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Re-thinking Transport Carbon - Getting to the 2050 targets

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Abstract:	In the aftermath of the Infrastructure Carbon Review (GCB, 2013), this paper looks at the UK present transport carbon emissions and their future projections in the wider context of the transport status quo and the plans for growth. Transport is a complex system that is integral to the national structure, without which society cannot function. At the same time, transport is a significant contributor to the national emissions footprint and requires a step change to achieve the legally binding reduction targets of the 2008 Climate Change Act. This paper reasons the urgency for rebalancing the transport modal mix, while integrating all in a seamless transport system with smart interfacing between modes and drivers for behavioural change.
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For the attention of For the attention of ICE Publishing

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Dear Sirs

Rethinking Transport Carbon - Paper submission for publication in the ICE Civil Engineering Proceedings

Please find uploaded our revised submission of the above paper, including a list of revised items. We believe that we have addressed all comments appropriately. We hope that this is now acceptable for publication.

Please do not hesitate to contact me for any clarifications or comments.

Yours faithfully

Heleni Pantelidou
Associate Director

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Re-thinking Transport Carbon – Getting to the 2050 targets

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Abstract (150 words)

In the aftermath of the Infrastructure Carbon Review (GCB, 2013), this paper looks at the UK present transport carbon emissions and their future projections in the wider context of the transport status quo and the plans for growth. Transport is a complex system that is integral to the national structure, without which society cannot function. At the same time, transport is a significant contributor to the national emissions footprint and requires a step change to achieve the legally binding reduction targets of the 2008 Climate Change Act. This paper reasons the urgency for rebalancing the transport modal mix, while integrating all in a seamless transport system with smart interfacing between modes and drivers for behavioural change.

Keywords chosen from ICE Publishing list

Environment; Transport planning; Government

Glossary

CO_{2e} Carbon dioxide equivalent of all greenhouse gases (GHGs). Carbon is also used throughout the paper as shorthand for CO_{2e}

The following terms are in accordance with the definitions provided in the Infrastructure Carbon Review (GCB, 2013):

Capital carbon (CapCO_2): CO_{2e} emissions associated with the construction and decommissioning of an asset; it accords with the concept of Capital Cost (CapEx) in finances

Operational carbon (OpCO_2): CO_{2e} emissions associated with the operation and maintenance of an asset; it accords with the concept of Operational Cost (OpEx) in finances

User carbon (UseCO_2) CO_{2e} emissions associated with the end users of an asset, e.g. tailpipe emissions from the vehicles on the road. Although not directly controlled by infrastructure asset owners, UseCO_2 can be influenced.

Territorial emissions: The UK emissions calculated based on a production-based (or territorial based) reporting methodology. They account only for the emissions occurring only within the UK's territorial border.

Consumptive emissions: The UK emissions calculated based on a consumption-based methodology, which includes all emissions activity (national or international) linked to the UK-economy. DEFRA research suggests the consumptive emissions to be 35% greater than the territorial ones.

Transport Roadmap: A national strategic plan for transport to achieve carbon reduction by 2050.

1. Introduction

The publication by the Green Construction Board (GCB) of the Infrastructure Carbon Review (ICR) (GCB, 2013) was a seminal point in the industry's initiative to lowering carbon in UK infrastructure. Two years ago, the report had the ambitious aim to inform, motivate and enthuse the industry in actively seeking low carbon solutions, through policy, design and commitments. This paper reviews the ICR numbers and examines their significance for the UK transport infrastructure and the way forward. It aims to suggest the changes that will enable the strategic move to a low carbon transport in the UK.

2. Transport definition

Transport is "*a system for carrying people or goods from one place to another*" (Oxford Dictionary). It is a critical component of economic development, globally and nationally. Transport availability and efficiency affect development patterns and can be a boost or a barrier to economic growth within individual nations (Krugman, 1991) and more widely. In the context of infrastructure, mobility can be seen as a utility, with decisions to be made on the optimum modal mix and coordination.

By creating links between disparate locations, transport encourages trade, growth and wellbeing. It provides access to a wider market, adding to economies of scale in production, specialisation, distribution and consumption. It is essential for geographical and social inclusion, spreading prosperity and encouraging development. By promoting opportunities, it allows a region to retain its young people who otherwise might move to a big city, draining the countryside of its vitality. Thus the examination of costs and benefits of transport is a complex subject, with many parameters other than just carbon affecting the wisest choice for a nation. The nature of these choices was explained in the ICE infrastructure low carbon trajectory (ICE, 2011)

If the underlying vision of Government is for continuing national prosperity and growth, it has to ensure that the national and international transport system is fit for purpose, providing connectivity that is efficient, socially enhancing and environmentally positive.

3. National emissions and transport now

The UK has off-shored much of its manufacturing, which has provided apparent territorial emission reductions, although less control of consumptive emissions, with manufacturing powered by grids elsewhere and contributing to the territorial emissions of others. The ICR provided the latest inventory of CO_{2e} in the UK, estimating the total national emissions to be 981MtCO_{2e} per annum on a consumptive basis, including imported emissions that were previously unaccounted for in the strictly territorial assessments.

More than half of these total UK emissions are due to the national infrastructure, of which transport is a significant 159MtCO_{2e} per annum (16% of total UK emissions). The majority of the transport emissions are from the use of the transport infrastructure - the tail pipe emissions from the cars on the roads, the trains on rails, the ships and the airplanes – rather than its construction and operation.

In 2010, over 60% of the transport emissions lay in the road use, whereas rail is an extremely low 2%, as graphically displayed in Figure 1. Road cars were the dominant mode, emitting 51% of the total transport sector, with the road freight third, responsible for 11%.

3.1 International transport

International aviation has grown over the last forty years at an annual rate of 5% (HMT, 2013). Shipping is a dominant force and globalisation of trade has led to significant increases in shipped volumes. Accounting for emissions from international aviation and shipping is problematic due to differing accounting methodologies. The allocation of consumptive emissions enters into the realms of higher level, international agreements. As a consequence, international aviation and shipping have not yet been included in the 2008 Climate Change Act in 2012 (CCC, 2012), despite the recommendations of the Committee on Climate Change (CCC) for their inclusion.

The ICR recognised the need to move from a territorial methodology to a consumption-based methodology and attempted to reconcile the two by considering international aviation and shipping on the basis of departing journeys. Therefore, emissions from flights and ships that depart from the UK are counted, but those that arrive are not. Thus, international aviation and shipping emissions account for 20% and 6% of the total UK transport respectively (Figure 1).

3.2 Wasted carbon

Understanding the efficiency of the national transport system requires understanding how much carbon the different transport modes waste. David MacKay (MacKay, 2008) presented the efficiency of different passenger transport modes in terms of energy consumption per passenger km travelled and speed of travel: walking and cycling are extremely energy efficient means of transport, but transport a single passenger over small distances at low speeds; a private car is high on wasted carbon for transportation of small number of passengers, with more luxurious cars even higher.

Per passenger kilometre travelled, public transport emits less than a car at average occupancy (Newman, 2000; US Department of Transportation 2010). Shifting away from private towards mass modes of transport will result in reducing wasted carbon per passenger km. However, such transformations can take time to achieve, involve a large carbon investment and there is a need to alter city fabric as well as public perception.

Figure 2 comes with some caveats that are extremely important when considering the sustainability of mass transit systems, requiring a holistic understanding of each transport mode and its sensitivity. Ridership and urban form will have a major impact on the capital carbon and cost of rail (Saxe et al, 2015). Buses and trains are particularly sensitive to ridership: a bus may be a better carbon alternative when full but this advantage degrades as ridership decreases. A real-time information supported transport network that can elastically respond to better match supply and demand can bring about large efficiency savings together with a reduced wasted carbon. The same information network can provide simple knowledge on likely waiting times to potential mobility consumers, which also encourages public transport use over the convenience of immediately available private transport. In time, with autonomous vehicles, there will be a blurring of the strict distinction between public and private transport.

3.3 Freight transport

Mackay (2012) also produced a similar plot comparing different freight transport efficiencies reproduced in Figure 3, which is very informative on the current national strategy of distribution and delivery of goods and resources and its emissions footprint. Road freight, which is the currently dominant form of land transport, is ten times less efficient in transporting the same load of goods over the distance compared to the rail freight.

Freight transportation is arguably a bigger generator of emissions and is frequently competing with passenger transportation on capacity on the same roads and railways. Thus a solution for one type of journey should be cognizant of its effects on others, and the big picture is most important in terms of strategic decision making on future expansion of transport and consideration of other technologies in the mix that to date have not been seriously considered in the UK (eg road freight-trains).

3.4 Transport and the city

Urban transport emissions are a significant part of the total national transport. Urban transport, is a super-complex system with socio-economic, political and geographical implications.

Large metropolises are single large transport emissions contributors to the national total. London accounts for about 13% of the total UK population and its 9.4MtCO_{2e} (TfL, 2011) is almost 10% of the total national ground-based transport emissions.

The density of a city dictates the wasted carbon from its transport. Barcelona and Atlanta have populations of about 5 million people, but Barcelona's dense nature and plentiful public transport allows its citizens to expend just a tenth of the carbon emissions on transport that sprawling Atlanta requires (The New Climate Economy, 2014).

Jahanshahi & Jin (2015) suggest that there are three types of population density across the UK, when considering the passenger transport distribution: 20% of the population lives in dense areas with access to good public transport and so can take advantage of it; 30% live in rural areas, where private car journeys are probably the only option; and the suburban areas of intermediate density in between for the remaining half of the UK population, where there is an opportunity for significant mode shift to less carbon wasteful modes of transport.

3.5 Behaviour

Recent policy decisions that aimed to reduce transport carbon emissions have had mixed results. The claimed efficiency benefits of diesel have proven to be a double error. Firstly, although lower carbon dioxide is achieved, large amounts of particulate matter have a much greater and more damaging to human health in the short term. Secondly, the improved efficiency has been offset by an increase in travel distances by journeys.

In the recent past, private car ownership had become a 'status symbol' with the run-down of public transport up to the 1980s. The famous apocalyptic quote from the Thatcher era: "*A man who, beyond the age of 26, finds himself on a bus can count himself as a failure*" best describes the mentality where private cars are prized possessions, irrespective of the practicalities or efficiencies as means of transport.

Public perception is now maturing, with the realities of ever increasing traffic congestion and cost of owning and running a private car leading to a public understanding of the advantages of mass transport alternatives.

Furthermore, the nature of private transport is evolving: in congested urban areas like London, walking and cycling are becoming a preferred alternative to short car trips. Recent statistics (Transport for London, 2012) indicate that one third of the 4.6Million daily car trips in London are less than 2km. Based on a very rough calculation, this is equivalent to at least 135,000 tonnes of CO_{2e} per year in heavily congested urban traffic. The 2km distance can be easily covered on foot or by bicycle and a modal shift from the short car journeys would directly eliminate these 135,000t direct tailpipe emissions (1.5% of the total London transport emissions) and, more importantly, additionally relieve stop-start emissions associated with congestion.

4. Transport in the future

Large infrastructure schemes have long gestation periods. Crossrail was first mooted in the 1940s, and hard planning for the current scheme started in 2001, with Parliamentary approval in 2008 and full opening expected in 2019, 18 years of continuous work, 7 years of design and planning, some 2 years of enabling works, then about 9 years of main construction. Likewise, High Speed 2 Ltd started work in 2009 with a view to phase 1 opening in 2026, a period of at least 17 years. Thus transformational infrastructure projects take about a generation from firm commitment to actual operation.

The ICR made use projections from 2010 to 2025 and through to 2050 (Figure 1). These are based on DECC's pathways to 2050 model (DECC, 2013), using the Markal 3.26 scenario. They considered a wide range of sources including governmental and international reports up to the year 2006, but not beyond that. These projections are not currently aligned with national business and growth aspirations and strategies, as described below. Alignment of growth with emissions targets must be realised across all infrastructure sectors and reflected in the Treasury's infrastructure pipeline – recognising the exceptionally long time for solutions to be implemented.

4.1 National transport

As we progress to 2025, road car emissions drop dramatically to 33% of the transport emissions and international aviation approaches parity with road cars. The projections suggest that Rail starts from a very low carbon contribution in 2010, which further reduces by 80% by 2050, predominantly a result of increased electrification using an increasingly decarbonised electricity supply. This is likely to include projects such as the Northern Hub and Great Western Electrification Schemes, as well as HS2, HS3 and maybe others. Considering the increased demand due to mode shift plus the electrification of traditional diesel lines, these savings are significant. However, to date Network Rail have assessed that only 60% of their lines offer a good cost benefit ratio for electrification (McNaughton, 2014).

Of all transport modes, Road has the greatest projected CO_{2e} savings, with an overall 82% reduction between 2010 and 2050, presumably due to electrification of vehicles and network upgrades. A long term decarbonisation solution for freight vehicles is yet to be found, so the forecasted long term road freight carbon reduction can only be achieved by strategically shifting freight onto rail or possibly domestic shipping. Road journey times are highly variable and so moving on to infrastructure with less journey time variability will carry low economic risk and likely hold positive economic benefits.

Domestic aviation, although initially small, projects an apparent 60% increase in emissions by 2050. This is at odds with the general trend of phasing out short haul flights and a shift towards High Speed Rail.

4.2 International transport

The growth in international aviation and shipping are predicted to continue, although at a slower rate. This growth is reflected in the ICR emission forecasts for the sectors, with a 51% increase in the aviation emissions and a massive 173% in the shipping emissions by 2050. Much of this growth will wipe out the hard earned savings of the road sector and others.

Aviation's energy requirements make it unsuited for traditional decarbonised electricity supply emission reduction efforts. The peak power requirements of take-off and landing necessitate calorific fuels and current battery technology capacities offer a power-weight paradox that is far from a viable technical solution and may not become so by 2050. However, flights remain the most efficient means of transport per passenger kilometre over long distance and long haul passenger travel will continue to be dominated by aviation, although the rate of growth could reduce. Measures such as reducing aircraft fuel consumption on the ground and through glide paths may moderate aviation emission impacts until technology catches up.

Shipping is more amenable to technological improvements for increased efficiency. Improvements such as improved hull design, engine and propulsion design can offer 20-30% savings (ABS, 2013). Research has identified the use of small nuclear reactor systems to power bulk goods carriers as a means of providing sufficient propulsion at the reduced carbon footprint, yet significant investment challenges and regulatory uncertainty pose real barriers (Dedes et al, 2011).

4.3 Subsidies

The role of fossil fuel subsidies on transport modal choice has historically been unknown. A recent IMF working paper (Coady et al, 2015) has put remarkable figures to the scale of the subsidies, at around $4.9 trillion in 2013 and rising to $5.3 trillion in 2015. The implications for this on the cost-benefit analysis of transport infrastructure planning are profound and the value of traditionally held modes will likely change as we move towards the UN Climate Change Conference in Paris 2015.

5. Strategic transport

Technological advancement is often considered the primary means for resolving the emissions problem. However, the impact of new technologies at the macro scale is difficult to quantify and hence effective policy is difficult to implement.

Almost independent from technological changes, a successful long term national strategy must ensure that Transport remains true to its definition and operates as a seamless system transporting people and goods, rather than the sum of different transport modes competing against one another.

If roads and rail are strategically considered as an integral part of the national connectivity system, then transport efficiency can be optimised. This is not currently the case. The bulk of freight is transported on roads, while rail freight competes with, and is constrained by passenger transport on the limited rail routes available. The newly formed Road Investment Strategy (RIS) (DfT, 2014) provides the long term vision for the Strategic Road Network (SRN) and a much needed longer term investment plan, but still considers the SRN in isolation from the rest of the transport system. As an example, the RIS plans for improvements of the road freight connections for the ports in the southeast, but without making the long term economic and carbon case compared to a freight rail option.

Meaningful transport carbon reduction can only result from considered rebalancing of the modal mix, together with smart interfacing between modes that is flexible to optimise ridership and eliminate congestion.

- Decarbonisation of road passenger transportation, together with upgrading road infrastructure, will play a major role in the reduction of the single biggest current polluter. This must be assisted by a shift of freight transport off the road network, as it is technologically difficult to decarbonise.
- Electrification of existing rail should be considered on the basis of value-benefit ratio, including wasted carbon reduction potential as well as capital cost.
- Increased capacity on passenger rail lines such as HS2 etc has the potential to free up freight capacity on the classic rail lines it bypasses and thus possibly lead to significant carbon savings as a result of enabling that substantial modal shift from road freight to electrified rail freight.
- New access provision to major distribution hubs such as ports and airports and new freight capacity should be created using the least carbon wasted means, favouring rail against road. This will reduce the disproportionately large carbon emissions that can be associated with the ‘last mile’ problem.
- Freight transport into urban environments should be overhauled, with goods distribution centres located outside the urban perimeter, from where goods are disseminated to urban destinations by means of (underground) light rail or other coordinated and least polluting modes.
- Individual freight companies are optimising their individual journeys; significant savings could be made by strategically connecting across companies in order to increase load factors on all journeys. This would require legislative support, such as taxation on void space in lorries and incentivising of cabotage and shared logistics.
- As freight transport is dominated by volume and not weight, there are efficiency opportunities through the use of longer and larger vehicles most especially for the trunk part of journeys.
- Substantial carbon savings can also be achieved with a shift from short haul passenger flights to high speed rail. Airport congestion will then be eased if short haul aviation is largely phased out, making space for the unavoidable long haul demand and demoting the need for airport creation and expansion.

- Carbon efficient mass transport passenger options should be developed to and from city centres for the suburban and rural areas that are currently mainly dependent on private transport.
- More fundamentally, reduction of the underlying need for travel should be addressed by better integrating land use and transport planning, aiming for reduction in demand of both number as well as length of journeys.

A strategic optimisation of the transport system will require both hard and soft interventions. The hard interventions will involve a substantial upfront capital investment in upgrading existing and constructing new infrastructure. The soft interventions should drive changes in the behaviour of transport users. There is a great deal of spare capacity on many sections of the network at different times that can and should be utilised as and when it is possible and appropriate. This second, policy aspect will require a drive for behavioural change, resulting from a realistic mapping of human interaction with infrastructure, which should also dictate and influence the engineering interventions. The revolution in large, crowd-based data sources will enable a better understanding, providing data and insights that were previously not possible. More fundamentally, it will also require behavioural change of the users that will drive the modal shift for increased efficiency.

6. Conclusions

The Climate Change Act 2008 was the beginning of the regulatory push to a lower carbon UK in order to avoid dangerous climate change. The Act requires an overarching reduction of 80% in emissions by 2050 compared to 1990 levels, but does not stipulate how or where these savings will come from. As time has progressed, it has become imperative to strategically identify the sectors that will be required to make savings and plan how those savings will be made. Emissions reduction must take centre stage in the Treasury's assessments of infrastructure investment in the UK, in line with the traditional economic metrics.

We are now less than ten years from the fast approaching 2025 and its interim targets. The encouraging trends observed in 2013 seem to have reversed (GCB, 2015), suggesting that some of them were due to the recent recession. The rate of change must accelerate to achieve the tangible results required. It is of great importance that we assess our progress to date and the implications of this for progress into the future.

The ICR (2013) was an important step in recognising how the significant infrastructure sector will contribute to reaching the 2050 target; given its systemic nature, the types of changes will be different to those proposed and implemented to make buildings more carbon efficient. This paper has attempted to put the transport section of the ICR into context and prime the necessary discussions for the strategic decisions to be made. Strategic carbon decisions must be made, which will involve major capital investment. Incremental improvements in transport efficiencies are not enough; considering the entire transport system as a whole and making strategic decisions is paramount. Modal shift is of fundamental importance that cannot be achieved on the scale required if each mode within the transport sector acts without strategic direction.

The control and optimisation of emissions will require:

a. Standardisation of the boundaries of life cycle assessments (as discussed by Saxe *et al* 2015 for rail); this is currently underway, with the draft PAS 2080 being undertaken by the Green Construction Board (Infrastructure Intelligence, 2015).
b. A coherent national strategic plan (roadmap) for transport for the next 35 years to 2050, setting out the main transformational projects that will be required and identifying a bespoke funding mechanism, recognising that each large transport project will take over half of that period to bring to fruition.
c. Within that transport roadmap, prioritisation of infrastructure projects that will bring the largest whole life carbon improvements in the national infrastructure system.
d. Enabling behavioural change on passenger transport choices through a mix of smart infrastructure provision and regulation.

This paper is not simply about the optimisation of the current transport paradigm. Rather, it is about a fundamental change to the modal mix and a transformation of the national transport system to best serve the national prosperity whilst enabling the substantial carbon reductions required.

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Figure captions (images as individual files separate to your MS Word text file).

Figure 1. 2010 user Carbon Transport Mode Distribution (GCB, 2013)

Figure 2. Efficiency of passenger transport modes (MacKay, 2012)

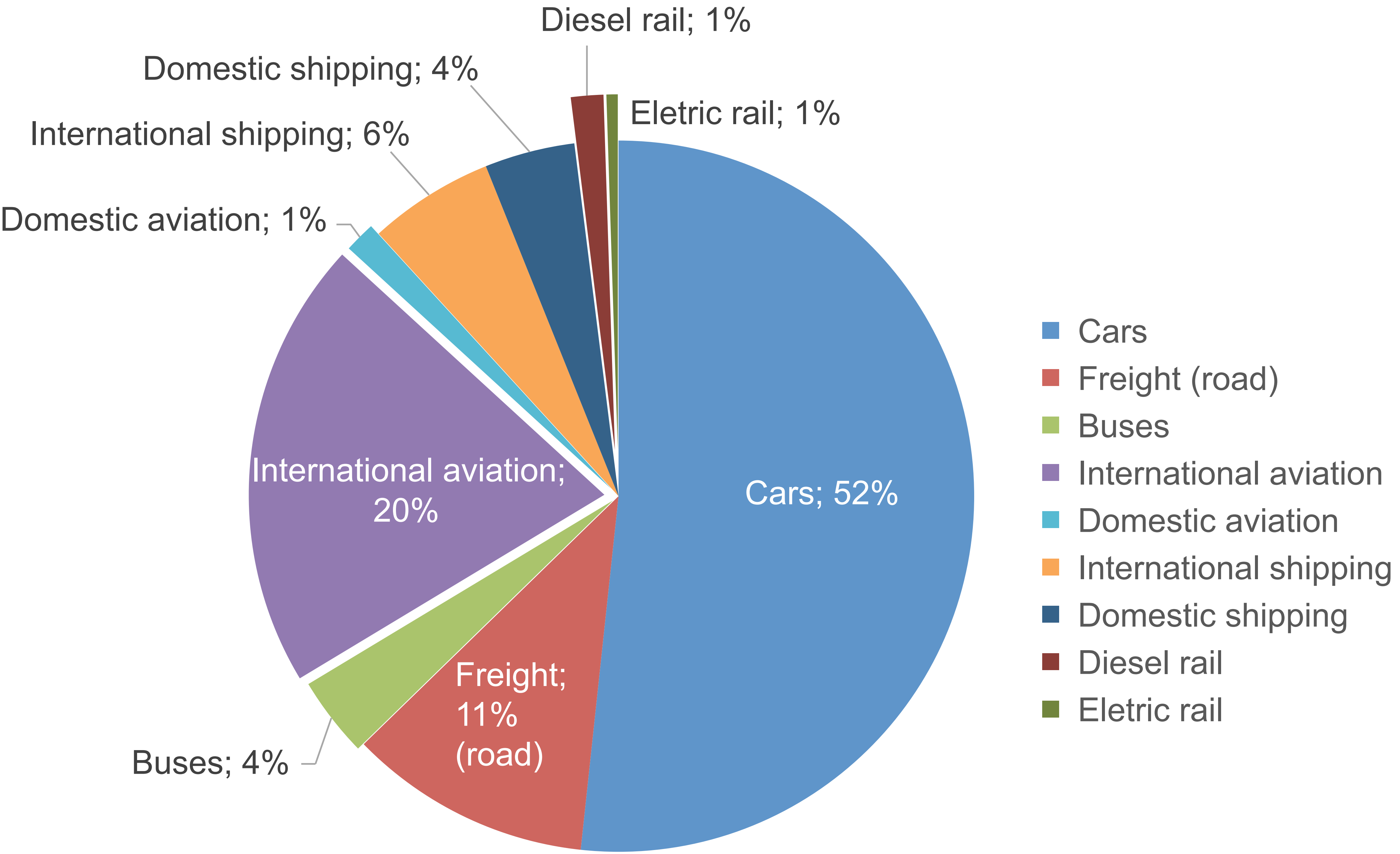
Figure 3. Efficiency of freight transport modes (MacKay, 2012)

Figure 4. Current transport emitters and future projections (GCB, 2013)

Figures 2 and 3 from:

http://www.inference.phy.cam.ac.uk/sustainable/book/tex/ps/individual302/

Figure 1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Domestic shipping; 4%
Eletric rail; 1%
International shipping; 6%
Domestic aviation; 1%
International aviation; 20%
Cars; 52%
Freight; 11% (road)
Buses; 4%
Cars
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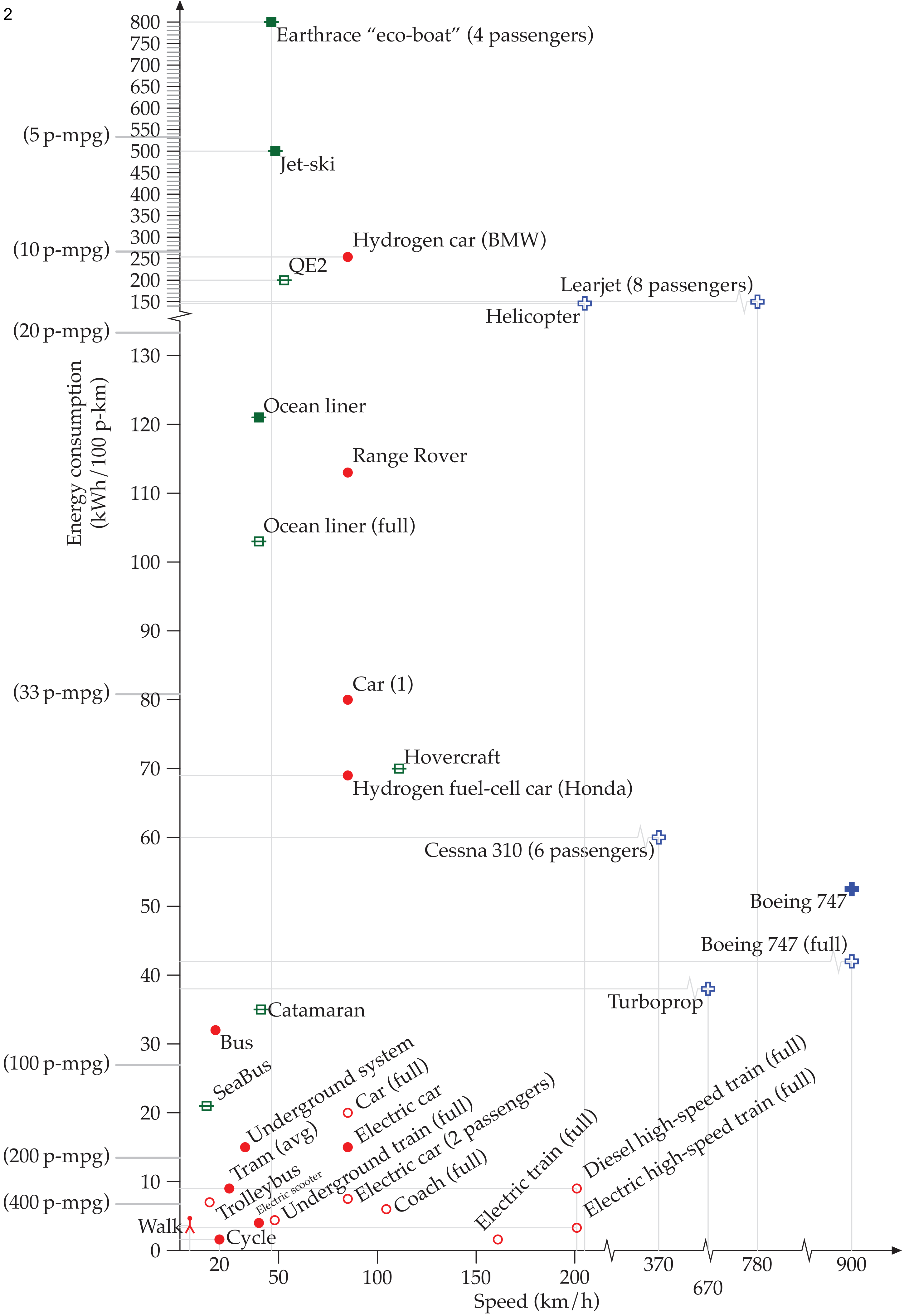
Buses
International aviation
Domestic aviation
International shipping
Domestic shipping
Diesel rail
Eletric rail

Figure 2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Jet-ski
Hydrogen car (BMW)
QE2
Learjet (8 passengers)
Helicopter
Ocean liner
Range Rover
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Car (1)
Hovercraft
Hydrogen fuel-cell car (Honda)
Cessna 310 (6 passengers)
Boeing 747
Boeing 747 (full)
Turboprop
Catamaran
Bus
SeaBus
Underground system
Car (full)
Electric car
Tram (avg)
Underground train (full)
Electric car (2 passengers)
Trolleybus
Electric scooter
Coach (full)
Electric train (full)
Diesel high-speed train (full)
Electric high-speed train (full)
Walk
Cycle
(5 p-mpg)
(10 p-mpg)
(20 p-mpg)
(33 p-mpg)
(100 p-mpg)
(200 p-mpg)
(400 p-mpg)
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700
650
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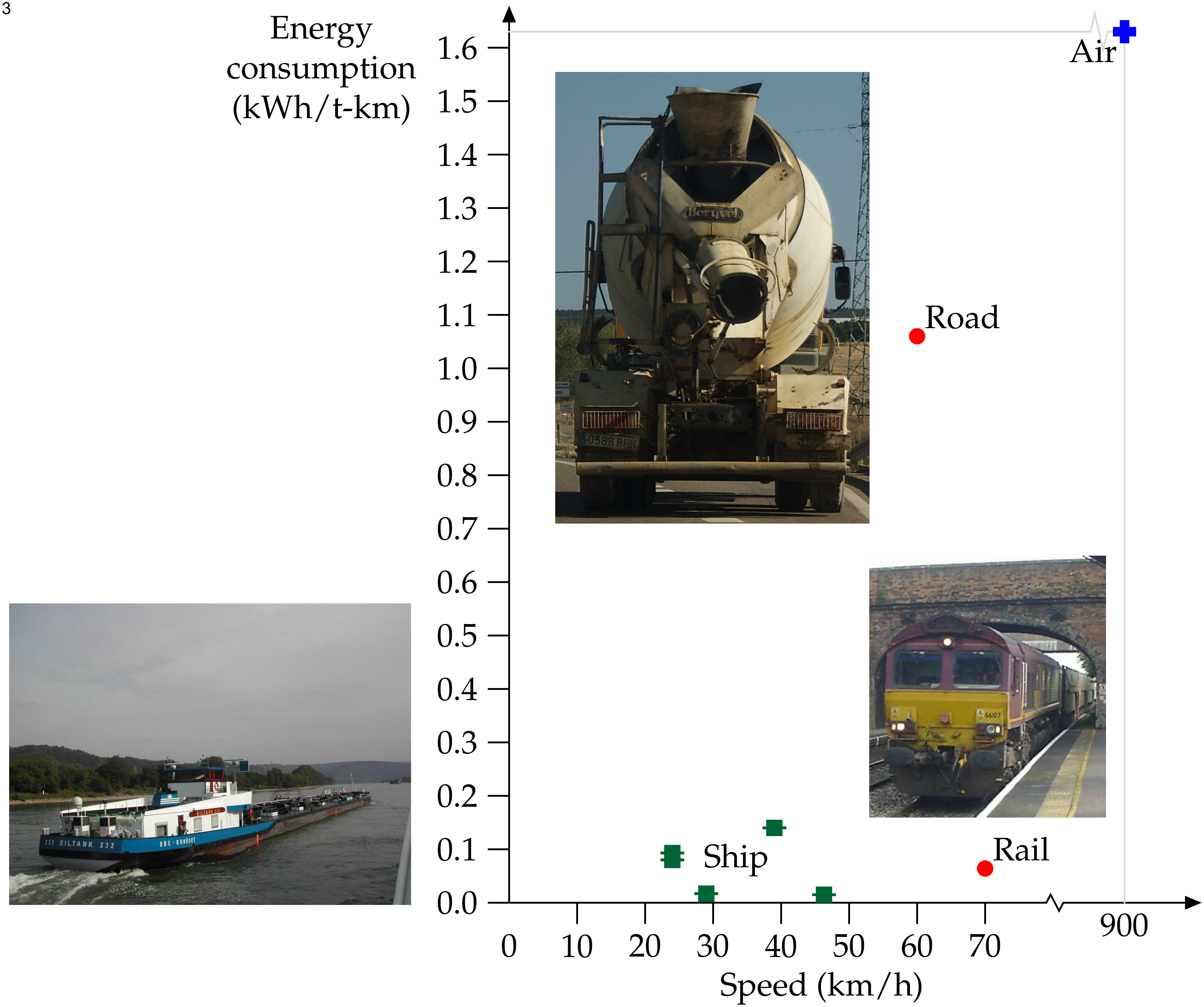
Speed (km/h)

Figure 3



Energy consumption (kWh/t-km)
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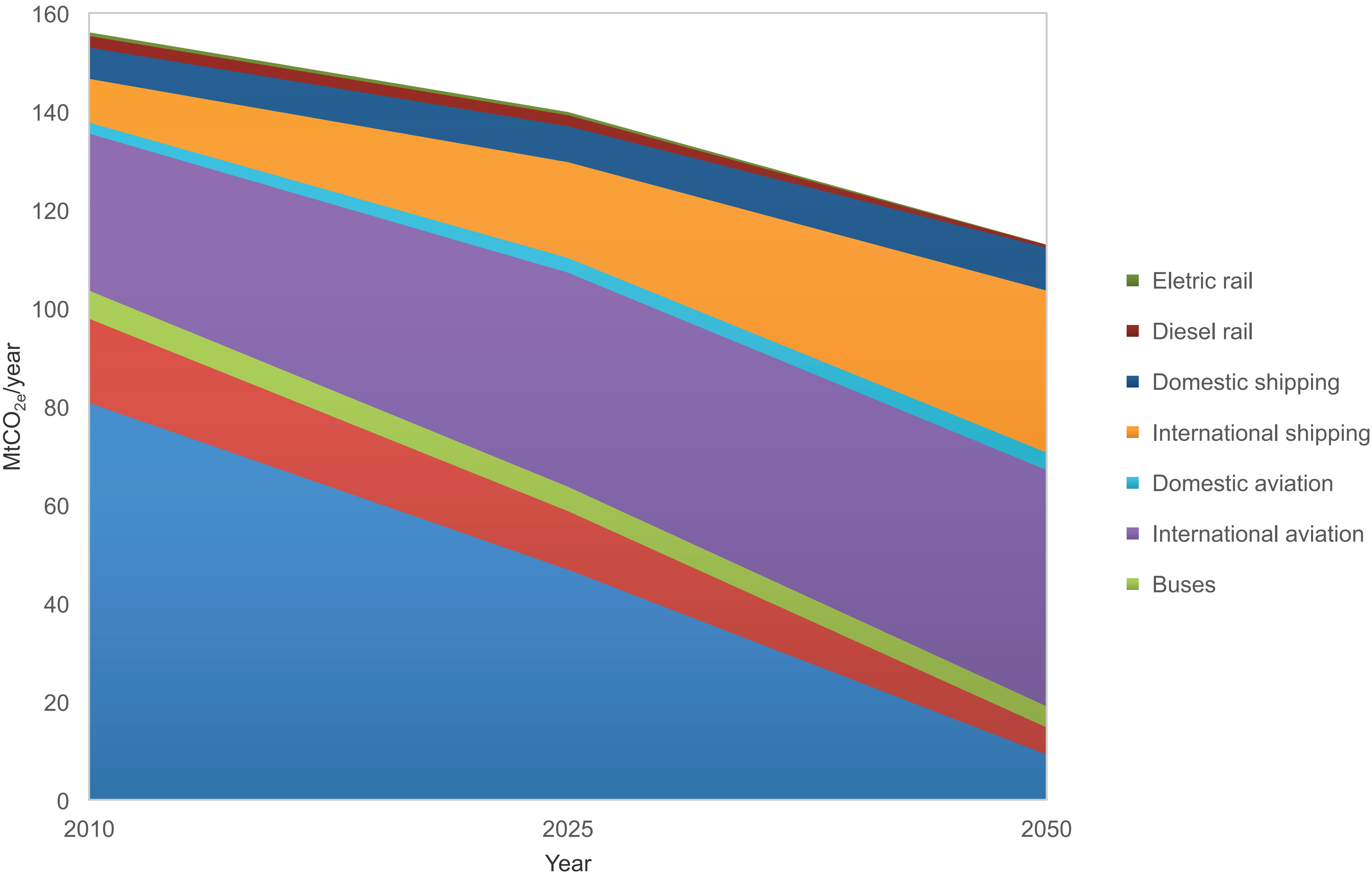
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Air
Road
Ship
Rail
0
10
20
30
40
50
60
70
900
Speed (km/h)

Figure 4


160
140
120
100
80
60
40
20
0
MtCO2e/year
2010
2025
2050
Year
Eletric rail
Diesel rail
Domestic shipping
International shipping
Domestic aviation
International aviation
Buses

Heleni Pantelidou

Gerard Casey

Tim Chapman

Kenichi Soga

Peter Guthrie

1

2

3

4

5

6

7

8

9

COMMENT
a) Post-nominal letters and affiliation (eg: BEng, CEng, MICE, senior engineer at Arup, London).
b) Co-authors' post-nominal letters and affiliations:
c) Keywords, available to download here.
d) Author photographs (it is the responsibility of lead author to provide these; the publisher will not include author photographs unless a complete set is provided)
e) Figures/tables/illustrations. Line drawings, graphs and figures should be no larger than A4 size and should be capable of bearing reduction (ie: sharp black lines).
f) It is your responsibility to obtain copyright permission to reproduce figures that you submit with your paper. Download a request form here.
g) You (and any co-authors) have signed a copyright transfer form. We cannot publish your article without this. Download the form here.
h) You have supplied references in Harvard style. For details, click here.

PEER REVIEW COMMENTS - Reviewer #2
please write in plainer language reducing the use of terms such as para 3 'consumptive emissions' and 'strictly territorial assessments' are not explained; para 6, the use of 'roadmap' is a confusing analogy; Para 5, emotive words like,'extremely' when 'disproportionate' would be more accurate.
Para 5 item b, the word 'bespoke' should be used in front of 'funding mechanism'.
Last sentence might come across better as, 'This paper is not simply about the optimisation of the current transport paradigm. Rather it is about a fundamental change to the modal mix and how government should respond to the needs of transport within the economy.'
Giving a specific car brand - Range Rover - is unfortunate (even if true) when so many accusations of emissive fraud are still emerging about other vehicles. Can this be a more generic statement?

Reviewer #3
this is a very timely paper and raises highly pertinent matters to be addressed in how the delivery and management of UK transportation needs to be re - visited to meet very stretching carbon emissions reductions targets. It has clearly been well researched with a comprehensive list of pertinent references. However, the paper as it stands I believe misses some good opportunities to explore and discuss more fully a number of the options for realistic carbon emissions reductions across the transport modes.
I would have especially liked to see some debate about how certain freight and travel choices directly (or otherwise) influence the objective of maintaining and growing the UK economy. That might draw out more clearly where the greatest carbon savings might reasonably be achieved with fewer risks of a direct detrimental effect on the overall economy.
For instance, in the highly challenging target of substantially reducing car / private vehicle carbon consumption (Figure 2 - and text accompanying it) - a useful cross reference to statistics from national travel surveys would have been helpful in demonstrating perhaps how much of this private vehicle consumption is associated with discretionary vehicle usage.

What might the benefits be from encouraging in a more meaningful way, shorter, potentially transferable journeys to adopt more sustainable modes - eg cycling, walking? The paper could also address in this area more on the potential benefits to come from better integration of land use and transport planning - in reducing the underlying need for travel, and potentially stemming (understood) increases in the trends of private vehicle annual mileage / commute distances etc.

These could negate or at least damp down the benefits to be gained from increasing fuel efficiency of the vehicle fleet. These suggested changes to the paper will help the reader to draw some fresh insight into how this complex matter might be better addressed at the national level.

Other changes:
Updated reference to carbon reduction trends in Section 6.

ACTION
✓
✓
✓
✓
✓
✓
✓

ACTION
✓ - Glossary introduced at the beginning to address these; including definition of roadmap Emotive word replaced
✓
Sentence changed to: *This paper is not simply about the optimisation of the current transport paradigm. Rather, it is about a fundamental change to the modal mix and a transformation of the national transport system to best serve the national prosperity whilst enabling the substantial carbon reductions required.*
Reference to Range Rover deleted - although still present in the figure from D. Mackay

ACTION
Noted
Comment added to address this.
Comment added to address this.

example added on the potential impact of replacing short driving distances with cycling or walking in London
Comment added on land use and planning

noted

New reference to GCB (2015) added.

Permission for figures 2 and 3