Tyndall°Centre
for Climate Change Research

Towards a culture of low-carbon research for the 21st Century

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Abstract

The research community has highlighted for several decades the implications of greenhouse gas emissions for climate change. In response, world governments have agreed to limit global temperature change to 2°C, which requires drastic reductions in greenhouse gas emissions. In advanced economies, a commitment to a 2°C limit generally represents a reduction of emissions of between 80-95% from the 1990 baseline. Despite this, emissions from international aviation increased by 53 % between 1990 and 2011 in those countries. Academic researchers are among the highest emitters, primarily as a result of emissions from flying to conferences, project meetings, and fieldwork. Here we review the rationale for and alternatives to the current high-carbon research culture. We find no clear obstacles to justify an exemption for the research community from the emission reduction targets applied elsewhere. While stimulating ideas and creating personal links of trust are important benefits of face-to-face meetings, these benefits may be outweighed by the opportunities to reach much wider communities by developing and using new social media and online platforms. We argue that the research community needs a roadmap to reduce its emissions following government targets, which ironically are based on findings of the research community. A roadmap to a low-carbon research space would need simple monitoring, an example of which is presented here and documents the Tyndall Travel Tracker, incentives from international and national research platforms and funders, and a fundamental change in the research culture to align the walk with the talk. Such a change in practice would strengthen the trust of the public in research.

1 Introduction

As experts in a field that is of profound importance to the wellbeing of future societies and ecosystems, it matters what climate scientists say and do. Often, the task of this communication will be to 'dispassionately explain' aspects of science (Pidgeon and Fischhoff,

2011) – in other words, for scientists to act as objective conduits of knowledge. The principles governing the IPCC affirm exactly such a remit, explicitly stating that its reports should be ‘policy neutral’ (IPCC, 2013). However, many involved in climate science perceive an obligation beyond this, entailing a responsibility to advocate for change in the policies and practices of society. One high profile example is the 2007 Bali Declaration, signed by over two hundred climate scientists, which urged the negotiators of the United Nations Conference of the Party (COP), where international climate change protocols are negotiated, to reduce and stabilise emissions. More recently, prominent climate scientists including James Hansen, Michael Mann, Michael Oppenheimer and Ralph Keeling have publicly stated their objection to the Keystone XL Pipeline project designed to bring oil from Canadian tar sands to the United States, arguing “its construction [runs] counter to both national and planetary interests (350.org, 2013)”. Many other researchers have argued for changes in individual-level behaviour to achieve emissions reduction (Dietz et al., 2009) and proposed a variety of public engagement approaches (Whitmarsh et al., 2011) and structured interventions (Abrahamse et al., 2005; Steg and Vlek, 2009) to bring this about.

The extent to which others see experts’ assertions in climate matters as credible and convincing will be determined by several factors. Research has shown that the perception of technical expertise is an important influence in determining trust in scientists, alongside other cognition-based attributes such as a perception of consistency and lack of bias (Renn, 1991). These attributes are likely to be especially important with respect to the credibility of formal knowledge claims. However, trust is also determined by more values-based considerations, and here social and interpersonal aspects become relevant, including perceptions of the integrity of authority figures (Terwel et al., 2009). Such interpersonal attributes are likely to be especially important with respect to the credibility of arguments concerning the need for personal and societal change.

Integrity in this context may be defined as a coherence between a person’s statements of belief on the one hand and their personal choices on the other, including in the domain of emissions reduction (Hourdequin, 2010). A lack of coherence, conversely, may be construed as evidence of hypocrisy in terms of not ‘practicing what you preach’(Monin, 2010; Nevins, 2013). This was indeed a charge levelled by some in the media against delegates to COP15, who were characterised as having been ‘flagrantly hypocritical’ for taking flights to the Copenhagen conference (Gavin and Marshall, 2011). Steve Schneider also raised the question whether the accumulation of large numbers of air miles in his position as Professor of Climatology constituted ‘hypocrisy’ for being far above the US average (Schneider, 2009).

Climate scientists are in an unusual position because their private choices cannot be viewed in isolation from their professional expertise (Nordhagen, 2014). Although any one scientist’s emissions will have a negligible effect upon the climate system, it is nevertheless critical to science communication whether or not their actions are perceived to be consistent with the message that real and urgent action is needed on emissions (Thompson, 2011). Particularly in the context of advocacy for changes in lifestyles and patterns of consumption, there is a pertinence, therefore, not just in what climate scientists *say*, but also in what they *do*. And yet, such research as there is has indicated that the work-related carbon footprints of climate researchers are substantial in comparative terms, particularly as they are comprised in large part by air travel (Stohl, 2008).

Within Europe, aviation is a sector whose emissions have grown more rapidly than any other over recent years (Bows et al., 2009) to the extent that future expansion of the sector is argued to be irreconcilable with emissions reduction targets (Bows and Anderson, 2007) with aviation emissions set to dominate carbon budgets unless they are offset in other sectors. Internationally, emissions are projected to double worldwide between the years 2005 and 2025 (Macintosh and Wallace, 2009). In cultural terms, whereas flying would once have been considered unusual, for many it has now become a routine, often essential practice (Randles, 2009; Urry, 2002).

That flying is seen as ordinary is perhaps particularly the case for those working in the higher education sector, with research suggesting that scientists are highly mobile travellers not least as a result of regular international conference participation (Gössling, 2012). International research collaboration is seen as integral to effective science and has become ever more commonplace (Sonnenwald, 2007). Many sustainability initiatives such as the new 'Future Earth' international research platform are specifically designed to facilitate new interactions between partners worldwide (Future Earth, 2013). Often ethical considerations will determine the location of prestigious meetings, such as those of the Intergovernmental Panel on Climate Change (IPCC), to ensure a fair and balanced international representation among participating countries and/or institutes. Such multiple objectives lead to the current culture of high-carbon research.

Carbon offsets have been increasingly purchased in an effort to compensate emissions from aviation by research communities. However there are many ethical and technical issues with carbon offsets (Anderson 2012), and they do not address the issue of research credibility as a result of both professional and personal choices (Nordhagen, 2014). Offsetting as a transition mechanism in the 1990's and early 2000's towards a future with reduced aviation emissions might have been appropriate. However continued use of offsetting instead of reductions in flights contributes to the continued growth in the aviation sector, which is inconsistent with mitigation targets post-2030 (Bows and Anderson 2007).

The value of being able to travel freely to pursue research objectives, and the value of curbing flights out of a motive of social responsibility thus represent contradictory pressures. We review here the facts, benefits, and motivations that drive travel emissions in research, and the technological and social alternatives that could lead to a cultural change in the research community. We also propose and document a simple way to keep track of travel emissions by researchers. Finally we argue that the research community needs to establish a common roadmap and understanding of acceptable practices to ensure continued research output delivered through a culture of practices that are aligned with its own research findings.

2 Benefits and consequences of travel for the advancement of research

At every stage of an academic career, there are strong incentives for travelling. For early-career researchers, evidence of an internationally-acknowledged profile and publication list is central to obtaining a faculty position. Once in a tenured post, there is an expectation that junior academics will initiate networks and partnerships that benefit their home institution – often requiring international collaboration. At the Professorial level, keynote lectures and strategic attendance at internationally recognised conferences are part of the job description and paramount to securing research funding in most fields. International travel is embedded in the culture of academia – and changing embedded practices is notoriously difficult.

Table 1 summarises the benefits of meeting physically, as reflected in our own experience of research practices. The fundamental benefits are the exceptional stimulation received from meeting in person that can lead to the generation of new ideas, and the personal connections that arise leading to the establishment of trust. Other positive aspects included the ease with which one can take stock of recent progress in the research field and recognition which is important for career promotions.

Online alternatives have a different set of benefits (Table 1). They offer a potential for contributions from a wider audience and access to multiple sources of information during the interactions. They make it easier to keep track of information and to trace impact through online metrics, from dataset downloads to Twitter followers (Priem et al., 2012b). Online tools are also mostly free and are more inclusive than in-person alternatives as they are accessible to a broader research base, enabling contributions from those with circumstances restricting their ability to travel such as caring commitments or health constraints, and from those with budget or timetable (e.g. teaching) constraints and partial interests in the event. Analysis of web-based learning has shown that it is at least as productive as face-to-face learning for students that are academically higher performing (Lu and Lemonde, 2013), and that better performance was related to the number of web hits that the students did while learning (Campbell et al., 2008).

Given these differences, a roadmap for low-carbon research would need to ensure that ideas can continue to be stimulated and personal contacts can continue to be fostered independently of the practice of flying to meetings, and the online alternatives are not used in *addition* to travel but as a substitution for it. Such a roadmap would need to provide guidance to ensure career development is not adversely affected by increased constraints on travelling, and consider alternative metrics of research activity and impact (Priem, 2010) , although these approaches are still in their infancy and not without their detractors (Colquhoun and Plested, 2014). A change in culture away from flying to meetings would lead to benefits in terms of cost reduction, increased transparency and inclusivity.

Table 1. Benefits of online alternatives compared to physical attendance.

Benefits of research interactions	**Advantages of online alternatives**	**Advantages of physical attendance**
Generate ideas	contributions possible from a wider audience provides access to multiple sources of information	exceptionally stimulating allows multi-way exchanges with researchers across the world
Make connections	low maintenance connections across a wider network easy to keep in touch with people's research output and activities options for personal 'chats' during online conferences	easy to build trust and be remembered facilitates international interactions across time zones provides support for hosting institutes
Assess progress	online record of discussions easy to revisit online 'interest groups' aggregating all the latest information can create a 'dynamic textbook' of the state of the art of specific areas	easy to take stock of step-changes in research field between conferences easier to replicate results
Disseminate and promote own work	wider audience, long-term record more ways to contribute potential for considerable reputation building through generating useful content and comment	recognised kudos from presenting work at conferences incentives from employers to lead activities
Financial costs	largely free removal of financial barriers for researchers from developing counries[1]	limiting for some conferences limiting for younger researchers train journeys generally more expensive than flights
Time cost	time saving from reduced travel[2]	generally an efficient use of time
Personal	reduced constraints for people less able to travel (e.g. people caring commitments or health constraints)	

[1]One 5-day conference at 12 hours per day (60 hours total) is equivalent to 1-2 hours per week across the year. A typical Tyndall researcher undertakes international travel around twice a year for work purposes.

[2]Provided access to online tools is possible.

3 Travel emissions for research

Aviation generates 6.3% of total UK carbon emissions for an average of 0.54 tCO_{2e} per person in 2013 (DECC, 2015). Rising income and cheaper tickets have contributed to significant rise in aviation (CCC, 2009). Yet according to the World Wide Fund for Nature (WWF), 45% of air journeys in Europe are less than 500km suggesting significant potential for modal shift. Business travel by UK residents accounts for a sizeable minority of 12% of aviation in the UK, 37% domestically, 10% on international flights (CAA, 2012). Travelling to conferences makes up 5% of UK resident's business travel; if all conference travel were by staff at academic institutions this would account for 4.7 trips a year (2.7 domestic; 2 international) (CAA, 2012; HESA, 2012). Dividing the total number of business passengers travelling through the surveyed airports by the number of people in employment in the UK indicates an average UK employee took 0.5 trips by air in 2011 (0.3 domestic; 0.2 international). This average will vary between employees in different sectors, for example internationally facing organisations such as bankers and consultants flying more frequently compared to more locally facing organisations such as NHS and council employees or those providing services to domestic markets (Wood et al., 2009).

As internationally facing organisations i.e. organizations with a significant overseas 'market' or audience, Universities are among those with an increased propensity to fly for business (Wood et al., 2009). Furthermore, as most academic staff have a great deal of autonomy over their choice to travel for business, the checking and procedural mechanisms that are used to monitor and moderate air travel in other, particularly private sector, internationally facing organisations are often not in place (or if they are in principle, in practice an academic's decision to travel is rarely questioned by colleagues) (*ibid*). This would suggest that University employees are likely to fly more than the average employee. English universities are tasked with reporting on their business travel emission to the Higher Education Statistics Authority and required to implement a strategy to reduce these (and other sources of) emissions (HEFCE, 2010, 2012), but these have not yet widely fed back into Academic practices.

We conducted an informal online survey of climate change researchers who were members of the Tyndall Centre for Climate Change Research in 2012. This survey was carried out to obtain measures of types of travel undertaken, and the factors considered to be important influences on flying behaviour in particular. We obtained 79 completed surveys from several disciplines (56% social science/economics; 27% natural science; 13% engineering). Although a small sample size, this nevertheless represents around 1 in 3 of the membership of the Tyndall Centre, and provides a confidence interval of ±9% for a 50% result, and ±5% for a 90% result (at a 95% confidence level).

We found that 78% of respondents had done some flying that year, with an average number of trips by air of 2.3 per person, higher than the UK employee average of 0.5. On average 0.2 flights were within the UK, 1.2 within Europe, and 0.9 for the rest of world. In comparison, employees of the Norwegian Institute for Air Research flew 3.0 times per year on average during 2005-2007, though these figures include all employees and not just researchers (Stohl, 2008).

With this distribution and given the distance travelled internationally, we found that 20% of the individuals within the Tyndall Centre were responsible for 55% of the emissions (Fig. 1). This distribution is comparable to emissions by individuals travelling to participate in the European Geophysical Union 2012 annual meeting, where 20% of the participants were responsible for 65% of the emissions. In contrast, the official delegates of the COP meetings showed a less skewed bias, with 20% responsible for 40% of the emissions, so far more distributed emissions among participants. There is no evidence that this distribution has changed through the years, although the total number of participants to the EGU and COP meetings has increased (by 40% for the EGU between 2005 and 2012).

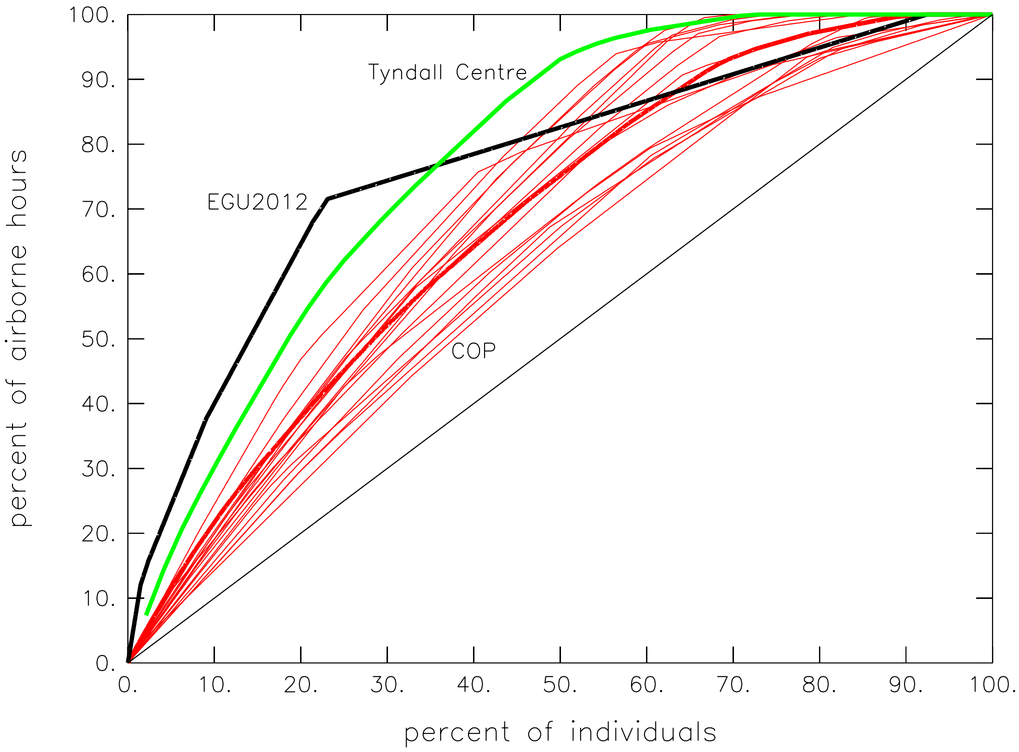

Figure 1. Distribution of emissions between individuals. Individuals were compared for the people attending the 2012 European Geophysical Union annual conference (black), officials attending the UN COP meetings (average in thick red, individual meetings in thin red based on data from Schroeder et al., (2012)), and for the annual travel habits of members of the Tyndall Centre for Climate Change Research (green). For the EGU meeting, the average airborne hours per participant was estimated from participants' country of work.

4. Motivations and decision-making related to travel in research

While there is literature on motivations and justifications for flying behaviour, most of this focuses on aviation for leisure and tourism. There are both instrumental and reasoned motives for flying such as cost and convenience (e.g., time constraints), and affective or symbolic motives such as enjoyment (e.g., the thrill of take-off and convenience (Steg and Vlek, 2009). There are also both individual and structural-level barriers to using alternative modes, such as lack of awareness of alternative travel modes, lack of perceived self-efficacy, 'displaced commitment' (i.e., referring to other environmental actions taken, such as recycling), and so on (e.g. Cohen and Higham, (2011)). Consequently, even the most environmentally aware often do not cut down flying (Barr et al., 2011) and reducing flying is one of the least popular low-carbon behaviours (Whitmarsh and O'Neill, 2010). In fact, multiple studies have found that there is no relationship between general environmental awareness and flying behavior (Kroesen, 2012).

Less work has been done to elicit the rationale for flying in a professional context in general or, specifically, within research. Motivations could overlap since business travel may often align with opportunities for leisure and tourism. In the context of international conferences, these include the prospect of social and cultural events, and the chance to experience a new or appealing part of the world (Høyer and Naess, 2001) although these types of extracurricular motivations have not been found to be an important factor for attendance at the UN Conference of the Party meetings (Neeff, 2013).

In our survey of Tyndall members, we did find that the value placed on being able to visit other parts of the world was the most commonly cited influence on flying behaviour for work purposes (see Fig.2) with close to four in five of those who flew agreeing this was relevant. Whilst this finding does not show that the appeal of international travel for its own sake is a principal motivation for flying, nevertheless it does indicate that it is likely to be a factor in many researchers' decision-making.

Other more practical considerations were also highly influential. As might be expected, the majority of respondents indicated that if they fly for business purposes, they do so because they perceive it to be a cheaper, quicker or sometimes the only way of reaching their destination. For climate researchers, as for the general public, there are structural barriers to using non-aviation means of transport. A large proportion of people also agreed that flying helped to maintain working relationships and networks and that if they flew less (or not at all), it would limit their career progression. Nevertheless, only a minority of the survey respondents (28%) held the view that it would be difficult to carry out their research if they did not fly.

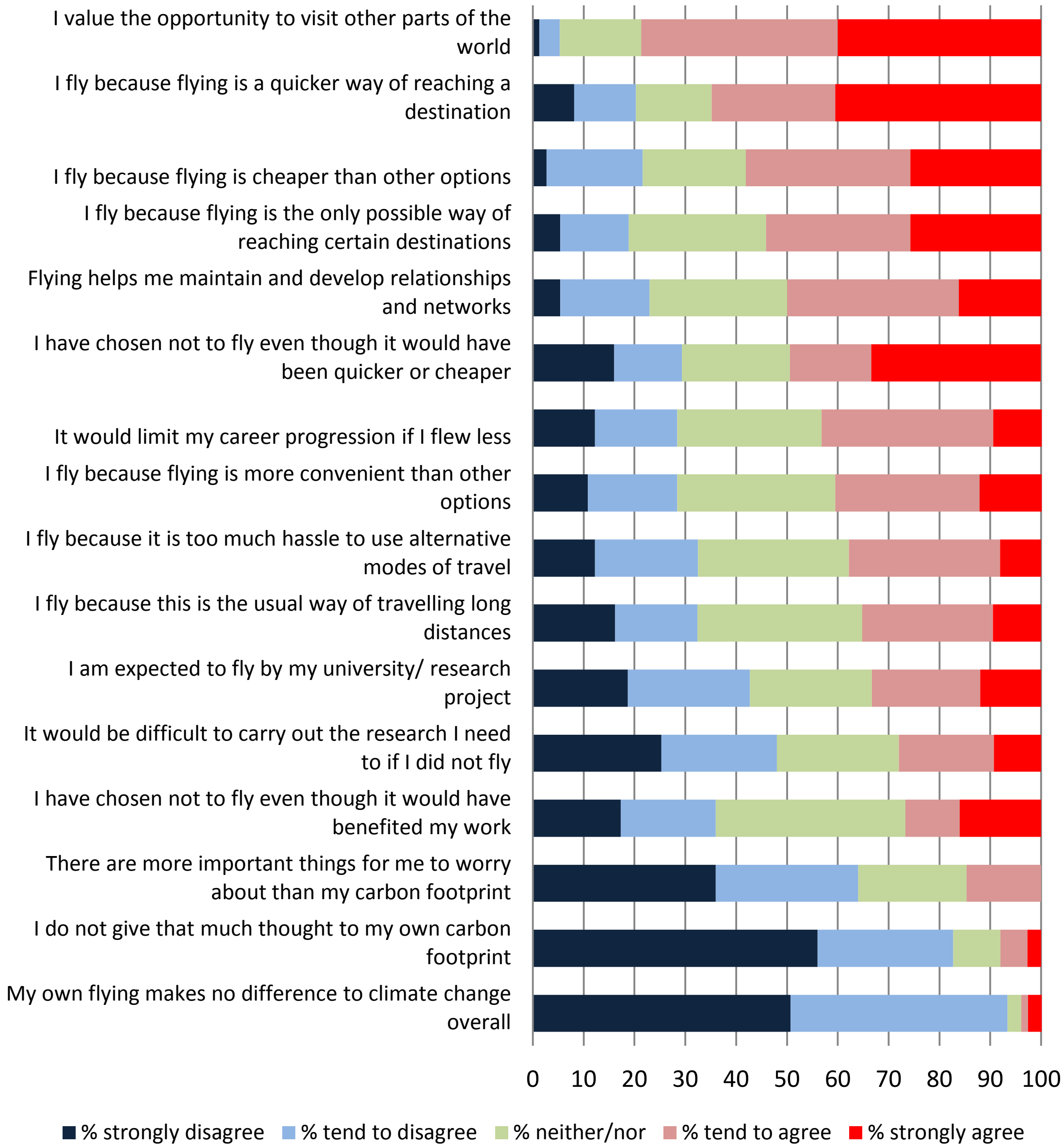

Figure 2. Climate change researchers' attitudes to flying. Survey conducted in 2012 among the members of the Tyndall Centre for Climate Change Research (n=79 with various levels of seniority). Respondents were asked "To what extent do you agree or disagree that the following have influenced your own flying behaviour. These statements apply for the purposes of work only." *Full item wording is abridged in some cases.*

Whilst most Tyndall researchers do fly to some extent, our survey indicates that almost two-thirds (63%) use non-aviation alternatives for European travel, and 9% had done so for travel beyond Europe. Furthermore, around 50% stated they had chosen not to fly even though it would have been quicker or cheaper, and a quarter had chosen not to fly even though it would have benefited their work (Fig. 2). The vast majority of researchers do not fly because they perceive their own flying makes no difference - i.e. flying is not a matter of a lack of self-efficacy. Researchers also have a good understanding of the impact of different modes on emissions. Our survey indicates no clear link between age/experience and whether people fly or not.

The survey also provides insights into barriers to modal shift (or reduced travel) and possible methods of overcoming these. Suggestions for encouraging use of non-aviation alternatives included potential inducements to fly less at the institutional level: financial support, and flexibility with respect to increased journey time required, were seen as having strong potential for encouraging non-aviation travel (Fig. 3). Open-ended responses also shed light on barriers to modal shift. For example, some suggested "a change in academic culture" is needed which rewards use of alternative modes "even if it takes a day longer " or tele-presence; (as climate researchers) leading by example rather than being "hypocrites… jetting around the world preaching on the need for reductions in carbon emissions whilst we rack them up ourselves"; as well as guidance on how to differentiate necessary from unnecessary travel. Others indicated barriers to reducing flying included family commitments, prevailing institutional pressures to fly and lack of structural incentives to cut down flights:

> "Working in a natural science field, not many people share the 'I'm a climate change scientist I can't fly' agony. A main perk of science, is the travel, but with climate change science you get a huge heap of guilt that cancels out the perk. You often get looked at like a weirdo for stating out loud, 'Thanks for the invite to the conference, but I've already got one international trip this year and I try to limit my flying because of the carbon'".

> "Rather than putting the onus on individuals who are probably already avoiding unnecessary travel anyway [there should be] campaigns to reduce the price of train fares, and increase the speed of trains in the UK [and] most importantly, get funding to really improve teleconferencing and videoconferencing technology".

Consistent with this, over 80% would support an organisation-wide policy to reduce flying, with only 6.5% opposed to it. Carbon offsetting is not seen as good option with 80% agreeing that "Carbon offsetting encourages people to carry on doing things that harm the environment".

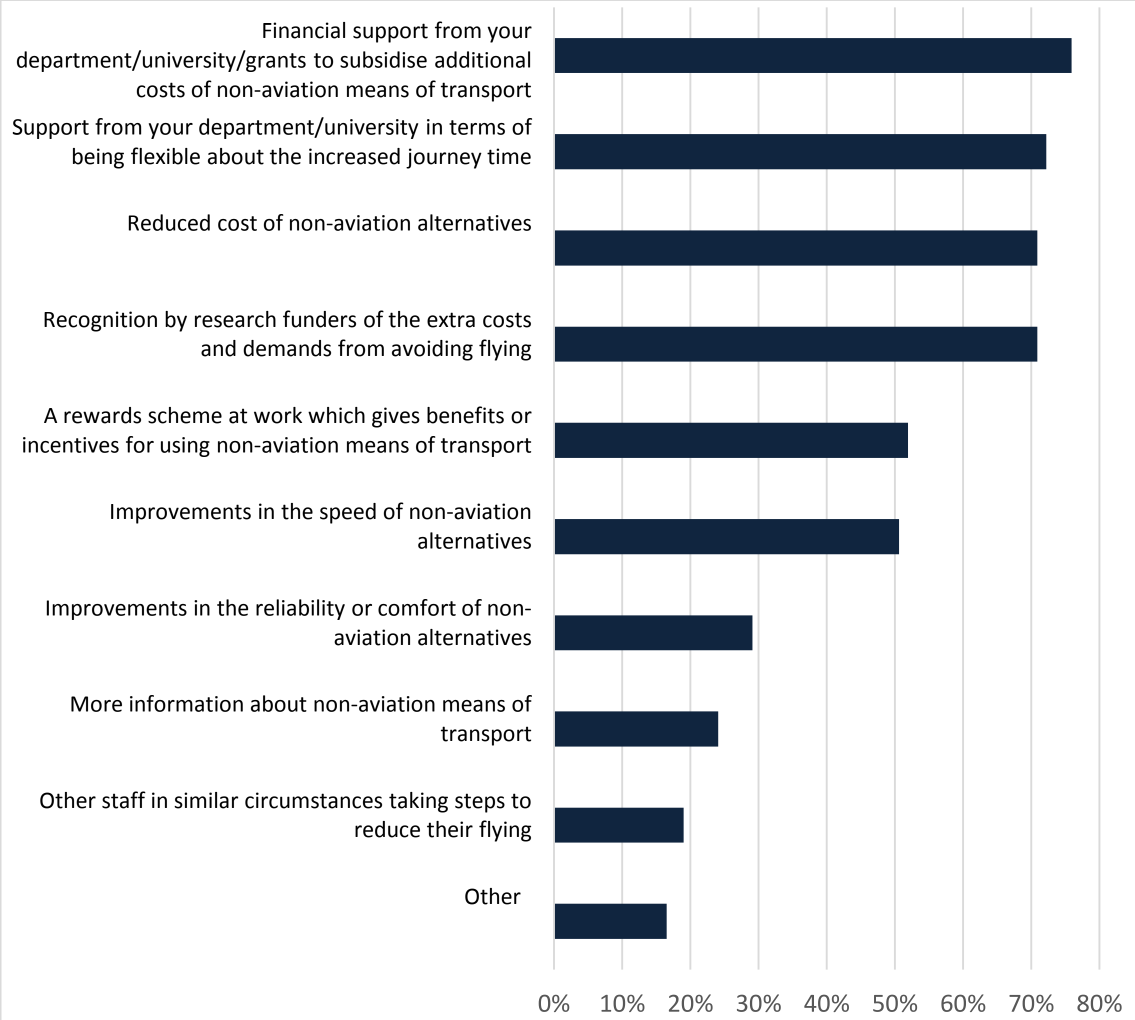

Figure 3. Factors that would encourage use of non-aviation alternatives for work purposes. Survey conducted in 2012 among the members of the Tyndall Centre for Climate Change Research (n=79 with various levels of seniority). *Respondents were asked* "Which of the following, if any, would encourage you to use non-aviation means of transport for work purposes?" *Full item wording is abridged in some cases.*

These results taken together suggest that personal factors – people's desire to visit other parts of the world, and their perception that their career prospects would be limited by flying less – may operate in parallel with structural factors like cost and expediency as influences on the decision to fly. They also point to possible interventions for reducing researcher carbon footprints. By encouraging reflection on travel choices through the use of aids like decision trees (Fig. 4), coupled with institutionally embedded support, concerns over the 'downsides' of not flying may be reduced.

The use of aids like decision trees is widespread in organisational culture, and provides one straightforward way of making explicit – and encouraging reflection on – the reasons for foreign travel. Organisations such as the Countryside Council for Wales (CCW) (now Natural Resources Wales), who provide advice to the UK Government on the natural environment, have a decision tree embedded into their Travel Management policy.   This type of 'enabling' style of policy making allows staff to take responsibility for their own travel choices whilst at the same time ensuring that such decisions are aligned with the overarching low carbon travel strategy of an organisation such as CCW. Fig. 4 provides a decision tree that could support low-carbon choices.

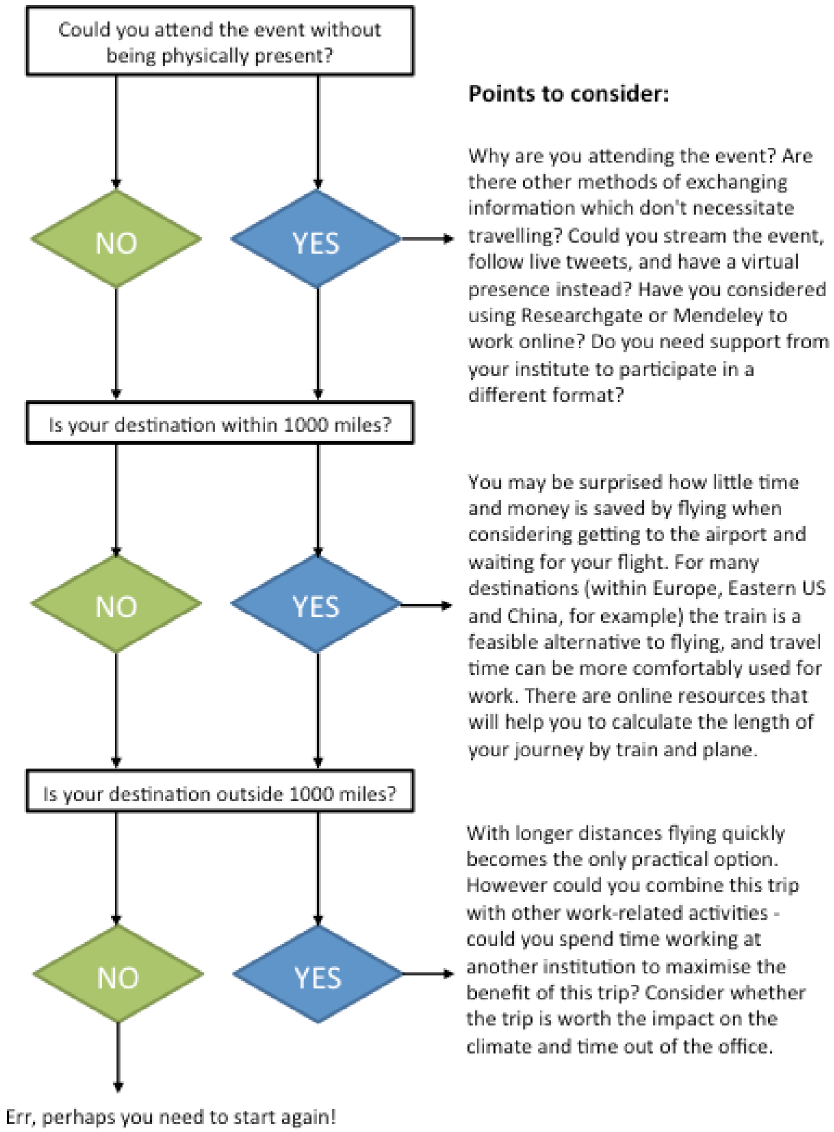

Figure 4. Decision tree to support choices that reduce the necessity to fly for research purposes. The distance of 1000 miles is illustrative and exact thresholds will depend on individuals and locations. 1000 miles corresponds approximately to travelling between London and Rome, which takes between 14 and 21 hours by train.

Institutionally embedded support is vital to enable researchers to make the choice to either use alternative travel or communication modes. This takes two forms, firstly practical support and secondly engendering a culture where travel by air is no longer requisite for a successful academic career. Practical support may include the provision of locally available, high quality video or telephone conferencing facilities or agreements from institutions and funders to meet potentially higher financial and time costs of surface travel when compared to air for certain journeys.

Engendering a low / no fly culture within an organisation that empowers researchers for example to say ‘no’ to certain trips or request additional time to travel by rail on longer journeys is far more challenging. Potential actions include: changing expectations on the frequency of international conference presentations and international references in performance assessment criteria; the provision of high quality communications to promote research of international standing to the global research community through alternative media; and allowing flexible work schedules to enable longer travel times by land and / or longer overseas trips to maximise the benefits of travel beyond simply one conference attendance or workshop.

However, while changing the culture of academia – and the individual behaviours of academics – may be challenging, there is a great deal of psychological and social science research that can be drawn on to inform processes of change (see, e.g., Capstick et al., (in press)). To take just one example, it is now well-established that promoting appropriate social norms – making others' positive behaviour visible – is one factor that influences whether people engage in low-carbon behaviour (Schultz et al., 2007). While this research has typically been conducted with members of the general public, there is no reason to think that the findings do not apply in an academic or work-based context. The research community should ensure, therefore, that the considerable body of knowledge about promoting low-carbon behaviours is brought to bear on its own practices.

5. Technological elements of decision-making related to travel in research

One of the major internet developments of the last decade is the rise of social media, facilitating community-driven generation of content, sharing of ideas and building of networks. Some of these are directly applicable to the research environment, others, arguably not. Sites used by researchers are constantly evolving and even the most established platforms can be replaced as technology moves on. All aspects of the internet are now 'social', with social bookmarking and discussion and the sharing of any content via blogs, Twitter, social networks etc. This provides the capacity to "stitch together" narratives and information from disparate information sources (Neylon, 2009), which has clear benefits to scholarly research, discourse, and to understanding (Campbell et al., 2008).

The uptake of online tools by the research community for their work has been rather slow relative to general usage and uptake by other sectors, but appears to be growing exponentially (Priem et al., 2012a; Van Noorden, 2014). Leading academic social networks Mendeley.com, Researchgate.net and Academia.edu each have over 2 million users and are seeing accelerating growth. It seems inevitable that in coming years it will be impossible to build an academic career and reputation without an active online presence.

The technology for finding online alternatives to travel- (and time-) intensive conferences is extant and in use for scholarly applications already (Arslan et al., 2011). Webcasting of conference sessions is functional and used in some communities, but there are also emergent tools and trends that enhance the social conference experience. For example, conference or session specific Twitter #hashtags commonly emerge from the audience during conferences (or increasingly are pre-defined by organisers). At some conferences the Twitter 'backchannel' is presented on a second screen in the auditorium, becoming "a multidirectional complex space in which the users make notes, share resources, hold discussions and ask questions" (Ross, 2011). It is easy to envisage the removal of the physical meeting entirely, rather moving the whole conference proceeding online, with participants giving presentations from their desks or uploading posters to a shared space. Such conferences have happened to these authors' knowledge only on a small scale to date (Arslan et al., 2011; Pawloff et al., 2014). There are obvious benefits to a 'virtual conference' whether running in parallel with an 'in person' conference or as a standalone event. The outputs from the conference, from posters (normally only displayed for a day or two) to discussions (normally held in person over coffee) are recorded for re-analysis by participants and can exist in perpetuity.

Virtual environments, where delegates' avatars meet in a virtual conference venue also present interesting possibilities. Fully virtual and parallel virtual and physical meetings (where the virtual auditorium broadcasts the audio and projections from the real auditorium) are not uncommon in some fields [e.g. Shirmohmmadi (2012)]. Virtual reality potentially allows the sharing of the *experience* of attending a conference or meeting as well as the content. Replacing large academic conferences with virtual ones may be a long way off, but this highlights that we are limited by what our research communities are prepared to embrace, rather than by the available technology.

Various models for reduction of the travel intensiveness of academic congress can be envisaged:

i) "Augmentation" of traditional conferences, where webcasting and social tools can embrace an audience much broader than the auditorium alone. This may not reduce the carbon emissions, but could enhance the scientific benefit resulting from them.

ii) "Nodal" conferences, where a conference is distributed over numerous sites around the globe, with high-bandwidth web links between auditoria (along with augmentation as above).

iii) Fully "distributed" meetings, where researchers participate from their desks via the web (see Arslan et al. (2011) for case study, technical implementation details and carbon emission analysis for 560 participant meeting).

iv) "Extensive" conference, where dissemination and discussion are on-going throughout the year using social media and specialist tools, rather than being intensive during short periods.

These four options are available with current technology, much of which is already widely available. However their efficient use in conferences requires technical support beyond what is factored into current planning of research interactions.

6. Monitoring travel emissions and their rationale

One of the most important steps before setting a roadmap to reduce emissions from research-driven travelling is to be able to measure, track and justify these emissions. The reporting should be simple, to reduce the administrative burden associated with monitoring travel. Given the widely different views on the importance of travelling, the set objectives could be self-determined but contain general guidelines, and offer researchers a way to provide feedback on performance compared to themselves (through time) and to others. Finally, the justification of travel emissions should consider the career stage and the reason for travel.

We propose here to monitor travel emissions by reporting all travel in terms of hours spent moving in different transport modes. Hours in motion are selected here because they are easy to remember, and thus do not require any further effort above the researchers willingness to record their travel. Emissions can be estimated based on the hours in motions and average national and international conversion factors (see Appendix A for emissions factors and Appendix B for details of the Tyndall Travel Tracker web-based application to record emissions). Based on UK and EU data, the error introduced among vehicles (e.g. different types of trains) is far less than the differences between travel modes (Table A1). Similarly, the error introduced by specific trips (e.g. under-loading of passengers) would cancel through time. Although this system would not be suitable for researchers that already use systematically low-carbon transportation mode, it would provide an easy first order estimate of the average researcher currently flying a few times per year including long-haul flights.

An important aspect of the decision-making with respect to flying depends on the purpose of the trip (Fig. 2). Here we argue that reasons for flying are justified based on the rationale for travel and the level of seniority of the researcher. For example, conducting field work, meeting contractual engagements, or informing policy would all be well justified (Table 2), whereas presenting and promoting your own research would diminish in justification as seniority increases.

The balance between emissions and the rationale for travelling can be quantified through the introduction of hours-equivalent to give a professional score independent of the career stage, which can be used to monitor emissions through time and to compare emissions between researchers. The proposed score is the product of a 'Weight' corresponding to the rationale associated with your travel that takes into consideration the specific need of the researchers' career stage (Table 2), multiplied by the emissions, normalized to the corresponding emissions per km train travelled ($Emissions_{norm}$, Table A1), multiplied by the number of hours in motion:

$$\text{Score} = \text{Weight} * \text{Emissions}_{norm} * \text{Hours} \qquad (1)$$

The score is provided in hours-equivalent (h_e). The score of a well-justified trip lasting 10 hours made by train would be equivalent to 10 h_e (or 86 $kgCO_{2e}$; see Appendix A). The score of a well-justified trip lasting 10 hours and made by plane would be 210 h_e (or 1.8 tCO_{2e}). The score of a poorly justified trip (Weight=4) lasting 10 hours and made by plane would be 840 h_e.

In order to encourage a culture of low-carbon research and transparency, the total emissions and hours-equivalent should be published for institutions that select to tackle their carbon emissions, and objectives set to reduce individual scores and institutional averages through time, which could be achieved using a range of the options discussed in this paper.

Table 2: Weight associated with different types of travel to be used in Equation 1. We refer to research stages as follows: Stage 1: Early Stage Researchers (for example up to 2 years after PhD); Stage 2: Intermediate Stage Researchers (for example, up to about 10 years after PhD); Stage 3: Established Researchers (for example, in permanent positions with over 10 years since PhD).

Weight	Justification
1	Well justified emissions, for example: Conduct field work. Travel informs directly policy on climate change and global sustainability (e.g. IPCC). Travelling to meet contractual engagement (e.g. from research grants), with no alternative options available. Risk of job loss with refusal to travel. And for Stage 1: Present and promote own research. Establish contacts. Attend and present work at project meetings.
2	Useful but with potential for using alternative options. Stage 1: Attend a workshop not directly related to own research. Stage 2: Travel to present own work and promote own research. Stage 3: Travel to explore new topics. Could lead to important research or funding for own or group/institute research. Travel acts to move projects or significant collaborations forward (e.g. the Tyndall Centre's collaboration with

	the University of Fudan, China).
3	Less well justified with much potential for using alternative options. Good value mainly for low-emissions travel. Stage 3: Travel to present own work and promote own research. Travel to establish or maintain own collaborations. Invited guest lectures.
4	Poorly justified emissions. Good value only for low-emissions travel. Travel to keep up to date or renew connections with colleagues. No results presented. Little pre-travel arrangements made to optimize the usefulness of the meeting.

7. Long-term objectives for low-carbon research

In the context of limiting climate change to 2°C of warming, many advanced economies have acknowledged that their emissions should decrease by 80-95% below 1990 levels in 2050. Yet international aviation emissions have generally increased worldwide, at a rate of 1.8% per year between 1990 and 2011 in the advanced economies listed in the Annex I of the Kyoto protocol (IEA, 2013). If this rate of growth persisted to 2015, an increase of nearly 60% of emissions from aviation will have taken place in advance economies. Thus, current aviation emissions from these economies stand at 8 to 32 times larger than emission levels required by 2050 in order to meet global climate objectives. Anticipated improvements in both aircraft efficiency and the fraction of biofuels that could replace kerosene are insufficient to deliver the required emission reductions given the rates of growth observed in the sector (Bows and Anderson, 2007; CCC, 2009). Counting on carbon offsets to 2050 would also be problematic given the scale of the reductions needed and competition with other sectors (Fuss et al., 2014). Thus the bulk of emissions reductions in aviation of 2.5-3% per year would need to come from a reduction in the number of trips and/or a reduction in the distance travelled.

Fig. 1 suggests that aviation emissions in research could be reduced by up to about 50% by reducing or eliminating long-haul trips, which account for a disproportionate fraction of the emissions. Additional reductions would need to be made from reducing the distance travelled, the number of trips, and the mean distance of participants to project meetings. Selecting the location of meetings to minimise the emissions by all participants combined can also lead to significant gains. For example, hosting the bi-annual meeting of the scientific steering committee of the Future Earth platform in Australia, South Africa, China, Argentina, or USA compared to Europe leads to an average of 1.8 times additional emissions. (Australia: 2.6; South Africa: 1.9; China: 1.7; Argentina: 1.5; USA: 1.5) The exact ratios depend on the composition of the group and the exact location of the meetings, but the difference is large and attention to the location of meetings can contribute to a long-term plan to reduce emissions. A near-complete suppression of travel emissions could be achieved but would require a change in the cultural mind-set of researchers in addition to technological support to replace face-to-face interactions.

8. Conclusions

This paper has examined the culture of high-carbon practices that currently prevails in research, including in climate change research. We show that stimulating ideas and creating effective professional relationships are the most important among the benefits of attending research conferences and meetings. Other benefits are easily compensated by the advantages of not travelling and meeting virtually. We raise the possibility here that the benefits of face-to-face meeting may be overrated simply because of the enshrined habits of the research community. We suggest that instead, a research culture that would value exchanges with a wider audience would benefit from moving away from secular conferencing systems towards more open platforms of exchanges distributed more evenly throughout the year.

This paper also proposes a simple approach to keep track of travel emissions through hours in motion in different modes of transport, which is easy to remember, requires no additional effort above the willingness to record travel, and can be compared between researchers and through time when coupled with a self-based justification. With a combination of change in culture, penetration of effective communication technology in research, and monitoring of progress, there is no reason why the overall objectives of reducing emissions by 80-95% from the 1990 baseline set by many advanced economies to address climate change should not be applicable to the transport emissions from the climate research community. Clear leadership and incentives from international research platforms, research funders, and universities, is needed, of the same level that is currently leading a quiet revolution in the open access of research outputs.

Acknowledgements: This paper emerged from discussions among researchers in the Tyndall Centre for Climate Change Research during 2012-2015 in efforts to reconcile their behaviour with their own research results. It forms the basis of the Tyndall Travel Tracker that provides a web-support for researchers to record their emissions and the Tyndall Travel Strategy.

Appendix A Emissions related to various modes of transport and how they relate to 'hours in motion'.

For each travel mode the direct and well to tank (WTT) CO_{2e} emission factor per pax km is reported, this figure represents the emissions directly emitted by the transport mode from fossil fuel combustion for propulsion and emissions associated with the extraction, refining and transport of the fuels to their point of use – the car or coach or power station. Well to tank emissions are sometimes referred to as 'Scope 3' emissions in some GHG reporting standards – they are not under the direct control of the transport / power station operator, but are emitted as a consequence of their demand for fossil fuels. For electrified transport, this is the CO_{2e} directly emitted by the appropriate electricity generation source and the upstream emissions associated with fuels used for electricity generation – either UK or the European average. Note that only CO_2 is reported for European electricity generation transmission and distribution in their direct emission factors, omitting the contribution of non-CO_2 greenhouses gases associated with combustion of fossil fuels during electricity generation. For consistency, the non-CO_2 emissions for EU electricity generation are assumed to be the same proportion (0.7%) of CO_2 emissions as for UK electricity and this figure is included in Table A1.

The aviation emission factors presented here include an 'uplift' to take into account non-Kyoto defined GHG radiative forcing associated with flights. In addition to emitting greenhouse gases, aircraft also have an additional radiative forcing impact on the climate associated with their release of NOx, sulphates, soot and water. While there is no comparable CO_2 global warming equivalent for this impact, an uplift factor is provided by DECC / Defra to reflect this additional radiative forcing from flights. Currently DECC and Defra recommend multiplying aviation CO_2 emissions by 190% to reflect this impact.

Table 2. Emissions factors used in the conversion of the emissions from the hours travelled to the $kgCO_{2e}$. The $Emissions_{norm}$ (Equation 1) is shown in the last column.

Transport Mode	Km / hour[1]	Wh /pkm[2]	gCO_{2e} /wh[3]	$kgCO_{2e}$ /pkm[4]	$kgCO_{2e}$ /hour	Normalised to EU HS Rail (unit less)
Car	100			0.2296[5]	23	2.6
Coach	90			0.0355	3.2	0.3
Ferry	46			0.1378[6]	6.3	0.7
Rail						
European high speed electric	200	70	0. 4310	0.0302	6.0	0.7
European Intercity electric	160	77	0. 4310	0.0332	5.3	0.6
European intercity diesel	160			0.0657	11	1.2
UK average	150			0.0576	8.6[8]	1.0
Air						
UK Domestic	850			0.3622	217	25

European	850		0.2135[7]	181[8]	21
International	850		0.2512	214	25

[1]Assumptions used here.

[2]Reported by IFEU (2010) based on statistics provided to them by the International Union of Railways.

[3]Direct and WTT CO_{2e} emissions per Wh from EU average electricity generation, transmission and distribution (DECC and Defra, 2013). The direct CO_2 figures have been increased by 0.7% to account for non-CO_2 emissions, following the UK's direct electricity generation CO_2:CO_{2e}.

[4]Direct and WTT CO_{2e} emissions per passenger km for modes other than European rail (DECC and Defra, 2013) or based on energy consumption figures (IFEU, 2010) and European grid average emissions (DECC and Defra, 2013).

[5]Average passenger car, unknown fuel, 1 passenger (DECC and Defra, 2013).

[6]Average all ferry passengers (i.e. foot or car; DECC and Defra, 2013).

[7]Short haul, average passenger figure includes radiative forcing from uplift.

[8]Factor used in the Tyndall Travel Tracker published on March 6 2015.

All the emission factors reported here are taken from DECC and Defra (2013) with the exception of international rail travel. The international rail emission factors reported by DECC and Defra (2013) are based on the Eurostar and this figure is not representative of the emissions associated with travel by train across the rest of Europe, due to differences in the electricity mix across Europe. Instead we have estimated an emission factor based on the power consumption per passenger km of European rail travel as reported by the IFEU and UIC. The figure is derived from a combination of datasets published by the UIC and reported by IFEU using a) power consumption by train by route type (high speed, intercity or regional) b) seat numbers by route type for each EU country and c) load factors by route type using survey data from selected countries from which a weighted average for Europe is used. The emission factor reported is a combination of the European average power consumption for rail travel per passenger km coupled with the EU average electricity emission factor reported by DECC and Defra (2013). Figures are provided for high speed, intercity electric or diesel and regional electric or diesel.

Data sources

DECC and Defra (2013) UK Government conversion factors for company reporting. AEA Ricardo and Carbon Smart for the Department for Energy and Climate Change and the Department for Environment, Food and Rural Affairs, London, UK. Available at: http://www.ukconversionfactorscarbonsmart.co.uk/

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Appendix B Development and Implementation Details of Tyndall Travel Tracker (TTT)
David Cutting, School of Computing Sciences, University of East Anglia

Interface:
For the system to be effective as a tool for recording and ultimately managing travel emissions it must be actually used. Any reporting or analysis of the data could only be as good as the data entered, and so the validity of analysis will be directly linked to the level of adoption. The more people who made use of the system and recorded their journeys, the higher quality and more representative the data will be.

A key requirement therefore was for the system to be as accessible as possible, and to provide a very easy path to record journeys made. The primary designed interaction was for a user to connect and record a journey. Other functionality such as viewing carbon reports, or exporting data for analysis, were secondary features that could require more interaction from the user. To make recording as easy as possible the basic use case was for a user to wish to simply record a journey from a handheld mobile device, such as a phone or tablet.

The user interface of the system was built on a mobile-first principle, in that it was specifically designed to operate correctly on a mobile device, with desktop browser support guaranteed but the design and layout being optimise for mobiles. A mobile-optimised interface included large buttons suitable for touch screens, and forms laid out for easy rendering and completion on mobile browsers.

The user journey from logging on to recording a journey is at most one or two selections, and with the option to save a common journey as a favourite which pre-fills travel times, can result in a journey being recorded in a matter of seconds. Such ease of accessibility from multiple platforms combined with direct access to recording journeys in a simple and transparent manner should encourage user participation, and increase the coverage of data captured.

Development:
Development of the system was performed in an incremental and iterative fashion. Having defined the key use cases, recording of and reporting on trips taken, and defined the underlying data storage schema, the overall system was built as a series of specific features. Using industry standard tools and languages such as PHP, MySQL, jQuery and git, development was not only transparent but also intended to offer longevity and maintainability. The use of the industry standard Model-View-Controller (MVC) architecture model also increased flexibility and the ability for future expansion or adaption to a new server environment.

To allow for flexibility all the options (for example career stages and travel methods) are not hard coded but stored as database records.

Data export was identified as one of the areas potentially requiring the greatest degree of short-term change. Initially a simple export is required, mimicking a spreadsheet tracker, and exporting in CSV format a list of all trips and relevant data. As it is envisaged that shortly more detailed exports will be required, for example summaries or emissions against target comparisons, a dynamic export structure was implemented.

The dynamic export system uses runtime adaptability where new export modes are defined as new classes. These classes are included at runtime and registered automatically within the data export manager, making them available immediately to system administrators. Each export type has the ability to specify options for output that are displayed, and then when run generates a series of data records. Data records are initially shown within the browser and there is an option to export as CSV data. The method of display (browser or CSV) is unknown to the export type, which just generates a set of records which are formatted by the export manager.

With this implementation adding new forms of export becomes a much simpler exercise and requires little or no understanding of the underlying system or data structure. Existing API calls or new SQL queries can be used to generate raw data that in turn is processed and output seamlessly in the format chosen.

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