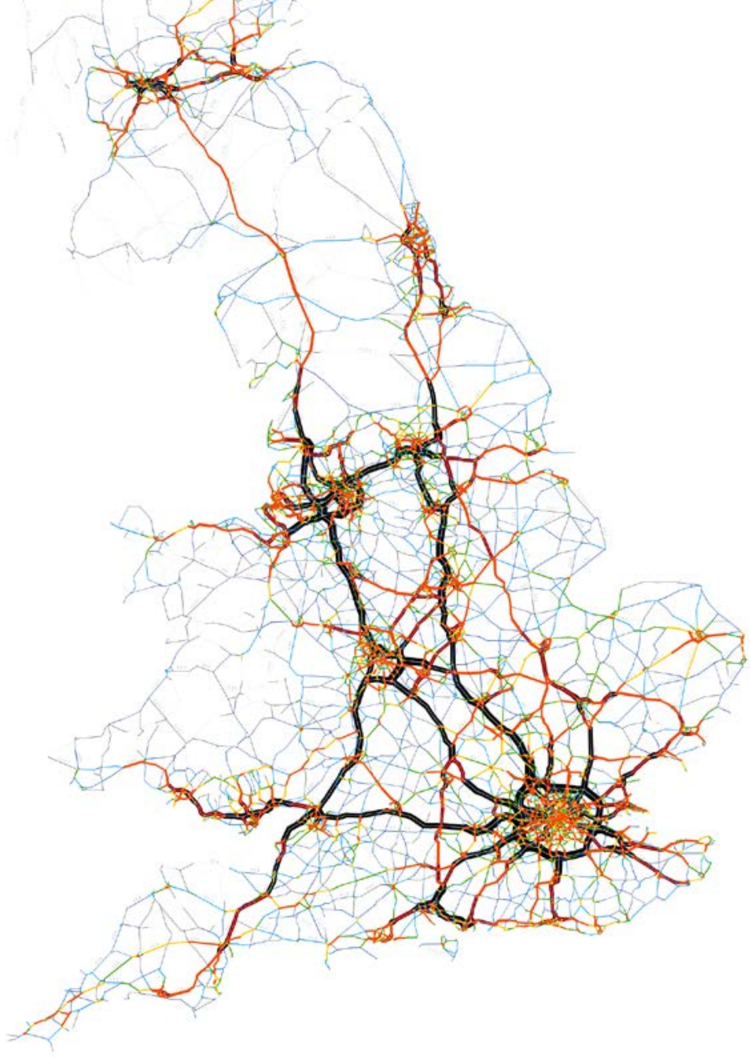
8. DfT provisional figures for 2017 are 670 billion passenger km for cars, vans and taxis compared to 80 for rail. Of course rail would not offer a viable alternative for some journeys, such as van journeys.

9. Hopkinson L. and Sloman L. (2019). **Planning for less car use**. Available from https://policy.friendsoftheearth.uk/insight/planning-less-car-use

10. Carmichael, R. (2019) **Behaviour change, public engagement and Net Zero**. A report for the Committee on Climate Change. Available at https://www.theccc.org.uk/publications/

Figure 1: Annual average daily flows (in thousands), 2015

Source: GB traffic open data (OGL) via https://en.wikipedia.org/wiki/Transport_in_the_United_Kingdom



Optimising efficiency

Electrifying road vehicles requires, in addition to a very substantial increase in national electrical power generation, significant mineral resources—as shown in Figure 2 overleaf—and there are concerns about becoming locked into a decarbonisation path that requires unsustainable quantities of them[11]. Electric trains offer greater spatial efficiency than road-based travel modes, greater efficiency compared to fuels like hydrogen, and fewer resource constraints compared to batteries. Therefore, for corridors with higher demand electrified railways are likely to remain the best option.

Optimisation, making private vehicles more energy efficient, lowers driving costs, and in turn creates rebound effects. Recent Norwegian research which has progressed rapidly along the path of electrifying its national car fleet, suggests a 1% increase in electric car registrations increases distance travelled by 0.63% in the short term and as high as 0.78% in the longer term[12]. All things being equal, a 50% increase in electric car registrations could therefore result in a significant traffic increase.

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11. National History Museum (2019) **Leading Scientists Set out Resource Challenge of Meeting Net Zero Emissions in the UK by 2050**. Available from **https://www.nhm.ac.uk/press-office/press-releases/leading-scientists-set-out-resource-challenge-of-meeting-net-zer.html**

12. Bauer G. (2018) The impact of battery electric vehicles on vehicle purchase and driving behaviour in Norway. **Transportation Research** Part D, 239–258

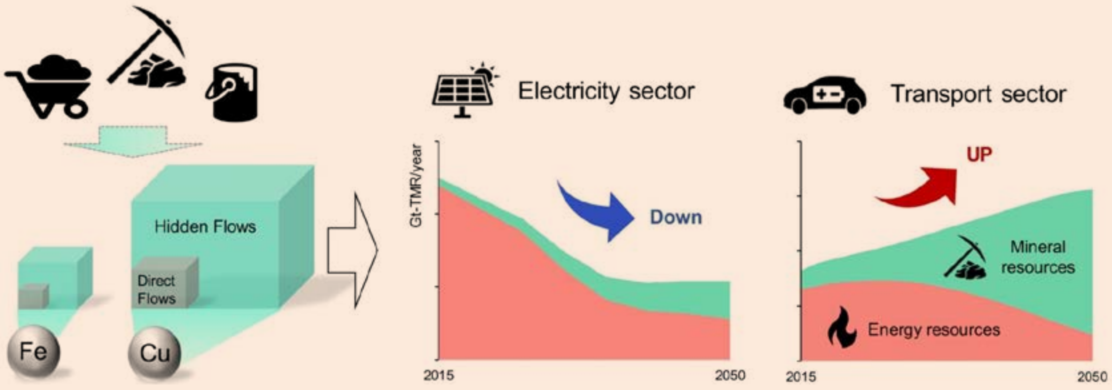

Figure 2: Criticality of earth metals for EV reliant transport transition[13]

Increasing capacity

Finally, in the hierarchy, is an increase in transport capacity for the most efficient and sustainable modes. Although a largely greenfield railway, HS2 would be highly space efficient itself—with the same capacity as a ten-lane motorway in normal use—and it also delivers more efficient use of three of the UK's main railway lines.

So HS2 represents an extremely important measure in any climate change mitigation strategy, likely to achieve by far the largest impact on car miles and air miles travelled of any measure available to increase capacity in sustainable travel modes (electrified rail). But the project needs to be seen in the context of the wider set of measures that, while not yet adopted, are going to be necessary to meet Government's targets for net zero carbon emissions.

13. Watari, T., McLellan, B.C., Giurco, D., Dominish, E., Yamasue, E., and Nansai, K. (2019) 'Total Material Requirement for the Global Energy Transition to 2050: A Focus on Transport and Electricity'. **Resources, Conservation and Recycling** 148, 91–103. Licensed under a Creative Commons Attribution 4.0 International Licence.

HS2's carbon: the story so far

Planning for HS2 started in 2009, in the wake of the historic enactment of the Climate Change Act 2008. After the route of Phase 1 to Birmingham was outlined in 2010, a high-level Appraisal of Sustainability was published in 2011. This analysed HS2's Life Cycle Carbon Emissions, referred to as its carbon footprint, in three different categories, which were: construction, operation and effects beyond the project itself, typically changes to road and air travel. The same categorisation is used in this report and is illustrated by the Figure 3 below, which shows forecasts made in 2016 for the full scheme.

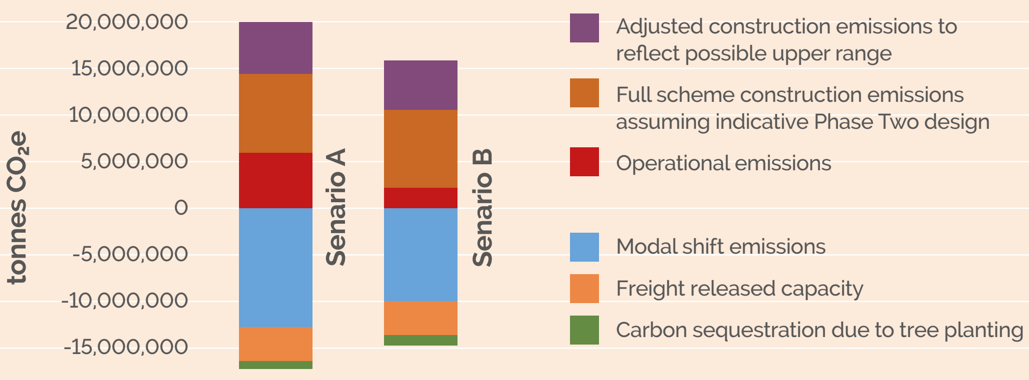

Figure 3: Carbon emissions for HS2 over the 60 years assessment period

Source: Sustainability Statement including Post Consultation Update (Nov 2016). Volume 1: Main report HS2 Ltd

The 2011 Appraisal had claimed that HS2 would be broadly carbon neutral, but the 2013 Environmental Statement, which by law had to assume the '**reasonable worst foreseeable**' case, calculated higher carbon impacts of construction and lower modal shift benefits. These assessments only focused on Phase 1—the most expensive in financial and also carbon terms due to requirements to tunnel out of London and under the Chilterns.

Because of the complexity of the consents required to construct and operate HS2, a hybrid bill was used to provide development consent. The Phase 1 bill was deposited in 2013, approved by the Commons in 2016 and the Lords in 2017. Arising from altercations between railway barons and aristocracy over the routes taken by the first railways, the process for hybrid bills focuses on protecting private rights and only one petitioner (disclosure: this report's author) was allowed to raise climate change as an issue, the first time this had been possible in front of a hybrid bill committee. The Commons committee failed however to even mention carbon in its report while the Lords simply touched on it in a short paragraph, the petitioner securing some assurances. Going forward, HS2's sustainability policy sets an ambition to be "the most sustainable high-speed railway of its kind in the world".

The greatest scope to influence the carbon footprint of a typical infrastructure project often comes early on, then declines until there is very little opportunity once it is in operation. By contrast, with HS2, it has huge potential to help reduce carbon emissions once it is in operation, and perhaps the greatest opportunities of all come through its wider interactions beyond the scheme's boundary and control (see Figure 4). Even though wider policies are not yet in place to deliver radical reductions in carbon emissions, the benefits of HS2 could still be enlarged as and when such policies are implemented in the years ahead—as it seems likely will prove necessary.

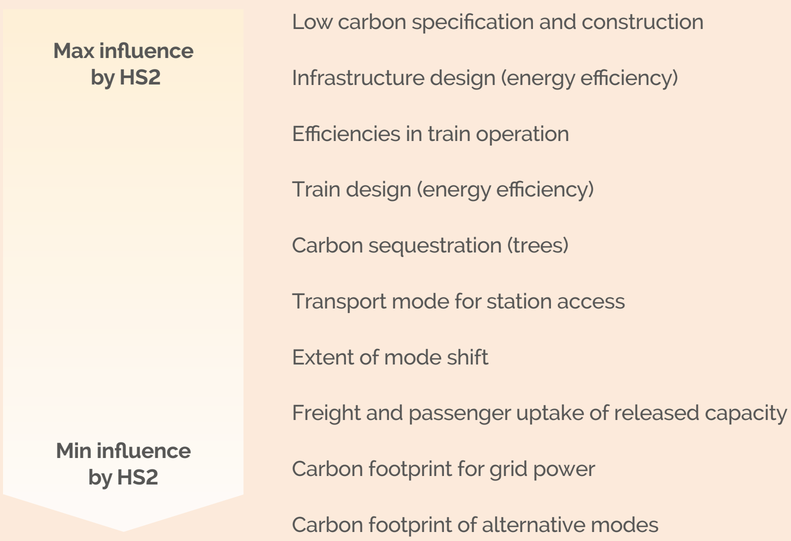

Figure 4: HS2 Ltd's influence and control over carbon footprint

Source: Sustainability Statement including Post Consultation Update (Nov 2016). Volume 1: Main report HS2 Ltd

Construction

The 2011 estimate for the emissions to construct Phase 1 was 1.2MtCO_2e but following a greater level of design and more conservative assumptions this had increased to 5.5MtCO_2e by 2013. Measures proposed to reduce Phase 1's local impact, such as longer tunnels, for instance, through the Chilterns Area of Outstanding Natural Beauty (AONB), secured in recognition of the importance of its historic landscape, raised the carbon footprint further to about 6MtCCO_2e by 2019 while the estimate for Phase 2a was 1.5MtCO_2e. For HS2 as a whole, the latest worst case estimate from 2016 is 14MtCO_2e, assuming the construction sector fails to reduce its footprint. The Environmental Statement for Phase 2b due in 2020 will provide more accuracy and detail.

From this high watermark, HS2 Ltd has adopted a stretch target to reduce embodied carbon emissions in the main works civil contracts by 50%. As the first megaproject to be fully digitalised through Building Information Modelling (BIM), as mandated in 2016 for publicly funded schemes, there is greater potential to optimise design and reduce the quantities of materials needed and minimise the distance earth needs to be moved. With each digger load being trackable, this is as different from previous construction sites as robot-operated warehouses are from the dusty stockrooms of the past.

HS2's sustainability approach has adopted circular economy principles, for instance designing elements such as noise barriers so they will be in good working order for as long as possible. Better designs can require greater embodied emissions in construction but then save on maintenance hence operational emissions, for instance noise barriers that will last 120 years rather than need to be replaced every 30 years.

Procurement decisions are supporting offsite construction that can make greater use of low-carbon concrete, which incorporates waste materials. A challenge that precluded adoption of this approach by Crossrail is its lack of certification, but this is now changing.

A year into their design work, contractor Align, working on the southern section of the Phase 1 alignment, has managed to secure carbon savings of 13% on the inherited design overall, with some individual assets reducing by as much as 97%. Final designs and specifications are still evolving but with the incorporation of low carbon electricity, an overall 20–30% carbon reduction is anticipated—as shown in Figure 5 overleaf.

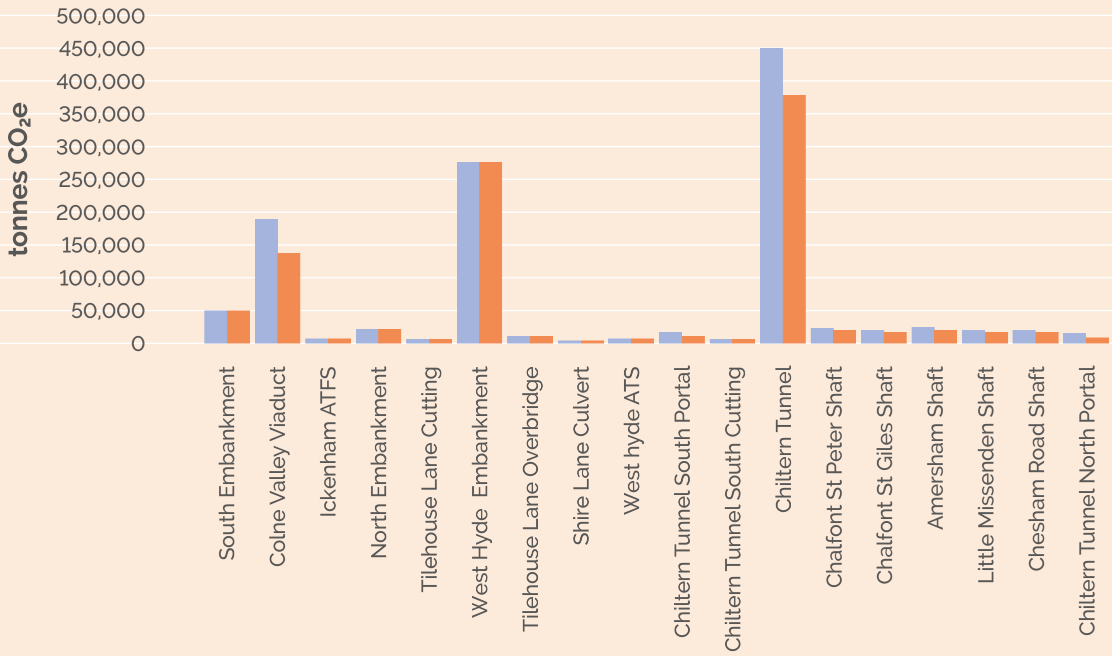

Figure 5: Carbon footprint savings from baseline to detailed design

Source: Align

Contractors have adopted innovations including hydrogen fuel cell powered mobile lighting towers and hybrid excavators, which can reduce fuel consumption by as much as 40%. The requirements of PAS 2080—the latest Carbon Management standard—are integral to the contractors approach, and have led to carbon reduction thinking being integrated into the design process not just within the lead contractors but also in the design houses through a knowledge management system, enabling the creation of a best practice legacy for the HS2 programme. Align and Eiffage Kier have both been recommended for Certification for PAS 2080 for the design phase of the project. Eiffage Kier has reduced the carbon footprint of green tunnels by an average of 39% and viaducts in one area by 49% through using pre-cast recycled concrete instead of energy intensive steel girders. Align has reduced the carbon footprint of the Colne Valley Viaduct by 28% through the redesign to a stronger, simpler design that requires less materials, and through the replacement of cement with waste material from the steel production process. Align's exemplar design for the shafts managed to reduce excavated materials by 66%, significantly reducing the carbon footprint of the shafts.

By comparison Crossrail's carbon footprint was calculated to be 1.7MtCO_2e, mainly consisting of 22km of tunnel plus stations, after securing a reduction of 19% over its estimate, well over the target of 8%[14]. To give a sense of scale, despite the fact that HS2 Phases 1 and 2A total around 175 route miles, its construction carbon footprint is only 50% greater than the impact of fuel duty being frozen since 2010[15]. For each year of construction, it would have a climate impact equivalent to less than a hundredth of UK aviation emissions or 0.5% of current road transport emissions[16].

The biggest component of HS2's carbon footprint is steel for its track, followed by concrete. Tunnelling significantly increases requirements for concrete. While there is a carbon impact from removing existing trees, as mature woodlands absorb more carbon dioxide that newly planted ones in their first years, it is a very small proportion, about 2%, of HS2's total carbon impact.

The House of Lords Committee considering the then High-Speed Rail (London–West Midlands) Bill in 2017 concluded that "[a]ll ancient woodland is irreplaceable, but the loss of less than one [hectare] out of about 11,000 in the AONB is, we consider, a remarkable achievement."

Balancing local and global impacts in an era of environmental transition is especially complex. One recent study noted that tunnelling under woods creates a higher carbon footprint and commented that "important decisions such as the percentage of the line that will run through tunnels [are] made more on the grounds of responding to political pressures, than considerations of long-term integrated environmental planning"[17]. That said, as the information above demonstrates, the scale of HS2 and its high environmental standards are enabling efficiencies to be made in reducing the carbon footprint of mitigation measures.

Operation

HS2's operational carbon footprint is made up of the electricity needed to power its trains and stations and from the maintenance of the railway, its trains and stations. Two factors are expected to reduce greatly the emissions forecasts from power. First the decarbonisation of the grid is happening faster than expected, and second, the delay in HS2's expected opening date means services will only start running after the grid is largely decarbonised. This means the question of HS2 operating speed—and the consequential energy requirements—is largely irrelevant to the calculation of the project's carbon impacts.

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14. Crossrail (2018). **Sustainability Summary**. Available from https://learninglegacy.crossrail.co.uk/wp-content/uploads/2018/07/Sustainability-Summary-2018.pdf

15. Greener Journeys (2019). T**he Unintended Consequences Of Freezing Fuel Duty**. Available at https://greenerjourneys.com/publication/the-unintended-consequences-of-freezing-fuel-duty/

16. 1/130th, based on 36.5MtCO_2e doubled to take account of radiative forcing.

17. Cornet, Y., Dudley, G., and Banister, D. (2018) 'High-speed rail: Implications for Carbon Emissions and Biodiversity'. **Case Studies on Transport Policy** 6 (3), 376–390.

Period	Proposed HS2 reference case for evaluation of energy strategy options (gCO_2e / kWh)
2026–2030	86
2031–2035	40
2036–2040	14
2041–2045	5
2046–beyond	0

Figure 6: HS2 Ltd assumptions on grid decarbonisation

Source: KPMG 2018

In the UK in 2018 300 TWh of electricity was generated, of which Network Rail is already the biggest single user, but only a very small proportion of total national electrical power consumption. With road transport and heating switching to electrical power, this could increase to around 600TWh by 2050. HS2 is expected to use 1.2TWh from phase 1 opening in 2010, increasing to 3TWh by 2040[18]. HS2 Ltd is assuming the pace of decarbonisation, shown in Figure 6 above, will enable HS2 to operate at as little as $8gCO_2e$ per passenger kilometre by 2030 and be zero carbon around 2050. HS2 would have very low operational emissions compared to Chinese high-speed rail , where the power grid intensity is currently as high as $1000gCO_2e$/kWh[19].

The increased penetration of renewables means marginal carbon intensity is increasingly dependent on the time of day when electricity is taken from the grid, with this being lowest during summer lunchtimes. HS2's peak demand would be winter evening rush hour when grid capacity is most constrained, so dedicated battery storage is being considered to enable greater use of cheaper, off-peak electricity. HS2 Ltd is also considering contracting directly for renewable energy through a Power Purchase Agreement (PPA), which would make it genuinely additional rather than simply meaning another user would be disadvantaged. This follows a trend by other large power users, for instance Google, which now has PPAs for 5.5MW of capacity[20]. The carbon footprint of this capacity contracted through a PPA would need to be added to the overall footprint for HS2 however.

18. KPMG (2018). **HS2 electricity strategy** – final report. Available from https://www.whatdotheyknow.com/request/487395/response/1177578/attach/4/FOI18%202020%20Annex%20A.pdf

19. Lin, J., Li, H., Huang, W., Xu, W., and Cheng, S. (2019) 'A Carbon Footprint of High-Speed Railways in China: A Case Study of the Beijing-& Shanghai Line'. **Journal of Industrial Ecology** 23 (4), 869–878.

20. Bradshaw, T. (2019) 'Google Touts "Biggest Ever" Wind and Solar Deals'. **Financial Times** [online]. 19 September. Available from https://www.ft.com/content/4cc42c88-db14-11e9-8f9b-77216ebe1f17

Seven million trees and shrubs will be planted along Phase 1. This planting will not only replace the trees that will be lost in construction but also mean an overall gain in tree coverage. The earlier trees are planted, the more chance they have to grow before summers become hotter still and the more carbon they will sequester and this will help the UK meet its future annual carbon budget targets.

Wider carbon impacts of HS2

Modal shift

To understand HS2's wider impacts it is necessary to compare not just where its users come from (modal shift) but the comparative emissions of different modes of transport and how HS2's stations are accessed.

Changes in distance travelled by mode and in cost of modes, albeit over different timescales are illustrated in Figures 7 and 8. While motoring costs are no higher today than five years ago, train fares increases have been significant. Nevertheless, rail demand has continued to grow strongly and with an increased market share.

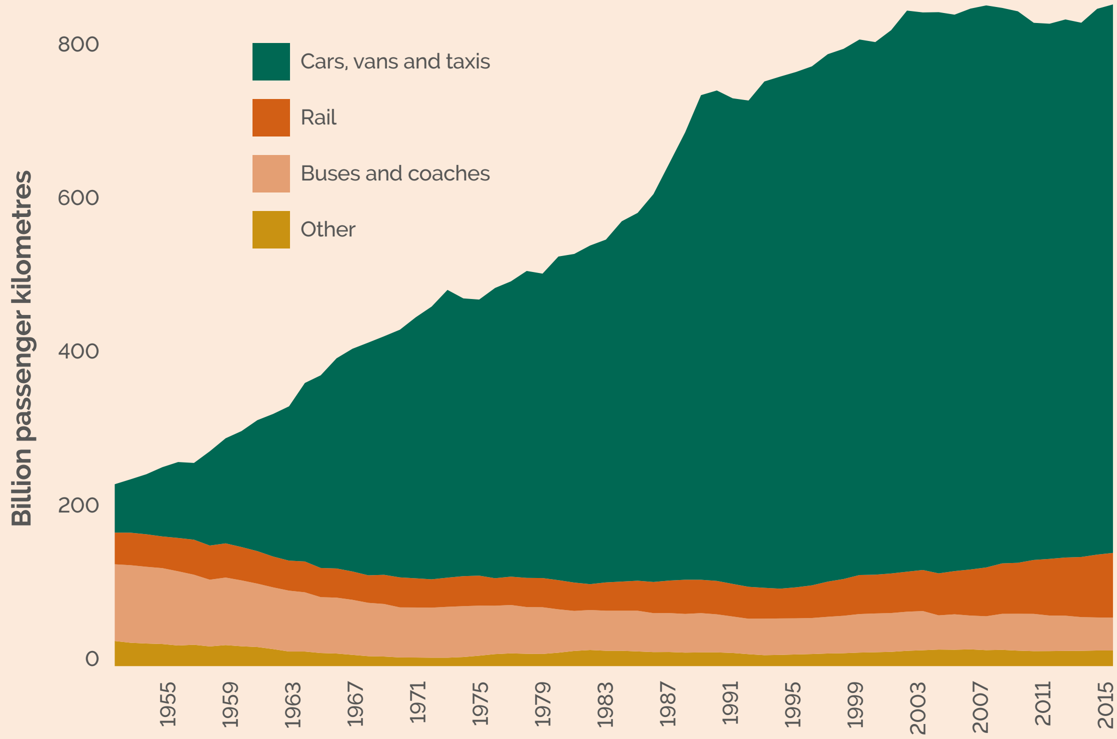

Figure 7: Trends in UK surface travel

Source: DfT 2018 (TSGB0101-0102)

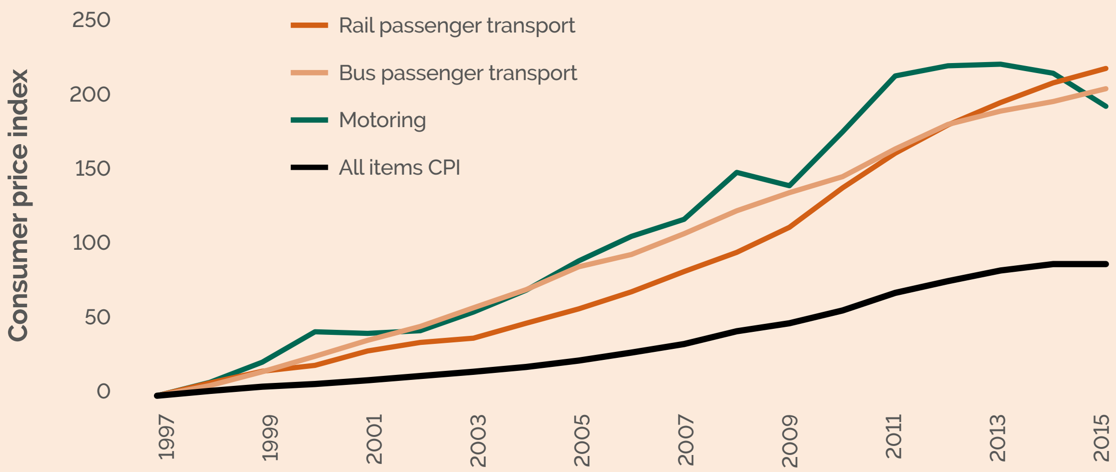

Figure 8: Trends in UK surface transport costs
Source: DfT 2018 (TSGB1308)

Another trend is the decoupling of urban and interurban traffic flow trends, with traffic stabilising on the former and increasing on the latter. The DfT acknowledges that its National Transport Model (NTM) does not provide accurate forecasts for London as the city discourages driving and benefits integrated public transport. Other cities may start following London's trend on reduced car use, especially if they reallocate road space towards sustainable modes and gain powers to deliver user friendly 'pay as you go' ticketing.

The low forecasts for modal shift, not materially changed since 2013, have been one of the biggest criticisms of the HS2 business case. Figure 9 contrasts the forecasts for HS2 once completed, against the European high-speed rail average as experienced.

There are three issues to bear in mind on this subject.

First, the HS2 forecasts are founded on assumptions that rail fares increase at RPI+1% while driving and flying become ever more affordable, through frozen fuel duty. The introduction of measures to manage air and road demand necessary to contribute towards achieving net zero (see 2050 net zero scenarios below) would radically change the forecast modal splits. Indeed, in this context, the creation of HS2 can be seen as providing what is likely to be regarded as a necessary counter-part to the demand management measures that are inescapably going to be needed across other travel modes to achieve compliance with the Government's carbon commitment.

	2013 forecast worst case scenario for full HS2 network	European average in practice
New trips	26%	25%
From conventional rail	69%	30%
From car	4%	15%
From aviation	1%	30%

Figure 9: Comparison of high-speed rail modal shift [21]

Second, unlike some European schemes designed to provide faster connections that leave minimal services on twisting alignments through depopulated areas, a key benefit of HS2 is freeing up congested, existing railways for new services. To understand HS2's true impact on modal shift, it is necessary to know the service patterns on these liberated lines since these services will also deliver modal shift from cars. Under the current structure of the industry, how capacity is re-used depends on complex interactions between DfT, Network Rail, franchises, the Office of Rail and Road plus now combined authorities. No firm plans have yet been released, although Network Rail is now consulting regional bodies.

Third, there is also an issue of the consequential wider impact of HS2 on land use development patterns: by unlocking major development HS2 would create significant effects, increasing the ability to shift away from car-dependent residential and commercial arrangements. But assessing the full extent of HS2's impact on modal shift, including how to develop a counterfactual, is difficult: how do you model where someone in 2040 would live in with and without HS2 cases, let alone how they would travel?

HS2 Ltd has modelled the impact of different rates of electrification and decarbonisation, with scenario A in the Figure 10 below assuming a less aggressive trajectory than scenario B. Neither scenarios assume wider policies to secure modal shift, however.

21. HS2 Ltd (2013). Economic Case for HS2 Preston, J. (2013) **The Economics of Investment in High-speed rail Summary and Conclusions** OECD, International Transport Forum. Available from https://www.itf-oecd.org/sites/default/files/docs/dp201330.pdf

Modal Type	Scenario A ($MtCO_2e$)	Scenario B ($MtCO_2e$)
Domestic aviation	-9.73	-9.73
Existing rail services	-0.53	-0.07
Long distance road	-3.21	-0.46
Road Access	+0.57	+0.05
Total	**-12.90**	**-10.21**

Figure 10: Comparison of modal impacts

Source: HS2 Phase 2b Sustainability Statement including Post Consultation Update (Nov 2016), Volume 1: Main report

Future emissions by mode

Although high-speed rail has the most favourable emission factor, in terms of CO_2 per passenger kilometre, most other modes are expected to decarbonise too. The DfT currently aims to stop the sale of petrol- and diesel-only cars and remove diesel-only trains by 2040, though that target would still allow hybrids. While there are marginal efficiency gains for planes, like trains they have a long lifespan and hybrid planes are not expected to be widespread even by 2050. Illustrating the complex interactions between technology and people, the trends are not always in the right direction. Although UK car efficiency improved some years, the increased popularity of SUVs has meant new car emissions have increased every year since 2016, more than offsetting the rise of Electric Vehicles (EVs). Autonomous Vehicles currently have a much higher energy consumption than human driven ones: though this uplift will decline over time, they would still put significantly greater pressure on the grid than has been modelled to date.

Carbon footprint of vehicles and supportive infrastructure

Despite concerns about the growing amount of carbon embodied in batteries required for EVs, it has not proved possible to source the necessary data to compare embodied carbon in trains and cars. Even if well loaded, trains are heavier per passenger than cars, but are far more intensively used and have much longer operational lives, so overall have a much lower embodied carbon per passenger kilometre. They are also not dependent on rare earth metals.

It is challenging to forecast how higher rates of rail use might translate into lower car ownership[22], not least with innovations such as Mobility as a Service (MaaS) potentially proving transformative in replacing mass car ownership[23].

While HS2's carbon footprint has faced criticism, in part this is because of the greater transparency in assessing the footprint of clearly specified new infrastructure subject to Parliamentary scrutiny. By comparison, the 2019 study informing the CCC on decarbonising HGVs was simply unable to assess either the comparative footprint of electrifying roads or of providing hydrogen infrastructure nationally.

Station access

In the early years of HS2's design development, forecasts for modal share of passengers accessing HS2 stations suggested high usage of unsustainable modes for out-of-town stations like Birmingham Interchange, eroding the carbon benefits of modal shift as well as congestion reduction. The proposed HS2 stations have since crystallised proposals for new public transport facilities and higher density mixed development. Sites previously proposed for large car parks at Birmingham Interchange and East Midlands Hub (Toton) are now planned to be filled by compact housing linked to new tram lines and integrated with new cycle route networks.

The stations proposed originally are morphing from parkways into sustainable urban extensions. While HS2's later opening means a higher proportion of station access will be by EVs, ambitious travel plans and targets should be set to minimise any negative impact on HS2's carbon footprint and deliver true beacons of sustainable development.

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22. Åkerman, J. (2011) op cit.

23. Kamargianni, M., Matyas, M., Li, W., and Muscat, J. (2018) Londoners' attitudes towards car-ownership and Mobility-as-a-Service: Impact assessment and opportunities that lie ahead. **MaaSLab – UCL Energy Institute Report, Prepared for Transport for London**. Available from https://www.maaslab.org/copy-of-maas-publications

Towards net zero scenarios

Traditionally the distinction between scenarios and strategies was that the former related to external and uncontrollable factors, while the latter set out those that were controllable. But there is no clear boundary, with issues like behaviour change straddling the divide. With growing uncertainty, scenarios are an important tool to tell the story of, and understand the range of, possible futures that infrastructure systems may inhabit. For systems such as transport, spatial demand is as relevant as aggregate demand[24].

Although cost, congestion and carbon have been described as the key factors, the reality is that public acceptability is a critical challenge too, as debates on road charging have shown. Net zero will require difficult policy choices, so it is simply not possible to forecast modal shift based on elasticities and changes to pricing. Adding to the complexity are socio-technical interactions, for instance the potential of "flight shaming" to lead to increases in long distance rail travel, or social trends redefining driving in cities as unacceptable as smoking is, helping the trend towards tech start-ups developing new forms of micro-mobility.

2050 net zero

The 2050 net zero commitment has not yet fed through to wider policies. A particular challenge will be how the National Infrastructure Strategy, due to be published this year, deals with net zero. This Strategy is the Government's response to the 2018 National Infrastructure Assessment (NIA) that assumed only an 80% reduction. The NIA did not examine the case for infrastructure that the Government had been presumed to have already decided to implement, including HS2, Heathrow's Third Runway and Road Investment Strategy 2. In 2020, the CCC is due to publish a report on the most cost-effective pathway as part of its advice on the sixth carbon budget covering 2033–37. It has repeatedly called for a shift in demand from roads to public transport and active modes but does not appear to have carried out analysis of the rail capacity potentially required for this[25].

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24. Hall, J.W. (ed.) (2016) **The Future of National Infrastructure: A System-of-Systems Approach**. Cambridge, UK ; New York: Cambridge University Press.

25. CCC (2019). **Net Zero** technical report.

There are two broad areas of uncertainty. In the shorter term, a no-deal Brexit means leaving the EU Emissions Trading Scheme, relevant to HS2 in terms of its impact on the power, aviation and industry (e.g. construction) sectors. To deliver net zero, the CCC has recommended both a higher carbon price, through some form of trading, and the use of other policy levers[26]. In the longer term, technologies such as bio-energy for Carbon Capture and Storage are required to deliver negative emissions to cancel out those remaining from construction and aviation. This remains unproven at the scale needed, however some argue for a steeper trajectory as an insurance policy, which in turn is likely to require more efficient use of land and energy. Germany is one of the few countries with targets to reduce end-use energy of transport, requiring a 10% reduction from 2005 levels by 2020 and a 40% reduction by 2050. Progress has been limited, however, other than for the rail sector, which has in the last 20 years halved its energy requirements per passenger and freight kilometre[27].

In terms of HS2's construction, the net zero target will change the context of what is "practicable" in HS2's policies. Construction can be expected to decarbonise faster as firms realise the importance of lower carbon innovation and investment, likewise to operational emissions from maintenance. The situation for electricity, assuming HS2 does not contract its own renewable power, is less clear. Net zero will encourage more renewable capacity to come on stream faster but also a faster pace of electrification of heat and transport, which by increasing demand for electricity, could slow the grid's decarbonisation trajectory[28]. Likewise, for modal shift, net zero is likely to increase the penetration of EVs but also require more road and air demand management policies. Finally, it is likely to change leisure trip patterns, reducing long haul flights that are less substitutable by rail, particularly if leading to a frequent flyer levy[29].

Additional options could be needed including double decker trains for services operating wholly on HS2, which could deliver a 40% reduction in operational energy required per seat. These would require using an international standard platform height.

Aviation

Biofuels were promoted as a major solution for reconciling aviation and the climate. One recent paper suggested "while airlines have the opportunity to switch to non-conventional jet fuels, e.g., biofuels, in order to reduce their own environmental footprint, the generation mix for electricity is heavily constrained"[30]. Yet the reality has quickly turned out very differently, with serious concerns about emissions from Indirect Land Use Change heavily constraining biofuel usage. By contrast plummeting prices for renewables led to decarbonisation of the UK national grid far faster than not long ago was considered unrealistic.

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26. CCC (2019). Letter: The future of carbon pricing.

27. Wilke, S. (2019) **Endenergieverbrauch und Energieeffizienz des Verkehrs** (Final energy consumption and energy efficiency of transport). German Environment Agency. Available from **https://www.umweltbundesamt.de/daten/verkehr/endenergieverbrauch-energieeffizienz-des-verkehrs**

28. CCC (2019). Net Zero The UK's contribution to stopping global warming.

29. Carmichael, R. (2019) op. cit.

30. D'Alfonso, T., Jiang, C., and Bracaglia, V. (2015) 'Would Competition between Air Transport and High-Speed Rail Benefit Environment and Social Welfare?' **Transportation Research Part B: Methodological** 74, 118–137.

Noting the challenges of other touted solutions such as electric planes, the CCC asked the Government in its forthcoming Aviation Strategy to demonstrate that any investments "make economic sense in a net-zero world and the transition towards it". Highlighting the importance of reducing demand, it suggests some combination of pricing, a frequent flyer levy, other taxation or airport capacity management is required, stating that continuing with Heathrow expansion would at best preclude growth at regional airports[31].

Rail's share of travel between Scotland's central belt and London increased from 20% to 33% between 2005 and 2015[32]. Virgin Trains were aiming for 50% by 2023 but this is still low by international standards. Network constraints between Cheshire/Lancashire and central Scotland limit the potential for modal shift from air and road freight to rail[33]. There is a strong case for an upgrade to be completed by the time HS2 opens to Crewe or soon thereafter to enable more trains and a London—central Scotland journey time of three hours, helped by potential high-speed rail investment within Scotland. Although rail's competitiveness against flying drops off for journeys of four hours or more, different pricing and social attitudes may in future increase this threshold, so modal shift for travel between Scotland, the North of England and the Midlands and cities like Paris and Brussels should not be ignored.

With HS1 providing the UK's only ultra-low carbon international connection, net zero policies are likely to lead to an expansion of international services. Additional international services on HS1 could link to HS2 at Old Oak Common for easy interchange[34]. While the carbon and financial cost of the additional tunnelling required would be considerable, the potential for modal shift from air would outweigh this.

Freight

Carbon pricing led to a shift away from coal that reduced rail freight but other products—aggregates for the building industry and containers to/from ports in particular—have continued to grow, year on year. Environmental charges could significantly increase rail freight demand. The DfT consulted in 2017 on modernising the HGV levy to a distance-based model and is going to need to progress this to tackle freight emissions. Such levies have made high speed freight services viable in Germany, for instance[35]. More generally, HS2 allows more rail freight paths on the West Coast Main Line, and any further switch from HGVs to rail freight will have a large beneficial carbon impact.

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31. CCC (2019). Letter: International aviation and shipping and net zero.

32. Transform Scotland (2017). **A green journey to growth**. Available from **http://transformscotland.org.uk/wp/wp-content/uploads/2017/08/A-Green-Journey-to-Growth-Transform-Scotland-report.pdf**

33. Greengauge 21 (2016). **Linking North to South**. Available from **http://www.greengauge21.net/linking-north-to-south/**

34. Greengauge 21 (2013). **Travel market demand and the HS1–HS2 link**. Available from **http://www.greengauge21.net/travel-market-demand-and-the-hs1-hs2-link/**

35. Liang, X.-H., Tan, K.-H., Whiteing, A., Nash, C., and Johnson, D. (2016) 'Parcels and Mail by High-speed rail–A Comparative Analysis of Germany, France and China'. **Journal of Rail Transport Planning & Management** 6 (2), 77–88.

Though HS2 is not designed for conventional rail freight, there is growing interest internationally for shifting high value freight from air to high-speed rail, in recognition of the carbon benefits. New research suggests that air freight is responsible for a fifth of all aviation emissions[36]. In China there are dedicated high speed freight trains for high volume routes but also the first train of the day, the inspection train, can be used for parcels. In 2018 Italy introduced Mercitalia Fast, a dedicated high-speed freight train.

Extreme ambition

The CCC set 2050 to achieve net zero as "the latest date for the UK credibly to maintain its status as a climate leader and the earliest to be credibly deliverable alongside other government objectives"[37]. Evidence of the climate changing faster than anticipated has led some to call for an earlier date, which would require a sense of purpose not seen since the 1940s. While Extinction Rebellion campaigns for 2025, Labour in its September 2019 conference adopted 2030 as the date and, being the policy of the Opposition, this date is used for this scenario.

To secure such a rapid decrease in emissions, policies would be required of a radical nature unseen since the oil crisis in the 1970s, when highway speed limits were reduced to 50mph and motorists issued with petrol ration books[38]. These would in turn lead to surging demand for rail travel that would make it even more challenging to upgrade the existing network as an alternative to HS2. There would be pressure to deliver the step-change in capacity offered by HS2 faster, potentially making it harder to reduce HS2's construction footprint at the same time.

A lower operating speed could be needed for HS2's first ten or so years as the need for rapid decarbonisation of all transport and heat as well as the grid would lead to surging electricity demand, but it would still offer substantial advantages over a road network restricted to much lower speeds.

36. Graver, B., Zhang, K., and Rutherford, D. (2019) **CO_2 Emissions from Commercial Aviation**, 2018. International Council on Clean Transportation. Available from https://theicct.org/publications/co2-emissions-commercial-aviation-2018

37. CCC (2019), op. cit. page 1.

38. Parish, D. (2009). The 1973—1975 **Energy Crisis and Its Impact on Transport**. RAC Foundation Report. Available at https://www.racfoundation.org/wp-content/uploads/2017/11/energy-crisis-parish-161009-report.pdf

Reduced ambition and unintended consequences

Despite the ever clearer science, some are still questioning the Paris Agreement's ambition, while others fail to convert supportive words into the level of action required. Constructing a scenario around reduced climate ambitions is not meant to challenge the science in any way but simply to stress test the case for HS2 further, exploring a future where air and road traffic continue to grow, net zero is not achieved and the climate becomes more extreme.

A slower policy pace on decarbonisation would be likely to mean relatively higher emissions in construction and operation, and minimal reduction from the current forecasts. The wider carbon impact would be significantly worse. Increased competition between HS2 and aviation could lead to lower flight prices. Another potential outcome is airlines maintaining connections to Heathrow given its hub status, albeit with smaller planes that have higher emissions per seat. There would be less likelihood of this with stronger demand management policies.

By providing faster journeys and by freeing up congested existing railways for new services, HS2 would initially reduce traffic on roads. However, where additional capacity is provided on congested roads, whether by adding space or taking away existing traffic, traffic flows can grow as much as high as 8–10% per year [39]. Without locking in the potential road decongestion effect, key environmental benefits could evaporate, which is why one academic article even recommended constructing HS2 on the lanes of an existing motorway to lock in reductions of capacity [40]. Even that would fail to lock in the benefits on roads alongside the three mainlines freed up by HS2, which only a comprehensive policy such as national road charging could deliver.

DfT forecasts suggest that rapid vehicle electrification would lead to cheaper driving and hence rapid traffic growth, unless fuel duty was replaced by another type of charge. This growth would increase congestion greatest on roads in and between the biggest cities. HS2 would have an increasing advantage due to offering reliable journey times; by contrast it would be regional and rural railways that could be more detrimentally affected.

39. DfT (2008). Roads—**Delivering Choice and Reliability**.

40. Cornet, Dudley, and Banister, op. cit.

Adaptation

Assuming lesser ambition translated into more extreme weather—though of course there is a lag—there would be notable changes in operation. The CCC advises "it is prudent to plan adaptation strategies for a scenario of 4˚C, but there is little evidence of adaptation planning for even 2˚C"[41]. Being nearly 200 years old in places, the conventional rail network has not been designed for weather extremes and has a twofold higher risk of flooding compared to the strategic road network, and a far higher risk of significant disruption from such flooding[42].

With limited awareness of geotechnical engineering in the Victorian era, the conventional railway network has a far higher risk of landslips and, because of a lack of diversionary routes, lines affected experience greater disruption when it does occur. By contrast HS2 has been designed for extreme weather events, hot and cold, drought and intense rain, for instance to cope with a 1-in-100 year plus climate change flood and to be resilient to a 1-in-1000 year event[43]. This increases its capital and carbon cost, for example by requiring longer viaducts, shallower earthwork slopes and more retaining walls, but it means HS2 will be the most resilient part of the national transport network in a more uncertain future.

From 2013 to 2018, a total of just nine trains on HS1 were delayed due to severe weather and seasonal challenges like leaf fall[44], making it far more reliable than the conventional rail network.

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41. CCC (2019). **Progress in preparing for climate change: 2019** Report to Parliament. Available from https://www.theccc.org.uk/publication

42. Environment Agency (2009). **Flooding in England: national assessment of flood risk**. Available from https://www.gov.uk/government/publications/flooding-in-england-national-assessment-of-flood-risk

43. Since the publication of the **Phase 1 and 2a Environmental Statements**, the Met Office published new climate predictions (UKCP18) that included a 4C increase. These should be taken account of in the phase 2B Environmental Statement due in 2020.

44. Office of Rail and Road (2019). **Annual report on HS1 Ltd 2018–19**. Available at https://orr.gov.uk/rail/economic-regulation/high-speed-1/annual-reports-on-hs1-ltd


HS2 visual by CAPITA

The wider choice on investment strategies

Recent literature[45] categorises strategies to manage infrastructure into four types:

- Minimum Intervention;
- Capacity Expansion;
- System Efficiency; and
- System Restructuring.

As continuing increases in carbon emissions demonstrate, continuing with Minimal Intervention or Capacity Expansion would be incompatible with net zero while the third—system efficiency—if focused simply on demand reduction, would come up against social and physical constraints. Only so-called System Restructuring was found to be robust enough in the long-term to meet carbon reduction commitments and for wider interactions such as extreme weather, though that analysis was before the net zero commitment.

HS2 is viewed as Capacity Expansion. The 2010 High-speed rail White Paper also made the case that by segregating service types, the existing railways network could effectively be restructured to offer three times the capacity, enabling existing congested railways to be reclaimed. HS2 could, particularly with complementary demand measures, be more appropriately viewed as System Restructing.

45. Hall (2016) op. cit.

De-scoping HS2

HS2's cost per mile, in financial or carbon terms, is generally greatest where it runs into cities due to the tunnelling required. Stopping it short of city centres has been suggested as one possible outcome of the Review of the project.

The impact on modal shift from reducing HS2's reach would be significant. At the strategic level an HS2 service that only travelled between suburbs rather than city centres would not enable significant changes to service patterns on existing lines, such as by strengthening local rail services and increasing the number of freight trains that can be accommodated; would jeopardise both HS2's ability to attract car users and its transformational wider impacts. With an out-of-centre location similar to that of airports, it would also remove one of rail's major advantages of convenience, reducing potential for modal shift from aviation. In terms of access, the modal split for sustainable travel would be worse, close to that of airports than city termini, increasing emissions and pressure for road expansion. If cities move forward with road user charging before HS2 opens, capacity on connecting services, for instance in London Crossrail at Old Oak Common would become even more strained. Cutting the network short could also reduce the benefits for urban regeneration and increase pressure to develop in the Green Belt. In short, such a change would be very harmful to the generation of carbon benefits from HS2.

Another way to rescope HS2, also apparently under consideration in the Oakervee Review, would be to remove its eastern arm—as discussed in the FT [46]. But there is a strong case for using the eastern arm to create new interregional services as well as those already planned, and this would increase its utilisation and its carbon reduction contribution [47].

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46. Plimmer, G. and Bounds, A. (2019) 'HS2 Rail Review Looks at Axing Eastern Extension to Leeds'. **Financial Times** 4 October. Available from https://www.ft.com/content/16593c8a-e693-11e9-b112-9624ec9edc59

47. Greengauge21 (2018). **Beyond HS2**, a plan for a national rail strategy. Available from http://www.greengauge21.net/beyond-hs2-a-plan-for-a-national-rail-strategy/

Alternatives to HS2

In the decade since HS2 was proposed, more alternatives have been considered than any other major transport scheme. Yet still the claim is made that there are cheaper yet better alternatives just waiting to be discovered, typically involving new lines with lower design speeds or upgrading the conventional railway network. Most recently the New Economics Foundation (NEF) proposed "more four track sections on the three core, north-south mainlines and of bridges to take slower, regional lines over intercity lines" while also claiming "more strategically focussed design compromising some speed for more and better interconnection would almost certainly be cheaper and likely to solve more capacity problems" [48].

The Government's reasons for preferring HS2 over upgrading the conventional railway network were twofold. First, there were simply no practical solutions to deliver such a transformational increase in capacity, as opposed to incremental increases that would only provide respite for a short period, perhaps at best around a decade based on current growth rates. Second, even though building HS2 would have some adverse rail impacts, the scale of disruption caused by upgrading three mainlines would be enormous. The NEF report criticised HS2's "highly optimistic assumptions for passenger growth", ignoring the likelihood of future modal shift policies, but acknowledged that the disruption from alternative upgrades could be "insurmountable".

Due to their weak strategic case, upgrades were not scoped in detail to enable their carbon footprints to be compared with HS2. But given HS2's efficiency in unlocking capacity on the conventional railway network by segregating non-stop trains, it is very unlikely that an upgrade approach would produce the operational carbon benefits that stem from the HS2 project. And there is no reason to suppose that changing HS2's alignment would result in any significant change in carbon impacts, unless the replacement route abandoned sections of tunnelling as a local environmental impact mitigation measure.

48. Pendleton, A., Salveson, P., and Kiberd, E. (2019) **A Rail Network for Everyone**. New Economics Foundation. Available from https://neweconomics.org/2019/03/a-rail-network-for-everyone

Unlocking sustainable housing through HS2

Over the years since HS2 was first announced, the consensus has grown on the need to provide more affordable housing in well-designed places. Although higher density development is being proposed around HS2 stations and the importance of this agenda was highlighted in the recent stocktake from HS2 Ltd's Chair Alan Cook, what has been missing from the debate so far is its importance to achieving net zero. With the forthcoming Road Investment Strategy 2 focused on unlocking car-dependent housing through road building, the potential for rail-oriented development which is crucial to unlock higher density patterns of housing requires highlighting.

Compact urban development, in comparison to detached housing, reduces not only occupants' car use[49] but also energy requirements for construction and use, by as much as a factor of four[50]. With higher densities, there is a far higher potential for district heating too, which can also enable district heat storage to be provided to tackle the challenge of windless winter weeks. Changes made in 2018 to the National Planning Policy Framework support this approach around new HS2 stations:

> **"122. Planning policies and decisions should support development that makes efficient use of land, taking into account:...(c) the availability and capacity of infrastructure and services—both existing and proposed—as well as their potential for further improvement and the scope to promote sustainable travel modes that limit future car use."**

The remaining challenge is for development in the immediate catchment of stations on the conventional network that could benefit from capacity being freed up by HS2. Because of the continuing lack of clarity around how capacity on the existing network liberated by HS2 has not yet catalysed 'good growth' and higher densities around these stations, which are many in number.

49. Hopkinson L. and Sloman L. (2019). **Planning for less car use**. Available from https://policy.friendsoftheearth.uk/insight/planning-less-car-use

50. Rode, P., Keim, C., Robazza, G., Viejo, P., and Schofield, J. (2014) 'Cities and Energy: Urban Morphology and Residential Heat-Energy Demand': **Environment and Planning B: Planning and Design**.

Wider decarbonisation interactions

The scale of HS2 has stretched the boundaries and capabilities of conventional appraisal that was created for far smaller interventions. The transformative change in capacity and journey times it offers is likely to go beyond normal thresholds and make accurate forecasting impossible. In the recent stocktake, HS2 Ltd's Chair Alan Cook proposed developing "a methodology that better reflects the long term and transformational changes that will be brought about by programmes such as HS2".

It is clear the current approach of simply monetising carbon emissions in a Value for Money assessment is hindering the DfT making its contribution to carbon budgets[51]. Switching to an approach that simply adds up a scheme's direct contribution to carbon budgets would need to consider different carbon reduction pathways. The challenge for such an assessment of HS2 is its multiple interactions between transport, energy and housing and the difficulty of comparing these to a do minimum alternative. Should the carbon footprint of renewable electricity generation be added to HS2's footprint, and if so, why not that required for millions of electric cars?

51. Hopkinson L. and Sloman L. (2019). **Getting the Department for Transport on the right track**. Available from https://policy.friendsoftheearth.uk/insight/getting-department-transport-right-track

Achieving net zero will require deep transitions in a range of interconnected socio-technical systems[52]. For those used to smaller schemes and slower, incremental, linear change, these systemic interactions can be particularly challenging to grasp.

What evidence is emerging about HS2's impact on transforming the supply chain's approach to carbon, compared to a package of smaller schemes? Drawing on literature on sustainable socio-technical transitions, four categories are suggested here for further exploration, namely:

- Technological: including critical constraints such as rare natural resources across different infrastructure systems;
- Institutional: agility and regulatory ease of entrenching the net zero trajectory;
- Market and financial: scaling across supply chains and interaction with wider systems, and
- Public: for example acceptability and behaviour change.

52. Geels, F.W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., Neukirch, M., and Wassermann, S. (2016) 'The Enactment of Socio-Technical Transition Pathways: A Reformulated Typology and a Comparative Multi-Level Analysis of the German and UK Low-Carbon Electricity Transitions (1990–2014)'. **Research Policy** 45 (4), 896–913

Conclusions

Delivering net zero requires major changes in travel patterns, which are as likely to improve HS2's value for money as well as its carbon case. Alternatives would not deliver the step change in capacity required while disrupting existing railways during their construction. Though there is considerable uncertainty about the future, on very high demand corridors like those that HS2 would serve, high speed rail has a strong case.

Net zero requires further action to sweat HS2's carbon benefits, however, including upgrading Anglo-Scottish railways and considering the potential for high speed high value freight. The wider benefits of rail capacity in enabling compact housing, which in turn leads to lower energy requirements for construction, heating and transport, will be increasingly important in a net zero UK and should be given further consideration.

HS2 would offer significantly greater resilience than existing railways and, with extreme weather becoming more prevalent, its key role as infrastructure for climate adaptation should be given more attention.

HS2—towards a zero carbon future

An independent review of the carbon case for HS2

by Ralph Smyth, November 2019

HIGH SPEED RAIL
INDUSTRY LEADERS