Technical University of Denmark

Indicators and beyond: Assessing the sustainability of transport projects

Cornet, Yannick; Gudmundsson, Henrik; Leleur, Steen

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Indicators and beyond: Assessing the sustainability of transport projects

Thesis

by

Yannick Cornet

M.Sc., Technological and Socio-Economic Planning, Roskilde University, 2013

B.Eng., Electrical Engineering, Université de Sherbrooke, 1997

Submitted to the Department of Transport in Partial Fulfilment of the Requirements
for the Degree of Doctor of Philosophy in Transport Governance and Policy
at the Technical University of Denmark

Supervisors:

Senior Researcher Henrik Gudmundsson

Professor Steen Leleur

Department of Transport

Technical University of Denmark

Kgs. Lyngby

18 July 2016

The public defence shall be held on

Monday 12 September 2016 at 13:00 hrs

Doctoral Committee:

Prof. Dr. Cathy Macharis, Mobility, Logistics and Automotive Technology Research Centre, Vrije Universiteit Brussel

Professor Greg Marsden, Institute for Transport Studies, University of Leeds

Senior Researcher Per Sieverts Nielsen, Department of Management Engineering, Technical University of Denmark (chair)

To my daughter Eleonora (the future generation)

Cornet, Y., (2016). Indicators and beyond: Assessing the sustainability of transport projects. PhD thesis. Department of Transport, Technical University of Denmark, Kgs. Lyngby

Preface

This PhD thesis entitled "Indicators and beyond: Assessing the sustainability of transport projects" is submitted to fulfil the requirements for obtaining a PhD degree at the Department of Transport, Technical University of Denmark. The PhD study has been supervised by Senior Researcher Henrik Gudmundsson and Professor Steen Leleur.

The thesis consists of the following papers, in chronological order:

Published

Article I **Cornet, Yannick**, and Henrik Gudmundsson. 2015. "Building a Metaframework for Sustainable Transport Indicators - Review of Selected Contributions" *Transportation Research Record: Journal of the Transportation Research Board* 2531: 103–12. doi:10.3141/2531-12

Article II Pryn, Marie Ridley, **Yannick Cornet**, and Kim Bang Salling. 2015. "Applying Sustainability Theory to Transport Infrastructure Assessment Using a Multiplicative AHP Decision Support Model." *Transport* 30 (3): 330–41. doi:10.3846/16484142.2015.1081281

In peer review

Article III **Cornet, Yannick**, Michael Bruhn Barfod, Merrill Jones Barradale, and Robin Hickman. "Incorporating a sustainability viewpoint into multi-actor MCA – the case of HS2."

Earlier version presented at the *International Conference on Multiple Criteria Decision Making* in Hamburg, August 2015. Submitted June 2016 to internal peer review process for a special issue in *European Journal of Transport and Infrastructure Research;* a cut-down version is to be resubmitted in September 2016.

Article IV **Cornet, Yannick**, David Banister, and Geoffrey Dudley. "High Speed Rail: A Mandate for Future Generations?"

Submitted September 2015 and presented at the *World Conference on Transport Research* (*WCTRS)* in July 2016. Accepted as B paper for publication in special issues of either WCTRS official journals (Transport Policy, Case Studies on Transport Policy) or partner journals (tbc).

Article V Banister, David, **Yannick Cornet**, Moshe Givoni, and Glenn Lyons. "From Minimum to Reasonable Travel Time."

Submitted March 2016 to *Transport Policy*; major revision requested by September 2016. Presented at the *World Conference on Transport Research (WCTRS)* in July 2016.

Other work

The following works were also realised during the PhD period, and deal with the general topic of the thesis, however, they are not presented as part of the defence.

Working paper **Cornet, Yannick**, and Tim Schwanen. “Resistance to Experimentation in Sustainable Transport Transitions.” Available upon request.

Policy report Anderton, Karen, Jonas Åkerman, Ralf Brand, Cécile Chèze, Merethe Dotterud Leiren, Henrik Gudmundsson, **Yannick Cornet**, Laurent Guihéry, Florian Kressler, Max Reichenbach, Jens Schippl. 2015. TRANSFORuM Transport 2050 Strategic Outlook. http://www.transforum-project.eu/fileadmin/user_upload/08_resources/08-01_library/TRANSFORuM_Strategic_Oulook.pdf

Yannick Cornet, 18 July 2016

Acknowledgements

The PhD is a journey. It brings the unique opportunity to explore in depth one specific subject and (if successful) to contribute to the advancement of human knowledge. In a global context where 30% of the world population is in a situation where time and creativity is spent on the task of daily survival[1], and where the others are likely to be busy meeting the demands of a post-industrialist and increasingly neo-liberal workfare, I am fully aware of the unique chance I was given. I am therefore very much indebted to both people and the mechanisms that have made this journey possible. In terms of enabling mechanisms, I am grateful first to the government of Denmark and its long tradition for investing public monies in higher education. The fact that Denmark pays its PhD ‘students’ a liveable salary[2] and considers them as employees is, in my view, key to attracting candidates for academic research who otherwise would rely on more uncertain or privileged sources of funding. I believe this is precisely what makes Denmark innovative and competitive in the global economy.

I also take this opportunity to thank my previous employer. This PhD thesis is one of the “1001 futures” that resulted from Nokia’s lay-off program as it ceased its activities in Denmark in 2011. Pursuing further studies would not have been possible without the support and time the company gave its staff to transition to new and fulfilling futures. I hope this can serve as a good example to other companies facing similar situation. About the content of this thesis, I also credit Nokia’s ‘People and Planet’ reporting that originally inspired me to formalise my education in the field of sustainability and planning. As it kept the top spot in the greenest electronics company in Greenpeace’s ranking[3], I became fascinated with the question: what if such reporting would internalise wider effects, such as the potential for mobile technology to reduce consumer’s own environmental footprint – for example, by sharing car rides? The basis for exploring assessment tools, indicator frameworks, sustainability and transport was set.

Much of the credit for making the PhD journey possible goes to my main supervisor Henrik Gudmundsson whom, with his dedicated work on sustainable transport indicators and frameworks and his methodical approach to research in transport governance, inspired me to pursue this research path. I thank you for your patience in training me as a researcher and for opening your network to me, which allowed me to join stimulating projects, conferences, and to spend a significant part of this PhD at the University of Oxford’s Transport Studies Unit. I also thank you for all your constructive and laser-sharp criticism of my work along the way, which taught me, among other things, the importance of both precision and self-criticism in research. I’m also very much grateful to Prof. Steen Leleur, my second supervisor. I thank you for introducing me early on to complex systems theory and multi-methodology approaches in transport planning, which provided the inspiration for going ‘beyond indicators’ in my research.

[1] According to the 2015 Multidimensional Poverty Index (MPI), which considers deprivations in health, education and standards of living on top of conventional income-based measures http://www.ophi.org.uk/multidimensional-poverty-index/

[2] For the international reader, here are the salaries of PhD students at the Technical University of Denmark http://www.dtu.dk/english/Education/phd/Applicant/Pre_acceptance-1-/Salary

[3] In 2009 and 2010: http://www.greenpeace.org/international/en/campaigns/climate-change/cool-it/Campaign-analysis/Guide-to-Greener-Electronics/

I'm truly indebted to David Banister and Tim Schwanen: I thank you both for welcoming me and sharing your time and expertise throughout the last year of this PhD. In my view Oxford lived up to its reputation as an inspiring place where great minds meet. The field of Geography also inspired me: while it would seem particularly well adapted to transport research, I found it to be much more than studying the spatial component of a phenomenon. I particularly appreciated what I describe as an open-mindedness to methodology, which I found quite empowering for my research. This last year in Oxford also illustrates the journey of the PhD itself, as I became more aware of the theories and methods that allowed me to reflect on the bigger picture in terms of philosophies of science. Although this is still work-in-progress, these learnings planted the seeds for developing further the concept of *sustainable transport appraisal* in this thesis.

Certainly not least, I must thank my immediate family, Annika and Eleonora, for putting up with me during the last three years and 6 extra months. I realise that was not quite .. sustainable. Thank you Annika for your unflinching support and love throughout this period. I apologise to you Eleonora for saying so often "No, I'm sorry, I cannot play with you, I need to work". It hurts me to think about it. Research appears to be a 24-hour occupation. I doubt what comes next will provide relief, but I at least make a promise to myself to make time for my own little future generation at home.

The Danish Strategic Research Council is acknowledged for having provided the funds to make this PhD study possible under the SUSTAIN research project. I'm also grateful to Idella fonden, Augustinus Fonden, Reinholdt W. Jorck og Hustrus Fond, and Otto Mønsted Fond for funding my external research stay in the UK.

Aside from those mentioned already, I would like to thank the following persons for their contribution, time or inspiration along the way (in alphabetical order): Tim Anderson and Elisabeth Hemmingsen, Karen Anderton, Michael Bruhn Barfod, Merrill Jones Barradale, Marianne Boelskifte, David Bonilla, Shaun Bortei-Doku, Paola Carolina Bueno, Lene Tolstrup Christensen, Elise Marie Barrella, Cécile Chèze, Elisabetta Cherchi, Hjalmar Christiansen, Candice Cornet, Michèle & Jimmy Cornet, Luca D'Acci, Justine & Søren Hébert Dinesen, Geoffrey Dudley, Mette Berner Dyrberg, Miroslawa Alunowska Figueroa, Mogens Fosgerau, Rasmus Frandsen, Christina Georgouli, Kerstin Geppert, Moshe Givoni, Agne Gvozdevaite, Ralph Hall, Naja Barlach Hansen, Sonja Haustein, Mette Heitmann, Robin Hickman, Simon Hunt, Bent Jacobsen, Thomas Christian Jensen, Anders Vestergaard Jensen, Sigal Kaplan, Annette Kayser, Clare and Timothy Kiggell, Irene Kouskoumvekaki and Gianni Panagiotou, Nina Kruglikova, Katrina Larsen and Carlos Alberto Zuniga Arenas, Todd Litman, Karen Lucas, Glenn Lyons, Yannick Maher, Lucy Mahoney, Stefano Manzo, Jennie Middleton, Melissa Moreno, Ismir Mulalic, Joel Thomas Mulligan, Amy and Abu Mulumba, James Palmer, Sally Pepperall, Jasmina Nedevska Törnqvist, Andre Neves, Per Sieverts Nielsen, Magnus Nilsson, Denver Nixon, Thomas Ross Pedersen, Rafael Henrique Moraes Pereira, Celia Peterson, Karen Uhrup Poulsen, Kirsty Ray, Hannah Rich, Marie Ridley Pryn, Harilaos N. Psaraftis, Kim Bang Salling, Kasper Sandal, Sunniva Sandbukt, Henrik Saxe, Niels Selsmark, Thomas Alexander Sick Nielsen, Saxe Skygebjerg, Graham Smith, Julio Soria-Lara, Mikkel Stave, Claus Hedegaard Sørensen, Chelsea Tschoerner, Andrés Felipe Valderrama Pineda, Marco Valente, Per-Åke Vikman, Dick Wolff, Gayle Wootton, Victoria Wyllie de Echeverria, Olga Wojciech Zarzecka, Joe Zietsman, Zichen Zhang and all concerned at Cyclox in Oxford, the Department for Transport in the UK, Transport for London, Oxford County and City Council, and all my dear colleagues at ex-DTU Transport and new Transport DTU, and the PhD study group at the University of Oxford's geography department.

Summary

Credibly demonstrating actual progress towards a genuinely sustainable transport situation remains a challenge. A key problem is that the incorporation of sustainability in transport policy and planning at present is not systematic.

A motivating assumption behind this thesis is that a transition toward a sustainable transport system will require strong support from decision-support processes and assessment tools that do not only adopt the language of sustainability, but fully integrate an explicit notion of sustainability in all of their conceptual, operational and procedural approaches. There is therefore a general need to improve processes, methods and tools applied in transport infrastructure decision making so as to make them more resonant to the needs of both current and future generations corresponding to the fundamental definition of sustainable development.

The *core focus* of the thesis is on how to ensure project impacts in terms of sustainability are identified and become inputs to decision making.

The benefits of increased mobility based on speed and capacity are significant and visible, creating a wide range of reachable activities for a great number of people. Negative externalities of transport systems such as accidents, local air pollution and noise have long been monetised and accounted for in conventional transport project appraisal. But the transport sector today (in Denmark, in the EU and globally) is also an increasingly large contributor to the two core planetary boundaries of climate change and biosphere integrity. Such wider, more complex and longer terms effects that are also external to local interests and market transactions are not only increasingly observed in transport but are also far less well accounted for. The risk here is that evidence-based decision-making becomes discredited, as was already found to be the case for high-speed rail appraisal in the UK, which is the most important case analysed in this thesis.

This thesis contributes to the following three challenges: the overarching conceptualisation of sustainable development as an ethos for transport infrastructure policy, the operational specifics of impact assessment based on indicators and methods for their prioritisation, and stakeholder representations applied in assessment procedures, with a particular focus on creating a explicit ‘future generations’ viewpoint. The research takes a starting point in Sustainable Transport Indicator Frameworks (STIFs), then expands to decision-support processes and assessment tools, and finally explores issues relevant for the wider field of transport planning and decision-making.

A main underlying concern of the research is to develop new thinking and assessment methods that bridge the techno-rationalist//instrumental approach of conventional impact assessment tools with a wider communicative planning rationality. This is needed because of the complex, dynamic and interdependent nature of transport planning and decision-making.

Methods
This thesis draws from multiple research methods which are both qualitative and quantitative. For the conceptual work, I rely on purposive literature reviews, including extensive reviews on sustainability theory and the implication of this body of knowledge for sustainable transport, as well as a detailed review of selected literature on the topic of sustainable transport indicator frameworks. Case study work draws upon extensive desktop-based analysis of impact assessment reports and other publically available material about real cases of large transport infrastructure appraisals. The HS2 high-speed rail (HSR) project appraisal in the

UK is used as a case study in three of the articles that compose this thesis, first because of the long tradition for comprehensive and open appraisal processes in the UK, and second for the significant wider environmental, social and economic impacts of the scheme, which is an opportunity to examine sustainability in the context of transport appraisal in more detail.

The work specifically concerned with the elaboration of assessment tools and decision-support processes is based on an adaptation of multi-criteria analysis tools (MCA) and more particularly on the Multi-Actor Multi-Criteria Analysis (MAMCA) approach, which gives more prominence to the explicit integration of stakeholders in transport project appraisal. Empirical work was conducted ex-post and consists of structured interviews based on online questionnaires following standard MCA steps. Finally in order to complement the research I also conduct exploratory work consisting of face-to-face unstructured interviews and structured observation of passengers' activities in actual high-speed rail trips in the UK.

Results

The first article in this thesis develops a metaframework for what should inform the analysis and eventually the design of STIFs. The article identifies and describes a total of 21 'metacriteria' that are grouped based on the framework function they are contributing to. Going beyond indicators, this article led to examining in more detail issues related to prioritising sustainability impacts, capturing trade-offs in the long term, and informing strategic sustainable transport choices, which are also relevant for other assessment and decision-support tools.

The second and third articles investigate the conceptual foundations and address the operational challenges in incorporating a sustainability viewpoint using multi-criteria analysis tools (MCA). The nested model of sustainability is found to be a useful approximation of strong sustainability principles when used as guidance for prioritising impacts. However a key contribution of these articles is the implementation of a 'future generations' stakeholder in transport appraisal processes, which in turn is proposed as a key feature for *sustainable transport appraisal* (STA) processes. One practical outcome of the research is a comprehensive list of project impacts for ex-ante assessment of large transport infrastructure projects like HSR. Structured interviews based on an online questionnaire are also found to be well adapted to the challenge of addressing biases in expert- and stalkeholder-based assessment methods. This approach provides a means to both address the need for quantifying and comparing complex impacts between various options, and to enable the systematic inclusion of stakeholders, therefore allowing for a level of reflexivity and 'democratic renewal' in appraisal processes.

In the fourth article, the issue of trade-offs between the two interrelated issues of biosphere integrity and climate change is investigated in more detail, where it is shown that current state-of-the-art decision-support processes and assessment tools lack formal ways of dealing with complex impacts with local and global implications that unfold over long periods of time. And finally the last article is a more conceptual piece that adopts a critical view on the historic emphasis for minimising travel time in transport planning, and contributes to a better understanding of the value of travel time from a traveller's perspective. The concept of reasonable travel time (RTT) is introduced, where travel time is reframed based on the traveller's experience of time in a total door-to-door journey. It is expected that RTT could lead to different thinking about the effectiveness of future transport investments, which is particularly relevant in a technological age where the overall quality of travel time can bring positive outcomes without necessarily changing the quantity.

Taken together, the articles and chapters that compose this thesis contribute to defining the emerging field of 'sustainable transport appraisal'. STA goes beyond the instrumental approach of conventional transport impact assessment methods that attempt to reduce, measure and forecast impacts in a cool, dispassionate way. It does so by adopting sustainability as an explict goal based on first-order principles, by integrating stakeholder perspectives in the decision-making process, and by incorporating the interests of future generations. Moving from impact assessment tools to appraisal processes means refocusing transport planning on decision-support and decision-making, which are technical and political endeavours that cannot easily be separated.

Resume

Det er en stor udfordring at påvise at der sker reelle fremskridt i retning af en bæredygtig udvikling i transportsektoren. Et hovedproblem i denne sammenhæng er at bæredygtighed ikke er systamatisk indarbejdet i dagens transportpolitik og -planlægning.

Den motiverende antagselse bag denne afhandling er at en omstilling til et reelt bæredygtigt transportsystem forudsætter et stærk understøtning gennem etablering vurderingsprocesser og bebeslutningssstøtteværktøjer som ikke blot benytter sig af bæredygtighed som terminologi, men som fuldt ud integrerer en egentlig bæredygtighedsforståelse i alle konceptuelle, operationelle og procedurale tilgange. Der er derfor et generelt behov for at udvikle de processer, metoder og værktøjer som beslutningstagningen omkring infrastrukturen er indlejret i så der bliver mere resonnante i forhold til både nutidige og fremtidige generationers behov svarende til den grundlæggende definition af bæredygtig udvikling.

Det centrale fokus for afhandlingen er hvordan bæredygtighedseffekter af transportprojekter kan identificeres og hvordan de kan operationaliseres som input til beslutningstagen.

Fordelene ved øget mobilitet i samfundet som udtrykt ved hastighed og kapacitet er betydelige og mærkbare, i og med at der derigennem bl.a. skabes adgang til en bred vifte af aktivitetsmuligheder for store befokningsgrupper. Ulemperne ved transport i form af negative eksternaliteter så som ulykker, lokal luftforurening og støj har, local air pollution and noise bliver der også taget højde i forbindelse med i de konventionelle samfundsøkonomiske vurderinger af transportprojekter. Men I dag er transportsektorens skadevirkninger (I Danmark, EU og globalt) ikke blot lokale men bidrager også med en stigende del af urfordrimgen af to af de såkaldte planetære grænser, nemlig klimaforandringerne og biosfærens integritet. Sådanne bredere, mere komplekse og langsigtede effekter, der også er eksterne i forhold til lokale interesser og markedstransaktioner kendeteger i voksende grad transportudviklingen, uden at man kan sige at de indregnes på særlig dækkende vis i de beslutninger der træffes på transportområdet. En mulig sideeffekt af at ignorere disse alvorlige problemstillinger i beslutningsprocessesn er at hele legitimiteten for evidensbaseret beslutningsstøtte bringes i fare, sådan det for eksempel kan siges at være sket i tilfældet med vurdering af fremtidige højshastighedstogforbindelser i Storebritannien som er den mest centrale case i denne afhandling.

Afhandlingen bidrager til at håndtere de følgende tre udfordringer: Den overordnede konceptualisering af bæredygtig udvikling som norm for transportinfrastrukturpolitikken, operationaliseringen af bæredygtighed i projektvurderingsssammenhæng gennem indikatorer og metoder for prioritering mellem dem, og endenlig inddregelse af aktører i vurderingsprocedurerne med særlig fokus på skabelsen af en eksplicit repræsentation for de 'fremtidige generationers' interesser i disse procedurer.

Analysen tager et afgrænset udgangspunkt i definition af et rammeværk (framework) for bæredygtighedsindikatorer for transportplanlægningen (=Sustainable Transport Indicator Framework; STIF), og bevæger sig derfra videre ud til behandling af beslutningsstøtte processer og vurderingsværktøjer, for endelig at åbne op for diskussuion af en række implikationer for transportplanlægning og beslutningstagen mere generelt.

En underliggende intention med den gennemførste forksning har været at udvikle nye former for tænkning og nye vurderingsmetoder som kan bygge bro mellem den teknisk-rationelle og instrumemntelle tilgang i konventionelle vurderingsværtøjer på den ene side og den kommunikative planlægnings rationalitet på den

anden. Dette nødvendiggøres af den kompleksitet, dynamik og interdependens som i stigende grad kendetegner transport planlægning og beslutningstagen.

Metoder

Afhandlingen trækker på en række forskellige undersøgelsesmetoder af både kvalitativ og kvantitativ art. I den konceptuelle del af arbejdet benytter jeg mig primært af målrettede litteraturstudier, inklusive omfattende analyse af bæredygtighedsteori og hvilke implikationer dette forsksningsfelt har for transportplanlægningen samt mere detaljeret behandling af litteraturen om indikator rammeværk for bæredygtig transport (STIF). Der er gennemført case studier af konkrete transportvurderinger som trækker på omfattende desktop- analyse af officielle vurderingsrapporter og andet offentligt tilgængeligt materiale. Det britiske højhastighedstogprojekt HS2 benyttes som case i tre af de artikler som udgør afhandlingen, for det første fordi UK har en lang og veldokumenteret tradition for omfattende og åbne projektvurderingsprocesser, og for det andet fordi det udvalgte projekt vil indebære en lang række markante miljømæssige, sociale og økonomiske effekter og dermed giver god mulighed for en detaljeret behandling af hvordan bæredygtighed håndretes i projektvurderingssammenhæng.

Den del af arbejdet som behandler vurderingsværktøjer og belutningsstøtteprocesser er baseret på Multi-Kriterie Analyse (MCA) værktøjer og mere specifikt en tilpasset udgave af Multi-Aktør Multi-Kriterie Analyse (MAMCA) tilgangen, som har særlig forkus på den eksplicitte inddragelse af stakeholders/aktører i transportprojektvurdering. Empirisk arbejde som blev udført efterfølgende består af strukturerede interviews baseret op et online-spørgeskema som følger en typisk MCA arbejdsgang. For at supplere denne analyse udførte jeg også explorativt arbejde som bestod i mere strukturerede personlige interviews samt strukturret observation af aktivitetsmønsteret hos passenger der benytter allerede eksisterende højhastighedstogforbindelser i UK.

Resultater

Denførste artrikel i afhandlingen udvikler et meta-rammeværk som definerer hvilke dimensioner der bør indgå i analyse af og udvikling af konkrete indikator-rammeværk for bæredygtig transport. Artiklen identificerer i alt 21 ‘meta-kriterier’ som grupperes i henhold til den funktionalitet i rammeværket som de bidrager til. Arbejdet med denne artikel førte videre forbi spørgsmålet om indikatorer som sådan til en mere detaljeret analyse af hvordan der kan prioriteres mellem bæredygtighedseffekter i forbindelse med projektvurdering, herunder afvejning mellem forskellge langsigtede effekter og udnerstøttelse af bæredygtige valg, hvilket også er releven for andre vurderings- og beslutningsstøtte værktøjer, udover indikatorer.

Den anden og tredje artikel undersøger de konceptuelle fundamenter og addresserer de operationelle udfordringer i forbindelse med at indkorporere et bæredygtighedssynspunkt ved brug a MCA værktøjer. Den såkaldte indlejrede bæredygtighedsmodel findes at være en anvendbar tilnærmelse til principper for stærk bæredygtighed, når den anvendes som retningslinie for prioritering mellem effekter. Et hovedbidrag fra disse artikler er implementeringen af en virtuel repræsentant for ‘fremtidige generationer’ i transportprojektvurderingsprocesser, hvilket igen foreslås som en hovedkomponent i hvad jeg definerer som bæredygtig transportbedømmelse, *Sustainable Transport Appraisal* (STA). Et praktisk resultat af undersøgelsen er en omfattende liste over effekter til brug for ex-ante vurdering af store infrastrukturprojekter såsom højhastighedsjernbaner. Strukturede interview baseret på online spørgeskema blev også fundet velegnede til den udfordring det er at håndtere bias i ekspert- og aktørbaserede vurderingsmetoder. Denne tilgang muliggør både at behovet for kvantificering og sammenligning af komplekse effekter på tværs af projektalternativer kan imødekommes, og samtidig at der åbnes for en systematisk inddraglse af aktører, hvilket igen tillader at et vist niveau af refleksivitet og ’demokratisk fornyelse’ kan finde sted indenfor rammerne af bedømmelsesprocessen.

Den fjerde artikel undersøger mere detaljeret afvejningen mellem to relaterede effektområder nemlig bevarelse af biosfærens integritet og modvirkning mod klimaforandringer, hvor det vises at dagens state-of-the-art beslutningsstøtteprocesser og vurderingsværktøjer mangler en formaliseret metode til at håndtere komplekse effekter med både lokale og globale implikationer som udfoldr sig over en lang tidshorisont.

Den femte og sidste artikel er et mere konceptuelt bidrag som anlægger et kritisk perspektiv på den tidsforståelse der typisk anlægges i transportvurderinger og hvor minimering af rejsetid følgelig kommer til at spille en altdominerende rolle. Artiklen bidreger til en ny forståelse af værdien af rejsetid set fra den rejsendes perspektiv. Konceptet ‘rimelig rejsetid’ (Reasonable Travel Time; RTT) introduceres, i hvilket rejsetiden omdefineres så den relaterer sig til den rejsende tidsoplevelse i en fuld dør-til-dør rejse. Det er forventningen at RTT-begrebet vil kunne lede til en anden måde at forholde sig til denfremtidieg effektitet af transportinvesteringer, hvilket er særligt vigtigt i en teknologisk tidsalder hvor kvaliteten af rejsetiden givetvis kan forøges uden at kvantiteten nødvendigvis øges.

Som helhed bidrager de artikler og kapitler som udgør denne afhandling til at definere det fremvoksende forksningområde ‘bæredygtig transportbedømmelse’ (Sustainable Transport Appraisal; STA). STA bevæger sig ud over den instrumentelle tilgang i de konventionelle transportprojektvurderingmethoder, som alene søger at reducere, måle og forudsige effekter på en kølig og uengageret måde. STA går videre ved at indoptage bæredygtighd som et eksplicit mål baseret på førsteordensprincipper, ved at inkorporere aktør-perspektiver på beslutningsprocessen og ved eksplicit at inddrage de fremtidige generationers interesser. At bevæge sig fra vurderingsværktøjer til bedømmelsesprocesser betyder at transportplanlægningen fokuseres på både beslutningsstøtte og beslutningstagen, som er tekniske og politiske elementer, der i realiteten ikke let lader sig skille ad.

Table of Contents

Acronyms

ASI	Avoid-Shift-Improve
BCR	Benefit-Cost Ratio
C2C	Cradle-to-Cradle
CBA	Cost-Benefit Analysis
EEA	European Environmental Agency
EIA	Environmental Impact Assessment
GHG	Greenhouse Gas
HS2	High-Speed Rail 2 project in the UK
HSR	High-Speed Rail
JSP	Just Savings Principle
LUTI	Land Use and Transport Interaction
MAMCA	Multi-Actor Multi-Criteria Analysis
MCA	Multi-Criteria Analysis
NSTP	National Sustainable Transport Planning
PB	Planetary Boundary
ROD	Rank Order Distribution
SD	Sustainable Development
SEA	Strategic Environmental Assessment
ST	Sustainable Transport
STA	Sustainable Transport Appraisal
STIF	Sustainable Transport Indicator Framework
TAG	Transport Analysis Guidance, also called WebTAG
TERM	Transport and Environment Reporting Mechanism
TNS	The Natural Step
WCED	World Commission on Environment and Development

Chapter 1 Introduction

1.1 Motivation

1 The motivation driving this thesis is an appreciation of the notion of sustainable development and the associated need for 'Transforming our World'[4] combined with a concern over the ways in which decisions on major transport policies and infrastructure projects are prepared and conducted today, ways which are not yet fully aligned with the overarching goal of sustainable development and the need for transformative actions. Considering the physical intrusion, substantial costs and longevity of transport infrastructure this is no small problem, if current infrastructure development locks society into decisions and systems that current and future generations will suffer rather than benefit from. With this focus I place my research contributions broadly within the emerging field of *sustainable transport appraisal*, a notion to be elaborated on and defined further in this thesis.

2 In practice, various aspects of sustainable development have long been addressed through transport planning and assessment. Economic appraisal methods are used to quantify and monetize combined costs and benefits of projects in many countries, often as part of wider frameworks (Mackie, Worsley, and Eliasson 2014). Environmental Impact Assessment (EIA) procedures and Strategic Environmental Assessment (SEA) high-level requirements are formalised as EU directives. Several countries including Denmark and the UK have adopted the broader language of sustainability when crafting plans and policies. Strategies and goals are regularly reframed through the prism of the three pillars of sustainable development, and assessment tools are expanding their scope to cover wider sets of economic, social and environmental externalities.

3 Despite such advances, several authors including Tengström (1999), Docherty and Shaw (2011), and recently Bueno et al. (2015) in a review of tools and methods for sustainability assessment of transport infrastructure projects, make clear that credibly demonstrating actual progress towards a genuinely sustainable transport situation remains a challenge. A key problem is that the incorporation of sustainability in transport policy and planning at present is not systematic, but partial, at best. A motivating assumption behind this research is that this needs to be corrected; a transition toward a sustainable transport system will require strong support from policy and planning frameworks that do not only adopt the *language* of sustainability and assimilate components of its terminology to conventional approaches, but fully integrate an explicit notion of sustainability in all of its conceptual, operational and procedural approaches.

4 The problem addressed manifests itself at different levels of decision-making on major infrastructure projects, from the analytic techniques applied to assess and summarize project impacts, to the general procedures adopted to ensure that such impacts are taken into account in political processes and decision making. There is a general need to improve processes, methods and tools applied in large-scale infrastructure decision making so as to make them more resonant to the needs of both current and future generations, in line with the fundamental concept of sustainable development launched by the Brundtland Commission (WCED 1987), and since adopted and reconfirmed numerous times worldwide.

[4] Wording unanimously adopted the by member states signing up to the post-2015 Development agenda including the 17 Sustainable Develomment Goals, in New York in September 2015.

5 The *core focus* of the thesis is on how to ensure project impacts in terms of sustainability are identified and become inputs to decision making. However, this cannot be seen in isolation from other levels of the infrastructure development and appraisal process, from the overarching conceptualisation of sustainable development as an ethos for transport infrastructure policy, to the operational specifics of impact assessment techniques such as indicators, valuation and aggregation methods, to the stakeholder representations applied in assessment procedures, which I will therefore also address.

6 In the following sections of this introduction, academic discourse on sustainability as a concern for transport policy and project appraisal (in section 1.2) is applied to these ideas, before delimitating the scope of the research (in section 1.3), introducing the associated frameworks and methodologies applied in the thesis work (sections 1.4 – 1.5), and finally introducing the contributions of the individual papers submitted as part of the thesis (section 1.6). In chapter 2, I go in more theoretical depth on the elements of sustainable transport appraisal that I have developed during this research, since it generally informs my inquiry and serves as the backdrop for the individual articles. In chapter 3, I present the overall conclusions of my work.

1.2 Expanding the key topics of the thesis

7 Given the transport sector's significant contributions to societal and environmental challenges, there is an urgent need to address transport from a sustainability point of view. Unfortunately, currently transport infrastructure appraisal processes fail to do so. This thesis takes the starting point that sustainable development (SD) includes sustainable transportation, meaning sustainability must be a core concern of transport project planning and decision-making. Despite strong traditions derived from half a century of experience of impact assessment in transport project appraisal, from the perspective of sustainability, current decision-support tools are lacking and inadequate (Bueno, Vassallo, and Cheung 2015; Bruun and Givoni 2015). When it comes to sustainability, decision-making is therefore more exposed to potentially biased and myopic political processes than necessary, considering recent and emerging advances in addressing sustainability at the theoretical and methodological levels. The limitations to current appraisal practices refer to capturing the benefit as well as the cost side of transport projects.

8 The *benefits* of increased mobility, speed and capacity are significant and visible, creating a wider range of opportunities that impact a greater number of people, potentially opening access to new goods and services including housing and employment opportunities, education facilities, public services, leisure activities and holiday destinations, and so on. Marchetti (1994) calls this basic instinct of man to expand its territory an anthropological invariant in travel behaviour. The benefits of mobility to society are captured most directly in transport appraisal by the aggregated quantification of travel time savings, which often becomes a decisive factor behind subsequent transport infrastructure spending. Critiques of the notion of 'travel time' treated as a context-independent commodity have however been raised within the transport appraisal literature (Metz 2008), and the thesis will address a way to resolve this issue in one of its contributions.

9 Full *costs* above and beyond the monetary costs of direct project investments have proven more challenging to identify, quantify, and address, and this has arguably been the main concern for the sustainable transport appraisal critique. While certain fairly tangible negative externalities such as accidents[5], local air pollution

[5] The World Health Organisation (WHO) reports 1.25 million fatalities from road collisions worldwide, per year. roughly equivalent to 13 airliners crashing daily. See

and noise have long been monetised and accounted for in conventional transport project appraisal (G. Santos et al. 2010), numerous wider, more complex and longer terms effects that are also external to market transactions are not only increasingly observed in transport but also far less well accounted for. These include, for example, transport-related carbon emissions[6] and biodiversity loss due to encroachment upon natural habitats (Selva et al. 2011). There are also the longer-term effects of transport provision choices on health and quality of life (Steg and Gifford 2005), their social equity implications (Jones and Lucas 2012), and the limited potential for increased provision to address traffic congestion in cities (Turner and Guranton 2009). What's more, certain land use patterns inherently requiring high mobility can cause a vicious cycle of transport network expansion and urban sprawl (Wegener and Fürst 1999; Owens 1995), which in turn exacerbates all of the above. Some of these issues have now reached a scale and impact level that the needs of future generations could be jeopardised.

10 Some research directly suggests that the current transport system trends based primarily on auto mobility, road transport, and fossil fuels is unsustainable (Sperling and Gordon 2008; Banister et al. 2011). However, assessing the sustainability of transport systems in the future to some degree depends on how 'sustainability' is defined and interpreted. If the transport system is assessed against so-called strong environmental sustainability principles – those that accept the concept of a 'safe' operating space for humanity (Steffen et al. 2015), as is discussed in Chapter 2 - the outlook is more gloomy, compared to weaker interpretations according to which environmental impacts can be compensated by equivalent economic gains (Pearce, Atkinson, and Dubourg 1994). In any case, the transport sector today (in Denmark, in the EU and globally) is an increasingly large contributor to the two 'core planetary boundaries' of climate change and biosphere integrity defined by Steffen et al. (2015), which makes it all the more critical to address. Even if some economic compensation mechanism could be envisaged, the costs of planetary replacement would likely be very high.

11 Despite the wide recognition of the need for sustainable transport systems, there is a huge implementation gap. Particularly challenging is that through "*automobility's strange mixture of coercion and flexibility*", we appear to be locked into the current patterns of development in transport (Urry 2008:p267; see also Schwanen 2015). Even in places where sustainability has been adopted as a political goal for transport policy, studies show that implementation remains slow and patchy: "*It has become gradually clearer that the problems hindering a transition are not so much related to a knowledge gap about what should be done, but rather problems in the implementation of this knowledge*" (Switzer, Bertolini, and Grin 2013:p2). The last decade of integrated transport plans – for example, from the UK or Germany - have yet to prove their capability to reverse these trends as economic imperatives have tended to supersede other considerations (Preston 2010; Schöller-Schwedes 2010; Docherty and Shaw 2011).

http://www.who.int/gho/road_safety/mortality/traffic_deaths_number/en/ and http://ec.europa.eu/transport/road_safety/specialist/statistics/.

[6] Transport is the only sector where emissions in the EU have increased since the Kyoto protocol 1990 base year (see http://maps.unfccc.int/di/map/ for a breakdown). The latest Transport and Environment Reporting Mechanism (TERM) report by the European environmental Agency (EEA) shows a peaking of CO2 emissions in 2007 (European Environmental Agency (EEA) 2015). However the report also notes the increasing divergence between test and real-world CO2 emission values, particularly since 2007, putting into question actual efficiency improvements and the efficacy of EU vehicle emission reduction policies.

Figure 1: "Distasteful though we find the whole idea, we think that some deliberate limitation of the volume of motor traffic is quite unavoidable" (Buchanan 1963)**.** The bulk of negative impacts is attributable to the road-based transport system. Lyngbyvej, seen from Tuborgvej, Metropolitan Copenhagen, Tuesday 8:30am, April 19, 2016 (author's picture).

12 With regard to the decarbonisation of transport, some of the research warned of a "*diminishing window of opportunity to act*" and therefore identified the need for policy that delivers genuine, rapid and transformative change (Hickman and Banister 2007:p386; Marsden and Docherty 2013). Addressing climate change would require urgent intervention, but it is not clear that we have the necessary decision-tools to support this goal, and transport system change tends to be slow and long term. Inertia of the built environment, vested interests in the system in place, travellers' habits and existing planning processes in transport institutions are among the number of factors that make intervening in transport particularly difficult and multi-faceted. This thesis is concerned with this last factor, the increasing complexity. Intervention requires taking decision: it is therefore important that decision-support tools used to assess transport projects adequately support the goals of sustainability within a context recognized as complex.

13 This suggests there is a need not only to assess transport projects for their contribution to a vision of sustainability, but to assess the strength of decision-support processes and assessment tools themselves with respect to the degree of support to sustainability they are likely to provide. The results of such a meta-reflection on assessment and decision-support tools will form the first component presented of the thesis work. A full review of sustainability for transport appraisal involves addressing the three following sets of challenges:

1) **Conceptual**: There is a need for translating high-level sustainability principles and global limits into more operationalisable sector-specific guidance and tools. Assessment and decision-support tools that refer to sustainability objectives often rely on the commonly used three pillars of sustainability and the one-line definition retained from the Brundtland report as a conceptual basis. But in practice, this approach leaves open the difficult issue of prioritisation between the potential trade-offs that arise from sometimes conflicting priorities, let alone to identify the trade-offs that emerge over broad geographic and temporal scales between seemingly remote and disconnected impacts. Sustainability is a holistic concept that does not lend itself easily to reduction. As an example, the review by Pei et al. (2010) on indicator frameworks that measure the performance of transport systems concludes on the need to *balance* among the different aspects of sustainability. But balancing does not necessarily imply giving equal weights, although this is sometimes the default approach adopted in indicator framework design.

Addressing this challenge must start from a comprehensive and holistic understanding of sustainable development, then lead to clear guidelines for prioritising amongst sustainability's different and often opposing facets. These facets include, among others, trade-offs between the short and the long term, between notions of fundamental human needs and materialistic standards of quality of life, between development being a cause of unsustainability or a means towards sustainability, or between humanistic solidarity (in the form of intra- or inter-generational equity) and personal liberty (Verburg and Wiegel 1997; Gibson 2006; Langhelle 1999; Lele 1991). While a number of environmental aspects can be informed by the natural sciences, many aspects of sustainability remain strongly normative: they depend on the visions that are set collectively about desirable futures, and they can therefore not be decided 'top-down'. This potentially poses particular challenges for internalising sustainability in decision-support processes and assessment tools that aim to provide objective, measurable and independent advice to decision-makers.

In this thesis, I have chosen to use guiding principles of strong environmental sustainability proposed by The Natural Step (G. Broman, Holmberg, and Robèrt 2000; G. I. Broman and Robèrt 2015) and the concept of Planetary Boundaries (Steffen et al. 2015) as ways to provide these conceptual underpinnings. I also develop the notion of 'future generation' stakeholders based on the understanding of sustainability provided by Brundtland. These notions will be explained in Chapter 2.

2) **Operational**: There is a need to critically review and improve the existing assessment tools and methods from the point of view of sustainability. The most basic tool for assessment is arguably the *indicator*, and the indicator *framework* is thus a key mechanism for making the conceptual aspects (above) operational. The importance of indicators for regularly assessing sustainability have been recognized at least since Agenda 21 adopted in Rio de Janeiro in 1992[7] and have become even more prominent with the adoption of the Sustainable Development Goals in 2015[8], This special role given to - but also expected of - indicators is summarised well by the following quote, taken from the United Nations Sustainable Development Goal indicators website:

"A robust follow-up and review mechanism for the implementation of the new 2030 Agenda for Sustainable Development will require a solid framework of indicators and statistical data to monitor progress, inform policy and ensure accountability of all stakeholders"

The important potential role of indicators also for transport impact assessment and the evaluation of policy performance towards sustainability goals has been highlighted by several authors (Zietsman and Ramani 2011; Pei et al. 2010; May, Page, and Hull 2008; Jeon and Amekudzi 2005). However, it has also been shown that indicators can be used selectively or ignored by the very policy bodies that adopt them, especially if they are not connected to actual prioritization and decision making (Gudmundsson and Sørensen 2013; Gudmundsson et al. 2016).

This points to a need to look beyond indicators into the role of broader assessment frameworks and methodologies that are actually used as decision support. In regard to this Bruun and Givoni (2015) in a recent comment in Nature suggest that current, first generation assessment tools based on cost-

[7] https://www.un.org/earthwatch/about/docs/a21ch40.htm
[8] http://unstats.un.org/sdgs/

benefit analysis and travel behaviour models are actually part of the problem when it comes to sustainability. Such tools have been applied to quantifying and monetising a widening range of costs and benefits in later years. Yet they have also become increasingly controversial because of a number of fundamental limitations and untenable assumptions - for example with regard to the values of time used under the assumption that travel time is 'wasted', or more fundamentally, with the applicability of the tools to aspects that, for practical or other reasons, cannot be reduced to a monetary value. Both for the case of large transport infrastructure, Meunier et al. (2014) report growing public distrust with Cost-Benefit Analysis (CBA) in France; whereas Dudley and Banister (2015) foresee the risk of a shift away from evidence-based decision-making due to current methods based on CBA becoming increasingly discredited in the UK.

The challenges of using economic indicators relevant to sustainability assessments are three-pronged. First, the focus on monetization risks giving more attention to those impacts which are more easily measurable (such as short-term economic benefits based on time savings or increased capacity) and leaving out more complex, qualitative or long-term environmental, social, or economic impacts (such as biodiversity loss, space consumption, comfort, beauty or wider agglomeration effects). Second, several critical choices need to be made with regard to key decision variables such as the discounting rate, which have raised concerns over the legitimacy of results (Mackie, Worsley, and Eliasson 2014). This is particularly relevant for greenhouse gas (GHG) emissions where there is little benefit of imposing limitations at the local level and in the short term (Meunier and Quinet 2015). Third, impacts distribute in time but also in space, which implies winners and losers. This in turn raises questions about how to group and assess stakeholders and related benefits and losses. For example it was found that investments in high-speed rail in France benefit mostly the highest income groups (Cour des comptes 2014). While CBA can be used to evaluate compensation amounts, in practice compensation is almost never paid out, and it is particularly difficult – perhaps impossible – to assess how costs and benefits will disperse in society in the long run (Mackie, Worsley, and Eliasson 2014). These critiques are particularly relevant for large-scale projects that result in significant change to time-space geographies, indicating that conventional methods may work well for incremental improvements for a specific mode, but less so for the type of interventions that disrupt the transport system as a whole (Vickerman 2007).

These considerations raise the need for new or improved assessment and decision-support tools to complement existing ones, both for adequately capturing a wider range of impacts, but also to appropriately prioritise them from a long term, strong sustainability perspective. Alternative approaches to decision support have been proposed. Some of these methods are based on indicator frameworks aiming to more comprehensively assess and benchmark sustainable transport development (Jeon and Amekudzi 2005; Zietsman et al. 2011). Under the heading of Multi-Criteria Analysis (MCA), a second generation of assessment methods has been developed to allow for the explicit inclusion of these indicators and their weighting in transport assessment (Browne and Ryan 2011; Barfod and Salling 2015). There are also a wide range of methodological challenges involved in using MCDA methods, including how to decide relevant weighting among assessment criteria and project alternatives. The thesis will present my work contributing to this field of methodology and discuss some of the challenges involved in applying them.

3) **Procedural**: There is a need to revise the procedures through which stakeholder views are being reflected in the assessment and decision making processes, and doing so beyond merely 'informing' the public as practiced through conventional impact assessment regulations. In response to both

growing complexity of society and a growing distrust with political and top-down planning processes, recent years have witnessed a broad range of social protests, cultural counter-movements such as postmodernism, as well as more practical attempts at a more bottom-up type of planning based on communicative rationality (Willson 2001; Sanderson 2001). Central to this approach is consultation and participatory debate - and therefore language, discourses, and the building of common understandings – in the appraisal process leading to decision-making. The discourse of Sustainable Development as adopted by the United Nations (from 'Agenda 21' in 1992[7] to 'Transforming our World in 2015'[9]) also calls for a wider inclusion of societal groups in partnerships to shape the future development of society. Banister, in his seminal contribution entitled "the sustainable mobility paradigm" (2008), sees broad and interactive engagement with stakeholders as a key to the effective implementation of sustainable mobility.

A third generation of assessment tools has brought focus to this 'democratic renewal' by proposing to complement techno-rationalist tools with improved capacity for stakeholder involvement and efficient public participation. A number of recent studies have applied this approach to various transport research areas such as integrated land-use and transport planning (Brömmelstroet and Bertolini 2012), the identification and selection of sustainable transport indicators (H. Castillo and Pitfield 2010), improving the integration of knowledge in environmental impact assessment (EIA) processes (Soria-Lara, Bertolini, and te Brömmelstroet 2016), as well as the appraisal of transport projects based on the multi-criteria analysis (MCA) method (Macharis, De Witte, and Ampe 2009). Although the participatory approaches face criticism due to the challenges "*regarding the inclusion of qualitative assessment and the value-laden judgments inherent to them*", the approach used as part of a 'sustainability toolkit' can help reinforce the legitimacy of the appraisal process as well as open up new thinking with regard to defining the problem, deciding upon the criteria to be assessed, and identifying the policy options that are available (Browne and Ryan 2011:p232).

14 The three challenges here also raise more fundamental epistemological questions on how to adequately understand and represent the reality in which large scale transport projects materialize. Whether techno-rationalist tools such as CBA, various forms of expert-based MCA methods, indicator frameworks or travel behaviour models can be expected to adequately capture complex and mutually influencing impacts in the long term is very much a question of one's position in the different philosophies of science[10]. Positivism assumes an objective (and therefore measurable and deterministic) reality, which sits well with mainstream economics, instrumental rationality in planning, and the dispassionate intentions behind such tools in conducting assessments (Geels, Berkhout, and van Vuuren 2016).

15 Yet as I described above, transport impacts are complex in their details, they are complex in the way they unfold and interact over time, and in terms of preferences for those with a stake in a proposed intervention and its various options[11]. The main implication from this is that it may simply not be possible to reduce a decision to an absolute 'right or wrong' - as benefit-cost ratios (BCRs) do for more simple investment

[9] https://sustainabledevelopment.un.org/post2015/transformingourworld
[10] Suffice to assume here that such comprehensive models will remain out of our reach for the foreseeable future, and that even if they do, that they will nevertheless face a problem of legitimacy, as "*results [from travel behaviour models] that can be comprehended only by the modellers are not transparent enough to support democratic decision-making*" (Bruun and Givoni 2015:p30).
[11] I borrow this litmus test for defining what a complex problem is from my second supervisor Steen Leleur's book on "Complex strategic choices" (Leleur 2012).

decisions that involve only direct costs and benefits (e.g. new vehicle technology development costs compared to expected sales) - or to an absolute 'best option' as some implementations of MCA suggest. In other words, "*it is unrealistic to expect [CBA with improvements offered by MCA] to capture all impacts in one score*" (Bruun and Givoni 2015). Because transport can be described as a complex socio-technical system that includes "*technology, policy, markets, consumer practices, infrastructure, cultural meaning and scientific knowledge*" (Geels 2012), there is likely to be multiple realities making 'best value for money' contextual upon on the various stakeholder perspectives.

16 As noted, the three sets of conceptual, operational and procedural challenges associated with incorporating sustainability in assessment methods and processes discussed above are all, to some extent, reflected in existing research studies. However, while examining them I identified a clear gap in this literature, namely in terms of how transport appraisal processes could incorporate explicitly the interests of *future generations*[12]. An interesting feature of the MAMCA method introduced above is that by integrating various stakeholder perspectives in a systematic manner, it also opens up the possibility for incorporating more explicitly the viewpoint of future generations as a distinct stakeholder group in transport appraisal. As noted, the concept of caring for the interests of future generations is a central point in the seminal Brundtland report of 1987 "our Common Future" (WCED 1987). Even if the idea of creating a type of 'sustainability ombudsman'[13] in appraisal may not be new in itself (Gudmundsson 2004), so far it remains to be demonstrated how an explicit 'future generations' stakeholder – or a 'sustainability viewpoint' - in decision-making can be operationalised. For assessment tools (whether CBA, MCA or indicator frameworks), much of this problem comes down to addressing the question of how to (re)prioritise the elements of a decision (e.g. project impacts) from a sustainability perspective. This is the main investigative thrust of this thesis.

17 The issue of raising interest and intimacy towards future generations is a challenging one, yet it is an idea that was raised also prior to the Brundtland report. This quote from Berger and Luckman exemplifies this challenge as well as the potential for 'typifying' the concept of future generations, something which a number of contributions in this thesis are concerned with:

"My successors, for understandable reasons, are typified in a … more anonymous manner - 'my children's children', or 'future generations'. These typifications are substantively empty projections, almost completely devoid of individualised content, whereas the typifications of predecessors have at least some such content, albeit of a highly mystical sort. The anonymity of both these sets of typifications, however, does not prevent their entering as elements into the reality of everyday life, sometimes in a very decisive way. After all, I may sacrifice my life in loyalty to the Founding Fathers - or, for that matter, on behalf of future generations." (Berger and Luckmann 1966)

[12] The discounting factor used in economic appraisal offers another methodological entry to address the balance between present and future generation's wellbeing within conventional project appraisal. Various solutions, such as lowering, dividing or differentiating the discount rate over time have been proposed (see e.g Chichilnisky 1996, Jonsson, 2008), and in some cases also implemented in national frameworks. However, this approach does not attempt to solicit the implications of adopting a future generations perspectives across all relevant impacts as part of the appraisal process as such, and I will not discuss it further in this thesis.

[13] Strictly speaking an 'ombudsman' would be somebody appointed to represent the interest of the public, take complaints, investigate issues and put pressure on government on their behalf. In transport there could for example be a 'traveller's' interest' ombudsman to safeguard and protect the rights of travellers (e.g. Salter 2011:p204). The term is therefore not entirely accurate when used in the context of transport appraisal tools, but it serves to illustrate the need for a type of advocate - or 'protector' – of the public's future interests in transport infrastructure decision-making.

1.3 Scope and delimitations

18 Because the thesis is a part of the SUSTAIN project on National Sustainable Transport Planning[14], the default geographical scope is national – or more accurately 'national' in the sense of a country which is a part of a supra-national entity such as the EU. This would be equivalent to the state or the province in a Canadian, American or Chinese context – or wherever the transport project planning authority stands[15]. However, such national decoupling is not entirely possible since large scale transport projects often need to be seen from their contribution to the continental scale, and inter-urban systems will have large impacts at the urban scale[16]. Related to this, the focus of the thesis is on transport *projects* of national significance, as opposed to national *policy* which would typically consist of a package of interventions, not all of which would be necessarily infrastructural (e.g. regulatory measures)[17].

19 Aside from article I, which could arguably apply to all forms of transport, in terms of the transport system delimitation and modes I chose to focus on land-based passenger transport[18]. Passenger transport is distinct from goods transport as it brings a range of behavioural complexities together with transport logistics, and is therefore more concerned with transport as a means to an end from a human needs perspective. Although there is some overlap and risks of unintended effects between the two types of transport, the research here is not intended to inform sustainable goods transport, which I assume to be more closely related to the rethinking of global production and consumption systems.

20 This thesis draws strongly from the various concepts of sustainable mobility developed by Gudmundsson in the IMPACT project (2007) as well as those developed in the seminal contribution by Banister (2008), some of which I will cover and elaborate in more detail in chapter 2.

21 Finally, although some of the learnings may apply and certainly have implications for transport agencies at various organizational levels, the scope of the articles is primarily intended to contribute to transport infrastructure project assessment that inform the transport planning aspects in policy-making. I do not address institutional structures (polity). Also outside the scope here is any in-depth analysis of political processes (politics), although I do comment where appropriate when there may be important political implications or concerns.

---

[14] http://www.sustain.transport.dtu.dk/english/

[15] This is particularly complicated in the case of the UK where the Department for Transport (DfT) jurisdiction is mostly limited to England, following the devolution of powers to the Scottish, Welsh and Northern Ireland respective parliaments / assemblies in the late 90s. Network Rail however owns and manages the rail network across the UK (see Marsden and Rye 2010 and particularly fig. 2 for more details).

[16] For example, the newly planned HS2 high-speed rail project in the UK may or may not connect effectively to international gateways (airports or the channel-tunnel rail link – HS1), and there are strong interests regarding the impacts of the scheme at the urban scale e.g. housing in London and urban redevelopment in Birmingham.

[17] I acknowledge that reducing the assessment of sustainability to a single project is problematic due to the holistic nature of sustainability. But so would be reducing sustainability to the transport sector at national level. I expect the learnings found in this research could apply (or become the topic of further research) to packages of transport interventions and national transport policy-making.

[18] However it is not possible to entirely decouple transport infrastructure from its impacts on freight transport. For example, freeing freight capacity on conventional rail lines was an important driver by proponents of building a new high-speed rail line in the UK.

1.3.1 Terminology

22 The core of this thesis examines how to improve transport assessment tools and processes from a sustainability perspective. One outcome of this thesis will be to introduce and define the concept of Sustainable Transport Appraisal (STA). I explain these terms below.

23 While the terms *assessment* and *appraisal* are often conflated, project *appraisal* is understood here as a planning *process* including project creation, option generation, *impact assessment*, as well as public participation procedures that inform *decision-making*. *Assessment* here refers primarily to the assessment of transport infrastructure projects' *impacts* (also sometimes called more generally effects). The choice of the word *impact* intends to confer an idea as to where in the causal chain we intend to focus the analysis. Based on the "Drivers, Pressures, State, *Impact* and Response" (DPSIR) framework as a means of structuring and analysing effects in long causal chains, *impact assessment* suggests the focus is on effects that are exceptionally important for management and decision-making, directly illustrating consequences of human action (impacts can be beneficial or detrimental i.e. benefits and costs).

24 *Appraisal* refers to the analysis of proposed actions (ex-ante), while *evaluation* refers to how actions have worked out in practice (ex-post)[19]. The results from the articles in this thesis can apply to either appraisal or evaluation, and similarly, assessment tools can support decision both in appraisal and evaluation processes. For example, assessing how impacts played out in reality after a project is implemented can influence how decisions are made for future projects. However, in a recent review of tools and methods, Bueno et al. argue the primary purpose of sustainability assessment it to inform decision-making *ex-ante* in transport planning, because "*at this point, decision-makers have great influence on the future sustainability performance of the project*" (Bueno, Vassallo, and Cheung 2015:p4). Methodologically, articles II and III really consist of ex-post evaluations of transport projects that have already been decided; but their purpose – and the purpose of this thesis overall – is of improving future appraisal processes. I will therefore speak only of *appraisal* hereon.

25 In theory, the ultimate outcome of an appraisal process is a project decision. But as we will also see in this thesis, an appraisal process does not consist of only one decision, but rather a series of decisions, taken iteratively, dynamically and continuously throughout the appraisal process, all more or less committing to narrowing intervention options. In this view, *decision-making* is an integral part of an appraisal process, for which a number of instruments, techniques, tools, methods, procedures or processes serve as *decision-support*. While the literature refers to all these terms sometimes indiscriminately, they can be organised by their level of specification or generalisation (e.g. a specific elicitation technique versus an assessment tool), or by their level of engagement with stakeholders. The term *method* seems to be more apt to include all types at a more generic level, although this should not be confused here with research methods. I hereby use the term *processes and tools* to convey the same generic idea as methods, but retain the point that some methods are based on instrumental rationality (e.g. measurement tools using quantitative data) and others on communicative rationality (e.g. stakeholder involvement processes).

26 I define *stakeholders* as any individual or group (organised or not) who is able to affect and/or is affected by the ultimate outcome of a particular issue (I also elaborate further on this in article III). I generally do not make a distinction between actors and stakeholders.

[19] For example, this distinction is clearly made in the UK in the Green Book 'appraisal and evaluation' guidance (HM Treasury 2011)

27 *Indicators* in a sustainability assessment context are closely linked to impacts insofar as their purpose is to make them tangible and understandable. Indicators are understood as "*variables selected to represent a certain wider issue or characteristic of interest*" (Gudmundsson et al. 2016:p138). A more detailed understanding of indicators and their role in transport appraisal is further explained in Chapter 2.

28 Finally throughout this thesis I have opted to use the term *transport*. This is based on the understanding of transportation from the engineering tradition, which is focussed on the provision of infrastructure and vehicles, technologies, and generally in meeting transport demands, increasing transportation capacity, ensuring safety, addressing congestion, and reducing travel time[20]. However *mobility* is a more accurate term when analysing transport through the prism of sustainability: mobility raises more clearly the *needs* transport is trying to answer from a users' perspective, and enables a focus upon the understanding of transport as a system that is part of and connected to wider societal systems. In this perspective, transport is not an end, but a means to an end. The term *corporeal mobility* is more accurate to convey the thesis scope, which is defined as: "*travel of people for work, leisure, family life, pleasure, migration and escape, organised in terms of contrasting time-space modalities (from daily commuting to once-in-a-lifetime exile)*" (Urry 2010). As one of the articles of this thesis will demonstrate, this understanding allows raising questions with the *experience* of travel, and whether the genuine need for co-presence must in fact be met with more and faster transport at all. For simplicity, I have opted to use the term *transport* throughout (and I make no difference between the British use of the term *transport* and the American *transportation*).

1.4 Analytical framework

29 In this section I present an analytical framework used to highlight the contributions of the articles contained in this thesis. This analytical framework also provides an overarching analytical tool and vocabulary to examine sustainable transport appraisal in more detail.

30 Three challenges pertaining to current assessment methods were previously introduced, namely: conceptual challenges, operational challenges, and finally procedural challenges. The working assumption for all sustainability decision-support processes and assessment tools is that they attend to all three. Each is briefly discussed in the following sections, while a discussion of how my articles contribute to each challenge is found in the final section of this chapter where each article is introduced.

1.4.1 Conceptual challenges

31 The area of conceptual challenges primarily concerns ensuring theoretical validity and, where needed, defining new concepts - or clarifying contested ones. For the specific case of selecting indicators, De Neufville observes "*most sets of indicators, if closely examined, reveal some of the dimensions of the paradigm that produced them*" (De Neufville 1978). Defining concepts is inherently normative. In order to assess sustainability, sustainability must be defined. Although sustainability is potentially less controversially normative today than it was at the time of the writing of the seminal Brundtland report, defining a 'sustainable transport paradigm' requires that fundamental ethical principles and value-orientations are

[20] The Department of Transport at the Technical University of Denmark has a long tradition and expertise in modelling road transport and improving its performance (e.g. in terms of reducing congestion , improving safety and measuring impacts like emissions , CO_2 and noise). The project financing this thesis is also called "National Sustainable *Transport* Planning".

settled upon (Sørensen, Gudmundsson, and Leleur 2013). Conceptualisation is therefore a necessary step needed to bring out the essential dimensions and assumptions to be used as a basis for operationalising sustainable transport appraisal.

32 For example, *sustainability* as a concept is understood in Brundtland as an anthropocentric project that assumes we should be concerned with preserving human life on Earth in the first place; caring for *future generations* assumes they have a 'right' to exist even if as their predecessors we have agency to prevent that; preserving *environmental integrity* assumes that interfering with natural systems could undermine human survival in the long term; and the concept of *accessibility* assumes we should be concerned with spatial and intra-generational justice in providing for mobility needs. Therefore examining conceptual challenges involves analysing or contributing to defining the normative assumptions of a sustainable transport paradigm, and the goals and implications thereof.

1.4.2 Operational challenges

33 The primary concern here is about operationalising the concepts set forth and producing evidence for decision-making. In practice this means providing practical tools, methods and processes that build knowledge on the consequences of planned transport interventions. Operationalisation from a sustainable transport appraisal perspective requires the careful analysis of whether an intervention is or will be a stepping stone towards sustainability or not. Tools can consist of actual indicator frameworks or various types of integrated transport impact assessment methods that serve to inform decision-making (Singh et al. 2009; Bueno, Vassallo, and Cheung 2015).

34 The use of the term 'tools' may presuppose the idea that we can *measure* a phenomenon as it 'truly is' in a cool and dispassionate way. But this may not necessarily be the case. Indicators are proxies for what they intend to represent, and must therefore not be confused with hard evidence. Sustainability is often said to be a wicked[21] problem for which there is no obvious single 'right' or 'best' solution. In other words, a working assumption for this thesis is that technical assessment tools and methods need to be adapted to the planning context to be effective, and bridging these two rationalities – that of how the reality can be measured and that of what the context perceives as the reality – is an important concern that I explore in more detail in Chapter 2. These concerns also bring us to the third and last challenges regarding assessment procedures.

1.4.3 Procedural challenges

35 Procedural challenges relate to the "*system of transport governance that should promote and implement changes towards sustainability through policies, programs and plans*" (Sørensen, Gudmundsson, and Leleur 2013). Although this statement applies to transport governance in the wider sense, a first concern here is the utilisation of expertise and knowledge in transport planning and decision-making. There are various ways in which assessment tools can be influential in prioritising transport projects at planning and policy levels. Beyond the expectation of having an instrumental role in directly influencing decision-making, knowledge tools can themselves have a shaping, enlightening role, where new knowledge may not influence immediate action but instead bring in new ideas and perspective (Gudmundsson and Sørensen 2013). For example, assessing the experience of transport or the diversity of users may shape a different understanding of transport – and therefore decisions - than assessing net time savings and capacity improvements. Inversely,

[21] The term 'wicked' is used to describe problems which consist of complex interdependencies with no clear set of solutions, or where solutions cannot clearly be determined as right or wrong, or where one solution may reveal other problems.

expertise can also be used ex-post to justify a decision already-made, even symbolically to give a rational appearance to a desired outcome, or be outright discredited if it conflicts with existing goals, visions, or predominant discourses (this thesis however is primarily concerned with instrumental or enlightening roles of assessment tools and appraisal processes).

36 Because procedural challenges are primarily concerned with the interface to governance, it should also answer the question ‘assessing for whom and by whose expertise?’ A conventional planning approach would perhaps assume decision-makers with institutional authority to be the default stakeholders and transport experts to be the default producers of knowledge. Yet effectively involving those ‘who have a stake’ – who are either affected or have an opinion about a specific transport intervention - has become an increasingly big concern in impact assessment. Overall, a working assumption is that technical assessment tools may not be sufficient to influence action.

37 These three challenges are not meant as definitive or independent of each other. Some important aspects are bound to overlap and there is no predefined order in addressing them. Sustainable transport assessment tools and processes are bound to be informed by theoretical and conceptual aspects, while also be shaped by governance and stakeholder preferences, and enabled or constrained by practical concerns such as data collection. Underlying all articles in this thesis is the idea that the key for theorising and addressing STA is precisely to shed light on all three of these challenges.

1.5 Methodology

In this section I introduce the choice of methods and cases in the articles that compose this thesis. The articles themselves are introduced in more detail in the next section.

1.5.1 Methods

38 I draw from multiple research methods across the articles in this thesis. For the conceptual work, I rely on purposive literature reviews. I have conducted extensive reviews on sustainability theory and the implication of this body of knowledge for sustainable transport, which I summarise in Chapter 2. The first article of this thesis is based on a detailed review of selected literature on the topic of sustainable transport indicator frameworks. For article V which is a conceptual paper, I not only rely on the seminal literature in the two distinctive fields of High-Speed Rail (HSR) assessment and the experience of time in transport, but I also engaged two of the leading researchers in those respective areas.

39 Empirical work for articles II, III and IV draws upon extensive desktop-based analysis of impact assessment reports and other publically available material for each of the case studies. Because of the large amount of textual data available, I have also used the qualitative data analysis software ‘NVivo’ to conduct the document review work and extract the specific topics of interest as a basis for the research (e.g. in order to find out the details about biodiversity impacts and how they were handled in the appraisal of a high-speed rail case in article IV).

40 For the work specifically concerned with the elaboration of assessment methods in articles II and III, this thesis builds on a research tradition at the Department of Transport about sustainable transport planning, appraisal and decision-support tools based on Multi-Criteria Decision Analysis (MCDA) tools and the use of elicitation techniques such as the Analytical Hierarchy Process (AHP) (Jeppesen 2009; Salling 2008; Barfod 2012; Jensen 2012). In the later work I draw more specifically from the application of Multi-Actor Multi-Criteria Analysis (MAMCA) to transport project appraisal, which gives more prominence to the explicit

integration of stakeholders in transport project appraisal (Macharis and Bernardini 2015). For this purpose I have elaborated an online questionnaire to structure a series of interviews and to collect assessment-related judgments from various groups of stakeholders. Devising the questionnaire was done in close collaboration with an experienced researcher in survey design methods at Copenhagen Business School. The validation of the MCDA approach was done with fellow researcher at DTU Transport specialising in decision-support. All calculations were done in Excel[22]. Although interviews were carried out in person or over Skype, I have used the online survey tool 'Qualtrics' for collecting data (a main reason for this software choice is that it allowed for an intuitive implementation of various weighing approaches).

41 In order to inform the concepts developed in the articles concerned with high-speed rail, I also conducted exploratory work consisting of structured observation of passengers' activities in an actual high-speed rail trip between London and Lille, which was followed by face-to-face unstructured interviews. Results in this case were represented using a variation of time-geography notation (in annex of article V).

1.5.2 Case selection

42 Three of the articles submitted as part of this thesis use the UK's high-speed rail (HS2) project as empirical material (articles III, IV and V). In this section I explain these choices (the UK, high-speed rail, and HS2).

43 First there are a number of advantages to picking a transport project in the UK as a research case:

1) There is a long tradition for environmental impact assessment in the UK, including for transport[23]. The current Transport Analysis Guidance (TAG) has evolved based on more than a decade of real-life applications, and it is based on a wider framework of national guidance called 'The Green Book', still valid and updated today (HM Treasury 2011). Methodologically, it is considered to be the 'state-of-the-art' and is often used as a benchmark by other countries (Mackie et al. 2013).

2) The transport appraisal guidance is underpinned conceptually by a wider framework of sustainability principles (see Figure 2). The UK has demonstrated high ambitions both for climate and biodiversity, the two core environmental planetary boundaries. For carbon emissions, The UK was the first country to set a legally binding goal and plan for carbon emission reductions up to 2050[24]. For biodiversity, guidance is based on the concept of 'not net loss' and 'biodiversity offsets'[25]. On

[22] The final version of the Excel sheets containing all data is available upon request.

[23] The Buchanan report of 1963 is usually credited for first raising concerns about the environmental consequences of expected growth in road traffic volumes, and for introducing methods for estimating environmental capacity and satisfying environmental norms in transport (Buchanan 1963).

[24] In 2008 the UK government legally committed to reducing its carbon emissions at least 80% below 1990 levels by 2050. So far the UK has met its planned carbon budgets, reaching 38% reduction as per 1990 levels in 2015 across sectors according to the preliminary report by the independent Committee on Climate Change (CCC) charged to monitor progress.

[25] The Lawton report introduced the concept of 'not net loss' and 'biodiversity offsets' in 2010, which became DEFRA policy in 2011 (Department for Environment Food & Rural Affairs 2011; Lawton et al. 2010). 'No net loss' applies to priority habitats, whereas 'biodiversity offsets' allows for 'compensation' of biodiversity losses by, for example, securing habitat expansion or restauration elsewhere and in a measurable way. However this 'natural capital' approach to biodiversity assessment has proven challenging to apply to irreplaceable life forms or ecosystems like ancient forests (see article IV)..

the other hand the UK faces the same challenges as other European countries with the difficulty to address the growing environmental impacts of transport[26].

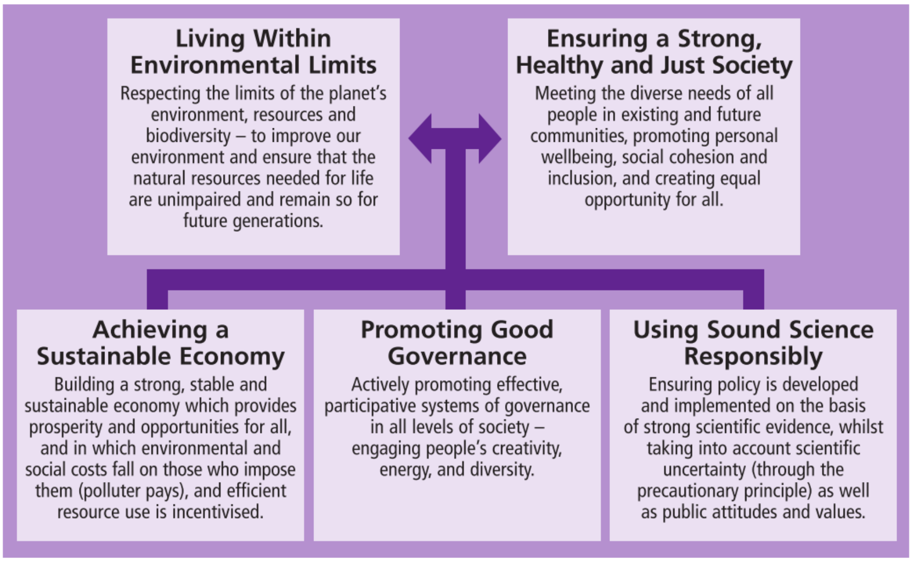


Figure 2: UK Framework of sustainable development principles (Department for Environment Food & Rural Affairs 2005)**.** This reference is still in use and was explicitly referenced by both the HS2 Appraisal of Sustainability (Booz & Co. and Temple 2011) and the Environmental Statement (HS2 Ltd 2013)**.**

3) The guidance recommends the complementary use of CBA and MCA methods in order to assess a wider set of impacts, monetised or not[27]. This is relevant for examining how the summing up, weighting and prioritising of the varied impacts under the topic of sustainability is in fact handled, which is one of the research objectives of this thesis.

4) The UK also has a long tradition for democratic processes and transparency, which translate into an elaborate system of public scrutiny and stakeholder engagement for major decision-making of proposed transport investments (e.g. public consultations, petitioning processes, special parliamentary committees etc.). This is relevant for this thesis objective to evaluate whether and how communicative planning tools may be used for operationalising a future generations' viewpoint.

5) At least until today, the UK is bound by EU regulations for Environmental Impact Assessments (EIA) and Strategic Environmental Assessments (SEA), which implies the learnings from the UK can, at least in theory and at a higher-level, be transferrable to other European contexts (although it is outside the scope of this thesis to evaluate transferability).

6) The guidance is in English and all the material is easily available online at no cost, making it an example of open documentation (called WebTAG)(Department for Transport 2014).

---

[26] Domestic transport emissions grew in 2014 and became the largest emitting sector of the economy in 2015, representing 29% - substantiating the fear that in terms of transport, monitoring frameworks "*have accomplished little other than highlighting the poor state of progress*" (Gudmundsson et al. 2010).

[27] The White Paper of 1997 called for "safe, efficient, clean and fair" transport based on supporting sustainable development goals (Department of the Environment Transport and the Regions 1998). It also introduced multi-criteria decision analysis (MCDA) framework in its New Approach to Appraisal (NATA). This was to become the basis for today's web-based Transport Appraisal Guidance (WebTAG)(Department for Transport 2014).

44 Second, High-Speed Rail (HSR) projects - and HS2 more specifically - are relevant to investigate because of their scale, sustainability implications, and timing:

1) Scale: High-speed rail has been shown to alter space-time geographies significantly (Givoni 2006; Spiekermann and Wegener 1994). This brings significant impacts of relevance to the national level, which is the intended scope of this thesis.

2) Sustainability implications: Because of the scale of high-speed rail, it is expected that such projects generate a wide range of significant impacts across all dimensions of sustainability and for the foreseeable future. This may be particularly true in the context of compact geography of the UK. Although rail is often seen and expected to be 'more green', not all impacts are necessarily positive. HS2 is therefore interesting to study from a sustainable transport appraisal perspective, both for assessing whether or how it can in fact serve as a stepping stone towards a more sustainable transport system in the UK, but more importantly in this thesis, for assessing the assessment tools themselves.

3) Timing: Contributing to the overarching trend of diversification in transport, HSR has become a 'hot topic' in Europe and also worldwide[28]. At the time of writing, the first phase of the HS2 project (from London to Birmingham in the West Midlands of central England) was in the final stages of parliamentary approval. However, the assessment tools as well as the project itself have faced much criticism[29]. There is therefore a potential to bring out insights from this case for improving STA processes, for example, in Denmark where negotiations over stepping stones to a high(er) speed rail network are currently taking place.

45 Studying high-speed rail is therefore relevant from a sustainable transport appraisal perspective because its impacts are potentially disruptive, complex, and long term which, as was already demonstrated in the HS2 case, pushed the 'state-of-the-art' appraisal processes beyond its capabilities (Dudley and Banister 2015). Overall, the appraisal of HS2 case can be viewed as a *critical* case according to Flyvbjerg's topology (2006): if the open, comprehensive and well-established decision-support processes and assessment tools in the UK fail to deliver an adequate and comprehensive appraisal of the impacts of HS2 from a sustainability perspective, it is considered unlikely to succeed elsewhere.

1.6 Presentation of the articles

46 In this section, I present in more detail each of the articles contained in this thesis. I also refer to the three challenges introduced earlier to qualify where needed the contributions of each article. I also explain some the research choices that led to these research topics.

[28] The EU's White Paper on transport calls for tripling the length of the high-speed rail network by 2030 and for shifting the majority of medium-distance passenger transport to rail by 2050 (European Commission 2011). China has been catching up with massive investments in HSR in the last decade (for more see the special issue by Marti-Henneberg 2015)

[29] For example, although the UK transport appraisal process was praised as "close to best practice in many areas", the need to adjust values of time and quantify wider economic benefits for HSR appraisal was already highlighted by the consultancy Steer Davies Gleave in 2004 (Steer Davies Gleave 2004:p69). It is these two factors that played to undermine the credibility of CBA tools in the assessment of HS2 (Dudley and Banister 2015).

47 This thesis addresses the problem of implementation gap in transport planning and decision-making from a sustainability perspective by contributing to the following overarching research goal:

> How can sustainability be transformed from general ideals to corresponding decision-support processes and assessment tools that genuinely support sustainable development in the transport sector?

48 This goal has been the key driver during the course of the thesis, and therefore underpins all the research work and articles contained here. Figure 3 illustrates the aspects of transport research relevant here, which helps narrow down this goal to the more specific research I conduct in my articles.

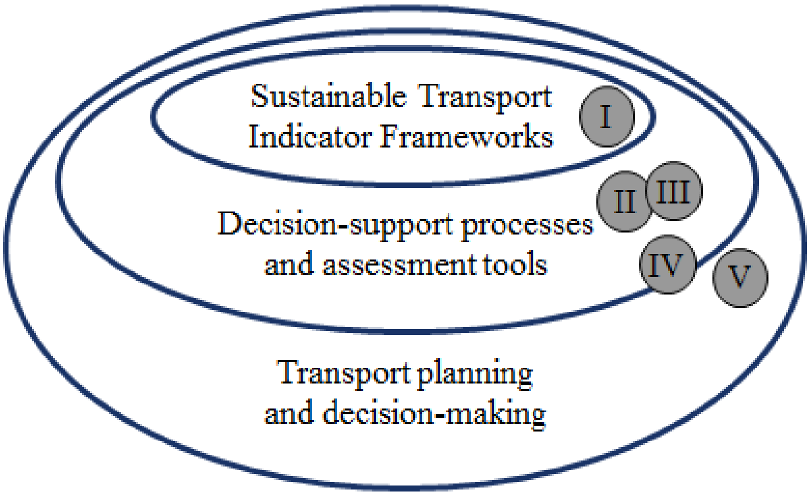


Figure 3: Contributions of the five articles in this thesis to the field of Sustainable Transport Appraisal (STA) research.

49 All five articles address some specific issue of sustainable transport appraisal. A key decision in pursuing my research was to look beyond indicators and investigate sustainability impacts as well as the STA tools dealing with them. Therefore articles II to IV shift focus to analysing impacts in appraisal context, as opposed to analysing indicators representing these impacts[30]. Figure 3 summarises this, showing that this research takes a starting point in Sustainable Transport Indicator Frameworks (STIFs – article I)[31], then expands to decision-support processes and assessment tools (articles II, III and IV), and finally explores issues relevant for the wider field of transport planning and decision-making (article V and partly article IV).

50 There are also a number of underlying foundational notions which are relevant to all articles, but for lack of space were not fully addressed in them. I develop these in chapter 2, namely: understanding of sustainability (section 2.1); definitions of sustainable transport (section 2.2); challenges of using indicators and indicator frameworks in the context of STA (section 2.3); and finally potential for stakeholder involvement to be an improvement in STA (section 2.4).

[30] However the two concepts (impacts and indicators) remain tightly connected, as illustrated by the use of the word 'impact' in article I's metacriteria. I explain further in chapter 2 the various ways in which indicators can be used to represent impacts (e.g. quantitative vs qualitative indicators).

[31] Independently of whether indicators are used to represent impacts of transport or goals towards a more sustainable transport system, indicators and indicator frameworks are placed in the centre in Figure 3 because they represent a lowest common denominator in STA – indicators are seen as a type of 'currency of knowledge'.

1.6.1 Article I – The state-of-the-art in STIFs and research needs

51 Article I, "Building a Metaframework for Sustainable Transport Indicators - Review of Selected Contributions" focuses on key challenges associated with the effective development and use of indicators to assess sustainability in the transport sector. With the expectation that learnings from the indicator frameworks literature can also serve to inform other types of decision-support processes and transport assessment tools, I analyse first the state-of-the-art with regard to the design and use of STIFs. One implication from the findings of article I is that the three metaframework functions also served to inspire the analytical framework – the three challenges - presented earlier. I refer to these below to further qualify the contribution of each of the remaining articles.

Purpose

52 The purpose of article I is first to clarify the key functions of indicator frameworks, and second to develop a metaframework for what should inform the analysis and eventually the design of STIFs (independently of whether they are intended for application in ex-ante, monitoring, or ex-post measurement).

53 Many sets of indicators have been proposed to assess sustainable transport, and the literature points to specific weaknesses, but it does not provide a broad or systematic approach for assessing STIFs. Context also matters: despite the overarching concern for sustainability, different contexts have different goals, different needs, and access to different data. The premise is therefore that it is preferable to develop guidance – a list of criteria - for analysing or designing indicator framework rather than attempt to provide a single, universally applicable indicator framework. There is therefore a need for a type of overarching frame – a *metaframework*[32] - to assess STIFs.

Method and findings

54 By analysing the research results from seminal literature on STIFs, the three functions of *conceptualization*, *operationalization* and *utilization* were found to provide a logical structure for analysing existing or emerging indicator frameworks, and therefore to produce a set of metacriteria to fulfil that purpose. Starting from an initial list of seven 'characteristics for robust indicator frameworks' by Pei et al. (2010), the article identifies and describes a total of 21 'metacriteria' that are grouped based on the framework function they are (most) contributing to.

55 Conceptual criteria include for example "Adopting an explicit, comprehensive, and holistic view on sustainability", "Allowing a long time horizon" and "Ranking of sustainability impacts" – all essential characteristics of a robust STIF. The research emphasises the need for embedding STIFs in a strategic sustainability planning process that would incorporate dimensions and aspects of sustainability from the start, rather than trying to adapt already existing indicator frameworks (e.g. for system optimization or government performance) to assess 'sustainable transport'.

56 Operationalization criteria used to inform the design and selection of indicators in general is a well-researched field. For assessing sustainable transport, long list of impact indicators are readily available (Hall 2006; Litman 2015; Marsden et al. 2005) and conditions for their selection has been covered elsewhere (Gudmundsson et al. 2016). The criteria raised here are applicable to indicator frameworks in a more general

[32] As De Neufville (1978) points out, there is a risk of 'infinite regress' in creating a framework to validate another framework. Yet this is needed because there are no commonly agreed set of criteria for how to measure and report on transportation sustainability.

sense (e.g. "Ensuring cost-effectiveness or monitoring") rather than specifically addressing *sustainable* transport indicator frameworks. These are nevertheless important as a type of sanity check, and they informed the methodological decisions in the later articles.

57 Utilization criteria examine the use and influence of tools in the context of transport planning and decision-making. For example the criterion "Engaging with stakeholders and context" is found to be particularly relevant in a wider process of sustainability appraisal. This also becomes a key concern in the following two articles of this thesis.

Selected research paths

58 The metaframework also opened up wider issues relevant for other assessment and decision-support tools[33]. This led me to focus on examining primarily issues related to the conceptualization of sustainability in STA, namely: prioritising sustainability impacts (articles II and III); adopting a comprehensive view on sustainability (article III); identifying and capturing trade-offs between impacts in the long term (article IV); and informing strategic sustainable transport choices (article V). In other words, the metacriteria found in this research opened up new research avenues, both for indicator research but also beyond it.

59 One avenue for further investigation is the actual application of the metaframework to assess existing frameworks e.g as used by transport agencies, to review how well they reflect and support different aspects of sustainability. More operational criteria for such a task were not developed in the thesis, but could be a topic for future research. This work can for example consist of examining empirically existing, state-of-the-art STIFs (such as CEEQUAL in the UK or INVEST in the US) in order to further develop the theory and the applicability of each metacriterion.

1.6.2 Article II - Operationalising a sustainability viewpoint in STA

60 Based on one of the research gaps found from the review in article I, in article II "Applying Sustainability Theory to Transport Infrastructure Assessment Using a Multiplicative AHP Decision Support Model" we investigate the *prioritisation* of impact indicators by the use of Multi-Criteria Analysis (MCA) methods.

Purpose

61 There is yet limited literature on the issue of prioritising impacts from a strong sustainability perspective in integrated assessment of transport projects. Holden et al. (2013) offer one such recent contribution based on principles from the Brundtland report. Jourmard and Nicolas (2010) suggest an approach based on the nested model that avoids substitution between the three traditional pillars of sustainability, where they also single out irreversible impacts on biodiversity and the climate. Robèrt et al. (2016) develop a stakeholder engagement approach based on the Natural Step sustainability principles (see Chapter II for more details on these foundational sustainability theories). Article II contributes to this topic by developing a method to integrate explicitly strong principles of sustainability as a means to inform the weighing of transport effects in a real appraisal context.

[33] The idea that metacriteria relevant for STIFs could also be relevant for decision-support processes and assessment tools in STA in general emerged at the Transportation Research Board general conference in January 2015. The Sustainability Research Subcommittee suggested we present the metaframework as a basis for framing future research on knowledge tools, guidance or even standards for how to incorporate sustainability in transport governance. http://www.trbsustainability.org/wp-content/uploads/2012/11/ADD40_Sustainability_Research_Subcommittee-_MinutesFinal.pdf

Method

62 This research examines a specific transport infrastructure project (a bridge in Denmark) using an existing set of eight assessment criteria drawn from this specific case. In this article, we operationalise sustainability by providing a simplified model of strong sustainability where each of the three conventional dimensions (economic, social and environmental) are nested. We compare this model to the principles set by the Brundtland report to clarify the strengths and weaknesses of this approach. We then devise and apply a MCA procedure to make explicit a sustainability viewpoint using both the nested model and input from a green think-tank to use as comparison. Part of the procedure involves the assessment of complex impacts using a pairwise comparison technique to assess the relative performance of various options to the main scheme proposed.

Findings

63 The nested model is found to be a useful approximation of strong sustainability when used as guidance for prioritising impacts (at the condition that the impacts assessed are all relevant, as is the case here). The outcome is however not intended to be used 'as is', but instead to provide a type of benchmark for comparing preferred project options between 'virtual sustainability advocates' and the perspective represented by the interests of decision-makers in this particular context. Two more practical conclusions are of particular relevance for the research that follows in article III. First this case raised the need for a wider (and perhaps standard) set of assessment criteria to be used in sustainable transport appraisal. Second, because of the need to involve experts, decision-makers and stakeholders as part of the assessment process, the approach showed the potential for the communicative role of MCA-based tools in a process of appraisal.

1.6.3 Article III – Expanding the sustainability viewpoint in STA

64 Article III "Incorporating a sustainability viewpoint into multi-actor MCA – the case of HS2", is motivated by the conclusion from article II for the need to expand the assessment criteria to a wider and more comprehensive set of impacts. We develop this research path by examining a different type of transport infrastructure project (high-speed rail).

Purpose

65 The main focus and contribution of this article is to develop and test a STA process on a large transport project. This article is a core part of this thesis both in terms of breath and depth: by developing a full STA method, we seek to incorporate sustainability by: 1) developing a comprehensive list of sustainability assessment criteria; 2) adapting and applying the multi-actor MCA (MAMCA) procedure; and 3) making explicit a sustainability viewpoint in three different ways[34]. One main objective of the research is to expand the instrumental rationality of assessment tools by integrating various stakeholder perspectives in a systematic manner. Therefore the article is mainly concerned with exploring the various methodological trade-offs that have to be made while still addressing conceptual challenges (validity of the data both from a scientific and a sustainability perspective), operational challenges (transparency, ease of use and cost-effectiveness), and procedural challenges (potential for reflexivity and influencing decision-making)[35].

[34] This paper is longer than a single journal article. It describes a substantial research project that represents a major portion of my doctoral research which, we think, has the potential to contribute to several publications. A shorter version of this paper is currently in the review process.

[35] These criteria are a subset of those developed in article I, adapted and simplified for this case.

Method

66 The first phase of the HS2 project (between London and the West Midlands) is selected as a case study for a number of reasons. A high-speed rail project of the scale of HS2 has potential to alter the space-time geography of the UK significantly, which brings a number of wider environmental, social and economic impacts that are difficult to assess with standard assessment methods. For this reason HS2 is an opportunity to examine sustainability in the context of transport appraisal in more detail. In this case, the existing state-of-the-art appraisal guidance of the UK was stretched and substantially discredited, leaving the actual decision-making of HS2 to a more arbitrary political process (Dudley and Banister 2015). On the other hand, a vast amount of data and documentation is readily available from the actual appraisal that took place, making it easier to reproduce and test, ex-post, an alternative appraisal process.

67 The method we develop draws from the MAMCA approach, a MCA method that gives an explicit concern to various stakeholder perspectives (Macharis, Turcksin, and Lebeau 2012). We follow and adapt standard MCA appraisal steps, which are summarised here:

1) The definition of the project objectives and options are predetermined based on the case study itself;
2) The list of criteria (impacts) was developed iteratively and interactively in the first phase of the research with interviews and by the research team;
3) The research team developed criteria for grouping stakeholders by interest; all stakeholders interviewed are transport professionals familiar with HS2, and a future generations viewpoint is obtained by eliciting the views of sustainability experts;
4) The selection, prioritisation and assessment of the criteria is done by conducting structured interviews based on an online questionnaire. The choice to carry out the response elicitation in person is motivated by the need to address known biases with this type of methodology (e.g. motivational bias);
5) The data analysis is conducted by the research team based on the multiplicative analytical hierarchy process (AHP) technique;
6) Robustness of the results is tested by varying consistency thresholds and the minimum number of assessments per criterion to be considered valid;
7) Project preferences are computed for all stakeholder groups, but they are not aggregated. For purpose of comparison, ‘virtual’ sustainability viewpoints are computed by applying weights for weak and strong sustainability (as was done in article II).

Findings

68 The key contribution of this paper is the incorporation of a ‘future generations’ stakeholder into the MAMCA process. In this case, neither the ‘bottom-up’ sustainability expertise viewpoint nor the ‘top-down’ virtual sustainability viewpoint comes out in favour of HS2 when compared with the option of upgrading the existing network. At a methodological level, the research demonstrates the usefulness of conducting semi-structured interviews in conjunction with an online questionnaire for the process of assessing and weighting a long list of sustainability impacts. The approach also provides a means of quantifying wider impacts relevant for STA, thereby making them visible and comparable.

69 The research also led to a number of more detailed findings with regard to the adaptation of MAMCA to this complex case, which can be summarised as follows. Validity for sustainable transport appraisal requires comprehensiveness in the long list of relevant impacts, and therefore criteria and their descriptions are cornerstones of the method (the considerations that led to the final list we used are explained in more detail in the paper's second appendix). While most respondents felt comfortable with the approach, some respondents expressed the need for exploring further how to decouple normative importance from contextual relevance in the assessment of the alternatives. Another important finding is the need for clear rules for grouping stakeholders into homogeneous groups, and therefore particular attention needs to be given to obtaining sufficient information on respondent traits. As MCA methods depend more directly on human judgment, validating who and how the questionnaire is answered is crucial to mitigate biases.

70 A final important finding is the potential for this approach to play a significant role in communicative forms of planning and decision-making. The process allowed the research team to experience reflexivity and learning on the part of respondents. Respondents realised the implications of their choices, which in some cases challenged their preconceived ideas on this specific case. This could be relevant in an actual STA process for reaching a greater consensus in decision-making, and therefore addressing the issue of "unstructured stakeholder involvement and inefficient public participation" raised by Soria-Lara et al (2016).

1.6.4 Article IV – Biodiversity loss and climate in STA

71 Continuing with the case of high-speed rail, in article IV "High Speed Rail: A Mandate for Future Generations?", we turn to analysing in more detail the challenges and trade-offs associated with assessing two interrelated environmental impacts for large transport projects, namely the two core planetary boundaries of climate change and biosphere integrity.

Purpose

72 In this article, we seek to answer the following research questions: 1) what are the difficulties of assessing jointly carbon and biodiversity impacts in the long term?; and 2) to what extent are these impacts given political salience in the decision-making of large infrastructure projects like HS2?

Method

73 Drawing from the concept of environmental planetary boundaries (Steffen et al. 2015), article IV explores in more detail the longer term environmental consequences of major infrastructure decisions that have to be made today. The article is based on the case of high-speed rail in the UK (the HS2 project phase I), which is used to illustrate the various complexities in assessing the two critical boundaries of climate and biodiversity. We then zoom in on the tunnelling of a protected area in the Chiltern Hills in order to illustrate the inherent difficulties in defining – let alone prioritising – an environmental legacy for future generations.

Findings

74 The actual appraisal of HS2 provides extensive data on both the operation and construction carbon footprint of the project. However we find that the claimed carbon savings of the full HS2 project (phase I+II) over the appraisal period of 60 years are likely to be offset entirely by the embedded footprint from construction. Much of the construction footprint comes from tunnelling (due to the steel and concrete required). From a biosphere integrity perspective, increased tunnelling reduces the impact of natural habitats, which is particularly relevant when dealing with local 'irreplaceable' natural capital such as ancient forests. But this brings global implications due to the significant upfront carbon emissions from tunnel construction

75 An important issue here is timing. While the actual numbers are sensitive to choices in terms of future scenarios, HS2 is found to be essentially ‘carbon neutral’. However, the construction footprint comes at an upfront ‘cost’, whereas the ‘benefits’ - which come mostly from a forecast of modal shift - will only start accruing once the line is operational. One implication is that HS2 will contribute negatively to the UK carbon budgets reductions until 2050.

76 Faced with such trade-offs - and despite a voluminous environmental impact assessment - we find that considerations for speed and costs take priority, whereas wider environmental questions are given a subsidiary role. In the appraisal process, there were no discussions over the adequate balance between climate and biodiversity impacts

77 This conclusion is relevant as a reflection about the three challenges: precise definitions and ambitions in terms of biodiversity, legally binding goals in terms of climate, and precise qualitative and quantitative assessment data on both carbon and biodiversity impacts do not suffice by themselves to guide a sustainability transition. This research therefore stresses a weakness of the WebTAG assessment framework: although individual impacts are assessed thoroughly for the expected lifetime of the project and even beyond (60 years, 120 years for some impacts), the framework lacks a formal way to report the evolving dynamics between impacts, to present explicitly the trade-offs that are involved, and to agree on their appropriate balance.

1.6.5 Article V – The concept of reasonable travel time in STA

78 Finally, in **article V,** “From Minimum to Reasonable Travel Time”, we revisit the concept of travel time in transport planning and develop the concept of Reasonable Travel Time (RTT).

Purpose

79 The main purpose of the article is to adopt a critical view on the historic emphasis for minimising travel time in transport planning, and to contribute to a better understanding of the value of travel time from a traveller’s perspective. The key assumption behind this approach is the concept of derived demand: transport in this view is seen as a ‘means to an end’. In economic terms, it is the benefits (or the utility) derived from the activities at destination that justify the costs (or disutility) of travel. The main implication is that travel time is considered ‘lost’[36]. This in turn puts times savings at the centre of transport analysis which drives development of transport solutions that speed up travel.

80 The aim of the article is to enrich (and to some extent challenge) the current planning paradigm by developing a more holistic conceptualisation of travel time for informing strategic sustainable transport choices in transport appraisal.

Method

81 The article starts by deconstructing the various elements that compose travel time. Journey durations play an important role in travel decisions. But from a traveller’s perspective, it is the total journey time that matters – the door-to-door travel time - which often can involve more than one transport mode. In contrast, the transport system is typically planned as a set of separate networks. A second important aspect is the need to

[36] Or ‘wasted’, or ‘locked’, although time spent travelling could also be seen as time ‘invested’, which has a less negative connotation. The exact terminology to use in future versions of the article was still being discussed at the time of submission of this thesis.

reconsider to use of time while traveling, particularly so in a technology-enabled age. Some economic tools (like the Hensher formula) already consider the possibility for adjusting values of travel time savings (VTTS) according to 'productivity' levels (although such approach still faces methodological and conceptual difficulties[37]). Third, travel time depends also on the number and type of activities at destination, for e.g. new activities may be added to a trip to compensate the efforts involved in reaching a destination. We distinguish such efforts as physical, cognitive and emotional, all of which could impinge on the traveller's total door-to-door experience of travel. A fourth aspect is reliability, which is a cross-cutting issue (it affects the door-to-door travel time, the experience, as well as the time needed as buffer to attend a specific activity)[38].

82 Because HSR is both speed and quality, the case of HSR is illustrative: reconceptualising travel time as any time upon which the transport system can either 'force' travellers to be physically, cognitively or affectively occupied, or 'free' the traveller to use the time for their own productive purpose brings important consequences for decision-making and the effectiveness of future transport investment in saving time. This finding could for example refocus investments towards High *Quality* Rail, as opposed to High *Speed* Rail[39].

Findings

83 This article is conceptual: we use our analysis as a basis for defining Reasonable Travel Time (RTT) as a normative and more holistic conceptualisation of travel time, which could challenge and enrich the 'Minimum Travel Time' approach as a guiding principle for transport planning and appraisal. This concept can inform future STA processes in making investments in transport that would allow travellers to 'reclaim' the time spent on transport, which could come at a fraction of the cost of major investments focused primarily on provision of high-speed transport.

84 Further research is warranted for 1) operationalising the concept (e.g. ICT tools already provide door-to-door travel information to passengers that could be used by planners) 2) assessing the full implications for transport planning institutions (e.g. increased focus on integrated, multi-modal planning) 3) developing further the concept of RTT, not only from a traveller's perspective, but also from a societal and environmental sustainability perspective[40].

[37] A recent study found a wide range of values of time, per mode and per country, in using this approach (Wardman and Lyons 2015). It also raises difficult questions as to how to attribute values of time (e.g. employer or own time) as well as equity issues.

[38] This concern for reliability is raised but not fully acknowledged as a fourth cross-cutting component of RTT. Reliability is likely to take a more central role in future versions of the article.

[39] As an example, two business passengers I interviewed on a Virgin train between London and Manchester found their ride so comfortable they felt it could have lasted longer!

[40] New framing of the fundamentals of transport planning will likely face opposition from the current regime. As an example, during the consultation period of HS2, Chilterns environmentalists raised the issue of "reducing the *need* for transport". From the tone of the exchange however, questioning the underlying discourse of 'unfettered movement' was out-of-scope, if not ridiculed: "*Does anyone else have any views on alternatives to High Speed 2, apart from not travelling as much?*" (House of Commons Transport Committee 2011: Q354).

Chapter 2 Theoretical foundations of STA

85 In this section I present the literature that forms the theoretical premise of this thesis: it introduces the bigger story my articles are a part of. The focus here is on sustainability theories that are relevant to framing Sustainable Transport Appraisal (STA), and more particularly those that can help inform the prioritisation of impacts and indicators in ex-ante transport assessment.

86 I present here the results of extensive literature reviews that have informed the articles but could not be fully contained within them. The reviews cover the following topics: sustainability theory, sustainable transport concepts, indicator frameworks, and finally on the involvement of stakeholders in decision-support processes and assessment tools in general.

2.1 Sustainability

87 This section unpacks the understanding of sustainable development I use in this thesis, which is drawing from the *strong* environmental sustainability position.

88 Operationalising a complex concept such as sustainability for transport project sustainability assessment requires some reduction – albeit a cautious one that retains a holistic approach (Gasparatos, El-Haram, and Horner 2008). Setting a pragmatic boundary would geographically be concerned with preserving human life on planet Earth and for the foreseeable future. Assuming humans depend on the existence and stability of the biosphere to exist requires that we minimise or closely manage impacts that risk interfering with the planet's natural systems. Defining a time boundary is rather difficult because it raises questions of justice, and therefore of intra- and inter-generational equity. Applying Rawls 'veil of ignorance' (2001) would give equal importance to all beings, now and well into the future. But this also implicates reducing the share of non-renewable resources for current generations to next-to-nil, which could in turn undermine the existence of this current generation, and therefore undermine the existence of future generations (!). While it is clear humanity today needs to survive for future generations to exist, these initial reflections tell us that there may not be one simple rule for defining sustainability.

89 In article I, I go some way in elaborating on this concept by providing a simplified picture of the Brundtland understanding of sustainability as a potentially useful normative basis for prioritising sustainable transport indicators. In articles II and III, I propose to use the 'nested model' of sustainability as a way to simplify and operationalise the Brundtland definition of sustainability. The nested model consists of representing the three pillars of sustainable development – economic, social, environmental - as nested: "*The global economy services society, which lies within Earth's life-support system*" (Griggs et al. 2013:p.306) . I provide perspective on this choice and thinking here.

2.1.1 Historical perspective

90 Sustainable development (SD) has been an exponentially used term in academia and in society since the late 1970s[41]. A pivotal moment for the acceptance and popularisation of SD is usually recognised to be the publication of the widely-cited report "Our common future" in 1987 by the Brundtland Commission (known as the World Commission on Environment and Development, or WCED), which was chaired and named after the former Norwegian Prime Minister, Gro Harlem Brundtland (I therefore refer to it as the Brundtland report hereon). But the Brundtland commission did not 'invent' sustainable development, nor did it invent the term. In an earlier attempt at reconciling development and environmental proponents, the International Union for the Conservation of Nature and Natural Resources (IUCN) proposed in 1980 "*the overall aim of achieving sustainable development through the conservation of living resources*" (Lele 1991). Earlier in 1976, a working group within the World Council of Churches wrote the following which, as it turns out, is close to the essential tenets of the Brundtland report:

"The twin issues around which the world's future revolves are justice and ecology. 'Justice' points to the necessity of correcting maldistribution of the products of the Earth and of bridging the gap between rich and poor countries. 'Ecology' points to humanity's dependence upon the Earth. Society must be so organized as to sustain the Earth so that a sufficient quality of material and cultural life for humanity may itself be sustained indefinitely. A sustainable society which is unjust can hardly be worth sustaining. A just society that is unsustainable is self-defeating. Humanity now has the responsibility to make a deliberate transition to a just and sustainable global society."

This in turn is similar to the mandate set by the conclusions from the book "Limits to Growth" of 1972: *"We are searching for a model output that represents a world system that is: 1. sustainable without sudden and uncontrolled collapse; and 2. capable of satisfying the basic material requirements of all of its people."* (Meadows et al. 1972).

91 While the terms sustainable development and sustainability may still be perceived to be relatively new, the notions of sustainable development can be traced much further back in time. As early as the mid-18th century in North America, Jared Eliot (1685-1763, a farmer and physician), became alarmed about the wearing and clearing out of agricultural land without concern for mending it. He wrote essays on improving 'field husbandry', which later became the environmental sciences spearheaded by conservationists such as George Perkins Marsh (1801-1882). Marsh is sometimes credited for being the precursor of sustainability, at least in the United States (Theis and Tomkin 2012). The preface to his 1864 book 'Man and Nature: Or, Physical Geography as Modified by Human Action' (1865), if not for the last sentence, could have well been a citation of the Brundtland report:

"The object of the present volume is: to indicate the character and, approximately, the extent of the changes produced by human action in the physical conditions of the globe we inhabit; to point out the dangers of imprudence and the necessity of caution in all operations which, on a large scale, interfere with the spontaneous arrangements of the organic or the inorganic world; to suggest the possibility and the importance of the restoration of disturbed harmonies and the material improvement of waste and exhausted

[41] The first academic article containing the word 'sustainability' (applied to environmental sciences) appeared in 1977, with rapid and exponential growth from 1986 and onwards: approximately 400 papers were published by 1990, 7000 by year 2000, 80000 by the end of 2013 (source: Scopus). This does not include the vast amount of grey literature on the matter.

regions; and, incidentally, to illustrate the doctrine, that man is, in both kind and degree, a power of a higher order than any of the other forms of animated life, which, like him, are nourished at the table of bounteous nature".

92 Similar concerns were voiced in Europe in relation to the fast disappearance of forests and the resulting acute scarcity of timber in the UK, France and Germany starting in the 17th century. One early use of the term 'sustainable' came from the 400-pages treatise 'Sylvicultura oeconomica' (1713) on sustainable yield forestry by Hannß Carl von Carlowitz (1645 – 1714, a German accountant and administrator). Carlowitz condemned the unrepairable damage resulting from what he judged to be short-term thinking for the purpose of quick profits by logging companies. He predicted a resulting economic crisis from the lack of timber, and proposed concrete solutions to care for the renewal of the resource "*so that timber could be used for ever, continuously and perpetually*". Historians point at numerous other pioneers of sustainability around the same epoch who inspired Carlowitz (Grober 2007). In his treatise 'Sylva, or A Discourse of Forest-Trees and the Propagation of Timber in His Majesty's Dominions (1662), John Evelyn (1620 – 1706, an English writer) talked of "*men should perpetually be planting, that so posterity might have Trees fit for their service*" and to "*forego the present profits, and rest satisfied with having handed down to posterity a blefsing of inestimable value*". In 'La Grande Ordonnance Forestière' (1669), Jean Baptiste Colbert (1619 – 1683, a French finance controller under King Louis XIV) suggested to "*reduce the use [of French forests] according to the capacity*".

93 Grober (2007) notes that many early authors such as Carlowitz and Evelyn themselves referred to the Bible's message "*Then the LORD God took the man and put him in the garden of Eden to tend and keep it*" (Genesis 2:15), where 'to tend' is understood as 'to till, to cultivate, to *develop'*, while 'to keep' as 'to take care of, to watch over, to *sustain.* The latest Roman Catholic Papal Enclyclical "Laudato Si': On Care For Our Common Home" (2015) makes precisely such argument (paras 66&67), calling the rupture of harmonious relationship between human beings and nature a 'sin'[42].

94 This historical perspective is relevant in demonstrating that many of the notions of sustainability have been long debated, showing that the struggle between environmental sustainability and human development is not new and indeed deeply rooted. From a philosophical angle, this struggle is also reflected in the dichotomy between the Cartesian "man as a master of nature" and Spinozan "man as part of nature". In conclusion, sustainable development is an age-old problem. However, as we will see now, human impacts have grown significantly enough now so that global and concerted action is needed.

2.1.2 Revisiting Brundtland

95 The Brundtland report of 1987 is the result of three years of deliberative meetings and public hearings in all regions of the world, which included 'hundreds' of senior government representatives, scientists and experts, research institutes, industrialists, representatives of non-governmental organizations, and the general public who provided more than 10,000 pages of evidence (see in Annexe 1 of the report, Public Hearings). The Brundtland report was adopted in the same year as it was published by the United Nations General Assembly through resolution 42/187, which enshrined the notion that SD had to become a central guiding principle of the United Nations, national governments and other institutions, public and private. The wide consultation

[42] http://w2.vatican.va/content/francesco/en/encyclicals/documents/papa-francesco_20150524_enciclica-laudato-si.html

process leading to the report and its official adoption internationally makes it particularly relevant to study as a credible and acceptable (and I argue, still relevant) basis for conceptualising sustainability.

96 The underlying assumptions are twofold. The first is based on the assessment of "*unprecedented growth in pressures on the global environment, with grave predictions about the human future*" (Annexe 1, The Commission's Mandate). The second is normative: it rests on the belief that changes towards a "*more prosperous, more just, and more secure*" future is possible provided that policies and practices are directed to "*expand and sustain the ecological basis of development*" (ibid).

97 The report is best known for formulating the de-facto definition of sustainable development: "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (World Commission on Environment and Development (WCED) 1987). This short definition and the report's title 'Our Common Future' set the normative ambition of SD to satisfy needs and aspirations of both current and future generations, thus putting the concepts of human needs and inter-generational equity at the centre. This anthropocentric concern forms the basic ethics of the report. In other words the report is not about environmental integrity or animal welfare in its own right, but is concerned with a utilitarian view of how preserving environmental systems is seen as a necessary condition for meeting the long-term needs and insuring the well-being of humans far into the future. The report acknowledges the existence of ultimate environmental limits. But it does not confine the environment to its own independent sphere. Instead it suggests a non-absolutist approach based on two principles, which are stated in the text immediately following the above definition:

"It [SD] contains within it two key concepts: the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs" (Chap.2 para.1).

98 This provides important clues to the prioritisation of interventions and their impact for their contribution to sustainable development. First, it gives priority to meeting basic human needs. This implies the existence of a social floor that should also be met for development to be sustainable. This has an important implication for richer countries. While the report claims poverty requires (economic) growth, past a certain level of consumption standard the report becomes far more concerned with the *quality* of growth. I have illustrated this thinking in article I and also more succinctly in article II, where I propose a 'reverse environmental Kuznets curve' as a basis for a conceptualisation of SD useful for assessment. The environmental Kuznets curve suggests that past a certain level of per capita income, specific and local environmental degradation reverses and improves (e.g. richer countries have the means to clean their rivers). Based on Brundtland, I argue that on the contrary impacts increase at the aggregate level as richer countries displace environmental impacts further away in space and time (e.g. increased carbon emissions). The Brundtland report echoes this understanding by shifting the focus from poverty reduction to ecological systems integrity once essential human needs are met:

"Living standards that go beyond the basic minimum are sustainable only if consumption standards everywhere have regard for long-term sustainability. Yet many of us live beyond the world's ecological means, for instance in our patterns of energy use. Perceived needs are socially and culturally determined, and sustainable development requires the promotion of values that encourage consumption standards that are within the bounds of the ecological possible and to which all can reasonably aspire" (Chap.2 para.5)

99 The second aspect to consider for prioritisation besides basic human needs is the state of technology, which may both exacerbate environmental problems but also may help shift ecological boundaries by for e.g. enhancing the carrying capacity of the resource base (chap.2 para.10). The report therefore calls for both fuller accounting of environmental factors in technological development (chap.2 para.68) and for a reorientation of technological development to resolve social and environmental problems (which often "fall outside the calculus of individual enterprises", such as pollution or waste disposal, or in the case of transport, adequate provision of public transport or infrastructure for active transport modes - chap.2 para.67).

100 For these reason the report has been criticised both for being too influenced by conservationist-environmentalist *and* for being biased towards traditional economic growth and the "technical fix" as the solution (Langhelle 1999:p135). But the treatment of sustainable development by Gro Harlem Brundtland is detailed and complex, and therefore escapes simple categorisations. Based on an in-depth analysis of the report, I summarise in Table 1 below 30 notions of SD found in the report, organised around 7 dimensions. These seven dimensions are themselves found again in alternative definition of SD offered by Brundtland:

"In essence, sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development; and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations" (preamble para.15)

101 This definition attests of the complexity in conceptualising and operationalising sustainability, yet suggests these seven dimensions for underpinning the concept: the idea of change as an underlying *process*, the criticality of *environmental* sustainability, the contribution of *economic* and technological development, the need for adequate institutional capacity and just *governance*, the concern for *inter-dependencies* and the need for integrated and consistent action, an expanded *time* perspective with concern for both the present and the long term, and the overarching *social* goal "to meet human needs and aspirations".

Table 1: Summary of the 30 notions of sustainable development found in the Brundtland report, organised around 7 dimensions

Dimension	Notion	Brundtland reference
Time	Inter-generational equity	§27
Social	Needs and aspirations, well-being and quality of life	§27, see also Chap.2 §42
	Poverty, intra-generational (international) equity	Chap.2§1
	Consumption standards	§29, see also Chap.2 §5
	Population size	§29, see also Chap.2 §48
	Harmony (among human beings and between humanity and nature)	§81
Environment	Limits and thresholds	Chap.2 §9,
	Ecosystem integrity	Chap.1 §23, Chap.2 §14
	Regeneration of renewable resources	Chap.2 §11
	Substitutability of non-renewable resources	Chap.2 §12
	Irreversibility	Chap.2 §13
	Sinks and wastes	§27, see also Chap2. §10
	System-wide effects	Chap.2 §11
Economic	Poverty requires growth	§28
	Equitable access to resources	§28
	Sustainable work opportunities	Chap.2 §43
	Quality of growth	Chap.2 §35, §37

	Full accounting & taxation	Chap.2 §36, §79
	Non-economic valuations	Chap.2 §38, §39, §40
Governance	Integrated governance	§31
	Change in national and international governance	§31, §104
	International justice	Chap.2 §26
	Collective impacts and responsibility	§103
	Vulnerability and risk analysis	§70
	Precaution with new technologies	§71
Process	Process of change	§30
	Effective participation	§28
	Political will	§30
	Urgency to act now	§104, §109
	Reorientation (changing trends / breaking out patterns)	§103, §104
Interrelationship	Environmental limits ← State of technology and social organisation	§27
	Global economy ← Sustainability of ecosystems	§75
	Risk of ecological/social 'catastrophe' ← Endemic poverty	§27
	Economic development ←→ Social development	Chap.2 §41

102 Assessing sustainability in a holistic way would therefore address these notions (giving credence to the idea that sustainability is indeed the 'science of everything'). The above table can serve as a checklist to analyse in more detail to which extent a sustainability assessment framework considers the full implications conducting such assessment entails.

103 In terms of prioritisation, Brundtland states in summary that first, overriding priority should be given to the essential needs of the world's poor (Chap2 §1), and therefore that poverty reduction is a precondition for environmental sound development (Chap3 §7). Second, priority should be given to preserving the basic overall integrity of natural systems that support life (the atmosphere, the waters, the soils, and the living beings - Chap2 §9) – what has been dubbed "*Brundtland's proviso of sustainability*" (Langhelle 1999:p133, citing Malnes 1990). Third and finally, priority comes to (re)considering the role of growth, technology, lifestyles, moral and value criteria, and patterns of behaviour in improving well-being and the opportunity to fulfil aspirations for a better life to all (§27). It is this overall prioritisation that in my view makes the Brundtland report relevant as conceptual basis for sustainable transport assessment, a report that is described by Langhelle as "*more coherent and potentially more radical than either adherents or critics seem to be aware of*" (Langhelle 1999:p130).

104 Articles II and III both contribute to operationalising this sustainability perspective. However sustainability in those articles was further reduced to three *nested* dimensions of sustainability. I now turn to explaining in more detail these dimensions and the choice for the nested model as a simplified representation.

2.1.3 The pillars of sustainability

105 The three dimensions of *social, economic* and *environmental* sustainability have become a de-facto starting point to conceptualising and assessing sustainable development in transport and elsewhere (Moldan, Janoušková, and Hák 2012). In his review of the concept, Connelly suggests the representation of the three dimensions of environment, society and economy as three overlapping yet distinct circles was first developed by the International Centre for Local Environmental Initiatives (ICLEI) in the early to mid-1990s (Connelly 2007). The three pillars of sustainability - as it is also called – have roots that can be traced back to the

traditional goals of *development*: to provide for basic needs while increasing the productivity of all resources - *human*, *natural* and *economic* (Lele 1991). Post-Brundtland reports from The World Bank, the United Nations Agenda 21, and the 1992 Rio Declaration are often credited for disseminating the terminology of the three dimensions (Munasinghe 1993; Gudmundsson 2004). In the industry, the social and environmental dimensions have received growing attention within corporate social responsibility (CSR) initiatives in parallel to Elkington's coining of the term 'the Triple Bottom Line (TBL)' (Elkington 1997).

106 There is no unanimous definition for each of the dimensions. Environmental sustainability can refer to environmental protection, resilience, integrity, regeneration, or any combination of this, applied to individual species, resources or entire ecosystems. The environment can be seen as static and utilitarian natural *assets* or ecological *services* (Munasinghe 1993), or as dynamic systems whose natural *cycles of adaptation* is the object of sustainable development (Holling 2001). Social sustainability can refer to the concern for meeting basic human needs, but also to the concept of intra- and inter-generational justice, or to the *societal* capacity to provide for human needs – this latter aspect is sometimes put into a fourth, *institutional* (or governance) dimension (Gasparatos, El-Haram, and Horner 2008). Although economic sustainability can be equated with financial viability (of a project) and the 'sustainability' of profits, it can also encompass wider societal concerns for prosperity and welfare that stem from economic vitality, and in the case of Brundtland, the important role of technology in shifting limits for all three dimensions.

107 These concepts are summarised together as dimensions in Figure 4. In this graph, a distinction is made between the 'what' and the 'how'. The 'what' refers to the three traditional pillars of sustainability. These three dimensions are those in focus for conventional sustainable transport assessment based on instrumental rationality, which is the topic of articles II, III and IV. The 'how' refers to sustainability as a process of change. The concern here shifts to a more communicative rationality, where stakeholder views, vested interests, political will, and discourses also play a role in enabling a transition towards a sustainable transport system. The stakeholder involvement aspects play an important role in articles II and III, and the implications of instrumental versus communicative rationality for transport assessment tools is discussed in more detail in article III.

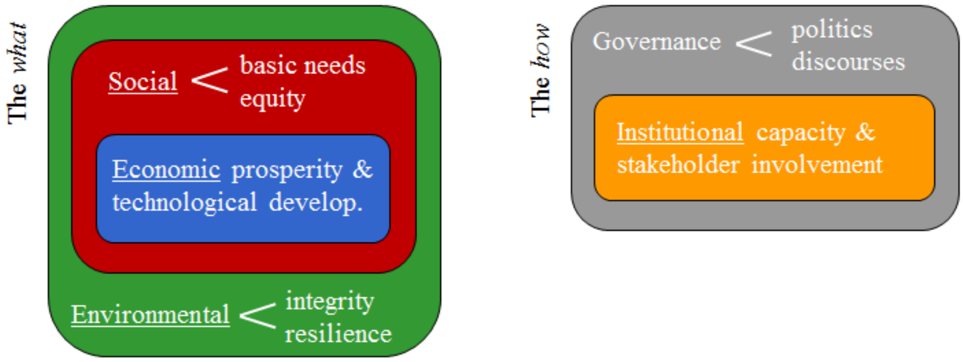


Figure 4: Nested sustainability dimensions, based on Brundtland conceptualisation. The 'what': sustainability as a state. The 'how': sustainability as a process of change.

108 But sustainability, even if reduced to a number of dimensions, remains contested and therefore it may be best to talk of *sustainabilities*, or sustainability *discourses* (Connelly 2007).

2.1.4 Sustainability discourses

109 An underlying debate is one of differing world views, which has been amply debated under the headline of the 'weak versus strong' environmental sustainability spectrum. These world views draw from the

discussions between neoclassical- and ecological-oriented economists (Costanza et al. 1997; Nelson 1995), between anthropocentrism and bio-centric holism in ethics (B. Becker 1997; Rydin 1999; Connelly 2007), and between prometheans (modernists) and deep greens (survivalists) in Dryzek's typology of environmental discourses (Dryzek 1997)[43]. I summarise here the 'weak versus strong' sustainability discussion to document and explain the strong position taken by the articles in this thesis.

110 *Weak* sustainability posits nature as a form of economic capital, and that natural capital can be substituted by other forms of capital, namely man-made capital or human capital (Pearce and Atkinson 1993). Based on the substitutability assumption (including unconstrained elasticities in substitution), sustainability becomes positive (including for future generations) if the sum of all forms of capital increase over time. This implies that, at its more extreme sense, humanity can continue to function without natural resources since such resources will have been put to fruitful use for development, or that technology can in theory be a substitute to nature (Hopwood, Mellor, and O'Brien 2005). Thus the weak position tends to portray the three dimensions of sustainability in a compartmentalized manner, as three overlapping dimensions, where sustainability becomes a balancing act between various trade-offs and where performance in one dimension can offset reduced performance in another. For this reason, indicator frameworks that are built around the three dimensions of sustainability and that are based (often implicitly) on the neoclassic weak position typically do not attempt to weight the dimensions (which is the same as giving them equal weight).

111 Pearce & Atkinson designed a national indicator of weak sustainability, showing developed economies such as Japan, Costa Rica and the Netherlands as 'sustainable economies', whereas Mali, Madagascar or Ethiopia were 'unsustainable' (Pearce and Atkinson 1993). These results support the environmental Kuznets curve theory, whereas past a certain point of economic development, a firm, industry or a country's environmental footprint decreases as its wealth increases. However the environmental Kuznets curve has been criticised for being applicable only to selected pollutants, at smaller geographical scales and over the short-term only, and otherwise overlooking cross-border transfers of resources use, pollutants, or wastes with long term or global impacts (Max-Neef 1995). In a study of sociological theories, York et al. (2003) conclude that evidence for an environmental Kuznets curve at national level via ecological modernisation is spurious[44]. These critiques lead us to the strong perspective on sustainability.

112 Environmentalists and the ecological literature deny the possibility of substitutability of natural capital (Daly 1990). The *strong* sustainability position suggests that some environmental assets simply cannot be quantitatively valued, and as such, are not substitutable: they should be accounted for separately and in their own right. Proponents such as Daly illustrate the strong position by stating that human-made capital cannot replace ecological systems that are vital to human existence: no amount of fishing boats can compensate for the lack of fish; no amount of saw mills can substitute for diminishing forests; and technical fixes to climate change or biodiversity loss are not likely to be conceivable (Daly 1990; Giddings, Hopwood, and O'Brien 2002; Hopwood, Mellor, and O'Brien 2005). In practice, it has been argued that both positions in their more extreme forms are absurd: for one, nobody believes in perfect substitutability (except perhaps in neoclassic economic theory). Similarly, nobody believes in keeping natural capital entirely untouched (Dobson 1996). Connelly (2007) and Hopwood et al. (2005) provide an analysis of discourses and draw a 2-dimensional map

[43] All of these positions can be traced back to the two opposing world views of Cartesian 'man as a master of nature' and Spinozan 'man as part of nature' introduced earlier.
[44] This said, a scenario where economic prosperity would continue to increase and would enable humanity to resolve its global environmental challenges would prove the environmental Kuznets curve right in the very long term.

from weak to strong with consideration for social and environmental aspects on each axis (see Figure 5). In both cases the strong position is said to be eco-centric if environmental protection is prioritised, and anthropocentric if justice and well-being are prioritised.

113 Hopwood et al. (2005) introduce a third variable, whereas higher concerns for environmental or social aspects translate into higher levels of ambition for change, from status quo at the weak end, through reform in its more mainstream discourses, to transformation at the stronger end. Both authors see eco-socialism as the political discourse representative of the strong position with equal consideration between the social and environmental dimension, and deep ecology as a particularly eco-centric discourse. Ecological modernization and the three pillars of sustainability fall closer to the weaker end, on the border towards reform with a concern for reducing negative environmental and social impacts. In this typology, Brundtland would appear to strike a balance both between the social and environmental axis and between the reform and transform types of change expected to achieve sustainable development.

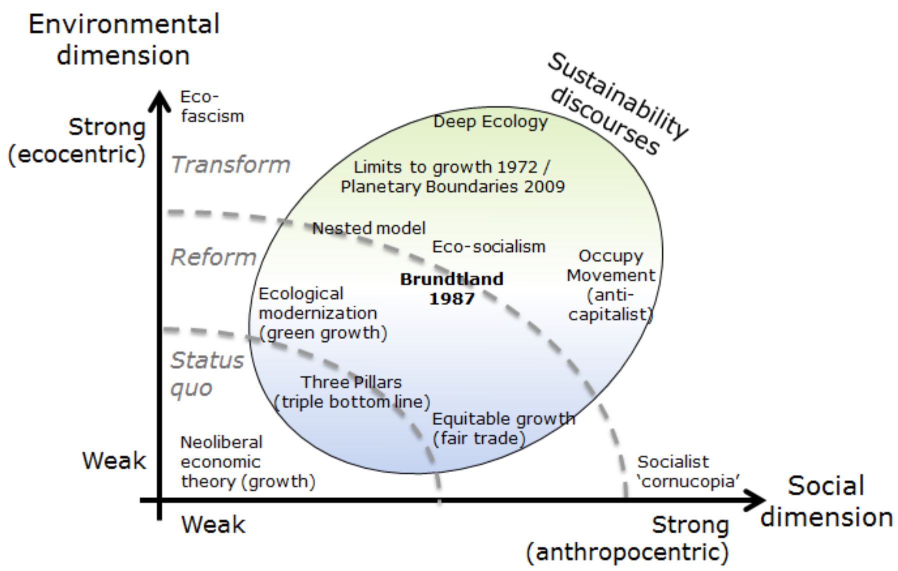


Figure 5: Mapping sustainability discourses, adapted from Hopwood et al. (2005), Connelly (2007) and Dobson's typology of environmental discourses (1996).

114 Exploring further the notion of criticality and irreversibility of natural capital, ecological economics distinguish the following four types: *renewable resources* such as forests or fish from within the biosphere; *non-renewable resources* such as fossil fuels and other mined resources from the lithosphere (i.e. extracted from under the Earth's crust); *eco-systems* and the services they produce such as biodiversity, the ozone layer or the water cycle; and *natural sinks* such as land, the air and the oceans. These types of natural capital all operate at different spatial and temporal scales (Holling 2001). Daly proposes sustainability principles for each type of natural capital (Daly 1990; see also Gudmundsson & Höjer 1996; or Moldan et al. 2012 for a more recent discussion). For renewable resources, Daly suggests harvesting rates should not exceed their long-term rates of natural regeneration (what he calls "sustained yields"). For the quasi-sustainable use of non-renewable resources, he states that exploitation "must be paired with a compensating investment in a renewable substitute", so that by the end of the life of the non-renewable, the renewable will be yielding an equal yearly sustainable income (Daly 1990). For wastes and sinks, he proposes that waste emissions (hazardous or polluting substances) should not exceed the natural assimilative capacities of ecosystems. As for more complex natural capital other than the above (such as ecosystem services), he proposes the overarching irreversibility principle that human throughput be at least within carrying capacity in order to

maintain ecological integrity. This is in aligned to the approach taken by Brundtland (see under 'Environment' in Table 1 earlier).

115 Presenting the economic, social and environmental dimensions as nested is controversial as it runs contrary to the widely accepted model focussed on balancing the three dimensions, and it also reverses the (often implicit) hierarchy given to economic development. The assumption however is consistent with Brundtland for the case of developed countries: it gives a general priority to safeguarding long-term ecological sustainability and promoting intra- and inter-generational equity over satisfying aspirations for improved standards of living: "*In the long term, harmonious economic development can only be guaranteed if, first, the environmental and social priorities of public projects are respected*" (Joumard and Nicolas 2010:p136; see also Holden, Linnerud, and Banister 2013). In other words, the nested model makes clear that societies are dependent on the environment for their long-term survival and that, as such, they must operate within the environment's carrying capacity. In a similar way, the economy (activities and technological development contributing to economic prosperity) in the nested model is seen as a subset of society, and therefore must respect social constraints, which I sum up in Figure 4 as the capacity to meet basic human needs and the fair distribution of benefits and burdens (equity).

116 Because of the priority given to environmental sustainability and integrity by Brundtland, I explore in more detail the dual concepts of environmental limits and precautionary principle in the next section.

2.1.5 Precaution and boundaries

117 One major concern of this thesis is measuring sustainability for transport. This requires some idea of what to measure, but also where in the causal chain and compared to what norm or standard. In this section I explore in more detail two concepts that are relevant to the strong conceptualisation of sustainability according to Brundtland: ecological limits, and the precautionary approach in the face of uncertainty. I argue below that these two approaches are complementary and necessary. Effect (or outcome) ecological indicators are useful because they measure what is of value and can provide a means to assess the efficiency of policies to address each effect (Turnhout, Hisschemöller, and Eijsackers 2007). On the other hand, effects may be the result of a number of diffused sources and complex causal chains that unfold over long periods of time, and focussing only on them may therefore fail to address root causes. In such cases, precautionary principles can be useful in preventing unsustainable patterns of development in the first place. This concept is illustrated in Figure 6.

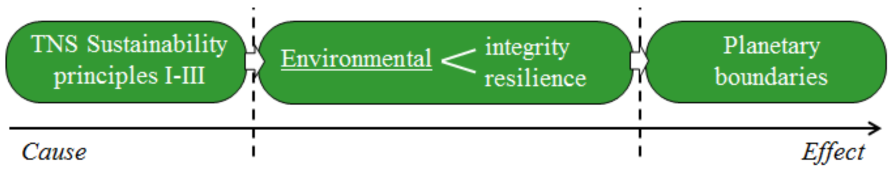


Figure 6: The environmental dimension of sustainability, expanded to include a precautionary approach (addressing root causes with The Natural Step principles of environmental sustainability) and safety thresholds (staying within global planetary boundaries in terms of outcome effects).

118 Numerous studies have attempted to establish limits and thresholds applicable to different types of natural 'capital' and their biogeochemical cycles, for example, in the form of critical loads of man-made emissions affecting the long term sustainability of each form of capital. In some cases, these studies led to the implementation of national or international legislation. Well known examples at various geographical scales include sulphur dioxide (SO_2, mostly from coil- and oil-burning power stations) and mono-nitrogen oxides (NO and NO_2, mostly from cars) emissions to prevent long-range transport of air pollution (LRTAP) and acid rain; maximum fishing quotas to maintain fish stocks of particular species; chlorofluorocarbon (CFCs)

emissions affecting ozone depletion in the stratosphere; or carbon emissions affecting ocean acidification and climate change. In one seminal study aimed at identifying the Earth's carrying capacity based on critical global natural systems and their thresholds, Rockström et al. introduced the nine 'Planetary Boundaries' (PBs) within which human systems are expected to operate to sustain the integrity of its ecological basis (Rockström et al. 2009; Steffen et al. 2015). The first seven boundaries are - in order of criticality: biosphere integrity (measured primarily by the rate of biodiversity loss), nitrogen and phosphorus inputs to the biosphere and oceans (eutrophication), climate change (with a safe boundary value set to 350 ppm CO2 and a point of no return value set to 450 ppm CO2), ocean acidification, land system change (transformation and occupation), freshwater consumption and depletion, and stratospheric ozone depletion. Two more boundaries were identified but thresholds were not set: introduction of novel entities (formerly chemicals dispersion only, but expanded to include "*other new types of engineered materials or organisms not previously known to the Earth system*") and atmospheric aerosol loading (particulate matter emissions). The 2015 update also introduced a hierarchy, whereas biosphere integrity and climate change were "*recognized as core planetary boundaries through which the other boundaries operate*" (Steffen et al. 2015). I explore in more detail in article IV the complex interrelation in time between these two core boundaries for the specific transport project of high-speed rail 2 in the UK.

119 While the limits and thresholds approach such as Rockström's have supported targeted responses to addressing specific environmental issues, critics have raised a number of concerns. For one, it puts a large burden on the natural sciences to identify successfully the harmful 'tipping points' of a growing number of pollution sources (Robèrt, Broman, & Basile, 2013). But can there be *absolute* environmental limits to complex issues such as biodiversity loss or chemical dispersion? Not all environmental impacts show clear cause-and-effect paths: some impacts may have long term systemic impacts that are not easily discernible (Robèrt et al. 2013; see also Gudmundsson 2007 for a thorough discussion). The case of devising effect indicators for chemicals dispersion exemplifies well the limits of the reductionist approach. Rockström et al. conclude that chemical pollution qualify as a global boundary, yet they concede that "*it is difficult to define a single planetary boundary derived from the aggregated effects of tens of thousands of chemicals*" (Rockström et al. 2009). Sources can be natural substances that become harmful in a certain context above a certain concentration level, or entirely synthetic chemical substances that have toxic effects at any concentration (such as benzene or DDT). Effects and toxicity also vary widely, from direct physiological effects on human health (e.g. neurotoxic or carcinogenic) to slower processes affecting other planetary boundaries such as biodiversity (e.g. endocrine disrupters, mutagenic, or chemical substances persistent in nature). The EU reports about 100,000 known (registered) chemicals, yet "*little is known about the toxicity of about 75% of these chemicals*"[45]. The problem becomes ever more complex as evaluating toxicity needs also to consider the potential 'cocktail effect' (or synergy) when several pollutants are combined in nature. Azar et al. point out that the frequent long time delays between a pollution source and its corresponding environmental damage, in addition to the complexity of ecosystems, may, in many cases, "*give a warning too late*" (Azar, Holmberg, and Lindgren 1996).

120 Proposing another pathway, Broman, Holmberg and Robèrt have developed and proposed precautionary principles based on biogeochemical cycles and the laws of thermodynamics to define, upstream, the necessary conditions for preserving human life on Earth (G. Broman, Holmberg, and Robèrt 2000; K.-H.

[45] Many chemicals, but limited toxicity data, by the European Environmental Agency: http://www.eea.europa.eu/publications/NYM2/page006.html

Robèrt et al. 2002; G. I. Broman and Robèrt 2015). These principles assume that it is necessary to maintain the balance in natural processes that evolved through millennia in order to sustain the Earth's systems that are conducive to human life. In other words, like the Planetary Boundaries concept, they take a systems perspective and assume we should preserve the state and dynamics of the most recent and stable geological period called the Holocene. They arrived at these principles by asking the question: if we were to irremediably destroy the support systems for human life on Earth, what should we do? They conclude on the following four non-overlapping first order 'systems conditions', formulated as negations of these principles for sure destruction (also called The Natural Step principles of sustainability – TNS):

"In a sustainable society, nature is not *subject to systematically increasing…*
I …concentrations of substances extracted from the Earth's crust,
II …concentrations of substances produced by society,
III …degradation by physical means, and in that society …
IV ...people are not subject to conditions that systematically undermine their capacity to meet their needs."

121 Aside from the (more obvious) principle of avoiding direct destruction of nature (principle III), they propose to compare the anthropogenic extraction flows of material from the lithosphere and the cumulative emissions of chemical compounds in the biosphere with their corresponding natural flows from natural processes such as weathering, volcanic activity or sedimentation (principles I and II). The higher the anthropogenic ratio is, the higher becomes the risk of impacting adversely natural ecosystems if the extracted material or emitted chemical substances are *not* kept under strict control and within a closed loop (ie within the 'technosphere')(see ratio examples in Azar, Holmberg, and Lindgren 1996). These first three environmental principles form the natural science basis for concepts like cradle-to-cradle (C2C), where products are continuously recycled and where wastes are reused as resources (i.e. kept in closed loops).

122 A possible next step from these reflections on causes and effects of environmental *un*sustainability is to extrapolate a similar framework for complementing the other two main pillars of sustainability. For example, principle IV can serve as a precautionary principle for the social dimension – or its more recently updated version which sets the principle as "*people not subject to structural obstacles to health, influence, competence, impartiality and meaning-making*" (G. I. Broman and Robèrt 2015). Similarly, other authors have looked at appropriate boundary indicators for establishing a social floor, such as the concept of the 'doughnut' (Raworth 2012b; Raworth 2012a) or the 'Sustainable Development Space (SDS)' which uses existing data such as the Human Development Index (HDI) and the Gini coefficient (for intra-generational equity) (Holden, Linnerud, and Banister 2014). It is outside the scope here to elaborate on this, however I can imagine such framework could include both driving sustainability principles on one hand and the concept of limits as measurable thresholds on the other for each of the three main dimension of sustainability, as illustrated in Figure 7.

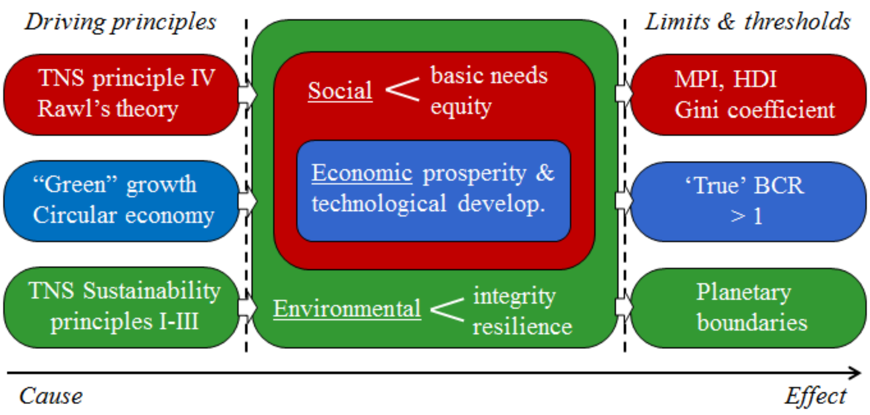


Figure 7: An expanded conceptual representation of the three conventional dimensions of sustainability, explicitly accounting for sustainability principles (causes, or higher order principles), and indicators of limits and thresholds (outcome indicators)

2.1.6 Example analysis – the electric car

123 Analysing the case of the electric car can be useful to illustrate the concepts covered in this section and demonstrate the relevance of a clear conceptualisation of sustainability that is founded on first-order principles.

124 On its own – assuming patterns of individual ownership and use do not change – the electric vehicle (EV) is a technological innovation that solves the issue of point source emissions related to fossil fuel combustion. Can it be deemed objectively sustainable – or more sustainable - than its internal combustion engine (ICE) predecessor? An analysis based on the sustainability conceptualisation in Figure 7 can show that other aspects of environmental and social sustainability remain only partly addressed, unaddressed, or bring other types of impacts further down the line.

125 From an environmental perspective, local air pollution (PB atmospheric aerosol loading) would benefit from a large transition to electric vehicles, but CO2 emissions (PB climate change) do depend on how and where the electricity is produced. Producing new electric vehicles will continue to require vast amounts of mined natural resource (TNS principle I) - which also does not improve the weight of vehicles and hence the amount of energy required to move them (which brings us back to the point about the energy source). While the electric car stock may serve to enable further the rollout of sustainable energy sources such as wind and solar by providing storage capacity in a smart electric network, the electric engine and battery technology require new, more rare, compounds and chemicals to be produced and thus introduced into nature at their end-of-life if they are released as waste (TNS principle I and II). Therefore going ahead with the introduction of EVs would require that all such material and chemicals be fully accounted for and recycled.

126 From a social perspective, the costs of new EVs may exacerbate issues of equity (ie the 'mobility divide'), where only the more affluent part of the population may gain access to the new technology and thus to mobility (TNS principle IV). With the advent of EVs, the mobility paradigm of the car itself remains unchanged, and thus electric cars are likely to continue to contribute to urban sprawl and other wider land use related impacts (TNS principle III and PB land system change), while the societal costs from accidents, congestion, space use, noise, barrier effect to humans (as well as for animals), and visual intrusion remain unaddressed (TNS principle IV). This is not to say that electric vehicles may not form part of a basket of sustainable transport interventions, but they may not be scalable to meet the mobility needs of 10~11 billion people.

127 The contention here is that this wider conceptualisation can allow for sustainability assessment to think beyond the substitution of benefits and costs within and between dimensions, to consider contributions to crossing possible safety thresholds, and to inform on the potential risk of unintended effects. Scaling EVs to any large quantity therefore requires more thinking to insure they indeed become a true stepping stone towards a vision of sustainable transport in the longer term.

128 In conclusion, the three dimensions of sustainability, even if conceptualised and operationalised as nested as done in article II and III, do not, alone, represent a complete understanding of sustainability according to the description made by the Brundtland report as a whole, and particularly so with regard to precautionary principles and boundaries.

2.1.7 Complex sustainability

129 I have a number of times used the term 'complex' to describe the intricacies inherent to the concept of sustainability. In this last subsection I explain shortly what I mean by 'complex', I summarise the main characteristics of sustainability, and I conclude on the key issue that motivated a number of the articles in this thesis: the need to account for the interests of future generations in (transport) appraisal.

130 The term 'wicked' is often used to describe problems which consist of *complex* interdependencies with no clear set of solutions, or where solutions cannot clearly be determined as right or wrong, or where one solution may reveal other problems. Planning for sustainable transport is a wicked problem in three different ways: it is complex in terms of its details, it is complex in terms of its dynamics, and it is complex in terms of preferences.

131 First, dealing with detailed complexity requires a certain level of precision, but at the same time this very precision is no guarantee of 'getting things right' at the systems level. This draws us back to the delineation of the system itself and to the point that sustainability cannot easily be reduced spatially. Based on the laws of thermodynamics, only at the level of the whole planet can the system be considered closed in terms of matter (G. Broman, Holmberg, and Robèrt 2000). Transport has global effects both on the natural environment and human societies. Setting a boundary of 'national transport' or 'urban transport' in search of sustainability improvement is inevitably partial: it "*raises questions of ethics, efficiency and effectiveness*" (Leleur 2012). The same can be concluded about the division of sustainability into the three pillars of environment, which can lead to the tendency to neglect interdependence and encourage making trade-offs at the onset (Gibson 2006). Reductionism thus becomes inherently 'risky' for hiding unintended effects outside the chosen system boundaries, or rebound effects within those boundaries.

132 Second, dynamic complexity is concerned with time and uncertainty. Considering the likely presence of critical states (or thresholds), it becomes difficult to make long-term forecasting based on patterns of causal chains. Small differences occurring in the system may lead to considerable and even irreversible changes down in time (Joumard and Nicolas 2010). Ecological systems and functions cannot easily be considered independently in time, as systems often interact with each other – for example, land-system change can impact climate change, and climate change can impact the availability of productive lands, both having further impacts on biodiversity loss (Rockström et al. 2009; I also explore this interdependency further in article IV). Thus interconnections among issues can both serve as synergies or hide important feedback loops that develop with time (Leleur 2012).

133 Third, sustainability is complex in its interests ('preference' complexity): there is potential for a lot of discordance between the various interests in the type of interventions preferred. Such preferences by

stakeholders are not static, they are defined and refined, "*shaped and discovered*", through processes of communication (Leleur 2012). Furthermore, as per the principal definition of sustainable development from the Brundtland report reviewed earlier, sustainability implies a consideration for inter-generational equity – that is, the future, as seen from the eye of future human beings with an interest in meeting their essential needs and aspirations. The next section discusses the notion of 'future generations' as a specific and distinct stakeholder.

134 That sustainable development is complex does not mean it is necessarily vague, undefined or nebulous as is often argued. It is not that there is no definition; it is that there are many definitions, all of which shed light from a different angle on this complex 'elephant'. What complexity theory tells us is that planning for sustainability requires a holistic approach. This implies "*some kind of completeness so that in principle 'everything' is taken into consideration*" (Leleur 2012). Complexity theory suggests to choose a number of approaches based on the specific context (Leleur 2012; Jeppesen 2009): only by using multiple lenses that highlight specific parts can we hope to draw a clearer image of the details, dynamics and preferences in processes of sustainable transport appraisal.

2.1.8 Future generations

135 Giving a voice to future generations in order to understand their priorities is an obviously problematic task. On one hand, future generations are a key element of the definition of sustainability. On the other hand, future generations have neither agency nor identity – because their existence depends on previous generations' action, they may not come to existence at all, which weakens the notion of considering future generations' interests in decision-making. But even with assuming a constant number of future people, 'future generations' remains an abstract concept – they are "empty projections" to reuse the wording from the quote in section 1.2. Therefore one of the main challenges of planning for sustainability is raising interest and intimacy for future generations in appraisal processes.

136 When monetising future benefits and costs, economic valuation approaches suggest using declining long-term discount rates. Using the rates from the UK Green Book (see Annex 6 - HM Treasury 2011), this implies the assessment of an impact 30 years in the future would be 'discounted' to 35% of its full effect, while a residual impact 500 years from now would have 0.02% of its value in today's terms. In practice, this means any impacts beyond 100 years would weigh less than 5% to the eye of the generation taking a decision today. This may be representative of the value current generations ascribe to impacts that unfold far into the future, but it raises issues of inter-generational justice. In other words, is it fair to discount a future impact to a fraction of its value if future generations are to experience it 100%? On the other hand, the future remains uncertain. In other words, is it fair to account for 100% of a long-term impact when taking a decision today if it cannot be certain the impact will actually take place? It is this uncertainty that discount factors also represent. While the use of discounting is practical, aside from the issues raised earlier about the limits of monetisation, it is also criticised for underestimating the importance of future generations and for lacking a mechanism to account for critical thresholds when assessing the impacts of transport infrastructure (van Wee 2013; Joumard and Nicolas 2010).

137 How far in the future should decision-support processes and assessment tools look into? The 'long term' is a relative concept (for e.g. some Roman transport infrastructure remains to this day). The time horizon in conventional transport assessment is usually limited to the useful life of a project. In the case of HS2, the appraisal process considered the construction period and a 60-year operation period, with some impacts like land-use and carbon being considered up to 120 years. For this thesis I indicatively define the 'long term' – and therefore future generations seen as a future community - as over 100 years up to 10000 years, based

both on the past duration of the stable geological period of the Holocene, and on the potential for human actions to affect the balance of the Holocene for the foreseeable future.

138 The issue of intergenerational justice is a difficult and contentious point. As a starting point, it can be assumed that future generations would be primarily concerned with the aspects of development that bring long and lasting impacts, positive or negative. Therefore, future generations would prioritize higher long term impacts in decision-making, since shorter term aspects would become all but invisible to them. Most – but not all- environmental impacts tend to be slow to unfold (this is illustrated in Figure 8). In article II, I argue that the nested model, by giving higher priority to environmental dimension, is a valid simplification of these assumptions.

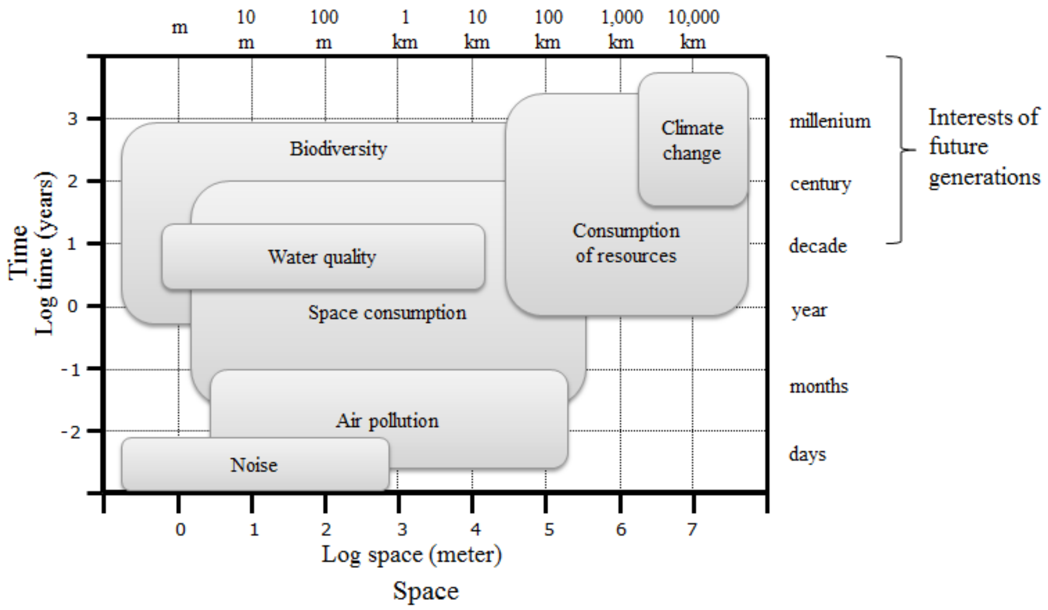


Figure 8: Illustrating the environmental impacts of article II using Holling's log-time and log-space graphical hierarchy (Holling 2001)**.** Future generations are assumed to be interested by long term and lasting impacts, positive or negative.

139 One of the most prominent guidance for institutionalising the concept of future generations comes from John Rawls' theory of justice (Rawls 2001). Applying the veil of ignorance, Rawls asks that decisions be taken with the perspective of being blind to which generation one belongs to, now or at anytime time in the long term future. In other words, for STA this would require asking whether future generations mandate – or at minimum agree - that a particular infrastructure project be approved. For this Rawls seeks a principle that all can agree to: "*Thus the correct principle is that which the members of any generation (and so all generations) would adopt as the one their generation is to follow and as the principle they would want preceding generations to have followed (and later generations to follow), no matter how far back (or forward) in time*" (Rawls 2001:p160). With this in mind, Rawls introduces the Just Savings Principle (JSP), which is based on the idea that people of any generation leave at least the equivalent of what they received from previous generations. It is argued that applying this approach would effectively sustain the common goods needed for upholding the future community.

140 It is based on this (short) summary of the concept of Future Generations and Rawls' theory that articles II and III further elaborate on the practical implementation of the future generations' viewpoint, which is one of the main focus of this thesis.

2.1.9 Process of change

141 I did not cover so far an important part of the literature on sustainability as a *process* of change, which includes both complex systems dynamics and the governance of sustainability transitions. None of my work included in this thesis has addressed this explicitly. It is therefore outside the scope here to cover these at length, suffice to highlight a few fundamental concepts which could form the basis for future research work:

- Backcasting, and visions of sustainability: particularly empowering is the idea of setting a sustainable (transport) system as a desired state, a vision to attain, where decisions are judged for their contribution as stepping stones towards such vision. This concept has a long history and is often presented as a means to break away from undesired futures that forecasting methods tell us we are heading towards (Dreborg 1996): it is an integral part of the original Natural Step framework (Holmberg and Robèrt 2000), it has been suggested for use with ecological indicators (J. Becker 2010) and transport (Geurs and Wee 2004; Banister and Hickman 2012; Karl-Henrik Robèrt et al. 2016);

- Sustainability transitions: this broad set of theories based on innovation theory is relevant for analysing the various and interrelated complexities that act as enablers or barriers of change (Geels 2010; Geels and Schot 2007), which has also been introduced to the field of transport. I have explored this path in other research work not included in this thesis (see working paper in the Preface). One aspect to consider is the possibility of such analytical frameworks to plan and manage change (as opposed to explaining change ex-post);

- Panarchy, and adaptive cycles of complex systems: particularly troubling is Holling's suggestion that complex (economic, ecological or social) systems follow deterministic patterns of "*growth and stability on the one hand, change and variety on the other*" (Holling 2001). First this further questions the concept of static thresholds such as those of the Planetary Boundaries, since limits may change through time as ecosystems evolve through their own adaptive cycles of 'creative destruction'. But this view would also suggest, rather counter-intuitively, that sustaining a system may in fact simply increase the scale of the phase of 'creative destruction' that inevitably will follow. Such view would turn sustainability on its head: whereas sustaining the current period of slow accumulation and transformation of resources would only push the crisis further in time, we could conclude about the desirability of precipitating smaller crisis to allow for more manageable "release and reorganisation", or to avoid the perfect storm of multiple and simultaneous large crisis.

142 In my view, these concepts should be tied to those covered so far in order to build a comprehensive framework for understanding the concept of sustainability, both as a desired state and as a process of change.

2.1.10 Concluding on SD for STA

143 As a summary to this section, and answering succinctly 'what should sustainable transport appraisal do?', I retain and propose the following basic points, which I adapted based on the above reflections and the already comprehensive consensus proposed by authors such as Becker (2007), Gasparatos et al. (2008), Moldan et al. (2012), Lange et al. (2013) and Waas et al. (2014):

- **Complex and dynamic systems approach**: STA ought to be holistic and therefore consider all the points here simultaneously;

- **Four integrated dimensions of sustainability**: STA ought to integrate environmental, social, economic and institutional issues in a harmonious manner as well as consider their interdependencies at a wide (global) geographical scale;
- **Time dimension and long term perspective**: STA ought to give a voice to the interests of future generations and consider the consequences of present actions beyond the here-and-now and well into the future (without any designated time limit);
- **Precaution and boundaries***:* STA ought to acknowledge the existence of uncertainties and the risk of tipping points concerning the result of our present actions and act with a precautionary bias, giving utmost priority to the two core planetary boundaries (biosphere integrity and climate change);
- **Wide and early engagement in decision-making**: STA ought to engage stakeholders widely and effectively in an open and systematic process of deliberation and account for the local context;
- **Fairness in meeting human needs**: STA ought to ensure equity in providing for fundamental human needs (e.g. gender equity, spatial equity, equity between income groups and between ethnic groups).
- **Visions of a sustainable society**: STA ought to recognise sustainability as a process of change where individual decisions act as stepping stones towards a desired (and therefore normative) vision of sustainability as a state.

144 The purpose for this whole section on sustainability was manifold. First it is to lay out the fundamental theories underlying my own thinking with regard to the complex – and often contested or misunderstood - topic of sustainability, before I jump in defining what this means for the transport sector. In practice, this is important to make it possible to return to fundamental principles when faced with conflicting results in STA. Second, one purpose is to root this understanding in systems and complexity theory. Third, it is to state that despite this complexity, sustainability is 'less normative' and more 'scientific' than it perhaps once was. Following complexity theory which suggests using various perspectives to explain complex phenomena, it might not be possible to sum up sustainability in a simple two-dimensional figure, but sustainability *can* be explained if complementary viewpoints are put together. While the three dimensions of sustainability alone are clearly not enough to comprehend sustainability (let alone to address it), I conclude from my research and literature reviews that the Brundtland's report, Rockström et al.'s Planetary Boundaries concept, and Robèrt et al.'s Principles of Sustainability offer promising and complementary perspectives that together can contribute to a more holistic understanding of sustainability as a desired *state* – albeit one that is constantly in flux.

2.2 Sustainable transport

145 In the previous section I covered the scientific and conceptual underpinnings for adopting a strong version of sustainability as a starting point in STA. Thus conceptualisation is based on the understanding of the Earth as a closed system, with limited resources, and a balanced yet fragile ecosystem amenable to sustaining human life. To 'be' objectively sustainable, human systems – including transport - need first to operate within these boundaries in a way that protects the integrity and the resilience of environmental systems. For transport, this requires for example that transport operates in a way that its footprint in terms of emissions, resource use,

and land-use becomes negligible (or in other words, to implement the principles of the circular economy to transport).

146 But transport is complex due to its many cross-dependencies between socio-technical, socio-economic, socio-political and natural systems. Because sustainability is a holistic concept, reducing it to one specific sector – such as sustainable *transport* – risks introducing new externalities, blind alleys or rebound effects. Is an 'intermediary' sustainable transport theory needed or would that be too narrow and prescriptive?

147 Yet if transport contradicts a number of basic sustainability principles such as those covered in the previous section, that would make it essentially unsustainable. This thesis is concerned with the assessment of transport *projects.* Although it can be difficult to demonstrate one single project to be sustainable by and per itself, it can contribute positively or negatively to (a vision of) sustainability. Therefore basic principles of what would make transport *more* sustainable can be drawn, which may be of help to planners and decision-makers. In article I, I suggest some avenues for defining sustainable transport. Here I explain further the theoretical background to this preliminary list of concepts.

2.2.1 Definitions

148 Brundtland does not provide a dedicated chapter to transport, and it could therefore be considered incidental that the report has something to say about transport[46]. Yet many considerations for the positive and negative impacts of transport, the closely related concept of land use planning, and the concern for fossil fuels dependency transpire throughout the report, which are summarised in table 2.

Table 2: Transport highlights in the Brundtland report (from the Overview chapter, unless explicitly noted).

Main concept	Details	Brundtland reference
Legitimate need for transport	Power, resources and trained personnel is needed to provide services and facilities for an *'adequate human life'*	§72, Chap.9 §9
	Need for an effective system of public measures for transportation and *distribution of food*	Chap.5 §103, Chap.8 §44
	Expected growth in demand for products and services, including transportation, due to growing populations	Chap.8 §27
Impacts of transport	Transport as a *main cause of impact on the biosphere* (air and water pollution, proliferation of toxic chemicals and hazardous wastes, erosion, desertification, acidification, new chemicals, new forms of waste)	§13, §35
	Emissions from combustion of fossil fuels pose three major interrelated problems: *climate change, air pollution and acidification* of the environment.	Chap.7 §11, Chap.7 §17, Chap.7 §18
	Serious levels of *air pollution in cities* (in both industrialized and developing countries), despite air-quality standards and control technologies	Chap.7 §30, Chap.7 §100
	Role of *oceans* for transportation and impacts of transportation on oceans, e.g. dumping from barges and ships; impacts are expected to increase from the growth of the world economy and demands for food and fuel	Chap.10 §4, Chap.10 §5

[46] This is an unfortunate tendency still today as sustainable transport failed to become a top-level goal in the Sustainable Development Goals (SDGs) agenda, albeit being recognised as an important contributor to 7 of the 17 goals - particularly goal #9 on resilient infrastructure and goal #11 on sustainable cities.

	Transport and export of wastes, toxic substances and *hazardous material*, and risks of dumping and unsafe disposal	Chap.8 §49, Chap.8 §78, Chap.8 §85
	Weapons manufacture and transportation impacts on scarce capital, labour skills and raw materials	Chap.11 §27
Land use planning & accessibility	Need for strategies to guide the *process of urbanization* and aligning transportation policies	§73
	Need for increased *housing* nearby main employment centres	Chap.9 §51
	Suggestion for *small neighbourhood* workshops to reduce cost of transport to building sites	Chap.9 §52
	Consider *species conservation needs* and opportunities in land use planning	Chap.6 §66
	Urban concentration leading to over-centralization, and economic and social imbalances eg. in transportation facilities; risk of the *megacity* growth, urban decline and poverty	Chap.9 §26, Chap.9 §27, Chap.9 §32
Shift to cleaner modes	Need for 'carefully planned *public transport* systems', addressing overcrowding and overuse	Chap.7 §102, Chap.9 §10
Efficiency improvements	Energy conservation and *efficiency* in powering transport vehicles, need for fuel efficient designs to convert energy into the services required	Chap.7 §2, Chap.7 §102
	Need for stable but high oil prices to maintain steady improvements in *energy efficiency gains* of transportation vehicles	Chap.7 §108, Chap.7 §111
Revenue generation	Possibility for revenue from the *use of international commons* eg. ocean transportation	Chap.12 §119
Integrated and empowered governance	*Integrating* ministries, institutions and policies eg. environmental and transportation at international and national level	Chap.1 §46, Chap.12 §36
	City governments require enhanced political, institutional and financial capacity to address urban problems including transportation	Chap.9 §39
Industrialised countries' responsibility to lead	*Limiting consumption*, shifting to non-polluting energy sources and technologies, and new policies in transportation systems	Chap.2 §62
Vulnerability and risk management	*Vulnerability* of mass transportation	Chap .2 §69

149 While these concepts from Brundtland can again serve as a type of checklist for defining sustainable transport, a more concise definition seems warranted. In 2001 the European Conference of Ministers of Transport (2004) adopted the definition below (see also in Table 3). This definition was slightly adapted from the original Canadian version developed for Transport Canada (The Centre for Sustainable Transportation 2005). Both versions are still in use today, for example as part of the Sustainable Urban Mobility Planning (SUMP) in Europe[47]. A sustainable transport system is one that:

"… Allows the basic access and development needs of individuals, companies and societies to be met safely and in a manner consistent with human and ecosystem health, and promotes equity within and between successive generations; Is affordable, operates fairly and efficiently, offers choice of transport mode, and supports a competitive economy, as well as balanced regional development; Limits emissions and waste

[47] http://www.eltis.org/glossary/sustainable-transport-system - although the 2011 White Paper and its vision of "Competitive and Sustainable Transport System" does not reference it (European Commission 2011).

within the planet's ability to absorb them, uses renewable resources at or below their rates of generation, and, uses non-renewable resources at or below the rates of development of renewable substitutes while minimising the impact on the use of land and the generation of noise" (European Conference of Ministers of Transport 2004)

150 As the Table 3 illustrates, the definition aligns well with the three pillars of sustainability and gives almost equal weight (i.e. numbers of words) to each dimension. The definition also brings concerns for equity, the long term, and refers almost word-for-word to Daly and Brundtland's differentiated treatment of natural capital, including an overall concern for sustaining ecosystem integrity ("ecosystem health"). But this definition has a number of limitations: it does not provide guidance as to prioritisation of the characteristics of sustainable transport; it does not internalise the tight coupling of transport with land-use; and it says nothing of institutional capacity for planning and leading processes of changes towards a more sustainable transport system.

Table 3: Sustainable Transport definition, dissected as per the three pillars of sustainability.
(X) means secondary contribution, for e.g. noise is often placed as an environmental impact but has clear social impacts.
(*) means this item of the definition was added in the EU version compared to the original Canadian version.

Definition	**Society (social justice)**	**Economy (economic prosperity)**	**Environment (environmental sustainability)**
Allows the basic access and development needs of individuals, companies and societies	X (human needs)		
to be met safely	X (needs)		
and in a manner consistent with human [health]	X (needs)		
and ecosystem health,			X (concept of env. integrity)
and promotes equity within [generations]	X		
and between successive generations;	X (long term)		
Is affordable,	(X)	X	
operates fairly (*)	X		
and efficiently,		X	
offers choice of transport mode,	X (needs)	(X)	
and supports a competitive economy,		X	
as well as balanced regional development; (*)	(X)	X	
Limits emissions and waste within the planet's ability to absorb them,			X (within limit)
uses renewable resources at or below their rates of generation,			X (within limit)
and, uses non-renewable resources at or below the rates of development of renewable substitutes			X (within limit)
while minimising the impact on the use of land			X (no stated limit)
and the generation of noise.	(X)		X (no stated limit)

151 Based on this definition, the European Environmental Agency originally proposed an extensive set of 40 indicators to assess transport (Table 4). This list is interesting as an example of a comprehensive attempt to operationalise a wide number of the sustainability concepts presented so far into an indicator framework for monitoring the transport system in Europe.

Table 4: Transport and Environment Reporting Mechanism (TERM) indicators from the European Environmental Agency (EEA), and last year of reporting X = 2015 (latest available report at the time of writing).

Indicators	**Description**	**Last reported**
TERM 01	Transport final energy consumption by mode	2015
TERM 02	Transport emissions of greenhouse gases	2015
TERM 03	Transport emissions of air pollutants	2015
TERM 04	Exceedances of air quality objectives due to traffic	2015
TERM 05	Exposure to and annoyance by traffic noise	2015
TERM 06	Fragmentation of ecosystems and habitats by transport infrastructure	2011
TERM 07	Proximity of transport infrastructure to designated areas	2002
TERM 08	Land take by transport infrastructure	2002
TERM 09	Transport accident fatalities	2011
TERM 10	Accidental and illegal discharges of oil at sea	2004
TERM 11	Waste oil and tires from vehicles	2001
TERM 11a	Waste from road vehicles (ELV)	2002
TERM 12a/b	Passenger transport volume and modal split	2015
TERM 13a/b	Freight transport volume and modal split	2015
TERM 14	Access to basic services	2003
TERM 15	Regional accessibility of markets and cohesion	2003
TERM 16	Access to transport services	2001
TERM 18	Capacity of infrastructure networks	2014
TERM 19	Infrastructure investments	2014
TERM 20	Real change in transport prices by mode	2015
TERM 21	Fuel prices and taxes	2015
TERM 22	Transport taxes and charges	2009
TERM 23	Subsidies	2005
TERM 24	Expenditure on personal mobility by income group	2011
TERM 25	External costs of transport	2009
TERM 26	Internalisation of external costs	2010
TERM 27	Energy efficiency and specific CO2 emissions	2015
TERM 28	Specific air pollutant emissions	2015
TERM 29	Occupancy rates of passenger vehicles	2011
TERM 30	Load factors for freight transport	2011
TERM 31	Uptake of cleaner and alternative fuels	2015
TERM 32	Size of the vehicle fleet	2014
TERM 33	Average age of the vehicle fleet	2015
TERM 34	Proportion of vehicle fleet meeting certain emission standards	2015
TERM 35	Implementation of integrated strategies	2004
TERM 36	Institutional cooperation	2004
TERM 37	National monitoring systems	2004
TERM 38	Implementation of SEA	2004
TERM 39	Uptake of environmental mgt. systems by transport companies	2000
TERM 40	Public awareness	2004

152 Finally, this thesis also draws strongly from the seminal contribution by Banister (2008) who contrasted the conventional transport planning paradigm to a newly defined 'sustainable mobility paradigm'. More specifically, articles II and III contribute to developing tools for "Multicriteria analysis to take account of environmental and social concerns" as opposed to conventional economic evaluations (Banister 2008:p75). Article V develops the concept of "Reasonable travel times" introduced by Banister, as opposed to conventional travel time minimization (ibid.).

2.2.2 Intervening in transport

153 Another angle introduced in article I is strategies to address the transport sector. This is relevant to assess the contribution of an intervention to visions of sustainable transport. Although it is not directly relevant for the articles in this thesis, there is a potential for further research on indicator frameworks concerned with measuring processes of change (e.g. monitoring institutional capacity or strategies supporting visions of sustainable transport based on best practice).

154 Although the literature uses a number of different terms, it is useful to consolidate the concepts under the three headings of Avoid – Shift - Improve, as originally suggested by Dalkmann and Brannigan (2007). The Avoid strategy is concerned with integrating transport with land-use planning and managing transport demand in order to reduce the *need* for transportation. The Shift strategy is concerned with accommodating growing transport demand by making less resource- and energy- intensive modes - such as walking, cycling, rail and other forms of public transport – more attractive and by promoting multimodal transport. The Improve strategy is concerned with promoting systems and technologies that are alternative to fossil fuel based transportation and making current modes more efficient. These three strategies have been widely adopted by the grey literature (UNEP 2011; Carlsson et al. 2012; European Environmental Agency (EEA) 2015) and the correspondence with similar concepts found in the academic literature is shown in Table 5.

Table 5: Avoid – Shift- Improve strategies to frame interventions addressing an unsustainable transport system

Reference	**Avoid**	**Shift**	**Improve**
General description by Dalkmann and Brannigan (2007)	Avoid travel by motorized modes	Shift to more environmentally friendly modes	Improve the energy efficiency of transport modes and vehicles technology
(Grütter 2007)	Reduction of distances or number of trips	Reduction of emissions per unit transported	Reduction of emissions per kilometre
(Banister 2008)	Substitution and Distance Reduction	Modal Shift	Efficiency Increase
(Litman 2010)	Accessibility-based Analysis	Mobility-based Analysis	Vehicle-travel-based Analysis
(Whitmarsh 2012)	Demand Management	Modal Shift	Transport Technologies
(Holden, Linnerud, and Banister 2013)	Reduction, or 'travel less'	Alteration, or 'travel differently'	Efficiency, or 'travel more efficiently'
Underlying trend addressing each strategy	*Densification* of cities *Digitalisation* of trips	*Diversification* of transport provision	*Decarbonisation* of transport modes

155 As policy packaging is a well-known approach to address transport issues (Givoni 2013; Owens 1995), this Avoid-Shift-Improve framework may be particularly powerful if juxtaposed over the types of policy instruments and intervention measures available to each strategy in a specific context. The grey literature suggests at least five main types of such instruments: planning (e.g. land-use or infrastructure provision), regulatory (e.g. standards, limits), economic (e.g. taxes, subsidies), information (e.g. campaigns, education), or technological instruments (e.g. clean-tech, traffic management systems) (Dalkmann and Brannigan 2007).

156 The case of high-speed rail in the UK used in articles III, IV and V in this thesis are concerned about infrastructure provision only, which is but one type of instrument to *improve* rail transport efficiencies and perhaps (but not yet demonstrated) *shift* passenger or freight transport from road to rail. Whether the impact of HSR on time-space geographies would in turn lead to urban densification (by making connected cities

more attractive) and therefore contribute to a reduction of the need to travel at aggregate level (*avoid* strategy) is unclear at this stage. But this frame in general allows singling out three trends in transport governance, each addressing one of the three strategies, respectively: *densification* of cities, *diversification* of transport provision, and *electrification* (and therefore *decarbonisation*) of transport modes.

157 Assessing a transport intervention for its contribution to sustainability could therefore not only consider the direct and indirect impacts of such a measure, but also how it contributes to a process of change supporting these three trends.

2.3 Indicators and frameworks

158 This section provides a critical review[48] of the role and potential of indicators in sustainable transport appraisal. Indicators are the starting point of this thesis. But it is also precisely some of the perceived limitations of indicators as tools to inform decision-making in transport planning and appraisal that paved the way for the articles in this thesis. The assumption here is that indicators are knowledge tools at the core of STA (see Figure 3), and therefore this section answers the question: what can we learn from the challenges behind the design and use of indicators that may be relevant and applicable to wider decision-support processes and assessment tools?

2.3.1 Indicator definition

159 In the broader sense, indicators seek to represent a phenomenon of interest. The sky turning grey might indicate imminent rain (i.e. a forecast of a future state in the weather system); the whistling of the kettle indicates the water is boiling (i.e. an alert of having reached a desired goal or state, but also a reference point in the form of a threshold or limit); a green traffic light indicates it is safe to go (i.e. it enables decision-making), etc. The key point here is that indicators are selected to best represent one or more attributes (qualities, characteristics, properties) of the system under study (Gallopín 1996). Therefore indicators can be understood as a just a ‘sign’ (information about a system meaning something to someone) or a specific ‘value’ (a measured quantity that reflects some attribute of a system).

160 But such wide definition would make indicators difficult to distinguish from information and broader knowledge. Waas et al. define indicators as “key operational information units” (2014), which suggests succinctly that they can be measured scientifically (“operational”), that they serve to communicate (“information”), and that they are deemed to be important (“key”). An often-cited definition of indicators is that of Gallopín: “*desirable* indicators are those that summarize or otherwise simplify relevant information, makes visible or perceptible phenomena of interest, and quantify, measure, and *communicate relevant information*” (1996:p108). Gudmundsson et al. define indicators as “a variable, or a combination of variables, *selected* to represent a certain wider issue or characteristic *of interest*” (2016:p139). Finally Asthleithner et al. suggest “a *policy-relevant* variable that is specified and defined in such a way as to be measurable over time and/or space” (2004). A variable here is understood as an operational and scientific representation of an attribute of a system, and that an indicator is a (set of) variable(s) *with a purpose*. I develop this point further here.

[48] The task of providing an exhaustive review has been more fully undertaken in Bell & Morse (2003), (N. H. Castillo 2004), Marsden et al. (2005), Hall (2006), Joumard & Gudmundsson (2010), and more recently by Gudmundsson et al. (2016), which I am all indebted to.

2.3.2 Representativity challenges

161 The first key point about indicators understood as scientific variables is that they can be *measured*[49] or observed by following a defined procedure. To be credible, indicators first should represent the phenomenon they intend to measure and be consistent in this representation. In other words they should meet criteria for scientific soundness - what Gudmundsson et al. call representativity (Gudmundsson et al. 2016): they should be clear (well defined), valid (based on confirmed causal mechanisms), reliable (predictable and reproducible via a measurement process), sensitive (accurately capture changes), and robust (insensitive to interferences). Closely related to this are concerns for measurability: this is mostly a practical concern about data availability or cost-effectiveness in obtaining data (in terms of effort, time, resources and skills), and in some cases about ethical issues (e.g. privacy concerns when collecting detailed travel data).

162 Below is an example of a indicator of car ownership compared to a national average in Nørrebro district, the Copenhagen neighbourhood where I live. The accompanying picture shows what a street with 'Meget lav' (very low) car ownership looks like in real life. Although the legend actually uses plain words, the data is based on a numerical variable based on an interval scale (deciles).

Figure 9: Example of an indicator of car ownership levels in Copenhagen using a named variable (from 'very low' to 'very high') based on an interval scale (numerically equal population deciles), compared to a national average, disaggregated geographically on a 100m2 raster. The lowest decile in car ownership is shown in orange. But is it useful?

163 Indicators summarise and simplify, and they are often indirect and approximate. What the geographically disaggregated interval indicator in Figure 9 illustrates is that indicators can be quite elaborate, but at the same time they can never fully represent or explain a phenomenon. While it may be considered a *fact* that the cell above indeed represents a low car ownership rate for this geographical area, it does not explain that a large portion of the streets are shared use areas limited to 15kph with no provision for on-street parking, that most of the neighbourhood has a number of bollards preventing through traffic, that Nørrebro is well known

[49] Measures are variables based on a standard unit, whereas a metric is a quantitative indicator based on two or more measures. Cardinal variables use an interval scale (with equal numerical intervals e.g. time) or a ratio scale (same as an interval scale but with a true zero e.g. distance travelled or CO2 concentrations) and are therefore quantitative by definition. Categorical variables are qualitative and use a nominal scale (e.g. categories such as vehicle types, or a binary state such as 'implemented'). Ordinal variables use a ranking scale (e.g. judgments such as modal preference on a Likert scale, where the intervals between positions on the scale cannot be said to truly represent equal distances between judgments). These variables can be absolute, relative to a specific target or norm, ratios between multiple aspects, or more complex aggregates forming an index. They can also be expanded on a timeline or in space.

for its high level of provision of wide and segregated cycling infrastructure, or that most residents may not be able to afford to buy or even to drive a car. Indicators, by being reductionist, are limited and therefore partial. In other words: "*Not everything that can be counted counts, and not everything that counts can be counted*"[50].

164 In many disciplines there is a tacit preference for putting numbers on what we know about reality as a way to express it scientifically: "Indeed, it is maintained that one of the essential functions of indicators is to quantify" (Gallopín 1996). Joumard & Gudmundsson explain that quantitative indicators are preferred "because of the potential precision and reproducibility provided by standard numerical metrics" (2010). According to Gallopín, qualitative indicators can be preferable when "the attribute of interest is not inherently quantifiable", or when the cost of obtaining (or modelling) quantitative data becomes prohibitive (1996). For example, measuring wider economic impacts of large transport infrastructure projects such as high-speed rail remains difficult due to the complex land-use interaction they induce (Mackie, Worsley, and Eliasson 2014). What makes quantification attractive is that under certain conditions, numerical values can be more easily compared, which is one of the fundamental purposes of indicators (Astleithner et al. 2004). The European Environmental Agency's (EEA) yearly Transport and Environment Reporting Mechanism (TERM) report is a good illustration of this: all its indicators are numerical and serve to compare values, whether it is between years, between countries, between transport modes, engine or vehicle types. In addition, most of the EEA indicators are intended to be compared to a numerical target (e.g. 95 grams of CO2 per kilometre as the fleet average to be achieved by all new cars by 2021[51]).

165 Yet the dispassionate assessment intended by numerical values risks hiding the subjectivity of the methodological choices and the assumptions made to devise such specific values. Money is often used as a common unit to allow comparison of transport impacts. However monetisation faces similar criticism: where do the valuations come from, and are they credible? (Mackie, Worsley, and Eliasson 2014). Setting a credible value can be particularly relevant for externalities of transport that diffuse internationally, since institutions may be reluctant to impose restrictions that bring little or no benefit to their own geographical remit.

166 A particularly intricate example of this is CO2 valuations to be used for transport appraisal, which are nationally and politically determined based on EU guidance. The range of value per ton varies between countries (7.8€/ton in the UK[52], 10.75-25.4€ / ton in Denmark[53] for 2016). But they can vary even more widely depending on whether they are tied to more practical reduction targets (e.g. Marginal Avoidance/Abatement Costs - MAC) or to attempts to monetise wider and long term, potentially catastrophic social costs (Social Cost of Carbon - SCC). In comparison to the figures above, some guidance suggests

---

[50] This quote is usually attributed to Albert Einstein, but sociologist William Bruce Cameron may have been the original source http://quoteinvestigator.com/2010/05/26/everything-counts-einstein/

[51] European Commission climate action for road transport http://ec.europa.eu/clima/policies/transport/vehicles/cars/index_en.htm

[52] UK Government Department of Energy & Climate Change updated short-term traded carbon values used for policy appraisal (2015) https://www.gov.uk/government/publications/updated-short-term-traded-carbon-values-used-for-uk-policy-appraisal-2015

[53] Danish Ministry for the Environment values: http://www2.mst.dk/common/Udgivramme/Frame.asp?http://www2.mst.dk/udgiv/publikationer/2010/978-87-92708-52-6/html/kap03.htm , but for transport models at DTU Transport the suggested value is based on European Emissions Trading System allowances (EU ETS), which are lower and set at a central value of 80kr/ton for 2016 (10.75€): http://www.modelcenter.transport.dtu.dk/Noegletal/Transportoekonomiske-Enhedspriser (v1.6).

more abrupt carbon values starting at 100€/ton to reflect better the cost of sparing one ton of CO2 today, arguing that the current practice of increasing valuations of carbon up to 2050 effectively signal that action can be delayed (Meunier and Quinet 2015; Maibach et al. 2008)[54]. Such variance and uncertainty in one of the more obvious environmental variables of sustainable transport assessment raises questions about the credibility of conventional assessment methods based on what was originally intended as value-neutral numerical indicators.

167 Aside from measurement and quantification methodology, partiality is also intrinsic in the selection of *sets* of indicators and in their aggregation. Indices are popular tools to provide an overview of a specific but complex phenomenon. For example, Denmark finds itself in the top 10 'greenest' countries on the 2015 Trilemma index by the World Energy Council (World Energy Council 2015), it is first on the 2016 World Happiness Index (Helliwell, Layard, and Sachs 2016), yet it is also the Western country with the highest ecological footprint per capita in the world (WWF 2014). While each of these indices claim to provide a more holistic picture, they have in common that they rely on a small set (6 to 8) of individual indicators. But why these and not others? For each index the choice of indicators and the methodologies for quantifying each of them are clearly outlined. However the types of aggregation differ. Often when addressing issues of sustainability it is said that a balanced view is needed. But assigning equal weights or no weights (or as in the case of the Trilemma index, assigning equal weighs to each of three dimensions) is a choice in itself that has potentially significant influence on the final values produced. CBA methods internalise the weighting process in monetary valuations that are pre-set, and indices tend to leave the weighting process up to the index designer. MCA, on the other hand, recognises and explicitly treats the weighting process as a value judgment, and MAMCA allows comparing various stakeholder perspectives in those judgments. It is precisely this concern for weighting that led me to explore further MCA approaches in articles II and III.

168 There is yet to come an internationally recognised, high profile sustainable transport index. There exist however numerous attempts at creating various urban sustainability and sustainable transport indices, but the exercise is fraught with the same difficulties regarding the selection, normalisation, weighting and aggregation of indicators. It would be interesting to provide a full review here, but that could easily be the topic of an article in itself. Zito and Salvo (2011), Santos and Ribeiro (2013), Jeon et al. (2013), Dur and Yigitcanlar (2015) and Alonso et al. (2015) provide recent reviews and systematic attempts of developing urban passenger transport indices. Yet it is interesting that, for example, Alonso et al. conclude from their Sustainability Composite Indicator that the "*richest and largest cities usually have more sustainable transport systems*", while richer countries appear to fall in the most *un*sustainable end of the Sustainable Transport Space indicator by Holden et al. (2013). Tanguay et al. examined in more detail 17 urban sustainability indicators and conclude that problems related to Sustainable Development Indicators (SDIs) are conceptual and operational: there is no standard interpretation of sustainable development, nor any standard approach to designing SDIs, and that, furthermore, SDI development is often constrained by data availability (2010).

169 The key point made here is that indicators are *constructed*: the targets they intend to support, the selection of the appropriate indicator(s), the elaboration of the method, their level of aggregation, and their presentation are all *choices*. I illustrate this partiality of indicators in Figure 10 below by showing how subjective choices

[54] See also https://www.gov.uk/government/publications/carbon-valuation-in-uk-policy-appraisal-a-revised-approach for a detailed discussion on the "impossibility of deriving a scientifically valid, ethically sound or policy-useful estimate of the social cost of carbon" (Ekins 2011) on the UK Government web site.

affect the representativity quality of indicators at every step in their design and selection, from the choice of method to the building of indices. As Tanguay et al. point out - also citing Niemejer and de Groot (2008) who reach a similar conclusion: "*selection of indicators is invariably subject to arbitrary decisions at one stage of the process or another*" (2010:p417). Gallopín also concludes the same 10 years earlier: "*value judgements enter the characterization of indicators at different levels*"(Gallopín 1996).

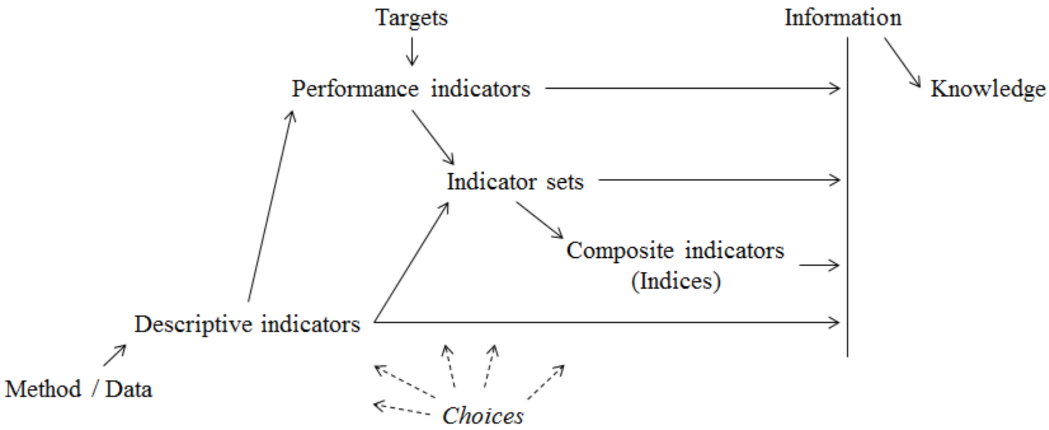


Figure 10: Construction of indicators, indicator sets, and indices ("Russian dolls") and the path to knowledge ("Chinese whispers") (Lyytimäki, Gudmundsson, and Sørensen 2014); figure adapted from (Waas et al. 2014) and types of indicators from (Lehtonen, Sébastien, and Bauler 2016)**.**

170 I therefore question the suggestion by Heink and Kowarik (2010) of the possibility of purely 'descriptive' indicators (although I do keep the term in Figure 10 for illustration). In order to 'make sense', indicators need to be compared to a reference value, whether that is "*a goal, a target, a norm, a standard or a benchmark*" – which is what distinguishes indicators from simple variables (Waas et al. 2014). For example, a value of 400ppm CO2 concentration becomes relevant when compared to the 350ppm threshold said to be a safe boundary. But to address this problem of partiality in indicators, should the answer be to try to improve objectivity, or to embrace subjectivity, or perhaps, if possible, to do both? Gallopín (1996) suggests for example to keep value judgments confined to targets, norms or standards, and seek to define performance indicators based on these. Connecting indicators to policy goals has received significant attention in the literature, which I now turn to.

2.3.3 Performance indicators

171 Perhaps partly because of the common adage that 'what gets measured gets done'[55], there is an increased tendency for public sector and transport policy to be driven by goals and targets, which helps agencies focus funding and interventions (Marsden and Bonsall 2006). Performance indicators provide a means to monitor progress and assess the effectiveness in reaching those goals (Ramani et al. 2011; Marsden, Kelly, and Snell 2006). This is increasingly the approach adopted by the European Commission for example. As current transport policy targets at EU level focus on fuel efficiency improvements, emissions and noise reductions, and modal shift, the latest report produces values and trends for these targets based on a subset of 14 core indicators only (See annex 2 of European Environmental Agency (EEA), 2015 for transport summary of transport targets and corresponding TERM indicator; see also Table 4 in previous section for a full list).

[55] This quote is often attributed to management guru Peter Drucker, but also to statistician W. Edwards Deming, or prior to them the physicist William Thomson.

172 This illustrates well the tension between having a set of focussed goals and the broader objectives of sustainability. Using the TERM report as example, four groups of indicators were not updated in 2015: 1) indicators about biodiversity impacts due to land use and fragmentation or discharged waste, 2) accessibility and personal affordability by income groups, 3) levels of internalisation of external costs of transport on society, and 4) all indicators related to institutional capacity and public awareness. The report continues to comment on these issues, yet also laments for example that "*the monitoring process would call for an update of the indicator on a regular basis to detect trends in landscape fragmentation development*", which one can only assume is not done precisely because such indicators do not relate directly to policy goals (European Environmental Agency (EEA), 2011:p39).

173 As the EEA example shows, target-based indicators risk being myopic as to the totality of issues and attributes that composes a complex system such as transport. Another related problem to representing a complex system is the interaction between indicators (Dahl 2012). Because these interactions are rarely captured, it opens the door for unexpected side-effects. A example of that could be the focus on carbon *emissions* reduction, as opposed to total life-cycle carbon footprint or to cumulative human-induced carbon flows in and out of the biosphere as The Natural Step principles would rather suggest (Azar, Holmberg, and Lindgren 1996)). The focus on end-of-pipe emissions excludes the possibility of accounting for the carbon embedded in infrastructure and vehicle construction, for example. I explore this particular issue in more detail for the case of high-speed rail in article IV, where we find that the amount of tunnelling comes at a trade-off between biodiversity and carbon impacts (the two principal planetary boundaries according to Steffen et al. 2015).

2.3.4 The role of indicators in STA

174 The use of indicators for assessing sustainability presents a difficult paradox: any real world system - such as the transport system - is complex both in its details and in its dynamics, and there are therefore a potentially unlimited number of attributes that could be considered to represent it.

175 The indicator definitions presented earlier all bear a subjective aspect that can help inform this selection: indicators are *desirable*, *policy-relevant*, and they are selected to represents issues of *interest*: "*Indicators that describe a condition that users in planning agencies are able to influence are more likely to induce instrumental utilisation; that is, use for action*" (Hezri and Dovers 2006). As seen in the previous section, one approach is to connect indicators with (existing or new) institutional goals and targets. But if the full scope of goals that are politically decided does not cover all that sustainability would require, then the expected instrumental use of indicators in guiding a transition to a more sustainable transport system in STA risks being jeopardised from its onset. What this assumes however is that indicators fulfil an *instrumental* role in directly influencing decision-making, which is "*simply not acknowledging the complexity of decision making, and the inherent discursiveness of policy making*" (Bauler 2012). In other words, 'knowledge is not enough to make you do anything'[56].

176 As Innes explains, there is a long modernist tradition in seeing planning as a rational activity that draws from expert knowledge and brings an expectation of science as a provider of disinterested and measurable facts (1998). But experts often disagree, and science by its nature is more concerned by being sceptical about its own produce than by claiming to have found a truth. It is beyond my capability and the scope of this thesis to

[56] Bruno Latour said this here https://www.youtube.com/watch?v=ApmtxIO1GvM

revisit at length the philosophy of science, but what is important here is that indicators can have useful purposes besides being used 'as is' in decision- and policy-making. The literature highlights the potential for indicators to have a number of *indirect* effects (Hezri and Dovers 2006; Gudmundsson and Sørensen 2013; Gudmundsson 2003; Bauler 2012). Indicators can gradually serve to *enlighten* and inform various groups of stakeholders (decision-makers, policy-makers, planners, but also other scientists or the public at large) of certain *worldviews,* which may then shape knowledge and influence policy *direction*. This *conceptual* impact of indicators can be seen in policy in terms of "how problems are framed, or which objectives are defined, or which types of measures are promoted" (Gudmundsson 2003). An example of this can be the various – and competing – ways of representing carbon emissions at national level: total annual emissions, total cumulative emissions, emissions per capita or emissions per unit of GDP imply different views on accountability and therefore policy. A third type of use is symbolic/tactical/political, which with some nuances generally consist of using indicators for legitimising decisions already taken or to be taken or for delaying decision (Bauler 2012; Hezri and Dovers 2006).

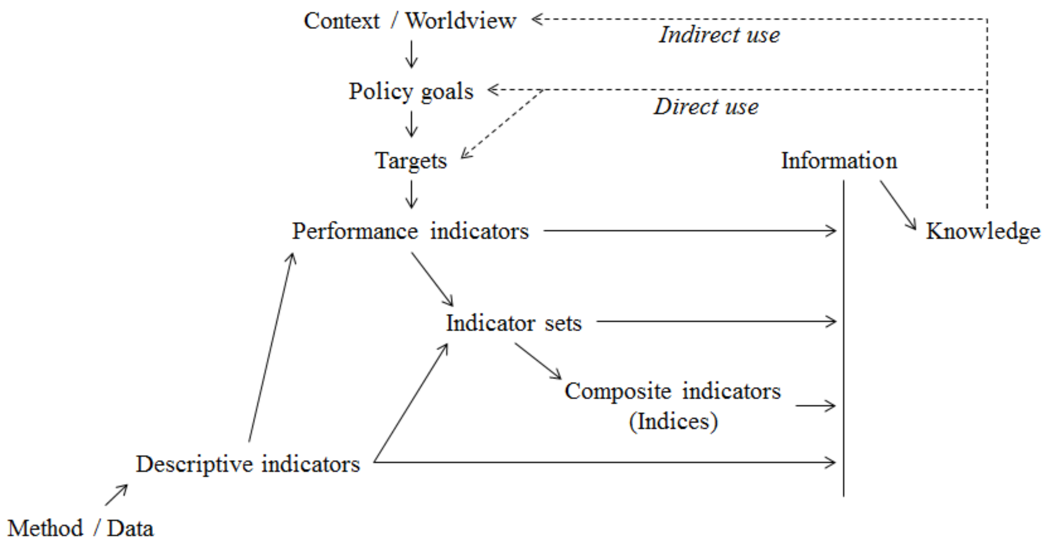


Figure 11: Update of Figure 10 with potential direct or indirect use of knowledge from indicators.

177 Some of the literature also highlights a fourth use, which is upon closer analysis related to all three uses above but rather seen from a constructivist, learning *process* perspective: 'usefulness' here stems from "the procedural interactions and learning processes which are linked to the information being commissioned and constructed" (Bauler 2012). In other words, indicators can be useful in supporting processes of transition such as creating shared understanding between groups of stakeholders, enabling coalition formation, and perhaps even providing grounds for enabling experimentation – independently of the actual content of their measure. Closely related to this process role is the potential for indicators to *challenge* the status quo in socio-technical transitions, by opening up policy discourses and questioning prevailing practices, frameworks of thought and hegemonic discourses (Lehtonen, Sébastien, and Bauler 2016). It is outside the scope here to analyse indicators from a transition theory perspective; suffice to say that I perceive a gap in the literature with regards to the contribution of indicators to transition processes, which calls for a closer look in ways to consolidate these two strands of knowledge in future research.

178 More recent literature on the matter talks of 'usability' to refer to the potential use, influence and impact of indicators (Bauler 2012). Hezri and Dover talk in a similar fashion of the 'marketability' of indicators (2006). I prefer to use the term 'acceptability' to make more explicit the role of stakeholders in designing and

selecting useful indicators that resonate well with their context, but that may also go *beyond* by inspiring new worldviews (i.e. beyond directly 'usable'), and that are not reduced to a simple cost efficiency (i.e. beyond 'marketable').

179 As a conclusion to the issues raised so far, Figure 12 provides a simple summary of the main steps involved in indicator design and selection, seen as an iterative (i.e. repeated and with no clear starting point) and interactive (i.e. requiring various stakeholders to be involved at each step) process.

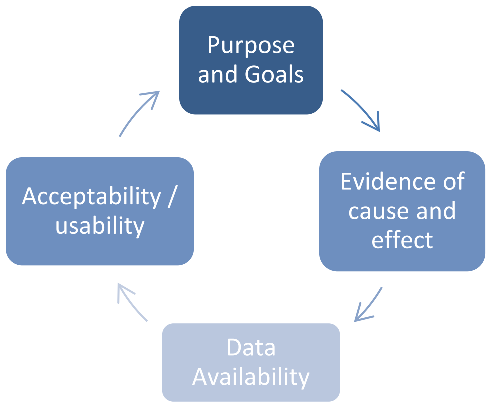


Figure 12: Four essential features of an iterative process of indicator development.

2.3.5 Indicator frameworks

180 When confronted with the complexity and uncertainty of the transport system, I conclude with Turnhout et al. that indicators cannot unproblematically be defined as fact-based and scientific, yet that they are not solely political (2007). In complex (but rather normal) transport planning contexts, indicators' role can range from technocratic benchmarks' to 'political ammunition' (Bauler 2012). But a shift from seeing indicators as objective representations of reality to a communicative tool does not necessarily render them instrumentally useless. That indicators are found to be more normative and political than originally thought is not necessarily a problem, but it raises wider questions about processes and criteria for their design and selection. While positivist thought was mostly concerned with the scientific robustness – the credibility – of indicators, the reflections above raise the question: what is then a good indicator for supporting effective governance of the transport system towards sustainability? Or in simpler terms: because indicators are selected and may not be as objective as originally thought – and while remaining aware of the risk of infinite regress in attempting to define indicators for designing and selecting indicators - answering this question could nevertheless require a coherent framework to guide such effort. De Neufville (1978) sums up the importance of using a valid frame for the design and selection of indicators by stating: "*Most sets of indicators, if closely examined, reveal some of the dimensions of the paradigm that produced them*".

181 Drawing from Gudmundsson (2004), article I introduces a list of meta-criteria organised under three main tasks in the process of design and selection of indicators, which we call indicator framework functions: *conceptualisation*, *operationalisation*, and *utilisation*. These three functions in this research effectively 'emerged' from gathering various criteria for indicators design from the existing and more recent literature on transport indicators, which may help confirm the potential utility of such categorisation. Although article I provides a more thorough description based on framework theory, the three functions are originally defined in this way:

"The first component is conceptualization, which defines what is to be monitored, in this case sustainable development aspects of transport. The second component is operationalization in which concepts are made measurable by selecting parameters and indicator types. The third component is utilization, which refers to the ways in which the indicators are drawn upon in analysis or policy"(Gudmundsson 2004:p38).

182 On the other hand, as is often the case with any analytical framework, they serve as a guide more than as mutually exclusive and ordered categories, as Gudmundsson foresaw: "*in practice, however, there is not always a clear line from concept to measurement to use*" (ibid.) – and I would add that there is not always a clear line between concept, measurement, and use. But regarding these three functions, other authors in recent years have reached similar conclusions. Waas et al. suggest to consider the following three challenges when attempting to understand the linkages between sustainability and decision-making: *interpretation, information-structuring,* and *influence* (2014). Interpretation refers to conceptual soundness in interpreting sustainability's basic organising principles applied to a specific context, which is precisely what the conceptualisation meta-criteria in article I cover. Information-structuring is similar to our function of operationalisation, which is concerned with the scientific process of reducing complexity into 'operational information units'. Finally, influence covers the concern for relevance and utility also found in our utilisation function, which aims to generate information that can "exert a real influence on decision-making and on the actual implementation of sustainable development" (Waas et al. 2014) - what Cash et al. call *salience* (Cash et al. 2002). In their evaluation of environmental indicators, Cloquell-Ballester et al. talk similarly of *conceptual coherence*, *operational coherence*, and *utility* as the three conditions for environmental indicators to be considered 'validated' (2006).

183 In their search for 'policy-resonant' sustainability indicators, Hezri and Dovers conclude similarly that advancement in the theory and practice is dependent on continuous *conceptual*, *methodological*, and *institutional integration* (2006). This aspect of institutional integration – or embeddedness - is a clear theme in a number of meta-criteria under the utilisation function of our meta-framework (e.g. Integrating vertically, Aligning with agency capabilities and constraints). Bauler also makes a strong case for analysing the embeddedness of indicators to assess their relevance and therefore their influence (2012). Innes explains: "*Information influences planning and public action by becoming embedded in the thought, practices, and institutions of a community, and thereby influencing action*" (1998). From this review I conclude that the meta-framework developed in article I retains its validity also when seen from the wider and more recent literature on indicator frameworks.

2.3.6 Concluding remarks

184 This section provided an overview of the nature and the challenges of indicators, and started touching the politics of indicators. My conclusions from the initial review that led to the metaframework in article I can be summarised as following. First, there is ample coverage and a good level of consensus in the literature on matters of operationalisation of indicators in general, particularly with regard to criteria for scientific credibility. Cash et al. also note that perhaps too much focus has traditionally been put on this basic requirement (2002).

185 Second, despite many claims that sustainability is ill-defined, much of the literature conceptualising sustainability brings forward a similar set of considerations. Yet there remain difficulties in both operationalising these concepts into indicators on one hand, and defining in more detail what the concepts of sustainability set forth implicate for transport. I chose to explore these aspects in two of my papers, article IV (on the interplay of climate and biodiversity impacts for high-speed rail assessment) and in article V (on the

need to reconceptualise transport in a more holistic perspective with regards to one of its fundamental variable: time).

186 Third, although the use and influence of indicators (and expert knowledge in general) has been the topic of research for quite many years, linking knowledge to action remains a (chronically) difficult task. There appears to be a need for further investigation of the "*inevitable politics of policy indicators*" (Bauler 2012). Drawing from these reflections, I conclude that indicators consist of "*carefully constructed information selected and aggregated for a specific purpose of promoting, consciously or subconsciously, a normative perspective//worldview//agenda by certain stakeholders*", and therefore that indicators are part of a basket of *knowledge tools* to communicate – as opposed to the more conventional and modernist view of indicators as objective measures of reality. This understanding is already a part of the original definitions provided earlier (as was shown in italic). Indicators can therefore be concluded to be both intendedly scientific but also inherently political: they are endogenous to the policy-making process, as opposed to the instrumental rationality view on indicators as exogenous, scientific, and value-free. This may be due to an underlying shift in thinking: while conceptualising and operationalising sustainable transport may keep us in the safe zone of scientific rationality, the use of knowledge clearly points at a more fluid and complex reality. The next section explores this further, particularly with one aspect of indicator development that I touched upon here but did not elaborate: stakeholder participation.

2.4 Stakeholders and future generations

187 An important part of this thesis takes further the notion of stakeholder involvement in STA (articles II and III particularly). In this section, I cover some of the theoretical background to this and how stakeholder involvement can be an improvement to conventional, 1st generation assessment tools. I also explore further the potential and limitations for considering future generations as stakeholders.

188 Complexity theory suggests two complementary avenues for dealing with complex topics such as planning for sustainable development: providing multiple perspectives, and doing so by engaging with stakeholders in a process of reflexive learning. Since the 90s, we are witnessing a turn in planning from classic instrumental rationality towards a postmodern 'Habermassian' communicative rationality (Sanderson 2001; Allmendinger 2009:Chap.8&9). The key intention of this planning approach is to enable a type of democratic renewal by enhancing deliberative capacity through new forms of participation, collaboration and learning. This approach represents a shift from traditional and technocratic 'governing' by a formal institutional authority to a more inclusive 'governance' that involves a wider range of stakeholders in policy development and delivery[57]. Governance is fundamentally motivated by "*the increasingly complex, dynamic and interdependent nature of contemporary policy-making*" (Lange et al. 2013:p406).

189 This open approach to planning would seem particularly well adapted to the challenge of steering a transition towards sustainability, which is normative (dealing with issues of fairness within and between generations), systemic (involving interactions between human and natural systems) and complex (long-term, spatially widespread and ultimately uncertain with no clear right or wrong)(Lange et al. 2013). Building institutional

[57] Communicative rationality in transport governance should not only be understood as just 'more public participation' however (Willson 2001). It represents a wider shift towards a social-constructionist view of putting language and meaning associated to language (i.e. dicourses) at the core of the planning process.

capacity for collaborative planning has been an evolving topic for both urban planning (Healey 1998) and transport planning (Willson 2001).

190 In many respects, the reflections started in the previous section depart from the rational-positivist view of indicators as instrumental and neutral tools to inform policy-making. A constructivist view turns this on its head, where "*indicators are seen as dynamic sites of conflict and co-operation between policy actors (..), they are perceived as a means by which actors seek to exercise power, retain status and strive towards policy goals*" (Astleithner et al. 2004). We are not far here from the actor-network theory perspective where indicators themselves become powerful 'actors' (Lehtonen, Sébastien, and Bauler 2016)[58].

191 Knowledge utilisation in STA is too broad a topic to give it fully justice here. Yet for the specific case of indicators, Cash et al. suggest to look beyond credibility and salience, and into *legitimacy*. Legitimacy is specifically concerned with representative participation and with the choices made on how information is produced and disseminated (2002). Furthermore, increasing legitimacy by increasing inclusiveness of various stakeholders and different knowledges can both influence credibility and salience, albeit positively or negatively (ibid.). According to Turnhout et al., the inclusion of various stakeholder perspectives can contribute positively to both the quality of indicators and to their acceptance (2007).

192 I was particularly motivated by these conclusions in article III, where we experiment with variants of multi-criteria analysis (MCA) tools that make explicit both the contribution of various stakeholders in evaluating impacts of transport (i.e. therefore addressing the credibility of the assessments) and the choice of relevant impacts (i.e. therefore addressing the salience of the assessment).

2.4.1 Limitations of communicative planning

193 These considerations however raise two interrelated potential problems. First, the participatory approach does suggest including non-scientists and lay-people in reviewing the choice and the quality of indicators on the grounds that, in the face of sustainability being complex and uncertain, experts too are 'amateurs' (Turnhout, Hisschemöller, and Eijsackers 2007, citing Funtowicz and Ravetz, 1992). But couldn't this approach risk giving undue weight to personal viewpoints with doubtful credibility? Surely there remains a role and purpose for scientific rationality to avoid pure subjectivity.

194 In communicative planning theory, Habermas' intention is to "*bridge and integrate science and ethics in an open, process-oriented model that supports a democratic social order*" and therefore suggests a number of criteria for assessing scientific credibility – or rather, 'valid communication' - such as clarity and accuracy of the statements made and the legitimacy and sincerity of the speaker (Willson 2001:p11; Allmendinger 2009:p203). I leave to others the tasks of drawing the line between objectivism and relativism in postmodernity, or to determine whether such a line even exists. I shall just say that in the case of STA, this commitment to transparency and inclusiveness has the potential to increase both the accountability of

[58] Lehtonen et al. here do not explicitly refer to actor-network theory (ANT), although they suggest in their conclusion that indicators are potentially powerful actors in their own right. This is similar to ANT's concept of 'actants' which include both human actors and non-human artefacts, and assumes all actants to have agency in the network they are a part of.

decisions and the possibility for 'opening up' transport planning to challenge not only the solutions proposed but also the assumptions and the underlying needs being addressed[59].

195 Secondly, another caveat of participatory methods for sustainability indicator development and STA in general is the simple question: can more stakeholder involvement actually deliver more sustainability? A recent contribution by Lehtonen et al. voices similar concerns: "*As demonstrated for instance by scholars in urban studies, sociology, geography and urban planning, even participatory indicator exercises cannot guarantee that indicators foster socially desirable objectives*" (Lehtonen, Sébastien, and Bauler 2016:p5).

196 In their treatise on the sociology of knowledge, Berger and Luckmann (1966) bring the point home that despite the power of language to transcend the 'here and now', our daily experience of reality as human beings is primarily a matter of spatial and temporal proximity. That stakeholders are undoubtedly more familiar with the context of their immediate physical surroundings makes a strong case for their involvement in decision-making. Although including wider perspectives creates difficulties with managing and aggregating the complexity of the resulting input (as was seen with the 50,000 or so pages produced as part of the assessment and consultation process of HS2), it is quite understandable how local knowledge obtained from such democratic approach brings potential for more acceptable solutions in the longer run (Bracken, Bulkeley, and Whitman 2014). Yet the question becomes: who should we then involve for getting a perspective from the future?

197 From the original technical challenges of indicator design and selection, this question about the operationalisation of the future generations' perspective in sustainable transport assessment has therefore become a main focal point in my research. This was done first in article II where I propose a simple re-weighting of impacts based on a strong conceptualisation of the three dimensions of sustainability, and later in article III where I complement this virtual sustainability perspective by a sustainable transport stakeholder formed by researchers in this specific field. The main assumption used here is that in lack of comprehensive and credible quantitative data from the positivist approach, the best instrument we have to deal with complexity is perhaps human judgment (at least so far). Stakeholders – in our case, sustainable transport 'experts' - were asked to assess, to the best of their knowledge, the various transport options from the perspective of a sustainability advocate. A well-developed methodology for capturing these judgments is then used to quantify and aggregate this perspective in a comparable form with other stakeholders (namely government and conventional transport planners).

198 The research for article III also provided insight in the role of scientists in communicative planning. Rather than meeting the instrumental rationality expectation of providing an objective and measurable truth, our role was to insure methodological clarity and quality – for example, by insuring a comprehensive and well-described list of (mostly) non-overlapping impacts based on stakeholders input. In other words, I became a researcher-facilitator.

2.4.2 Impossible sustainability?

199 From these reflections, it is tempting to conclude that the problem of integrating principles of sustainability into STA remains entire, and that the modernist approach to transport planning, even if augmented with participatory processes, offers a depressing picture for any such integration in the near future. The objectivist

[59] As an example of this, throughout my research on HS2 I found this last aspect of early and influential stakeholder involvement to be particularly lacking, despite the rather long and extensive consultation process that took place.

paradigm in instrumental rationality can be questioned for not quite being able to represent adequately the complex phenomenon of sustainability, or for being prone to represent only what is of interest to those involved in the production of knowledge. Yet the explicit inclusion of wider – and supposedly wiser – groups of stakeholders is no guarantee that the interest of future generations be taken into account, let alone that a solution leading to an improvement in sustainability be selected.

200 The *process* of indicator development may very well serve the important purpose of stakeholder education, but Becker raises the risk "*that ultimately little will be accomplished beyond this if those involved do not understand the fundamental ends of sustainable development and the means with which to implement them*" (2007:p138). Holden et al. depart from the common wisdom that local stakeholder participation is key to achieving sustainable development: "*we disagree with the proposition that the choice of sustainable dimensions, indicators and threshold values should depend on what local stakeholders agree to include*" (2013:p69). Instead they argue for the need for a global consensus – for which they refer to the Brundtland report. I reach the same conclusion from my research so far.

201 Overall, I do not think it is necessary to give in to complexity, absolute relativism or 'impossible sustainability' for two reasons. The first is that the science of sustainability such as The Natural Step principles and the Planetary Boundaries concept posit some fundamental physical requirements for human life to continue to flourish. From this I reuse the words of Shove and Walker (2007) and conclude that "*it is perhaps possible to imagine some shared, technically determined specification of environmentally 'benign'*". Therefore some form of indicators, however reductionist, incomplete or biased, are likely to continue being useful as communicative tools in STA processes set to retain such characteristics.

202 The second reason for 'optimism' is that the future depends on the decisions made. Assuming a future sustainable transport scenario for humanity exists, there is a need to develop further decision-support processes and assessment tools in STA that supports a process of transition towards such vision (whether the concepts and tools introduced in the articles composing this thesis will serve as a stepping stone remains to be seen).

203 Considering transport projects have clear implications for humans in the future, it would seem 'fair' (from a Rawlsian perspective) that current generations 'put themselves in their shoes' when taking important decisions. This suggests extending the concept of democracy to explicitly account for future generations' interests and develop decision-support processes and assessment tools that incorporate those interests. Interestingly, this conclusion just recently appeared in the report by Oxford's Future of Humanity on global catastrophic risks (Cotton-Barratt et al. 2016).

Chapter 3 Conclusions and Outlook

204 In this third and last chapter, I conclude by summarising the learnings from this research on assessing the sustainability of transport projects. These learnings, taken together, go beyond the use of indicators and serve to further define the concept of Sustainable Transport *Appraisal* (STA). Following this, I share some general reflections on the future of sustainable transport.

3.1 Sustainable transport appraisal

205 The overarching research objective for this thesis was concerned with operationalising sustainability in transport appraisal: "How can sustainability be transformed from general ideals to corresponding decision-support processes and assessment tools that genuinely support sustainable development in the transport sector?" In this section, I summarise the learnings from my research that contribute to answering this question.

- Sustainability is holistic; therefore incorporating sustainability into transport assessment requires broadening its scope. This was a first finding from analysing sustainable transport indicator frameworks. Not only the literature makes a case (as expected) about the importance of operational practicalities for designing 'good' indicators, it also makes clear that underlying conceptualisations matter just as well, and that the interface with wider planning processes – the actual utilisation of the tools – matter too (article I). In practice, these considerations are not always explicitly addressed (as it was found in the critical case of the HS2 appraisal process – article IV).

- For conceptualisation, there is a gap in current decision-support processes and assessment tools with regard to the inclusion of the wider set of criteria that a comprehensive assessment of sustainability would require. More particularly, there is a clear need to improve the assessment tools with more systematic guidance on the issue of prioritisation of these criteria from a genuine sustainability perspective (articles II and III).

- About the prioritisation issue, it was outside the scope of this thesis to inform how to improve valuations in conventional methods such as CBA. However, it was shown that MCA methods can be adapted to provide a strong sustainability viewpoint by repriorisiting impacts from a future generations' perspective and by making this viewpoint explicit in decision-making. This viewpoint is akin to a 'future generations' *stakeholder*', which can serve as a type of benchmark for supporting decisions that aim to represent sustainability objectives and constraints.

- The sustainability viewpoint can be derived from existing literature on strong sustainability theory, which provides top-down guidance for prioritising impacts based on high order principles from the natural and social sciences (articles II and III, and also Chapter 2.1). For example, the planetary boundaries concept defines climate change and biosphere integrity as core boundaries, which can then be given higher priority using simple weighing methods such as random order distribution (ROD). However, because this approach is theoretical, it also risks being insensitive to the local context, and its results is therefore not intended to be used 'as is', but instead to be compared to other stakeholder perspectives in a process of communicative planning.

- Another approach for creating a sustainability viewpoint for prioritising impacts in STA is to implement the just savings principle suggested by Rawls' theory of justice. This can be done by capturing the prioritisation of impacts from respondents who are asked to take a future generations perspective behind the 'veil of ignorance' (done both in articles II and III, where article III explores in more depth the more appropriate ways to do so). In this way it is possible to both consider what is of importance to the interests of future generations as well as the relevance of the impacts in the actual context under study. In the two cases where this approach was applied, the results from this bottom-up approach were shown to match the top-down approach based on theory only.

- Further empirical research is needed to find out whether the approach of providing an explicit 'future generations' viewpoint can indeed influence decisions in the practice. Learnings from the use of knowledge tools like indicators shows that influence can indeed happen, but it may be indirect rather than direct (conceptual rather than instrumental, i.e. enable new world views as opposed to directly changing the outcome of decision-making – Chapter 2.3).

- It was also found that there is a need for guidance on the assessment of interactions between assessment criteria in the long term. Although concepts like the Planetary Boundaries provide clearly defined global thresholds to watch for, the two core boundaries of climate change and biosphere integrity are closely related and bring a number of trade-offs that unfold over time. The current UK state-of-the-art transport appraisal guidance does not yet provide a means to properly identify the trade-offs involved (article IV, and also Chapter 2.1).

- For utilisation, the research confirms the potential role for stakeholders to complement the assessment of sustainability of transport projects. MCA methods such as AHP are mature enough to be used in a basket of assessment tools for assessing complex criteria that cannot (yet) be 'measured' by conventional methods. However the approach is not without its own challenges. On the basis that quality of the input data is to MCA what quantity is to CBA valuations, there is a need for further research for producing guidance on addressing known cognitive biases. Structured interviews were found to be a promising approach to insure the validity of this input data, as well as for enabling self-learning by the stakeholders during the elicitation process (although because of the focus on individual interviews, it did not allow interactive learning or negotiation *between* stakeholders - article III).

- The explicit inclusion of various stakeholder perspectives raises important epistemological considerations for the assessment of transport projects. As decision-support processes become more democratic and open up to multiple stakeholders outside the traditional realm of planners, it also opens up its decision-making. Conventional planning based on instrumental rationality sees decision-support and assessment tools as distinct from decision-making, whereas communicative planning effectively turns the decision-support and assessment tools into a decision-making *process*. Although further research is needed on this topic, it became clear from conducting this research that for the case of HS2 (and with current tools), decision-making was not a single outcome of the appraisal, but instead a continuous and iterative process which eventually funnel to the project's implementation. The implication of this is that decision-support and decision-making are a core and tightly intertwined part of Sustainable Transport Appraisal.

206 On this last point, I therefore conclude on a few essential characteristics of Sustainable Transport Appraisal:

1) The analysis of the design of STA processes involves explicitly addressing conceptual, operational and procedural challenges,

2) Conceptual: STA is based on first-order principles of sustainability,

3) Operational: STA is political. The core process of STA is decision-making and sustainability is a goal,

4) Procedural: STA is democratic. It makes the perspectives of stakeholders explicit in the decision-making process,

5) STA expands democracy to incorporating explicitly the interests of future generations, and

6) Epistemologically, STA is a combination of various rationalities. It bridges consultation and participatory debate (constructivism), with the multiplicity of alternatives and the idea of no single best option (relativism), with general and deterministic laws about nature and sustainability (positivism).

3.2 The future of transport

207 This section offers some final reflections on the future of transport and transport research. Although it is not the immediate purpose of this thesis to analyse or comment on the (un)sustainability of the current transport system, there is a few reasons to do so. First, I introduced the known externalities and the challenges of transport in the early part of the motivation section. I then introduced in more detail in Chapter 2 what sustainable transport entails, both from its potential definitions derived from higher order sustainability principles, and also from the perspective of intervening in transport at policy level. I therefore conclude here on this specific topic. The second reason is that these reflections have some implications for STA, which I explain where relevant. The third is that, as a transport researcher, I do often get asked: ‘what is the future of transport?’ (and for this reason the tone here is more that of an editorial or popular article).

208 We perhaps find ourselves at a crossroad. On one hand, everything is becoming ‘greener’. We have greener cars, greener energy, greener habits, greener policies, and greener discourses. Yet overall, when looking at sustainability from an environmental planetary boundary perspective, the window of opportunity for taking action is narrowing. The reuse the language from the Natural Step: humanity is in a funnel.

209 Transport is an increasingly important contributor to the challenge of sustainability. This thesis established (in Chapter 2) that we can no longer hide behind ‘not knowing what sustainability or sustainable transport is about’. Although context does matter, sustainability as a concept is less normative and more scientifically grounded than it once was. Similar problems related to transport such as sprawl, air pollution, congestion, habitat fragmentation etc. are found on every corner of the planet. Yet sustainable transport assessment so far has failed to deliver significant changes with that regard – instead, delivering more of the same. As far as HS2 is concerned, we simply do not know whether it is or not a stepping stone towards a sustainable transport system. It is currently for time and luck to decide, but it is not the result of astute planning.

210 This thesis has narrowed down where the problems of delivering a genuinely sustainable development of transport could be. First, the ‘sustainable’ in sustainable transport assessment is not always sufficiently

conceptualised in the practice, and therefore not genuinely internalised. While transport research centres and transport authorities can be heard claiming ‘sustainability is part of everything we do’, the case of HS2 in the UK presented in this thesis (articles III and IV) show that despite a state-of-the-art appraisal framework and a timely post-Copenhagen and post-Paris context, sustainability was not an explicit goal in the first place.

211 Second, it may be due to a lack of operationalisation. The techno-rationalist sciences have so far failed to deliver expertise that manages to address the uncertainties inherent to planning for sustainability. As I have shown in this thesis (articles II and III), various scientific methods can lead to diametrically opposed preferred solutions. Connecting the contribution of transport to overarching theories of sustainability seems to be an urgent and critical challenge for transport research if expertise and evidence-based planning is to carry on at all. Staying within economic principles, the sustainability challenge would require to internalise the full costs and benefits of transport – as opposed to only those that we can in fact quantify and monetise. But even for this to happen, there is a need to develop and integrate a set of tools that tell us what those wider impacts are and how they unfold over the long term.

212 Third, processes of transitions towards sustainable mobility are complex and inherently political. This does not mean nurturing change is not possible. But it does mean that nurturing change will require an equally complex and holistic thinking that considers explicitly the enabling or disabling role of competing technologies, interests and markets, user behaviours, preferences and needs, regulations, institutions, knowledge, appraisal processes, and discourses. If the failure of planning tools persists – or if model-based forecasts take us where we do not want to go - perhaps vastly different approaches are warranted. This requires more – and not less – research in transport governance and processes of change.

213 It is maybe telling that the Department of Transport at the Technical University of Denmark is being discontinued in its current form at the time this thesis was being completed. Transport research now joins Management Engineering. On one hand, this move recognises that transport is no longer strictly a bounded civil engineering and transport planning issue. The conventional transport planning approach based on predicting and fulfilling (mostly motorised transport) demands, while ‘limiting’ externalities (mostly safety issues, congestion and emissions) has run its course[60]. In lieu of that, this move suggests transport demand and supply need to be better *managed,* and promising transport innovations need to be better shielded, nurtured and empowered. On the other hand, management engineering is primarily concerned with technology and industry. It is not a fundamental departure from the modernist belief in the “technical fix” - a promise that problems can be solved with technology. This also resonates well with Denmark’s strategy to promote Green Growth – a promise that *marketable* technologies can resolve sustainability problems. It is an attractive position, if not only because it does not fundamentally question the current production and consumption model based on economic growth, efficiency improvements and incremental changes. But this incrementalist position is also being fervently criticised by conservationists and environmentalists as ultimately unsustainable. Faced with little progress in reducing either car- or oil-dependency in transport, a number of sustainable transport researchers have raised the need for more transformational change – and for research on processes of change.

[60] In practice, DTU Transport had already grown beyond this conventional transport planning and road traffic modelling fields to embrace a wider array of research fields, including behaviour, governance, policy, risk assessment, gender issues, cycling transitions, interaction with land use systems in urban context etc.

214 But transformational change is happening already. During the course of this thesis, transport has in my view become ‘sexy’. Short of making it explicitly on the United Nations Sustainable Development Goals, transportation in this period (2013-2016) saw numerous innovations reaching critical mass: electric cars have finally become more common place and so have electric bicycles; car-sharing and car-pooling have transformed mobility in many cities worldwide; bus rapid transit and high-speed rail development have soared; greener propulsion is being trialled in many forms; and transport infrastructure is slowly but surely being retrofitted around more liveable, less car-oriented concepts.

215 Four trends are emerging, which can be pinned down to the original Avoid-Shift-Improve strategies (chap. 2.2). The electrification of transport is improving the energy profile of transport. This enables further down the line (and further down in time, hand-in-hand with a transition on energy supplies) a *decarbonisation* of transport. The *diversification* of transport brings the potential for shifting from high impact transport modes to lower-impact transport modes. Not one solution is perfect, but high-speed rail, bus-rapid transit, self-driving mini-buses, shared vehicle ownership, and the full panoply of electric vehicles from the mono-wheel to the larger cargo-bikes are opening up an array of new means to meet (genuine) needs for co-presence. This diversification is also blurring the traditional lines between strictly walking, cycling, public transport and the personal car, not the least as various modes could be used in conjunction to one another on a single (but multi-purpose) door-to-door journey. This is bound to bring transport planning authorities (and STA processes) a headache even in the short term in terms of infrastructure provision and regulation (unless perhaps if the idea of completely open and low-speed shared space takes hold). Finally, increased urbanisation coupled with the setting of physical limits to city expansion may go a long way in embedding sustainable transport in the very fabric of the city (as opposed to a previous planning approach where transport vehicles dictated the shape of cities). The dual effect of *densification* of cities and the general trend for *digitalisation* of services (e.g. virtual mobility) is working to give people more of what they want where they are, hence reducing the need for passenger transport in the first place. In other words, people may well have genuine needs for exceptional long-distance travel, but our basic daily needs could be met locally.

216 In fact this conclusion already has made itself to the highest level of policy at the EU as the final sentence of the strategy outlook for 2050, which I repeat here as a final conclusion:

“There is an underlying need, not to curb mobility, but to curb the need *for mobility, which can strategically support all four White Paper goals over the long-term. This requires the rethinking of urban form, production and consumption systems, the role of HSR in favour of other medium- and long-distance modes, and the role of technology in both facilitating and supplanting the need for travel.” (Anderton et al. 2015)*

References

Allmendinger, Philip. 2009. *Planning Theory*. Edited by Yvonne Rydin and Andrew Thornley. 2nd ed.

Alonso, Andrea, Andrés Monzón, and Rocío Cascajo. 2015. "Comparative Analysis of Passenger Transport Sustainability in European Cities." *Ecological Indicators* 48. Elsevier Ltd: 578–92.

Anderton, Karen, Jonas Åkerman, Ralf Brand, Cécile Chèze, Merethe Dotterud Leiren, Henrik Gudmundsson, Yannick Cornet, et al. 2015. *TRANSFORuM Transport 2050 Strategic Outlook*. http://www.transforum-project.eu/fileadmin/user_upload/08_resources/08-01_library/TRANSFORuM_Strategic_Oulook.pdf.

Astleithner, Florentina, Alexander Hamedinger, Nancy Holman, and Yvonne Rydin. 2004. "Institutions and Indicators – The Discourse about Indicators in the Context of Sustainability." *Journal of Housing and the Built Environment* 19 (1): 7–24.

Azar, Christian, John Holmberg, and Kristian Lindgren. 1996. "Socio-Ecological Indicators for Sustainability." *Ecological Economics* 18 (2): 89–112.

Banister, David. 2008. "The Sustainable Mobility Paradigm." *Transport Policy* 15 (2). Elsevier: 73–80.

Banister, David, Karen Anderton, David Bonilla, Moshe Givoni, and Tim Schwanen. 2011. "Transportation and the Environment." *Annual Review of Environment and Resources* 36 (1): 247–70.

Banister, David, and Robin Hickman. 2012. "Transport Futures: Thinking the Unthinkable." *Transport Policy*, August. Elsevier, 1–10.

Barfod, Michael Bruhn. 2012. "Optimising Transport Decision Making Using Customised Decision Models and Decision Conferences." Technical University of Denmark.

Barfod, Michael Bruhn, and Kim Bang Salling. 2015. "A New Composite Decision Support Framework for Strategic and Sustainable Transport Appraisals." *Transportation Research Part A: Policy and Practice* 72. Elsevier Ltd: 1–15.

Bauler, Tom. 2012. "An Analytical Framework to Discuss the Usability of (Environmental) Indicators for Policy." *Ecological Indicators* 17. Elsevier Ltd: 38–45.

Becker, Barbara. 1997. *Sustainability Assessment: A Review of Values, Concepts, and Methodological Approaches*. *Issues in Agriculture*. The Consultative Group on International Agricultural Research.

Becker, Joanna. 2007. "How Frameworks Can Help Operationalize Sustainable Development Indicators." *World Futures* 63 (2): 137–50.

Becker, Joanna. 2010. "Use of Backcasting to Integrate Indicators with Principles of Sustainability." *International Journal of Sustainable Development & World Ecology* 17 (3): 189–97.

Bell, Simon, and Stephen Morse. 2003. *Measuring Sustainability: Learning by Doing*. London: Earthscan.

Berger, Peter L., and Thomas Luckmann. 1966. *The Social Construction of Reality: A Treatise in the Sociology of Knowledge*. *Allen Lane*. http://wps.pearsoncustom.com/wps/media/objects/6714/6875653/readings/MSL_Berger_Luckmann_Construction.pdf.

Booz & Co., and Temple. 2011. “HS2 London to the West Midlands Appraisal of Sustainability.”

Bracken, L.J., H.A. Bulkeley, and G. Whitman. 2014. “Transdisciplinary Research: Understanding the Stakeholder Perspective.” *Journal of Environmental Planning and Management* 0568 (January): 1–18.

Broman, Goran, John Holmberg, and Karl-Henrik Robèrt. 2000. “Simplicity Without Reduction: Thinking Upstream Towards the Sustainable Society.” *Interfaces* 30 (3): 13–25.

Broman, Göran Ingvar, and Karl-Henrik Robèrt. 2015. “A Framework for Strategic Sustainable Development.” *Journal of Cleaner Production*, 1–15.

Brömmelstroet, Marco, and Luca Bertolini. 2012. “Land Use and Transport Information That Matters.” In *Transition towards Sustainable Mobility - The Role of Instruments, Individuals and Institutions*, 15:251–69.

Browne, David, and Lisa Ryan. 2011. “Comparative Analysis of Evaluation Techniques for Transport Policies.” *Environmental Impact Assessment Review* 31 (3). Elsevier Inc.: 226–33.

Bruun, Eric, and Moshe Givoni. 2015. “Six Research Routes to Steer Transport Policy.” *Nature* 523: 29–31. http://www.nature.com/news/sustainable-mobility-six-research-routes-to-steer-transport-policy-1.17860.

Buchanan, Colin. 1963. *Traffic in Towns: A Study of the Long Term Problems of Trafic in Urban Areas (The Buchanan Report)*.

Bueno, P.C., J.M. Vassallo, and K Cheung. 2015. “Sustainability Assessment of Transport Infrastructure Projects: A Review of Existing Tools and Methods.” *Transport Reviews*, no. June 2015: 1–28.

Carlsson, Carl-magnus, Tareq Emtairah, Britta Gammelgaard, Anders Vestergaard Jensen, and Åke Thidell. 2012. *Rethinking Transport in the Øresund Region - Policies, Strategies and Behaviours*. Øresund Ec. Lund: Lund University. http://www.interreg-oks.eu/se/Menu/Projektbank/Projektlista+Öresund/Øresund+EcoMobility.

Cash, David, William Clark, Franck Alcock, Nancy Dickson, Noelle Eckley, and Jill Jäger. 2002. *Salience, Credibility, Legitimacy and Boundaries: Linking Research, Assessment and Decision Making*. http://www.proyectoibera.org/centroibera/download/cursos/doc/salience_credibility_etc.pdf.

Castillo, Herb, and David E. Pitfield. 2010. “ELASTIC – A Methodological Framework for Identifying and Selecting Sustainable Transport Indicators.” *Transportation Research Part D: Transport and Environment* 15 (4): 179–88.

Castillo, Nicodemus Herb. 2004. “A Methodological Approach for Indicator-Based Sustainable Transport Assessment.” Loughborough University. https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/7696.

Connelly, Steve. 2007. “Mapping Sustainable Development as a Contested Concept.” *Local Environment* 12 (3): 259–78.

Costanza, Robert, Ralph D’Arge, Rudolf de Groot, Stephen Farberk, Monica Grasso, Bruce Hannon, Karin Limburg, et al. 1997. “The Value of the World ’ S Ecosystem Services and Natural Capital” 387 (May): 253–60.

Cotton-Barratt, Owen, Sebastian Farquhar, John Halstead, Stefan Schubert, and Andrew Snyder-Beattie. 2016. *Global Catastrophic Risks 2016*.

Cour des comptes. 2014. *LA GRANDE VITESSE FERROVIAIRE : UN MODÈLE PORTÉ AU-DELÀ DE SA PERTINENCE*.

Dahl, Arthur Lyon. 2012. “Achievements and Gaps in Indicators for Sustainability.” *Ecological Indicators* 17 (June). Elsevier Ltd: 14–19.

Dalkmann, Holger, and C Brannigan. 2007. “Transport and Climate Change. Module 5e. Sustainable Transport: A Sourcebook for Policy-Makers in Developing Cities.” *Deutsche Gesellschaft Für Technische Zusammenarbeit (GTZ)*. http://www.gtz.de.

Daly, HE. 1990. “Toward Some Operational Principles of Sustainable Development.” *Ecological Economics* 2. http://www.sciencedirect.com/science/article/pii/092180099090010R.

De Neufville, Judith Innes. 1978. “Validating Policy Indicators.” *Policy Sciences* 10 (2-3): 171–88.

Department for Environment Food & Rural Affairs. 2005. *Securing the Future - Delivering UK Sustainable Development Strategy*. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69412/pb10589-securing-the-future-050307.pdf.

Department for Environment Food & Rural Affairs. 2011. *Biodiversity 2020 : A Strategy for England’s Wildlife and Ecosystem Services*. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69446/pb13583-biodiversity-strategy-2020-111111.pdf.

Department for Transport. 2014. “Transport Analysis Guidance: WebTAG,” no. November. https://www.gov.uk/guidance/transport-analysis-guidance-webtag.

Department of the Environment Transport and the Regions. 1998. *A New Deal for Transport: Better for Everyone - White Paper*. http://webarchive.nationalarchives.gov.uk/+/http:/www.dft.gov.uk/about/strategy/whitepapers/previous/anewdealfortransportbetterfo5695.

Dobson, Andrew. 1996. “Environment Sustainabilities: An Analysis and a Typology.” *Environmental Politics* 5 (3): 401–28.

Docherty, Iain, and Jon Shaw. 2011. “The Transformation of Transport Policy in Great Britain? ‘New Realism’ and New Labour’s Decade of Displacement Activity.” *Environment and Planning A* 43 (1): 224–51.

Dreborg, Karl H. 1996. “Essence of Backcasting.” *Futures* 28 (9): 813–28.

Dryzek, John S. 1997. *The Politics of the Earth: Environmental Discourses*. http://www.cabdirect.org/abstracts/19981806028.html.

Dudley, Geoffrey, and David Banister. 2015. “Expertise and the Dynamics of Decision Making in Large Infrastructure Projects: From UK Trunk Roads to High Speed Rail 2.” In *Paper Presented at the UTSG Conference, City University, London.*, 1–15.

Dur, F., and T. Yigitcanlar. 2015. “Assessing Land-Use and Transport Integration via a Spatial Composite Indexing Model.” *International Journal of Environmental Science and Technology* 12 (3): 803–16.

Ekins, Paul. 2011. *A Note on the Impossibility of Deriving a Scientifically Valid, Ethically Sound or Policy-Useful Estimate of the Social Cost of Carbon*.

Elkington, J. 1997. *Cannibals with Forks - The Triple Bottom Line of the 21st Century Business*. *The Top 50 Sustainability Books*. http://www.ingentaconnect.com/content/glbj/top50sb/2009/00000001/00000116/art00024.

European Commission. 2011. *WHITE PAPER Roadmap to a Single European Transport Area – Towards a Competitive and Resource Efficient Transport System*. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:EN:PDF.

European Conference of Ministers of Transport. 2004. "Assessment & Decision Making for Sustainable Transport," 1–235.

European Environmental Agency (EEA). 2011. *Laying the Foundations for Greener Transport - TERM 2011: Transport Indicators Tracking Progress towards Environmental Targets in Europe*. http://www.eea.europa.eu/publications/foundations-for-greener-transport.

European Environmental Agency (EEA). 2015. *Evaluating 15 Years of Transport and Environmental Policy Integration*. http://www.eea.europa.eu/publications/term-report-2015.

Flyvbjerg, B. 2006. "Five Misunderstandings About Case-Study Research." *Qualitative Inquiry* 12 (2): 219–45.

Gallopín, Gilberto C. 1996. "Environmental and Sustainability Indicators and the Concept of Situational Indicators. A Systems Approach." *Environmental Modeling & Assessment* 1 (3): 101–17.

Gasparatos, Alexandros, Mohamed El-Haram, and Malcolm Horner. 2008. "A Critical Review of Reductionist Approaches for Assessing the Progress towards Sustainability." *Environmental Impact Assessment Review* 28 (4-5): 286–311.

Geels, Frank W. 2010. "Ontologies, Socio-Technical Transitions (to Sustainability), and the Multi-Level Perspective." *Research Policy* 39 (4). Elsevier B.V.: 495–510.

Geels, Frank W. 2012. "A Socio-Technical Analysis of Low-Carbon Transitions: Introducing the Multi-Level Perspective into Transport Studies." *Journal of Transport Geography* 24 (September). Elsevier Ltd: 471–82.

Geels, Frank W., Frans Berkhout, and Detlef P. van Vuuren. 2016. "Bridging Analytical Approaches for Low-Carbon Transitions." *Nature Climate Change* advance on (6). Nature Publishing Group: 576–83.

Geels, Frank W., and Johan Schot. 2007. "Typology of Sociotechnical Transition Pathways." *Research Policy* 36 (3): 399–417.

Geurs, Karst, and Bert Van Wee. 2004. "Backcasting as a Tool for Sustainable Transport Policy Making : The Environmentally Sustainable Transport Study in the Netherlands." *European Journal of Transport Infrastructure Research* 4: 47–69.

Gibson, Robert B. 2006. "Beyond The Pillars: Sustainability Assessment as a Framework for Effective Integration of Social, Economic and Ecological Considerations in Significant Decision-Making." *Journal of Environmental Assessment Policy and Management* 8 (3): 259–80.

Giddings, Bob, Bill Hopwood, and Geoff O'Brien. 2002. "Environment, Economy and Society: Fitting Them Together into Sustainable Development." *Sustainable Development* 10 (4): 187–96.

Givoni, Moshe. 2006. "Development and Impact of the Modern High Speed Train: A Review." *Transport Reviews* 26 (5): 593–611.

Givoni, Moshe. 2013. "Addressing Transport Policy Challenges through Policy-Packaging." *Transportation Research Part A: Policy and Practice,* November.

Griggs, David, Mark Stafford-Smith, Owen Gaffney, Johan Rockström, Marcus C Ohman, Priya Shyamsundar, Will Steffen, Gisbert Glaser, Norichika Kanie, and Ian Noble. 2013. "Policy: Sustainable

Development Goals for People and Planet." *Nature* 495 (7441): 305–7.

Grober, Ulrich. 2007. "Deep Roots: A Conceptual History Of'sustainable development'(Nachhaltigkeit)," no. February. http://www.econstor.eu/handle/10419/50254.

Grütter, Jürg M. 2007. *The CDM in the Transport Sector*. *Module 5d. Sustainable Transport: A Sourcebook foPolicy-Makers in Developing Cities*. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:The+CDM+in+the+Transport+Sector#0.

Gudmundsson, Henrik. 2003. "The Policy Use of Environmental Indicators–learning from Evaluation Research." *The Journal of Transdisciplinary Environmental Studies* 2 (2). http://www.journal-tes.dk/vol 2 no 2/Henrik Gudnundsson_lav.pdf?id=00029.

Gudmundsson, Henrik. 2004. "Sustainable Transport and Performance Indicators." *Issues in Environmental Science and Technology*, no. 20: 35–64. http://trid.trb.org/view.aspx?id=900794.

Gudmundsson, Henrik. 2007. *Sustainable Mobility and Incremental Change - Some Building Blocks for IMPACT*. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Sustainable+Mobility+and+incremental+change+–+Some+building+blocks+for+IMPACT#0.

Gudmundsson, Henrik, Ralph P. Hall, Greg Marsden, and Josias Zietsman. 2016. *Sustainable Transportation - Indicators, Frameworks and Performance Management*.

Gudmundsson, Henrik, and Mattias Höjer. 1996. "Sustainable Development Principles and Their Implications for Transport." *Ecological Economics* 19: 269–82.

Gudmundsson, Henrik, Mary Lawler, Maria Figueroa, and Miles Tight. 2010. "How Does Transport Policy Cope with Climate Challenges? Experiences from the UK and Other European Countries." *Journal of Transportation Engineering*, no. June: 383–92.

Gudmundsson, Henrik, and CH Sørensen. 2013. "Some use—Little Influence? On the Roles of Indicators in European Sustainable Transport Policy." *Ecological Indicators*, no. 35. Elsevier Ltd: 43–51.

Hall, Ralph P. 2006. "Understanding and Applying the Concept of Sustainable Development to Transportation Planning and Decision-Making in the US." http://18.7.29.232/handle/1721.1/34555.

Healey, P. 1998. "Building Institutional Capacity through Collaborative Approaches to Urban Planning." *Environment and Planning A* 30 (December 1996): 1531–46. http://www.environmentandplanning.com/epa/fulltext/a30/a301531.pdf.

Heink, Ulrich, and Ingo Kowarik. 2010. "What Are Indicators? On the Definition of Indicators in Ecology and Environmental Planning." *Ecological Indicators* 10 (3): 584–93.

Helliwell, John, Richard Layard, and Jeffrey Sachs. 2016. *World Happiness Report 2016, Update (Vol. I)*. Vol. I. New York. http://worldhappiness.report/ed/2016/.

Hezri, Adnan a., and Stephen R. Dovers. 2006. "Sustainability Indicators, Policy and Governance: Issues for Ecological Economics." *Ecological Economics* 60 (1): 86–99.

Hickman, Robin, and David Banister. 2007. "Looking over the Horizon: Transport and Reduced CO2 Emissions in the UK by 2030." *Transport Policy* 14 (5): 377–87.

HM Treasury. 2011. *The Green Book: Appraisal and Evaluation in Central Government*.

Holden, Erling, Kristin Linnerud, and David Banister. 2013. “Sustainable Passenger Transport: Back to Brundtland.” *Transportation Research Part A: Policy and Practice* 54 (August). Elsevier Ltd: 67–77.

Holden, Erling, Kristin Linnerud, and David Banister. 2014. “Sustainable Development: Our Common Future Revisited.” *Global Environmental Change* 26 (May). Elsevier Ltd: 130–39.

Holling, C. S. 2001. “Understanding the Complexity of Economic, Ecological, and Social Systems.” *Ecosystems* 4 (5): 390–405.

Holmberg, John, and Karl-Henrik Robèrt. 2000. “Backcasting from Non-Overlapping Sustainability Principles–a Framework for Strategic Planning.” *International Journal of Sustainable Development and World Ecology*, 291–308. http://www.fysiskplanering.se/ste/tmslm.nsf/attachments/Holmberg and Robert 2000 - Backcasting from non-overlapping_pdf/$file/Holmberg and Robert 2000 - Backcasting from non-overlapping.pdf.

Hopwood, Bill, Mary Mellor, and Geoff O’Brien. 2005. “Sustainable Development: Mapping Different Approaches.” *Sustainable Development* 13 (1): 38–52.

House of Commons Transport Committee. 2011. *High Speed Rail: Tenth Report of Session 2010-12 Volume II Oral and Written Evidence (HC 1185-II)*. Vol. II. http://www.publications.parliament.uk/pa/cm201012/cmselect/cmtran/1185/1185ii.pdf.

HS2 Ltd. 2013. “HS2 Phase One Environmental Statement: Documents.” https://www.gov.uk/government/collections/hs2-phase-one-environmental-statement-documents.

Innes, Judith E. 1998. “Information in Communicative Planning.” *Journal of the American Planning Association*. http://www.tandfonline.com/doi/abs/10.1080/01944369808975956.

Jensen, Anders Vestergaard. 2012. “Appraisal of Transport Projects: Assessing Robustness in Decision Making.” Technical University of Denmark.

Jeon, Christy Mihyeon, and Adjo Amekudzi. 2005. “Addressing Sustainability in Transportation Systems: Definitions, Indicators, and Metrics.” *Journal of Infrastructure Systems* 11 (1): 31–50.

Jeon, Christy Mihyeon, Adjo a. Amekudzi, and Randall L. Guensler. 2013. “Sustainability Assessment at the Transportation Planning Level: Performance Measures and Indexes.” *Transport Policy* 25 (January). Elsevier: 10–21.

Jeppesen, Sara L. 2009. “Sustainable Transport Planning - A Multi-Methodology Approach to Decision Making.” Technical University of Denmark.

Jones, Peter, and Karen Lucas. 2012. “The Social Consequences of Transport Decision-Making: Clarifying Concepts, Synthesising Knowledge and Assessing Implications.” *Journal of Transport Geography* 21 (March). Elsevier Ltd: 4–16.

Joumard, Robert, and Henrik Gudmundsson. 2010. *Indicators of Environmental Sustainability in Transport*. Recherches. http://hal.archives-ouvertes.fr/hal-00492823/.

Joumard, Robert, and Jean-Pierre Nicolas. 2010. “Transport Project Assessment Methodology within the Framework of Sustainable Development.” *Ecological Indicators* 10 (2): 136–42.

Lange, Philipp, Peter P J Driessen, Alexandra Sauer, Basil Bornemann, and Paul Burger. 2013. “Governing Towards Sustainability—Conceptualizing Modes of Governance.” *Journal of Environmental Policy & Planning* 15 (3): 403–25.

Langhelle, O. 1999. “Sustainable Development: Exploring the Ethics of Our Common Future.” *International*

Political Science Review 20 (2): 129–49.

Lawton, J.H., P.N.M. Brotherton, V.K. Brown, C. Elphick, A.H. Fitter, J. Forshaw, R.W. Haddow, et al. 2010. *Making Space for Nature : A Review of England ' S Wildlife Sites and Ecological Network. Report to DEFRA*. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/218690/201009space-for-nature.pdf.

Lehtonen, Markku, Léa Sébastien, and Tom Bauler. 2016. "The Multiple Roles of Sustainability Indicators in Informational Governance: Between Intended Use and Unanticipated Influence." *Current Opinion in Environmental Sustainability* 18: 1–9.

Lele, SM. 1991. "Sustainable Development: A Critical Review." *World Development* 19 (6): 607–21. http://www.sciencedirect.com/science/article/pii/0305750X9190197P.

Leleur, Steen. 2012. *Complex Strategic Choices*. http://books.google.com/books?hl=en&lr=&id=FkFC_2mAUjwC&oi=fnd&pg=PR5&dq=Complex+Strategic+Choices&ots=nM1I8mtSIS&sig=4J5cE2s8QvCdgguqtfCm4z2_CSM.

Litman, Todd. 2010. *Evaluating Accessibility for Transportation Planning - Measuring People's Ability To Reach Desired Goods and Activities*. http://www.vtpi.org/access.pdf.

Litman, Todd. 2015. *Well Measured: Developing Indicators for Sustainable and Livable Transport Planning*. *Victoria Transport Policy Institute*. http://www.vtpi.org/wellmeas.pdf.

Lyytimäki, Jari, Henrik Gudmundsson, and Claus Hedegaard Sørensen. 2014. "Russian Dolls and Chinese Whispers: Two Perspectives on the Unintended Effects of Sustainability Indicator Communication." *Sustainable Development* 22 (2). John Wiley and Sons Ltd: 84–94.

Macharis, Cathy, and Annalia Bernardini. 2015. "Reviewing the Use of Multi-Criteria Decision Analysis for the Evaluation of Transport Projects: Time for a Multi-Actor Approach." *Transport Policy* 37. Elsevier: 177–86.

Macharis, Cathy, Astrid De Witte, and Jeroen Ampe. 2009. "The Multi-Actor, Multi-Criteria Analysis Methodology (MAMCA) for the Evaluation of Transport Projects: Theory and Practice." *Journal of Advanced Transportation* 43 (2): 183–202.

Macharis, Cathy, Laurence Turcksin, and Kenneth Lebeau. 2012. "Multi Actor Multi Criteria Analysis (MAMCA) as a Tool to Support Sustainable Decisions: State of Use." *Decision Support Systems* 54 (1). Elsevier B.V.: 610–20.

Mackie, Peter, Tom Worsley, and Jonas Eliasson. 2014. "Transport Appraisal Revisited." *Research in Transportation Economics* 47. Elsevier Ltd: 3–18.

Mackie, Peter, Tom Worsley, Charlotte Kelly, Gerard de Jong, Jonas Eliasson, Glen Weisbrod, Neil Douglas, and Ian Wallis. 2013. *International Comparisons of Transport Appraisal Practice Overview Report*. *Prepared for Department for Transport*. https://workspace.imperial.ac.uk/ref/Public/UoA 14 - Civil and Construction Engineering/Wider economic Impacts/K Worsley report.pdf.

Maibach, M., C. Schreyer, D. Sutter, H.P. van Essen, B.H. Boon, R. Smokers, A. Schroten, C. Doll, B. Pawlowska, and M. Bak. 2008. *Handbook on Estimation of External Costs in the Transport Sector: Internalisation Measures and Policies for All External Cost of Transport (IMPACT)*.

Marchetti, C. 1994. "Anthropological Invariants in Travel Behavior." *Technological Forecasting and Social Change* 47 (1): 75–88.

Marsden, Greg, and Peter Bonsall. 2006. “Performance Targets in Transport Policy.” *Transport Policy* 13 (3): 191–203.

Marsden, Greg, and Iain Docherty. 2013. “Insights on Disruptions as Opportunities for Transport Policy Change.” *Transportation Research Part A: Policy and Practice* 51 (May). Elsevier Ltd: 46–55.

Marsden, Greg, Charlotte Kelly, and Carolyn Snell. 2006. “Selecting Indicators for Strategic Performance Management.” *Transportation Research Record: Journal of the Transportation Research Board*, no. 1956 (January): 21–29.

Marsden, Greg, Charlotte Kelly, Carolyn Snell, and John Forrester. 2005. *DISTILLATE C1 - Improved Indicators for Sustainable Transport and Planning Sustainable Transport Indicators : Selection and Use*. www.distillate.ac.uk.

Marsden, Greg, and Tom Rye. 2010. “The Governance of Transport and Climate Change.” *Journal of Transport Geography* 18 (6). Elsevier Ltd: 669–78.

Marti-Henneberg, Jordi. 2015. “Challenges Facing the Expansion of the High-Speed Rail Network.” *Journal of Transport Geography* 42: 131–33.

Max-Neef, M. 1995. “Economic Growth and Quality of Life: A Threshold Hypothesis.” *Ecological Economics* 15: 115–18. ftp://131.252.97.79/Transfer/ES_Pubs/ESVal/ecol_econ_general/maxneef_1995_ee_15_p115.pdf.

May, Anthony D., Matthew Page, and Angela Hull. 2008. “Developing a Set of Decision-Support Tools for Sustainable Urban Transport in the UK.” *Transport Policy* 15 (6): 328–40.

Meadows, Donella H., Dennis L. Meadows, Jørgen Randers, and William W. Behrens III. 1972. *The Limits to Growth*. Universe Books.

Metz, David. 2008. “The Myth of Travel Time Saving.” *Transport Reviews* 28 (3): 321–36.

Meunier, David, Alain Quinet, and Emile Quinet. 2014. “Project Appraisal and Long Term Strategic Vision.” *Transportation Research Procedia* 1 (1). Elsevier B.V.: 67–76.

Meunier, David, and Emile Quinet. 2015. “Valuing Greenhouse Gases Emissions and Uncertainty in Transport Cost Benefit Analysis.” *Transportation Research Procedia* 8. Elsevier B.V.: 80–88.

Moldan, Bedřich, Svatava Janoušková, and Tomáš Hák. 2012. “How to Understand and Measure Environmental Sustainability: Indicators and Targets.” *Ecological Indicators* 17 (June): 4–13.

Munasinghe, Mohan. 1993. *Environmental Economics and Sustainable Development*. http://books.google.com/books?hl=en&lr=&id=VmKwJa2iNOsC&oi=fnd&pg=PP6&dq=Environmental+Economics+and+Sustainable+Development&ots=QYghcvIfyw&sig=YWrICWBSH2-wRx0kjJcP32jDEbA.

Nelson, RH. 1995. “Sustainability, Efficiency, and God: Economic Values and the Sustainability Debate.” *Annual Review of Ecology and Systematics*, no. 71. http://www.annualreviews.org/doi/pdf/10.1146/annurev.es.26.110195.001031.

Niemeijer, David, and Rudolf S. de Groot. 2008. “A Conceptual Framework for Selecting Environmental Indicator Sets.” *Ecological Indicators* 8 (1): 14–25.

Owens, Susan. 1995. “From ‘predict and Provide’ to ‘predict and Prevent’?: Pricing and Planning in Transport Policy.” *Transport Policy* 2 (1): 43–49.

Pearce, David W., G.D. Atkinson, and W.R. Dubourg. 1994. "The Economics of Sustainable Development." *Annual Review of Energy and the Environment* 19: 457–74.

Pearce, David W., and Giles D. Atkinson. 1993. "Capital Theory and the Measurement of Sustainable Development: An Indicator of 'weak' Sustainability." *Ecological Economics* 8 (2): 103–8.

Pei, Yi Lin, Adjo a. Amekudzi, Michael D. Meyer, Elise M. Barrella, and Catherine L. Ross. 2010. "Performance Measurement Frameworks and Development of Effective Sustainable Transport Strategies and Indicators." *Transportation Research Record: Journal of the Transportation Research Board*, no. 2163 (December): 73–80.

Preston, John. 2010. "What's so Funny about Peace, Love and Transport Integration?" *Research in Transportation Economics* 29 (1). Elsevier Ltd: 329–38.

Ramani, TL, Josias Zietsman, Henrik Gudmundsson, Ralph Hall, and Greg Marsden. 2011. "Framework for Sustainability Assessment by Transportation Agencies." *Transportation Research Record: Journal of the Transportation Research Board*, no. 2242: 9–18.

Rawls, John. 2001. *Justice as Fairness*. Cambridge, MA: Harvard University Press.

Raworth, Kate. 2012a. *A Safe and Just Space For Humanity: Can We Live within the Doughnut? Oxfam Discussion Papers*. http://www.oxfam.org/en/grow/policy/safe-and-just-space-humanity.

Raworth, Kate. 2012b. "Living in the Doughnut." *Nature Climate Change* 2: 225–26.

Robèrt, K.-H., B. Schmidt-Bleek, J. Aloisi de Larderel, G. Basile, J.L. Jansen, R. Kuehr, P. Price Thomas, M. Suzuki, P. Hawken, and M. Wackernagel. 2002. "Strategic Sustainable Development — Selection, Design and Synergies of Applied Tools." *Journal of Cleaner Production* 10 (3): 197–214.

Robèrt, Karl-Henrik, Sven Borén, Henrik Ny, and Göran Broman. 2016. "A Strategic Approach to Sustainable Transport System Development - Part 1: Attempting a Generic Community Planning Process Model." *Journal of Cleaner Production*, 1–9.

Robèrt, KH, GI Broman, and George Basile. 2013. "Analyzing the Concept of Planetary Boundaries from a Strategic Sustainability Perspective: How Does Humanity Avoid Tipping the Planet?" *Ecology and Society* 18 (2). http://www.bth.se/fou/Forskinfo.nsf/all/42fc9f51c37f973bc1257b75004dd8d0/$file/Analyzing the concept of planetary boundaries.pdf.

Rockström, J, W Steffen, K. Noone, Å. Persson, III F. S. Chapin, E. Lambin, T. M. Lenton, et al. 2009. "Planetary Boundaries: Exploring the Safe Operating Space for Humanity." *Ecology and Society* 14 (2): 1–23. http://www.ecologyandsociety.org/vol14/iss2/art32/main.html.

Rydin, Yvonne. 1999. "Can We Talk Ourselves into Sustainability? The Role of Discourse in the Environmental Policy Process." *Environmental Values*. http://www.ingentaconnect.com/content/whp/ev/1999/00000008/00000004/art00004.

Salling, Kim Bang. 2008. "Assessment of Transport Projects - Risk Analysis and Decision Support." Technical University of Denmark.

Salter, R. 2011. "Technologies for Climate Change Mitigation-Transport Sector." *UNEP*. https://www.etde.org/etdeweb/details_open.jsp?osti_id=1013767.

Sanderson, Ian. 2001. "Participation and Democratic Renewal: From 'Instrumental' to 'Communicative Rationality' ?" *Policy & Politics* 27 (3): 325–41.

Santos, Andrea Souza, and Suzana Kahn Ribeiro. 2013. "The Use of Sustainability Indicators in Urban Passenger Transport during the Decision-Making Process: The Case of Rio de Janeiro, Brazil." *Current Opinion in Environmental Sustainability* 5 (2). Elsevier B.V.: 251–60.

Santos, Georgina, Hannah Behrendt, Laura Maconi, Tara Shirvani, and Alexander Teytelboym. 2010. "Part I: Externalities and Economic Policies in Road Transport." *Research in Transportation Economics*. Elsevier Ltd.

Schöller-Schwedes, Oliver. 2010. "The Failure of Integrated Transport Policy in Germany: A Historical Perspective." *Journal of Transport Geography* 18 (1). Elsevier Ltd: 85–96.

Schwanen, Tim. 2015. "Automobility." In *International Encyclopedia of the Social & Behavioral Sciences*, 2:303–8.

Selva, Nuria, Stefan Kreft, Vassiliki Kati, Martin Schluck, Bengt Gunnar Jonsson, Barbara Mihok, Henryk Okarma, and Pierre L. Ibisch. 2011. "Roadless and Low-Traffic Areas as Conservation Targets in Europe." *Environmental Management* 48 (5): 865–77.

Shove, Elizabeth, and Gordon P Walker. 2007. "CAUTION! Transitions Ahead: Politics, Practice, and Sustainable Transition Management." *Environment and Planning A*, 1–10. http://eprints.lancs.ac.uk/761/2/A_cautionary_note_on_transition_managementv5.pdf.

Singh, Rajesh Kumar, H R Murty, S K Gupta, and A K Dikshit. 2009. "An Overview of Sustainability Assessment Methodologies." Edited by M Horner, C Hardcastle, A Price, and J Bebbington. *Ecological Indicators* 9 (2). Elsevier Ltd: 189–212.

Sørensen, Claus Hedegaard, Henrik Gudmundsson, and Steen Leleur. 2013. *National Sustainable Transport Planning – Concepts and Practice*. http://www.sustain.transport.dtu.dk/english/-/media/Subsites/Sustain/publications/Working papers/Arbejdsnotat NSTP-samlet-2013-09-23.ashx?la=da.

Soria-Lara, Julio A., Luca Bertolini, and Marco te Brömmelstroet. 2016. "An Experiential Approach to Improving the Integration of Knowledge during EIA in Transport Planning." *Environmental Impact Assessment Review* 56. Elsevier Inc.: 188–99.

Sperling, Daniel, and Deborah Gordon. 2008. "Two Billion Cars: Transforming a Culture." *TR News* 259: 3–9.

Spiekermann, K., and M. Wegener. 1994. "The Shrinking Continent: New Time-Space Maps of Europe." *Environment & Planning B: Planning & Design*. http://www.scopus.com/inward/record.url?eid=2-s2.0-0028561035&partnerID=tZOtx3y1.

Steer Davies Gleave. 2004. *High Speed Rail: International Comparisons (Final Report)*. http://webarchive.nationalarchives.gov.uk/20110304132839/http://cfit.independent.gov.uk/pubs/2004/hsr/research/pdf/hsr.pdf.

Steffen, Will, Katherine Richardson, Johan Rockström, Sarah E Cornell, Ingo Fetzer, Elena M Bennett, Reinette Biggs, et al. 2015. "Planetary Boundaries: Guiding Human Development on a Changing Planet." *Science* 347 (6223).

Steg, Linda, and Robert Gifford. 2005. "Sustainable Transportation and Quality of Life." *Journal of Transport Geography* 13 (1): 59–69.

Switzer, Andrew, Luca Bertolini, and John Grin. 2013. "Transitions of Mobility Systems in Urban Regions: A Heuristic Framework." *Journal of Environmental Policy & Planning* 15 (2): 141–60.

Tanguay, Georges A., Juste Rajaonson, Jean Fran??ois Lefebvre, and Paul Lanoie. 2010. "Measuring the Sustainability of Cities: An Analysis of the Use of Local Indicators." *Ecological Indicators* 10 (2): 407–18.

Tengström, Emin. 1999. *Towards Environmental Sustainability?: A Comparative Study of Danish, Dutch and Swedish Transport Policies in a European Context*. Ashgate.

The Centre for Sustainable Transportation. 2005. *Defining Sustainable Transportation*. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Defining+sustainable+transportation#5.

Theis, Tom, and Jonathan Tomkin. 2012. *Sustainability : A Comprehensive Foundation*. Houston: Rice University. www.earth.illinois.edu/sustain/sustainability_text.html.

Turner, Matthew A, and Gilles Guranton. 2009. "The Fundamental Law of Road Congestion: Evidence From Us Cities" 101 (October): 2616–52.

Turnhout, Esther, Matthijs Hisschemöller, and Herman Eijsackers. 2007. "Ecological Indicators: Between the Two Fires of Science and Policy." *Ecological Indicators* 7 (2): 215–28.

UNEP. 2011. *Towards a Green Economy. Transport: Investing in Energy and Resource Efficiency*. http://www.unep.org/greeneconomy/Portals/88/documents/ger/10.0_Transport.pdf.

Urry, John. 2008. "Climate Change, Travel and Complex Futures." *The British Journal of Sociology* 59 (2): 261–79.

Urry, John. 2010. *Mobilities*. Polity Press.

van Wee, Bert. 2013. "Transport and Long-Term Sustainability: A Discussion on Intergenerational Justice." In *13th WCTR, July 15-18*, 1–15. Rio de Janeiro, Brazil.

Verburg, RM, and V Wiegel. 1997. "On the Compatibility of Sustainability and Economic Growth." *Environmental Ethics*. http://secure.pdcnet.org/enviroethics/content/enviroethics_1997_0019_0003_0247_0265.

Vickerman, Roger. 2007. "Cost - Benefit Analysis and Large-Scale Infrastructure Projects: State of the Art and Challenges." *Environment and Planning B: Planning and Design* 34 (4): 598–610.

Waas, Tom, Jean Hugé, Thomas Block, Tarah Wright, Francisco Benitez-Capistros, and Aviel Verbruggen. 2014. "Sustainability Assessment and Indicators: Tools in a Decision-Making Strategy for Sustainable Development." *Sustainability (Switzerland)* 6 (9): 5512–34.

Wardman, Mark, and Glenn Lyons. 2015. "The Digital Revolution and Worthwhile Use of Travel Time: Implications for Appraisal and Forecasting." *Transportation*.

Wegener, Michael, and Franz Fürst. 1999. *Land-Use Transport Interaction: State of the Art*. http://papers.ssrn.com/sol3/Delivery.cfm?abstractid=1434678.

Whitmarsh, Lorraine. 2012. "How Useful Is the Multi-Level Perspective for Transport and Sustainability Research?" *Journal of Transport Geography* 24 (September). Elsevier Ltd: 483–87.

Willson, R. 2001. "Assessing Communicative Rationality as a Transportation Planning Paradigm." *Transportation* 28 (1): 1–31.

World Commission on Environment and Development (WCED). 1987. "Our Common Future." United Nations. http://www.un-documents.net/wced-ocf.htm.

World Energy Council. 2015. *2015 Energy Trilemma Index - Benchmarking the Sustainability of National Energy Systems*. London.

WWF. 2014. *The Living Planet Report, 2014*.

York, Richard, EA Rosa, and Thomas Dietz. 2003. "Footprints on the Earth: The Environmental Consequences of Modernity." *American Sociological Review* 68 (2): 279–300. http://www.academia.edu/download/30466815/yorkrosadietz.pdf.

Zietsman, Josias, and Tara Ramani. 2011. *Sustainability Performance Measures for State DOTS and Other Transportation Agencies*.

Zietsman, Josias, Tara Ramani, Joanne Potter, Virginia Reeder, and Joshua DeFlorio. 2011. *NCHRP REPORT 708 A Guidebook for Sustainability Performance Measurement for Transportation Agencies*. Vol. 708. Transportation Research Board.

Zito, Pietro, and Giuseppe Salvo. 2011. "Toward an Urban Transport Sustainability Index: An European Comparison." *European Transport Research Review* 3 (4): 179–95.

The articles

Article I Building a Metaframework for Sustainable Transport Indicators – Review of Selected Contributions

Where do we go now? Adapted from "Economic Indicators", Walt Handelsman, in Newsday, 2012.

Building a Metaframework for Sustainable Transport Indicators

Review of Selected Contributions

Yannick Cornet and Henrik Gudmundsson

Several recent papers presented at the annual meeting of the Transportation Research Board, Washington, D.C., and elsewhere have reported on efforts to make sustainability manageable. To this end, the papers suggested the use of indicators and performance measures to help conceptualize and operationalize sustainability for transportation-related planning and decision making. Often these studies presented frameworks that would allow sustainability indicators and measures to be included in, for example, agency strategies and practices. Moreover, some papers suggested criteria for the selection of individual indicators and performance measures. The studies, however, did not always agree on the definition of a framework or how to use one to make sustainability-based decisions, and they tended to differ on underscored aspects and concerns. The current study addressed the issue of frameworks more generically and explored what was termed a "metaframework" with a set of associated criteria to guide the framing of indicators for sustainable transportation. On the basis of an explicit framework theory, the three functions of conceptualization, operationalization, and utilization were found to provide a logical structure of complementary features with which to build indicator frameworks. Characteristics of robust indicator frameworks were evaluated in terms of their significance for the three key functions, and they were collected in a list of criteria. A review of the Brundtland Report provided an example of how a more finely grained understanding of sustainability can inform the conceptualization criterion ranking of sustainability impacts. The metaframework was intended primarily as a basis for empirical analysis and for meta-evaluation of existing practice frameworks with respect to the strength of the level of sustainability that they are likely to provide.

Despite the complexity associated with sustainability, it no longer would be fair to depict it as a marginal or exotic concern in the assessment of transportation policies, plans, programs, or projects. On the contrary, many agencies in the United States and around the globe have adopted notions of sustainability principles or goals for parts of their activities or even as a more general direction to take. Several recent reports, papers, and guidance documents have sought to make sustainability manageable. To that end, they suggested indicators and performance measures as tools to help conceptualize and operationalize sustainability for planning and decision making. According to several studies in this field, the best approach is not to simply add a few sustainable transportation indicators (STIs) to an agency's existing performance measurement system. The recommendation is rather to integrate sustainability principles and goals at the highest level of strategic planning and performance measurement and then to derive a set of indicators that serves this purpose (*1–4*). If successful, this approach is likely to result in a more meaningful approach to sustainability by an agency than simply to parachute a few indicators into an otherwise unaltered practice.

These studies highlighted the importance of framing: they proposed frameworks to allow sustainability indicators and measures to be effectively selected and included in, for example, agency strategies and practices. Some studies went a long way to typologize various existing frameworks (*1*), and some suggested criteria for what should be covered in STI frameworks (*2*). However, the studies did not always agree on what was meant by a framework, or on what was assumed to be the precise role of the framework in practice, or how a framework was meant to help agencies make decisions that were more sustainable. Arguably, an adequate comprehension of sustainability needs to be part of a framework from the outset but sometimes is lacking in the frameworks currently in use (*3, 5*). The conceptualization of sustainability in transportation is a significant task in itself. Equally important, however, is the actual use of indicators to ensure that sustainability is integrated into key activities and actions in practice, the absence of which has been identified as a weakness of various sustainability indicator systems in years past (*6–8*).

A metaframework should serve as a framework for such a comprehensive framing exercise. The metaframework proposed here aims to span three key functions of an indicator framework, described as (*a*) conceptualization, (*b*) operationalization, and (*c*) utilization (*9*).

The organization of the paper is as follows: first, an elaboration of the notions introduced here is provided in the following section. Next, the paper presents the analysis of key recent scientific studies on STI frameworks in terms of what they propose to build a metaframework and to allocate criteria to the three framework functions. The section on the development of the metaframework describes the selection of the papers, how they were analyzed, and illustrates the qualitative method used in the analysis. The main findings of the analysis are presented in Table 1. In the section on criteria exemplification, a framework criterion for sustainability explicitness is used to illustrate the possibility of a deeper level of analysis. The discussion section considers key lessons learned from the construction of the framework as well as some important limitations in the proposed approach to allocate criteria to functions. The conclusion points to further work and subsequent application of the metaframework to empirical analysis.

The background for the paper was a Danish research project on national sustainable transport planning called SUSTAIN. This

Department of Transport, Technical University of Denmark, Bygningstorvet 115, DK-2800 Kongens Lyngby, Denmark. Corresponding author: Y. Cornet, yancor@transport.dtu.dk.

Transportation Research Record: Journal of the Transportation Research Board, No. 2531, Transportation Research Board, Washington, D.C., 2015, pp. 103–112.
DOI: 10.3141/2531-12

TABLE 1 Sustainable Transport Indicator Framework Criteria

Number	Criterion	Summary of Rationale	Factor[a]	References[b]
Conceptualization				
1	Adopting an explicit, comprehensive, and holistic view on sustainability	Sustainability should be explicitly conceptualized, with a firm grounding in sustainable development theory (*3, 5*). The conceptualization should be comprehensive in addressing all relevant factors, reflecting fundamental and nonnegotiable principles of sustainability (*2, 12*). A holistic perspective on sustainability recognizes the transport system as a complex and dynamic aspect of larger social, environmental, economic, and governance systems (*2, 12*). It considers the transport system boundaries with a view to risks of unintended, induced, or rebound effects outside of it (*9, 25*).	I-1 I-2 (I-3)	*2, 3, 5, 12, 14* See also *9, 25, 29, 30*
2	Allowing a long time horizon	The time horizon considered should be covering the long term, including future generations perspectives, to allow assessment of impacts affecting intergenerational equity (*22*). Slowly evolving dynamics such as transportation–land use interactions or potential health–quality of life impacts are especially relevant in long-range sustainability planning (*3*).	I-10	*3, 12, 22, 25* See also *20, 31*
3	Integrating land use and transportation on a broad geographic scale	The interactions of land use and transportation should be explicitly conceptualized and addressed, when relevant, with inputs and outputs of land as a scarce resource that affects transportation needs and planning outcomes (*22, 26*). This criterion is particularly important to ensure that changes to urban form and travel patterns can be evaluated with regards to spatial aspects of equity (*12, 28*).	I-21 (I-4)	*3, 12, 14, 22, 23* See also *25, 26, 28–30*
4	Capturing interactions to identify trade-offs	Recognizing the multiple points of interconnection between sustainability notions over broad temporal and geographic scales is necessary to identify and address potential trade-offs between seemingly remote and disconnected impacts (*2, 12*). Trade-offs should be summarized and carefully considered, not ignored or minimized (*5*).	—	*2, 5, 12, 14* See also *25, 29*
5	Supporting consistency between transport and sustainability objectives	If consistency with sustainability objectives is not secured there is a risk of tunnel vision effect (*3*), in which indicator sets are built on existing or inherited policies and goals with little consideration for sustainability. Transport goals and objectives should be mapped to sustainability principles identified in Criterion 1. This can take the form of an explicit table such as that proposed by Ramani et al. (*12*).	I-5 I-15 I-16	*3, 5, 12, 14, 24*
6	Ranking of sustainability impacts	Determining the relative importance of various impacts associated with sustainability principles while taking into account factors such as irreversible effects allows a framework to deal more effectively and consistently with value conflicts and trade-offs. Conceptualization should include a strong, yet nuanced normative framework to allow the placement of certain indicators at a higher level (*5*) [e.g., the nested model (*12*)]. The need for a refined sustainability model is further discussed in the text.	I-19	*3, 5, 12* See also *28, 35*
7	Informing strategic sustainable transport choices	The conceptualization should include transportation-specific sustainability goals and impacts as well as strategic options and levers for sustainable transport planning. This should include guidance to help differentiate between higher and lower impacts of targets and measures towards a sustainable transport paradigm (*1*). This can allow for objective ways to decide among alternative policies (*5*). What this may include is shortly introduced in the text.	I-6 I-7 I-8	*5, 12* See also *1, 28, 33*
Operationalization				
1	Creating an indicator system logic based on an understanding of linkages	Sustainable transportation indicator systems should be designed to make explicit causal chains from driving forces to final impacts (*1, 22, 27*). Depending on the particular planning context, decision-support tasks, and intended indicator applications, the system logic may emphasize linkages to strategic policy objectives, agency actions (processes), changes (outputs), intermediate and key outcomes (goals) (*2, 3, 12, 25*). Pressure–state–response or similar root cause analysis and influence diagramming tools can be used to highlight such linkages (*4, 25, 28*).	I-11	*2–5, 12, 14, 22* See also *1, 9, 25, 27, 28*
2	Supporting well founded target setting	When connected to transport models and other prospective tools and methods, indicators can support a process of condensing visions and goals to more tangible and evidence-based targets (*3*). The use of forecasting models, trends interpolation, or scenarios based on long term visions may allow to fix the relationship between indicators and enable more effective planning to break the status quo (*5, 22*).	I-13	*3, 5, 22*
3	Supporting integrated assessment	Decision making based on a comprehensive view of a wide range of impacts requires a mechanism for integration across indicators. Aggregation or monetization are sometimes used, but bear the risk of concealing meaningful data, double counting of impacts, or importing hidden value judgments (*3, 5, 14*). A cautious option is to keep outputs in their natural units and avoid weighting, summing or other transformations (2). Another example is the use of disaggregate geographical information (GIS tools) as a way to allow assessment with sensitivity to spatial scales where necessary (*26*).	—	*2, 3, 5, 14* See also *9, 26, 28, 29*

(continued)

TABLE 1 *(continued)* **Sustainable Transport Indicator Framework Criteria**

Number	Criterion	Summary of Rationale	Factor[a]	References[b]
4	Ensuring cost-effectiveness of monitoring	Comprehensiveness is limited by the costs of data collection, which implies a general requirement for data availability, timeliness (including periodical updates), level of detail, and ease of measurement (*2–4*). Coordinating the collection of common indicators is one suggested approach (*3*). More innovative approaches may include crowdsourcing (involving the public in collecting or analyzing data, such as livability measures or noise levels) or big data (combining data from various sources such as mobile network operators and transport service providers to track travel behaviors) or both.	—	*2–4*
5	Making the framing process explicit and transparent	Various processes have been proposed to integrate the steps in building an indicator framework (*3, 12*). Some are mostly expert based, while others involve stakeholders or policy makers in an iterative validation process. An explicit and transparent indicator framing process can be expected to increase the appreciation and acceptance of the information provided.	I-9	*3, 12, 14, 22, 23*
6	Applying indicator selection quality criteria	Sustainable transportation indicators support a range of descriptive, analytic, evaluative and communicative purposes. Many quality criteria for individual indicator selection have been proposed, inter alia: representation validity, sensitivity to changes, responsiveness to trends and cumulative impacts, reliability, measurability, data availability, comparability, interpretability, transparency, noncorruptibility, target relevance, and actionability (*3, 4, 14*). These criteria can guide choices for selecting indicator types (nominal, quantitative, qualitative), their level of aggregation (absolute, relative, index) and where in the causal chain they should be placed (causes versus symptoms) (*19*).	I-16	*3, 4, 14, 22* See also *19, 28*
Utilization				
1	Connecting to goals and strategies	A widely emphasized criterion is connecting the framework to the visions, goals, and policies of the agency or sets of bodies governing the transport system. This should also involve connecting it to new goals adopted as part of sustainability planning processes. Long-term visions and scenario-based methods may help to produce more robust outcomes (*5, 22*). This gives a rationale between agency actions and desired outcomes (*2*).	I-14 I-13	*2, 4, 5, 12, 14, 22, 23* See also *25, 29, 30*
2	Integrating vertically	Tying indicator sets between different levels of agency control into a common framework allows more effectiveness (*2, 12*). Enabling a more unified framework requires both top-down and bottom-up approaches, from the level of the whole agency and by specific business units (*12*). Integrating with higher levels of governance (outside an agency) into a hierarchy of plans, performance measures and reporting allows to unify strategic and operational decisions in support of sustainability (*22*).	I-29 I-27 I-12	*2, 12, 22, 23* See also *9, 27–29*
3	Integrating horizontally	Because of the overlap of sustainability aspects across sectors and spatial scales (*22*), interagency cooperation and coordinated reporting initiatives may allow synergy in the design of more coherent policies as well as managing unintended effects on other sectors (for example on health or the environment) (*12*).	I-22 I-23	*2, 12, 22* See also *9, 27, 29*
4	Engaging with stakeholders and context	Taking into consideration the local context via stakeholder input is considered a vital part of indicator framework development. It may include debates on how best to connect monitoring with sustainable transport goals (*3, 12*) or how to connect stakeholder concepts of sustainable transport with agency goals (*2*). Avoiding top-down predefinition may also allow for stakeholder awareness and buy-in (*23*).	I-26	*2, 3, 12, 14, 23* See also *9, 20*
5	Communicating externally	To allow communication with the general public, indicator sets should include measures that correspond with the public's expectations and own experience (*3*). Indicators of progress against targets (*3*) or indicators highlighting distributive effects may increase the relevance and buy-in by politicians (*5*).	I-20	*3, 5* See also *6, 26*
6	Aligning with agency capabilities and constraints	Taking into consideration the agency context in terms of mandate, capabilities, and constraints allows for more realistic goals and measures to be established and achieved (*2*). It is suggested to connect to specific agency focus areas and business units (*12*) and to consider the skills required to collect and analyze data.	I-11 I-30	*2, 12, 23* See also *20, 29*
7	Leadership for adapting to and enabling change	Use of indicators may not automatically mean influence on policies or processes (*6*). Entrepreneurial, proactive and innovative leadership is required to support the role of indicator frameworks towards a sustainable transport paradigm (*12, 23*). Enablers of transition may include engaging with the private sector in creating funding regimes (such as public–private partnerships), investing in and experimenting innovative solutions, developing partnerships for coordinating efforts and building legitimacy, being opportunistic about advantageous conditions for change (*22, 23*), and passing supportive laws (*12, 22*). This criterion is further exemplified in the text.	I-28 I-24 I-17 I-18	*12, 22, 23* See also *6*
8	Providing periodic feedback	Periodic feedback allows for adapting to contextual changes, fine-tuning the indicator framework, fostering self-learning (*2*) and continual improvements through the critical role of education (*1*).	I-25 I-31 I-32	*2, 12, 23* See also *1*

NOTE: — = no assessment factors could be ascribed to this criterion; GIS = geographic information system.
[a]Examples of factors to look for in existing frameworks are extracted from Barrella et al. (*13*).
[b]References do not necessarily reflect every part of the description, but rather broadly contributed to the understanding of the criteria. References under "See also" refer to selected non-TRR papers.

research was conducted in close collaboration with a defined user group, which represented national agencies and consultancies in the practice field. The metaframework presented here is, however, not intended as direct guidance for practitioners. The main aim of the metaframework is to support empirical research in actual practice and in frameworks adopted by transportation agencies, including the level of guidance that the (explicit or implicit) frameworks provide in terms of the full set of framework functions. It is thus an analytic tool to metaevaluate existing practice frameworks. The resultant analysis will support the development of guidance to improve practice.

THEORY

This section briefly presents the theoretical understanding of sustainability, complexity, and indicators that in general informed this research. The notion of frameworks then is explored in more depth before the paper elaborates on the three metaframework functions.

Overall Understanding

In this present research, sustainable transportation was envisaged as embedded within the wider notion of sustainable development, whose overarching aim was the comprehensive, fair, and persistent improvement of human well-being, which considered social, economic, and environmental conditions. It thus becomes clear why the measurement of progress toward sustainable transportation is not trivial. It involves highly complex interrelations between systems (e.g., transportation, economy, technology, society, environment, governance) and drivers such as quality of life and distributional considerations. These interrelations are not well understood, especially if a longer time horizon is adopted. When the proper measurement of progress in society is an ongoing topic for social and scientific debate (*10*), it is not to be expected that a sustainable transportation equation can easily be found. Yet to deal with sustainability in transportation in a random fashion is not the solution, given the potential for further environmental degradation, and given the potential societal benefits to be had from transformation and improvement in systems.

Within such a vision, the measurement of progress toward sustainable transportation should rely on a broad set of indicators, understood as variables selected to represent the partly hidden phenomena of sustainability in transportation. They should be measurable in corresponding values and support understanding or action. Indicators can be depicted as approximations and as boundary objects that ideally form a bridge between science and policy deliberation (*11*). Potential risks that arise from reliance on this instrument have been identified, (e.g., inadequate conceptualization, lack of resources to collect necessary data, nonuse, symbolic use, distorted use of indicators in decision making) (*5, 6*).

Concept of Frameworks

Several comprehensive reviews, such as the one by Jeon and Amekudzi, showed a wide variety of frameworks in practical use to organize sustainability indicators in some logical fashion (*1*). However, ideas differed in the theoretical literature of what a framework was and what its functions were to measure sustainable transportation. Ramani et al. provided a comprehensive framework for sustainability assessment intended for direct application in U.S. transportation agencies (*12*). Barrella et al. provided a framework to enable agencies to self-assess their practices from a sustainability point of view (*13*). Joumard et al. focused on a framework for the construction, assessment, and use of individual indicators (*4*). Johnston was more concerned with a conceptual framework to support decision making through indicators for analysis and prioritization (*5*). Marsden et al. also spoke of a framework to select (performance) indicators but referred to the need for a wider framework for transport strategy development (*3*). Pei et al. referred to conceptual frameworks (e.g., triple bottom line) used to develop STIs, and they made suggestions for a framework to develop sustainable transportation strategies (*2*). Litman was one of the few to provide a definition of indicator frameworks, which were understood to be conceptual structures that linked indicators to a theory, purpose, or planning process (*14*).

The following section combines several of these aspects to provide a metaframework to evaluate STI frameworks.

Framework Functions

At a general level, in this paper a framework is understood as an abstraction: a type of mental and communicative construct to help build a coherent world view. A framework is not always visible to the user, but a framework for the use of indicators in a decision-making context should be designed in a conscious, communicative process (*15*). Assmuth and Hildén defined frameworks as "the conceptual and procedural constructs that assimilate, process, and give meaning to information" (*16,* p. 73). This definition highlights two dimensions to help frameworks precisely to become such constructs: (*a*) the conceptual dimension that aims to capture the substance or essence of what is to be measured and elucidated (e.g., frameworks to measure sustainability organized in the triple bottom line domains), and (*b*) the procedural or operational dimension, which refers to more practical concerns (e.g., who needs to do what to collect, produce, and report the required information).

A third important dimension, which Assmuth and Hildén's definition does not highlight (*16*), concerns the purpose of the information, termed here as the utilization function. As reported by Ramani et al. specifically for a sustainable transport assessment, the types or combinations of indicators that are needed may not be the same for different indicator applications (e.g., decision making, communication, performance accounting) (*12*). Indicators that disregard a specific utility or purpose are likely to be misinterpreted or ignored.

Conceptualization, operationalization, and utilization are adopted here as the key functions in a metaframework for STI frameworks to be built by transportation departments or agencies (*9, 17*). In the paragraphs that follow, the three functions used in the metaframework are explained, the concept of a metaframework is defined, and its use is explained.

Conceptualization refers to the theoretical grounding of a framework (i.e., what De Neufville called theoretical validity) (*18*). Conceptualization provides an opportunity for scientific and normative consistency in the process that will drive framework and indicator design. Although conceptualization typically is theory-driven, the concept of sustainability itself evokes significant normative considerations (e.g., to take a position on desired futures, whether to adopt a strong or weak interpretation of sustainability criteria) (*17, 19*). Validation of a framework for adequate conceptualization requires verification that the selected sustainability theories are explicit and justified adequately.

Operationalization refers to the practical concerns involved in the translation of concepts into practice, procedures, tools, and indicators. This function builds on the theories and normative concepts elaborated in the conceptual function, and it considers the practical feasibility of their measurement (*17*). Operationalization involves, for example, human resources, costs, logistics, and data collection, as well as decisions on the structure, number, and aggregation level of indicators. This function may partly be data-driven but should not be purely dictated by mundane practical concerns. Operationalization also requires careful analysis of whether indicators that support a policy or a given agency action represent a stepping stone toward sustainability. Testing the operational validity of a framework involves primarily a concern for feasibility and instrumentality, while all the while a connection is ensured to the underlying concepts set forth (*18*).

Utilization, the third function, refers to the strategic implementation of the framework in its context of governance. It is strategic in that it refers to the links to the existing institutional arrangement and the various visions, strategies, and goals that institutions already are pursuing, and the indicators needed for different planning or management tasks. In other words, the utilization function is policy-driven: the function is concerned with making indicators useful for the various planning and policy applications. Utilization could also involve indicators that support transitions beyond existing policies (*20*). Under this function lies the idea that frameworks or indicators, if not used, are of little value. Validation of a framework or indicators for the utilization function involves a concern for intuitiveness [i.e., what De Neufville calls experiential validity (*18*)].

Metaframework Purpose

A metaframework is understood as an overarching frame for what should inform the analysis and eventually the design of STI practice frameworks, which mean frameworks used by or provided for transportation policy and planning bodies to select and apply indicators for sustainable transportation. The metaframework is not a general theory, nor a master framework to be adopted directly by agencies, but a classification and evaluation device. It should, above all, make it possible to structure the empirical analysis of frameworks adopted by agencies in practice. Such analysis will be done to review how the conceptual, operational, and utilization functions of a case framework are performed, and how the most important criteria for each function are fulfilled. These criteria should allow a comprehensive analysis of the strengths and weaknesses of different practical frameworks with regard to how well they manage to connect sustainability theory to action.

The empirical analysis could be directly helpful in practice. A case agency could, for example, be informed that its framework embodied a limited concept of sustainability, constrained by the use of an existing data set used for project review. Or the agency might be informed that, despite its well-integrated understanding of sustainability, its framework lacked a strategy to translate measured results into timely policy recommendations. Comparative analysis on the basis of a metaframework could identify common features and gaps, and be used as a basis to test hypotheses on how indicators influenced decisions on option generation, design, operation, maintenance, and other aspects of transportation systems. Eventually, such a metaframework should help transform sustainability measurement in transportation planning from a niche, ad hoc, or add-on activity into something like an organizing principle for transportation agencies, which was how it was formulated recently in NCHRP Report 750 (*21*).

METAFRAMEWORK DEVELOPMENT

Literature Selection

The primary literature reviewed consisted of articles published in the *Transportation Research Record.* They were complemented by select studies that dealt specifically with STI frameworks in other Institute for Scientific Information journals. The selection process consisted first of a search in Elsevier's SCOPUS bibliographic database with the following keywords: (transport* OR mobility) AND (indicator OR benchmark OR metric OR measure* OR eval*) AND (framework) AND (sustainab*). The focus of the review was on land transportation sustainability studies relevant to the design of frameworks. Consequently, contributions were excluded that focused on a narrower area of transport, such as a single impact (e.g., noise), type (e.g., freight), mode (e.g., air), scale (e.g., specific city), or tool (e.g., GIS). Also excluded in this iteration were larger studies, doctoral theses, book chapters, and papers with no current citations. Gray literature such as existing (supra-) national STI frameworks were not considered, although the analytical approach developed could inform a complementary phase of analysis of such practice frameworks. The resultant list of reviewed papers consisted of 10 *Transportation Research Record* contributions (*2–5, 12–14, 22–24*) and another nine complementary papers (*1, 9, 20, 25–30*).

Method

In the review, characteristics for robust indicator frameworks were first collected and evaluated in terms of their significance for the three functions of conceptualization, operationalization, and utilization. Because Pei et al. proposed the most extensive and explicit list of characteristics for an STI framework, their study was useful to illustrate the approach to build a metaframework (*2*). The evaluation method applied was qualitative, and the scoring method used is illustrated in Table 2, which shows the evaluation of Pei et al. The fact that most criteria in this example had some relevance to all functions underscored that the functions were interrelated and could not easily be ascribed to strictly one of the three functions. For example, conceptual choices may raise operational difficulties, utilization aspects may influence operational choices, and operational or utilization constraints may obscure or force the reconsideration of conceptual choices. Each criterion was allocated to the function for which it was likely to have the most relevance.

Additional characteristics were extracted through the review of the remaining papers. In this process, a characteristic was accepted as a potential criterion if at least three papers in the *Transportation Research Record* addressed it. Characteristics identified in fewer than three papers were either put aside, merged with a similar one, or included if enough support was provided by the complementary papers. Consideration also was given as to whether a characteristic was explored in-depth or simply mentioned in passing.

Finally, to provide examples of which features to look for when a criterion is used in empirical research, Table 1, fourth column, refers to a classification system proposed by Barrella et al., who defined a set of internal factors that were found to be well-matched to the metaframework criteria and could serve as preliminary checklists to help practitioners understand what fulfillment of a criterion might entail (*13*). Although these examples apply to the agency level in general and not necessarily to performance measurement systems, they lay the groundwork for the use of such STI frameworks. Some

TABLE 2 Attributions of Framework Criteria to Key Framework Functions

Characteristic for Robust Indicator Framework[a]	Key Framework Function		
	Conceptualization	Operationalization	Utilization
Comprehensive, holistic, and balanced view of sustainability	***	**	*
Connection to goals and objectives	**	*	***
Vertical and horizontal integration	*	**	***
Capturing the effects of interactions and identifying trade-offs	*	***	**
Reflecting stakeholder perspectives	*	**	***
Consideration for agency and stakeholder capacity and constraints	*	**	***
Flexibility and fostering learning	*	**	***

NOTE: ***primary challenge; **has implications for; *inspired or driven by factors.
[a]From Pei et al. (*2*).

examples and discussion of these assessment factors are provided in the section of this paper that describes the three key criteria. However, not all 32 factors could be presented in detail here.

This approach led to a list of criteria, which now forms the metaframework presented in Table 1.

CRITERIA EXEMPLIFICATION

Table 1 summarizes the rationales for all criteria, which require further explication and operationalization for empirical analysis, with relevant literature in each criterion field. It is important to avoid crude generalizations to interpret the criteria. Unfortunately, a full discussion of each criterion is not possible here. However, this section illustrates how a rich analysis could be undertaken for each criterion.

To make sustainability operational requires a meaningful underlying conceptualization. Two criteria related to the explicitness of sustainability are first explored: ranking of sustainability impacts (Criterion 6) and informing strategic transport choices (Criterion 7).

Pei et al. suggested a balance between the different dimensions of sustainability but provided no guidelines to achieve such a balance. Marsden et al. noted the "difficulty in determining the relative importance of different indicators within the monitoring framework" (*3,* p. 28). Ramani et al. suggested that a nuanced yet strong approach to sustainability might be more desirable to provide such guidance (i.e., to view the traditional three dimensions of sustainability as nested circles) (*12*). Johnston succinctly concluded: "Some normative framework that allows the aggregation of indicators or at least the placement of certain ones at a higher level in the analysis is needed." (*5,* p. 147) This statement is what Criteria 6 and 7 of the conceptualization function convey for sustainability in general and sustainable transport, respectively.

Any straightforward solutions offered to satisfy the needs presented in these comments would quite likely be contested at this point. However, some pathways for consideration follow.

Ranking of Sustainability Impacts: Brundtland Report Revisited

The following assessment factor from Barrella et al. provides an example of Criterion 6 (Table 1): "Sustainability ethics and policies are translated into *concrete guidance* for planning and project development" (emphasis added) (*13,* Table 1, p. 45). To consider what form such guidance could take, the Brundtland Report was consulted (*31*). Published in 1987, this report, named for the chair of the commission appointed by the United Nations to produce it, helped to popularize the term "sustainable development."

Besides the report's oft-quoted definition of sustainable development, an alternative definition also was offered: "In essence, sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations" (*31,* p. 45). This latter definition attests to the complexity involved in attempts to conceptualize sustainability and make it operational. It also encompasses the seven notions of sustainability recurrent in the report: change as an underlying process; environmental sustainability; economic and technological development; appropriate governance; the need for integrated and consistent action; expanded time perspective with concern for both the present and the long term; and the overarching social objective "to meet human needs and aspirations" (*31,* p. 45). Although this last anthropocentric concern forms the basic, normative ethics of the report, a closer reading of its 400 pages reveals a strong analytical basis and a large number of strategic implications that can inform Criteria 6 on the ranking of notions of sustainability.

In the report, the language used to address essential human needs, particularly those of the world's poor, possibly was the strongest and the clearest. A number of paragraphs describe what can be called the paradox of poverty: how poverty contributes to a vicious cycle of environmental degradation, detrimental health impacts, and general vulnerability, which in turn contributes to a further gap between rich and poor (*31,* Ch. 1.3, 1.8, 1.14; 2.42; 5.36). As a result, the Brundtland Report placed present-generation human needs as primary objects of concern, as well as social justice (equity) within and among nations, with a clear focus on enabling poor households to meet minimum consumption standards (*31,* Ch. 2.26, 2.43; 3.7).

The report was prescriptive on the role of economic growth to combat poverty and to meet essential needs (*31,* Ch. 1.49; 2.6, 2.29–33, 2.37). However, it did not seem to endorse the environmental Kuznets curve theory, which stipulates that, as income per capita grows, environmental impacts first increase and then decrease in an inverted "U" shape. On the contrary, this theory can be termed the paradox of affluence (i.e., increased income per capita, past a certain point, leads to increased environmental impacts, often on a global scale and long term in nature). A certain level of economic growth was necessary to provide for basic human needs. Once this level was reached, however, the Brundtland Commission committed to the preservation of nature's life support systems over quantitative economic growth, and called for what the report termed the "quality" of economic growth (*31,* Ch. 2.35). As a result, with respect to more affluent populations, the Brundtland Report was clear on the need to bring lifestyles and patterns of behavior (i.e., levels of consumption, energy, and resource use) in line with the planet's ecological means with regard to long-term sustainability (*31,* Ch. 1.45; 2.5, 2.42). This condition was refined by the recognition that environmental limits depended on the state of technology, social organization, and the capability of the biosphere to absorb the effects of human activities.

The report was as prescriptive on the role of technology as it was on economic growth. Both were considered important means, and both faced the same constraints. The orientation of technology development needed to change to take fuller account of environmental factors (*31,* Ch. 2.65, 2.67). For industrialized countries, such as Denmark, preservation of the basic overall integrity of natural systems that supported life was concluded to be a minimum requirement for sustainable development (i.e., what Langhelle called the Brundtland Report's proviso of sustainability, Ch. 2.9) (*32*).

Figure 1 summarizes the two overarching priorities of sustainable development as seen from the Brundtland Commission's perspective: (*a*) satisfy basic human needs and (*b*) safeguard long-term ecological sustainability.

Although this initial model was fairly high level, the seven notions of sustainability presented were further detailed in the report, which provides additional guidance to address and evaluate trade-offs. For example, not all environmental aspects operate within the same time or spatial scales. Thus different types of natural capital command different treatment. Some (e.g., the protection of an endangered species and its ecosystem) or a planetary boundary (e.g., the ozone layer) indicate that some environmental protection cannot be easily traded, or substituted for, by benefits in other dimensions. To achieve environmental sustainability, the report suggested that each type of environmental capital be addressed strategically, namely through regeneration of renewable capital (*31,* Ch. 2.11), substitution of non-renewables (*31,* Ch. 2.12), compliance with thresholds for wastes and emissions (*31,* Ch. 2.9, 2.10), precaution with respect to irreversible capital (*31,* Ch. 2.13), and consideration for systemwide effects and integrity (*31,* Ch. 1.23; 2.11, 2.14).

Thus a more thorough reading of the Brundtland Report provided clues as to what weight, rank, or status different indicators could be given in a particular context. Whereas the triple bottom line approach would typically rank all three dimensions as equal, a Brundtland framing would consider the significance of indicators to take into account different sustainability aspects in more detail.

To refer to it here is not to say, however, that the Brundtland Report ought to be the authoritative guide to indicator selection, aggregation, or the weighting process toward a sustainable transport paradigm. Some of the notions presented in the report can be found in the literature reviewed for this present study. For example, Johnston raised the need and presented an overall theory of well-being as an anthropocentric basis of sustainability and, on the basis of the concept of genuine wealth and genuine savings, was aligned with the Brundtland Report on the need to more fully internalize natural capital into economic development (*5*). Quality of life, issues of equity within and between generations, and preservation of ecological integrity also are recurrent principles in the literature (*12, 14, 22, 25*). However, aside from Johnston, no clear principles for prioritization or weighting are suggested, and the role of economic development often is assumed, rather than clarified as it is in the Brundtland Report. Other approaches (e.g., the planetary boundaries concept; the natural step principles of sustainability) also exist, although they have not, as of yet, been adopted in any resolution by the United Nations General Assembly.

From the perspective of practitioners, this exploration of Criterion 6 implies that agencies should find ways to emphasize indicators that are most significant from a sustainability point of view,

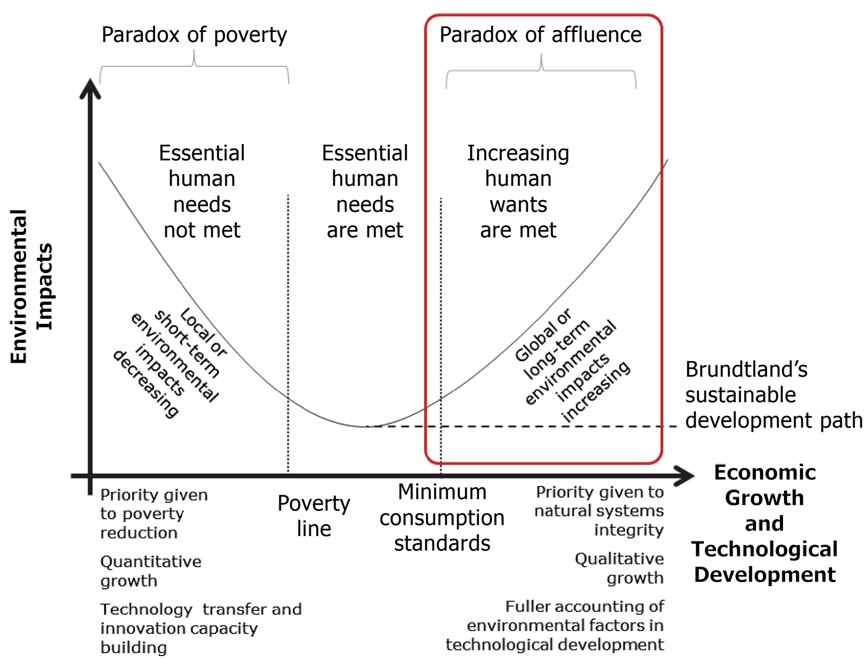


FIGURE 1 Model of sustainability on basis of Brundtland Report.

such as ones that measure the impacts on irreversible natural capital. These indicators could be included among top performance indicators at the agency level, or used to discriminate between alternatives in connection with project selection. Overall, more refined sustainability models are necessary to guide indicator framework development and avoid the pitfalls of more simplistic representations, such as the nested circles or the more common triple bottom line.

Informing Strategic Sustainable Transport Choices

Similar conclusions can be made with respect to Criterion 7. To reflect back to a complex sustainability model for indicator selection might be a far fetch for most transport agencies, and thus suggests the need for a conceptual middle layer in line with general sustainability paradigms, theories, and norms. This middle layer could consist of sustainable transport definitions, strategic levers relevant for transport policy and transport planning, goals, norms, models, lists of impacts, or actual indicators. Further exploration of this area is outside the scope of this paper. However, numerous pathways exist, such as the following:

- Definitions. The commonly accepted definition of sustainable transportation by the Centre for Sustainable Transportation of Canada, Winnipeg, Manitoba, or its equivalent version by the European Conference of Ministers of Transport, Paris;
- Strategies. The avoid–shift–improve strategies often used (under different names) in the literature;
- Paradigms. The priority given to accessibility and active modes of transport in the seminal sustainable mobility paradigm developed by Banister (*33*);
- Policy measures. The relevance of policy packaging to create synergy in the implementation of sustainable transport (*34*);
- Norms. The general conclusion in much of the sustainable transportation literature (sometimes implied, often stated) that automobile dependence ought to be addressed as a first priority; and
- Lists. The more detailed compilations of sustainable transportation impacts and goals, as expanded on by the research reviewed here.

As an example of a checklist to evaluate agencies with respect to Criterion 7, the following three assessment factors by Barrella et al. are proposed (emphasis added): "Policies and system planning *emphasize* multimodal investment and integration of modes to achieve a sustainable transportation system" (assessment factor I-6); "Policies and system planning *prioritize* maintenance and rehabilitation of existing infrastructure" (I-7); and "Policies and system planning *promote* operational improvements and demand management (e.g., [intelligent transportation system] ITS, variable tolling, [vehicle miles traveled] VMT reduction) over new capital investment" (I-8) (*13,* Table 1, p. 45).

The emphasis was added to the quotations from Barrella et al. to show how some sustainable transportation-specific actions are to be prioritized over others. It is the purpose of the explicit sustainable transportation conceptual middle layer suggested here to inform such prioritization in a contextually relevant manner.

How to connect these sustainable transportation pathways more clearly to theories and principles of sustainability, on the one hand, and to checklists to guide the practice, on the other, would be useful pursuits for future research. This work has already begun. For example, Holden et al. recently revisited the Brundtland Report in their provision of four main and secondary dimensions of sustainable development for the selection and prioritization of passenger transport indicators (*35*).

Leadership for Adapting to and Enabling Change

Like the conceptualization function, the utilization function may be particularly challenging to make operational, because it relates to factors that stretch farther away from the immediate concern of sustainable transportation frameworks. However, both functions are equally relevant to the use, or the nonuse, of performance measures. The previous two example criteria explored qualitative considerations toward the definition of more operational categories or checklists for the empirical phase. Here Criterion 7 for the utilization function (i.e., leadership for adapting to and enabling change) is described briefly.

Again, some of the assessment factors of Barrella et al. are useful (*13*). One suggested factor addresses the role and importance of an agency's leadership: "Sustainability is supported by executives and managers at all levels and across units as demonstrated by performance evaluations" (assessment factor I-28). This factor implies that an effective sustainable transportation framework should receive management support and not, for example, exist only as a silo within one dedicated organization. Two more factors refer to the financial outcome of such leadership: "Percentage of funds allocated for transit, bicycle, pedestrian, and other more sustainable modes" (I-17) and "Percentage of funds allocated for operating and maintaining existing infrastructure" (I-18). Those factors refer to a finer understanding of sustainable transportation as already discussed with respect to Criterion 7 for the conceptualization function, as well as potential revised priorities from a better informed and supportive leadership.

Development of checklists to assess this criterion would require further research, and could lead, for example, to the establishment of a clearer understanding of the role and commitment of managerial and political leadership, and how they affected the use of sustainable transportation in practice.

DISCUSSION OF RESULTS

This section presents what was learned from the experience of building the metaframework and conclusions from the challenges that arose in this process. These lessons relate primarily to the assumption of an existing broader transport policy or strategic process and its relation to the indicator metaframework.

The selected papers used in this study contributed to different functions of the metaframework and represented various levels of ambition as to sustainability and comprehensiveness. Some contributed more explicitly to the conceptualization function (*5, 23*), some to the operational function (*4, 14*), some to the utilization function (*2*), and others addressed more than one function (*3, 12*). The three functions were intended to support this first level of categorization of the extracted criteria. However, other ways of seeing things (i.e., dimensions or lenses) exist. For example, levels of governance differ. Some of the research reviewed clearly focused on transportation agencies (and their potential leverage), while other studies referred to the wider process of transport governance at a more general level. Some research defined sustainability in terms of what was achievable by a specific business unit within a transportation agency, which was itself within a specific national context, whereas others took a helicopter view on the basis of general principles of sustainability or sustainable transportation. The literature thus indicated that there was scope to expand the metaframework to accommodate further dimensions not considered here.

Further, some research clearly embedded the indicator selection process within the higher-level planning process of goal and strategy definition (*3, 12*), while other studies took a wider process for granted and considered it external (*4, 14*). This variation raised a question: to what extent should the metaframework tackle issues that traditionally fall outside the more practical scope of indicator selection? In the case of Criterion 1 for the utilization function, performance measures tied indicator selection to goal development, which already was well demonstrated in the reviewed literature. This criterion does not require an agency indicator framework to contain guidance on how to create sustainability goals per se, but it does require that such processes exist, along with a commitment to plan for sustainable transportation. The same can be said for most conceptualization and utilization criteria, which tend to fall farther outside the obvious scope of indicator frameworks. As demonstrated by the sustainability explicitness criterion, the assessment of those softer criteria revealed the difficulty of the requirement that the metaframework provide specific assessment methods (and an accompanying grading system) for each.

Rather than a recipe to be applied directly by agencies, the metaframework is first and foremost a scheme by which to conduct further empirical analysis of existing frameworks. The next step is to refine and apply the criteria through empirical analysis of how frameworks have been developed and used in real world conditions. Eventually, this process will lead to the construction of a robust set of criteria on the bases of theory as well as realism.

CONCLUDING REMARKS

As Banister noted in a reference to failed attempts at effectively planning for sustainable transportation, a schizophrenic path occurs when “it is clear that action is needed but no effective action is taken to remedy the solution” (*33,* p. 74).

The assumption of this study was that the potential role of indicator frameworks, if designed and embedded properly, could guide agency strategies and practices to bridge this implementation gap. The perspective taken had its basis in an explicit framework theory, and it was found that the three functions of conceptualization, operationalization, and utilization provided a logical structure of complementary features to use to build indicator frameworks that could support a transition toward sustainable transportation, not as a separate theoretical or practical exercise, but as part of the same process that focused on the potential influence of indicators in decision making and governance.

Through the use of this approach, a review of recent contributions to the literature allowed for the collation of a set of disparate criteria into a type of metaframework to be used in subsequent empirical analyses. The diversity of the literature provided extensive guidance on the creation of such a framework. However, some possible improvements also presented themselves.

First, the metaframework suggested an ambitious approach if all criteria were to be fulfilled in practice. Few agencies would likely be prepared to build indicators with maximum fulfillment in all categories. Guidance that took into account the disparity of contexts and governance levels would be helpful to create priorities in this respect, and the empirical analysis would explore how agencies were meeting this challenge.

Second, criteria were found to have implications for more than one function, and it would be useful to explore this interaction further in empirical studies of agency practice. One example would be the potential clash between ideal, theory-based conceptualizations versus the implications for indicator systems from strongly utilization-focused policy applications (e.g., innovation, green economy initiatives).

Third, an observation previously made in the literature was noted again, namely that effective indicator systems were likely to be the ones that emerged from strategic sustainability planning, rather than from mere indicator building exercises. Such a strategic context should likely provide stronger support to conceptualization as well as to utilization, and should also bolster efforts to attract human resources and funding to the operational function.

In this context, conceptualization must be seen as a potentially significant element in the building of a system that supports decision making grounded in sustainability, rather than simply one that maps out possible topics for measurement. Empirical examination of the extent to which agencies make use of the strong decision-support capacities embedded in the original concepts of sustainability and sustainable transportation should become a key theme.

The metaframework is thus proposed as a foundation for future empirical work within the scope of the SUSTAIN project in collaboration with international research partners.

ACKNOWLEDGMENTS

The authors are grateful to the Strategic Research Council of Denmark for its support of the SUSTAIN research project. The authors thank SUSTAIN project partners, the user group, and colleagues at the Technical University of Denmark and Copenhagen Business School for valuable discussions and inspiration. The authors also thank four anonymous reviewers for their insights and helpful comments.

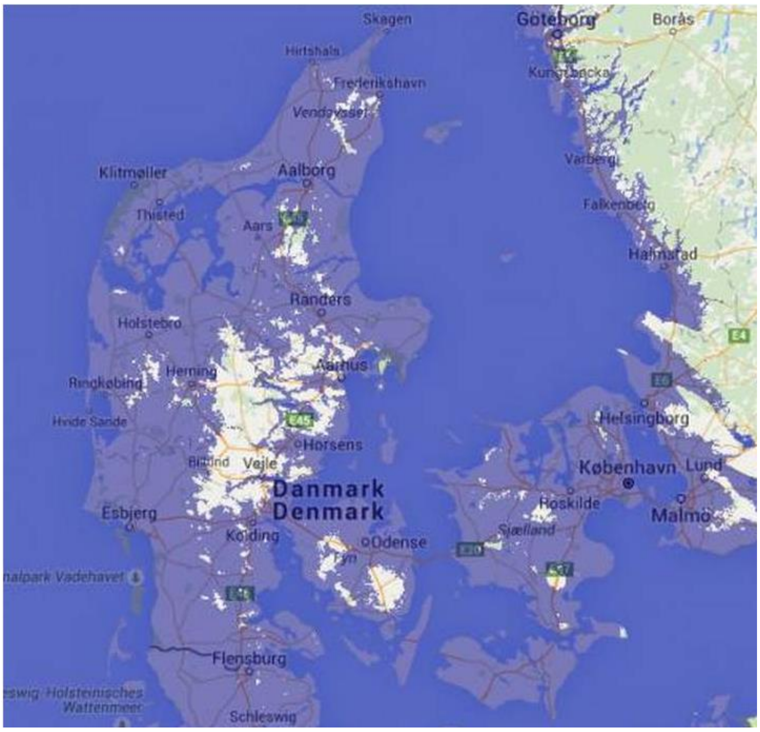
REFERENCES

1. Jeon, C. M., and A. Amekudzi. Addressing Sustainability in Transportation Systems: Definitions, Indicators, and Metrics. *Journal of Infrastructure Systems,* Vol. 11, No. 1, 2005, pp. 31–50.
2. Pei, Y. L., A. A. Amekudzi, M. D. Meyer, E. M. Barrella, and C. L. Ross. Performance Measurement Frameworks and Development of Effective Sustainable Transport Strategies and Indicators. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2163,* Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 73–80.
3. Marsden, G., C. Kelly, and C. Snell. Selecting Indicators for Strategic Performance Management. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1956,* Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 21–29.
4. Joumard, R., H. Gudmundsson, and L. Folkeson. Framework for Assessing Indicators of Environmental Impacts in the Transport Sector. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2242,* Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 55–63.
5. Johnston, R. A. Indicators for Sustainable Transportation Planning. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2067,* Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 146–154.

6. Gudmundsson, H., and C. Sørensen. Some Use—Little Influence? On the Roles of Indicators in European Sustainable Transport Policy. *Ecological Indicators,* No. 35, 2013, pp. 43–51.
7. Lyytimäki, J., P. Tapio, V. Varho, and T. Söderman. The Use, Non-Use, and Misuse of Indicators in Sustainability Assessment and Communication. *International Journal of Sustainable Development and World Ecology,* Vol. 20, No. 5, 2013, pp. 385–393.
8. Hezri, A. A., and S. R. Dovers. Sustainability Indicators, Policy and Governance: Issues for Ecological Economics. *Ecological Economics,* Vol. 60, No. 1, 2006, pp. 86–99.
9. Gudmundsson, H. Sustainable Transport and Performance Indicators. In *Issues in Environmental and Technology* (R.E. Hester and R.M. Harrison, eds.), Vol. 20, Transport and the Environment, Royal Society of Chemistry, Cambridge, United Kingdom, 2004, pp. 35–64.
10. Stiglitz, J. E., A. Sen, and J.-P. Fitoussi. Report by the Commission on the Measurement of Economic Performance and Social Progress. *SSRN Electronic Journal,* 2010. https://www.vorarlberg.at/pdf/berichtderstiglitz-kommis.pdf.
11. Turnhout, E., M. Hisschemöller, and H. Eijsackers. Ecological Indicators: Between the Two Fires of Science and Policy. *Ecological Indicators,* Vol. 7, No. 2, 2007, pp. 215–228.
12. Ramani, T., J. Zietsman, H. Gudmundsson, R. P. Hall, and G. Marsden. Framework for Sustainability Assessment by Transportation Agencies. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2242,* Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 9–18.
13. Barrella, E. M., A. A. Amekudzi, and M. D. Meyer. Evaluating Sustainability Approaches of Transportation Agencies Through a Strengths, Weaknesses, Opportunities, and Threats Framework. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2357,* Transportation Research Board of the National Academies, Washington, D.C., 2013, pp. 41–49.
14. Litman, T. Developing Indicators for Comprehensive and Sustainable Transport Planning. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2017,* Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 10–15.
15. Innes, J. Information in Communicative Planning. *Journal of the American Planning Association,* Vol. 64, No. 1, 1998, pp. 52–63.
16. Assmuth, T., and M. Hildén. The Significance of Information Frameworks in Integrated Risk Assessment and Management. *Environmental Science and Policy,* Vol. 11, No. 1, 2008, pp. 71–86.
17. Sørensen, C. H., H. Gudmundsson, and S. Leleur. *National Sustainable Transport Planning—Concepts and Practice.* Working paper, Technical University of Denmark, Kongens Lyngby, 2013.
18. De Neufville, J. I. Validating Policy Indicators. *Policy Sciences,* Vol. 10, No. 2–3, 1978, pp. 171–188.
19. *Indicators of Environmental Sustainability in Transport* (R. Joumard and H. Gudmundsson, eds.). Recherches, Les collections de l'INRETS, Bron, France, 2010.
20. Gudmundsson, H., A. Wyatt, and L. Gordon. Benchmarking and Sustainable Transport Policy: Learning from the BEST Network. *Transport Reviews,* Vol. 25, No. 6, 2005, pp. 669–690.
21. *NCHRP Report 750: Sustainability as an Organizing Principle for Transportation Agencies, Vol. 4. Strategic Issues Facing Transportation.* Transportation Research Board of the National Academies, Washington, D.C., 2014.
22. Amekudzi, A. A., L. Thomas-Mobley, and C. Ross. Transportation Planning and Infrastructure Delivery in Major Cities and Megacities. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1997,* Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 17–23.
23. Maurer, L. K., T. J. Mansfield, L. B. Lane, and J. Hunkins. Blueprint for Sustainability: One Department of Transportation's Pursuit of Performance-Based Accountability. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2357,* Transportation Research Board of the National Academies, Washington, D.C., 2013, pp. 13–23.
24. Mansfield, T. J., and A. M. Hartell. Institutionalizing Sustainability at the Level of State Departments of Transportation: Qualitative Assessment of Transportation Sustainability Plan Quality. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2271,* Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 9–18.
25. Richardson, B. C. Sustainable Transport: Analysis Frameworks. *Journal of Transport Geography,* Vol. 13, No. 1, 2005, pp. 29–39.
26. Bertolini, L., F. le Clercq, and L. Kapoen. Sustainable Accessibility: A Conceptual Framework to Integrate Transport and Land Use Plan Making. Two Test Applications in the Netherlands and a Reflection on the Way Forward. *Transport Policy,* Vol. 12, No. 3, 2005, pp. 207–220.
27. Gudmundsson, H. Making Concepts Matter: Sustainable Mobility and Indicator Systems in Transport Policy. *International Social Science Journal,* Vol. 55, No. 176, 2003, pp. 199–217.
28. Black, J., A. Paez, and P. Suthanaya. Sustainable Urban Transportation: Performance Indicators and Some Analytical Approaches. *Journal of Urban Planning and Development,* Vol. 128, No. 4, 2002, pp. 184–192.
29. Marsden, G., and C. Snell. The Role of Indicators, Targets, and Monitoring in Decision-Support for Transport. *European Journal of Transport and Infrastructure Research,* Vol. 9, No. 3, 2009, pp. 219–236.
30. Meunier, D. Towards a Sustainable Development Approach in Transport Assessment. *Procedia Social and Behavioral Sciences,* Vol. 48, 2012, pp. 3065–3077.
31. World Commission on Environment and Development, United Nations. *Our Common Future,* 1987. http://www.un-documents.net/wced-ocf.htm. Accessed Feb. 14, 2013.
32. Langhelle, O. Sustainable Development: Exploring the Ethics of Our Common Future. *International Political Science Review,* Vol. 20, No. 2, 1999, pp. 129–149.
33. Banister, D. The Sustainable Mobility Paradigm. *Transport Policy,* Vol. 15, No. 2, 2008, pp. 73–80.
34. Givoni, M. Addressing Transport Policy Challenges Through Policy Packaging. *Transportation Research Part A: Policy and Practice,* Vol. 60, 2013, pp. 1–8.
35. Holden, E., K. Linnerud, and D. Banister. Sustainable Passenger Transport: Back to Brundtland. *Transportation Research Part A: Policy and Practice,* Vol. 54, 2013, pp. 67–77.

The Standing Committee on Transportation and Sustainability peer-reviewed this paper.

Article II Applying Sustainability Theory to Transport Infrastructure Assessment Using a Multiplicative AHP Decision Support Model



We may need a longer bridge after all.

Transport

ISSN: 1648-4142 (Print) 1648-3480 (Online) Journal homepage: http://www.tandfonline.com/loi/tran20

Applying sustainability theory to transport infrastructure assessment using a multiplicative ahp decision support model

Marie Ridley Pryn, Yannick Cornet & Kim Bang Salling

To cite this article: Marie Ridley Pryn, Yannick Cornet & Kim Bang Salling (2015) Applying sustainability theory to transport infrastructure assessment using a multiplicative ahp decision support model, Transport, 30:3, 330-341, DOI: 10.3846/16484142.2015.1081281

To link to this article: http://dx.doi.org/10.3846/16484142.2015.1081281

Published online: 02 Oct 2015.

TRANSPORT
ISSN 1648-4142 / eISSN 1648-3480
Special Issue on Smart and Sustainable Transport / 2015 Volume 30(3): 330–341
doi:10.3846/16484142.2015.1081281

APPLYING SUSTAINABILITY THEORY TO TRANSPORT INFRASTRUCTURE ASSESSMENT USING A MULTIPLICATIVE AHP DECISION SUPPORT MODEL

Marie Ridley Pryn*, Yannick Cornet*, Kim Bang Salling
Dept of Transport, Technical University of Denmark, Denmark

Submitted 30 November 2014; accepted 18 February 2015

Abstract. It is generally expected that the three dimensions of the economy, society and the environment must be included in any measurable sustainability pathway. However, these do not provide much guidance as to how to prioritize impacts within and between the dimensions. A conceptualized approach to sustainability based on the nested model is therefore presented seeking to provide an alternative approach to sustainable transportation assessment, namely the SUSTAIN Decision Support System (DSS) model. This model is based on a review of basic notions of sustainability presented by the Brundtland Commission report, which is used to validate the nested model of sustainability for countries operating under the paradox of affluence. This provides a theoretical rationale for prioritising longer-term ecological integrity over shorter-term economic concerns, in line with the stronger conceptualisation of sustainability supported by ecological economists. This conceptualisation is operationalized by the use of Multi-Criteria Decision Analysis (MCDA) and a multiplicative version of the Analytic Hierarchy Process (AHP). The planning and decision-making process related to a new connection across the Roskilde Fjord in Frederikssund, Denmark, is used as a case study. It is found that the SUSTAIN DSS model results provide a type of benchmark for connecting to the essence of sustainable development as well as to integrate sustainability more explicitly into the planning and assessment practice.

Keywords: sustainability; transportation; assessment; MCDA; multiplicative AHP/Rembrandt; Brundtland; Frederikssund.

Introduction

The transport area in Denmark is subject to massive investments in these years and from an official hold, there is a great focus on sustainability, green technology and modal shift towards active and public transportation as a means to reduce the level of CO_2 emissions. Accordingly, planning for sustainability has become a global trend and is becoming an integrated focus when assessing new initiatives (EC 2011). However, this focus is often lost along the process between visioning and implementing. Many policies attempt to reduce the externalities of transport, but despite this, initiatives taken tend to be isolated rather than holistically oriented and sometimes fail in meeting the visions presented (Pryn 2013). Planning for sustainable transportation has faced tremendous barriers in the form of path dependencies established by large institutional, corporate, cultural and discursive incumbents (Voß *et al.* 2009). Banister calls these planning attempts *schizophrenic paths*, since it is '*clear that action is needed but no effective action is taken to remedy the situation*' (Banister 2008).

Despite these difficulties, the three dimensions of social, economic and environmental sustainability have become a de facto starting point to conceptualize and operationalize sustainable development in transport and elsewhere (Connelly 2007; Munasinghe 1993; Lélé 1991). However, there is no common guidelines for which criteria to assess and how to balance them. The Cost-Benefit Analysis (CBA) approach has provided a way to translate impacts into comparable monetary units, although it has been found to hold certain limitations when incorporating and assessing attributes such as environmental or social issues (Banister 2008; Joumard, Nicolas 2010; Beukers *et al.* 2012). The methodology of Multi-Criteria Decision Analysis (MCDA) provides a possibility for incorporating such factors that are not easily quantifiable (Beukers *et al.* 2012).

This paper presents the SUSTAIN Decision Support System (DSS) model, which is based on an MCDA approach combined with the concept of the nested model of sustainability. This concept is proposed in the ecological economics literature, which places the three well-

Corresponding author: Marie Pryn
E-mail: *mapry@transport.dtu.dk*

*Both authors contributed equally to this paper (co-first authors) known dimensions in a certain order of priority and thereby expresses a stronger understanding of sustainable development (Joumard, Nicolas 2010).

The background for the paper is a Danish research project on national sustainable transport planning called SUSTAIN. This research is conducted in close collaboration with a defined 'user group' representing national agencies and consultancies in the practice field. The DSS model presented here is intended as direct guidance for practitioners enabling a type of sustainability benchmark when planning and assessing transportation infrastructure projects.

The following section introduces the basic notions of sustainability and the nested model. Then the DSS model is presented and tested on the case study of a new fixed link connection crossing Roskilde Fjord in the municipality of Frederikssund, Denmark. The discussion section analyses the results with regards to their implications and suggests potential improvements to the methodology. Finally, the conclusion confirms the potential of the proposed approach in setting a type of sustainability benchmark in transportation infrastructure assessment.

1. Theory

This section briefly presents the theoretical understandings of sustainability, and revisits the Brundtland report entitled 'Our Common Future' in order to provide the theoretical underpinning for prioritising the various notions of sustainable development (World Commission on Environment and Development (WCED) 1987). This review provides a basis for presenting the nested model and informing on its assumptions and potential limitations.

1.1. Sustainable Development

The three dimensions of sustainability – also sometimes called the three pillars of sustainability, or the triple-bottom line (Elkington 1999) – often consists of representing the economy, society and the environment as three equal and intersecting circles. Although interpretations for each of the three dimensions vary, at its most simple level, it is understood that addressing all three dimensions will support a process towards sustainability.

In practice, the three dimensions do not provide much guidance to planners and policy-makers as to how to prioritize between the conflicting and interacting factors that can often emerge. This concept has been criticised both for encouraging trade-offs and overlooking the interdependence of these factors (Gibson 2006). In practice, the issue of trade-offs can lead to the default prioritization of effects that can be quantified and monetized, often to the detriment of more complex and long term impacts that often characterize the social and environmental dimensions (ibid.). In order to address these limitations, the nested model is proposed as an alternative approach to conceptualising the three dimensions. The nested model, as opposed to the intersected model, depicts the three dimensions of sustainability as

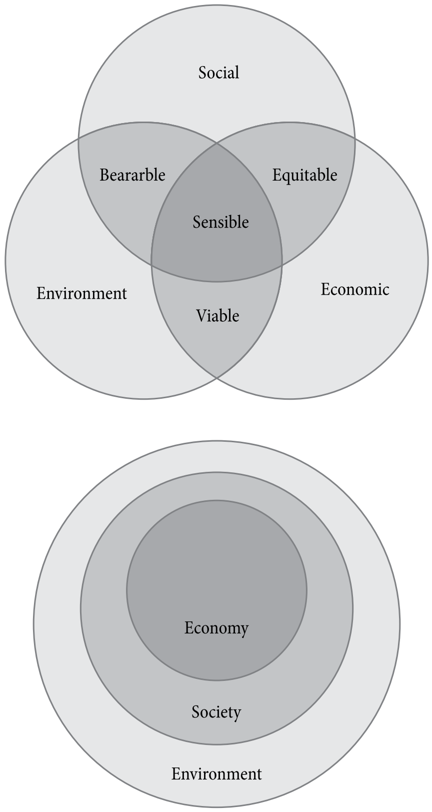


Fig. 1. Intersected and nested models of the three dimensions of sustainability

three nested spheres, where the economic circle is nested within the social circle, and the resulting socio-economic circles are in turn nested within the environmental circle. The two models are shown in Fig. 1.

In the following sections, the nested model is demonstrated to be an improvement over the intersected model by revisiting the Brundtland report. The defining elements of the Brundtland report are reviewed here in order to analyse the nested model from a theoretical perspective.

1.2. Revisiting the Brundtland Report

The Brundtland report was adopted by the United Nations General Assembly in 1987 and it is remembered for formulating the oft-quoted one-line definition of sustainable development: '*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*' (WCED 1987). Beyond this definition, the report also provides an exhaustive attempt at clarifying the concept of sustainable development as well as dealing with issues of trade-off.

The sustainable development definition above (together with the report's title) sets the normative ambition to satisfy needs and aspirations of both current and future generations, thus clearly putting the anthropological needs at its core. However, the report makes a clear distinction between what could be termed the paradox of poverty versus the paradox of affluence. For countries within the paradox of poverty, the report gives overriding priority to meeting the essential needs of the poor and to provide for minimum consumption standards. This is justified on the basis that poverty generally contributes to a vicious cycle of environmental degradation, health impacts and general vulnerability. Yet, past a certain point of income-per-capita, Brundtland warns about increasing environmental impacts, often of global scale and long-term nature (such as climate change or biodiversity loss). This can be termed the paradox of affluence. For countries within the paradox of affluence, the primary concern shifts to preserving nature's life support systems.

As a result, Brundtland is clear on the need for more affluent populations to bring their lifestyles, values, patterns of behaviour, levels of consumption, energy and resources use in line with the planet's ecological means with regard to long-term sustainability. Thus preserving the basic overall integrity of natural systems that support life is concluded to be a minimum for sustainable development, what Langhelle calls Brundtland's proviso of sustainability (Langhelle 1999).

About the economic dimension, Brundtland is prescriptive on the role of economic growth and technological development to combat poverty and meet human needs. In the paradox of affluence, quantitative economic growth is replaced by a type of growth and development that takes full account of environmental and social factors, what is termed the 'quality' of economic growth. Conceptualizing economic growth and technological development as a means to an end within social and environmental constraints also fits well with the nested model that depicts the economic dimension nested within the social and environmental circles.

Assuming Denmark is generally beyond the basic concerns of ensuring that essential needs and minimum consumption standards are met, it can be said to be operating within this paradox of affluence. The Brundtland understanding of sustainable development is summarised in Fig. 2.

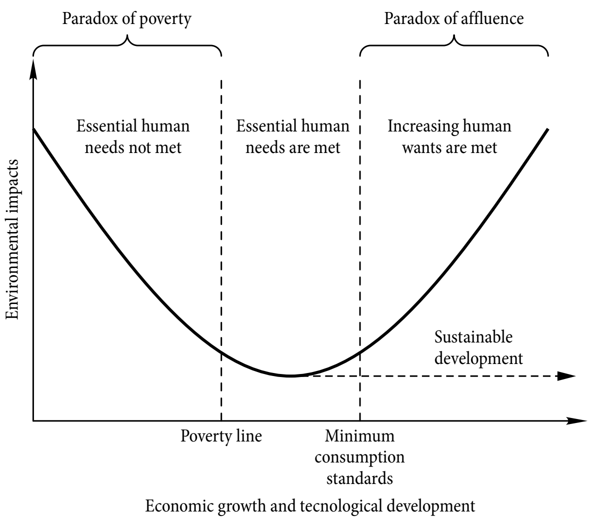


Fig. 2. Sustainable development by Brundtland, adapted from Cornet, Gudmundsson (2015)

1.3. The Nested Model of Sustainability

The nested model is a simple visual representation of the tenets presented by ecological economists such as Daly and Costanza (Daly 1990; Costanza *et al.* 1997), who distinguish between weak and strong sustainability. Weak sustainability assumes that three types of capital – natural, human and economic – can be substituted. The weak position matches the commonly used intersected model of the three equally important dimensions of sustainability, where performance in one dimension can offset reduced performance in another. The strong position on the other hand suggests that some types of natural capital – such as the ozone layer or biodiversity – cannot be substituted by man-made capital. Because such ecological systems are vital to human existence, they in fact cannot be called natural 'capital', but rather should be accounted for separately and in their own right (Daly 1990; Giddings *et al.* 2002; Hopwood *et al.* 2005). This approach brings forth the concept of irreversibility, where a small impact may in fact become very penalizing in the long term if it is irreversible (such as a species loss or an ecosystem collapse).

Consequently, rather than viewing the three circles as three distinct but complementary dimensions of sustainable development, the nested model adopts the premise that a sustainable environment is a necessary condition for a sustainable society, and that a fair and equitable society is also a necessary condition for sustaining economic activity. In other words, the model is based on the strong sustainability understanding that society and its economy can only exist within the limits and carrying capacity of natural systems, and both depend on the integrity and proper functioning of these systems. This understanding also offers a consideration of the three dimensions as operating on different temporal and geographical scales, where for example environmental impacts are considered to generally operate over longer time scales while economic impacts tend to be of shorter-term nature. Based on this, the nested model assigns a default hierarchy between the three dimensions.

The nested model has been proposed for use in both practice and academic literature, see e.g. Joumard and Nicolas (2010), The Natural Step (2014), Griggs *et al.* (2013). At a general level, the nested model can be seen as an adequate representation of the concept of sustainable development elaborated by Brundtland. The Brundtland prioritisation of ecological integrity in the paradox of affluence corresponds well with the nested model placing the environment as an outer boundary to the socio-economic circles. However, the nested model introduces simplifications that the Brundtland report can also help illuminate. The next section presents some of the assumptions behind the nested model.

1.4. Assumptions of the Nested Model

By bundling together all environmental impacts under the environmental dimension, the nested model assumes all impacts to be equally relevant, while Brundtland distinguishes between different types of natural capital. Not all-environmental capital is critical or irreversible, which implies that not all environmental criteria should receive the same treatment or priority. On this matter, Brundtland shares the views of ecological economists: *regeneration* of renewable capital, *substitution* of non-renewables, *compliance with thresholds* on wastes and emissions, *precautionary principle* for irreversible capital, and consideration for system-wide effects and *integrity*. This lack of precision in the nested model may lead to an overall over- or under-prioritisation of the environmental dimension compared to what a more fine-grained analysis would suggest.

The same argument applies to time scales. Although the nested model attempts to prioritize a longer-term horizon, not all environmental impacts belong to long-term natural processes of concern to future generations. Noise is a good example of a non-economic, yet short-term and local impact, which may not be of particular relevance to future generations or to maintaining environmental integrity.

A third related concern is the lack of 'veto' power. Although impacts on nature are given a higher priority, the fundamental assumption that the dimensions can be traded remains. If the perceived economic or social benefits of a new infrastructure project are high enough, critical or irreversible capital that contribute to the Earth's life support systems may be sacrificed nevertheless. This implies that the nested model is in fact 'weaker' than what strong sustainability and the Brundtland report call for. One way to overcome this would be to set a requirement that all three dimensions must improve for a project to be allowed to go ahead, or to give critical and irreversible capital a category of their own, as was done by Joumard and Nicolas (2010).

A last potential weakness of both the intersected and the nested models is that they only explicitly cover three dimensions of sustainability while leaving other areas implicit or external. The time dimension and the interrelationship of the dimensions are implicit in the models, while issues of governance and processes of change are considered external. For these reasons, the nested model in itself is not enough, it is meant as a tool that needs to be inscribed within a strategic planning and policy-making process. Table 1 summarises the strengths and weaknesses of the nested model of sustainability.

This section illustrated that the nested model is a useful representation of sustainability. However, similarly to the common intersected model, it is a rather simplistic representation of the full complexity of sustainable development. For this reason, the model's assumptions and potential weaknesses need to be kept in mind when operationalising it. Nevertheless the nested model brings the advantage of providing general guidance on the difficult issue of prioritisation of impacts based on a stronger understanding of the precepts of sustainability. The next section shows how the nested model can be operationalised for transportation assessment.

2. Method

This section presents the methodology for supporting decision-making adopted in this paper. The DSS model is first presented, and then three approaches for prioritising assessment criteria are elaborated before being applied to the case of an existing transportation infrastructure project.

2.1. Decision Support Model

The decision support model illustrated in Fig. 3 is designed to expand the foundation for decision-making by allowing for the systematic inclusion of impacts that are not easily quantifiable or monetized. The model introduces MCDA, which is based on value measurement using qualitative input from a ratifying group to overcome this issue.

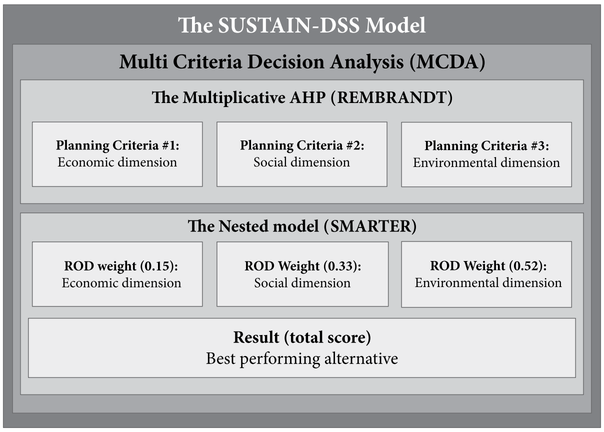


Fig. 3. A schematic overview of the SUSTAIN DSS model – here with the nested model prioritisation using Rank Order Distribution (ROD) weights, adapted from Salling, Pryn (2015)

Table 1. Nested model strengths and weaknesses

Strengths	Weaknesses
Prioritising environmental integrity is in line with Brundtland and is applicable for a rich country.	Different types of environmental capital are not explicitly considered, e.g. critical, irreversible, non-renewable or renewable.
Long-term impacts are implicitly prioritised, giving a voice to future generation concerns.	Not all environmental impacts are long term or relevant to keeping natural systems intact. Not all social or economic impacts are short term.
The existence of global or local environmental thresholds suggests an overriding priority for some environmental impacts.	Limits may still be crossed. There is no explicit 'veto' in the model. Gains between dimensions may still be traded.
All three dimensions economy – society – environment are addressed, providing a more holistic picture.	Issues of governance and change process are considered external.

The MCDA methodology extends information from a multiplicative version of the Analytic Hierarchy Process (AHP) by Saaty (2012), also known as the REMBRANDT technique, which has been proven well suited for group decision making (Lootsma 2011). As in the original AHP, the REMBRANDT technique is based on a procedure of pairwise comparisons of alternatives. The comparisons are performed by stating the preference for one alternative over another according to a semantic scale going from indifference to very strong preference expressed on a scale from 0 to 8 where 0 indicates indifference. The scale and associated preferences can be found in Appendix. For example, Alternative 1 and 2 are evaluated against each other for the first criteria, and then Alternative 1 and 3 are compared, and so on. The process is complete when all possible comparisons are made. Combining the evaluations from a range of stakeholders or experts allows building an objective evaluation of how each alternative performs with regards to each criterion.

2.2. Case-Based Prioritisation of the Criteria

A standard MCDA approach for providing a contextual ranking of the criteria is to involve stakeholders in weighting criteria against each other for their relative importance. This is done by using the same process of pairwise comparisons described above. In this way, it is possible to determine the case-based prioritisation, taking the perspective of the main stakeholders of the project (for e.g., the municipality responsible for a new transport infrastructure project implementation).

2.3. Nested Model Prioritisation of the Criteria

To align with the priorities sustainability theory suggests, the model applies the Simple Multi Attribute Rating Technique Exploiting Ranks (SMARTER), which provides a means of assigning direct weights to criteria based on an importance ranking. Predetermined surrogate weights can then be assigned directly to this ranking thereby simplifying the process for decision makers. In this paper, the Rank Order Distribution (ROD) weights are used (Roberts, Goodwin 2002).

One caveat in using ROD weights is that as the number of criteria grows, the weight given to the lowest ranked criteria becomes marginal. For this reason, the criteria within each of the three dimensions of sustainability are given equal weights in this paper, while ROD weights are applied as a whole to each of the three dimensions of sustainability. The ranking of the dimensions reflects the hierarchy suggested by the nested model presented earlier. The corresponding ROD weights are given in Fig. 3.

The main purpose of this approach is to provide a rational and objective way of weighting criteria according to the understanding of sustainability. However, for this approach to be valid, the relative *importance* of each of the criteria needs to be comparable. For example, a negligible impact on air pollution would by default be ranked higher than, say, a very large impact on costs due to the default prioritisation of environmental impacts in general. Thus, applying top-down weighting of each sustainability dimension based on sustainability theory may be considered too context insensitive. This implies that the nested model prioritisation can be used as a type of sustainability 'yardstick', but some adjustments on the default ROD weights could be permissible depending on the actual context. Alternatively, contextually relevant weights could be assigned to criteria *within* each dimension to compensate for this.

An important extension of this argumentation is that the choice of criteria needs to be representative and relevant in the given context. The process of criteria selection is explained in more detail in the case study below.

2.4. Sustainability Advocate Prioritisation of the Criteria

In order to create a comparison to the nested model, an alternative prioritisation can also be produced by returning to the standard MCDA approach of eliciting preferences from a group of stakeholders or experts, who, this time, would be taking an explicit 'sustainability advocate' perspective (Jeppesen 2009). This sustainability advocate view can be produced by answering the pairwise comparison of the criteria, this time not by taking the 'here-and-now' perspective of current stakeholders as in the case-based prioritisation above, but by taking a 'future generations' perspective. This can be informed by explicit sustainability theories or be based on experts' own understanding of sustainability.

The methodology presented here requires first that project alternatives have been determined, and second that a list of contextually relevant yet comprehensive assessment criteria exist. The section below elaborates on the case study concerning a new fixed link across Roskilde Fjord in Frederikssund. It presents the four alternatives that are considered as well as the set of planning criteria that were extracted from the original project documentation.

3. Case Study

In order to test the applicability and effect of the DSS model, it is applied on a case study concerning the decision process of constructing a new connection crossing Roskilde Fjord in the municipality of Frederikssund, Denmark. The planning of the connection has been an on-going project since the 1960's, until March 2013 when the government provided the legislative framework for a high level bridge crossing south of Frederikssund, to be funded mainly through user charges (Pryn 2013).

The current bridge has faced increasing congestion for several decades, but due to a location within a Natura 2000 protected area (*http://www.natura.org*), the construction of a new bridge has not been so straightforward. The bridge forms a local and regional link, but is not of national importance, and raising the money for a new connection has therefore been difficult (Pryn 2013). Furthermore, the growth of the city of Frederikssund

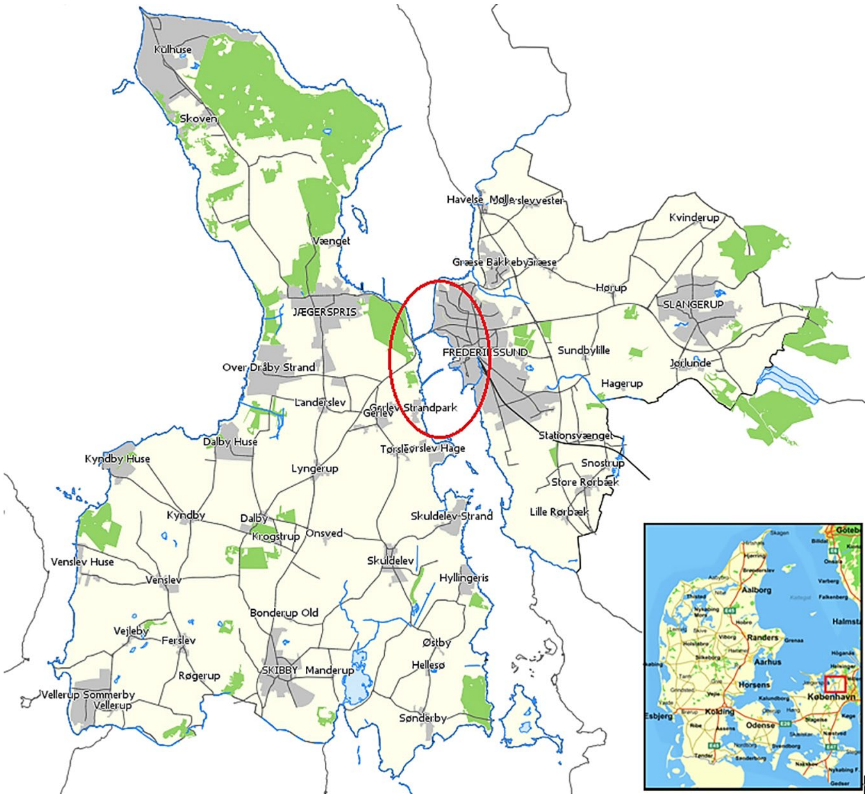


Fig. 4. Map of Frederikssund (sources: *http://infokort.frederikssund.dk/borger/kort.htm*; *http://www.krak.dk*)

over time has resulted in the bridge being situated in the very city centre, putting restraints on the possibilities for expanding the current connection. The type of solutions listed in the Environmental Impact Assessment (EIA) report are found to be similar to those proposed when the problem was first acknowledged in the 1960's (Vejdirektoratet 2010a). The case study shows that no alternatives to building a new link have been seriously considered e.g. solutions that are not car-oriented or other traffic-reducing measures. This calls for a wider set of alternatives to be considered.

3.1. Alternatives

In this paper, four alternatives are evaluated. The first two alternatives are based on the EIA and follow the conventional 'predict-and-provide' approach (Owens 1995). The final two alternatives are proposed by the authors in order to evaluate options that would support a shift to other modes than the car. The alternatives are:

- *Alternative 1* is identical to the officially decided solution and consists of a high level bridge located south of the city centre and funded through user charge;
- *Alternative 2* is an expansion of the current bridge in the city centre, also funded through user charge;
- *Alternative 3* is a light rail link established on a new bridge exploiting an existing dam construction, connecting the western peninsula with the train station in Frederikssund;
- *Alternative 4* is a service of free shuttle busses on the existing connection funded through user charge applied to other modes using the bridge.

Since Alternative 1 has already been selected for implementation, the case thereby serves to exemplify the assessment procedure of the DSS model.

3.2. Criteria

The set of assessment criteria to be used in the model intends to reflect the context as well as mirror the considerations that took place in the various stages of the planning process preceding the actual decision for the new connection. The criteria have been extracted and formulated directly based on the background literature of the case study, as well as through a coding of current trends in planning as described by Owens (1995). This combined inductive and deductive approach resulted in an explicit set of eight assessment criteria presented below.

In this case study, the assessment criteria have been particularly difficult to extract due to the various stages in the decision process. The first stage concluded with the first EIA and resulted in a recommendation for the southern high level bridge connection from the Road Directorate. The second stage of the process built upon this recommendation but was of a more economic kind. Accepting user charge as means of funding became a condition for the new connection, which led to a problematic undermining of many of the assessments made in the first stage (for e.g. due to changed forecasts in terms of expected traffic). This also meant that the criteria planned for in the first stage changed importance in the second. The traffic-related impacts and the extent of environmental impacts would naturally change under the new conditions, but no new assessment was conducted to investigate the scale of this change.

However, it seems without doubt that both the increased mobility and the economic viability of the project received high priority throughout the planning process and constituted main elements in the basis for decision. They are therefore included in the set of assessment criteria, where the economic viability is assessed based on the infrastructure and operations costs.

Based on the EIA and public hearings, the impacts of major concerns to both residents and politicians were noise and air pollution (Vejdirektoratet 2010a, 2010b). They are therefore included in the set of assessment criteria. In relation to air pollution, impacts on the climate and global warming are conspicuous by their absence in the assessment. Increases in CO_2 levels are stated in the EIA, but no actions to reduce the levels are suggested. Consequently, it becomes clear that immediate, short-term impacts with a direct incidence on the local population were of a much higher concern than the distant, global, less tangible impacts like climate change. For this reason, 'CO_2 emissions' is not included as an explicit criterion, but because it is likely to be highly correlated to air pollution, one can consider this criterion to act as a valid proxy for climate change impacts in general.

Due to the very unique and characteristic nature of the fjord and its surroundings which constitute a significant part of the identity of the area, any harm done to nature was not only of general environmental concern, but also of local concern. Local biodiversity impacts are thus included as well as a criterion about 'built aesthetics and identity'. The project was expected to meet and if possible enhance these characteristics as a part of the local identity. This was an important argument presented by contractors, which was adopted by local politicians (Roskilde Fjord – Ny fast… 2005).

The technical characteristics of the project (such as road capacity and speed) are part of meeting expected road traffic demand and thereby future proofing the project. This criterion supports the notion of speed and private motoring being desirable objectives, but also reveals the paradox and conflicts between some of the planning objectives: increasing speeds and relieving congestion can be considered to benefit time savings for car users, but it also constrains future mobility choices (Owens 1995).

Finally, accessibility within the municipality has been a strong and stated argument for increasing road capacity, and should be seen in the context of achieving a coherent municipality. On the other hand, this type of accessibility is limited to those able or willing to drive and own a car, while other socio-economic groups may not benefit directly.

Based on this review process, the final set of criteria used for the assessment of the four alternatives are summarised in Table 2.

These eight criteria reflect the foundation for the decision-making done in the case study. The assessment of each alternative used here as well as the weighting of the criteria for the case-based and the sustainability

Table 2. Final set of assessment criteria

No	Criteria	Description
C1	Transportation and mobility	This criterion relates to the expected mobility improvements for the current users as well as co-benefits for goods transportation. It includes the expected time-saving gains, reachable distances (such as 30 min isochrones), and potential to relieve congestion. It should also consider users' travel costs, which in this specific case include potential user charges where applicable.
C2	Infrastructure and operations costs	This criterion includes the direct costs consisting of the construction costs, vehicles costs (in the case of a public transport alternative), operation and maintenance, and decommissioning. The criterion also considers risks related to the feasibility or complexity of the project, whether new technology is required etc.
C3	Noise exposure	This criterion is concerned with annoyances from noise arising from the use phase of the project. This criterion does *not* include noise as an impact to wildlife.
C4	Air pollution	This criterion refers to perceivable local air pollution such as fine particulates and other health-related emissions.
C5	Local biodiversity impacts	This criterion encompasses all damages on nature with particular focus on the risk for irreversible damages to the local fjord ecosystem. This includes impacts on water flow, bird life, wildlife, the marine environment, underground water, soil etc.
C6	Built aesthetics and identity	This criterion refers to the contribution of the project to creating a sense of identity to the region as well as adapting aesthetically to the surrounding built environment.
C7	Traffic demand and future proofing	This criterion relates more specifically to the project's expected ability to absorb expected future growth in *vehicular traffic* based on current forecasts and modelling practices. In this case future proofing may include meeting expected demands from the development of the city of Frederikssund.
C8	Coherence with in municipality	This criterion is concerned with local coherence in the transport network in terms of connecting various parts of the municipality. Accessibility to services, to jobs and to recreation is implicit in this criterion. In this case, the municipality is physically split by the fjord where the congestion experienced on the current bridge increases disparity in accessibility levels.

Table 3. Categorisation, ranking and weighting of the criteria

No	Criteria	Sustainability dimension	Case-based		Nested model		Sustainability advocate	
			Rank No	Weight	Rank No	Weight	Rank No	Weight
C1	Transportation and mobility	Economic	1	0.28	3	0.05	4	0.05
C2	Infrastructure and operations costs	Economic	2	0.19	3	0,05	7	0.04
C3	Noise exposure	Social	6	0.08	2	0.11	3	0.12
C4	Air pollution	Environmental	4	0.12	1	0.26	1	0.56
C5	Local biodiversity impacts	Environmental	5	0.08	1	0.26	2	0.15
C6	Built aesthetics and identity	Social	8	0.03	2	0.11	8	0.01
C7	Traffic demand and future proofing	Economic	3	0.14	3	0.05	5	0.04
C8	Coherence within municipality	Social	7	0.07	2	0.11	6	0.04

advocate assessments have been done by a user group of 16 professionals with a background in transport engineering and planning. The weights and rankings for each of the three assessments appear in Table 3, while the assessment of the alternatives for each criterion can be seen in Appendix.

4. Results

4.1. Case-based Municipality Prioritization

The four alternatives are assessed by the user group in an MCDA using the eight criteria described above. The criteria are compared against each other from a municipality perspective and thereby ranked and assigned weights (see Fig. 5 and Table 3). This analysis forms a basis for using the model by representing the standpoint of one of the main stakeholder group in the planning process.

The assessment results in a very close scoring of the four alternatives and gives no clear recommendation as to which solution is favoured by the municipality (Fig. 5). Despite an actual decision process resulting in the recommendation of Alternative 1, this fictive reconstruction of the municipality preferences points to indifference between the four alternatives, which cannot be concluded from the actual process. However, the actual process only considered Alternative 1 and 2 along with a range of other similar alternatives and thereby the conditions for assessment have been changed for this experiment. In addition to this, this experiment only tries to reproduce the position of the municipality, while the final decision was taken at a national political level and included recommendations from several stakeholders as well as other political considerations. For these reasons, the assessment performed by the user group is still considered valid for exemplifying the use of the nested model in this paper.

4.2. Nested Model Prioritization

To test the effect of the nested model, the same set of criteria is applied to the DSS model. The assessment of each alternative within each criterion remains the same, but the weighting is altered according to the nested model based on the affiliation of the criteria to each dimension. Within the dimensions, the criteria are assigned equal weights summing up to the weight assigned for each dimension (see Fig. 6 and Table 3).

Interestingly, the preference of the alternatives shifts to the favour of Alternative 3 and 4 following this

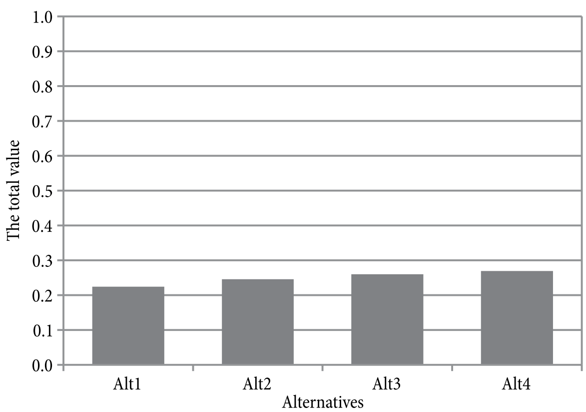


Fig. 5. Resulting graph of the case-based municipality assessment

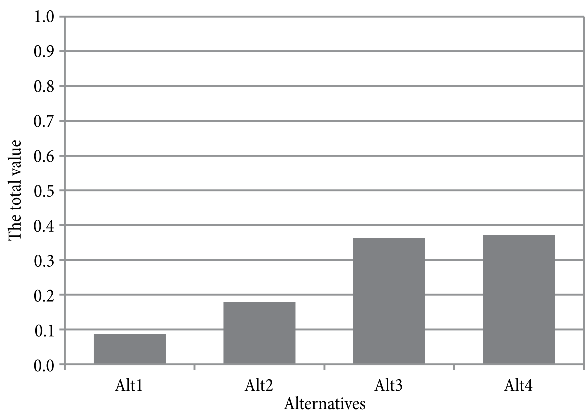


Fig. 6. Resulting graph of the nested model assessment

change in weighting. This is so since the criteria where Alternative 4 performs well now receive a higher weighting, while, on the other hand, the criteria weights where Alternative 1 performs well are diminished (Fig. 6).

4.3. Sustainability Advocate Prioritization

The assessment using the sustainability advocates priorities results in an even more distinct scoring of the four alternatives separating the car based alternatives from the non-car based alternatives. This can be explained by the underlying understanding of sustainable development as a mainly an environmental problem and thus causing the very high weights given to the environmental criteria. The fact that the light rail alternative (Alternative 3) now overtakes the shuttle bus alternative (Alternative 4) compared to the nested assessment could indicate a local context where the solution should be seen in connection to the already existing high class public transportation system (Fig. 7).

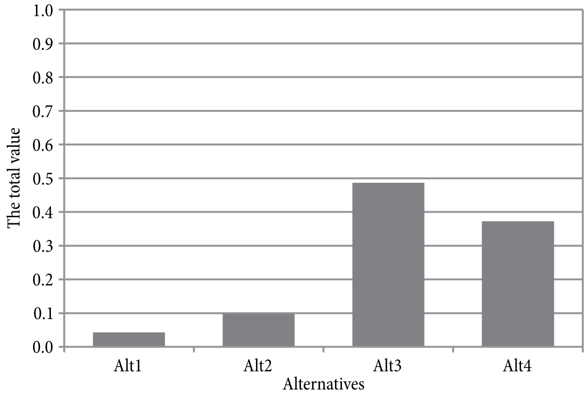


Fig. 7. Resulting graph of the sustainability advocate assessment

5. Discussion

From the results above, it is clear yet unsurprising that a different set of priorities changes the outcome of the planning process, even when the set of criteria and their individual assessment remain unchanged. In this case, applying the nested model of sustainability leads to a higher preference for the light rail as well as the free shuttle bus alternatives as the 'more sustainable' options. This should be compared to the sustainability advocate prioritisation, which provides a contextual and more distinct ranking of the four alternatives.

The three assessments present an insight on how new weighting can affect the preferred alternative. However, different results may occur if a new set of criteria is used for assessing the alternatives. The municipal assessment is indicative of an underlying car-based mind-set, while the nested as well as the sustainability advocate assessments illustrate the potential for a new paradigm in assessment. The sustainability ranking or the division and prioritisation of the existing eight criteria into the three dimensions do not provide a guarantee per se of meeting sustainability demands. Furthermore, the eight criteria secure no special attention to a number of wider sustainability issues, as they are rather a reflection of the current and contextual planning objectives.

This conceptual difficulty suggests the need for new and if possible, standard set of criteria for assessing sustainable transportation altogether. This ideal set of criteria would ensure a more holistic approach that could include more multi-modal and long-term considerations. For example, Banister elaborated in some depth what a wider understanding of sustainable mobility could include (Banister 2008). Such criteria could also address some of the limitations that were raised concerning the nested model approach, namely the lack of consideration for different types of natural capital affected and concepts such as irreversibility.

Nevertheless, it was shown that the nested model of the three dimensions of sustainability is conceptually accurate as well as simple to understand and operationalize into an MCDA process. However, it must also face the tough question: is it useful in driving change?

On one hand, a stronger conceptualisation of sustainability implies a basic reframing of the ethics behind the planning for sustainable transport. Using the nested model may at the very least '*contribute to shape knowledge and/or introduce new ideas*' (Gudmundsson, Sørensen 2013). Compared to the more traditional approach consisting of producing a CBA analysis complemented by an EIA report, the MCDA approach provides the opportunity to integrate both monetized and non-monetized effects into one common tool. This alignment of effects may contribute to an earlier and more holistic assessment of all impacts. In addition to this, the very process of MCDA requires an early engagement with experts and stakeholders in assessing the various alternatives against all possible impacts, which may help build a sense of ownership and gain acceptance for the project. Finally, the process requires explicitness on the criteria used as well as their prioritisation. Such transparency provides clarity to all stakeholders involved in the decision-making process.

On the other hand, although the tool is intended for instrumental use rather than just inspirational, it cannot replace decision-making. In suggesting a 'more sustainable' alternative, it is limited by the set of criteria that are considered. As it was already highlighted in the theory about the nested model, factors falling outside of the three dimensions of economy – society – environment are not explicitly considered. In a context of governance, such factors may include strategic fit with existing goals and visions, agency knowledge and capacity, the presence of effective leadership, or the barriers posed by norms and public expectations (Cornet, Gudmundsson 2015). However, based on the assumption that a decision departing from the results provided by the tool would require proper justification, the process may help increase accountability and thereby avoid *symbolic* use – where the assessment process is used as a means to justify a decision that has already been taken (Gudmundsson, Sørensen 2013).

Naturally, validating the process presented here in a real planning context could inform further on its potential and limitations in enabling 'more sustainable' alternatives to come through.

Conclusions

This paper uncovered some of the conceptual and analytical limitations of the planning approach illustrated by the case of a new connection across Roskilde Fjord in Frederikssund, and it proposed some pathways to overcome them. At a conceptual level, a stronger and more fine-grained understanding of sustainability is suggested as a starting point, and at the analytical level, the use of weights based on the nested model of sustainability is exemplified as a way to operationalize this.

Although the nested model is simplistic in that it does not accurately reflect the numerous complexities that compose sustainability theory, it was shown that this simplicity also renders its operationalization possible and provides valuable insights to the challenge of planning for more sustainable transportation. More particularly, it was shown that the reprioritisation of the environmental dimension above the socio-economic dimensions is consistent with the definition of sustainable development endorsed by the Brundtland report of 1987. Whereas the model bundles different types of natural capital into one and does not prevent critical thresholds to be crossed, it allows concerns for long term environmental integrity to supersede more narrow and short term considerations that traditional methods allegedly fail to do. This future generations' perspective embedded in the protection of long-term environmental integrity is the basic of the new ethics proposed by Brundtland that is deemed applicable for developed countries such as Denmark.

For the case of a new bridge connection across the Roskilde Fjord in Frederikssund, it was shown that applying the model leads to a clearer conclusion on the preferred alternative from a sustainability perspective. Overall, the alternative of a free shuttle bus service operating over the existing connection and the alternative of a light rail reusing existing infrastructure crossing the fjord are considered 'more sustainable' than the officially decided solution of building a new southern high level bridge for car-based traffic. When weights based on a stakeholder defined 'sustainability advocate' are used, the overall preference for the light rail alternative becomes clearer. However, while this approach may be more contextually relevant, it is also more dependent on stakeholders own understanding of sustainability.

This paper thus demonstrates the value of revisiting in more detail sustainability theories in order to beat the *schizophrenic paths* revealed by Banister (2008). The overall challenge raised is to arrive at a more precise understanding of sustainability that can inform prioritisation of often-conflicting issues and integrate that knowledge into existing processes of governance. The Brundtland report was selected for its wide acceptance and universal adoption, and it was found that, when reviewed beyond its one line definition, it can serve as useful guidance for such prioritisation.

Thus, the nested model approach proposed here is meant as a method, on one hand, for reaching further and connecting better to the essence of sustainable development, and on the other hand, to integrate this understanding into real planning and assessment practice. Because of its simplicity, the nested model serves as this 'bridge' between conceptualisation and operationalization of sustainable transportation planning. Although its results are not expected to be used 'as is', they can inform practitioners in taking a more explicit sustainability perspective – a type of benchmark – for comparing with decisions based on more traditional methods. However further research is needed to demonstrate whether the SUSTAIN Decision Support System model can also serve as a bridge to its strategic utilisation in a complex, democratic political process where paths dependencies and myopic interests may form serious barriers to change.

Acknowledgements

The authors are grateful to the Strategic Research Council of Denmark (*Innovationsfonden*) that is supporting the SUSTAIN research project.

The authors wish to thank SUSTAIN project partners, user group, as well as colleagues for valuable discussions and inspiration.

References

Banister, D. 2008. The sustainable mobility paradigm, *Transport Policy* 15(2): 73–80. http://dx.doi.org/10.1016/j.tranpol.2007.10.005

Beukers, E.; Bertolini, L.; Brömmelstroet, M. T. 2012. Why cost benefit analysis is perceived as a problematic tool for assessment of transport plans: a process perspective, *Transportation Research Part A: Policy and Practice* 46(1): 68–78. http://dx.doi.org/10.1016/j.tra.2011.09.004

Connelly, S. 2007. Mapping sustainable development as a contested concept, *Local Environment: The International Journal of Justice and Sustainability* 12(3): 259–278. http://dx.doi.org/10.1080/13549830601183289

Cornet, Y.; Gudmundsson, H. 2015. Building a meta-framework for sustainable transport indicators – a review of selected contributions, *Transportation Research Record: Journal of the Transportation Research Board* (in press).

Costanza, R.; D'Arge, R.; De Groot, R., *et al.* 1997. The value of the world's ecosystem services and natural capital, *Nature* 387: 253–260. http://dx.doi.org/10.1038/387253a0

Daly, H. E. 1990. Toward some operational principles of sustainable development, *Ecological Economics* 2(1): 1–6. http://dx.doi.org/10.1016/0921-8009(90)90010-R

Elkington, J. 1999. *Cannibals with Forks: Triple Bottom Line of 21st Century Business*. Capstone Publishing Ltd. 424 p.

EC. 2011. *White Paper: Roadmap to a Single European Transport Area – Towards a Competitive and Resource Efficient Transport System*. COM(2011) 144 final. 28.3.2011, Brussels. Available from Internet: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52011DC0144:EN:NOT

Gibson, R. B. 2006. Beyond the pillars: sustainability assessment as a framework for effective integration of social, economic and ecological considerations in significant decision-making, *Journal of Environmental Assessment Policy and Management* 8(3): 259–280. http://dx.doi.org/10.1142/S1464333206002517

Giddings, B.; Hopwood, B.; O'Brien, G. 2002. Environment, economy and society: fitting them together into sustainable development, *Sustainable Development* 10(4): 187–196. http://dx.doi.org/10.1002/sd.199

Griggs, D.; Stafford-Smith, M.; Gaffney, O., *et al.* 2013. Policy: sustainable development goals for people and planet, *Nature* 495: 305–307. http://dx.doi.org/10.1038/495305a

Gudmundsson, H.; Sørensen, C. H. 2013. Some use – little influence? On the roles of indicators in European sustainable transport policy, *Ecological Indicators* 35: 43–51. http://dx.doi.org/10.1016/j.ecolind.2012.08.015

Hopwood, B.; Mellor, M.; O'Brien, G. 2005. Sustainable development: mapping different approaches, *Sustainable Development* 13(1): 38–52. http://dx.doi.org/10.1002/sd.244

Jeppesen, S. L. 2009. *Sustainable Transport Planning – A Multi-Methodology Approach to Decision Making*: PhD Thesis. Department of Transport, Technical University of Denmark. 203 p.

Joumard, R.; Nicolas, J.-P. 2010. Transport project assessment methodology within the framework of sustainable development, *Ecological Indicators* 10(2): 136–142. http://dx.doi.org/10.1016/j.ecolind.2009.04.002

Langhelle, O. 1999. Sustainable development: exploring the ethics of our common future, *International Political Science Review* 20(2): 129–149. http://dx.doi.org/10.1177/0192512199202002

Lélé, S. M. 1991. Sustainable development: a critical review, *World Development* 19(6): 607–621. http://dx.doi.org/10.1016/0305-750X(91)90197-P

Lootsma, F. A. 2011. *Multi-Criteria Decision Analysis via Ratio and Difference Judgement*. Springer. 286 p.

Roskilde Fjord – Ny fast forbindelse. Afrapportering af idékonkurrence omkring Offentlig-Privat Partnerskab. 2005. Idékonkurrence omkring OPP-projektet. (in Danish).

Munasinghe, M. 1993. *Environmental Economics and Sustainable Development*. http://dx.doi.org/10.1596/0-8213-2352-0

Owens, S. 1995. From 'predict and provide' to 'predict and prevent'?: Pricing and planning in transport policy, *Transport Policy* 2(1): 43–49. http://dx.doi.org/10.1016/0967-070X(95)93245-T

Pryn, M. R. 2013. *Sustainable Decision Support – a Contextual Analysis of the Importance of Planning Criteria Using MCDA*. Department of Transport, Technical University of Denmark.

Roberts, R.; Goodwin, P. 2002. Weight approximations in multi-attribute decision models, *Journal of Multi-Criteria Decision Analysis* 11(6): 291–303. http://dx.doi.org/10.1002/mcda.320

Saaty, T. L. 2012. *Decision Making for Leaders: the Analytic Hierarchy Process for Decisions in a Complex World*. 3rd edition. RWS Publications. 323 p.

Salling, K. B.; Pryn, M. R. 2015. Sustainable transport project evaluation and decision support: indicators and planning criteria for sustainable development, *International Journal of Sustainable Development & World Ecology* 22(4): 346–357. http://dx.doi.org/10.1080/13504509.2015.1051497

The Natural Step. 2014. *The Four System Conditions of a Sustainable Society*. Available from Internet: http://www.thenaturalstep.org/sustainability/the-system-conditions

Vejdirektoratet. 2010a. *Ny Fjordforbindelse ved Frederikssund*. Sammenfattende rapport. Copenhagen. (in Danish).

Vejdirektoratet. 2010b. *VVM-Undersøgelse for en ny Fjordforbindelse ved Frederikssund: Offentlig Høring af VVM-Redegørelsen*. Høringsnotat. (in Danish).

Voß, J.-P.; Smith, A.; Grin, J. 2009. Designing long-term policy: rethinking transition management, *Policy Sciences* 42(4): 275–302. http://dx.doi.org/10.1007/s11077-009-9103-5

WCED. 1987. *Our Common Future*. Report of the World Commission on Environment and Development (WCED). Oxford Paperbacks. 400 p.

APPENDIX

Assessment of Project Alternatives per Criterion by User Group

REMBRANDT assessment scale

Intensity of preference	Definition
0	Indifference
2	Weak
4	Definite
6	Strong
8	Very strong
1, 3, 5, 7	Compromise between

Criterion 1: Transportation and mobility

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Normalized score
Alternative 1	0.00	2.31	2.75	5.67	0.77
Alternative 2	–2.31	0.00	0.75	2.04	0.13
Alternative 3	–2.75	–0.75	0.00	0.74	0.07
Alternative 4	–5.67	–2.04	–0.74	0.00	0.03

Criterion 2: Infrastructure and operations costs

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Normalized score
Alternative 1	0.00	–4.35	0.34	–5.89	0.02
Alternative 2	4.35	0.00	1.01	–1.83	0.21
Alternative 3	–0.34	–1.01	0.00	–3.01	0.05
Alternative 4	5.89	1.83	3.01	0.00	0.72

Criterion 3: Noise exposure

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Normalized score
Alternative 1	0.00	–2.01	–3.76	–1.97	0.05
Alternative 2	2.01	0.00	–0.48	–0.38	0.21
Alternative 3	3.76	0.48	0.00	–0.03	0.47
Alternative 4	1.97	0.38	0.03	0.00	0.72

Criterion 4: Air pollution

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Normalized score
Alternative 1	0.00	–1.03	–5.27	–4.25	0.,02
Alternative 2	1.03	0.00	–4.28	–3.12	0.03
Alternative 3	5.27	4.28	0.00	1.03	0.41
Alternative 4	4.25	3.12	–1.03	0.00	0.30

Criterion 5: Local biodiversity impacts

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Normalized score
Alternative 1	0.00	–3.88	–1.74	–3.91	0.03
Alternative 2	3.88	0.00	0.72	–2.24	0.24
Alternative 3	1.74	–0.72	0.00	–1.35	0.15
Alternative 4	3.91	2.24	1.35	0.00	0.58

Criterion 6: Built aesthetic and identity

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Normalized score
Alternative 1	0.00	0.40	0.28	1.17	0.33
Alternative 2	–0.40	0.00	–0.32	0.02	0.21
Alternative 3	–0.28	0.32	0.00	0.95	0.29
Alternative 4	–1.17	–0.02	–0.95	0.00	0.17

Criterion 7: Traffic demand future proofing

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Normalized score
Alternative 1	0.00	2.69	0.50	2.26	0.52
Alternative 2	–2.69	0.00	–0.45	1.07	0.14
Alternative 3	–0.50	0.45	0.00	0.85	0.23
Alternative 4	–2.26	–1.07	–0.85	0.00	0.10

Criterion 8: Coherence within municipality

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Normalized score
Alternative 1	0.00	1.27	0.65	1.46	0.41
Alternative 2	–1.27	0.00	–0.69	0.66	0.18
Alternative 3	–0.65	0.69	0.00	1.18	0.28
Alternative 4	–1.46	–0.66	–1.18	0.00	0.13

Article III Incorporating a sustainability viewpoint into multi-actor MCA – the case of HS2

STOP HS2 campaign sign found in the Chilterns Area of Outstanding Natural Beauty, photo by author.

Incorporating a sustainability viewpoint into multi-actor MCA – the case of HS2

Yannick Cornet
Affiliation: Department of Management Engineering, Technical University of Denmark

Michael Bruhn Barfod
Affiliation: Department of Management Engineering, Technical University of Denmark

Merrill Jones Barradale
Affiliation: Centre for Corporate Social Responsibility, Copenhagen Business School

Robin Hickman
Affiliation: Bartlett School of Planning, University College London

Note: This paper is longer than a single journal article. It describes a substantial research project that represents a major portion of my doctoral research which, we think, has the potential to contribute to several publications. A shorter version of this paper is currently in the review process. This version also includes the following five appendices:

Appendix A: Project descriptions (as they were presented to respondents)
Appendix B: Criteria dimensions (the various ways to frame impacts, ensure consistency, and avoid-overlapping)
Appendix C: Criteria discussions (a summary of the reflections that took place to produce the final list of impacts)
Appendix D: Final criteria descriptions (as they were presented to respondents)
Appendix E: Robustness analysis for project preferences (details about testing results for a range of consistency thresholds and minimum responses)

1. Introduction: Motivation & Purpose

Large-scale transport infrastructure projects involve substantial economic, social, and environmental impacts, affecting both present and future generations. As the process through which projects are prioritised, transport appraisal[1] methods matter greatly. In the case of transport mega-projects – costing billions of pounds, affecting millions of people, and impacting the environment for decades and centuries to come – the effectiveness of appraisal methods, which play a key role in decisions to build such infrastructure, matters even more.

Despite the clear need for methods for analysing and comparing transport strategies and measures against a wide range of competing goals, including mobility, economic growth, regeneration, environmental issues, safety, social inclusion and equity, and cost control, there currently exists no standardized process for transport appraisal against sustainability objectives, with practices varying widely across countries (Mackie et al. 2013; Hayashi and Morisugi 2000).

Investment decisions for High Speed Rail do typically extend beyond traditional cost-benefit analysis (CBA) to include such factors as wider economic impacts, environmental impacts and national pride. In some cases the strategic goals may even take precedence over the results of conventional economic analysis. However, such factors are not generally compared or weighed in a systematic manner (Steer Davies Gleave 2004). Due to the size and complexity of HSR projects, expertise regarding the effects of projects can become contested, as various 'experts' disagree not only on outcomes but also on assessment methods (Dudley and Banister 2015).

CBA itself has been the subject of decades-long criticism, and although various attempts have been made, both in theory and in practice, to broaden the criteria considered, as well as the stakeholders involved, current transport appraisal methods still consist of little more than CBA supplemented by qualitative assessments and public consultation. While smaller-scale projects may arguably be better served by CBA, the planned High-Speed Rail 2 (HS2) in the UK (the largest single transport project ever proposed in the UK) has pushed this framework beyond its limits, leading to broad discontent with the process (Dudley & Banister, 2015). Current transport appraisal methods have been substantially discredited as a result. There is a need both to develop methods capable of integrating a wide range of stakeholder perspectives in a systematic manner and to test these for large-scale projects. Furthermore, addressing the sustainability challenge described in the Brundtland report (World Commission on Environment and Development (WCED) 1987) suggests a need for explicit incorporation of long-term impacts into appraisal processes for transport projects.

The purpose of this paper is to develop and test precisely such project appraisal methods. This paper contributes to the Multi-Criteria Analysis (MCA) literature (whose goal is to broaden the criteria considered and/or the stakeholders involved) by building on the Multi-Actor Multi-Criteria Analysis (MAMCA) method developed by Macharis et al. (2009; 2012) and applying this to the case of HS2 Phase I. The MAMCA process is adapted for the specific

[1] Terminology: in the UK, *appraisal* refers to the analysis of proposed actions (ex-ante), while *evaluation* refers to how actions have worked out in practice (ex-post) – although they are sometimes used interchangeably (HM Treasury 2011). Project appraisal is understood in this paper as a process including assessment as well as public participation procedures, where *assessment* refers more specifically to the analysis of *impacts* (also sometimes called more generally *effects*). Impacts can be detrimental or beneficial.

case of HS2 by conducting a series of structured interviews with key stakeholders based on a common MCA questionnaire. This stakeholder-judgment based approach is aimed not at reaching a definitive conclusion or assessment of project options, but rather, at complementing existing transport appraisal methods by making the different perspectives more explicit.

Finally, in an effort to give future generations a voice in decisions that will impact them, the paper proposes two methods for deriving a "sustainability viewpoint" to represent the interests of future generations (among other stakeholder perspectives): 1) a bottom-up approach in which we identify sustainability expertise among transport professionals; and 2) a top-down approach where we use weights to construct what "should" constitute "strong" and "weak" sustainability viewpoints.

2. Theory & Case Selection

Ever since the growth of environmental awareness in the 1960s, there has been a long tradition of relatively comprehensive *ex-ante* transport assessment in Europe and the UK (Vickerman 2000). In the UK, for example, legally binding requirements for Environmental Impact Assessments (EIA) and Strategic Environmental Assessments (SEA) have provided mechanisms for judging large-scale transport investments, which by their nature bring complex, and often disruptive, network-wide effects (Tomlinson 2011). We look at how three generations of transport appraisal methods have interpreted the role of these assessments in supporting decision-making.

1st generation: CBA and objectivist-positivist assumptions

CBA was developed as the standard approach for quantifying various types of impacts based on national or supra-national guidance (see, for example, Korzhenevych et al., 2014). CBA is concerned with efficiency in allocation of economic resources, and thereby aims to translate and aggregate into monetary terms impacts across space and time. This common unit brings obvious advantages of comparability, both across a range of impacts and between a set of alternatives. More importantly, for its proponents, CBA serves as formal appraisal guidance, "a way of civilising" decision-making, which otherwise would be dependent on (limited) human cognitive abilities (see the OECD report by Atkinson and Mourato, 2006 and Mackie et al., 2014 for a thorough review of CBA strenghts and weaknesses). CBA therefore confers a sense of objectivity and legitimacy to contested decisions.

Underpinned by objectivist-positivist assumptions, instrumental rationality tools such as CBA are helpful in considering many aspects of transport projects; however they have long been criticised for their failure to adequately address the consequences of transport development and for being too narrow in terms of criteria considered (Beukers, Bertolini, and Te Brömmelstroet 2012). In terms of sustainability specifically, CBA is said to favour the pursuit of easily measurable economic objectives at the expense of more complex and long-term social and environmental goals (De Brucker, MacHaris, and Verbeke 2013). One reason is that valuation methods such as willingness-to-pay (for benefits) and willingness-to-accept (for costs or disutility) may work well for valuing private goods, but less well for public goods such as climate stability. Furthermore, social discount rates are set by national governments based on various forms of pricing[2] that raise concerns about reliability (Mackie, Worsley, and Eliasson 2014). Another well-known difficulty in CBA is the distribution of costs and benefits across society (Martens 2011). Aside from the challenge of setting discount rates to account (or not) for intergenerational fairness (van Wee 2012), CBA methods pose particular challenges for large-scale transport projects: as size increases, so does uncertainty, and therefore the cost of trying to establish certainty too early in the appraisal process (Vickerman 2007).

2nd generation: MCA, MCDA and the extension of instrumental rationality

The MCA literature proposes a wide range of techniques to assess impacts that are currently not feasible or practical to monetise (Browne and Ryan 2011; Barfod and Salling 2015). Multiple-Criteria Decision Analysis (MCDA) is a form of MCA whose main application is the appraisal of policy options and as an aid to complex decision making (Department for Communities and Local Government 2009; Zopounidis and Pardalos 2010; Belton and Stewart 2002).

The MCA approach comprises the following standard eight steps (von Winterfeldt and Edwards 1986):

1. Identify the objectives within the decision context
2. Identify the stakeholders, decision makers and other key players
3. Identify options for achieving the objectives
4. Identify and organize the criteria to be used for comparing options
5. Weigh the criteria to reflect their relative importance to the decision
6. Score the expected performance of each option against the criteria
7. Combine weights and scores to derive an overall value for each option
8. Conduct a sensitivity analysis of the results to changes in weights and scores

The UK has been at the forefront of MCA developments for transport project assessment, and its Transport Analysis Guidance (WebTAG) combines CBA and MCA approaches in a wider decision-support framework (Department for Transport 2014c; Department for Transport 2014b). A key outcome of the impact assessment of transport appraisal is the completion of an Appraisal Summary Table (AST) which summarises all economic, environmental and social impacts, qualitatively and quantitatively (Department for Transport 2014a). For HS2 Phase I, the EIA process, by itself, is said to have generated almost 50,000 pages of material (HS2 Ltd 2013c; HS2 Ltd 2013a). This input then feeds into the MCA that analyses more broadly the strategic, economic, financial, delivery and commercial case (Department for Transport, 2014c see Figure 3 p6).

---

[2] Some countries use shadow pricing based on carbon emission reduction targets; others base it on the CO2 tax of motor fuels; still others on the EU Emissions Trading System (ETS) – all of which differ from each other and possibly also from the long-term cost of emitting an extra ton of CO2, which at some point may pass an environmental boundary where costs become infinite. This does not invalidate the method: low or infinitely high values can be set to represent this. But CBA is not always explicit about the underlying normative/political choices made in setting impact values, treating them as ‘given’. The cool, dispassionate assessment CBA confers is thus a “false simplicity” that hides these problems and stands in the way of evaluating transport projects in ways that are consistent with the goals of sustainability.

However, the impact assessment literature has recently raised questions about the actual effectiveness of technical-rationalist tools such as CBA, MCA, EIAs and SEAs for supporting greater achievement against sustainability objectives (Fischer, Jha-Thakur, and Hayes 2015). In practice, there remains a strong political dimension to decision-making, often resulting in projects that are questionable not only in terms sustainability, but even in terms of rational efficiency. To avoid having to choose between reliance on incomplete or lengthy technical assessments on the one hand and on an arbitrary political process on the other, some of the planning literature has suggested a 'communicative rationality' approach based on broader public involvement (Willson 2001; Sanderson 2001; Healey 1998; Allmendinger 2009; Næss 2006). Although public participation is already incorporated in the EIA and SEA directives,[3] in practice there is little room for integrating different types of stakeholders in the tools of instrumental rationality. EIAs are often subject to "unstructured stakeholder involvement and inefficient public participation" (Soria-Lara, Bertolini, and te Brömmelstroet 2016).

In sum, second-generation appraisal methods are characterized by a broadening of criteria considered (first and foremost) or by a broadening of stakeholder involvement (secondarily). However, while the integration of multiple criteria is quite systematized, the integration of multiple stakeholders is much less so. Hence the need for a third generation of appraisal approaches.

3rd generation: MAMCA and communicative rationality

Because of the complexity of the sustainability challenge, it is proposed to complement techno-rationalist tools (in the form of models, quantitative assessments and qualitative reporting) with a social rationality that would increase the emphasis on stakeholder involvement and value judgments. Communicative rationality aims precisely at enabling a "democratic renewal" by enhancing capacity for deliberation and decision-making (Willson 2001; Dryzek 1990). This approach focuses on inclusive and interactive processes: it assumes that early and effective involvement of the public will help unearth conflicts, generate mutual understanding, allow for negotiation, and eventually build partnership (i.e. trust) in decision-making – thereby leading to better decisions by maximising the number of winners over losers (Sanderson 2001; Healey 1998). Addressing these challenges requires a different, more qualitative and discursive approach to assessment.

The Multi-Actor Multi-Criteria Analysis (MAMCA) method has formalized the inclusion of various competing stakeholder interests for transport appraisal (Macharis and Bernardini 2015; Macharis, De Witte, and Ampe 2009; Macharis, Turcksin, and Lebeau 2012).[4] In this paper, we follow and build upon this method. We define stakeholders, based on the strategic

---

[3] Of particular relevance here are the provisions for public participation (aligned in 2003 with the Aarhus Convention), requiring member states to ensure the public is given "early and effective opportunities to participate in the environmental decision-making procedures". By this, the public is "entitled to express comments and opinions *when all options are open* to the competent authority or authorities *before the decision on the request for development consent is taken*" (The European Parliament and the Council of the European Union, 2014, article 6 para. 4).

[4] In MAMCA, steps 1 and 3 from the standard MCA approach (defining objectives and alternatives) are conflated into one single step, and so are steps 4 and 5 (defining criteria and setting weights). We think overall there is some value in keeping those separate (see implementation). MAMCA has a 7th 'Implementation' step, which is concerned with making and implementing the final decision. This is out of scope for our purpose, which is to test a method and not to conduct an actual appraisal.

stakeholder management literature, as any individual or group (organised or not) who is able to affect or is affected by (or both) the ultimate outcome of a particular issue (De Brucker, Macharis, and Verbeke 2011; Macharis, Turcksin, and Lebeau 2012). The selection of those who share a stake is particularly critical, since ultimately it is their judgments that form the basis of the appraisal.

The essential focus of third-generation tools is on *how* multiple stakeholders are integrated within MCA approaches. A necessary component of the third generation is that stakeholder perspectives be integrated in a *systematic* manner. Another component of stakeholder treatment is whether or not the different perspectives end up as part of the *end product*. Macharis et al. refer to this as "input" and "output" involvement (Macharis, Turcksin, and Lebeau 2012). Are stakeholders involved only in contributing to deriving "the" answer, or are they part of the output? Although Macharis et al. do propose a mechanism for synthesizing perspectives to come up with project recommendation(s), they also stress the importance of including the *descriptions of multiple perspectives as part of the final output.*

Precisely because third-generation appraisal methods emphasize the making explicit of multiple perspectives, they also open up the possibility of incorporating sustainability viewpoints in particular into transport appraisal.

A sustainability viewpoint

In order to give future generations a voice in decisions about transport infrastructure that will impact them, we suggest it is necessary to make explicit a sustainability viewpoint that represents the interests of future generations. The idea of creating an explicit sustainability advocate in decision-support is not new (Jeppesen 2011; Pryn, Cornet, and Salling 2015), yet operationalising sustainability principles in impact assessment is still the subject of research and debate (see for example De Brucker et al., 2013).

We derive such a sustainability viewpoint in two different ways and then compare the results. The first is a bottom-up, expert-based approach in which we seek to identify "sustainable transport professionals" based on expertise in environmental and sustainability issues. The second is a top-down, principle-based approach in which we construct two virtual sustainability viewpoints: one representing "strong sustainability" and the other representing "weak sustainability." The strong viewpoint is inspired by a view of the Earth from a systems' perspective, the laws of thermodynamics and minimum social foundations (Griggs et al. 2013; Raworth 2013; Johnston et al. 2007). This approach warrants the use of thresholds and boundaries, such as the global Planetary Boundaries concept developed for the environmental dimension (Steffen et al. 2015). When applying this concept to our own derivation of a virtual sustainability viewpoint, we rely on a simplification involving the nested model of sustainability (further details will be described along with the presentation of results based on these sustainability perspectives).

Case Selection: Why HS2 Phase I?

HS2 is a proposed high-speed railway network connecting major cities in Britain. Phase I will connect London and Birmingham in the West Midlands (221 km), and Phase II will extend the network to Manchester, Sheffield and Leeds (for a total of about 530 km of high speed rail lines). Construction of the first phase is to begin in 2017 with an indicated opening date of 2026. The full network is expected to be completed in 2033.

There are three main reasons for selecting a High-Speed Rail case and HS2 Phase I in particular: project scale, sustainability implications, and timing. Firstly, in terms of scale, HS2 Phase I is so large that it challenged the ability of the current, state-of-the-art, second-generation appraisal methods to deliver meaningful results. Benefit-cost ratios were criticised early in the appraisal process due to a number of untenable assumptions (e.g. the value of time savings for business travellers which assumes time spent aboard trains is wasted – see Castles et al., 2011; Wardman et al., 2013), as well as the lack of accounting for wider economic benefits, distributional effects, and other transport network impacts (Dudley and Banister 2015).

Secondly, the case provides an excellent opportunity to examine sustainability in the context of transport appraisal. Although HSR instinctively seems environment-friendly, HSR alignments may establish new transport corridors in less built areas, which is more likely to disrupt protected areas and biodiversity (this is particularly significant in the compact geography of the UK). Tunnelling is effective, but significantly increases costs, disruption, waste, and embedded carbon associated with construction (Cornet, Dudley, and Banister 2016). The assumption that HS2 would be of benefit to the two core planetary boundaries of climate change and biodiversity loss (Steffen et al. 2015) thus may not be founded. From a social justice perspective, HSR alters the space-time geography significantly, which can exacerbate rather than resolve regional disparities in accessibility (Givoni 2006; Vickerman 2014)[5]. Economically, HS2 is expected to bring wider economic benefits than can be accounted for in conventional CBA, but how much of the generated growth may just be a spatial reorganization of economic activity remains the subject of debate (Castles, Parish, and 51m 2011; Graham and Melo 2012).

Thirdly, timing provides a good opportunity for investigation. The data collection for this research took place during 2015-16, at the time when the official environmental impact assessment had already been completed and the Hybrid Bill authorising the works for Phase I was progressing through the final stages of parliamentary approval[6]. A vast amount of documentation is available to inform the case, including the early Appraisal of Sustainability (Booz & Co. and Temple 2011), the full Environmental Statement (HS2 Ltd 2013a), as well as consultation reports and large amounts of oral and written evidence from the House of Commons and the House of Lords (House of Commons Environmental Audit Committee 2014; House of Lords 2015; House of Commons Select Committee on the (London - West Midlands) Bill 2016). Phase I is selected to narrow the scope of study and make the research more tractable for survey respondents.

3. Methods

This section provides details about our adaptation of the MAMCA process to the HS2 Phase I case. First we describe meta-criteria for evaluating the validity, usability, and applicability of

[5] In France, 28% of trips by TGV (Train à Grande Vitesse, HSR in French) are made by the top 10% of the population in terms of income, compared to 50% of trips by conventional trains being made by the lowest three deciles of income. This is compounded by the fact that TGV travellers tend to be residents of larger agglomerations (see Annex no 5 and 6 respectively in Cour des comptes, 2014).

[6] http://services.parliament.uk/bills/2015-16/highspeedraillondonwestmidlands.html

our appraisal method. Next we describe our data collection methods: semi-structured interviews plus structured questionnaire. We then move on to describe the steps of our appraisal process in terms of stages of the survey process: questionnaire design, response elicitation, and data analysis.

Meta-criteria for appraisal methods

Various meta-criteria have been proposed in the literature to assess the potential of transport indicator frameworks (Cornet and Gudmundsson 2015) and MCA methods (Cinelli, Coles, and Kirwan 2014) in order to conduct sustainability assessments, and for such methods to adequately represent stakeholder views in an institutional approach (De Brucker, Macharis, and Verbeke 2011). These requirements fall under three main headings: conceptual soundness (validity, from a scientific and sustainability perspective), practicality of implementation (feasibility and transparency), and procedural adaptability (flexibility and applicability in a governance context) (Cornet and Gudmundsson 2015). These criteria are used to inform the design of the method and to adapt MAMCA to our case (Table 1).

Table 1: Meta-criteria used for the selection and design of the appraisal method.

Category	Meta-criterion	Short description
Conceptual soundness		
	Validity – sustainability	Consideration of impacts is comprehensive, long-term, and broad in geographic scope
	Validity - scientific	Robustness, in terms of representativeness of both the stakeholder value structure and the assessment of options
Practical usability //implementation		
	Ease of use	The method should be easy to understand and straightforward to reproduce in various contexts
	Cost-effectiveness	Reduce costs of data collection, particularly in terms of time and effort
	Transparency	Easy to compute, reproduce and verify results in order to avoid the 'black box syndrome'
Procedural adaptability //applicability		
	Process flexibility	Level of engagement of respondents and ability to influence the process, not only the results
	Learning potential	Fostering self-learning and reflexivity as an important outcome, not only the decision 'result'
	Enabling change	Ensuring results and their presentation can influence decision-making and support change processes

As our method is intended to be applicable *ex-ante* (at a time when little or no quantitative data is yet available), it relies exclusively on qualitative judgments for both weighting and scoring criteria. The Analytic Hierarchy Process (AHP) is one of the most common MCA elicitation techniques used in the transport field (Macharis and Bernardini 2015). The pairwise comparison approach applied in AHP is easy to understand by respondents, and the inclusion of redundancy provides a consistency check. Scientific robustness (e.g., known rank reversal issues) can be addressed by using multiplicative AHP (Olson et al. 1995). This is also an improvement on all implementation criteria[7] as the method does not require any specialized software, only a standard spreadsheet. AHP requires that criteria be non-overlapping, mutually exclusive, and limited in total number so as to avoid an exponential number of comparisons.[8]

Data collection methods

A variety of data collection methods is available for collecting stakeholder input, ranging from exploratory to prescriptive, unstructured to structured, interactive to individual. At one end of the spectrum are unstructured interviews and interactive settings such as workshops and focus groups. Brucker et al. suggest that "by bringing together all stakeholders in a carefully designed forum…it may become much easier to construct and implement solutions acceptable to the community of stakeholders, thereby creating value added for society as a whole."(De Brucker, Macharis, and Verbeke 2011). As ideal as this sounds, however, it is often costly in terms of time and effort to bring all relevant stakeholders into a single forum – if at all possible (see e.g., Soria-Lara et al., 2016). This may be particularly true for such large-scale transport infrastructure projects as HS2.

At the other end of the spectrum, electronic surveys are highly structured and (usually) non-interactive (both between respondent and interviewer and among respondents). Surveys constrain respondents to a narrow predetermined path and are prone to misunderstanding and misinterpretation, as well as low response rates. This is particularly problematic for highly complex applications such as transport appraisal.

In our data collection, we aim for a balance between these two extremes, combining personal interaction with the structure of an online questionnaire. Specifically, we conducted in-person interviews, integrating semi-structured discussion with completion of the questionnaire. This had the advantage of enabling the researcher to ensure data quality and provide clarification of the steps, criteria, scales and other complexities (similar to a workshop setting). In contrast to a workshop setting, however, there is no interaction among respondents. This may have disadvantages when the research goals are exploratory (e.g., when defining objectives), but may have advantages when the goal is to collect a variety of perspectives (e.g., avoiding group-think; providing confidentiality which encourages respondents to share views more fully with interviewer). In addition, particularly early in the process, we conducted semi-structured interviews without filling in the online questionnaire. The semi-structured format, whether combined with the structured online format or not, provides a rich source of qualitative data which can serve as input to improving the process or reaching a fuller understanding of the case.

Our overall target group was "transport planners and experts," consisting of both practitioners and researchers, employed in all sectors (public, private, non-profit, academic). We were primarily interested in transport professionals in the UK, but we also included some from other parts of Europe who were involved with HS2.

[7] A multiplicative structure is introduced to fit the ratio judgments made during the comparisons, the scale is adjusted to fit the multiplicative structure (-8, -6, …0, …6, 8), and the aggregation of scores is based on simple geometric means (Olson et al. 1995).

[8] Alternative methods exist when criteria have strong mutual dependencies e.g. ANP, Analytic Network Process (Zopounidis and Pardalos 2010)

To identify potential respondents, we relied on three sources: 1) a long list of attendees from private and governmental institutions present at a large seminar on appraisal methods at University College London held in 2014; 2) the official parliamentary reports listing all petitioners with their evidence; and 3) our own network of transport planners and academics.

We contacted potential respondents by email, asking them to participate in an "academic query" about HS2. The email briefly described the main area of enquiry ("selection and prioritisation of appraisal criteria from different stakeholder perspectives"); explained that the interview would be based on an online questionnaire; and proposed a location of their convenience (their office, the Bartlett School of Planning at University College London, University of Oxford's Transport Studies Unit, or by Skype – all of which took place). The research was introduced as addressing the "Appraisal of National-Scale Transport Infrastructure Projects". In order not to 'colour' the respondents, the survey introduction made no specific reference to 'sustainability' (except for acknowledging the project's funding coming from an initiative called "Transport Planning – Sustainability, Institutions and Tools").

In all, we interviewed ca. 40 transport professionals, 33 of whom filled in the questionnaire.

Overview of appraisal steps and survey process

The steps of our appraisal process are comparable both to von Winterfeldt and Edwards (1986)'s eight-step MCA process and to Macharis et al. (2012)'s seven-step MAMCA process. Our appraisal steps are best described in terms of stages of the survey process:

A. Appraisal steps conducted as part of questionnaire design
    - Defining objectives, project options, and criteria
    - Designing questions to identify stakeholder groups
B. Appraisal steps conducted through response elicitation
    - Selecting and prioritizing criteria
    - Assessing project performance
C. Appraisal steps conducted during data analysis
    - Identifying stakeholder groups
    - Calculating project preferences for each stakeholder group

A detailed list of our appraisal steps is given in Table 2.

Table 2: Our Appraisal Process. (1) (HS2 Ltd 2013c); (2) High-Speed Rail along M1 motorway (HS2 Ltd 2012), West Coast Main Line (WCML) upgrade (Atkins 2012; HS2 Ltd 2013b).

Survey stage	Appraisal step	Conducted how	By whom	Novel
Questionnaire Design	Define objectives	Predetermined	DfT (1)	
	Define list of project options	Predetermined (mostly)	DfT (2); research team	
	Define list of criteria	Iteratively and interactively	Interviewees; research team	X
	Define stakeholder groups of interest (e.g., sustainable transport professionals)	Develop questions to elicit respondent traits	Research team	X
Response Elicitation	Select criteria from list	Binary/Mark any number	Survey respondents	
	Prioritize selected criteria	Direct weighting (swing weights)	Survey respondents	
	Assess project performance for selected criteria	Pairwise comparison of projects (multiplicative AHP) for each criterion	Survey respondents	
Data Analysis	Average performance assessments across all respondents for each criterion	Geometric mean of all assessments (multiplicative AHP) for each criterion	Research team	
	Identify robust criteria to be used for project appraisal	Consistency thresholds and minimum number of assessments	Research team	
	Identify respondents with sustainability expertise; assign to stakeholder groups	Decision rules based on respondent traits	Research team	X
	Calculate criteria weights for each stakeholder group	Arithmetic mean of group members' weights for each robust criterion	Research team	
	Calculate project preferences for each stakeholder group based on own criteria weights and all-respondent performance assessments	Multiplicative aggregation	Research team	
	Calculate project preferences for virtual sustainability viewpoints	Assign criteria weights for strong and weak sustainability	Research team	X

As we progress through the appraisal steps and stages of the survey, we will also address some of the biases that could arise along the way. The literature has highlighted a number of potential risks with the elicitation and quantification of human judgments. Based on the work of Montibeller & von Winterfeldt (2015), Table 3 summarises the cognitive biases that will be addressed in our appraisal process. Because the topic of HS2 was very much current at the time of this research and therefore politically sensitive, particular attention will be given to motivational bias.

Table 3: Selection of cognitive biases to look out for, inspired from Montibeller & von Winterfeldt (2015).

#	Biases	Short description	Covered where
1	Myopic problem representation	When the problem is over-simplified e.g. failure to question underlying needs and objectives. This is particularly relevant for sustainability assessments which by definition encompass a wider scope in time and space	Project options
2	Omission bias	When an important variable is overlooked, which limits respondents' answers e.g. missing criterion or a too narrow set of alternatives	List of criteria
3	Proxy bias	When a proxy is used and receives a higher weight than what it intends to measure e.g. due to different positioning in a long cause-effect chain	List of criteria
4	Splitting bias	When the way criteria are grouped affects their weights e.g. in a value tree	List of criteria
5	Overconfidence bias	When a respondent overestimates a criterion because he/she is more knowledgeable (or the opposite)	Performance assessment
6	Desirability (or motivational) bias	When a respondent distorts judgments in order to favour a preferred alternative	Performance assessment

We now follow the stages of the survey process to describe our appraisal methods.

Questionnaire design

Several of the initial appraisal steps were conducted and defined during the process of designing the questionnaire.

Project objectives

Objectives should be defined before projects are assessed. A statement of objectives clarifies what the decision is trying to achieve, yet it also frames the problem at hand, thereby limiting the options that may be considered. The defining of objectives therefore has considerable influence on subsequent appraisal steps. In a full MAMCA process, the definition of the problem and brainstorming about alternatives (options generation) is an important part of the reflexive process.

In the real world of transport planning, however, objectives are typically set by governments, and not always in transparent ways. In the case of HS2, the objectives laid out by the UK government are as follows (HS2 Ltd, 2013:section 3.1):

- Provide sufficient *capacity* to meet long term demand, and to improve *resilience* and *reliability* across the network; and
- Improve *connectivity* by delivering better *journey times* and making *travel easier*

We reproduced these objectives "as is" in the first section of the questionnaire. Limiting the scope in this way requires respondents to accept the validity of the stated objectives and arguably raises concerns about addressing wider sustainability issues. However, conducting a full MAMCA process was beyond the scope of this research.

Project options

During the early stages of the HS2 Phase I appraisal process, a number of alternatives were proposed and assessed. In the questionnaire we selected two rail proposals for further analysis and comparison. One is an alternative high-speed rail alignment following an existing transport corridor (the M1 motorway alignment, see HS2 Ltd, 2012). The other is an extended upgrade to the existing West-Coast Main Line. This upgrade would tackle 'bottlenecks' and provide additional capacity mainly through a programme of train lengthening, increased frequency, modernisation of junction designs as well as the provision of additional tracks in some locations (HS2 Ltd 2013b; Atkins 2012). Having decided to adopt the official HS2 goals for our own appraisal process, we selected these particular proposals because they, too, accept the objectives of HS2 as given and seek to meet those same objectives through alternative projects. Furthermore, both are rail projects, which aids comparison with HS2. Finally, both proposals were sufficiently well developed for there to be plenty of information available on the potential impacts of each.

The questionnaire displayed a summary table with key features of each project (see Table 4), as well as a map showing the three alignments (see Figure 1). More detailed descriptions of the three projects (see Appendix A) were available by clicking a button in the online survey or from the interviewer. Attention was given to writing the descriptions as impartially as possible to avoid inferring potential positive or negative impacts.

Table 4: Summary of the three project options assessed in our survey.

	HS2 Phase I	Alternative 1: **West Coast Main Line upgrade**	Alternative 2: **High Speed Rail along M1 motorway**
Base investment cost	ca. £20 billion (£19.4-21.4bn)	ca. £3 billion (£2.6-3.8bn)	ca. £22 billion (£2.2bn more than HS2 Phase I)
Journey time between London Euston and Birmingham	49 minutes	73 minutes *Currently: 85 minutes*	55 minutes
Maximum speed	250 mph (=400 kph)	140 mph (=225 kph) *Currently: 125mph (=200kph)*	186 mph (=300 kph) *Same as HS1 between London and Paris*
Key features	• New dedicated line from London to Birmingham with no stations in between • Route avoids major population centres by running mostly through rural areas • Route passes through Chilterns Area of Outstanding Natural Beauty (AONB)	• Line passes through and serves many population centres between London and Birmingham • Requires very little additional land • Some disruption of existing service expected during upgrade	• New dedicated line from London to Birmingham with no stations in between • Route passes through or near many population centres • Avoids Chilterns Area of Outstanding Natural Beauty (AONB)

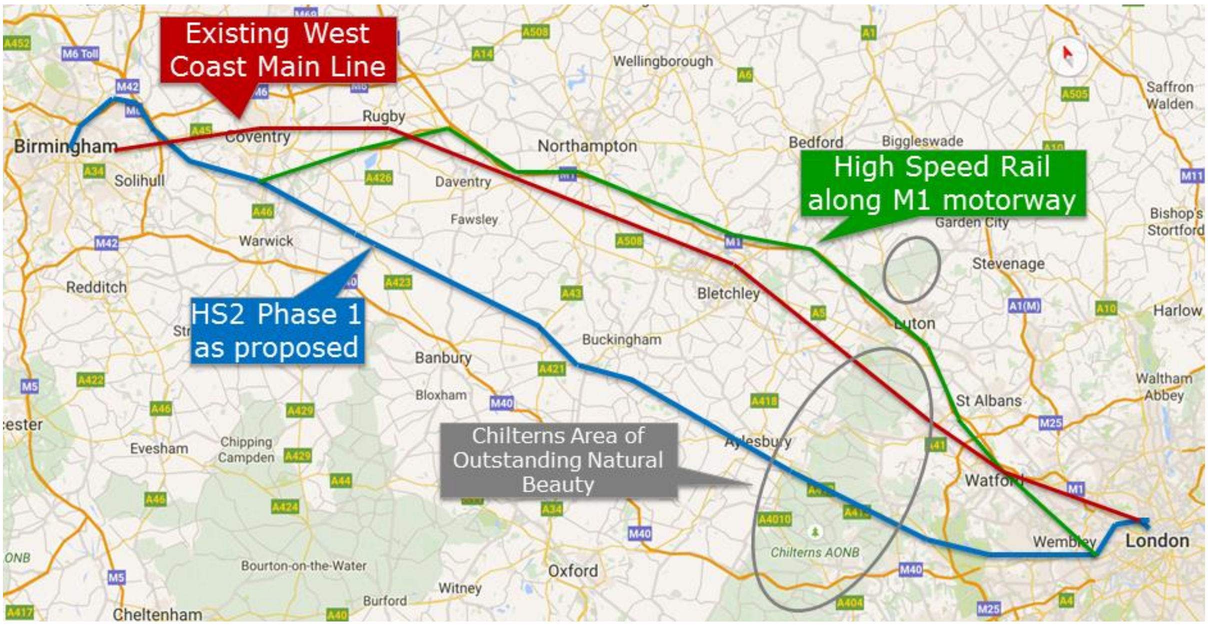


Figure 1: Alignment of the three project options assessed in our survey.

In order to address the 'myopic problem representation' bias, the questionnaire gave respondents the possibility of adding a fourth project option of their choice. A number of respondents chose to do so,[9] in which case the questionnaire incorporated this additional option into subsequent performance assessment questions. On the one hand, allowing the inclusion of such options raises comparability challenges since they do not meet the stated project goals; on the other hand, doing so provides an opportunity to record the feedback and proceed with the survey.

List of criteria

Producing a comprehensive and coherent list of criteria from which respondents could pick and prioritize is one of the significant contributions of this research. Our team put considerable effort into developing and implementing a process that was both iterative and interactive, resulting in a robust list of criteria that not only contributes to the quality of our results, but that we believe can be applied with minor adaptation to a broad range of transport projects.

We chose to define the appraisal criteria in terms of "impacts" (for example, "climate" is not an impact, whereas "climate change" is). Proxy bias was addressed by adopting a uniform definition of 'impact' inspired by the "Drivers, Pressures, State, *Impact* and Response" (DPSIR) framework as a means of structuring and analysing effects in long causal chains. Furthermore, the choice of the word 'impact' suggests a focus on effects that are

[9] Several respondents added a "Do minimum" option, some because they saw a need to establish a neutral baseline, others because they contested the stated goals of increased capacity and speed (arguing for example that accessibility, affordability and quality of journey experience on the rest of the network was more important in the UK context). A few others contested the geographical scope and chose to add investment in urban mobility (centred around improving public transport and cycling facilities) as a more realistic and cost-effective alternative for improving mobility (defined mostly in terms of accessibility) and for reducing carbon emissions.

exceptionally important for management and decision-making, thus directly illustrating consequences of human action. Impacts can be positive (benefits), negative (costs), or both.

Our aim was to create a list of impacts that encompasses all three dimensions of sustainability: economic, social, and environmental. To this end, we categorized impacts based on social cost theory, distinguishing between internal costs and benefits (direct project impacts including user impacts and net project cost to government) and external costs and benefits (indirect impacts or externalities). The latter was then subdivided into societal impacts and environmental impacts. This categorization also helped respondents grasp the criteria more quickly when viewing them onscreen.

In terms of scope, we sought to include all potentially relevant impacts – in other words, not just those which are specifically known or agreed upon, but any that might be of interest to various stakeholders, including future generations. The purpose of comprehensiveness is to address omission bias and ensure conceptual validity in terms of sustainability (where comprehensiveness is key, see Table 1). Pryn et al. highlight the need for "new and if possible, standard set of criteria for assessing sustainable transportation altogether", as criteria in MCA are otherwise limited to the planning objectives (2015:p338). Macharis et al. suggest MAMCA would naturally cover all the effects as they would be "reflected in the goals of the stakeholders (if all relevant stakeholders are included)" (2009:p188).

Therefore we adopted an iterative, mixed deductive/inductive approach to developing a final list of criteria. The starting point was the already comprehensive list contained in the official Transport Analysis Guidance (WebTAG) by the UK government (Department for Transport 2014c) and the (older but still relevant) environmental assessment guidance for roads and bridges (Standards for Highways, n.d.). These were complemented by the impacts assessed in the HS2 Appraisal of Sustainability (Booz & Co. and Temple 2011) and Environmental Statement documents (HS2 Ltd 2013a). These two reports were helpful in pointing out a number of more detailed HS2 and rail-specific criteria (e.g. 'solid waste and disposal' due to tunnelling).

Our approach also involved gathering input from transport professionals and sustainability experts. The feedback we received in interviews and discussions on each version of the criteria was extremely helpful in augmenting the list of relevant impacts and refining their names and definitions.

Finally, the approach involved in-depth discussions among the members of our research team, who encompass a broad range of expertise in transport, energy, environment and sustainability. In order to ensure consistency and clarity in the criteria names and definitions, we established a checklist of dimensions to consider (e.g., magnitude vs. uncertainty; outcomes vs. causal mechanisms; see Appendix B for details). Furthermore, we documented our discussions and the reasons for our choices (see Appendix C).

There were a number of tensions to resolve to ensure impacts were comprehensive and mutually exclusive, yet limited in number. It was decided for example to use 'carbon footprint' to capture all greenhouse gas-related impacts, regardless of source: embedded carbon from construction, fuel-related emissions arising from transport operations, and potential modal shift from road and/or air to rail. Although modal shift can be seen as an important goal, it is a mechanism contributing to carbon footprint, not an impact.

To make assessment as user-friendly as possible, we chose criteria names that could be easily understood by respondents, were consistent with names of other impacts (e.g., carbon footprint and material footprint), and were as succinct as possible without losing accuracy in terms of what they covered in the detailed descriptions. To avoid conflicting assessments, it was important to consider whether components of an impact could diverge when assessing options, which would therefore require two separate impacts (e.g. rail capacity for freight vs. passengers as distinct variations). Another consideration was for impacts to adequately capture what mattered to the respondent. For example, although ‘capacity for freight’ and ‘carbon footprint’ may be correlated (if an increase in rail capacity leads to a shift of freight from road to rail and a corresponding decrease in carbon emissions), these are still two distinct impacts: modal shift is not the only potential benefit of increase in rail capacity, nor the only driver of carbon emissions. The descriptions refer to the connections, but also guide the respondents toward the impact that is most essential to their concern. Although the full descriptions were available for display by clicking a button available throughout the questionnaire, conducting interviews helped greatly in ensuring the correct criterion was selected depending on what the respondent ‘had in mind’.

One of the challenges we faced in defining the boundaries of impacts was the appropriate choice of dimension for delineation in cases where multiple dimensions were deemed useful and reasonable. For example, instead of distinguishing between users and non-users, it is possible to distinguish along dimensions of time and space. In general impacts are assumed to apply to all phases of the project’s life cycle, but some impacts are more relevant during the construction phase (e.g., waste disposal and therefore road traffic disruption), while some impacts differ in quality between phases (e.g. noise from construction is not comparable to noise from operation). Where relevant, these considerations were included in the impact descriptions. In terms of the spatial dimension, geographic scope is assumed to be the entire railway line. Yet some impacts are more relevant in an urban context (e.g., housing in the London area) and others in rural areas. One could consider deconstructing the problem into phases and into the official 26 line segments (Community Forum Areas, see HS2 Ltd., 2013). But that would also result in an exponential number of assessments and would defeat the purpose of comparing between full alternatives with similar geographical footprints. These were therefore left to the consideration of the respondents.

The final list of 28 impacts is presented in Table 5, with full definitions provided in Appendix D.

Table 5: Final list of 28 criteria based on official documents and interviewee input.

Direct project impacts *(internal costs & benefits)*	**Indirect societal impacts** *(externalities - people)*	**Environmental impacts** *(externalities - planet)*
1. Journey cost & affordability	1. Accessibility	1. Agriculture, forestry & soils
2. Journey experience	2. Accidents & safety	2. Air quality
3. Journey reliability & system resilience	3. Community disruption & severance; blight	3. Biodiversity & nature
4. Journey time	4. Equity & distributional effects	4. Carbon footprint
5. Project costs	5. Land use & urban development	5. Material footprint
6. Project delivery risks	6. Landscape, townscape & cultural heritage	6. Noise & vibration
7. Rail capacity for freight	7. Prestige & image	7. Solid waste & disposal
8. Rail capacity for passengers		8. Water & land contamination
9. Traffic & transport disruption		9. Water resources & flood risk

10. Transport integration & connectivity	8. Rail industry growth & innovation 9. Regional economic development & regeneration

Questions to identify stakeholder groups

For the purposes of identifying stakeholder groups, and in particular transport professionals with a sustainability viewpoint, we asked respondents questions about their professional background and experience. The questions covered

- educational background, including transport and environmental studies
- sector of employment
- type of involvement with HS2/transport infrastructure
- areas of focus/analysis within transport planning and appraisal (e.g., social and environmental impacts)

Questionnaire structure

Table 6 summarises the structure and components of the full questionnaire. The commercial survey tool by Qualtrics was selected for two main reasons: visually appealing question types for handling the core of the process (parts 3, 4 and 5); and flexibility with regard to integrating respondents' extra project options and criteria (parts 1 and 2) seamlessly into the subsequent flow of questions.

Table 6: Questionnaire structure and summary. C=space for adding comments or explaining reasoning. P=button for displaying project descriptions. I=button for displaying criteria definitions ('impacts'). S=button for displaying scale (multiplicative AHP).

Part	Title	Description	C	P	I	S
Intro	(University/funding partner logos)	Introduction to the research and general purpose, usual disclaimers, basic instructions and contact information	-	-	-	-
1/8	HS2 Phase I and its alternatives	Presentation of 3 pre-selected project options, with possibility to add one more	X	X	-	-
2/8	Criteria definitions	Presentation of 28 appraisal criteria, with possibility to add up to 3 more	X	X	X	-
3/8	Criteria selection	Mark between 3 and 28 criteria (suggested number: 6-9)				
4/8	Criteria prioritisation	Sliders to rate the relative importance of each criterion selected	-	X	X	-
5/8	Assessment of project options	9-point scale for assessing relative performance of each pair of project options on each criterion selected; randomised iteration through all selected criteria; extra fields if a 4th project option was added in part 1	X	X	X	X
6/8	Sustainability dimensions	5-point scale for weighing relative importance of each pair of sustainability dimensions (economy, environment, society) (optional section)	X	-	-	-
7/8	Satisfaction with official appraisal	4-point scale (very-somewhat-not satisfied, don't know) plus comment field for each criterion selected (optional section)	X	-	-	-
8/8	Your background	Involvement with HS2, sector of employment, level and type of analysis (if applicable), education and training, whether (and where) personally affected by HS2	X	-	-	-
End	(Thank you screen)					

As parts 6 and 7 of the questionnaire were not directly related to the appraisal process, we left these as optional.

Response elicitation

The next three appraisal steps were conducted through the elicitation of responses to our online questionnaire.

Criteria selection

The questionnaire presented the list of 28 criteria shown in Table 5, along with a button for displaying full definitions. Respondents were given the opportunity to add (up to 3) additional criteria, in case they felt some were missing. Respondents were also given the possibility to add open-ended comments.

Evidence that we achieved comprehensiveness in the list is suggested by the fact that in discussing early versions of the list with interviewees, many additional criteria were suggested, but with later versions, far fewer. In the final version of the questionnaire, very few respondents commented or added to the list provided.

From the full list of 28 criteria (plus any the respondent had added), respondents were asked to select "at minimum 6." The software was set up to require at least 3 but could accommodate any number up to 28 (plus any added criteria). From an analysis perspective, more is better; from a user perspective, fewer is better, as each additional criterion lengthens the assessment process. In balancing the benefits of more vs. fewer criteria, we suggested that respondents select "at minimum 6." In practice, respondents rarely picked more than 9.

There was some debate as to the necessity of distinguishing between *contextual relevance* and *normative preference* (importance) as the basis for criteria selection. Some respondents considered this to be a critical distinction, with the former representing an objective judgment as to whether particular criteria are relevant for specific projects and the latter an opinion as to which impacts we should care about. One respondent, for example, rated biodiversity and carbon footprint very highly in principle, yet did not deem it necessary to select them in this particular case, because he considered the marginal *differences* among the three projects to be too small to matter.

We chose to circumvent the issue through careful phrasing of the question to avoid mentioning either "relevance" or "importance"; we simply asked respondents which criteria they thought "*should be used* for assessing the pros and cons of HS2 Phase I and its alternatives [emphasis added]." In other words, we elected to let respondents select criteria on whatever basis they chose. Most respondents were content with this lack of specificity, perhaps intuitively conflating relevance and importance in their selection. Some respondents, however, expressed concern that criteria which are less relevant for *this particular case* might nonetheless be given high prioritisation.

Criteria prioritisation
In the next step respondents were asked to prioritize the criteria they had selected. Specifically, they were asked to "rate the relative importance of each criterion".

While pairwise comparisons are known to produce more accurate results, it also increases the number of judgements exponentially. We therefore opted for direct weighing using a sliding scale rated between 0 and 10. Respondents were asked to set their most important criterion to 10 and rate the others relative to that one (swing weights). Respondents were found to be comfortable with using sliders, which provided an easy-to-understand and consolidated visual representation of their preferences (see Figure 2).

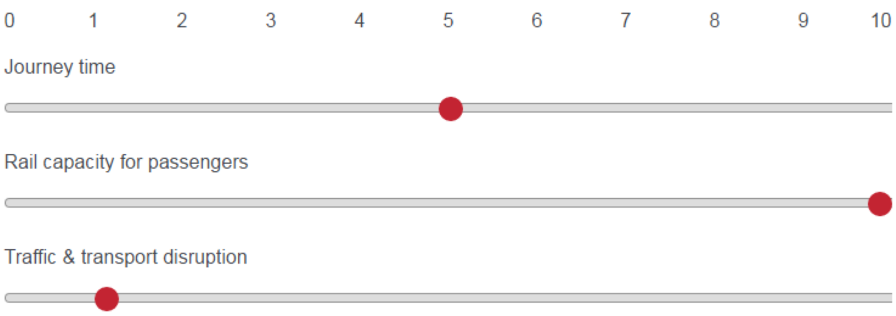


Figure 2 Questionnaire part 4: sliders used for criteria prioritisation

Performance assessment
As the assessment of project performance forms the basis of the entire appraisal, it is important to address issues of accuracy and objectivity. Accuracy involves both the assessor (whose judgement is solicited) and the assessment process (how the judgement is elicited). Determining who should conduct the assessment involves a value judgement about who is sufficiently qualified to be able to make an accurate assessment of project performance.

On this issue we made a key methodological choice to ask the same people who had selected and prioritized criteria in the previous step to also conduct the assessments. Procedurally this involved each respondent assessing project performance for each criterion he/she had selected. This approach is unusual: more commonly, the prioritization of criteria is decoupled from the assessment of project performance, with the latter performed by 'experts' using available knowledge and forecasts (Macharis and Bernardini 2015). However, relying on traditional transport experts may introduce overconfidence bias with respect to those criteria that transport experts are accustomed to assessing, such as capacity and traffic impacts, at the expense of wider economic, social and environmental impacts, with which they may be less familiar.

We therefore decided to give precedence to a more social-constructionist approach. Since our interviews specifically targeted transport professionals who were familiar with HS2, we felt it was reasonable to assume a generally sufficient level of competence among respondents. We also assumed that those respondents who selected particular criteria were also best qualified to make an expert judgment about them. Because this may not always be the case, however, the phrasing of our question about project performance explicitly asked respondents to "evaluate to the best of your ability, however feel free to skip directly to the next question if you have no opinion." One improvement could be to ask respondents to rate their level of confidence in their own assessments, but we perceived it to be more efficient to ask respondents generally to explain their ratings. This qualitative approach helped respondents clarify their answers and improve the quality of the input and also provided the researchers with a more finely grained understanding of the numerous complexities hidden behind the assessment of a single criterion.

The assessment process itself also influences the accuracy of assessment data: in particular whether the process elicits people's judgements accurately (in other words, does it accurately capture people's judgements?). We therefore selected the Analytical Hierarchical Process (AHP) for conducting the assessments. Because of its cognitive simplicity (reducing complex decisions down to a series of pairwise comparisons), AHP captures people's judgements accurately and has been shown by many researchers in many settings to be a reliable and robust method. In order to give flexibility in the number of project options considered (since respondents had the possibility in part 1 of the questionnaire to add an option) without losing accuracy in the calculations, we selected the multiplicative variant of AHP (Olson et al., 1995).

The questionnaire iterated randomly through all selected criteria and asked respondents: "For each pair of project options below, which one do you believe would perform better in terms of *<criterion>*)" (see Figure 3). This formulation is important so that each alternative is assessed from the perspective of a positive performance, independently of whether the criterion is a cost or a benefit. The multiplicative AHP scale was adapted to this case based on Lootsma (1999; 1993) and explained to respondents as in
Table 7.

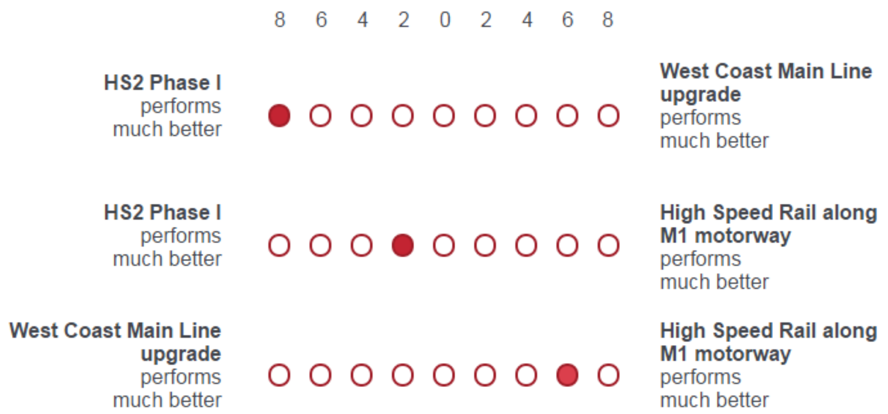


Figure 3: Questionnaire part 5: 9-point scale matrix table used for pairwise comparisons in the assessment of project performance

Table 7: Multiplicative AHP scale, adapted to the project assessment question.

Scale	Definition	Explanation
0	Perform equally	The two project options perform equally on this criterion and are equally desirable
2	Performs slightly better	Experience and judgment slightly favour one project option over the other for this criterion; this option is somewhat more desirable
4	Performs better	Experience and judgment definitely favour one project option over the other for this criterion; this option is (definitely) more desirable
6	Performs much better	A project option is favoured strongly over the other for this criterion; its dominance is demonstrated in practice, this option is much more desirable

8	Performs vastly better	The evidence favouring one project option over the other for this criterion is very strong; this option is vastly more desirable

In addition to accuracy, objectivity is also considered to be an important aspect of assessment quality. Ideally assessments of project performance should be "objective" and value-free – in other words, separate from people's preferences or desires. In reality, however, respondents may be subject to motivational bias (e.g., exaggerating the 'objective' assessment in favour of their preferred option), whether consciously or unconsciously. In an effort to reduce motivational bias due to the potential influence of vested interests (at least at an organizational level), respondents were asked to answer questions from their "individual perspective based on your cumulative knowledge and experience, not just as a representative of your current organization or job." We also tested for motivational bias in the results.

Although it can be questioned how objective such assessments are or can be, it is worth pointing out that even if not objective in *outcome*, they are at least *procedurally* objective in that the assessment process is separated from the prioritization process, and the assessment of each criterion is conducted in exactly the same way, regardless of how important the criterion is considered to be.

4. Results

Performance assessments for each criterion

The project performance assessments for each criterion form the basis of the appraisal. The first step is to combine the assessments of all respondents to come up with an average performance assessment for each of the 28 criteria. This is computed as the geometric mean of all individual pairwise comparisons. The calculation of the individual results for the assessment example in Figure 3 is computed in Table 8 below. All formulas applied are standard calculations detailed in Olson et al. (1995).

Table 8: Calculations for assessment example shown in Figure 3. Calculations based on (Olson et al. 1995).

$\delta(j,k)$	HS2	WCML	M1
HS2	0	8	2
WCML	*-8*	0	-6
M1	*-2*	*6*	0

$e^{\ln(2)\cdot\delta(j,k)}$	HS2	WCML	M1	*Assessment*	Results (geomean)	Normalised
HS2	$e^{\ln(2)\cdot 0} = 1$	$e^{\ln(2)\cdot 8} = 256$	$e^{\ln(2)\cdot 2} = 4$	HS2	$\sqrt[3]{1\cdot 256\cdot 4} = 10.07937$	79.8%
WCML	0.00390625	1	0.015625	WCML	0.039373	0.3%
M1	0.25	64	1	M1	2.519842	19.9%
				∑	12.63858	100%

Figure 4 presents the results of all assessments by all respondents for our case. The bars show the results for each criterion independently of other criteria and are ranked from best to worst performance on HS2 Phase I (for viewing purposes). This graph not only shows respondents' assessment of the relative performance of each project on each *criterion*, but also provides an overview of how well each project performs on each of the three *impact categories:* direct impacts (DIR), indirect societal impacts (SOC), and environmental impacts (ENV). The results also show how many respondents selected each criterion, demonstrating wide variance in the perceived relevance/importance of various criteria.

HS2 is expected to perform relatively better on most direct project impacts, particularly in terms of having less *traffic & transport disruption* (mostly because of running through less populated areas and not requiring service reductions as in the case of upgrading WCML). HS2 is also expected to perform well on *journey time*, *passenger capacity*, *freight capacity* (resulting from freed-up passenger capacity on conventional lines), and *reliability*. Notably, HS2 Phase I is expected to outperform alternatives in terms of *regional economic development & regeneration*, a goal which has become increasingly important in the debate surrounding HS2.

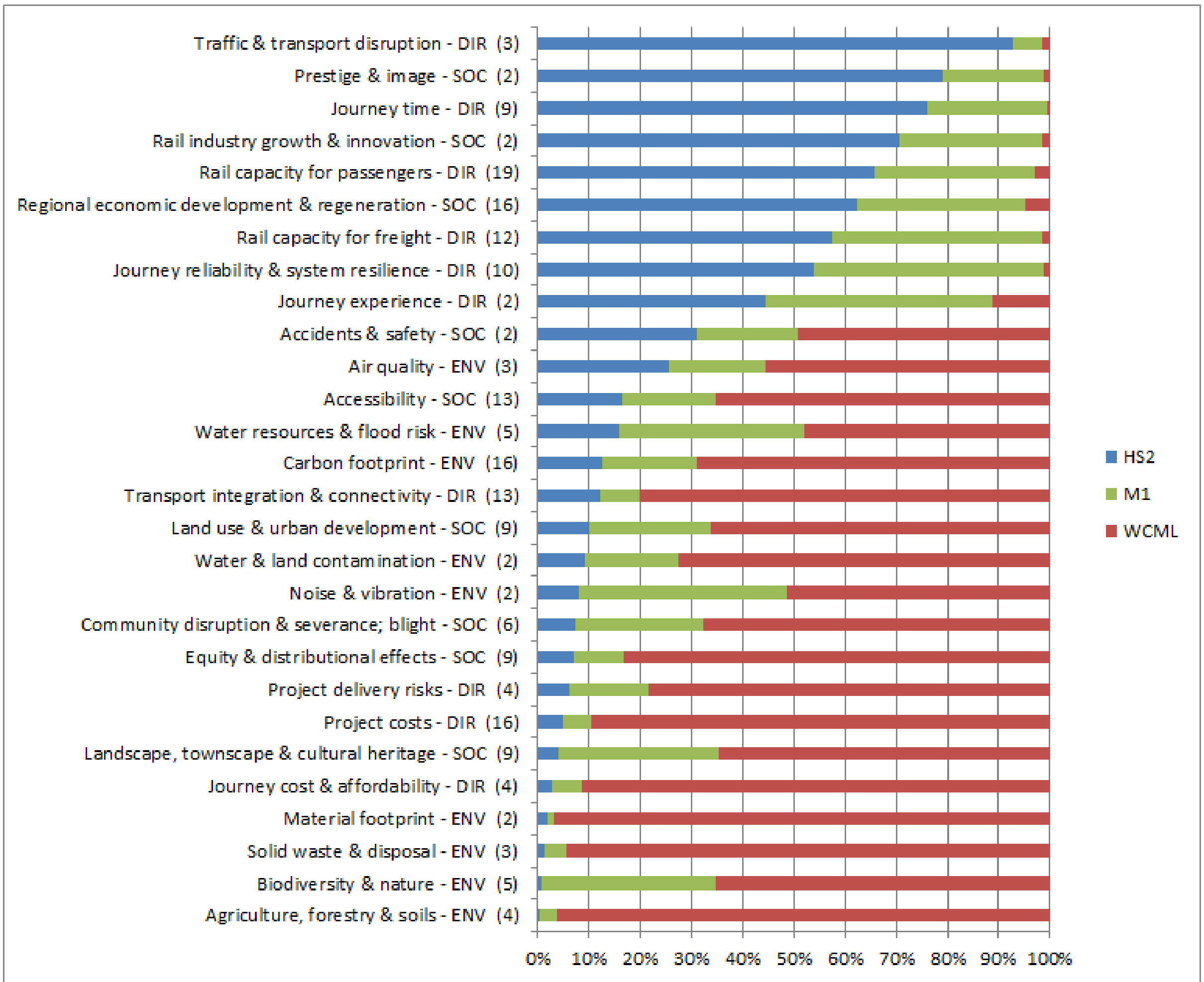


Figure 4: Performance assessments for all 28 criteria based on pairwise comparison of projects (HS2, M1, WCML). DIR=Direct impacts, SOC=Indirect societal impacts, ENV=Environmental impacts. Criteria ranked in order of performance on HS2 Phase 1. (x) = number of valid assessments with 33% consistency threshold. All criteria with fewer than 4 valid assessments are ultimately excluded from the appraisal.

The assessment therefore confirms the official position towards HS2 when seen from the original goals. Of all the official goals of HS2, only *transport integration & connectivity* is assessed as performing poorly compared to the WCML upgrade option. This was explained in interviews as being due to the nature of HSR (limited number of stations) as well as to the lack of direct connection with existing transport hubs (e.g., the New Street station in Birmingham, and to some extent to airports).

However, the M1 alignment alternative and particularly the WCML upgrade outperform HS2 Phase I on most environmental criteria. The assessment confirms the expected (and particularly controversial) poor performance of HS2 Phase I on *biodiversity & nature* raised by the House of Commons environmental committee report (House of Commons Environmental Audit Committee 2014). HS2 Phase I performance is also poor on a number of societal criteria, such as *accessibility*, *land use*, *landscape*, and *equity & distributional effects*.

The projects have different expected performance on *carbon footprint* (the environmental criterion receiving by far the most assessments). This is noteworthy because all three are *rail* projects and thus ought to perform similarly in terms of carbon emissions during operation and possibly even in terms of the potential for modal shift. Respondents explained this assessment to be due to the much higher footprint of embedded carbon associated with construction and tunnelling for either HSR option.

Criteria used for appraisal

With 28 criteria in total and each respondent selecting only 6-9 for assessment, there were not enough assessments for every criterion to warrant keeping all 28 in the appraisal. This is especially true since the assessments were not evenly distributed across the criteria. Based on research on the number of interviews required for reaching "saturation" (where answers converge and new judgments do not add new information or influence the overall result), theory suggests a target of 12 and a cut-off of 6 consistent assessments for each criterion to ensure validity (Guest 2006). According to the AHP process, consistency checks are calculated and all inconsistent judgments (>10%) should be excluded. Therefore a strict application of theory would require eliminating any assessments with an inconsistency higher than 10% and any criteria assessed by fewer than 6 respondents.

In practice, however, we found this eliminated too many of the respondents' input and left too few criteria. The AHP process often includes a review session/round where inconsistent answers are discussed and adjusted. The questionnaire-based process consisted of one round, leaving only the option to include or exclude answers deemed invalid[10]. A strict consistency cut-off was found to favour answers that gave more equal performance to all three options, whereas allowing higher cut-offs allowed for more clear-cut answers to be included. Below 50%, the intention of respondents was still clear even if the use of the scale was not entirely accurate[11].

[10] The online questionnaire did not calculate consistency immediately. Although this could be added, doing so is also a trade-off with the amount of time required from each respondent. 1h to 1h½ was usually seen as acceptable and we tried to respect that.

[11] For example, in terms of Journey experience, one respondent assessed HS2 as being definitely more desirable than the M1 alignment or the WMCL upgrade (value = 4 for both), but also stated the WCML upgrade was definitely less desirable than the M1 alignment (value = -4). This implies that a higher performance for HS2 over WMCL should have been entered (e.g. a value of 6 or 8), but the 'spirit' of the answer is clear and this way of answering was quite frequent. In this particular case, the consistency was 40% and the input was therefore not included within the 33% cut-off. As a result, the criterion Journey experience was excluded due to the resulting lack of valid assessments.

We examined a range of cut-offs for data validity. Table 9 shows the impact of various cut-offs (a combination of consistency threshold and minimum assessments required) on the exclusion of assessments and criteria that might be used for subsequent analysis. By tightening the quality, some criteria need to be dropped: applying a 33% consistency threshold with a minimum of 4 valid assessments results in excluding 10 criteria.

We deemed two of these cut-off points to provide a reasonable balance between data quality and suitable coverage of each of the three impact categories: 20%-min3 and 33%-min4. Although 20%-min3 would have kept more criteria in the analysis and represents greater consistency, we opted for the 33%-min4 cut-off for our subsequent analysis. Greater leniency in consistency means we prioritised incorporating people's views, even if expressed somewhat inconsistently, over categorically excluding people who fit less well into a particular rationality framework. On the other hand, we decided to require more respondents to have assessed each criterion for it to be included (again, our priority was to "listen" to more respondents rather than fewer).

Table 9: Criteria drop out as validity thresholds are tightened: consistency of assessments and minimum number of valid assessments per criterion. DIR=Direct impacts, SOC=Indirect societal impacts, ENV=Environmental impacts. We use 33% with minimum 4 respondents when referring to preference percentages in the text.

Consistency threshold	Minimum assessments per criterion	Criteria	DIR	SOC	ENV	Valid assessments	Criteria excluded
None	None	28	10	9	9	238	None
50%	2	28	10	9	9	216	None
33%	4	18	8	6	4	179	Experience, Safety, Prestige, Innovation, Material, Noise, Waste, Contamination Air, Traffic
20%	3	20	9	6	5	166	Experience, Safety, Prestige, Innovation, Material, Noise, Waste, Contamination
10%	6	11	5	5	1	100	Experience, Safety, Prestige, Innovation, Material, Noise, Waste, Contamination Air, Traffic Affordability, Risks, Community, Soils, Biodiversity, Water

Because those criteria dropped were the least often selected implies they were overall less relevant for this case, and when they were selected they tended to receive lower relative weights. The 18 criteria left for assessment are those that figure among the top 10 highest weighted criteria for each group. Therefore the final list of 18 criteria for assessment can be said to represent best the major decision points for this case. Table 10 shows the 18 criteria we retained for our appraisal process.

Table 10: List of 18 criteria retained for project appraisal, based on 33% consistency threshold and minimum 4 assessments per criterion.

Direct project impacts (8)	Indirect societal impacts (6)	Environmental impacts (4)
• Journey cost & affordability • Journey reliability & system resilience • Journey time • Project costs • Project delivery risks • Rail capacity for freight • Rail capacity for passengers • Transport integration & connectivity	• Accessibility • Community disruption & severance; blight • Equity & distributional effects • Land use & urban development • Landscape, townscape & cultural heritage • Regional economic development & regeneration	• Agriculture, forestry & soils • Biodiversity & nature • Carbon footprint • Water resources & flood risk

Assignment to stakeholder groups

We assigned respondents to stakeholder groups in two steps (see Figure 5): 1) applying a "sustainability expertise" filter; and 2) categorizing by sector of employment. In order to qualify as a "sustainability expert," the respondent had to meet two of the following three criteria:

- Have formal education in environmental studies (university degree or university-level coursework)
- Conduct environmental analysis of HS2/transport infrastructure "to a great extent"
- Conduct analysis of HS2/transport infrastructure primarily at "society-level (wider economic impacts, social/environmental issues)" rather than "project-level (system design, user benefits, project costs, etc.)"

As it turned out, the sectors aligned closely with sustainability expertise, with only the academic sector containing both, but this would not have to be the case. It is significant to note that *none* of the respondents employed in government/public sector met the criteria for sustainable transport professional. Also significant, though unsurprising, is that *all* NGO respondents did meet the criteria.

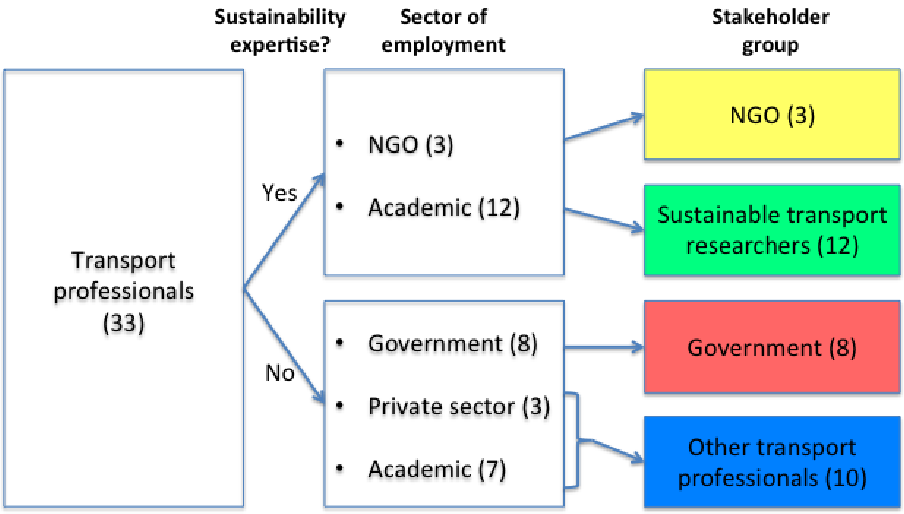


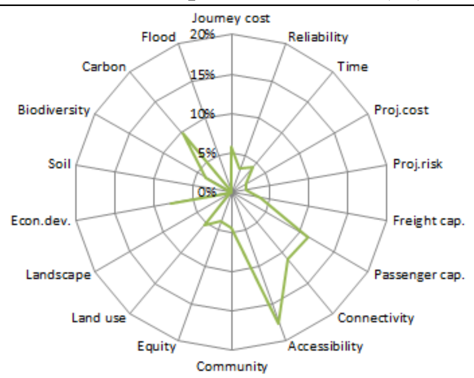
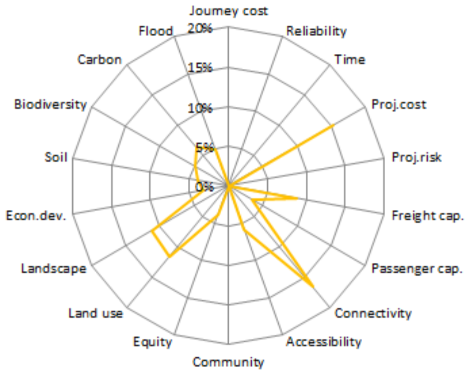
Figure 5: Assigning transport professionals to stakeholder groups. First filter: sustainability expertise. Second filter: sector of employment.

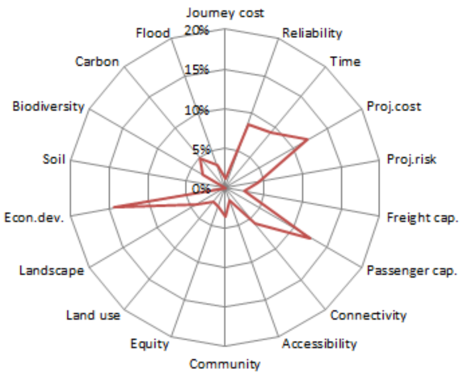
In determining stakeholder groups, we decided to separate out NGO respondents from other sustainable transport professionals. Although a small group (3 respondents), we did this for two reasons: 1) an NGO perspective is interesting to examine; and more importantly, 2) as identifying a sustainability perspective is one of the key purposes of this research, we thought it prudent to remove the possible influence of vested interests. As it contains only academics, we decided to call this stakeholder group "sustainable transport researchers." Next, we decided to separate out government as another stakeholder group, because we consider the perspective of government, who proposed and ultimately decided upon HS2 Phase 1, to be particularly relevant. The remaining transport professionals included both academics and private sector, whom we decided not to split out, partly because the sample was so small and because the perspective of "other transport professionals" was of less targeted significance for this research.

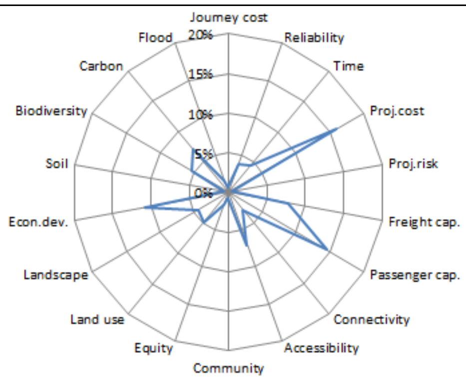
Criteria weights for each stakeholder group

Criteria weights were recorded to one decimal place and normalised (normalisation allows for grouping by types of respondents). These are for the 18 criteria retained in the appraisal.

Table 11: Criteria prioritisation: percentage weights and ranking per stakeholder group.

Sustainable transport researchers (12)			**NGOs (3)**		
					
1	Accessibility	18%	1	Connectivity	17%
2	Passenger cap.	11%	2	Proj.cost	15%
3	Connectivity	11%	3	Land use	12%
4	Carbon	10%	4	Landscape	11%
5	Econ.dev.	8%	5	Freight cap.	9%
6	Journey cost	6%	6	Carbon	6%
7	Land use	5%	7	Accessibility	6%
8	Community	4%	8	Biodiversity	5%
9	Time	4%	9	Flood	5%
10	Equity	4%	10	Soil	4%
Government (8)			**Other transport professionals (10)**		





1	Econ.dev.	14%	1	Proj.cost	16%
2	Passenger cap.	13%	2	Passenger cap.	14%
3	Proj.cost	12%	3	Econ.dev.	11%
4	Time	9%	4	Freight cap.	8%
5	Reliability	8%	5	Accessibility	7%
6	Connectivity	6%	6	Carbon	7%
7	Carbon	5%	7	Biodiversity	5%
8	Landscape	4%	8	Land use	5%
9	Proj.risk	4%	9	Time	4%
10	Community	4%	10	Landscape	4%

Project preferences for each stakeholder group

Table X shows project preferences for each stakeholder group, based on the stakeholder-group average criteria prioritization and all-respondent average performance assessments. These results are robust for a wide range of consistency thresholds and minimum number of assessments (see Appendix E).

Table X: Project preferences by stakeholder group.

Stakeholder group	Project preferences (percent)		
	HS2	M1	WCML
Sustainable transport researchers	28	31	41
NGOs	13	23	64
Government	37	39	24
Other transport professionals	32	38	31

Transport experts in government are found to favour a High-Speed Rail solution, but they are ambivalent regarding alignment: the proposed HS2 alignment and the M1 motorway corridor are equally preferred. The main reason for favouring the HSR options is the higher prioritisation given to *regional economic development & regeneration*, on which both HSR options score highly. A strong preference for HS2 is visible only if singling out the official position within government stakeholders: in this case, HS2 is given a 49% preference and the M1 alignment a lower 38% preference, with clearly lower 13% for the WCML upgrade – which seems to match well with reality. Other transport experts tend to prefer a M1 alignment over HS2, mostly because of a relatively lower importance given to *journey time*. In their case the WCML upgrade option is also deemed a realistic alternative, mostly due to a higher prioritisation given to *project costs* despite uncertainties with actual costs of an upgrade.

Testing for motivational bias

One potential complication with the proposed approach where stakeholders are those assessing the performance of the criteria is if they attempt to 'outsmart' the method by rating their preferred option higher than what could be validated by the AHP scale. Face-to-face interviews allow addressing this by challenging the choices made by the respondent if she/he appears to be biased. But unless the assessments are inconsistent, the method expects these outlying answers to average out over all respondents (hence the need for a minimum of assessments per criterion to ensure validity). A way to test for motivational bias ex-post is to compare project preferences using the respondent's *own* performance assessments against those generated by all respondents. Although performance assessments are expected to differ between respondents (which is what allows them to converge towards an overall assessment), the final project preference for one single respondent should in theory not depart with either sets of assessments.

After closer analysis, three respondents (one in each group except NGOs), were found to depart significantly. The extent of this motivational bias is illustrated in Table 12 with one particular respondent who during the interview was openly and strongly in favour of the HS2 Phase I option.

Table 12: Uncovering motivational bias, comparing one respondent's criteria prioritisation with own and overall performance values from Figure 4.

Own performance assessments			**Overall performance assessments**		
HS2	M1	WCML	HS2	M1	WCML
87%	12%	1%	62%	25%	13%

The interesting result is that the overall priority and preference does not change, but the strength of the preference is less pronounced with the overall assessments.

Sustainability viewpoints made explicit

The sustainability viewpoint provided by sustainable transport researchers sees the WCML upgrade as clearly preferable to both HSR options, with a slight preference for the M1 alignment as a second choice. This is due to the low priority given to *journey time* and also to the high prioritisations given to *accessibility*, *transport integration & connectivity*, and *carbon footprint*.

To provide a benchmark for comparison, we also construct two virtual sustainability viewpoints: "strong" and "weak." The strong viewpoint is based on the nested model of sustainability, giving higher priority to the environmental dimension over the social dimension and to the social dimension over the economic dimension. We operationalize this concept by considering our three impact categories as representing these three sustainability dimensions and then applying rank-order distribution (ROD) weights (Roberts and Goodwin 2002) as follows: direct impacts (15.3%); indirect societal impacts (32.4%); and environmental impacts (52.3%). See (Pryn et al., 2015:Table 1) for pros and cons of this approach. For the weak sustainability viewpoint, we apply equal weight (33.3%) to each of the three impact categories. For both the strong and weak sustainability viewpoints, the criteria within each category are assigned equal weights.

Figure 6 shows project preference results for the two virtual sustainability viewpoints. Based on performance assessments from Figure 4, the strong sustainability viewpoint unsurprisingly concludes on a significant preference for the WCML upgrade over both HSR options, although the M1 alignment is significantly preferred over HS2 Phase I alignment. From the weaker viewpoint of 'balancing' the three dimensions of sustainability, results are the same, albeit slightly less pronounced. In practice, this approach inflates the importance and relevance of environmental and societal impacts, in effect reversing the default practice of assigning higher weights to direct economic impacts as was seen with both governmental and other transport experts above.

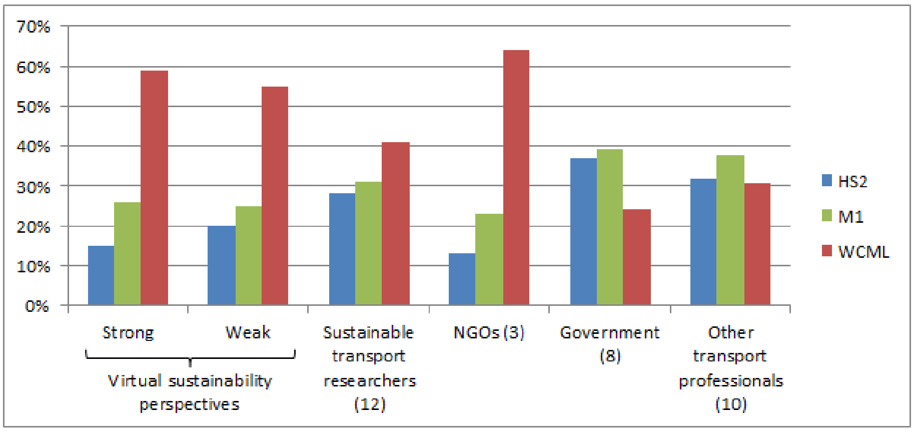


Figure 6: Results for all sustainability viewpoints (two virtual, one expert-based) compared to other stakeholder groups.

NGOs were found to strongly support the conclusions of sustainability advocates with regard to preferring a WCML upgrade, but for different reasons: they were more concerned about impacts to *land use* and *landscape & cultural heritage*. During interviews, another main critique made by NGOs about either HSR option was the lack of intermediary stations, which makes it difficult for residents near the line to support the project. The consultation process has sometimes dismissed this as a form of 'NIMBYism'[12], criticising such stakeholder groups for not thinking in terms of the wider national interest. Even as such criticism may be more dismissive than legitimate, the mere fact of its existence suggests that a "sustainability viewpoint" may not garner as much broad support if it is perceived to include self-interested groups. Although this consideration supports our decision to separate out NGO respondents from the sustainable transport researchers representing the expert-based sustainability viewpoint, we wish to emphasize that this in no way suggests that NGO representatives are inherently less expert in sustainability or that their views are less valuable – they are an important stakeholder group.

In summary, these two types of sustainability viewpoint – one bottom-up, expert-based and one top-down, principle-based – can serve as a benchmark in evaluating stakeholder preferences from a wider sustainability viewpoint.

5. Discussion: Reflections on our procedure & the appraisal

While on one hand the 'recipe' for MAMCA is clear and straightforward, this study shows that a number of details need to be carefully considered to meet conceptual, practical and

[12] NIMBY = Not In My BackYard

procedural requirements for its application to this case. The first challenge was to meet the needs for comprehensiveness required by the nature of sustainability and to insure scientific validity with regard to addressing various cognitive biases known to MCA methods, and yet at the same time keeping the method simple, transparent and cost-effective. The tool should also balance the need for obtaining presentable final results (the positivist side of transport appraisal), yet at the same time enable learning and 'negotiation' (the reflexive side of transport appraisal). A few important lessons can be learned:

Conceptual soundness

- Criteria and their descriptions are cornerstones of the method. Validity for sustainable transport appraisal requires comprehensiveness in the long list of relevant impacts (Appendix II). Defining this list required a lot of effort and thinking, which highlighted the need for an analytical framework to inform the naming and descriptions. The result of this is presented in Appendix III.
- Ensuring an understanding of what respondents have in mind for selecting a specific criterion is necessary to insure weights and assessments are properly ascribed so they can later be summed over respondents. The interview format allows this to happen. The implication is that a 'hands-off' assessment in the form of an online survey is much less likely to be answered properly, if at all.
- While some respondents expressed concerns with bundling together *relevance* and *importance* in the selection and weighing of criteria, most respondents felt it was natural to do so. One respondent rated biodiversity and climate very highly in principle, yet in this case he did not think it was necessary to select them as the contributions of the three projects in this case were marginal – effectively giving them a zero weight. Yet there is potential for exploring further how to decouple normative importance from more contextual relevance and relative assessments.
- The grouping of stakeholders into homogeneous groups can be particularly challenging in practice. At one extreme, there are as many stakeholder types as there are respondents. Yet patterns in preferences do emerge. In this case, those who favoured more conventional transport decision criteria such as capacity and speed were found to be supportive of HS2, while those who self-identified as 'sustainable transport experts' were by far more likely to opt for criteria where the West Coast Main Line upgrade option performed well.
- The formulation of a virtual sustainability perspective needs further thinking. The approach based on the nested model of sustainability and the application of ROD priority weights to each dimension risks artificially growing aspects that are not relevant to the problem. Yet in this case the results were found to match that of the sustainable transport expert group.
- The multiplicative AHP method appears to be robust in effectively capturing judgments. Although including or rejecting judgments by varying consistency levels reduces the number of criteria, as a whole, the final preferences do not change much.

Practical usability

- The structured interview format is key to ensure the quality of stakeholders' input. It allows the assessor to clarify the steps along the way, to address concerns about the method, and to align the understanding of the alternatives, criteria and scales used.

- The presence of the assessor helps obtain the views of those respondents who are openly against the project or the method, or who would normally stay more 'quiet' in a bigger group workshop.
- The individual interview based on a common questionnaire is more effective in terms of respondents' use of time, as they need to commit 1h~1h30 (as opposed to with workshops) and it can be scheduled (or rescheduled) at a time of their convenience.
- Structured interviews insure the questionnaire is actually answered - as opposed to an emailed mass survey that, even if well designed and comprehensive, is too easy to dismiss (we tried, but without much success).
- While it is important that all impacts are covered to avoid omission bias, it is not necessary for all respondents to assess them all. A large enough number of respondents will eventually cover all aspects of the scheme, and assessments of options eventually converge. This reduces demands on respondents.
- The process uses proven weighting and aggregation methods and requires only standard spreadsheet software for calculating and presenting results. However complexity does increase with the number of respondents and criteria to handle, and more particularly with the need for testing and visualising robustness.

Procedural adaptability

- It seemed particularly important to avoid too much top-down predefinition by allowing for flexibility and iterativeness in the process as respondents felt the need to qualify or even add their own criteria or options along the way. This also allowed ensuring criteria comprehensiveness in the earlier stages of survey design.
- The approach uncovers and quantifies some level of desirability bias. The interview format allowed experiencing first-hand when respondents were openly keen to give their preferred option higher performance for the criteria they selected, and to verify the extent of the bias.
- Deconstructing the issue into criteria and preferences enabled reflexivity and learning on the part of respondents. Progressing through the questionnaire, respondents realised the implications of their choice of criteria and of their assessment. Sometimes their choices could go against their preferred initial choice. Depending on respondents' own character, some openly accepted and reflected upon this result, while others instead chose to try to 'outsmart' the assessment.
- More research on this particular aspect seems warranted, as this challenges the assumption of 'objective' expert assessments: what would constitute a threshold to exclude overly biased assessments?
- There is potential for providing further sensitivity analysis to illustrate which criteria affect the differences in ranking between groups, which in turn could inform the decision-making processes.

6. Conclusion & Future Research

Although the official goals of HS2 Phase I (London to West Midlands corridor) were limited to traditional transport objectives such as capacity and speed, HS2 is worthy of broader investigation due to its complex and far-reaching impacts on current and future generations. As a *de facto* case of importance for multiple dimensions of sustainability, HS2 pushed the

UK's conventional technical-rationalist assessment approach past its limits, highlighting the need for new tools to support decision-making.

Motivated by a concern that standard transport appraisal methods do not adequately incorporate diverse perspectives and by the need to think more strategically about our responsibility toward future generations, this research aimed to develop and test new ways of integrating multiple stakeholder perspectives, including that of future generations, explicitly and systematically. We evaluated the feasibility of applying a modified MAMCA to assess the implications of large transport infrastructure projects for sustainability. Our research accomplished two objectives: 1) demonstrating the usefulness of conducting semi-structured interviews in conjunction with an online questionnaire for the assessment and weighting process; and 2) creating explicit sustainability viewpoints.

The proposed comparative stakeholder approach to sustainable transport appraisal seems promising for providing planners and decision-makers with a means of quantifying indirect impacts, thereby making them more visible and comparable. In the context of sustainable transport appraisal, gaining such visibility is critical if we are to avoid giving default priority to those impacts that are more easily quantifiable and monetizable, a bias inherent in first-generation assessment tools[13].

More fundamentally, the approach developed here contributes to the shift towards more participatory, discursive and civic types of assessment. It can help develop more systematic "active stakeholder management" procedures which make it possible to "assess the extent to which stakeholder preferences are conflicting or converging" (De Brucker, Macharis, and Verbeke 2011). Perhaps projects that generate widely diverging views should be scored negatively in the appraisal, and those with greater consensus gain positive scores – the degree of support thus becoming a criterion within the MCA. Yet the key contribution of this paper and the suggested path for future research is the implementation of a 'future generations' stakeholder in MAMCA. In the case of HS2, both the 'bottom-up' sustainability expertise viewpoint and the 'top-down' virtual sustainability viewpoint based on the nested model concurred: despite the hype, high-speed rail as proposed with HS2 does not represent a sound investment in sustainability for the UK context after all.

Future research

This project opened up new horizons for future research in Sustainable Transport Appraisal (STA). First, from a practical perspective in addressing sustainability, there is the need for a more standard and comprehensive set of sustainable transport criteria that could be used for appraisal (ex-ante), monitoring and evaluation (ex-post) (Pryn, Cornet, and Salling 2015). If the list of criteria is sufficiently comprehensive to include impacts of a wide range of transport projects, then in theory even projects with very different goals could be compared.

[13] While it may never be possible to fully integrate the two approaches of CBA and MCA, a question that arises is: shouldn't they really concur, and if they don't, why not? Is it a methodological issue (neither method is sufficiently developed or able to consider everything, therefore each can provide only a partial picture) or an ontological one (the idea that there is one single truth out there waiting to be measured and that there is one single best solution is perhaps wrong; transport is too complex)? A parallel evaluation of both methods through various stages of appraisal of a large scale transport project such as HSR seems particularly relevant for further exploration.

This research highlighted a number of gaps and inconsistencies in the existing, state-of-the-art WebTAG guidance. We feel the long list produced in this research based on the extensive HS2 case is a step in that direction. With this in mind, further research on implementing *normative preference* x *contextual relevance* x *relative performance* more formally in MCA/MAMCA seems necessary when the full range of sustainability impacts need to be considered (and not only the goals of a specific scheme).

Second, there is a need for further investigating methods to give a voice to future generations in a more rigorous manner. This might amount to creating a virtual future generations 'ombudsman'//'advocate' in the process. However the top-down, theoretical approach is limited by its lack of contextuality, whereas the bottom-up, stakeholder- based approach is bound by the expertise and own boundary thinking of those interviewed. Yet, taking a more constructionist view, there is perhaps not one single best, most effective solution. We therefore conclude for now that addressing complexity can benefit precisely from making explicit these various perspectives.

There is also much evidence from the actual HS2 appraisal material that stakeholders involved critiqued the government for not genuinely considering alternatives to HS2. From an appraisal process perspective, we therefore note that there may be great advantage in formalising the use of 3rd generation MCA-based approaches early in the appraisal process, at a stage when wider options are still being considered. Because MCA requires options to compare against and because the results are expressed in terms of relative desirability of projects, it requires the explicit consideration of more than one project, and these projects must be considered on "equal" terms. This approach effectively systematises the inclusion and assessment of options in STA. Doing so would provide much-needed understanding of conflicting views, transparency of process, and more accountability towards future generations.

Flyvbjerg uncovered a number of motivations that drive megaproject developments, ranging from technological "longest-tallest-fastest" motivations that engineers are pleased about, the pride and visibility politicians can generate for themselves and for their causes, the revenues and jobs generated by construction and operation, or the simple beauty of iconic designs which are often a trademark of megaprojects. But because of this, he concluded that often "the worst projects get built rather than the best" (Flyvbjerg 2014). We would hope that further advances in 3rd generation sustainable transport appraisal can help support the delivery of transport projects that would contribute to a genuine legacy to future generations.

Acknowledgements

The authors are grateful to the Strategic Research Council of Denmark (Innovationsfonden) that funded the SUSTAIN research project.

References

Allmendinger, Philip. 2009. *Planning Theory*. Edited by Yvonne Rydin and Andrew Thornley. 2nd ed.

Atkins. 2012. *High Speed Rail Strategic Alternatives Study - Update Following Consultation*. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/3664/hs2-strategic-alternatives-study-update.pdf.

Atkinson, Giles, and Susana Mourato. 2006. *Cost-Benefit Analysis and the Environment: Recent Developments*. http://trid.trb.org/view.aspx?id=795431.

Barfod, Michael Bruhn, and Kim Bang Salling. 2015. "A New Composite Decision Support Framework for Strategic and Sustainable Transport Appraisals." *Transportation Research Part A: Policy and Practice* 72. Elsevier Ltd: 1–15.

Belton, V, and T. J. Stewart. 2002. *Multi Criteria Decision Analysis: An Integrated Approach*. Kluwer Academic Publishers.

Beukers, Els, Luca Bertolini, and Marco Te Brömmelstroet. 2012. "Why Cost Benefit Analysis Is Perceived as a Problematic Tool for Assessment of Transport Plans: A Process Perspective." *Transportation Research Part A: Policy and Practice* 46 (1). Elsevier Ltd: 68–78.

Bond, Alan, Angus Morrison-Saunders, and Jenny Pope. 2012. "Sustainability Assessment: The State of the Art." *Impact Assessment and Project Appraisal* 30 (1): 53–62.

Booz & Co., and Temple. 2011. "HS2 London to the West Midlands Appraisal of Sustainability."

Browne, David, and Lisa Ryan. 2011. "Comparative Analysis of Evaluation Techniques for Transport Policies." *Environmental Impact Assessment Review* 31 (3). Elsevier Inc.: 226–33.

Cashmore, Matthew, Tim Richardson, Tuija Hilding-Ryedvik, and Lars Emmelin. 2010. "Evaluating the Effectiveness of Impact Assessment Instruments: Theorising the Nature and Implications of Their Political Constitution." *Environmental Impact Assessment Review* 30 (6). Elsevier B.V.: 371–79.

Castles, Chris, David Parish, and 51m. 2011. "Review of the Economic Case for HS2 (Appendix 2)," no. July. http://www.51m.co.uk/wp-content/uploads/2013/08/App-2.pdf.

Cinelli, Marco, Stuart R. Coles, and Kerry Kirwan. 2014. "Analysis of the Potentials of Multi Criteria Decision Analysis Methods to Conduct Sustainability Assessment." *Ecological Indicators* 46. Elsevier Ltd: 138–48.

Cornet, Yannick, Geoffrey Dudley, and David Banister. 2016. "High Speed Rail : A Mandate for Future Generations ? (Submitted)." In *World Conference on Transport Research - WCTR 2016 Shanghai. 10-15 July 2016*.

Cornet, Yannick, and Henrik Gudmundsson. 2015. "Building a Meta-Framework for Sustainable Transport Indicators - a Review of Selected Contributions." *Transportation Research Record: Journal of the Transportation Research Board* 2531.

Cour des comptes. 2014. *LA GRANDE VITESSE FERROVIAIRE : UN MODÈLE PORTÉ AU-DELÀ DE SA PERTINENCE*.

De Brucker, Klaas, Cathy Macharis, and Alain Verbeke. 2011. "Multi-Criteria Analysis in Transport Project Evaluation: An Institutional Approach." *European Transport* 47: 3–24. http://etabeta.univ.trieste.it/dspace/handle/10077/6171.

De Brucker, Klaas, Cathy MacHaris, and Alain Verbeke. 2013. "Multi-Criteria Analysis and the Resolution of Sustainable Development Dilemmas: A Stakeholder Management Approach." *European Journal of Operational Research* 224 (1). Elsevier B.V.: 122–31.

Department for Communities and Local Government. 2009. *Multi-Criteria Analysis: A Manual*.

Department for Transport. 2014a. *Guidance for the Technical Project Manager*. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/427078/webtag-tag-guidance-for-the-technical-project-manager.pdf.

Department for Transport. 2014b. *TAG Unit A1.1: Cost-Benefit Analysis*. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/427086/TAG_Unit_A1.1_-_Cost_Benefit_Analysis_November2014.pdf.

Department for Transport. 2014c. "Transport Analysis Guidance: WebTAG," no. November. https://www.gov.uk/guidance/transport-analysis-guidance-webtag.

Dudley, Geoffrey, and David Banister. 2015. "Expertise and the Dynamics of Decision Making in Large Infrastructure Projects: From UK Trunk Roads to High Speed Rail 2." In *Paper Presented at the UTSG Conference, City University, London.*, 1–15.

Fischer, Thomas B., Urmila Jha-Thakur, and Samuel Hayes. 2015. "Environmental Impact Assessment and Strategic Environmental Assessment Research in the Uk." *Journal of Environmental Assessment Policy and Management* 17 (01): 1550016.

Flyvbjerg, B. 2006. "Five Misunderstandings About Case-Study Research." *Qualitative Inquiry* 12 (2): 219–45.

Flyvbjerg, Bent. 2014. "What You Should Know About Megaprojects and Why: An Overview." *Project Management Journal* 45 (2): 6–19.

Givoni, Moshe. 2006. "Development and Impact of the Modern High Speed Train: A Review." *Transport Reviews* 26 (5): 593–611.

Glucker, Anne N., Peter P.J. Driessen, Arend Kolhoff, and Hens A.C. Runhaar. 2013. "Public Participation in Environmental Impact Assessment: Why, Who and How?" *Environmental Impact Assessment Review* 43. Elsevier Inc.: 104–11.

Graham, Daniel J., and Patricia C. Melo. 2012. "Assessment of Wider Economic Impacts of High-Speed Rail for Great Britain." *Transportation Research Record: Journal of the Transportation Research Board* 2261 (2261): 15–24.

Griggs, David, Mark Stafford-Smith, Owen Gaffney, Johan Rockström, Marcus C Ohman, Priya Shyamsundar, Will Steffen, Gisbert Glaser, Norichika Kanie, and Ian Noble. 2013. "Policy: Sustainable Development Goals for People and Planet." *Nature* 495 (7441): 305–7.

Guest, G. 2006. "How Many Interviews Are Enough?: An Experiment with Data Saturation and Variability." *Field Methods* 18 (1): 59–82.

Hayashi, Y., and H. Morisugi. 2000. "International Comparison of Background Concept and Methodology of Transportation Project Appraisal." *Transport Policy* 7 (1): 73–88.

Healey, P. 1998. "Building Institutional Capacity through Collaborative Approaches to Urban Planning." *Environment and Planning A* 30 (December 1996): 1531–46. http://www.environmentandplanning.com/epa/fulltext/a30/a301531.pdf.

HM Treasury. 2011. *The Green Book: Appraisal and Evaluation in Central Government*.

House of Commons Environmental Audit Committee. 2014. *HS2 and the Environment (HC 1076)*. http://www.publications.parliament.uk/pa/cm201314/cmselect/cmenvaud/1076/1076.pdf.

House of Commons Select Committee on the (London - West Midlands) Bill. 2016. *High Speed Rail (London - West Midlands) Bill - Second Special Report of Session 2015–16*.

House of Lords. 2015. *The Economics of High Speed 2*.

HS2 Ltd. 2012. "Review of HS2 London to West Midlands Route Selection and Speed - A Report to Government by HS2 Ltd," no. January. https://www.gov.uk/government/publications/review-of-hs2-london-to-west-midlands-route-selection-and-speed.

HS2 Ltd. 2013a. "HS2 Phase One Environmental Statement: Documents." https://www.gov.uk/government/collections/hs2-phase-one-environmental-statement-documents.

HS2 Ltd. 2013b. *London-West Midlands Environmental Statement: Volume 5 Technical Appendices Alternatives Report*. Vol. 5. https://www.gov.uk/government/publications/hs2-phase-one-environmental-statement-volume-5-alternatives-report.

HS2 Ltd. 2013c. *The Strategic Case for HS2*. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/260525/strategic-case.pdf.

HS2 Ltd. 2013. "HS2 Phase One Environmental Statement Volume 2: Community Forum Area Reports and Map Books." https://www.gov.uk/government/publications/hs2-phase-one-environmental-statement-volume-2-community-forum-area-reports-and-map-books/hs2-phase-one-environmental-statement-volume-2-community-forum-area-reports-and-map-books.

Jeppesen, Sara Lise. 2011. "Exploring an Explicit Use of the Concept of Sustainability in Transport Planning." *Systemic Practice and Action Research* 24: 133–46.

Johnston, Paul, Mark Everard, David Santillo, and Karl-henrik Robèrt. 2007. "Reclaiming the Definition of Sustainability." *Environmental Science and Pollution Research* 14 (1): 60–66. http://www.ncbi.nlm.nih.gov/pubmed/17352129.

Korzhenevych, Artem, Nicola Dehnen, Johannes Bröcker, Michael Holtkamp, Henning Meier, Gena Gibson, Adarsh Varma, and Victoria Cox. 2014. *Update of the Handbook on External Costs of Transport: Final Report*. http://ec.europa.eu/transport/themes/sustainable/studies/sustainable_en.htm.

Lootsma, F. A. 1999. *Multi-Criteria Decision Analysis via Ratio and Difference Judgement*. Kluwer Academic Publishers.

Lootsma, Freerk a. 1993. "Scale Sensitivity in the Multiplicative AHP and SMART." *Journal of Multi-Criteria Decision Analysis* 2 (2): 87–110.

Macharis, Cathy, and Annalia Bernardini. 2015. "Reviewing the Use of Multi-Criteria Decision Analysis for the Evaluation of Transport Projects: Time for a Multi-Actor Approach." *Transport Policy* 37. Elsevier: 177–86.

Macharis, Cathy, Astrid De Witte, and Jeroen Ampe. 2009. "The Multi-Actor, Multi-Criteria Analysis Methodology (MAMCA) for the Evaluation of Transport Projects: Theory and Practice." *Journal of Advanced Transportation* 43 (2): 183–202.

Macharis, Cathy, Laurence Turcksin, and Kenneth Lebeau. 2012. "Multi Actor Multi Criteria Analysis (MAMCA) as a Tool to Support Sustainable Decisions: State of Use." *Decision Support Systems* 54 (1). Elsevier B.V.: 610–20.

Mackie, Peter, Tom Worsley, and Jonas Eliasson. 2014. "Transport Appraisal Revisited." *Research in Transportation Economics* 47. Elsevier Ltd: 3–18.

Mackie, Peter, Tom Worsley, Charlotte Kelly, Gerard de Jong, Jonas Eliasson, Glen Weisbrod, Neil Douglas, and Ian Wallis. 2013. *International Comparisons of Transport Appraisal Practice Overview Report. Prepared for Department for Transport*. https://workspace.imperial.ac.uk/ref/Public/UoA 14 - Civil and Construction Engineering/Wider economic Impacts/K Worsley report.pdf.

Martens, Karel. 2011. "Substance Precedes Methodology: On Cost–benefit Analysis and Equity." *Transportation* 38 (6): 959–74.

Montibeller, Gilberto, and Detlof von Winterfeldt. 2015. "Cognitive and Motivational Biases in Decision and Risk Analysis." *Risk Analysis* 35 (7): 1230–51.

Olsen, David L., Gene Fliedner, and Karen Currie. 1995. "Comparison of the Rembrandt System with Analytic Hiearchy Process." *European Journal of Operational Research*.

Pope, Jenny, and Barry Dalal-Clayton. 2011. "From SEA to Sustainability Assessment?" In *Handbook of Strategic Environmental Assessment*, edited by Barry Sadler, Ralf

Aschemann, Jiri Dusik, Thomas B. Fischer, Maria R. Partidario, and Rob Verheem, 547–65. Earthscan.

Pryn, Marie Ridley, Yannick Cornet, and Kim Bang Salling. 2015. "Applying Sustainability Theory to Transport Infrastructure Assessment Using a Multiplicative Ahp Decision Support Model." *Transport* 30 (3): 330–41.

Raworth, K. 2013. "Defining a Safe and Just Space for Humanity." In *State of the World 2013: Is Sustainability Still Possible?*, 28–38.

Roberts, R O N, and Paul Goodwin. 2002. "Weight Approximations in Multi-Attribute Decision Models." *Journal of Multi-Criteria Decision Analysis* 303 (June): 291–303.

Sanderson, Ian. 2001. "Participation and Democratic Renewal: From 'Instrumental' to 'Communicative Rationality' ?" *Policy & Politics* 27 (3): 325–41.

Soria-Lara, Julio A., Luca Bertolini, and Marco te Brömmelstroet. 2016. "An Experiential Approach to Improving the Integration of Knowledge during EIA in Transport Planning." *Environmental Impact Assessment Review* 56. Elsevier Inc.: 188–99.

Standards for Highways. n.d. "Design Manual for Roads and Bridges (DMRB): Volume 11." http://www.standardsforhighways.co.uk/ha/standards/ghost/dmrb/vol11/index.htm.

Steer Davies Gleave. 2004. *High Speed Rail: International Comparisons (Final Report)*. http://webarchive.nationalarchives.gov.uk/20110304132839/http://cfit.independent.gov.uk/pubs/2004/hsr/research/pdf/hsr.pdf.

Steffen, Will, Katherine Richardson, Johan Rockström, Sarah E Cornell, Ingo Fetzer, Elena M Bennett, Reinette Biggs, et al. 2015. "Planetary Boundaries: Guiding Human Development on a Changing Planet." *Science* 347 (6223).

The European Parliament and the Council of the European Union. 2014. *Informal Consolidated Version of the EIA Directive*. http://ec.europa.eu/environment/eia/pdf/EIA_Directive_informal.pdf.

Tomlinson, Paul. 2011. "SEA and Transport Planning." In *Handbook of Strategic Environmental Assessment*, edited by Barry Sadler, Ralf Aschemann, Jiri Dusik, Thomas B. Fischer, Maria R. Partidario, and Rob Verheem, 177–89. Earthscan.

van Wee, Bert. 2012. "How Suitable Is CBA for the Ex-Ante Evaluation of Transport Projects and Policies? A Discussion from the Perspective of Ethics." *Transport Policy* 19 (1). Elsevier: 1–7.

Vickerman, R. 2000. "Evaluation Methodologies for Transport Projects in the United Kingdom." *Transport Policy* 7 (1): 7–16.

Vickerman, Roger. 2007. "Cost - Benefit Analysis and Large-Scale Infrastructure Projects: State of the Art and Challenges." *Environment and Planning B: Planning and Design* 34 (4): 598–610.

Vickerman, Roger. 2014. "High-Speed Rail and Regional Development: The Case of Intermediate Stations." *Journal of Transport Geography*.

von Winterfeldt, D., and W. Edwards. 1986. *Decision Analysis and Behavioral Research*. Cambridge University Press. https://books.google.dk/books/about/Decision_Analysis_and_Behavioral_Researc.html?id=eUo7AAAAIAAJ&redir_esc=y.

Wardman, Mark, Richard Batley, James Laird, Peter Mackie, Tony Fowkes, Glenn Lyons, John Bates, and Jonas Eliasson. 2013. *Valuation of Travel Time Savings for Business Travellers*. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/251997/vts_for_business_main_report-dft-005.pdf.

Willson, R. 2001. "Assessing Communicative Rationality as a Transportation Planning Paradigm." *Transportation* 28 (1): 1–31.

Zopounidis, Constantin, and Panos M. Pardalos. 2010. *Handbook of Multicriteria Analysis*. Springer. http://link.springer.com.proxy.findit.dtu.dk/book/10.1007/978-3-540-92828-7/page/1.

Appendix A – Project descriptions

HS2 Phase I	HS2 is a new high-speed passenger railway network that has been proposed by the Government to connect major cities in Britain. Phase I will connect London and Birmingham in the West Midlands (221 km), and Phase II would extend the network to Manchester (an additional 150 km) and Leeds (an additional 185 km). Construction of Phase I is scheduled to begin in 2017 with an indicated opening date of 2026, while completion of the entire network is proposed for 2033. The overall aim of HS2 is to vastly improve inter-urban rail service through increased capacity and improved connectivity between London, the Midlands, and the North. Phase I will release capacity on the existing rail network between London, Birmingham and the West Midlands (West Coast Main Line). This might enable WCML to focus more specifically on freight and regional passenger services. With a maximum speed of 250 mph, trains are expected to travel between London and Birmingham in 49 minutes. More than half the Phase I route will be in cuttings or tunnels, with about 90 km partially or totally hidden to reduce visual impacts and noise. For example, in the Chilterns Area of Outstanding Natural Beauty (AONB) over 18 km of the route will be in tunnels, green tunnels or cuttings, with just over 2 km of the line on the surface. HS2 is a publicly funded project. The total budget for Phase I is £21.4 billion (£15.6 billion projected cost, plus £5.8 billion contingency). The total budget for Phase II is £21.2 billion (£12.5 billion projected cost, plus £8.76 billion contingency). There will also be £7.5 billion spent on new rolling stock. *For more information see https://www.gov.uk/government/collections/the-strategic-case-for-hs2*
WCML upgrade	Train service between London and Birmingham is currently provided by the West Coast Main Line (WCML). This section of the WCML is a very busy four-track railway that caters primarily to short commuter journeys between neighbouring cities along the route (Watford, Milton Keynes, Northampton, Rugby, and Coventry). The proposed upgrade is aimed at making the WCML more suitable for long-distance travel. The specific WCML upgrade alternative considered here consists of (1) increasing passenger capacity on the existing rail line through a programme of (a) lengthening the trains that provide intercity and suburban services; (b) increasing frequency (up to 16 trains per hour on the fast lines); and (c) switching first class coach to standard class in order to increase the number of seats available; (2) increasing train speed on the existing rail line through infrastructure improvements to (a) tackle bottlenecks; (b) modernise junctions; and (c) provide additional tracks in certain locations. This upgrade is expected to increase maximum train speed to 140 mph (from 125 mph today) and reduce travel time between London and Birmingham to 73 minutes (from 85 minutes today). This rail package is expected to cost in the region of £2.6 billion, but could be expanded incrementally (e.g., upgrading the Chiltern line). *For more information see https://www.gov.uk/government/publications/high-speed-rail-strategic-alternatives-study-update-following-consultation and https://www.gov.uk/government/publications/hs2-phase-one-environmental-statement-volume-5-alternatives-report and https://www.gov.uk/government/collections/the-strategic-case-for-hs2*
High Speed Rail along M1 motorway	This alternative high-speed rail route would follow existing motorways. This alignment would follow the proposed HS2 route from Euston to Old Oak Common, where it would then head due north following the M1 and M45/A45 towards Birmingham. The alignment along the M1 corridor through Luton is the only viable route between London and the West Midlands that can avoid the Chilterns Area of Natural Beauty

	(AONB). This alternative would therefore have lower impacts on nationally protected ecological sites, ancient woodlands and Biodiversity Action Plan habitats. Following the curvature of the M1 motorway requires lower speed. The maximum speed would be 186 mph, which is the same as HS1 between London and Paris. Travel time between London and Birmingham on this route would be 55 minutes. By following the M1, this route would encounter several large population centres, including Hemel Hempstead, Milton Keynes, and Luton (a combined population of 480,000 people). In order to reduce the impact on communities, this route involves substantial sections of tunnelling, thus increasing the project's cost and complexity. Lower speed would reduce noise, thus also helping to reduce the impact on communities. Still, this alternative involves demolition of numerous dwellings. The cost of constructing this route would be £2.2 billion more than for the proposed HS2 route. *For more information, see https://www.gov.uk/government/publications/review-of-hs2-london-to-west-midlands-route-selection-and-speed*

Appendix B – Criteria dimensions

1. Magnitude vs. Uncertainty
    - Impacts can be quantified in terms of magnitude (expected value, mean) and in terms of uncertainty (risk, variance). Both aspects are relevant, though one is sometimes considered more salient than the other.
    - Are both aspects of a particular impact included in the same criterion or separated out (e.g., journey time and journey time reliability)?
    - When both aspects are included in the same criterion, should this be made explicit or is it sufficient to leave it implicit (e.g., CO_2 emissions)?
    - In an effort to condense the criteria, is it better to group by type of impact (e.g., cost vs. performance) or to group various risks together (e.g., project delays, cost overruns, underperformance)?

2. Quantity vs. Quality
    - Some impacts are primarily quantitative (e.g., journey time), some are primarily qualitative (e.g., journey experience), and some have both quantitative aspects (e.g., number of hectares of wilderness) and qualitative aspects (e.g., location and distribution of wilderness).
    - Are those criteria that refer exclusively to one or the other clear about that?
    - For those impacts that involve both elements, is it best to group them together (e.g. impacts on wilderness) or separately?

3. Outcome vs. Mechanism
    - Should criteria focus on outcome only (e.g., tons of CO_2 emitted) or on causal mechanisms (e.g., modal shift)?
    - We've agreed to focus on outcomes; however there is a "marketing" issue here: people often don't think about impacts without reference to the causal mechanism.

4. Construction vs. Operating Phase
    - Most impacts are relevant during both the construction and the operation phases (e.g., costs, accidents, emissions, etc.)
    - Should these be grouped together, and if so, does the description make this explicit?
    - Are there some impacts that are associated exclusively or primarily with one phase, and is this clear?

5. Passenger vs. Freight Transport
    - Some impacts are relevant only for passenger transport (e.g., journey comfort), and some are relevant for both.
    - For those that are relevant for both, does it make sense to group them together (e.g., accidents; innovation; landscape) or separately (e.g., passenger capacity and freight capacity)?

<u>Three related dimensions</u>

6. Absolute vs. Relative

- Is the criterion expressed in absolute terms (can be measured/understood on its own) or relative terms (is inherently comparative to some assumed base number)?
- Example: "passenger capacity" is absolute (number of person-km per day), whereas "time savings" is relative (you have to know compared to what)

7. Gross (total) vs. Net
   - Is the criterion measured in terms of total impact or in terms of net impact (taking into consideration what it replaces)?
   - Are we describing the project in a vacuum, or are we considering it in the context of various scenarios (i.e., assumptions about follow-on effects and/or what developments would occur otherwise)?
   - In some cases this is the same as absolute vs. relative (e.g., passenger capacity vs. passenger capacity increase; journey time vs. journey time savings), but not always (e.g., operating costs: is this total, or net of revenue from train tickets?)

8. Positive vs. Negative
   - Is the criterion phrased in positive, negative, or neutral terms (e.g., air quality vs. air pollution; carbon footprint vs. energy efficiency; climate vs. climate protection)? Sometimes it's not clear whether something should be considered positive or neutral (e.g., air quality) or negative or neutral (e.g., journey time).
   - I think it's ok to mix positive, negative and neutral criteria (after all, many of these can represent either costs or benefits or both, depending on the project), but it's worth considering whether the mixture is confusing (makes it harder to evaluate criteria side-by-side) or introduces unwanted bias.
   - Closely related: is the criterion phrased as an explicit cost or benefit (e.g., time savings)?

Appendix C – Criteria discussions

Direct project impacts *(internal costs & benefits)*

Final Version	Original Version	Content Changes	Wording Changes
Journey cost & affordability <u>Journey cost</u> (proposed or expected) is the price passengers pay for a trip. In this context, <u>affordability</u> is defined narrowly in terms of whether *this particular means of transport* is expected to be affordable to would-be users. If your concern is about what might happen to *other* means of transport, whether currently in existence or proposed for the future, as a result of this project being realized, please refer to "Equity and distributional effects."	N/A Journey cost was previously missing. Affordability was included under equity.	Journey cost is a key user impact and should therefore be included as a criterion. (mjb) <u>Methodological issue</u>: it is suboptimal to add a new criterion which previous respondents did not have the option of considering. In the end we decided it was worth the trade-off, as it seemed sufficiently important to add such a key impact. Affordability is included here because of its direct association with journey cost; in fact, it is the inverse: the less a ticket costs, the more affordable is that means of transport, and vice versa. In order to avoid confusion with notions of equity, affordability here is narrowly defined in relation to this particular means of transport only. Both this definition and the definition of **Equity & distributional effects** emphasize the difference between affordability narrowly defined and affordability broadly encompassing follow-on effects to other forms of transport. <u>Recoding</u>: see **Equity & distributional effects**	We considered whether "affordability" should be included in the criterion title or only in the definition: + Gives the term "affordability" a "place" even without reading definitions. – Could cause confusion with "equity", especially for those who don't read definitions. + Might increase general awareness and consideration of issues of social concern (even with the emphasis here on narrow aspects of affordability)
Journey experience <u>Journey experience</u> is a measure of the real and perceived physical and social environment experienced while travelling. It includes the overall quality of facilities and infrastructure (stations and rolling stock), as well as more tangible factors like availability of seats, comfort, provision of relevant information, safety & security, crowdedness and other stress factors. Moreover, experience of	**Level of service and journey experience** Journey quality is a measure of the real and perceived physical and social environment experienced while travelling eg. facilities and infrastructure quality including stations and rolling stock, comfort, available seats, crowdedness, safety & security and stress factors. Moreover, experience of time as perceived by users includes information provision, travellers	Final version is slightly narrower. Standard definition of "level of service" includes quantitative measures such as journey time and reliability (cg). Since these are treated as separate criteria in this survey (yc), to avoid confusion, "level of service" was removed from title. We consider journey experience to be a qualitative measure. <u>Recoding</u>: move some *Level of service & journey experience* respondents to **Journey time** and/or **Journey reliability**? • Probably not possible to determine in which cases this would be justified.	The original version, which defined "journey experience" by describing "journey quality," caused confusion with its inconsistency between title and definition. It was decided that "journey experience" is the better term and that the definition should be changed to match. 3 aspects of journey experience described in the literature (yc): 1) Cognitive aspects: perceived security; pleasantness of the architecture and scenery; annoyances and disruptions like announcements or intrusive advertising; 2) Physical aspects: comfort (seating, noise, smells, motion sickness, personal space); availability of services (wifi, entertainment, food); physical

Final Version	Original Version	Content Changes	Wording Changes
time as perceived by users includes entertainment and scenery.	view and frequency of transit as a measure of the level of service.	• Furthermore, it's not clear that respondents actually misunderstood this criterion: because journey time and reliability were listed separately, they probably interpreted this criterion as referring primarily to qualitative aspects of service level and journey experience.	accessibility, etc.; 3) Affective aspects: stress experienced due to lack of information provision, unreliability, etc. We considered using these terms in the definition but decided that for the purposes of explanation in the survey, it would be more useful to emphasize concrete examples than theoretical categories.
Journey reliability & system resilience Journey reliability refers to variability in journey time that individuals are unable to predict due to recurring events (e.g., congestion) or non-recurring events (e.g., accidents). For public transport this is usually measured as the standard deviation of lateness divided by average lateness. Resilience refers to the ability of a transport system or network to recover from disruptions caused by natural disasters or human factors. Resilience and reliability are related in that when resilience is high it is reflected in reliability as well.	**Reliability & resilience** Journey time reliability refers to variation in journey times that individuals are unable to predict due to recurring congestion (eg. day-to-day variability) or non-recurring events (eg. accidents). For public transport this is usually measured as the ratio of the standard deviation of lateness to the average lateness. Resilience is a mode service characteristic which refers to the ability of an intermodal transport network to recover from disruptions due to natural or human-caused disaster. (Resilience is related to reliability in the sense that when resilience is high it is reflected in reliability as well).	No change. We briefly considered combining journey time and reliability into a single criterion for two reasons: 1) Time and reliability are not really separate impacts, but rather, the mean and variance of the same impact; 2) There's some concern that user benefits are getting too much emphasis, with so many separate criteria devoted to journey-specific impacts. However, in the transport field, time and reliability are considered sufficiently important as separate criteria that they have been kept separate.	Original title was unclear: reliability *of what?* resilience *of what?* Among transport experts, these may be clearly defined terms on their own, but they are less likely to be clear to non-experts. The confusion is compounded by putting the two terms together when the "of what" is different for each. "Reliability" was therefore replaced by "journey reliability". We considered taking resilience out of title and keeping it only in description, because it is considered to be of secondary importance as a user benefit, especially as it ends up reflected in reliability anyway (i.e., one mechanism driving reliability). In general, we have been removing mechanisms from criterion titles. However, Yannick and Christina pointed out that "journey reliability" by itself *sounds* very narrow, even if resilience is in the description. Therefore we kept resilience in the title and added "system" to clarify "of what" (although it makes the title a bit long).
Journey time Journey time is defined as travel time from station of origin to station of destination. High-speed rail is aimed at reducing travel time.	**Journey time savings** Journey time refers to total travel time required from an origin to a destination. Possible time savings can add value in terms of alternative activities to be taken instead of traveling.	No change.	Change from a relative to an absolute measure. We added "station to station" to clarify this is not door-to-door.
Project costs Total cost of project to taxpayers, comprising both	**Capital & operating costs** Full whole-life costs of the scheme. Base investment	No change.	To distinguish from user-level impacts, where "journey" has been added, it is helpful to add "project" to clarify that this is project-level.

Final Version	Original Version	Content Changes	Wording Changes
upfront and ongoing costs. Upfront capital investment includes construction costs from main work contracts (stations, tracks, rolling stock, power and signalling), land and property costs (acquisition and compensation), administrative costs (design, management, consultation). Ongoing costs include train and station operations, maintenance, and renewal costs.	(capital) costs include construction costs from main work contracts (stations, tracks, rolling stock, power and signalling), land and property costs (acquisition and compensation), administration costs (management, consulting, design, consultation). Operating costs include train and station operating, maintenance and renewal costs.		Title can be shortened by removing “capital and operating” without loss of understanding. Description now refers to “ongoing costs” instead of “operating costs,” because usage of the term “operating costs” does not always include maintenance. “Full whole-life costs” has also been taken out of the description to avoid invoking discussions of life cycle analysis and/or assumptions about project lifetime and discount rate. “Taxpayer” has been added to clarify costs to whom (i.e., not contractors or travellers).
Project delivery risks Uncertainties during planning and construction stages regarding final project outcome. These risks include cost overruns, construction delays, and underperformance of new technology. Risks can be mitigated by consulting key experts and stakeholders early in the process and by conducting pilot studies. Risks can be exacerbated when cost estimates are subject to optimism bias (underestimation, whether intentional or unintentional).	**Risks & uncertainty** Risks from changes in policy or legislation, delivery risks (time, budget, design), operation, demand, or technology risks. Level of mitigation eg. early consultation, pilot studies, use of leading edge technology. Optimism bias (risk of intentional underestimation due to different motivational factors) in cost estimates.	Final version is narrower. • Original version included all types of uncertainty (a cross-cutting criterion covering variance of all impacts). This was considered too broad to be meaningful (as well as inconsistent, since variance of some impacts is clearly included elsewhere). • Final version includes variance of project delivery only (cost overruns, construction delays, underperformance). This is a project-level impact. This is primarily a construction-phase impact: once the project has been “delivered” (i.e., is operating), *construction* is no longer delayed or continuing to incur costs. However, underperformance and O&M cost overruns may be ongoing. <u>Recoding</u>: move some *Risks & uncertainty* respondents to other categories? • Probably not possible to determine which specific risk(s) respondents meant. • Check respondent comments.	
Rail capacity for freight Any increase in rail capacity will also increase the capacity available for freight, whether directly through the construction of new tracks available to freight	**Freight capacity & modal shift** Expected change of the amount of freight taken on the rail network leading to a change in amount of road freight in number of road kilometres	Final version is narrower: no longer includes modal shift. Original treatment of modal shift was inconsistent: modal shift for freight was considered a direct impact, whereas modal shift for passengers was categorized as an environmental impact.	“Rail” added to clarify that “capacity” means “rail capacity.” Also, the explicit reference to rail may prompt people to reflect on the significance of different modes of transportation. Now that “modal shift” has been removed from the criteria titles, this may be helpful, at least

Final Version	Original Version	Content Changes	Wording Changes
and passengers, or indirectly through the construction of new passenger lines, thus freeing up tracks that were previously shared with passengers. An increase in rail capacity available for freight transport would be able to meet growing demand for freight transport and/or reduce rail costs for freight users. This in turn could result in shifting freight from roads to rail. If your interest in rail capacity is primarily related to modal shift and the resulting possibility of reducing CO2 emissions, please refer to "Carbon footprint." If your interest is more generally in increasing capacity and reducing costs for freight users, please select this criterion.	replaced. Operating costs savings for freight users and possible (positive) impacts from modal shift.	To determine where modal shift belongs, we considered why modal shift matters and decided its significance lies in the potential for reducing the carbon intensity of transportation and therefore does not belong under direct impacts. Next, we considered whether modal shift merits its own criterion and decided no, for two reasons: 1) Modal shift is a mechanism, not an impact; 2) Its primary impact is CO2 emissions and therefore belongs under **Carbon footprint**. However, removing explicit references to "modal shift" from the criteria titles may reduce people's consideration of this important mechanism. The descriptions therefore now emphasize modal shift. <u>Recoding</u>: move some *Freight capacity & modal shift* respondents to **Carbon footprint**? • Probably not possible to determine which respondents were more interested in modal shift than in freight capacity per se. • Check respondent comments and other criteria selected.	indirectly, in triggering consideration of the concept.
Rail capacity for passengers <u>Passenger capacity</u> is the total number of people a means of transport is able to transfer in a given period (measured for example in person-km per day). Increasing passenger capacity is particularly relevant when travel demand is expected to grow and policymakers want to satisfy that demand. One way of increasing passenger capacity is to increase frequency of service, which is also made possible by increasing train speed. Other methods of increasing capacity include lengthening trains or building new tracks/routes. In addition to	**Passenger capacity** Capacity refers to the total amount of people a mode of transport is able to transfer. Increasing capacity is one of the policies considered when there is a need to satisfy growing travel demand. It is a measure related to frequency levels as more frequent transportation allows for more capacity.	<u>No change</u>. Description now better describes the relevance of passenger capacity and its connection to frequency (a user impact) and to modal shift and carbon footprint (an environmental impact).	"Rail" added to clarify/emphasize that "capacity" means "rail capacity."

Final Version	**Original Version**	**Content Changes**	**Wording Changes**
meeting growing travel demand, increasing passenger capacity may also encourage a shift from other modes of passenger transport (air, car) to rail. If your interest in rail capacity is primarily related to modal shift and the resulting possibility of reducing CO2 emissions, please refer to "Carbon footprint." If your interest in rail capacity is more directly about meeting passenger needs for travel, please select this criterion.			
Traffic & transport disruption Welfare impacts on rail users caused by <u>transport disruption</u> during project construction (e.g., WCML upgrade) and/or on non-rail users caused by <u>traffic congestion</u> from construction trucks (HS2). This is primarily a construction-phase impact. If your interest is in longer-term impacts on traffic patterns and other infrastructure conflicts, please refer to "Community severance" and/or "Land use & urban planning." If your interest in traffic patterns is related to CO2 emissions, please refer to "Carbon footprint."	**Transport disruption & traffic** Welfare impacts on rail users and non-rail users caused by a project, both during construction and operation, including traffic, congestion and transport impacts on other modes.	Title is essentially unchanged, but final version of definition is narrower, with an emphasis on construction-phase impacts. Along the way, we did consider more substantial changes, but ended up closer to the original version. The original definition was all-encompassing, covering users as well as non-users, construction as well as operation. When we realized the implications of such a broad definition – that some of the included impacts were really indirect rather than direct impacts and that some of them overlapped with **Community disruption & severance** – we considered recategorizing several related criteria. <u>Considerations</u> (mjb): The problem with the original definition is that it includes non-users. The only impact here that I consider to be a direct impact is "transport disruption for current rail users" (which as I understand is a problem only for WCML upgrade). Setting aside the rail users, let's focus for a moment on the non-users (i.e., recipients of indirect impacts). If we consider all disturbance and disruption related impacts, then we could logically divide these along either of two dimensions: • travellers vs. non-travellers; or • construction (temporary) vs. operating (permanent) The original criteria are divided along the former, placing	In the original title "traffic" was by itself with no modifiers, thus raising the question, "what aspect of traffic?" Switching the word order fixes this by implying (albeit not unambiguously) that disruption refers to traffic as well as transport. This seems appropriate, as the traffic congestion referred to (that caused by trucks during construction) is a form of disruption. Furthermore, "disruption" suggests temporary, which reinforces the fact that we are referring primarily to construction phase impacts.

Final Version	Original Version	Content Changes	Wording Changes
		impacts that affect folks when they're trying to move around under "transport disruption & traffic" and impacts that affect them when they're sitting at home and can't see their neighbour's house under "community disruption & severance." It might be preferable to divide these into temporary and permanent changes, as permanent changes in infrastructure affect communities and movement patterns alike: is it really possible to draw the line? Perhaps we should move all non-users to the indirect category and then distinguish between temporary and permanent impacts: • *Community and traffic disruption* [during construction] • *Community severance and traffic patterns* [during operation] Under this scenario, *Transport disruption* would cover impacts on rail-users during construction only, and all non-users would be moved to indirect societal impacts, where we would split **Community disruption & severance** into two separate criteria and then add traffic and transport impacts to each, depending on whether the impact is temporary or permanent. <u>Reactions</u> (cg, yc): This approach might be useful if we were starting from scratch, but it would be enormously complicated to recode. In the end we decided it would definitely be too complicated to make changes affecting so many criteria, so we went back to the original version, but with an emphasis on construction-phase impacts. Meanwhile, the final definition also guides respondents who are interested in longer-term impacts to other [existing] criteria.	
Transport integration & connectivity Extent to which the proposed project would be integrated with and connected to other transport. This includes <u>intermodal integration</u>, which refers to how well different modes of transport	**Integration with other transport & connectivity** Intermodal integration refers to how well different modes of transport are connected and/or integrated with the existing network. This includes smooth connections to the rail network	<u>No change</u>. We briefly considered whether frequency should be included here, but decided against it (see **Frequency** discussion below).	The original definition described two terms: "intermodal integration" and "transit connectivity." As it's best to use the same terms in the title so as to avoid confusion between title and definition, we initially considered changing the title to one of the following (order of terms was switched from original for purposes of alphabetization within the criterion list): • *Transit connectivity & intermodal integration* • *Transit connectivity & integration*

Final Version	Original Version	Content Changes	Wording Changes
(train, bus, ferry, etc.) are interconnected. Intermodal integration can also refer to provisions for active modes of transport (cycling, walking, etc.). When such connections are smooth and convenient, intermodal integration can play an important role in promoting green and healthy/active travel. <u>Transport integration</u> also includes connectivity of travel segments within the same mode of transport (train-to-train, bus-to-bus, etc.). <u>Connectivity</u> is a closely related concept that considers, alongside total travel time, passenger discomfort associated with waiting, transfer, and access/egress times. Transit connectivity aims to provide attractive and "seamless" transfers along multimodal paths as part of the door-to-door passenger chain.	with alternative modes of transport (bike, foot etc) promoting active and green travel. Transit connectivity considers travel time, passenger discomfort associated with waiting, transfer and access or egress times, attractiveness and "seamless" transfers along multimodal paths as part of the door-to-door passenger chain (Ceder, 2007)		However, the term "transit" is often used in other contexts, particularly when referring strictly to public transport (yc), so adding it to the title was not the best idea, as it would add emphasis to a potentially problematic term. We therefore agreed to replace "transit" with "transport" and to de-emphasize "transit" in the definition by focusing on "connectivity" instead of "transit connectivity." In the course of discussing whether the title should include both "integration" and "connectivity", or just one (the consensus was both), several new words were introduced: multimodal (yc), intermodality (cg), and interconnectivity (cg). This led to a broader discussion of inter vs. multi modality. Should the title include inter/multimodal in some form, and if so: • Which one: inter or multi? • As a noun or adjective? As a noun, inter/multimodality can stand alone, but as an adjective, inter/multimodal must modify something, in which case: ○ What should it modify: transport or integration? We considered the following titles: • *Transport connectivity & intermodal integration* • *Transport connectivity & integration* • *Transport integration & connectivity* • *Multimodal transport integration and connectivity* • *Multimodal transport integration* • *Transport connectivity & intermodality* yc: There is a paper called "Multimodal public transport: an analysis of travel time elements and the interconnectivity ratio" that describes the interconnectivity ratio as a measure of time lost in transferring and waiting between different parts of a multimodal journey. And yes, some call this intermodality – the number of interpretations is quite large! The latter has a focus on connections, thus let us say it is synonymous with connectivity, which, according to our description, "considers travel time, access/egress time, waiting time, service reliability, frequency, and 'seamless' transfers along multimodal paths." See: https://www.researchgate.net/post/What_is_the_difference_

Final Version	Original Version	Content Changes	Wording Changes
			between_Multimodal_and_Intermodal_in_transportation_networks The following considerations ultimately led us to conclude that it would be best to leave inter/multimodal out of the title (but keep it in the description): • The above-referenced paper does help clarify the distinction between inter- and multimodal; however, it also seems that both terms are used primarily (though not exclusively) in connection with freight transport, whereas we are interested in passengers; • Of relevance to passengers are the connections not just between different *modes* (bus-rail, car-rail, foot-rail, etc.), but between *any 2 segments* of travel (train-to-train, bus-to-bus, etc.); • It's not clear that either intermodal or multimodal actually makes sense as a criterion for evaluating projects that are neither. None of the 3 rail projects being evaluated in this survey is, in and of itself, either intermodal or multimodal. So we don't really want inter/multimodality directly to be the criterion (mjb). Rather, we care about the projects' potential to connect to and integrate with other transport, regardless of what that transport is.

Frequency

We had a lengthy discussion about how and where to include frequency among the direct project impacts:

- Is it a mechanism or an impact? (both)
- As an impact, should it be a separate criterion or part of another criterion? (consensus: not separate)
- As part of other criteria, should it be included in the title or only in the definition? (consensus: definition only)
- Which criterion/criteria should it be part of? (this discussion is presented in the table below)

As part of…	Why it makes sense	Why it doesn't make sense	Conclusion
Passenger capacity	Frequency definitely contributes to capacity, and planners will most likely associate it with capacity. (yc)	Frequency is certainly a mechanism that contributes to capacity (though only one of several). However, frequency is also a characteristic that has value in and of itself, and in this context, it has nothing to do with capacity. (mjb)	Frequency is mentioned in the definition as one mechanism driving capacity.

Journey experience	Frequency is a characteristic of journey experience. (cg) Travellers will most likely associate frequency with journey experience. (yc)	This criterion focuses primarily on the qualitative aspects of journey experience, and so including frequency here may be inconsistent with having taken out other quantitative aspects associated with level of service, such as journey time and reliability.	Not mentioned (This may be an oversight; I thought we meant to include it in the definition among the factors contributing to experience.) (mjb)
Journey reliability	Frequency can be a substitute for reliability: travellers don't care so much if one particular train is late as long as the next one is coming soon (the more frequent the service, the less reliability matters). (mjb)	Reliability is a bigger issue. What is meant here is timetable reliability. (yc)	Not mentioned
Connectivity	The definition of transit connectivity includes waiting time, which is a direct consequence of frequency. (mjb)	This criterion focuses more on the transport system as a whole (integration with other modes, synchronization, etc). (cg)	Not mentioned

Indirect societal impacts *(externalities - people)*

Final Version	**Original Version**	**Content Changes**	**Wording Changes**
Accessibility Accessibility reflects the range of opportunities and choices people have in connecting with employment, education, essential services, and social networks. It can be measured as a catchment area and is concerned with travel horizons (journey times and distances). It is more holistic than transport user benefits, as it considers the availability and physical accessibility of a transport service in connection with the location of other services and activities. Accessibility also includes option value (the value of the existence of the service for convenience or unplanned trips) and non-use value (appreciating that a service is available for others).	**Accessibility** Accessibility reflects the range of opportunities and choices people have in connecting with employment, education, essential services, and social networks. It can be measured as a catchment area and is concerned with travel horizons (journey times and distances). It is more holistic than transport user benefits as it also consists of the availability and physical accessibility of a transport service considered in connection with the location of services and activities. Accessibility also includes option and non-use value (the value of the existence of the service for convenience or unplanned trips).	No change.	Description now distinguishes between option value and non-use value (they are not the same thing!)
Accidents & safety Risk of individuals (both transport users and non-users) being killed or injured as a result of accidents, usually measured in number of casualties, fatalities or injuries in a given period. Refers to both construction and operation phases. Expected casualties will vary with infrastructure design and route, depending for example on road intersections, crossings/bridges, and size of the neighbouring population.	**Accidents & safety** Risk of individuals being killed or injured as a result of accidents (for both transport users and non-users) usually measured in number of casualties, fatalities or injuries. Referring both during construction and operation, the design and route of infrastructure may create conflicts with neighboring population or passing road and rail traffic e.g. crossings/ bridges.	No change.	

Final Version	Original Version	Content Changes	Wording Changes
Community disruption & severance; blight Community disruption refers to the temporary, disruptive impacts of project construction on residential property, public spaces, and communities as a whole. It includes impacts on the amenity of residents in the remaining parts of the residential development, including pleasantness and visual intrusion. Community severance refers to the more lasting impacts on a community, even after construction is finished and the transport system is operating. Severance is the real or perceived isolation of residential properties or community facilities due to physical or visual barriers caused by transport infrastructure or traffic flows. Severance is usually measured as a physical barrier to pedestrian movement, but also to cyclists, equestrians, children or other vulnerable groups. Blight is the reduction in property or neighbourhood value near proposed project sites. Blight takes place as soon as a potential project or route is proposed and is particularly of concern when the design and consultation period extends over many years. Blight becomes less of a problem once a decision has been reached, as property values in areas of rejected projects may	**Community severance, disruption & blight** Community severance refers to real or perceived isolation of residential properties or community facilities due to physical or visual barriers caused by transport infrastructure or by traffic flows. Severance is usually measured as a physical barrier to pedestrian movement, but also cyclists, equestrians, children or other vulnerable groups. Community disruption includes general effects on residential property, public spaces and communities as a whole during the construction, and impacts on the amenity of residents in the remaining parts of the residential development, including pleasantness, blight and visual intrusion. Blight is the reduction of property or neighbourhood value (compensation for land or property), which can take effect as soon as a route (or alternatives) are announced.	No change. We did consider two substantial changes: 1) adding changes in traffic patterns here; 2) dividing disruption and severance into separate criteria. However, we decided against both (see **Traffic & transport disruption** discussion above). The definition of blight was changed to fix two inaccuracies: • The original definition implied that blight was compensated, but in that case it should be considered a part of project cost and not blight. We agreed the part about compensation did not belong here; the whole point about blight is that it is not compensated. • The original definition also described this criterion as "not monetized," but blight is in fact monetized (a decrease in the resale value of property). We decided the criterion should therefore be described as "partially monetized," but then we ended up taking out the "monetized" column for all criteria.	Since disruption is associated with the construction phase and severance with the operating phase (in that severance is more permanent), it makes more sense to list and describe these in chronological order. Although blight comes even earlier, it is less connected to disruption and severance and so seems reasonable to list as a separate component at the end.

Final Version	Original Version	Content Changes	Wording Changes
recover and property owners affected by realized projects may be compensated. However, it is very much a problem for anyone who wants to sell affected property before a final decision has been reached.			
Equity & distributional effects Concerns about the distribution of project costs and benefits across different social groups or geographical locations. Equity is concerned about equality of opportunity, with a particular focus on vulnerable groups. Affordability of transport (usually measured as proportion of income spent on transport) is related to equity when the realization of a particular project results in a change in the options available to others. This could happen if existing transport receives less funding as a result of another project being selected. Closely related is the concept of opportunity cost: what else could the money be spent on? Whereas equity emphasizes *who* receives the benefits (e.g., transportation for whom?), opportunity cost emphasizes *what* the money is spent on (transportation? education? sports? and within transportation, what *kind* of transport?) Both opportunity cost and equity involve prioritizing the spending of public money: on what and for whom?	**Equity & personal affordability** Variance of transport intervention impacts across different social groups or geographical scales, equality of opportunity with focus on vulnerable groups. Considerations of personal affordability are a key distributional impact, usually measured as proportion of income spent on transport.	Final version is narrower: no longer includes affordability (narrowly defined). Although affordability in the narrow sense of the inverse of ticket price for a proposed project is now included under **Journey cost & affordability**, affordability in the broader sense of encompassing follow-on effects to other forms of transport is still included here. We added the concept of opportunity cost to the definition, because of its parallel outcome for vulnerable groups. The connection between opportunity cost and equity lies in the prioritization of public spending: on what and for whom? Recoding: move some *Equity & affordability* respondents to **Journey cost & affordability**? • Probably not possible to determine in which cases this would be justified. • Check respondent comments.	"Affordability" was taken out of the title to avoid confusion with **Journey cost & affordability**. "Distributional effects" was added to title to increase the number of terms associated with this criterion. We considered putting opportunity cost in title, but strictly speaking, it's the inverse of project cost.
Land use & urban development	**Land use pattern & housing** Land use & transport planning	No change.	The original title had two problems (mjb):

Final Version	Original Version	Content Changes	Wording Changes
Impacts that new transport projects have on land use (residential, industrial or commercial) and allocation of activities – also referred to as Land-Use & Transport Interaction (LUTI). Changes in the transport system affect accessibility, which reallocates land uses and determines the location of new activities. Transport policies and measures (e.g., TOD, transit-oriented development) can lead to more energy-efficient urban forms. Of particular importance in the context of urban development is whether housing will be actively built along with transport infrastructure.	interaction (LUTI). Effects that new transport projects have on land-uses (residential, industrial or commercial) and allocation of activities. Changes in the transport system has an impact on accessibility which reallocates land uses and determines the location of new activities. Transport policies and measures (eg. TOD) can lead to more energy-efficient urban forms.		• “Land use pattern” is an awkward-sounding phrase; • More importantly, it is totally unclear what housing means in this context (what does transport have to do with housing?) We first considered the benefits of changing the title to *Land-use & transport interaction* (LUTI): • LUTI is an industry-standard phrase (cg); • Housing could be included in the definition, where it could be more fully explained and thus avoid causing confusion. (mjb) However, one of the interviewees had stressed the importance of housing, and it’s not clear that people would easily associate LUTI with housing. (yc) In an effort to come up with a title that either included housing or clearly invoked it, but without causing confusion, we considered the following options: • *Land use & urban development* • *Land use & residential development* • *Land use & housing development* “Urban development” is a well-known term that people easily associate with housing yet also includes other relevant things like commercial development, green spaces, etc. (mjb) “Residential development” and “housing development” both invoke housing, even more explicitly than “urban development” does. In addition, they are not limited to urban settings, and housing is not just an urban issue. (yc) On the other hand, is housing really such a critical issue in remote areas? Surely the importance of considering housing in the context of land use and transport planning is most relevant in urban settings. (mjb) In the end we all preferred *Land use & urban development*.
Landscape/ townscape & cultural heritage <u>Landscape/townscape</u> impacts	**Landscape/townscape & cultural heritage** <u>Landscape/townscape</u> impacts	<u>No change</u>.	

Final Version	Original Version	Content Changes	Wording Changes
refer to changes in the physical and cultural characteristics of the land and perceptions that make up and contribute to landscape character ("sense of place"). It consists of impacted topography, views, tree cover (for landscape) and all aspects of the urban form (for townscape), from construction plans along the route to overhead lines, stations, depots, tunnels and ventilation shafts, fences and barriers, bridges, etc. Cultural heritage impacts refer to archaeological and paleo-environmental remains (ancient burials; ancient environments), historic landscapes and buildings, and the built environment (both designated and non-designated assets), known collectively as heritage assets.	refer to changes to the physical and cultural characteristics of the land and perceptions that make up and contribute to landscape character ("sense of place"). It consists of impacted topography, views, tree cover (for landscape) and all aspects of the urban form (for townscape) from construction plans along the route eg. overhead lines, stations, depots, tunnels and ventilation shafts, fences and barriers, bridges etc. Cultural heritage: Impacts on archaeological (ancient burials) and paleo-environmental (ancient environments) remains, historic landscapes and buildings, and the built environment (both designated and non-designated assets**)**, known collectively as heritage assets.		
Prestige & image Prestige, public recognition, and positive media coverage that may be generated for the nation, a region, or public officials. Public exposure that a project may generate for its proponents or for politicians. This may also include the potential contribution of a project to creating a sense of regional or national identity or pride.	**Image & national identity** Media visibility, political public exposure or prestige a project may generate for its proponents; this may include the contribution of a project to creating a sense of identity for the region or nation (eg. national pride).	No change.	We made two changes to the title: 1) dropped "identity" The original version is inconsistent in its specification of identity: in the description identity is regional or national, whereas in the title it is only national. Adding "regional" would the title too long, so we decided instead to drop identity from the title (but still keep it in the definition). 2) added "prestige" The original description uses the word "prestige," which sounds like a perfect word to include in the title. (mjb) We considered the following variations: • *Prestige & image* • *Prestige & reputation*

Final Version	Original Version	Content Changes	Wording Changes
			• *Image & reputation*
Rail industry growth & innovation Contribution to strategic goals of encouraging technological innovation, growth of commercial expertise within a specific industry, and development of new skills in the labour force. This may include the creation of dedicated training centres.	**Innovation & rail industry growth** Contribution to strategic goals of encouraging (technological) innovations, including growth of commercial expertise within a specific industry and the development of new skills in the labour force. This may include the creation of dedicated training centres.	No change.	Sounds better. Also clearer that innovation is associated with rail industry.
Regional economic development & regeneration Regional economic development refers to welfare benefits that are broader than transport user benefits. These wider economic impacts (WEI) affect the labour market, product market and land market: 1) agglomeration effects: accessibility of firms to other firms, products and workers; the increase in labour productivity from increased proximity, knowledge and technology spillovers; 2) welfare gain for firms whose goods and services require transport; and 3) increased tax revenues from the labour market. Regional development also includes rebalancing the national economy and bridging the North-South divide. When infrastructure is located in areas designated for economic development under UK or EU regeneration programmes, projects can help meet	**Regional development & economic growth** Wider impacts refer to economic welfare additional to transport user benefits, such as impacts on the labour market, product market and land market: 1) agglomeration impacts: accessibility of firms to other firms, products and workers, the increase in labour productivity from increased proximity, and knowledge and technology spillovers 2) welfare gain from firms increase in profitability for good and services requiring transport 3) increased tax revenues from labour market. Regional regeneration impacts on regional economic activity and employment in areas designated for specific policy purposes related to economic development under UK or EU regeneration programmes. Rebalancing the national economy (eg bridging the North-South divide).	No change.	Title now better matches content. Description edited for clarity.

Final Version	Original Version	Content Changes	Wording Changes
regeneration goals by stimulating economic activity and employment.			

Environmental impacts *(externalities - planet)*

Final Version	Original Version	Content Changes	Wording Changes
Agriculture, forestry & soils Soil quality impacts on agricultural and forestry land. The driver is land "taken" from agriculture and forestry for an infrastructure project, but the impact of concern is not an acreage issue, but rather the loss of *high-quality* farm soil. For infrastructure projects, a hectare is a hectare. But for farms, there are differences in soil quality, and this may not get compensated in the land price. Protecting high-quality agricultural and forestry land may also be considered a priority for society.	**Land quality (soil, agriculture & forestry)** Effects on agricultural soils and forestry resources resulting directly from land required (both temporarily and permanently) for construction and operation (eg. impacts on farming and woodland planting; ancient woodlands or protected areas are covered under Land take & biodiversity). Potential effects associated both with the disturbance of contaminated land and with any ground contamination that could occur from construction or operation (e.g. leaks or spillages within depots from line-side equipment or from trains).	Final version is narrower. Earlier version had combined two ES impacts ("Land quality" and "Agriculture/forestry/soil"), because both involve soil. However, they involve different types of land and different types of impacts. These two ES impacts have now been split apart again. This impact now refers strictly to loss of high-quality farm/forestry soil and is the same as the ES impact by the same name. The other ES impact included in the earlier version ("Land quality") is now included under **Water & land contamination**. <u>Recoding</u>: move some *Land quality (soil, agriculture & forestry)* respondents to **Water & land contamination**? • Unnecessary, because nobody picked this criterion initially.	Clarifications: Refers to agricultural and forestry land only (i.e., land in economic production, not wilderness areas). This is a qualitative, not a quantitative, measure. Does not reflect changes in *amount* of land, only changes in *quality* of that land. Driver of these changes in [average] soil quality is land take, not pollution or contamination. Construction and operating phases.
Air quality Impacts on local and regional air quality from dust and emissions during both project construction and operation. Impacts can be both positive (e.g., decreased emissions from road transport if modal shift occurs) and negative (e.g., increased emissions from diesel locomotives or increased road traffic around stations and depots). Pollutants impacting local	**Air quality** Dust and emissions/pollutants related to construction and operational traffic, including as a result of road traffic increase around stations and depots and the use of diesel locomotives. Impacts can be local or regional. Pollutants include carbon monoxide (CO), oxides of nitrogen (NOx), volatile organic compounds/hydrocarbons (VOC/HC/PAH), particulate matter (PM), sulphur	<u>No change</u>.	General improvements to make definition clearer.

Final Version	Original Version	Content Changes	Wording Changes
and regional air quality include oxides of nitrogen (NOx), volatile organic compounds/hydrocarbons (VOC/HC/PAH), particulate matter (PM), oxides of sulphur (SOx), ozone (O3), carbon monoxide (CO), and trace metals. Global air pollutants (CO2 and other greenhouse gases) are covered under "carbon footprint".	dioxide (SO2), ozone (O3) and other trace metals. Rail impact on emissions lies mainly with the saving in emissions from road transport brought about by modal transfer. Carbon dioxide (CO2) is covered under climate.		
Biodiversity & nature Impacts on nature conservation arising from habitat loss and degradation, fragmentation of sites, severance of ecological corridors and networks, noise and visual disturbance, barrier effects to movement of fauna, artificial lighting, changes in water quality and quantity, air pollution, and mortality as a result of collisions with trains. Included here are impacts on protected species and habitats, such as Sites of Special Scientific Interest (SSSIs), Areas of Outstanding Natural Beauty (AONBs), National Parks, Environmentally Sensitive Areas (ESAs), and ancient woodlands, as well as general ecological value beyond site boundaries.	**Land take & biodiversity** Effects on nature conservation arising from habitat loss, fragmentation of sites, severance of ecological corridors and networks, noise and visual disturbance, barrier effects to movement of fauna, lighting, changes in water quality and quantity, air pollution, and mortality as a result of collisions with trains. It is particularly concerned with protected species and habitats such as Sites of Special Scientific Interest (SSSIs), Areas of Outstanding Natural Beauty (AONBs), National Parks, Environmentally Sensitive Areas (ESAs), ancient woodlands, and general ecological value beyond site boundaries.	No change.	In the original, 4 different criteria contained the word "land," making distinctions unclear: land quality vs. land take suggested a distinction between quality and quantity of land; land use vs. land take suggested a distinction between using and losing the land; yet the primary distinctions in all cases involved the *type* of land impacted (urban, agricultural, wilderness), not *how* it was impacted. Land "take" is not specific to wilderness areas: agricultural land and residential properties can also be taken for infrastructure projects; this term is therefore inaccurate for referring to this particular context. The essence of this criterion is that it refers to wilderness (undeveloped land). What to call this type of land? Habitat is too narrow. We looked into standard terms used in nature conservation circles (e.g., IUCN), and "wilderness area" best comprises the various categories listed in the description. In the end we came up with "nature" and decided to use that. This measure is both quantitative and qualitative.
Carbon footprint All greenhouse gas (GHG)	**Climate** All greenhouse gas	No change.	"Carbon footprint" is more explicit than "climate" and broader than "CO2 emissions".

Final Version	Original Version	Content Changes	Wording Changes
emissions associated with a project expressed as carbon dioxide equivalent (CO_2e). Aside from CO_2, which is the most significant GHG associated with transportation and energy use, GHGs include methane (CH_4) and nitrous oxide (N_2O). A project's carbon footprint comprises both embedded carbon and fuel carbon. Embedded carbon refers to CO_2 emitted during project construction as well as in connection with producing the materials used in infrastructure (cement, steel etc.). Fuel carbon refers to CO_2 emitted during transport operations. Fuel carbon emissions are driven by two factors: (1) efficiency of energy form (electricity vs. liquid fuel); and (2) energy source (renewable vs. fossil fuel). To the extent that rail transport is more fuel and/or carbon efficient than road transport, modal shift from road and/or air to rail could lead to a net reduction in carbon footprint.	emissions (carbon dioxide CO_2, nitrous oxide N_2O and methane CH_4), including those resulting from the production of materials used in any infrastructure, for example cement, steel etc. (otherwise known as embedded carbon), as well as those resulting from changes to the use of transport fuels.		Reference to carbon specifically is considered legitimate since CO_2 is the main greenhouse gas associated with transport, and description can explain that other GHGs are also included (where applicable) in CO_2-equivalent terms. Description to include drivers of carbon footprint: carbon embedded in infrastructure and carbon emissions from transport operations. Latter can be subdivided into efficiency of energy form (electricity vs. liquid fuel) and energy source (renewable or fossil fuel).
	Passenger modal shift (car, air) Improvements in rail infrastructure and services can possibly attract more passengers. Better journey	Now part of **Carbon footprint**, because it's a mechanism, not an impact. Recoding: move to **Carbon footprint**.	

Final Version	Original Version	Content Changes	Wording Changes
	experience and level of service can lead to passenger modal shif from car or/and air to rail transportation. Positive impacts may also arise from shifting to more environmental friendly transportation (eg. from air to rail).		
Material footprint Similar to carbon footprint, this measure looks at a project's use of raw materials (e.g., metal and minerals), both embedded in the infrastructure and related to operations. It measures both "used" extraction (the portion of materials that end up in the infrastructure) and the "unused" extraction (the material waste associated with mining and extraction).	N/A Material footprint was previously missing.	Material resource consumption is an important impact (yc) and should not be combined with solid waste disposal (mjb). <u>Methodological issue</u>: it is suboptimal to add a new criterion which previous respondents did not have the option of considering. In the end we decided it was worth the trade-off, as it seemed sufficiently important to add such a key impact.	
Noise & vibration Nuisance to people caused by noise and vibration from road and rail traffic, during both project construction and transport operation. Impacts can be on individual dwellings (residential) and on communities (non-residential, e.g., open spaces, schools, hospitals, offices, hotels).	**Noise & vibration** Nuisance to people caused by road and rail traffic-related noise and vibration. Effects arise from the construction or operation of transport on individual dwellings (residential) and communities (non-residential, eg. open spaces, schools, hospitals, offices, hotels, etc.).	<u>No change</u>.	
Solid waste & disposal	**Waste & material resources**	<u>No change</u>.	Original title was taken from ES, but ES title is not sufficiently clear. According to the description,

Final Version	Original Version	Content Changes	Wording Changes
Refers to solid waste from construction (e.g., earthworks) and operating activities (e.g., wastes from stations, rolling stock or track operation and maintenance), as well as the impacts associated with its disposal. Of particular concern in the case of large infrastructure projects is the need to excavate enormous quantities of dirt to make way for the project and the resulting need to dispose of vast quantities of soil, some of which may be contaminated from previous land use. In addition to the quantity of waste generated, this criterion covers impacts associated with where and how (e.g., landfill vs. recycling) waste will be disposed of.	Effects from the off-site disposal to landfill of solid waste from construction (eg. earthworks) and operation activities (eg. wastes from stations, rolling stock or track operation and maintenance).		• this is **solid** waste only, so let's be clear about that; • this refers to waste **disposal** only, not – as implied by the term "material resources" – to resource consumption (e.g., how much cement is needed? how much steel?). Revised title better reflects actual content. The concept of material resource consumption is sufficiently important (yc), however, that we agreed to add **Material footprint** as a separate criterion, thereby avoiding confusion with ES's questionable use of the term "material resources."
Water & land contamination Water contamination can result either directly from the disposal of liquid waste into surface and ground water or indirectly through soil contamination. Soil contaminants often leach into surface and ground water, which is why land and water contamination are interconnected. Ground contamination can occur either during construction or during operation and	**Land quality (soil, agriculture & forestry)** Effects on agricultural soils and forestry resources resulting directly from land required (both temporarily and permanently) for construction and operation (eg. impacts on farming and woodland planting; ancient woodlands or protected areas are covered under Land take & biodiversity). Potential effects associated both with the disturbance of contaminated land and with	This impact category represents a change from earlier versions as well as a departure from ES. It now includes the ES impact "land quality" together with liquid waste disposal, which ES includes under "water resources and flood risk." Similar to **Air quality**, this is a measure of pollution/contamination impacts on soil and water and includes: 1) the ES impact "land quality," which refers specifically to *contaminated* land, past and future. In the case of land that is already contaminated, soil disruption is not such a great idea, so there's concern about HS2 stirring around contaminated soil. In addition, the project may contribute some of its own contaminating (during construction or operation – ES specifically mentions contamination alongside train tracks). Soil contamination often leads to surface and groundwater contamination, which is why ES includes those under this category;	Change of title from ES: • "land contamination" is clearer than "land quality" • "water contamination" makes clear that water quality impacts belong here

Final Version	Original Version	Content Changes	Wording Changes
includes leaks and spillages from line-side equipment and trains, in depots or along train tracks.	any ground contamination that could occur from construction or operation (e.g. leaks or spillages within depots from line-side equipment or from trains). **Water environment & flood risk** Impacts on surface water features (natural or artificial) and ground water (where not related to contamination – a land quality issue). Flood risk and drainage networks (eg. bridges and embankments obstructing path of floodwaters). Disposal of liquid waste.	2) liquid waste disposal, which ES considers part of "water resources and flood risk." ES's distinction between this and "surface and groundwater contamination" that are part of "land quality" is too subtle. The former presumably refers to pollutants dumped directly into the water, whereas if they are dumped onto the ground, and then they leach into the water, it should be considered part of "land quality." This distinction is sure to be missed by respondents; not to mention the fact that we're back to mechanisms again! If the water's polluted, the water's polluted. Hence all **water quality** impacts have been combined with **contaminated land**, since these are quite difficult to separate.	
Water resources & flood risk Impacts (other than contamination) on structure and flow of surface waterways, both natural and artificial (e.g., changing the course of streams or channels; emptying lakes or reservoirs). Impacts on drainage networks (e.g., bridges and embankments obstructing path of floodwaters) and associated implications for flood risk.	**Water environment & flood risk** Impacts on surface water features (natural or artificial) and ground water (where not related to contamination – a land quality issue). Flood risk and drainage networks (eg. bridges and embankments obstructing path of floodwaters). Disposal of liquid waste.	Final version is slightly narrower. We have now separated out the quality aspect of water (i.e., water contamination) from the flow aspect (how much and where). The title already alluded primarily to the flow aspects of water; now the impact definition also reflects this. Recoding: move some *Water environment & flood risk* respondents to **Water & land contamination**? • Probably not (would only be justified if someone who chose "water environment & flood risk" were concerned primarily with "liquid waste disposal") • Only 1 or 2 people selected the earlier version; even in these cases it is unlikely respondents were thinking about liquid waste, since the original title doesn't really invoke images of water quality	Title has been changed back to original ES title, although definition has been narrowed. ES title is a clear reference to the main component of this criterion, namely all impacts on structure/flow of surface waterways, both natural and artificial (do we change the course of rivers, empty lakes, etc.?) and not to the component that has now been eliminated (liquid waste disposal).

Appendix D – Final criteria descriptions

Direct project impacts *(internal costs & benefits)*

Criterion	Definition	References
Journey cost & affordability	Journey cost (proposed or expected) is the price passengers pay for a trip. In this context, affordability is defined narrowly in terms of whether *this particular means of transport* is expected to be affordable to would-be users. If your concern is about what might happen to *other* means of transport, whether currently in existence or proposed for the future, as a result of this project being realized, please refer to "Equity and distributional effects."	
Journey experience	Journey experience is a measure of the real and perceived physical and social environment experienced while travelling. It includes the overall quality of facilities and infrastructure (stations and rolling stock), as well as more tangible factors like availability of seats, comfort, provision of relevant information, safety & security, crowdedness and other stress factors. Moreover, experience of time as perceived by users includes entertainment and scenery.	TAG Unit A4.1
Journey reliability & system resilience	Journey reliability refers to variability in journey time that individuals are unable to predict due to recurring events (e.g., congestion) or non-recurring events (e.g., accidents). For public transport this is usually measured as the standard deviation of lateness divided by average lateness. Resilience refers to the ability of a transport system or network to recover from disruptions caused by natural disasters or human factors. Resilience and reliability are related in that when resilience is high it is reflected in reliability as well.	TAG Unit A1.3
Journey time	Journey time is defined as travel time from station of origin to station of destination. High-speed rail is aimed at reducing travel time.	
Project costs	Total cost of project to taxpayers, comprising both upfront and ongoing costs. Upfront capital investment includes construction costs from main work contracts (stations, tracks, rolling stock, power and signalling), land and property costs (acquisition and compensation), administrative costs (design, management, consultation). Ongoing costs include train and station operations, maintenance, and renewal costs.	TAG Unit A1.2
Project delivery risks	Uncertainties during planning and construction stages regarding final project outcome. These risks include cost overruns, construction delays, and underperformance of new technology. Risks can be mitigated by consulting key experts and stakeholders early in the process and by conducting pilot studies. Risks can be exacerbated when cost estimates are subject to optimism bias (underestimation, whether intentional or unintentional).	TAG Unit A1.2 & A5.3 (rail)
Rail capacity for freight	Any increase in rail capacity will also increase the capacity available for freight, whether directly through the construction of new tracks available to freight and passengers, or indirectly through the construction of new passenger lines, thus freeing up tracks that were previously shared with passengers. An increase in rail capacity available for freight transport would be able to meet growing demand for freight transport and/or reduce rail costs for freight users. This in turn could result in shifting freight from roads to rail. If your interest in rail capacity is primarily related to modal shift and the resulting possibility of reducing CO2 emissions, please refer to "Carbon footprint." If your interest is more generally in increasing capacity and reducing costs for freight users, please select this criterion.	TAG Unit A5.3

Rail capacity for passengers	Passenger capacity is the total number of people a means of transport is able to transfer in a given period (measured for example in person-km per day). Increasing passenger capacity is particularly relevant when travel demand is expected to grow and policymakers want to satisfy that demand. One way of increasing passenger capacity is to increase frequency of service, which is also made possible by increasing train speed. Other methods of increasing capacity include lengthening trains or building new tracks/routes. In addition to meeting growing travel demand, increasing passenger capacity may also encourage a shift from other modes of passenger transport (air, car) to rail. If your interest in rail capacity is primarily related to modal shift and the resulting possibility of reducing CO2 emissions, please refer to "Carbon footprint." If your interest in rail capacity is more directly about meeting passenger needs for travel, please select this criterion.	
Traffic & transport disruption	Welfare impacts on rail users caused by transport disruption during project construction (e.g., WCML upgrade) and/or on non-rail users caused by traffic congestion from construction trucks (HS2). This is primarily a construction-phase impact. If your interest is in longer-term impacts on traffic patterns and other infrastructure conflicts, please refer to "Community severance" and/or "Land use & urban planning." If your interest in traffic patterns is related to CO2 emissions, please refer to "Carbon footprint."	TAG Unit A5.3, ES
Transport integration & connectivity	Extent to which the proposed project would be integrated with and connected to other transport. This includes intermodal integration, which refers to how well different modes of transport (train, bus, ferry, etc.) are interconnected. Intermodal integration can also refer to provisions for active modes of transport (cycling, walking, etc.). When such connections are smooth and convenient, intermodal integration can play an important role in promoting green and healthy/active travel. Transport integration also includes connectivity of travel segments within the same mode of transport (train-to-train, bus-to-bus, etc.). Connectivity is a closely related concept that considers, alongside total travel time, passenger discomfort associated with waiting, transfer, and access/egress times. Transit connectivity aims to provide attractive and "seamless" transfers along multimodal paths as part of the door-to-door passenger chain.	Popoks et al. (2013), Ceder (2007)

Indirect societal impacts *(externalities - people)*

Criterion	**Definition**	**References**
Accessibility	Accessibility reflects the range of opportunities and choices people have in connecting with employment, education, essential services, and social networks. It can be measured as a catchment area and is concerned with travel horizons (journey times and distances). It is more holistic than transport user benefits, as it considers the availability and physical accessibility of a transport service in connection with the location of other services and activities. Accessibility also includes option value (the value of the existence of the service for convenience or unplanned trips) and non-use value (appreciating that a service is available for others).	TAG Unit A4.1 & 4.2
Accidents & safety	Risk of individuals (both transport users and non-users) being killed or injured as a result of accidents, usually measured in number of casualties, fatalities or injuries in a given period. Refers to both construction and operation phases. Expected casualties will vary with infrastructure design and route, depending for example on road intersections, crossings/bridges, and size of the neighbouring population.	TAG Unit A4.1

Community disruption & severance; blight	Community disruption refers to the temporary, disruptive impacts of project construction on residential property, public spaces, and communities as a whole. It includes impacts on the amenity of residents in the remaining parts of the residential development, including pleasantness and visual intrusion. Community severance refers to the more lasting impacts on a community, even after construction is finished and the transport system is operating. Severance is the real or perceived isolation of residential properties or community facilities due to physical or visual barriers caused by transport infrastructure or traffic flows. Severance is usually measured as a physical barrier to pedestrian movement, but also to cyclists, equestrians, children or other vulnerable groups. Blight is the reduction in property or neighbourhood value near proposed project sites. Blight takes place as soon as a potential project or route is proposed and is particularly of concern when the design and consultation period extends over many years. Blight becomes less of a problem once a decision has been reached, as property values in areas of rejected projects may recover and property owners affected by realized projects may be compensated. However, it is very much a problem for anyone who wants to sell affected property before a final decision has been reached.	TAG Unit A4.1, ES
Equity & distributional effects	Concerns about the distribution of project costs and benefits across different social groups or geographical locations. Equity is concerned about equality of opportunity, with a particular focus on vulnerable groups. Affordability of transport (usually measured as proportion of income spent on transport) is related to equity when the realization of a particular project results in a change in the options available to others. This could happen if existing transport receives less funding as a result of another project being selected. Closely related is the concept of opportunity cost: what else could the money be spent on? Whereas equity emphasizes *who* receives the benefits (e.g., transportation for whom?), opportunity cost emphasizes *what* the money is spent on (transportation? education? sports? and within transportation, what *kind* of transport?) Both equity and opportunity cost involve prioritizing the spending of public money: on what and for whom?	TAG Unit A4.2, Lucas et al. (2007)
Land use & urban development	Impacts that new transport projects have on land use (residential, industrial or commercial) and allocation of activities – also referred to as Land-Use & Transport Interaction (LUTI). Changes in the transport system affect accessibility, which reallocates land uses and determines the location of new activities. Transport policies and measures (e.g., TOD, transit-oriented development) can lead to more energy-efficient urban forms. Of particular importance in the context of urban development is whether housing will be actively built along with transport infrastructure.	Wegener & Fürst (1999)
Landscape/ townscape & cultural heritage	Landscape/townscape impacts refer to changes in the physical and cultural characteristics of the land and perceptions that make up and contribute to landscape character ("sense of place"). It consists of impacted topography, views, tree cover (for landscape) and all aspects of the urban form (for townscape), from construction plans along the route to overhead lines, stations, depots, tunnels and ventilation shafts, fences and barriers, bridges, etc. Cultural heritage impacts refer to archaeological and paleo-environmental remains (ancient burials; ancient environments), historic landscapes and buildings, and the built environment (both designated and non-designated assets), known collectively as heritage assets.	TAG Unit A3, ES
Prestige & image	Prestige, public recognition, and positive media coverage that may be generated for the nation, a region, or public officials. Public exposure that a project may generate for its proponents or for politicians. This may also include the potential contribution of a project to creating a sense of regional or national identity or pride.	Flyvbjerg (2014), Pryn et al. (2015)

Rail industry growth & innovation	Contribution to strategic goals of encouraging technological innovation, growth of commercial expertise within a specific industry, and development of new skills in the labour force. This may include the creation of dedicated training centres.	
Regional economic development & regeneration	Regional economic development refers to welfare benefits that are broader than transport user benefits. These wider economic impacts (WEI) affect the labour market, product market and land market: 1) agglomeration effects: accessibility of firms to other firms, products and workers; the increase in labour productivity from increased proximity, knowledge and technology spillovers; 2) welfare gain for firms whose goods and services require transport; and 3) increased tax revenues from the labour market. Regional development also includes rebalancing the national economy and bridging the North-South divide. When infrastructure is located in areas designated for economic development under UK or EU regeneration programmes, projects can help meet regeneration goals by stimulating economic activity and employment.	TAG Unit A2.1 & A2.2

Environmental impacts *(externalities - planet)*

Criterion	**Definition**	**References**
Agriculture, forestry & soils	Soil quality impacts on agricultural and forestry land. The driver is land "taken" from agriculture and forestry for an infrastructure project, but the impact of concern is not an acreage issue, but rather the loss of *high-quality* farm soil. For infrastructure projects, a hectare is a hectare. But for farms, there are differences in soil quality, and this may not get compensated in the land price. Protecting high-quality agricultural and forestry land may also be considered a priority for society.	ES
Air quality	Impacts on local and regional air quality from dust and emissions during both project construction and operation. Impacts can be both positive (e.g., decreased emissions from road transport if modal shift occurs) and negative (e.g., increased emissions from diesel locomotives or increased road traffic around stations and depots). Pollutants impacting local and regional air quality include oxides of nitrogen (NOx), volatile organic compounds/hydrocarbons (VOC/HC/PAH), particulate matter (PM), oxides of sulphur (SOx), ozone (O3), carbon monoxide (CO), and trace metals. Global air pollutants (CO2 and other greenhouse gases) are covered under "carbon footprint".	TAG Unit A3, ES
Biodiversity & nature	Impacts on nature conservation arising from habitat loss and degradation, fragmentation of sites, severance of ecological corridors and networks, noise and visual disturbance, barrier effects to movement of fauna, artificial lighting, changes in water quality and quantity, air pollution, and mortality as a result of collisions with trains. Included here are impacts on protected species and habitats, such as Sites of Special Scientific Interest (SSSIs), Areas of Outstanding Natural Beauty (AONBs), National Parks, Environmentally Sensitive Areas (ESAs), and ancient woodlands, as well as general ecological value beyond site boundaries.	TAG Unit A3, ES

Carbon footprint	All greenhouse gas (GHG) emissions associated with a project expressed as carbon dioxide equivalent (CO_2e). Aside from CO_2, which is the most significant GHG associated with transportation and energy use, GHGs include methane (CH_4) and nitrous oxide (N_2O). A project's carbon footprint comprises both embedded carbon and fuel carbon. Embedded carbon refers to CO_2 emitted during project construction as well as in connection with producing the materials used in infrastructure (cement, steel etc.). Fuel carbon refers to CO_2 emitted during transport operations. Fuel carbon emissions are driven by two factors: (1) efficiency of energy form (electricity vs. liquid fuel); and (2) energy source (renewable vs. fossil fuel). To the extent that rail transport is more fuel and/or carbon efficient than road transport, modal shift from road and/or air to rail could lead to a net reduction in carbon footprint.	TAG Unit A3; Dobruszkes 2011 (for air modal shift of HSR)
Material footprint	Similar to carbon footprint, this measure looks at a project's use of raw materials (e.g., metal and minerals), both embedded in the infrastructure and related to operations. It measures both "used" extraction (the portion of materials that end up in the infrastructure) and the "unused" extraction (the material waste associated with mining and extraction).	Wuppertal Institute (resource extraction)
Noise & vibration	Nuisance to people caused by noise and vibration from road and rail traffic, during both project construction and transport operation. Impacts can be on individual dwellings (residential) and on communities (non-residential, e.g., open spaces, schools, hospitals, offices, hotels).	TAG Unit A3, ES
Solid waste & disposal	Refers to solid waste from construction (e.g., earthworks) and operating activities (e.g., wastes from stations, rolling stock or track operation and maintenance), as well as the impacts associated with its disposal. Of particular concern in the case of large infrastructure projects is the need to excavate enormous quantities of dirt to make way for the project and the resulting need to dispose of vast quantities of soil, some of which may be contaminated from previous land use. In addition to the quantity of waste generated, this criterion covers impacts associated with where and how (e.g., landfill vs. recycling) waste will be disposed of.	ES
Water & land contamination	Water contamination can result either directly from the disposal of liquid waste into surface and ground water or indirectly through soil contamination. Soil contaminants often leach into surface and ground water, which is why land and water contamination are interconnected. Ground contamination can occur either during construction or during operation and includes leaks and spillages from line-side equipment and trains, in depots or along train tracks.	ES
Water resources & flood risk	Impacts (other than contamination) on structure and flow of surface waterways, both natural and artificial (e.g., changing the course of streams or channels; emptying lakes or reservoirs). Impacts on drainage networks (e.g., bridges and embankments obstructing path of floodwaters) and associated implications for flood risk.	ES, DRMB

TAG: Department for Transport. 2014. "Transport Analysis Guidance: WebTAG." *https://www.gov.uk/transport-analysis-guidance-webtag*

ES: Department for Transport and High Speed Two (HS2) Limited. 2013. "HS2 Phase One Environmental Statement: Documents." *https://www.gov.uk/government/collections/hs2-phase-one-environmental-statement-documents*

DMRB: Standards for Highways. 2013. "Design Manual for Roads and Bridges (DMRB): Volume 11 Environmental Assessment." *http://www.standardsforhighways.co.uk/ha/standards/ghost/dmrb/vol11/section3.htm*

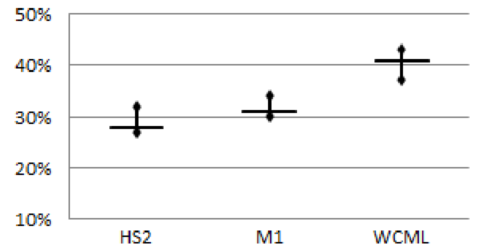
Appendix E – Robustness analysis for project preferences

We tested for robustness by varying the consistency threshold between 10% and 50% and the minimum number of required assessments for each criterion from 2 to 6.

Robustness tests show that final results are strong for all stakeholder groups: project preferences do not vary significantly (see Table 1).

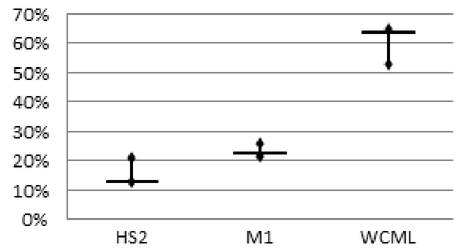
Table 1: Project preferences by stakeholder group. — = value for 33% consistency and minimum 4 respondents per criterion. | = range of results with consistency thresholds between 10% and 50%, and up to 6 minimum assessments per criterion.

Sustainable transport researchers (12)



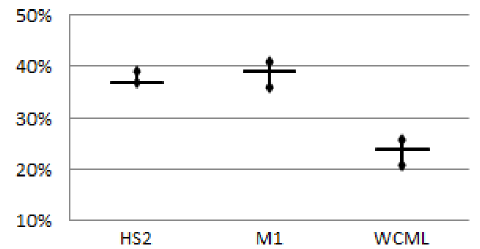
	HS2	M1	WCML
50% (all)	27%	30%	43%
33% (min 4)	28%	31%	41%
20% (min 3)	27%	34%	39%
10% (min 6)	32%	31%	37%

NGOs (3)



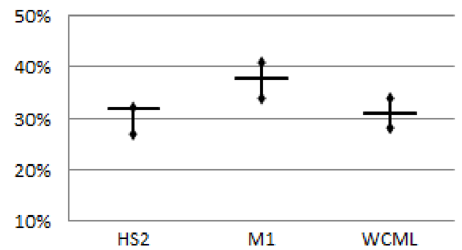
	HS2	M1	WCML
50% (all)	13%	22%	65%
33% (min 4)	13%	23%	64%
20% (min 3)	13%	26%	61%
10% (min 6)	21%	26%	53%

Government (8)



	HS2	M1	WCML
50% (all)	39%	37%	24%
33% (min 4)	37%	39%	24%
20% (min 3)	37%	41%	21%
10% (min 6)	38%	36%	26%

Other transport professionals (10)



	HS2	M1	WCML
50% (all)	30%	35%	34%
33% (min 4)	32%	38%	31%
20% (min 3)	32%	41%	28%
10% (min 6)	27%	34%	29%

Article IV High Speed Rail: A Mandate for Future Generations?

The punctiform city, reproduced with permission by Luca D'acci http://www.urem.eu/punctiform-city/

Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 00 (2017) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2016 Shanghai. 10-15 July 2016

High Speed Rail: a Mandate for Future Generations?

Yannick Cornet [a,*], Geoffrey Dudley [b], David Banister [b]

[a] *Technical University of Denmark, Transport Department, Bygningstorvet 116B, Kgs. Lyngby, 2800, Denmark*
[b] *University of Oxford, Transport Studies Unit, South Parks Road, Oxford, OX1 3QY, United Kingdom*

Abstract

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

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

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

1. Introduction

High-Speed 2 (HS2) is a £40 Billion high speed rail (HSR) project designed to connect London to Birmingham, with further extensions to Manchester, Sheffield and Leeds. It is the result of a long and debated strategic process of revitalising the rail network in the UK (Table 1). Although the Eddington Report is now a decade old (2006), the advice to government given at that time was unequivocal. The Report was set up to examine the "long term links between UK's economic productivity growth and stability, within the context of sustainable development". It was concluded that in the UK context of a compact economic geography, competing transport demands and an overloaded transport system, priority should be given to improving capacity, reliability and comfort of the existing network, thus putting on hold "ambitions and dreams of extensive new networks" (Paras I51 and I76-7 [1]). The Report also showed concern for the environmental consequences of "excessive provision" in meeting unconstrained demand (Para I.3). Referring explicitly to the Stern report for the role of transport in emissions of greenhouse gases, and with regard to HSR more specifically, the Report openly questioned the "assumption that more and faster are always better" (Paras I.3 and I.50). The Eddington Report provides a good starting point, as it was about this time that a serious debate began to take place over the construction of a new HSR in the UK.

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

2214-241X © 2017 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

the economic analysis, there has been much debate over environmental issues, with the promoters of the HS2 proposal producing one of the largest environmental assessments ever carried out on a transport project, extending to about 50,000 pages.

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

Table 1: The HS2 Proposals. Notes: The BCR ratios used are the latest ones from DfT [4], and the ones used in the text come from Castles and Parish [3], and are based on DfT [5] and other reports available at that time. In the map: the link between HS1 and HS2 is currently proposed but provision has been made in HS1 for this future development. The nature of connection between Euston and St. Pancras stations has not been decided but in any case will require disembarking from the HSR. Sources: Butcher [6], DfT [5], DfT [4] and other sources

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

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

Legislation is now proceeding through Parliament as a Hybrid Bill – submitted in November 2013 and to be completed in 2016.

The project will be publicly funded and the total cost of Phase 1 will be £15.6 B, with a contingency of £5.8B and a total budget of £21.4B – Phase 2 will cost £12.5B, with a contingency of £8.76B and a total budget of £21.2B. There will also be £7.5B spent on new rolling stock. All figures for October 2013 (2011 prices).

+

High Speed 1 (2007)
High Speed 2 (proposed)
The High Speed Rail (London – West Midlands) Bill

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

2. Review and Approach

Traditionally, rail has been seen as being 'good' for the environment, as it provides an efficient and fast form of transport, with high load factors. It has normally had the support of environmental groups for these reasons, but this unanimity among the different environmental groups has substantially weakened with respect to the HSR debate, as the energy requirements increase with speed, and consequentially the CO2 emissions factors also increase, given the high carbon content of the energy mix in the UK. But not all environmental groups are concerned about the global issues of greenhouse gas emissions, and many are more concerned about the local issues of protecting their environment. Included here is the impact of HSR on the natural environment (e.g. landscape, cultural heritage, biodiversity, water resources and flooding), as well as on their own communities (e.g. air quality, noise and vibration, health and wellbeing) and the use of resources more generally (e.g. land resources, waste and the use of materials).

One of the central themes in the Brundtland Report [7] was the concern over future generations, and the difficulty of taking important decisions today on infrastructure investment that have consequences for future generations. The construction of new rail infrastructure (tunnelling and track) has high carbon costs that may affect the global climate for future generations, but equally the destruction of local environment (woods, habitat and biodiversity) may affect the quality and diversity of their local environment. The purpose of this paper is to highlight the longer term consequences of some of these choices on future generations.

2.1. Planetary Boundaries

There has been much debate, particularly since 2009, about the limits to the global ecosystems, sometimes called boundary conditions. Rockström et al. [8] and Steffen et al. [9] in *Nature* and *Science* defined the 'safe' operating space for nine planetary life-support systems, where different measures were used to determine the boundaries, together with their respective current and pre-industrial levels, and they were then mapped to show where 'safe' boundaries have been exceeded. In four of the systems, the 'safe' limits had already been exceeded: climate change, loss of biosphere integrity (previously called biodiversity loss), land-system change, and altered biogeochemical cycles (phosphorus and nitrogen). Two of these systems, climate change and biosphere integrity, are what the scientists call "core boundaries". Significantly altering either of these "core boundaries" would "drive the Earth System into a new state". They also acknowledged the complexity of the system and the nonlinearities, suggesting that once critical thresholds are exceeded, then subsystems (for example, the jet streams and the monsoon system) could shift to a new state with potentially significant consequences for humans [10].

Climate change and biosphere integrity are the two planetary boundaries taken here to illustrate the environmental choices that need to be made with respect to HS2. The question addressed here is whether the investment decision has effectively considered these two planetary boundaries.

2.2. Complexity

The complex environmental choices presented here are problems which consist of complex interdependencies with no clear set of solutions, or where solutions cannot clearly be determined as right or wrong, or where one solution may reveal other problems. As an example, forests are in constant flux, both with regard to the species they harbour and to their carbon content. There may be many competing options, or no right solution, to attain the dual goals of halting biodiversity loss and reducing carbon emissions.

At least three types of complexities need to be considered when analysing strategic decision-making in complex contexts: detail complexity, dynamic complexity, and preference complexity [11]. Detail complexity consists of a problem where a large number of variables are relevant and require a certain level of precision to be dealt with, but processing them in combination is difficult, if not impossible. Dynamic complexity involves temporal aspects. Exemplified by the Butterfly Effect, complex dynamic interactions make long-term forecasting also difficult because small differences in starting conditions may bring considerable variability later in time. Detail and dynamic complexity taken together imply that the behaviour of a system cannot be reduced to the sum of its parts. A wicked problem is thus unique, and offers little opportunity to learn by trial-and-error, although patterns can emerge as opportunities to learn [12].

The third type of complexity refers to preferences, or interests. These preferences are "dependent on the issues raised and debated"; they depend on the various interpretations of the problems, which are not immediately obvious but must be "shaped and discovered" (citing Habermas [11]). Complex contexts therefore require more interactive communication than more simple domains where cause-and-effect relationships are more evident or discoverable [12].

In order to go behind the complexities introduced above, the paper will unpack some of the detail, dynamic, and preference complexities relating to climate change and biosphere integrity for the case of HS2.

2.3. Sustainable Transport Assessment

Ever since the growth of environmental awareness in the 1960s, there has been a long tradition for relatively comprehensive transport assessment procedures in the UK. A first milestone is the Buchanan Report (1963) which prescribed a new and more environmentally sensitive approach to traffic planning. Although the report, together with the Beeching Report of the same year, opened the way for the 'motor age' and sizing down dirty, cost-inefficient and 'futureless' trains, it also introduced the concept of minimum environmental standards [13], [14]. Concerned with the maintenance of good environmental conditions despite expected traffic volumes, Buchanan introduced methods for estimating environmental capacity and the idea of satisfying environmental norms as an absolute requirement. In 1997, a transport white paper set a 'new deal' for "safe, efficient, clean and fair" transportation, based on supporting sustainable development goals [15]. The white paper also introduced multi-criteria decision analysis (MCDA) framework in its New Approach to Appraisal (NATA). This was to become the basis for today's web-based Transport Appraisal Guidance (WebTAG) that is central to all evaluation in the UK.

Both climate change and biosphere integrity are two fairly abstract threats that are more difficult for proponents in the here-and-now to fully consider. Recent research has highlighted how ambitious high level climate goals in the UK are largely symbolic when looking at their implementation in the transport sector. This lack of implementation is said to be due to the lack of clear targets and accountability at departmental and local level [16]. Similar conclusions are echoed in the environmental assessment literature: “most impact assessment (IA) has sustainable development as the stated goal, but it doesn’t deliver sustainable outcomes”[17]. Others have attributed this to the very technical-rationalist model of environmental impact assessments (EIA), calling for strategic environmental assessments (SEA) that would take an advocacy role for sustainability, rather than the narrow concept of SEA usually found in EIA-based approaches [18].

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

2.4. Data and timeline

One characteristic of the UK appraisal process for HS2 is the vast amount of readily available material: official appraisal guidance, environmental assessments, reports from parliamentary committees, the Government responses to these reports, transcripts of oral and written evidence presented during the consultations, petitions, official correspondence and speeches, etc. are available online and easily searchable, all from one single site (GOV.uk). As per the Aarhus convention, stakeholder involvement in the form of public consultations (and later petitioning) were carried out at various stages, with no less than seven parliamentary committees mandated to examine HSR strategy or HS2 plans at various points in time (Table 2).

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

Table 2: HS2 phase I main appraisal documents and timeline

Type of documents	Release date	References used in this paper
HS2 Phase I official appraisal documentation		
Appraisal of Sustainability (AoS)	February 2011	[19]–[22]
Environmental Statement (ES)	November 2013	[23]–[34]
- Chilterns data		[35]–[40]
HS2 Phase I parliamentary committees and evidence from consultations		
House of Commons Transport Committee (HC 1185)	November 2011	[41], [42]
House of Commons Environmental Audit Committee (HC 1076)	April 2014	[43], [44]
House of Lords Economic Affairs Committee (HL 134)	March 2015	[45]
House of Commons High Speed Rail Bill Select Committee (HC 338)	July 2015 (preliminary)	[46]–[48]

3. HS2 and Carbon

The UK Government is committed to making an 80 percent reduction in net UK carbon emissions, covering all six Kyoto greenhouse gases[1] by 2050 (on 1990 levels), meaning that the total levels of emissions will have to fall from 809.4 Mt CO2e (1990) to 161.9 Mt CO2e (2050). Good progress has been made, as the current level is 520.5 Mt CO2e (2014), a reduction of 36 percent over 24 years, but the next steps are crucial, and all major energy intensive decisions, including large scale infrastructure projects, need to contribute to this carbon reduction target (Table 3 [49]). Transport is the one sector where CO2 emissions dominate and it has proved difficult and costly to reduce emissions levels – these have remained almost unchanged over the 24 years (Transport CO2 emissions are 116.9 Mt CO2e in 2014).

The carbon issue with respect to HS2 has not featured prominently in the debate, and HS2 Ltd as the main promoter of the project has remained rather ambivalent on the issue [50], as their Sustainable Policy states the aim is to “minimize the carbon footprint of HS2 as far as practicable and deliver low carbon long distance journeys that are supported by low carbon energy”. Part of the case is strong, as rail overall is a relatively small contributor to carbon emissions in terms of the operation of transport systems (4.4 Mt CO2e per annum, or about 0.8 percent of all emissions), and even within the transport sector, this figure amounts to 3.26 percent. Rail is also (rightly) seen as being more efficient than travelling by car and air over the same distances, and that

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

over time the carbon profile of rail will improve as power generation is decarbonized. If HS2 was available today, it is estimated that carbon emissions from a trip by HSR would be 73% lower than making the equivalent journey by car [51].

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

Table 3: Based on Table 1 in Temple-ERM [52] and other information.
Note: Tree planting includes 4 million trees split equally between the two Phases

Emissions Source	**Scenario A** (Mt CO_2e)	**Scenario B** (Mt CO2e)
Operational emissions	+5.27	+2.15
Modal shift emissions	-10.49	-8.21
Freight uptake of released capacity	-3.25	-3.25
Carbon sequestration from tree planting	-1.00	-1.00
Scenario A: This is based on the Economic Case for HS2, using the emissions factors for the different modes of travel, distance and mix.	**Scenario B**: This uses the assumptions in the 4th Carbon Budget [53] – this is more ambitious in the future reductions in carbon from the decarbonisation of the power sector and greater take-up of clean vehicle technology.	

3.1. Modal Shift

Firstly, it is estimated that almost all the air passengers will switch only when the full system is opened (2033), and that the CO_2 savings for air travel from Phase 1 are negligible [51]. So the full carbon savings (Table 1) from the modal shift will only materialise if and when the whole system is completed. These modal shift 'benefits' seem to account for about two thirds of all the carbon 'savings'. Secondly, there is the issue about how the released capacity will be used (the air slots and the take-up of the released road capacity by both cars and freight), but this is not addressed, and HS2's response has been that this is a commercial decision of private companies (para 6.10 [50]) and not the responsibility of HS2. This is true to some extent, but it is also an example of the need for a coherent national transport policy that includes all modes, viewed as an integrated system.

Related to this is a third issue, namely that accessibility to HS2 deteriorates with the limited number of access points and as a consequence overall journey distances (and carbon emissions) are likely to be longer (higher). For example, Martínez Sánchez-Mateos and Givoni [54] used travel time to London as the main benchmark to measure accessibility of a station on the current (conventional) and future (high-speed) rail networks, and they examined the likely winners and losers from the construction of the HSR. They concluded that the accessibility benefits from the HSR are relatively limited in terms of geographic spread, and that many cities close to the line would not see any travel time reductions on journeys to London. It is the door-to-door journey time that is important to travellers, and not only the high speed part of that journey. This has implications in terms of use of the HSR and the overall carbon emissions for the total journey. More generally, there are issues such as the potential contribution of HS2 to longer distance commuting and the impact that it might have on the location of businesses and residences. The numbers estimated to be switching from car and air to HSR are quite small, as the main beneficiaries will be existing rail travellers (65 percent) and new trips (22 percent) (para 7.3 [55]).

Finally, there is the speed issue, as higher speeds are usually associated with more energy use and more carbon. Simulation studies carried out for HS2 show that a London to Birmingham journey on HS2 would consume 23 percent more energy at a maximum speed of 360 km/h as compared with a 300 km/h maximum [56]. This difference is reduced when the unit of measurement is carbon emissions per passenger km, as the increased HSR energy consumption (and carbon emissions) as compared with conventional rail, as the trains carry more passengers and there is less stopping and starting, where most of the energy is used. These similar figures are used in other HSR systems. These range from 0.023 kWh/seat km (Japanese - Shinkansen) to 0.065 kWh/seat km (German – ICE3), and the differences relate to operating speed, the number of stops, drag factors, and the number of passengers. The Eurostar travelling at 300 km/h has an energy use of 0.055 kWh/seat km, and if the carbon intensity is 200 g CO2/kWh, this translates to 11g CO2/seat km (para 7.6 – figure for 2030 [55]). A central assumption here is the high occupancy factors assumed for HS2 (70 percent), when those for Eurostar are lower (about 60 percent) and for the UK InterCity network even lower (40 percent) (paras 7.7-7.10 [55]).

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

There is always considerable uncertainty, when looking at longer term futures, hence the use of scenarios (Table 3). Yet the assumptions used in the HS2 case do seem to be rather cautious in terms of the potential for reduction in carbon emissions from cars. Since 2010 there has been some reduction in the CO2 emissions figures for new cars in the UK, with the 2014 figure of 124.6 g CO2/km, down from the 2000 figure of 181.0 g CO2/km (a 31 percent reduction over 14 years, equivalent to about 2.5% yearly reduction on average) [57]. This will be reflected in the overall car stock carbon profile in about 5-6 years, when the 2014 new car CO2 profile will become the total stock average (in about 2020). There is also the EU requirement for all new cars to have an average of 95 g CO2/km by 2020.

In conclusion, the potential for modal shift from air and car to HSR is rather limited in Phase 1 (2026), and it will only become substantial when Phase 2 is also completed (2033), but even then it is the door-to-door travel time that is important and not just the time spent on the HSR. So the levels of modal shift may be optimistic. In the shorter term, it is existing rail users that will benefit. There is some uncertainty over the use of the air slots and road capacity that might be released as a result of modal shift to HSR, as this may mean more capacity and more carbon use (but not in the rail sector). The carbon savings from HSR rely mainly on the energy mix, and this is expected to undergo decarbonisation over the next 30 years, but there are still many uncertainties.

3.2. Time for Change

The timing of the changes is also important, as not all carbon savings will take place immediately. Certainly, there will be no carbon savings until HS2 is open (2026 and 2033), but even then questions must be raised over the phasing of the modal transfers, the freight (and passenger) uptake of released capacity, the carbon sequestration from tree planting (Table 3), and the decarbonisation of the energy system. For example, if the planting of the trees takes place in 2026 and 2033, as is likely as it is one of the last activities to take place in the construction process, then how long will it be that the benefits of carbon fixing becomes effective? This depends on the type of tree planted, the rate of growth, and when maturity is reached, and this is in addition to the numbers of trees (estimated to be 2 million trees for each Phase of construction). Typically, a tree takes 20-30 years to reach maturity, and it then increases its carbon fixing for the next 50-70 years before reaching a plateau [58]. If this is the case, and the time also depends on whether the trees are actively managed or not, the earliest that substantial carbon sequestration takes place will be about 2050 when the UK carbon emissions target of an 80 percent reduction has to be reached. There is also some doubt about the net effect of sequestration with forest planting [59], where it has been concluded that although carbon sequestration has been very effective, the benefits of unharvested forests is far less clear.

Perhaps the time element should be presented in periods of 10 years to determine when carbon savings accrue rather than averaged over a sixty year period, as this gives the impression that these savings are immediate rather than cumulative. For example, for all the 10 Mt CO2e savings over the 60 year period (Table 3 – average), a linear increase might suggest that about 5 percent of carbon savings occur in the first ten years, 9.5 percent in years 10-20, and so on until about 28.6 percent on savings are realised in years 50-60. This thinking is particularly important where there is carbon accounting and budget periods over which clearly specified targets need to be met, as in the UK [53].

3.3. Construction and Carbon

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

As part of the London to West Midlands Environmental Statement (ES) [23], a detailed analysis has been carried out on the carbon created over the construction process. This extremely useful assembling of data from a wide range of sources demonstrates the seriousness with which this issue has been addressed by HS2 Ltd. Three different cases have been calculated for Phase 1 of HS2 (Worst, Central and Stretch) to cover the scope elements (embedded, transport, labor and plant) and the design elements (viaducts, roads, tunnels). Here the Central case is presented in Table 4 with commentary that looks at the other two variants. The main differences in the Worst and Stretch cases were higher (or lower) costs for bridges and viaducts (+25 percent and – 9 percent respectively) and for tunnels (+21 percent and -9 percent respectively), together with smaller adjustments in some of the other categories.

Table 4: HS2 Phase 1 Construction Carbon Footprint for the Central Case. Source HS2 Ltd. [32]

Element	**Embedded ($t\ CO_2e$)**	**Transport ($t\ CO_2e$)**	**Labour and Plant ($t\ CO_2e$)**	**Total ($t\ CO_2e$)**
Earthworks	0	390,000	200,000	590,000
Construction and demolition waste	0	40,000	0	40,000
Land use – change and forestry	100,000	0	0	100,000
Bridges and viaducts	520,000	30,000	180,000	730,000
Roads	100,000	10,000	10,000	120,000

Retaining walls, cuttings and embankments	140,000	10,000	90,000	240,000
Tunnels, portals and dive-unders	1,170,000	80,000	10,000	1,260,000
Tunnel boring machine	30,000	500	250,000	280,000
Stations and depots	520,000	10,000	120,000	650,000
Track	970,000	30,000	160,000	1,160,000
Rolling stock	230,000	0	0	230,000
Other	140,000	20,000	30,000	190,000
Total	3,920,000	620,000	1,050,000	5,590,000

It is surprising that the largest single transport infrastructure intervention in the UK this century will be making no contribution to reducing the UK's CO2 emissions, and that this this conclusion has not been of much greater importance in the debate over HSR. These carbon construction costs can be set against the operational costs as they relate to the two scenarios (Table 3). In summary it can be seen that the carbon associated with construction amounts to about 5.6 Mt CO2e (Table 4), and these are all incurred before HS2 opens over the 10 year construction period (2017-2026), whilst the net carbon savings (about 3 Mt CO2e) will all occur over the next 60 years. Even after 70 years (2086), there will still be 'residual carbon' deficit of about 2.6 Mt CO2e, only balanced out over the next 60 years (2146). It should also be noted that the carbon costs associated with Phase 2 have also been calculated, but only a range can be given as the time horizon is obviously much longer and uncertain, and as the route has not been finalised. The figures are between 2.18 Mt CO2e and 7.7 Mt CO2e (Table 2 in Temple-ERM [52]). The carbon costs of construction are high, while those associated with the operation of the railway are low, yet both aspects require consideration.

Another aspect of this is that most of the embedded emissions and operational emissions would be covered by either the European emission trading system (ETS) or other policy frameworks, such as the binding UK Climate Change Act (paras 5.1.17-19 [27]). As noted above, direct emission reductions from modal shift can be challenged in a number of ways (e.g. more transport capacity tends to generate more transport in the long run). However, building a new motorway would multiply operational emissions by a factor of 10 over the 60 years of the appraisal period (para 5.1.15 [27]).

In the case of the proposed HS2 route, one of the major costs is the tunnelling that will take place, principally for environmental reasons and to maintain areas of outstanding natural beauty, including ancient woodlands and unique habitats. For Phase 1, some 39.1 kms will be in twin bore tunnels and a further 8.2 kms in twin cut and cover tunnels. The total of 47.3 km accounts for about 21 percent of the total route [60]. Tunnelling has considerable costs associated with it, both in financial and in carbon terms (some 28 percent of the total carbon embedded in the construction of the HSR). The question here is that while more tunnelling helps allay the concerns of communities and the natural environment that would be affected by the railway, at the same time it raises the costs. The global environmental costs (carbon) are being raised and the local environmental costs (biodiversity) are being reduced, but there seems to be no discussion over the appropriate balance between the two concerns.

4. HS2 and Biosphere Integrity

The UK Government ambition regarding biodiversity is to move to a 'net gain' in the value of nature, and this includes a halt to the loss of habitats and species and the degradation of landscapes, and (perhaps ambitiously) to restore biodiversity by creating a resilient ecological network [61], [62]. However, the UK, just as the rest of Europe, has so far failed to meet its commitment to halt biodiversity loss by 2010 [63]. For the UK, this goal has now been set for 2020 [62].

Unlike carbon, there isn't one simple measure for biosphere integrity, and quantification of impacts for biodiversity is difficult. While there is clearly some economic benefit to be gained through the use of natural resources, maintaining biodiversity is crucial to biosphere integrity [64]. Recent work on biodiversity indicators shows progress in terms of volunteer time spent in conservation activities, the total protected or sustainably managed areas, the availability of biodiversity data, and public expenditure on UK biodiversity. But the long-term downward trends for species group indicators - including the UK priority species - remain to be reversed [65].

The impact of transport infrastructure on long term biodiversity and habitats is complex. Within the Chilterns alone, the National Biodiversity Network Gateway reports more than 7000 species, of which 219 are listed on the UK Biodiversity Action Plan (BAP)[66]. The latter comprises a wide variety of small insects (moths, butterflies and beetles), various types of lichen, moss and fungus, reptiles, amphibians, birds, flowering plants, and small mammals such as bats and mice, and biodiversity relates to species, genetic diversity, and to the interactions between all aspects over time. Official appraisal guidance is based on a natural capital approach, requiring a consideration for both designated and non-designated areas, and establishing an assessment of the magnitude of the impact together with the relevance of key features based on their substitution possibilities – for example, whether a habitat is technically replaceable, or whether species can be relocated (para 9.2.4 [67]).

HS2 Ltd endorsed early on the ambition of demonstrating 'no net loss' with regard to biodiversity, both in the Appraisal of Sustainability (AoS [19]) and later in the Environmental Statement (ES) (para 4.8 [34], para 9.8.6 [25]). Its Sustainability Policy commits to "minimise impacts where they occur and deliver enhancements as far as practicable to ensure there is no net loss to the natural environment." [68]. This commitment to no net loss has not dominated the debate, but the goal has been called anything from 'incredibly ambitious' by the Department for Transport to 'window-dressing' by some opponents [45]. HS2 Ltd pointed out that building HS2 will inevitably cause effects on the natural environment, but committed nevertheless to looking for "environmental enhancements and benefits" [68].

With regard to ecology, the ES reports on effects arising from both construction and operation, such as habitat loss, fragmentation of ecological sites and corridors, noise, lighting, or mortality as a result of collisions with trains (para 8.5.1 [25]). Ecological effects for each of the 26 community forum areas (CFAs) along the route are reported in volume 2 of the ES (chap.7 [26]); volume 5 provides ecological baselines for designated sites, flora and fauna [33], and a summary of cumulative effects is laid out in the ecology chapter of volume 3 on route-wide effects [27]. Of particular interest are the avoidance, mitigation and compensation measures for each CFA, as well as the expected residual effects. Habitat loss within statutory and non-statutory sites will both see compensatory habitats created elsewhere. For example, the ES reports a loss of 330 ha of habitats of principal importance (BAP), including 280ha of lowland mixed deciduous woodland and 165ha of lowland meadow. As compensation, approximately 520ha of habitats of principal importance will be created (chap.8 [27]). Eleven of the 26 CFAs report some level of ancient woodland to be lost, totalling 32ha (see Table 5). While ancient woodlands are categorized as irreplaceable, the Chilterns ES (CFA9) mentions the planting of (over) 40ha of new semi-natural broad-leaved woodlands which will be a benefit when mature.

Table 5: HS2 Phase I impacts on ecology (sites and habitats only) (chap.8 [27], [26])

Element	Description
Designated sites	
Statutory sites	Habitat loss and fragmentation of 2 Sites of Special Scientific Interest (SSSI, of national value for nature conservation, CFA7)
Non-statutory sites	Habitat loss or fragmentation at 89 Local Wildlife Sites (LWS), 61 of which result in significant adversity on the integrity of the site
Habitats	
Ancient woodlands	Loss of 32ha, 19 woodlands will be directly affected. 10.2ha in the Chilterns Area of Outstanding Natural Beauty (AONB)
Broadleaved woodland	Loss of 310ha, of which 195ha is semi-natural woodland
Grassland	Loss of 170ha, including 11ha of species rich grassland (CFA25)
Fen, marsh and swamps	Loss of 19ha
Hedgerows	Loss of up to 490km

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

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

4.1. No net loss

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

On one hand, not net loss is a traditional conservationist position, which can also be justified from ecological economists' logic of strong sustainability where human and natural capital are not substitutable [69]. This approach implies development should contribute positively to all three dimensions of sustainability, including the environmental dimension. On the other hand, no net loss allows for substitution *within* the environmental dimension. First introduced in the Lawton report [63], the UK Government has been keen to test and further develop biodiversity offsetting [61], [62]. With this approach, genuinely unavoidable biodiversity losses are to be offset, "not by replacing the rare and threatened by the commonplace, but by ensuring the natural environment remains diverse and continues to provide essential services" (para. 3.10 [62]). In light of this, HS2 Ltd adopted the Lawton report's recommendation to avoid impacts first, to mitigate impacts second, and to compensate for inevitable damage (Figure 1). The latter puts responsibility on developers to secure compensatory habitat expansion or restoration elsewhere as a last resort, once reasonable efforts have been made to consider the mitigation strategy at an earlier stage.

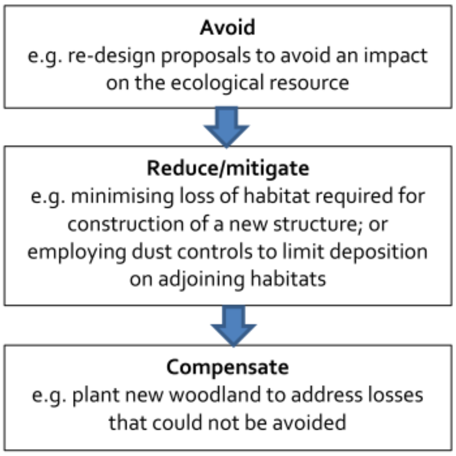


Figure 1: Mitigation hierarchy for HS2 (Annex D Ecology – Technical note #4 ‘Methodology for demonstrating no net loss in biodiversity’ [29])

Essential to this approach is the metrication of biodiversity. According to the somewhat buried technical note for demonstrating no net loss in biodiversity [29], the ES explains the use of so-called biodiversity units to determine the extent of required compensation for loss of habitat. This is based on scores given for distinctiveness, current habitat condition, and coverage. There is the issue of how to account for environmental limits and irreplaceable natural capital, for which HS2 Ltd used a new, ‘very high’ score for habitat distinctiveness. This received considerable attention, as the House of Commons Environmental Audit Committee recommended in its final report that the Government aim higher than ‘no net loss’, due to the expected damages on sites of high ecological value such as Sites of Special Scientific Interest (SSSIs), Local Wildlife Sites (LWSs) and ancient woodlands. For ancient woodlands, the Committee recommended that they be treated separately from the ‘no net loss’ accounts, or at minimum, that they be given ‘very high’ for all three scores to “recognize their irreplaceability” [43].

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

4.2. Alignment

The choice for the route proposed for HS2 Phase I has been the subject of dispute (see for e.g. Q345 [41]). The current route was settled in the Appraisal of Sustainability and has remained largely unchanged since. Assembling a full length route was done via a weighting process of biodiversity impacts similar to the one conducted in the ES. But instead of using (time-consuming) absolute biodiversity units, the approach used qualitative expert assessments to compare route segments (Para 5.3.2 [22]). This stage of option generation was criticized for imposing from the start a 400km/hr maximum operating speed and a connection to Heathrow via Old Oak Common, which was said to ultimately favor the current alignment (see High Speed UK written evidence para 10 [45], also [70]).

A number of opponents proposed alternatives, particularly to avoid the crossing of the Chilterns Area of Outstanding Natural Beauty, some of which were considered in more detail by HS2 Ltd [31], [71], [72] (Figure 2). The first, preferred by proponents such as High Speed UK (HSUK), suggested that any high-speed rail development should follow existing transport corridors. This is expected to have lower biodiversity impacts, particularly on SSSIs, LWSs, ancient woodlands, and BAP habitats (para 3.3.1 [72]). However a route following the M1 motorway would also encounter more populated areas, which would require (possibly costly) mitigation measures and was likely to be more controversial (see written evidence from Lord Adonis para 222 [45]). A 10 percent additional cost premium was estimated for this route (£2.2bn)[72]. Another issue is speed. Following the motorway curvature would only allow speeds up to 186mph (similar to HS1, between the Channel Tunnel and London) and would likely create a number of unusable islands of land, essentially cutting off communities or biodiversity between a highway and a high-speed rail line.

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

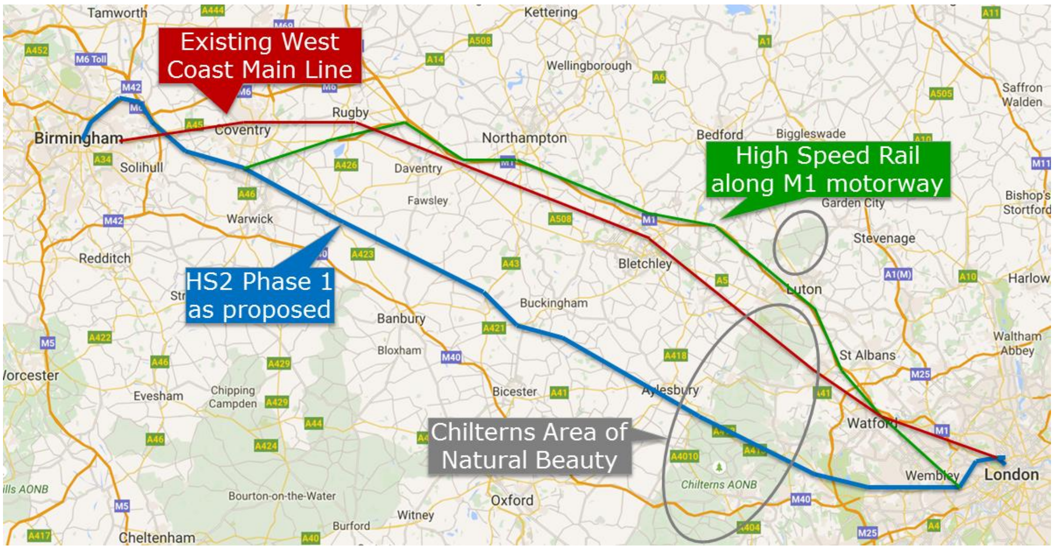


Figure 2: Alternatives along existing transport corridors considered for HS2 Phase I:
Slower route along the M1 motorway (green); Upgrade of the existing West Coast Main Line (red).

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

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

4.3. The Chilterns Ancient woodlands

The Chiltern Hills, or the Chilterns, cover a large area of valleys and countryside situated in the north-western outskirts of London. The Chilterns are a designated Area of Outstanding Natural Beauty (AONB), which belongs to the same family as National Parks. This means they enjoy protection from development except under exceptional circumstances. The proposed HS2 route is the largest infrastructure project crossing the Chilterns since the construction of the M40 in the late 60s. The selected route also crosses the AONB at its widest point (around 20 km).

Effects on the Chilterns were first identified in the 2011 appraisal of sustainability (AoS), which was to serve as basis for the environmental statement (ES):"Although a significant proportion of the route through the Chilterns is in bored tunnel there would be localised loss of woodland habitat, notably north of Amersham at (..) Sibley Coppice, Mantles Wood and Farthings Wood (ancient woodlands)" (para 8.6.6 [20], p14 [21]). The report concluded potential land take of up to 19 ancient woodlands along the full route, but that fragmentation and habitat loss in the Chilterns is "limited and considered not significant" and that "impacts on BAP habitats is less severe than other route options in much of the route" (p14 [21]). The Chilterns Mantle's Wood, Farthings Wood and Sibley's Coppice are to be directly crossed by the proposed route (Figure 3), leading to the permanent loss of 6.2ha (31%), 0.5ha (15%), and 2.5ha (31%) respectively ([24] and para 2.5.14 [27]).

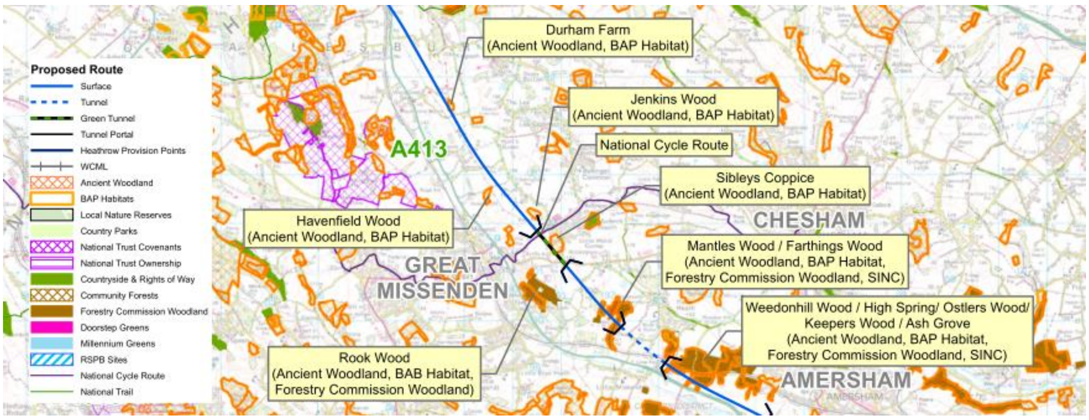


Figure 3: Ancient woodlands and BAP habitats impacted in the Chilterns AONB.

All three woodlands are designated as LWS and consist of replanted lowland mixed deciduous woodland managed for forestry during the past 100 years, parts of which qualify as habitat of principal importance (local BAP habitat [35]). The Forestry Commission categorises the three woods as 'managed plantations on ancient woodland sites'(PAWS) [73]. Mantle's Wood is connected to adjacent Farthings Wood via hedgerows and lines of trees, and is part of the wider landscape of woodland and agricultural land that is dominant in the area (Figure 4).

Figure 4: Farthings Wood ancient beech trees, with some oak and hazel. Intensively managed. Moss is indicative of old forest (left). Agricultural land between Mantle's and Farthings Wood (top-right). Mantle's wood, with many grass species and birch trees (bottom right).

The AoS and ES have been systematic in following transport appraisal guidance, and to a remarkable level of detail in the ES, even though access was not always granted for surveying onsite (para 4.4.41 [35]). The length and breadth of the ES is also a test of the complexity required to report such impacts (Table 6). Both the guidance and the ES acknowledge explicitly that ancient woodlands are irreplaceable. Thus the various organisations overseeing the Chilterns had little to add to the impact coverage, but all parties concluded that permanent fragmentation of habitat and loss of irreplaceable ancient woodlands habitat was inevitable [74]–[76].

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

Impact	Description	Ref.
Ancient woodland	Mature beech maidens (80-100 years old) with occasional cherry and oak, hornbeam, large mature field maples and locally some mature large ash. The understorey has holly, maple and regenerating hornbeam and cherry.	[35]
Ground flora	Bluebell and wood millet	[35]
Birds	33 species recorded: Marsh tit, Song thrush (red list) and Dunnock, Green woodpecker, Mistle thrush (Amber list). Red kite is listed. Barn owl was recorded in farmland habitat nearby.	[36]
Bats	Strips of woodland and hedgerow that provide suitable bat commuting habitat, 6 species were recorded (low levels): common pipistrelles, soprano pipistrelle, noctule and Myotis species.	[37], [40]
Invertebrates	Bark and sapwood decay, grassland and scrub matrix serve as habitats for Scaphidema metallicum, Stenus fuscicornis, Anaglyptus mysticus, Dryodromya testacea (nationally scarce or notable).	[38]
Amphibians	Small population of great crested newt in nearby pond.	[36], [39]

A number of organisations and residents opposed the route via the Chilterns area from early on, and they are protected by various layers of legislation: "The line is planned to cross the widest point of the Chilterns, an AONB. What is the point of establishing protected areas if they are ruined?" (written evidence from a resident of the Chilterns [42]). This is in contrast with the rest of the HS2 route which traverses large areas of rural areas and intensive farmland, considered of 'relatively low ecological value' (p14 [21]). The general consensus was that the current route would be devastating for the Chilterns. Following the publication of the AoS in February 2011, organisations such as Campaign to Protect Rural England, the Chilterns Conservation Board, and the National Trust requested the government to consider other routes which follow existing transport corridors (as was done with HS1), instead of running through 'virgin countryside' (see for example Q321/Q340 in the House of Commons Transport Committee evidence [41]). HS2 and the proposed route though the Chilterns was nevertheless approved for a full environmental statement by the then Secretary of State for Transport in January 2012 – albeit with the promise for further consideration and mitigation for the Chilterns [77].

The ES was published in November 2013. It committed to the translocation of all displaced ancient woodland soils and associated seedbank to form the basis for 40 ha of new woodland planting ([24] and Para 2.9.1 [30]). It concluded "The loss of woodland and the loss and severance of agricultural land will have an effect, although this will reduce over time as planting matures. By year 60 of operation, planting will have further matured and integrated the project into the AONB so that the effect will not be significant" [24].

4.4. Tunnelling

Following public consultations, the Chilterns as a geographical area as a whole received the largest volume of responses, warranting a section by itself in the independent assessor's report [78]. Much of the feedback was organised around the demand for full tunnelling under the Chilterns. The House of Commons Environmental Audit Committee report of April 2014 was critical about the ES with regard to ancient woodlands: "The Woodland Trust told us that the destruction of ancient woodlands raised questions about the application of the mitigation hierarchy, and illustrated it argued by a lack of explanation about why a Chilterns Tunnel ("that would save one third of the ancient woodland threatened along the route") would not be taken forward. Environment Bank, similarly, said it was necessary to use tunnels rather than cuttings to minimise damage to ancient woodlands." (Para 13 [43]).

Following the report, in a series of correspondence between DfT, HS2 and the newly formed HS2 Bill Committee, the Audit Committee raised a number of concerns about fully addressing environmental impacts, particularly with the offsetting regime, "for HS2 puts even the modest Government aim of delivering 'no net biodiversity loss' in doubt" [44]. The Government refused to raise the ambition for no net loss, judging it adequate, and in effect relegating any environmental concerns to the petitioning process of the HS2 Bill Select Committee .

In a final round of consultations regarding the HS2 Bill, local environmental groups petitioned independently to contest the loss of ancient woodlands and the policy of offsetting, with different shades of "green". These include the Chilterns Conservation Board (petition 415): "As ancient woodland is irreplaceable there is no mitigation possible for this loss, and the destruction of it is of national significance"; the Royal Society of Wildlife Trusts (petition 1293): "Your Petitioners share the concerns raised by the Environmental Audit Select Committee of your honourable House in their recent report on HS2 and the Environment relating to biodiversity offsetting"; the Chiltern Countryside Group (petition 1288): "Planting should be carried out as early as possible as the scheme progresses through the AONB. Monitoring at the expense of the Promoter should extend over a 60 year period during which replacement trees should be planted, should the original planting fail"; and the Woodland Trust (petition 1508): "Your Petitioners would humbly ask that opportunities to realign the track should be taken to avoid the destruction and damage of irreplaceable habitats such as ancient woodland. Your Petitioners have calculated that 33% of the ancient woodland to be lost to the line falls within the Chilterns AONB. However, this loss is being caused by less than 4.5% of the line. Bored tunnelling throughout the Chilterns AONB could significantly reduce the environmental impact of the scheme" (petitions 415, 1293 [46]). Other petitioners included the National Trust, the Buckinghamshire Wildlife Trust, The Chiltern Ridges Action Group, the Chiltern Society, Conserve the Chilterns and Countryside, the Berkshire, Buckinghamshire and Oxfordshire Wildlife Trusts etc.

The turnaround came following a visit by the Bill Select Committee to Little Missenden in June 2015 [47]. By July, the committee reported that the case for tunnelling under the ancient woodlands had been made [48]. A 2.6 km extension of the Chiltern tunnel was confirmed in a letter by the Government in late August [79].

5. Comment

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

5.1. Global versus local

At the time of the AoS publication, economic reviews by the Department for Transport recognised the high cost of tunnelling to avoid the Chilterns: "although tunnels would make up 13% of the total route length, they would contribute to some 23% of the construction cost" (para 4.6.6 [80]). Since much of the route through the AONB would be either in tunnel, in cutting, or alongside transport corridors, it was argued the line would be hidden from many views (para 8.5.5 [20]). This argument that only a small portion of the line through the Chilterns would be at or above surface was repeated in official speeches by all three

Secretaries of State for Transport [81]–[83]. Despite such reassurances, concerns about the visual effects on the landscape and the AONB designation prompted HS2 Ltd to just about double the length of the Chiltern tunnel by the time of the ES (from 6.7km to 13.5km) (para 12.3.4 [28]). But the area passing through the three ancient woodlands of Little Missenden were still planned as deep cuttings. Some noted the extra costs in tunnelling along the full line had already surpassed the extra costs of mitigating for populations on the M1 route.

The desire for more tunnelling along the route came again as a primary concern in the ES independent assessor's report [78]. Top concerns for the Central Chilterns area (CFA9) were very local in nature, namely the impacts of construction on transport and traffic, the impacts on community and tranquility, the landscape and visual impacts, and the noise and vibration effects (in this order) [78]. Related to disruption from construction is the issue of spoil. Deep cuttings (typically 65-90m wide at the top and 15m deep) within the AONB generate more spoil than tunnels, thus increasing both local HGV traffic and emissions from earthworks (e.g. see written evidence from the Chiltern Countryside Group para 6.2.9 [42]) (Figure 5). In the report, ecology came 8th, and sustainability (a proxy for climate change and carbon emissions) came 14th. Forestry and agriculture were of higher concern than ancient forests, biodiversity or carbon emissions.

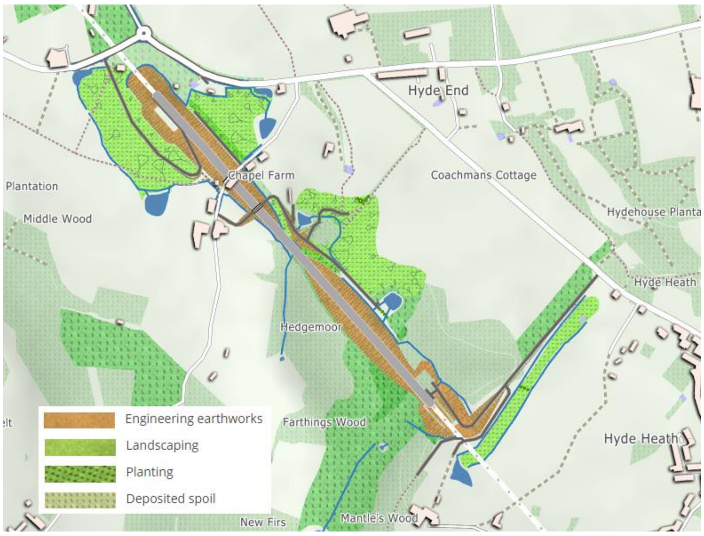


Figure 5: Landscape impacts and deep cuttings through Farthings Wood and Mantle's Wood [84].

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

5.2. Reconciling carbon and biodiversity integrity

The connection between increased tunnelling and costs was clear. The fact that high speeds both prevented the scheme from contributing to carbon emission reductions and dictated a more direct route was also understood. For example, the HS2 Action Alliance submitted evidence in support of the WCML upgrade to the first Transport Committee: "upgrades are environmentally preferable, the lower speeds give rise to lower carbon emissions, they follow existing rail corridors and so do not require the sacrifice of an AONB or tranquil countryside." [41]; or in this evidence from the first Transport Committee "Slower speeds permit greater track curvatures and reduced tunnelling and associated costs, as well as significantly reduced embedded carbon impacts." [42]. This conclusion was repeated by the Environmental Audit Committee, which suggested trains should operate at slower speeds in the first years, to allow for the UK to decarbonise its electricity production. But slower speeds also impacted the business case based on journey times, and it was argued that it would likely result in less mode shift, which in turn would lead to an increase in emissions [77]. The House of Lords also requested the Government to review opportunities to reduce costs by lowering speeds, which was rejected based on HS2 commitment to deliver "a world class railway that stands the test of time" [85].

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

Table 7: Estimates of costs and carbon emissions for the Chilterns South Heath tunnel extension. Costs vary depending on length, radius, topography, number of shafts, and type of boring machine. HS2 estimate: £33m per single tunnel km [86]. Peter Brett Associates: £25m per single tunnel km [87]. Carbon emissions estimates: 37ktons CO2e per km (bored), 30ktons CO2 per km (cut-and-cover) (central case data from Table 4).
Carbon content for old-growth forest: 420 tons C /ha [58] (weight factor C to CO2 = 3.67) [58].
Carbon sequestration rate of northern hemisphere temperate old-growth forest: 2.4 tons C /ha /year (data for up to 800 years) [88].

South Heath tunnel extension	Values
Length	2.6km
Gross construction costs (twin bore tunnel)	£130m - £172m

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

Although the appraisal process in the UK does not attempt to monetise impacts on biodiversity, the net avoidance costs can provide an implicit value to those forests. Cost calculations above only provide an average per kilometre, which is likely higher than the marginal cost of extending the existing tunnel. It must also be said that lifetime maintenance costs of a tunnelled route are also considerably less than an overground route. Additionally, savings from the green tunnel and deep cuttings that will no longer be needed should also be deducted. These costs are not available, however evidence from Buckinghamshire County submitted to the House of Lords expects the extra tunnelling to be cost neutral (para 24 [45]), and an earlier independent feasibility study for full tunnelling of the Chilterns concluded the scheme would actually save money to HS2 Ltd [74].

A deep-bore tunnel comes at a 25% premium to a green (cut-and-cover) tunnel in terms of embedded carbon. The bulk of the emissions come from the use of carbon-intensive materials such as concrete and steel. On paper, the increased cost of 'saving' the ancient forests in terms of carbon emissions is approximately three times the carbon sink potential of the forest over 60 years. Carbon sequestration processes from old-growth forests remain somewhat unclear, but recent studies report that mature deciduous trees absorb more carbon than fast-growth forests, and that both trees and top soils in ancient woodlands continue to accumulate carbon over centuries [88]–[90]. If this is the case, the carbon footprint of the extra tunnelling would be offset in about 800 years. These findings could call for the protection of ancient woodlands, not only because they harbour a wider range of species, but also for their role as carbon sinks in the long term.

In conclusion, the immediate carbon emissions from the loss of woodlands are relatively low, contributing less than 2% of the total embedded emissions (using HS2 methodology and central case from Table 4, assuming mature forests are carbon neutral). Reducing embedded carbon emissions would hence require minimising the total amount of tunnels, viaducts and earthworks construction. In this context, if the priority was to contribute to reducing net transport-related carbon emissions, modal shift from air or road to rail should be a top priority. But that also means that the released capacity is not taken up by more road or air travel (this is true for both passenger and freight). Therefore revising the route alignment to not only follow an existing motorway, but to replace a number of lanes on an existing motorway would likely deliver far higher carbon emissions reductions, as well as offering reduced impacts on biodiversity from habitat fragmentation or degradation. The physical footprint of HSR is not fundamentally different to that of motorways (approximately 23 metres of land take, as opposed to 33 metres). The tracks themselves take 5 metres in each direction, leaving much of the remaining area suitable for some wildlife. Unlike Germany or Sweden, fencing is mandatory in the UK, and this acts as a barrier to larger animals. But HSR can be more easily elevated (to allow for dedicated animal underpasses), and it is likely to produce significantly less chemical runoffs, and the transport corridor would be free of pesticides or fertilizers, otherwise common in the intensive farmlands it crosses. Whether HSR is a 'Berlin wall for wildlife' or a type of 'Green corridor' remains to be more precisely assessed and understood (Q463 [41]).

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

5.3. Systems planning

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

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

This raises the issue of delineation of the system itself [11]. As required by the European Commission directive on the assessment of projects on the environment, the ES sets its boundary to the project itself (HS2 Phase I)[91]. But addressing the three types of complexities mentioned earlier (Section 2.2) requires an integrated, multi-modal, transport network perspective on the goals and the possible means to achieve them [92]. This is something that could be covered by Strategic Environmental Assessments (SEA), which by definition provide a broader perspective to environmental assessments than EIAs. The environmental audit committee identified the absence of a formal SEA process for HS2 [43], and this was also raised as a potential breach to EU regulation in consultations for both the AoS and the ES ([93], [78]).

HS2 Ltd defended the level of detail in the AoS as adequate and compliant with SEA requirements (para 8.1.3 [22], para 3.1.1 [93]). But the key issue here may be related to the understanding of a ‘programme’. While it is correct that for strategic purposes, the level of detail required in a EIA is not required in a SEA, as SEAs require identifying, describing and evaluating “reasonable alternatives taking into account the objectives and the geographical scope of the plan or programme” (article 5 para 1 [94]). The understanding of SEA in transportation is that it serves as the means to judge investments on their network-wide, cumulative effects. A SEA intends to provide a robust analysis of alternatives to competing goals of transportation, economic growth, environmental protection, equity and costs. Therefore a SEA applies to the transport system as a whole, across all modes, and in relation to other national plans [92]. This goes quite beyond the scope of HS2’s AoS, which in comparison served as a type of early EIA. But even a comprehensive SEA may not have the answers to all the questions being raised.

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

At the other end of the planning spectrum, the National Planning Policy Framework (NPPF) was also criticised for having a presumption in favour of development. The guidance, intended to support better bottom-up planning by local authorities, mixes strong language for sustainable development – including limits - but at the same time allows for a lot of margin in the implementation. In short, the NPPF serves as a pragmatic tool to relativise and reduce the initial ambitions set in, for example, “The Natural Choice” guidance by DEFRA [61]. This may give an impression in the UK of high ambition over the scale of new infrastructure projects, but it really allows for business as usual to proceed. This might just be a feature of democratic systems, but the interesting issues raised are outside the scope of this paper.

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

6. HS2 and Defining a Legacy

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

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

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

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

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

Acknowledgements

The authors are grateful to the Strategic Research Council of Denmark (Innovationsfonden) that is supporting the SUSTAIN research project. The authors wish to thank colleagues at the Transport Studies Unit of Oxford School of Geography and the Environment, and at the Department of Transport of the Technical University of Denmark for valuable discussions and feedback.

Acronyms

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

References

[1] R. Eddington, *The Eddington Transport Study - The case for action: Sir Rod Eddington’s advice to Government*, no. December. 2006.

[2] House of Commons Transport Committee, “Delivering a sustainable railway: a 30-year strategy for the railways? (HC219),” 2008.

[3] C. Castles, D. Parish, and 51m, “Review of the Economic Case for HS2 (Appendix 2),” no. July, 2011.

[4] HS2 Ltd, “The Strategic Case for HS2,” 2013.

[5] Department for Transport, “High Speed Rail,” 2010.

[6] L. Butcher, “Railways : HS2 Phase 1,” 2015.

[7] World Commission on Environment and Development (WCED), “Our Common future,” 1987. [Online]. Available: http://www.un-documents.net/wced-ocf.htm. [Accessed: 14-Feb-2013].

[8] J. Rockström, W. Steffen, K. Noone, Å. Persson, I. F. S. Chapin, E. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. Schellnhuber, B. Nykvist, C. A. De Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P. K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R. W. Corell, V. J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, and J. Foley, “Planetary boundaries: exploring the safe operating space for humanity,” *Ecol. Soc.*, vol. 14, no. 2, pp. 1–23, 2009.

[9] W. Steffen, K. Richardson, J. Rockström, S. E. Cornell, I. Fetzer, E. M. Bennett, R. Biggs, S. R. Carpenter, W. De Vries, C. A. De Wit, C. Folke, D. Gerten, J. Heinke, G. M. Mace, L. M. Persson, V. Ramanathan, B. Reyers, and S. Sörlin, “Planetary boundaries: Guiding human development on a changing planet,” *Science (80-.).*, vol. 347, no. 6223, 2015.

[10] T. M. Lenton, H. Held, E. Kriegler, J. W. Hall, W. Lucht, S. Rahmstorf, and H. J. Schellnhuber, “Tipping elements in the Earth’s climate system.,” *Proc. Natl. Acad. Sci. U. S. A.*, vol. 105, no. 6, pp. 20561–20563, 2008.

[11] S. Leleur, *Complex strategic choices*. 2012.

[12] D. J. Snowden and M. E. Boone, “A Leader’s Framework,” *Harv. Bus. Rev.*, vol. 85, no. 11, pp. 68–76, 2007.

[13] C. Buchanan, *Traffic in Towns: A Study of the Long Term Problems of Trafic in Urban Areas (The Buchanan report)*. 1963.

[14] British Railways Board, *The Reshaping of British Railways (The Beeching report)*. 1963.

[15] Department of the Environment Transport and the Regions, *A New Deal for Transport: Better for everyone - white paper*. 1998.

[16] I. Bache, L. Reardon, I. Bartle, M. Flinders, and G. Marsden, “Symbolic meta-policy: (Not) tackling climate change in the transport sector,” *Polit. Stud.*, vol. 63, pp. 830–851, 2014.

[17] A. Bond, “What Is the Role of Impact Assessment in the Long Term?,” *J. Environ. Assess. Policy Manag.*, vol. 17, no. 01, p. 1550006, 2015.

[18] M. R. Partidario, “A Strategic Advocacy Role in Sea for Sustainability,” *J. Environ. Assess. Policy Manag.*, vol. 17, no. 01, p. 1550015, 2015.

[19] HS2 Ltd, “HS2 London to the West Midlands Appraisal of Sustainability,” 2011. [Online]. Available: http://webarchive.nationalarchives.gov.uk/20111005090740/http://highspeedrail.dft.gov.uk/library/documents/appraisal-sustainability.

[20] N. Giesler, A. Bryant, A. Mayes, A. Pownall, S. Mann, S. Turner, T. Selwyn, and Y. Ali, “HS2 London to the West Midlands - Appraisal of Sustainability (Main Report Volume 1),” 2011.

[21] N. Giesler, A. Bryant, R. Cooper, A. Mayes, J. Fisk, S. Mann, S. Turner, S. Villa, and T. Selwyn, “HS2 London to the West Midlands - Appraisal of Sustainability (Main Report Volume 2),” 2011.

[22] N. Giesler, A. Bryant, A. Mayes, S. Mann, and S. Turner, “HS2 London to the West Midlands - Appraisal of Sustainability (Appendix 1 - The Appraisal Process),” 2011.

[23] HS2 Ltd, “HS2 Phase One environmental statement: documents,” 2013. [Online]. Available: https://www.gov.uk/government/collections/hs2-phase-one-environmental-statement-documents.

[24] HS2 Ltd, “London-West Midlands Environmental Statement: non-technical summary,” 2013.

[25] HS2 Ltd, “London-West Midlands Environmental Statement: Volume 1 introduction to the Environmental Statement and the Proposed Scheme,” 2013.

[26] HS2 Ltd, “HS2 Phase One environmental statement volume 2: community forum area reports and map books,” 2013. [Online]. Available: https://www.gov.uk/government/publications/hs2-phase-one-environmental-statement-volume-2-community-forum-area-reports-and-map-books/hs2-phase-one-environmental-statement-volume-2-community-forum-area-reports-and-map-books.

[27] HS2 Ltd, “London-West Midlands Environmental Statement: Volume 3 Route-wide effects,” 2013.

[28] HS2 Ltd, “London-West Midlands Environmental Statement: Volume 5 Technical Appendices Scope and methodology report,” 2013.

[29] HS2 Ltd, “London-West Midlands Environmental Statement Volume 5 Technical Appendices - Scope and methodology report addendum,” 2013.

[30] HS2 Ltd, “London-West Midlands Environmental Statement: Volume 5 Technical Appendices Wider effects report,” 2013.

[31] HS2 Ltd, “London-West Midlands Environmental Statement: Volume 5 Technical Appendices Alternatives Report,” 2013.

[32] HS2 Ltd, “London-West Midlands Environmental Statement Volume 5 Technical Appendices - Summary carbon calculations outputs (Climate),” 2013.

[33] HS2 Ltd, “HS2 Phase One environmental statement volume 5: ecology,” 2013. [Online]. Available: https://www.gov.uk/government/publications/hs2-phase-one-environmental-statement-volume-5-ecology/hs2-phase-one-environmental-statement-volume-5-ecology.

[34] HS2 Ltd, “High Speed Rail (London - West Midlands) - Draft Environmental Minimum Requirements - Annex4 Draft Environmental Memorandum,” 2013.

[35] HS2 Ltd, “London-West Midlands Environmental Statement - Volume 5 Technical Appendices - CFAs 7 to 15 Central Chilterns - designated sites, habitat surveys and flora ecological baseline data,” 2013.

[36] HS2 Ltd, “London-West Midlands Environmental Statement - Volume 5 Technical Appendices - CFA7-15 Colne Valley to Lower Boddington - Ecological baseline data: amphibians, reptiles and birds,” 2013.

[37] HS2 Ltd, “London-West Midlands Environmental Statement - Volume 5 Technical Appendices - CFA7-15 Colne Valley to Lower Boddington - Ecological baseline data: mammals,” 2013.

[38] HS2 Ltd, “London-West Midlands Environmental Statement - Volume 5 Technical Appendices - CFA7-15 Colne Valley to Lower Boddington - Ecological baseline data: invertebrates and fish,” 2013.

[39] HS2 Ltd, “London-West Midlands Environmental Statement - Volume 5 Technical Appendices - CFA7-15 Colne Valley to Lower Boddington - Ecology Register of local level effects,” 2013.

[40] HS2 Ltd, “London-West Midlands Environmental Statement - Volume 5 Technical Appendices -CF9 Central Chilterns Ecology - Bat trapping/radio tracking study - Mantles Wood,” 2013.

[41] House of Commons Transport Committee, “High Speed Rail: Tenth Report of Session 2010-12 Volume II Oral and written evidence (HC 1185-II),” 2011.

[42] House of Commons Transport Committee, “High Speed Rail: Tenth Report of Session 2010-12 Volume III Additional written evidence (HC 1185-III),” 2011.

[43] House of Commons Environmental Audit Committee, “HS2 and the environment (HC 1076),” 2014.

[44] House of Commons Environmental Audit Committee, “Correspondence published on HS2 environmental impact assessment,” 2014. [Online]. Available: http://www.parliament.uk/business/committees/committees-a-z/commons-select/environmental-audit-committee/news/hs2-correspondence/.

[45] House of Lords Select Committee on Economic Affairs, “The Economic Case for HS2 - Oral and Written Evidence,” 2014.

[46] High Speed Rail (London - West Midlands) Bill Select Committee, “Petitions against the High Speed Rail (London - West Midlands) Bill Session 2014 - 15,” 2015. [Online]. Available: http://www.publications.parliament.uk/pa/cmhs2/petitions/petcontents.htm.

[47] House of Commons High Speed Rail (London – West Midlands) Bill Select Committee, “Select Committee Site Visit - CFAs 8 & 9 Amersham and Chesham MP Constituency,” 2015. [Online]. Available: http://www.parliament.uk/documents/commons-committees/hs2/Visits/2015-16/22 06 15_Cttee_visit_Amersham.pdf.

[48] House of Commons High Speed Rail (London – West Midlands) Bill Select Committee and R. Syms, "Text of interim Chilterns tunnel decisions announced 21 July 2015," 2015. [Online]. Available: http://www.parliament.uk/documents/commons-committees/hs2/Statement/Text-of-interim-Chilterns-tunnel-decisions-announced-21-July-2015.pdf.

[49] Department of Energy & Climate Change, "2014 UK Greenhouse Gas Emissions, Provisional figures," 2015.

[50] HS2 Ltd, "High Speed Two Information Paper E10: Carbon," 2015.

[51] Greengauge 21, "High Speed Rail: The carbon impacts of High Speed 2," 2012.

[52] Temple-ERM and HS2 Ltd., "Sustainability Statement Appendix F – HS2 and Carbon Assessment of carbon emissions for Phase One and Two," 2013.

[53] Committee on Climate Change, "Fourth Carbon Budget Review – part 2 The Cost-effective path to the 2050 target," no. December, p. 90, 2013.

[54] H. S. Martínez Sánchez-Mateos and M. Givoni, "The accessibility impact of a new High-Speed Rail line in the UK – a preliminary analysis of winners and losers," *J. Transp. Geogr.*, vol. 25, no. December, pp. 105–114, Nov. 2012.

[55] The Institution of Engineering and Technology and The Royal Academy of Engineering, "High Speed Rail – response from the IET and Royal Academy of Engineering," 2011.

[56] HS2 Ltd and Imperial College London, "HS2 Traction Energy Modelling," no. December, 2009.

[57] Society of Motor Manufacturers and Traders (SMMT), "New Car CO2 Report 2015 The 14th report Office for Low Emission Vehicles," 2015.

[58] B. Lippke, E. Oneil, R. Harrison, K. Skog, L. Gustavsson, and R. Sathre, "Life cycle impacts of forest management and wood utilization on carbon mitigation: knowns and unknowns," *Carbon Manag.*, vol. 2, no. 3, pp. 303–333, 2011.

[59] V. Bellassen and S. Luyssaert, "Managing forests in uncertain times," *Nature*, vol. 506, no. 7487, pp. 153–5, 2014.

[60] HS2 Ltd, "High Speed Two Information Paper D7: Tunnel Construction and Methodology," 2015.

[61] Department for Environment Food & Rural Affairs, "The Natural Choice: securing the value of nature (white paper)," 2011.

[62] Department for Environment Food & Rural Affairs, "Biodiversity 2020 : A strategy for England's wildlife and ecosystem services," 2011.

[63] G. R. Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J., & Wynne, "Making Space for Nature : A review of England ' s Wildlife Sites and Ecological Network. Report to DEFRA," 2010.

[64] B. Chevassus-au-Louis, J.-M. Salles, S. Bielsa, D. Richard, G. Martin, and J.-L. Pujol, "Approche économique de la biodiversité et des services liés aux écosystèmes," p. 376p, 2009.

[65] Department for Environment Food and Rural Affairs, "UK Biodiversity Indicators 2014," 2014.

[66] National Biodiversity Network Gateway, "Species groups with records for 'Chilterns.'" [Online]. Available: https://data.nbn.org.uk/Reports/Sites/GA0006965/Groups.

[67] Department for Transport, "Tag Unit A3 - Environmental Impact Appraisal," 2014.

[68] HS2 Ltd and A. Munro, "Sustainability Policy," 2013.

[69] H. Daly, "Toward some operational principles of sustainable development," *Ecol. Econ.*, vol. 2, 1990.

[70] L. Butcher, M. Keep, A. Rehfisch, and A. Minnis, "High Speed Two (HS2): the debate," 2011.

[71] Atkins, "High Speed Rail Strategic Alternatives Study - Update Following Consultation," 2012.

[72] HS2 Ltd, "Review of HS2 London to West Midlands Route Selection and Speed - A report to Government by HS2 Ltd," no. January, 2012.

[73] Forestry Commission, "Ancient Woodland and SSSI's within the Chilterns," 2006.

[74] Peter Brett Associates, Conserve the Chilterns & Countryside, and Chiltern Ridges Action Group, "HS2 The Case for a full Chilterns Tunnel," 2012.

[75] The Chilterns Conservation Board, “High Speed 2’s Impacts on the Chilterns - Facts and Figures,” 2011.

[76] The Chilterns Conservation Board, “HS2 within the Chilterns Route Revisions,” 2012.

[77] House of Commons Transport Committee and J. Greening, “High Speed Rail: Government Response to the Committee ’ s Tenth Report of Session 2010-12 (HC 1754) + Letter from MP,” 2012.

[78] HS2 Independent Assessor and Golder Associates, “High Speed Rail (London - West Midlands) Bill: Summary of Issues raised by comments on the Environmental Statement,” 2014.

[79] HS2 Ltd, “HS2 confirms tunnel extension for South Heath,” 2015. [Online]. Available: https://www.gov.uk/government/news/hs2-confirms-tunnel-extension-for-south-heath.

[80] Department for Transport, “Economic Case for HS2: The Y Network and London – West Midlands,” 2011.

[81] Department for Transport and The Rt Hon Philip Hammond MP, “High speed rail: consultation launch - Speech,” 2011. [Online]. Available: https://www.gov.uk/government/speeches/high-speed-rail--29.

[82] Department for Transport and The Rt Hon Justine Greening MP, “Making HS2 happen - Speech,” 2012. [Online]. Available: https://www.gov.uk/government/speeches/making-hs2-happen.

[83] Department for Transport and The Rt Hon Patrick McLoughlin MP, “Campaign to Protect Rural England annual lecture on transport and the countryside - Speech,” 2012. [Online]. Available: https://www.gov.uk/government/speeches/campaign-to-protect-rural-england-annual-lecture-transport-and-the-countryside.

[84] Campaign to Protect Rural England, “Landscape impact of High Speed 2.” [Online]. Available: http://hs2maps.com/landscape_map.html.

[85] House of Lords Economic Affairs Committee, “The Economics of HS2 - Government Response,” 2015.

[86] HS2 Ltd, “A guide to tunnelling costs,” 2015.

[87] Residents’ Environmental Protection Association, R. Craig, and Peter Brett Associates, “Proposal for a South Heath Chilterns Tunnel Extension Contents + Engineering Report on South Heath Chilterns Tunnel Extension,” 2013.

[88] S. Luyssaert, E.-D. Schulze, A. Börner, A. Knohl, D. Hessenmöller, B. E. Law, P. Ciais, and J. Grace, “Old-growth forests as global carbon sinks.,” *Nature*, vol. 455, no. 7210, pp. 213–215, 2008.

[89] N. L. Stephenson, a J. Das, R. Condit, S. E. Russo, P. J. Baker, N. G. Beckman, D. a Coomes, E. R. Lines, W. K. Morris, N. Rüger, E. Alvarez, C. Blundo, S. Bunyavejchewin, G. Chuyong, S. J. Davies, a Duque, C. N. Ewango, O. Flores, J. F. Franklin, H. R. Grau, Z. Hao, M. E. Harmon, S. P. Hubbell, D. Kenfack, Y. Lin, J.-R. Makana, a Malizia, L. R. Malizia, R. J. Pabst, N. Pongpattananurak, S.-H. Su, I.-F. Sun, S. Tan, D. Thomas, P. J. van Mantgem, X. Wang, S. K. Wiser, and M. a Zavala, “Rate of tree carbon accumulation increases continuously with tree size.,” *Nature*, vol. 507, no. 7490, pp. 90–3, 2014.

[90] G. Zhou, S. Liu, Z. Li, D. Zhang, X. Tang, C. Zhou, J. Yan, and J. Mo, “Old-growth forests can accumulate carbon in soils.,” *Science*, vol. 314, no. 5804, p. 1417, 2006.

[91] The European Parliament and the Council of the European Union, “Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment,” *Off. J. Eur. Communities*, 2011.

[92] P. Tomlinson, “SEA and Transport Planning,” in *Handbook of Strategic Environmental Assessment*, B. Sadler, R. Aschemann, J. Dusik, T. B. Fischer, M. R. Partidario, and R. Verheem, Eds. Earthscan, 2011, pp. 177–189.

[93] Department for Transport, “Review of HS2 London to West Midlands - Appraisal of Sustainability (A report to Government by HS2 Ldt),” 2012.

[94] European Commission, *Directive 2001/42/EC of the European Parliament and of the Council on the assessment of the effects of certain plans and programmes on the environment*, vol. 197. 2001, pp. 30–37.

[95] Nef (the new economics foundation), “High Speed 2: The best we can do? Creating more value from £33 billion,” 2013.

[96] G. Dudley and D. Banister, “Expertise and the Dynamics of Decision Making in Large Infrastructure Projects: From UK Trunk Roads to High Speed Rail 2,” in *UTSG*, 2015, no. January, pp. 1–15.

[97] D. Higgins and HS2 Ltd., “HS2 Plus: A report by David Higgins,” 2014.

Article V From Minimum to Reasonable Travel Time

Compartment C Car, 1938 by Edward Hopper

Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 00 (2017) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2016 Shanghai. 10-15 July 2016

From Minimum to Reasonable Travel Time

David Banister[a], Yannick Cornet[b], Moshe Givoni [a,c], and Glenn Lyons[d]

[a] *University of Oxford, School of Geography and the Environment, Transport Studies Unit, Oxford, United Kingdom.*
[b] *Technical University of Denmark, Department of Transport, Kgs. Lyngby, Denmark. yancor@transport.dtu.dk (corresponding author).*
[c] *Tel Aviv University, Department of Geography and the Human Environment, Transportation Research Unit, Tel Aviv, Israel.*
[d] *University of the West of England, Centre for Transport & Society, United Kingdom.*

Abstract

This paper introduces the concept of reasonable travel time (RTT) as "a total journey time that is acceptable to the passenger for reaching a particular destination, given the conditions provided to turn 'forced time' to 'useful time' while travelling". It makes the case for a new debate that moves beyond the historic emphasis on minimising travel time in transportation planning. Although the commodification of travel time has advantages, it only represents part of a more holistic conceptualisation of travel time that should also include door-to-door travel time, the overall travel experience and the types of activities at destination. High-Speed Rail is used as a focus to explore further the notion of RTT. It is concluded that a new debate taking a broader perspective on travel time is needed in a technological age, where time has many different uses, where the overall quality of travel time brings positive outcomes for users, and where there are important implications for investment and planning decisions made on transport systems.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: Transportation planning; reasonable travel time; door-to-door travel time; travel experience; use of time; high-speed rail

I'm porous with travel fever
But you know I'm so glad to be on my own
Still somehow the slightest touch of a stranger
Can set up trembling in my bones

Joni Mitchell, Hejira Lyrics (1976, verse 7)

1. Introduction

Travel time is at the centre of transport analysis, in terms of how journey durations can influence travel decisions. It has also been central in terms of the monetary cost associated with time devoted to travel and in turn the value that can be attributed to travel time savings resulting from new transport schemes or investments. Such considerations have been built around the core notion of travel as a derived demand, suggesting that the costs (monetary and otherwise) of getting to a destination are more than outweighed by the benefits received at the destination. In this context, travel is seen as a means to an end with a central assumption that travel time should be as short as possible. It is strongly implied in such thinking (if not stated or indeed fully intended) that travel time itself has no inherent value to the traveller: it is wasted time. In turn this results in solutions that speed up travel. As a consequence, travelled distances have increased within relatively constant overall travel time budgets. It is not that we are doing more in terms of participating in more activities, but that we are travelling further in order to reach preferred or essential activity destinations. The economic interpretation of these patterns of travel is based on the concept of choice, where it

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

is assumed that more choice brings greater societal welfare [1]. As people become more mobile, they may choose to travel further as they have a greater choice of destinations (work, school, hospitals, shops etc.) and because there is a consumer benefit (otherwise they would not do it). There are also strong economic incentives for such a change, as it leads to economies of scale and the provision of a wider range of services and facilities, at least for those who can travel those longer distances. Over time, land uses can change such that suitable destinations become more remote to those seeking them.

This argument is based on the rationale that all travel is ‘wasteful’ [2] and that travel time ought to be minimised, and it is complemented by a slightly weaker argument that greater choice is beneficial. Hence a better transport system provides a wider range of destinations, but it also raises the issue about the marginal benefit of increased choice in spatial opportunities. The inevitable consequence of this thinking is to promote speed as the clear primary objective of transport systems to ‘save time’. This leads to longer travel distances, has distributional outcomes (greater inequality), and results in greater use of resources, as higher speed increases energy consumption and carbon emissions.

This paper sets out a much wider interpretation of travel time that reflects concerns over its value and use. This serves to bring into question the way in which we interpret the purpose and design of our transport systems, and how they are used and with what consequences. The paper moves to question this dominant paradigm through introducing and examining the notion of reasonable travel time (as distinct from shortest travel time) as a possible goal for transport’s development. Reasonable travel time addresses the way we interpret the wider consumption of time and the associated potential benefits, and it recognises the role travel time use has in our lives alongside the more traditional purpose of transport systems seeking to get us from A to B as quickly as possible. The paper then considers this further in one particular context where it might be most significant for future developments, namely High-Speed Rail, where both speed and quality are combined. Within the debate over HSR, these two essential qualities can be seen as complementary and therefore could be traded against each other to achieve a higher level of Reasonable Travel Time (RTT). The paper also includes anecdotal evidence collected from rail passengers in the UK to illustrate some of the arguments made. These issues and further research directions are presented in the conclusion.

2. Elements of travel time

Travel time as experienced by travellers can be broken down into several components. These are central to the way travel time is conceptualized in transport planning. At present, the first element discussed below, that of travel time as a commodity, is what drives the planning of the transport system, but we argue that all elements need to be considered as they are all parts of what we define as 'Reasonable Travel Time'.

2.1. Commodification of time and utility

Classic theory sees time as uniformly progressing in a linear way, and importantly, that it progresses at the same pace for all, that it is “uniquely serial” [3]. This view was formalised with the concept of *clock time*, originally introduced to synchronise railway schedules in the early UK rail system[1]. This concept of objective, modern, industrial time has led to the commodification of time, where time is decontextualized and monetized. There is certainly truth in this concept, as life is indeed bound by death, making time universally finite for all, and thus probably worth saving – or at least worth spending wisely.

Spending time wisely often requires taking part in activities. Transport provides the means to overcome distance in order to participate, and it has traditionally been seen as a means to an end. Transport is derived from the demand to be somewhere to reach and realise valuable opportunities – hence the term ‘*derived* utility’ (referring to the benefits gained from connectivity provided by transport). From this notion, travel time is considered a disutility: the disbenefit or cost represented by having to invest time in order to realise destination benefits. If the transport system can help minimise this disutility then more time is available for activities. Such logic has provided the underpinning for economic appraisal of transport schemes internationally. It has provided the motivation to monetise the benefits of saved travel time that result from investments in transportation in order to justify the investment costs.

Amongst transport economists concerned with examination of valuation of travel time savings (VTTS) in transport as part of economic appraisal, there is an acknowledgement that not all travel time is wasted. Conceptually, Hensher [4] outlined how productive use of travel time might influence VTTS (later codified by Fowkes et al., [5]. Fowkes [6] also argues that provided not all travel time is productive, then any time that is saved by speeding up a journey will relate to the unproductive part of journey time. This is argued to support a long-held appraisal assumption that saved time is released from being unproductive within the journey to being put to productive use in activities outside the journey.

---

[1] Railway time was introduced in the November 1840 on the Great Western Railway in the UK, when it was decided that a uniform time was required for the scheduling of trains. Prior to then, clock time was different in different parts of the UK – for example Bristol time was 10 minutes behind London time, and Oxford’s was 5 minutes behind. - http://wwp.greenwichmeantime.com/info/railway.htm

Milakis et al. [7] translate the understanding that not all travel time is 'wasteful' to argue that for each journey there is an "acceptable travel time" and an "ideal travel time". These travel times are derived from combining the utility derived from getting to the destination, the (dis)utility from travelling *and* any utility that can be derived from the travel itself (the intrinsic utility of travel). "Ideal travel time" corresponds to peak intrinsic utility, while acceptable travel time is longer than ideal travel time and corresponds to peak total utility from making the journey.

Stemming from commodification of time have also come assumptions regarding ownership of time. It has been taken that travel (and travel time) during the course of work is ‘owned’ by the employer while travel outside the course of work (in UK appraisal at least) is owned by the individual traveller (including commuting). Furthermore and in line with the 'economic productivity' rationale, the custom is to assign a higher value of time for work travel time in comparison to commuting, and higher still in comparison to travel for leisure purposes. The transport planning implications are large. It means that saving a minute of work travel time is worth more than saving any other minute of travel time. It also means that it is more important to save a minute from an individual's commute journey than from the journey of that individual to visit friends or relatives. Aside from the equity issues that arise from this practice of valuing travel time savings, ownership of time is complex, especially for those working in the knowledge economy where activities are not tied to particular times or locations [8].

The commodification of time and the concept of (dis)utility are probably the most influential factors in the design of our transport system, evident in the large expansion of High-Speed Rail (Section 4). While this concept has merit, it cannot be used alone to conceptualize and understand 'travel time' and be the sole (or most important) guiding principle in transport planning. Other elements must be considered as well. For a more detailed explanation of approaches to valuing travel time savings in economic appraisal and critical commentary see Wardman and Lyons [9].

2.2. Experiential time

It is largely research by social scientists and ethnographers that has given greater prominence to the fact that, for some people on some journeys, the time spent travelling is not always wasted – especially, it might appear, in a new age of mobile digital technologies that accompany the traveller. Travel time can be spent on a range of (technology enabled) activities [8], [10] (see also see Kenyon and Lyons [11] for a more extensive list of activities). This implies a level of positive utility from the experience of time while travelling [12]. Travelling can therefore, as noted earlier, provide a certain level of intrinsic utility, where time spent travelling becomes useful in and for itself, which some authors have called the “joy of travel” [7] or the “gift of travel time” [13]. As one traveller put it: “I don’t know why, but I am very productive on trains. I usually read and think. I think it's the passing landscape which helps me reflect. This is where I get my best ideas” (Traveller interview, Oxford, February 2015). In its more extreme form, travel can be the only purpose - travel for its own sake [12], or “travel with meaning” - which underpins the nascent slow travel movement [14]. This *experienced time* affects the value of time (not necessarily in economic but more in normative terms) and by implication could affect the value (not the monetized value) of any time removed from a journey by making it quicker.

The value of experienced time depends on a range of external factors that provide the option for time to become useful. Cases where intrinsic utility never becomes positive can be imagined, for example, where there simply is no opportunity for using travel time purposefully. Lyons et al. [10], referring to Stradling [15], offer a simple typology of three different forms of effort that may impinge on how travel time is experienced: physical effort, cognitive effort, and affective effort. Physical effort is the effort asked of and imposed on the body in undertaking travel. Cognitive effort is the mental focus that is needed to execute the journey successfully. Affective effort is the emotional influence of undertaking the journey. Lyons et al. “infer that less effort devoted to travel itself yields more potential opportunity for the fruitful spending of travel time” [10]. It should be noted, however, that such efforts do not always have a negative connotation – for instance physical effort may be a positive stimulus for a sense of emotional wellbeing which in turn heightens the (perceived) fruitfulness of time use.

Travel experience (accounting for efforts involved and how time is used and experienced) determines the extent to which travel time is a disutility or indeed offers positive intrinsic utility. It depends very much on the extent to which the travel environment provides the conditions to use travel time for 'something', other than for getting to destinations. There are many ways to improve aspects of the travel experience and to improve the conditions to use time. These include: reducing transport connections; improving travel comfort (including reduced crowding); reducing unwanted distractions; improving the perceived security or pleasantness of travel; improving the familiarity with the transport system; improving the ability to plan effectively; and improving overall reliability. The goal should be to avoid turning travel time into *forced time*. We define this as time that individuals cannot choose to allocate to an activity they need or wish to participate in (apart from travel itself) due to physical, cognitive or affective efforts imposed by the transport system, which therefore becomes *wasted*. In this respect, the transport system should be planned with the intention to give back the time it ‘steals’ from its travellers and in turn not concern itself only with reducing absolute travel time.

Quantitative and qualitative insights highlight these issues to the extent that forced or unforced time is influenced by the mode of travel. Not all transport modes offer the same level of opportunity for productive time. Car drivers can use their travel time productively by making phone calls, or as valuable time-out, or “me-time” for transitioning between work and home [13], [9]. Empirical evidence shows productive time is particularly prevalent on train journeys, where a greater range of activities can be undertaken, and there is no need for the physical and attentive demands of controlling the vehicle. A modal hierarchy seems apparent in relation to productive travel time use with rail at the top, followed by air, bus, and finally car [9], [16]. This does not stem from the unique characteristics of a particular mode, but from its current design, which tends to couple speed and quality.

Such consideration of experiential time suggests that the commodification of time and its direct translation to (dis)utility units may be offering too narrow a framework to properly assess travel time, and this in turn means that transport planning and policy options have also been too narrowly defined.

2.3. Door-to-door travel time

The transport system is very much planned as a set of separate networks, with each catering for a specific mode of transport. Many of the limitations of the current system are associated with the lack of an integrated transport system. But for the passenger there is only one transport system, made up of different modes and transfers between them. Thus, the travel experience discussed above relates to – or should relate to - the total journey time from door-to-door. For longer distance journeys, the ‘door-to-door’ appeal of the car, for example, is apparent while alternatives to the car usually involve a combination of modes and thus expose users to the issues associated with changing between modes during a door-to-door journey. The travel experience discussed above can risk conflating door-to-door experience and mode-specific experience (for a given leg of a journey). While HSR provides the conditions for a positive travel experience, the journey to and from the HSR station might result in a poor overall experience. In practice, travel experience concerns the total journey time from door-to-door. Most surveys only consider the main part of the journey, often the ‘trunk’ section that covers the main mode and time (or distance), but not the time taken to access the main mode and the time and means needed to reach the final destination (the 'egress' journey). Each journey, with the exception of walking, consists of several segments in which the experience will vary substantially. This holds especially when using public transport.

In addition there is the 'transfer' time that must also be included, and while speed is close to zero (waiting time is often the main element of the transfer), the experience can vary substantially, depending also on the journey circumstances and personal characteristics. The implications for travel time considerations are far reaching as it means that it is not only the total travel time that matters but how this time is divided between different segments of the journey and between different modes of transport. Moreover, because of the inconvenience and uncertainty associated with transferring between modes of transport (and changing from one transport network to the other) transfer time is considered, in the traditional economic-time approach, as the most expensive time. It is already the custom to allocate a different value of time for in-vehicle travel time and out-of-vehicle travel time, and further break the latter into several categories (wait and walk being the main ones). Empirical evidence shows that the disutility of out-of-vehicle travel time is considerably larger than in-vehicle time [17].

In planning terms, the concern is over the efficient operation of the transport system as a whole and how the various elements complement each other. One means by which this can be measured is the interconnectivity ratio, calculated as the access and egress time as a proportion of total trip time [18]. In a multimodal journey, this interconnectivity ratio would need to include transfer and wait time as well as access and egress travel times. Perhaps interestingly, Brons and Rietveld [19] show how accessibility to train stations and other factors related to the door-to-door journey have become *more* important through time for Dutch rail travellers, while Givoni and Rietveld [20] and Brons et al. [21] conclude that in order to increase its number of passengers, Dutch Railways ought to invest in the stations as well as in the access and egress journeys to/from them and not only invest in the actual rail journey.

2.4. Destination time and multi activity

A journey is not necessarily only from point A to point B, and for a single purpose. A traveller may justify a trip by planning to undertake a number of activities at or near to the primary destination [22]. Alternatively they may plan activities at different locations along an overall route to an end destination. It must be recognised that travel time and travel experience are situated in a wider context of the combined time invested both in getting to and participating in activities, and how this combined time is distributed (spatially and temporally).

Schwanen and Dijst [23] explored the notion of a travel-time ratio (see also [24], [25]). This travel-time ratio is obtained by dividing the travel time by the sum of the travel time and activity duration, and it provides one means to measure the relationship between the time spent travelling and the time spent at the destination, or in the various activities undertaken whilst away from the home. Schwanen and Dijst [23] found that the travel-time ratios of Dutch commuters can be placed into three groups. The first group consists of people who work up to four hours a day. For these individuals their commuting time tends to be stable and therefore not depending on the duration of their stay on the workplace. The second group of commuters shows a different result. For people in this group, who work for between four and eight hours a day, the commuting time tend to rise similar with the duration of workplace stay. Finally, the people who work more than eight hours a day have a stable commuting time. This could possibly be explained by biological factors, where after eight hours of working, only a certain amount of energy is left to spend on commuting.

The above means that there are interdependencies between the destination and the planned activity at the destination on the one hand and travel time on the other. To compensate for the efforts involved in reaching a destination, other activities might be added. For example, for a business meeting that an individual must attend, a leisure activity like visiting a friend or a relative might be added. This means that the journey characteristics (time, comfort and money especially) could influence the (number of) destination and activity choices, and not only the other way round.

With context provided from these four elements of travel time, the next section of the paper introduces the concept of Reasonable Travel Time which leads to the suggestion of a modified goal for transport planning, policy and investment beyond what might appear a somewhat myopic focus on speed.

3. Reasonable Travel Time (RTT)

There is clearly an imperative to transcending distance with some degree of speed, unless all our needs for accessing people, goods, services and opportunities could be met quite literally on our doorsteps. It is also apparent that within the current economic approach to travel time as a 'waste of time', some attention is given to the importance of having some reasonable if not luxurious experience of the journey itself. Yet, and for no obvious reason , experience is coupled with speed; and for both, a premium has to be paid. For journeys by train or plane in particular, travellers may have options of paying more for more direct and quicker options to a given destination and for upgrade to a higher 'class' of travel which offers a better experience.

The notion of generalised travel cost that is well established in transport planning [26] already recognises that the costs of a journey by a particular mode are not only monetary. Alongside travel time (in-vehicle and out-of-vehicle) as non-monetary costs, it seeks to capture the apparent appeal of one mode over another, when time and monetary costs are equal, through a ‘modal penalty’ term. This, in a broad sense, can be taken to reflect the issues of effort and positive intrinsic utility referred to earlier. However, this has been used as a ‘catch all’ term for the aspects of travel that are less tangible than monetary cost and amount of time spent. The measurement of demand for transport is much more complicated today, and it is based on a wider range of variables, not all of which are related to time per se, and some even account for the intrinsic utility of travel. But this measurement is still entirely based on quantities and their minimization, namely minimizing travel time or minimizing disutility from travel.

In contrast, RTT is intended as a normative conceptualization of travel time with which to challenge, and in due course modify, the ‘Minimum Travel Time’ approach as a guiding principle for transport policy and planning. It is also assumed to much better represent what is really of importance to the passenger and what determines travel behaviour.

In our definition, RTT is a function of three main components: the door-to-door travel time; the overall travel experience (throughout all parts of the journey); and the characteristics of the destination(s) travelled to (this includes what we do there and for how long). There is a direct and reciprocal relationship between the first two components in the transport domain, and the third component that embraces the land use domain. RTT, however, is mainly concerned with the transport system and its planning: the door-to-door travel time and overall experience.

a) *Door-to-door travel time* is, importantly (and as noted in section 2.3), distinct from point to point travel time for the trunk mode of a long-distance journey (notably by train or plane). The time taken to access/egress the trunk mode and the transfer times between the different legs comprising the door-to-door journey can comprise a considerable proportion of the door-to-door travel time and thus average door-to-door speed.
b) *Travel experience* relates to the overall experience across the different parts of the journey and the transfer between them. More importantly, the travel experience can be considered to be mainly a factor of the ability to use travel time for 'something', other than for getting to the destination (section 2.2).
c) *Destination characteristics* are also important. These cover both the nature of the activities that are undertaken and the duration of those activities, as the concept of RTT is not independent of what is done at the destination. This reflects the classic interaction between transport and land use as both contribute to (in terms of Milakis et al. [7] conceptualisation) total utility (section 2.1).

Based on these three components we define Reasonable Travel Time from a passenger perspective as follows:

> *Reasonable Travel Time is a total journey time that is acceptable to the passenger for reaching a particular destination, given the conditions provided to turn 'forced time' to 'useful time' while travelling.*

If a journey experience is intolerable then completing the journey as quickly as possible will be important. If a journey experience is high quality, and journey time can be put to a useful activity, then speed may be less of an imperative, notwithstanding a limit to how long someone would wish to be in the process of getting from A to B. In this context, journey speed and experience are likely to trade off with one another in many aspects.

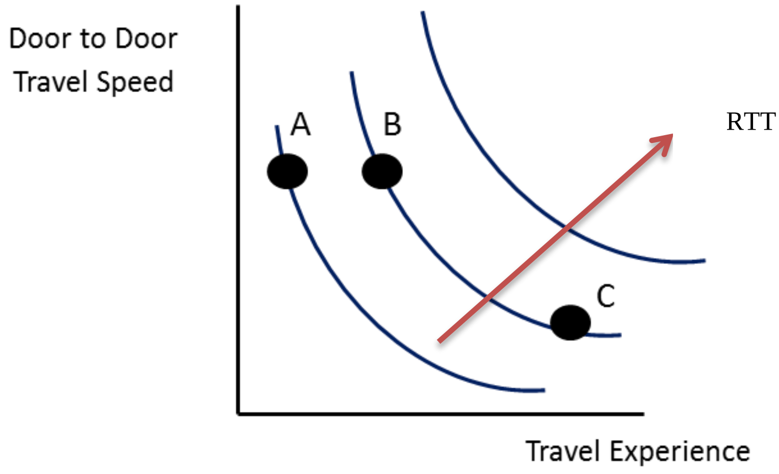


Figure 1: Reasonable Travel Time Curves (iso-RTT curves)

Figure 1 suggests that there is a trade-off between increasing the door-to-door travel speed and improving the travel experience to yield the same level of RTT. The figure in turn depicts what might be termed iso-RTT curves. For illustration, and for simplicity focusing on a single journey for a single purpose - if current RTT for a particular journey is the result of the travel speed and travel experience combination at point A (in Figure 1) an improvement would be a mix of these journey attributes as represented at points B or C. However, since both points B and C offer the same level of RTT (both higher than that offered at Point A), the traveller would be indifferent to the level that is provided. The implications of this for transport planning are far reaching (and discussed later). It should be noted that the shape of the iso-curves is contestable - in particular the implication that quicker journeys are better in the face of travel experience also improving. This may be true for longer distance journeys of the sort covered by HSR or air travel. However, for much shorter journeys, it is possible that a traveller would find it unattractive for a journey, especially one that has high quality experience, to be shortened in duration (too much).

Our definition and discussion, at this point, avoid making a reference to the monetary cost of travel, as this relates more to issues of competition, regulation and subsidies in transport. Furthermore, our definition focuses on the individual, while Reasonable Travel Time from a societal perspective might be somewhat different. We touch on these issues in our conclusions.

Having defined and introduced the notion of RTT, we now move to consider the particular case of high-speed rail which serves to explore and apply the RTT thinking further and for which RTT may be especially pertinent in terms of design and service provision.

4. Examining High-Speed Rail from an RTT perspective

A number of accessibility studies analyse the contraction of space from reduced travel times for high-speed rail (HSR), examining for example weighted average travel time and contours in China [27], territorial cohesion in Spain and Portugal [28], [29], wider economic impacts in sub-regions of France and the UK [30], and time-space effects of existing [31] and future [32] high-speed lines in the UK. However there remains limited attention in the literature to aspects of the *experience* of travelling by high-speed rail. The standard definition of HSR relates only to speed [33].

From a traveller perspective, crowding, comfort and other quality features play an important role in making rail attractive [34], [35] and HSR even more so. A study based on a customer satisfaction index in Taiwan has revealed the importance of personal space on HSR [36]. From a utility perspective, research on the Madrid-Barcelona HSR corridor has shown an inversely proportional relationship between the value of travel time savings and levels of comfort [37]. Greater comfort and better quality of services are important factors in the success of HSR, and this can be relevant for attracting business travellers away from flying [38]. A business traveller in the UK (on the upgraded West Coast Main line to Birmingham) talked of the positive experience in this way: “We sat in front of each other [with a colleague], and we worked on our presentation on the way there and we reviewed our notes on the way back. More time would have been beneficial” (Traveller interview, London, January 2016).

In terms of travelling experience, high-speed rail can provide a compelling alternative to the car (for shorter distances) and to the plane (for longer distances) [38], [39]. For example, some travellers may feel physically constrained by the limited seating space in planes or cars. Others experience motion-sickness in road transport, therefore physically limiting the possibility to use travel time. Cognitively, the HSR traveller is freed from any obliged tasks – like driving – the main advantage over the car, or from restrictions on some activities (mainly during take-off and landing) – the main advantage over the plane. By imposing fewer demands on the traveller, HSR brings the potential to turn forced time into worthwhile time. In many instances a traveller would be able to reach a particular city destination in a similar door-to-door time either via HSR or plane. The derived utility will be the same but the positive experience could be substantially higher for the HSR-based journey, as more of the time will be spent in-vehicle where opportunities to use the time are greater. In other words, HSR typically offers a higher ratio of main mode travel time to total journey travel time - its main advantage over the much faster plane. Returning to Figure 1, if a journey by plane is represented by point A, the HSR will be represented by point B – it offers similar door-to-door travel time but a better experience. Not surprisingly, Eurostar (HSR) captures more than 74% of the market share between London and Paris, and 68% for the London to Brussels route[2].

This opportunity to use time for something can be observed in practice and is illustrated in Appendix A, which depicts a number of travellers' observed activities on an HSR journey between London (UK) and Lille (France). It shows that in addition to being fast and contributing to travel time savings, HSR also contributes to improving the travel experience. The type of activities passengers were engaged on can all, with the exception of 'waiting', be seen as having a positive utility on their own (i.e. an activity a passenger would choose and not forced to engage in). By providing the conditions to engage in such activities, the HSR experience is one where the 'burden' of travelling is reduced, maybe even to the point that it becomes a positive experience (a passenger would not object to travel time being a few minutes longer). In this sense, HSR is not only High-Speed Rail, but also High-Quality Rail (HQR).

Passengers' activities while travelling question the assumption of travel time being 'wasted', inherited from conventional road transport appraisals at a time when information and communication technologies were not yet widespread. The appraisal process for HS2 - the UK's planned new high-speed rail network between London and the North - is a case in point. The cost-benefit ratios supporting the business case were originally based on travel time-savings, largely attributed to expected business users with a high value of time. As it became evident business travellers would be using at least part of their travel time for working, decision-making became characterised by unpredictable and idiosyncratic processes [40].

The high quality experience of high-speed rail illustrates well the concepts of worthwhile versus forced time. Yet, these qualities of the HSR should be examined considering the full door-to-door journey, which will shed a different view of HSR travel. Using the example of HS2 in the UK, a retired couple of British train travellers and residents of Coventry[3] were quick to point out that the new line will make the trip to London *longer* for them than the current conventional and slower train journey (Onboard interview, January 2016). HSR infrastructure is prone to the "excitement engineers and technologists get in pushing the envelope for what is possible in 'longest-tallest-fastest' types of projects" [41]. HS2 is designed for a state-of-the-art maximum speed of 400 kph (250mph). But achieving higher speeds imposes a limit on the number of stations along the way as each additional stop increases the journey time by 10 to 15 minutes [42]. In practice, HS2 will pass near Coventry on the way North from London but will not stop until Birmingham Airport. Furthermore the new HS2 station in Birmingham will not be under the same roof as the current conventional rail station on New Street. For the retired couple from Coventry a journey to London by HSR will entail additional transfer. From a multi-modal door-to-door perspective, using HS2 (and benefiting from travel time savings) will require long access and transfer times, and this will erode the travel time savings. This echoes the analysis by Martínez and Givoni [32] showing that many cities along the proposed HS2 line will, as a result of developing the HSR, experience longer travel time by rail to London.

When talking about HSR, questions are raised about the type of 'high-speed' we ought to be concerned with: maximum speed is the speed that often gets the headline; average speed station-to-station is the speed the passenger experiences when using HSR; but, average speed *door-to-door* is really the speed that matters [42]. It is this speed that should mainly concern transport planners. Likewise, considerations of the travel experience must be applied to the door-to-door journey, not only the station-to-station (trunk mode and section of the journey). In a study of intermodal hubs in China, Hickman et al. [43] observed that poor experience was prevalent, largely due to problems including "Wi-Fi availability, waiting and seating, the availability of door-to-door ticketing, crowdedness, access to the hub, time of travel through and waiting in the hub"(p175).

The concept of RTT places a new perspective on the high costs of investing in fast (rail) travel but then limiting access to the service and 'wasting' passengers' time on transfers, both in absolute and experiential terms. Meeting the needs of the traveller in RTT terms would therefore require the provision of "high quality door-to-door travel" [44]. Given the prohibitive cost of rail infrastructure, HSR in particular, the rational for providing both 'top' speed and experience can be questioned, even more so when speed often comes at the expense of more stations and thus results in longer journeys door-to-door for many passengers. Based on their analysis of the Amsterdam area, Givoni and Rietveld [45] conclude that "it may be worthwhile to let high-speed trains stop in more than one station in large cities", which will slow them down.

A reasonable 'rule-of-thumb' for long distance travel, for example by HSR, is that the main part of the journey (the HSR travel station-to-station) could take about 30% of the door-to-door journey duration, the remaining 70% is spent on access and egress journeys and transfer/wait time. Speeding up travel should focus on this 70%. Firstly, by trying to reduce wait times (where

---

[2] http://www.telegraph.co.uk/travel/rail-journeys/Eurostars-20th-anniversary-what-now-for-the-rail-operator/

[3] Coventry is a large city in the UK, located about 30km east to Birmingham where the HS2 network is planned to have two stations, but none is planned in Coventry. At present, and before the construction of HS2, Coventry is a major node on the UK rail network.

speed is 0) – standard check-in time for international HSR services can be up to an hour for example. Secondly, by increasing the speed of the access/egress journey, the concept of RTT similarly applies. On these journeys RTT can be increased by improving the travel experience and/or increasing speed. Increasing speed in this case can be in the form of, for example, increasing bus service frequency to the station [20]. In many HSR projects, like with the first Japanese and French HSR lines, the Chinese HSR network and the planned HS2 line in the UK, a rationale for increasing speed is the desire to increase route capacity. Yet, if speed is gained by not stopping (at intermediate cities) an increasing travel time to many (passengers in those cities) the rational for speed needs to be questioned.

4.1. Conclusions – High Speed or High Quality transport

The notion of 'time is money' dominates current transport planning considerations through the commodification of time and monetization of travel time savings [46], [47]. Maybe time is money for some or many travellers but this does not mean that all or most travel time is a waste of time since it can be used, and even be 'productive' (in economic terms). What is likely to be wasteful in economic, but also environmental, terms is the effort to minimize travel time, partly since this could lead to increasing travel distance and travel time (in response to any travel time saved). Efforts to minimize travel time cost a lot and could be counterproductive. An alternative approach to travel time minimization as a guiding transport planning principle is to use the broader concept of RTT, as introduced in Section 3. This means that a passenger should be assumed, from a transport planning perspective (especially for longer distance journeys), to be 'better off' when the door-to-door travel time is shortened (where total journey average speed is increased) *and* when the travel experience is improving (increasing), meaning there are more and better opportunities to use travel time for 'something' (Figure 1).

Rather than being concerned with the narrow consideration of travel time and speed, transport planning should aim to increase Reasonable Travel Time. It can be assumed that as a general rule, improving the journey experience would be easier and cheaper to achieve compared with reducing the door-to-door travel time and this is where efforts should turn to first. As discussed earlier, increasing travel comfort (by improving seating availability or the availability of services en-route), reducing travel anxiety (improving the reliability or the ability to plan a trip effectively) or simply improving the pleasantness of the travel environment could contribute a lot towards improving the travel experience (such as the free provision of Wi-Fi services on board or in stations). Some "experience" improvements, like reducing crowding on commuter rail services during peak hours could be complicated and very expensive, but still more worthwhile than increasing the speed of these commuter trains.

This does not mean that no attention should be given to travel time and speed, as they are still central to determining the level of (un)Reasonable Travel Time. But efforts to cut door-to-door travel time (increase average speed) ought to focus on particular parts of a journey, like the access and egress journey to (HSR) rail stations and the transfer between these journeys and trunk mode journey.

There are also important mode-specific and mode choice implications embedded in the RTT concept. This means that attention in considering the development of, and investment in, particular modes of transport should include the mode-specific experience conditions. As noted, HSR in particular provides what are probably the best travel conditions; and rail technology, other things being equal, probably provides better travel experience conditions than bus technology. In turn, rather than developing and promoting Bus Rapid Transit (BRT), Bus Quality Transit (BQT) ought to be invested in and innovative technologies used to reduce 'travel-sickness' on board buses (inter-city services in particular), and this could go a long way towards increasing their positive bus experience. At the same time it must be asked, what would happen if modes of travel allowed for travel time to be put to worthwhile use, and would this increase the time spent travelling, or reduce it, or make no difference? This becomes critical to address with the prospects of widespread use of Autonomous Vehicles [48], [49], which essentiality might provide the HSR travel experience, door-to-door, using the private car.

For improving the current transport system, and ultimately making it more sustainable, there will be a need to make a decision that balances the attention or weight given to speed and the experience components of RTT to achieve what might be termed an efficient investment – one that minimizes the level of investment to achieve a certain level of RTT. It raises questions as to whether or not return on investment in improved journey experience could in some cases be greater than that for investment in improved journey speed. Return on investment here could concern the individual traveller and the choices they make (where different viable travel options exist for them) to get the best outcome. It could also concern transport providers in terms of the influence on demand (including price elasticity of demand) of improvements in speed versus improvements in experience. There is also the question of what different consequences arise environmentally and in terms of longer-term land use developments. These economic and financial considerations will also impact, directly or in-directly (through subsidies), the monetary cost of travel and will affect issues of competition in and regulation of transport services. An important principle for transport planning that can be derived is that investment to improve RTT should be efficient, meaning that it provides the most improvement in RTT per investment cost, and this will likely mean favouring investing in experience over investing in speed.

Being both qualitative and normative, the RTT approach to transport planning might seem more subjective than the current approach, but this is not necessarily so. It is however much more difficult to operationalise, as it should not aim to be a maximum or minimum of some travel attributes, but a combination of a range of attributes that can be combined to achieve a certain 'reasonable' travel time. The components have been introduced (Section 2) and the concept defined (Section 3), but usable values will need to be empirically or normatively determined. However, our first intention in this paper is to further raise the need to question what principles are guiding the design of our transport systems, and by that open new directions for research and practice.

What level of ‘Reasonableness’ should be aimed at remains open and, importantly, will change from one journey to another. It will very much depend on the specific journey circumstances, especially the journey destination(s) and purpose(s) including the duration of the activity(s) engaged in at the destination. Each destination's characteristics will imply a different RTT for each traveller. In addition, ‘Reasonableness’ depends on attitude, age, mood, goals and other traveller characteristics.

Furthermore, ‘Reasonableness’ in this context, is not detached but is directly dependent on and linked to contemporary social norms and practices, which in turn are influenced by technological developments. Central here are Information and Communication Technologies (ICTs), for example the widespread use of smartphones and other mobile devices, or the deployment of Intelligent Transport Systems (ITS), which both serve to empower the traveller. Social norms and technological developments are embodied in the increased practices of multi-tasking and real-time trip planning, and any discussion about travel time should take full account of the impact of technology on time use, and even to think about how this might change in the future (e.g. with the development of the Driverless, Autonomous car).

The definition and discussion of RTT in this paper are focused on the individual and should serve as the platform for planning the transport system. However, planning of the transport system with a view to advancing sustainability should account for ‘Reasonableness’ in travel time from a societal perspective. A 'Social' RTT will likely be different to an 'Individual' RTT from economic, social and environmental perspectives, but consists of the same components and considerations.

5. Acknowledgements

This paper was partly funded by the Strategic Research Council of Denmark (Innovationsfonden).

6. References

[1] D. Metz, “The Myth of Travel Time Saving,” *Transp. Rev.*, vol. 28, no. 3, pp. 321–336, May 2008.

[2] B. W. Hamilton, “Wasteful Commuting Again,” *J. Polit. Econ.*, vol. 97, no. 6, pp. 1497–1504, 1989.

[3] M. Halewood and M. Michael, “Being a Sociologist and Becoming a Whiteheadian: Toward a Concrescent Methodology,” *Theory, Cult. Soc.*, vol. 25, no. 4, pp. 31–56, 2008.

[4] D. A. Hensher, *Value of Business Travel Time*. Oxford: Pergamon Press, 1977.

[5] A. S. Fowkes, P. Marks, and C. A. Nash, “The value of business travel time savings, Working Paper 214,” University of Leeds, Institute for Transport Studies, 1986.

[6] A. S. Fowkes, “Principles of Valuing Business Travel Time Savings, Working Paper 562,” University of Leeds, Institute for Transport Studies, 2001.

[7] D. Milakis, R. Cervero, B. van Wee, and K. Maat, “Do people consider an acceptable travel time? Evidence from Berkeley, CA,” *J. Transp. Geogr.*, vol. 44, pp. 76–86, 2015.

[8] D. Holley, J. Jain, and G. Lyons, “Understanding business travel time use and its place in the working day,” *Time Soc.*, vol. 17, no. 1, pp. 27–46, 2008.

[9] M. Wardman and G. Lyons, “The digital revolution and worthwhile use of travel time: implications for appraisal and forecasting,” *Transportation (Amst).*, 2015.

[10] G. Lyons, J. Jain, Y. Susilo, and S. Atkins, “Comparing rail passengers’ travel time use in Great Britain between 2004 and 2010,” *Mobilities*, vol. 8, no. 4, pp. 560–579, 2013.

[11] S. Kenyon and G. Lyons, “Introducing multitasking to the study of travel and ICT: Examining its extent and assessing its potential importance,” *Transp. Res. Part A Policy Pract.*, vol. 41, no. 2, pp. 161–175, 2007.

[12] P. L. Mokhtarian and I. Salomon, “How derived is the demand for travel? Some conceptual and measurement considerations,” *Transp. Res. Part A Policy Pract.*, vol. 35, no. 8, pp. 695–719, Sep. 2001.

[13] J. Jain and G. Lyons, “The gift of travel time,” *J. Transp. Geogr.*, vol. 16, no. 2, pp. 81–89, Mar. 2008.

[14] L. M. Lumsdon and P. McGrath, “Developing a conceptual framework for slow travel: a grounded theory approach,” *J. Sustain. Tour.*, vol. 19, no. February 2015, pp. 265–279, 2011.

[15] S. G. Stradling, “The Psychology of Travel. Review commissioned for the Foresight ‘Intelligent Infrastructure Systems’ project.,” London, 2006.

[16] G. Lyons and J. Urry, “Travel time use in the information age,” *Transp. Res. Part A Policy Pract.*, vol. 39, no. 2–3, pp. 257–276, Feb. 2005.

[17] M. Wardman, “A review of British evidence on time and service quality valuations,” *Transp. Res. Part E Logist. Transp. Rev.*, vol. 37, no. 2–3, pp. 107–128, 2001.

[18] S. Krygsman, M. Dijst, and T. Arentze, “Multimodal public transport: an analysis of travel time elements and the interconnectivity ratio,” *Transp. Policy*, vol. 11, no. 3, pp. 265–275, 2004.

[19] M. Brons and P. Rietveld, “Improving the Quality of the Door-to-Door Rail Journey : A Customer-Oriented Approach,” *Built Environ.*, vol. 35, no. 1, pp. 122–135, 2009.

[20] M. Givoni and P. Rietveld, “The access journey to the railway station and its role in passengers’ satisfaction with rail travel,” *Transp. Policy*, vol. 14, no. 5, pp. 357–365, 2007.

[21] M. Brons, M. Givoni, and P. Rietveld, “Access to railway stations and its potential in increasing rail use,” *Transp. Res. Part A*, vol. 43, no. 2, pp. 136–149, 2009.

[22] G. Lyons, “Business travel - The social practices surrounding meetings,” *Res. Transp. Bus. Manag.*, vol. 9, pp. 50–57, 2013.

[23] T. Schwanen and M. Dijst, “Travel-time ratios for visits to the workplace: The relationship between commuting time and work duration,” *Transp. Res. Part A Policy Pract.*, vol. 36, no. 7, pp. 573–592, 2002.

[24] M. Dijst and V. Vidakovic, “Travel time ratio : the key factor of spatial reach,” *Transportation (Amst).*, no. 1979, pp. 179–199, 2000.

[25] D. Hunink, “Travel-time ratios for commuters in the Netherlands between 2005, Unpublished paper,” University of Utrecht, Department of Geography, 2013.

[26] J. de D. Ortúzar and L. G. Willumsen, *Modelling Transport*, 4th ed. London: John Wiley & Sons, Ltd., 2011.

[27] J. Cao, X. C. Liu, Y. Wang, and Q. Li, “Accessibility impacts of China’s high-speed rail network,” *J. Transp. Geogr.*, vol. 28, pp. 12–21, 2013.

[28] E. Ortega, E. López, and A. Monzón, “Territorial cohesion impacts of High-Speed Rail at different planning levels,” *J. Transp. Geogr.*, vol. 24, pp. 130–141, 2012.

[29] E. Ortega, B. Martín, E. Gonzalez, and E. Moreno, “A contribution for the evaluation of the territorial impact of transport infrastructures in the early stages of the EIA : application to the Huelva (Spain)-Faro (Portugal) rail link,” *J. Environ. Plan. Manag.*, vol. 59, no. 2, pp. 302–319, 2016.

[30] C. L. Chen and P. Hall, “The wider spatial-economic impacts of high-speed trains: a comparative case study of Manchester and Lille sub-regions,” *J. Transp. Geogr.*, vol. 24, pp. 89–110, 2012.

[31] C. L. Chen and P. Hall, “The impacts of high-speed trains on British economic geography: a study of the UK’s InterCity 125/225 and its effects,” *J. Transp. Geogr.*, vol. 19, no. 4, pp. 689–704, 2011.

[32] H. S. Martínez Sánchez-Mateos and M. Givoni, “The accessibility impact of a new High-Speed Rail line in the UK – a preliminary analysis of winners and losers,” *J. Transp. Geogr.*, vol. 25, no. December, pp. 105–114, Nov. 2012.

[33] M. Givoni, “Development and Impact of the Modern High Speed Train: A Review,” *Transp. Rev.*, vol. 26, no. 5, pp. 593–611, Feb. 2006.

[34] M. Wardman and G. Whelan, “Twenty Years of Rail Crowding Valuation Studies: Evidence and Lessons from British Experience,” *Transp. Rev.*, vol. 31, no. 3, pp. 379–398, 2011.

[35] S. Blainey, A. Hickford, and J. Preston, “Barriers to passenger rail use: a review of the evidence,” *Transp. Rev.*, no. February 2015, pp. 675–696, 2012.

[36] J. S. Chou, C. Kim, Y. C. Kuo, and N. C. Ou, “Deploying effective service strategy in the operations stage of high-speed rail,” *Transp. Res. Part E Logist. Transp. Rev.*, vol. 47, no. 4, pp. 507–519, 2011.

[37] C. Román, R. Espino, and J. C. Martín, “Competition of high-speed train with air transport: The case of Madrid-Barcelona,” *J. Air Transp. Manag.*, vol. 13, no. 5, pp. 277–284, 2007.

[38] P. Hall, “Magic carpets and seamless webs: Opportunities and constraints for high-speed trains in Europe,” *Built Environ.*, vol. 35, no. 1, pp. 59–69, 2009.

[39] M. Givoni and F. Dobruszkes, “A Review of Ex-Post Evidence for Mode Substitution and Induced Demand Following the Introduction of High-Speed Rail,” *Transp. Rev.*, vol. 33, no. 6, pp. 720–742, Nov. 2013.

[40] G. Dudley and D. Banister, “Expertise and the Dynamics of Decision Making in Large Infrastructure Projects: From UK Trunk Roads to High Speed Rail 2,” in *Paper presented at the UTSG Conference, City University, London.*, 2015, no. January, pp. 1–15.

[41] B. Flyvbjerg, “What You Should Know About Megaprojects and Why: An Overview,” *Proj. Manag. J.*, vol. 45, no. 2, pp. 6–19, 2014.

[42] M. Givoni and D. Banister, “Speed: The less important element of the High-Speed Train,” *J. Transp. Geogr.*, vol. 22, no. June, pp. 306–307, May 2012.

[43] R. Hickman, C.-L. Chen, A. Chow, and S. Saxena, “Improving interchanges in China: the experiential phenomenon,” *J. Transp. Geogr.*, vol. 42, pp. 175–186, 2015.

[44] D. Banister and M. Givoni, “High-speed rail in the EU27: Trends, time, accessibility and principles,” *Built Environ.*, vol. 39, no. 3, pp. 324–338, 2013.

[45] M. Givoni and P. Rietveld, “Do cities deserve more railway stations? The choice of a departure railway station in a multiple-station region,” *J. Transp. Geogr.*, vol. 36, pp. 89–97, 2014.

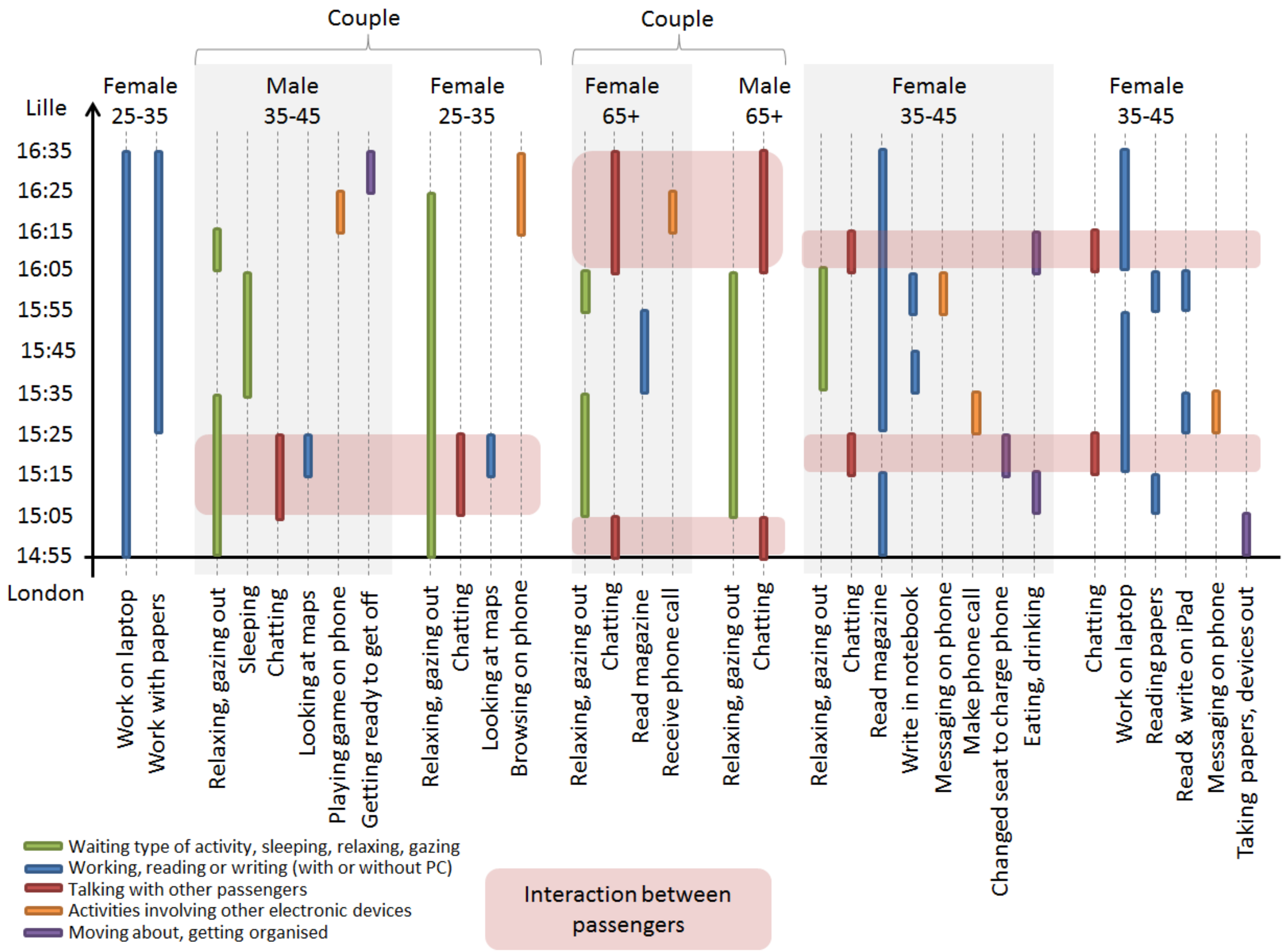
[46] D. Banister, “The sustainable mobility paradigm,” *Transp. Policy*, vol. 15, no. 2, pp. 73–80, Mar. 2008.

[47] D. Banister, “The trilogy of distance, speed and time,” *J. Transp. Geogr.*, vol. 19, no. 4, pp. 950–959, Jul. 2011.

[48] E. Bruun and M. Givoni, “Six research routes to steer transport policy,” *Nature*, vol. 523, pp. 29–31, 2015.

[49] N. Thomopoulos and M. Givoni, “The autonomous car—a blessing or a curse for the future of low carbon mobility? An exploration of likely vs. desirable outcomes,” *Eur. J. Futur. Res.*, vol. 3, no. 1, p. 14, 2015.

7. Appendix A: Structured observations of activities on board a HSR journey between London (UK) and Lille (France).



Note: Detailed observations of passengers activities were recorded for each 10-minute intervals by one researcher. This was done for 8 passengers seating in direct vicinity on a trip from London to Lille (April 2015). A follow-up interview was held with one couple to confirm the experience, but was not possible for all other passengers (some of whom continued on to Brussels). This summary graph for 6 of those passengers is a visual representation inspired from time-geography notation. The categories of activities are based on the notes collected and not on any predefined categories.

This thesis is responsible for generating 15.0 tons of CO_2 equivalent emissions from air travel, which represents the main carbon footprint component compared to a baseline ‘had the thesis work not been conducted’. In line with current practices by the European Environmental Agency, equivalent offsets were purchased from Gold Standard accredited suppliers (e.g. atmosfair.de).