

Personal air and car travel – just don't do it!

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Abstract

Greenhouse gas emissions from personal transport have risen steadily in the UK and most other countries of the EU. Yet surprisingly little is known about *who* exactly is contributing to the problem at the personal level and the extent to which different groups of the population will be affected by the any responses to the climate change problem. This paper describes an innovative methodology and evaluation tool for profiling annual climate change emissions from personal travel across all modes of travel. A case study application of the methodology involving surveys of UK residents provides an improved understanding of the extent to which individual and household travel activity patterns, choice of transport mode, geographical location, socio-economic factors and vehicle technology choice impact on greenhouse gas emissions. Air travel dominates overall emissions, particularly when including climate effects of non-CO₂ greenhouse gas emissions. Conversely, land based public transport accounts for a very small proportion of emissions on average. There is a highly unequal distribution of emissions amongst the population, independent of the mode of travel, location and unit of analysis (individual/household). In particular, there are large disparities between individuals/households: some 20 % of the respondents drove but did not fly although the same number flew but did not drive. The top 10 % of emitters are responsible for 43 % of emissions and the bottom 10 % for only 1 %, with those in the top 10 % flying 5 times more than the sample average. The area analysis (urban vs. rural) shows higher levels of urban emissions due to higher

propensity to travel by air. Air travel emissions of flyers and non-flyers are also significantly influenced by income levels. Key policy implications of the results are discussed. The paper concludes by suggesting potential applications of the methodology and evaluation tool.

Introduction

RESEARCH MOTIVATION AND OBJECTIVES

In 2004, greenhouse gas (GHG) emissions from personal travel activity represented 18 % of all UK domestic GHG emissions (DEFRA, 2006a). This share is significantly higher when international travel by air and shipping is included (Cairns and Newson, 2006). Travel by car and air make up the lion share of these emissions, with significant increases expected over the coming decades (DEFRA, 2006a). Yet surprisingly little is known about *who* is contributing to the problem, what the GHG profile of the population is and the extent to which different groups of the population will be affected by any responses to the problem. Research by, for example, Hillman and Walley (1983), Banister (1993), Hughes (1994), Greening (1997), Anable (1997), and more recently Greening (2004) identify that different subgroups in the population, described by various socio-economic, demographic and other personal characteristics, have different levels of emissions from personal motorised transportation. The focus of national initiatives to mitigate climate change has so far been on vehicle technology fixes and economic instruments such as differential fuel/vehicle taxation and pricing road usage (IPPR, 2003). Many believe (e.g. Bristow et al., 2004, Hickman and Banister, 2006) that the UK government's recent commitment to a 60 % cut in carbon

dioxide (CO₂) emissions between 1990 and 2050 as set out in the Energy White Paper (DTI, 2003) is unlikely to be achieved by technology fixes and market-based measures alone. A whole raft of measures are likely to be required to meet this goal, in particular with regards to including private vehicle use and international aviation. As the world community is facing tough choices as how to respond to climate change, it is crucial to know who is contributing to the problem and to what extent will different groups of the population be affected by those choices. Part of this debate is hampered by the apparent lack of information on the GHG distribution within the transport sector, in particular with regards to *annual* travel activity and *international* travel at the personal level. This lack of appropriate data makes policy development difficult. Most national work on UK transport energy use (e.g. Stead, 1999, Banister and Banister, 1995) is based on travel activity data from the National Travel Survey (NTS) (ONS, 2005) and emissions factors from national sources such as the National Atmospheric Emissions Inventory (currently under review, with the most recent inventory reported in NETCEN, 2003). However, the NTS is inappropriate for capturing annual and international travel as it collects disaggregate data in a weekly timeframe, long-distance trips are under-recorded (ONS, 2005: p.22) and, crucially, includes only trips within Great Britain. A new data collection method was needed.

The goal of the research summarised in this paper was to develop and test an innovative methodology for profiling climate change emissions from personal travel at the local, household and individual levels and to use this information to develop measurement, information and forecasting tools for use in (a) the assessment and monitoring of transport strategies and policies, (b) awareness raising, feedback and advice to households and individuals and (c) aggregate emissions forecasting. To achieve this aim, this research had the following working objectives:

- To extend previous work on travel emissions profiles (Anable et al., 1997) to include public transport, air travel, motorcycling, walking and cycling in a broader geographical setting;
- To develop a detailed evaluation 'tool' of GHG emissions at the household and individual levels;
- To collect, via conventional paper-and-pen based and web-based surveys, detailed disaggregate data as a basis for travel emissions auditing at the household and individual levels;
- To validate the evaluation 'tool' using the data collected in the surveys;
- To assess policy implications for local and national governments.

GHG emissions are expressed as mass of carbon dioxide equivalent (CO₂^{eq}), a metric measure used to compare the emissions from various GHGs based upon their 100-year Global Warming Potential (GWP) (Houghton et al., 2001), with respective 100-year GWP of 23 and 296 for CH₄ and N₂O expressed in terms of CO₂. The one exception is air travel, where GWP can not be used and no comparative metric currently exists (Wit et al., 2005, Shine et al., 2005). To make a more general assess-

ment of relative emissions impacts, this research applies the Precautionary Principle (UNCED, 1992) in using an alternative 'weighting' coined the *Aviation Impacts Multiplier (AIM)*, with values based on the most up-to-date figures for the Global Temperature Potential metric (between 1.5 and 3, with central value of 2, according to Wit et al., 2005) and the most reliable estimations of the Radiative Forcing metric by the IPCC (Penner et al., 1999) and more recently the TRADEOFF project (Sausen, 2005). For the purposes of this research, the new multiplier is represented by low (1.5), central (3) and high (4) values.

THIS PAPER

The paper will begin by briefly reviewing the background to personal travel and its relevance to climate change. Secondly, the methodology used to collect disaggregate travel behaviour and emissions data on a sample population of UK residents is outlined, as is the use of a newly developed GHG emissions evaluation tool to derive integrated travel emissions profiles. Thirdly, the individual, household and area-wide emissions profiles are analysed and examined as to how they differ with respect to geographical location, socio-demographic factors and other personal characteristics. The implications for those responsible for the design of greenhouse gas emissions reduction policies are discussed. Finally, the potential applications of the methodology and tool are outlined.

Personal Travel and Climate Change

The UK Department for Transport ascribes the huge growth in personal travel to a number of factors including increasing car ownership, falling real costs of motoring, falling car occupancy levels and increasing average trip lengths, based on empirical evidence collected in the NTS (ONS, 2005). Household car availability has continued to rise in Great Britain, with 74 % of households having access to a car in 2004, compared with 62 % and 72 % in 1985/86 and 1998/2000 respectively (ibid). Income is a factor relating to the number of trips and distance travelled. In 2004, people in the highest income quintile did 28 % more trips than those in the lowest income quintile and travelled nearly three times further (ONS, 2005). In particular, those in the highest income group did twice as many trips and travelled over three times further by car than those in the lowest income quintile group. Rail use is much higher in the highest income quintile, partly because commuters to London in the highest income band account for a considerable proportion of rail travel. In particular, people on low incomes walk more than the national average and walking is more common in urban areas (The Pedestrians Association, 2001).

Travel patterns vary according to demographics, socio-economic aspects (e.g. gender, income, age, economic activity), ethnicity and culture (e.g. Banister and Banister, 1995, Carlsson-Kanyama and Linden, 1999, Stead, 1999, Cameron et al., 2003, Best and Lanzendorf, 2005). Travel patterns and behaviour also vary according to environmental consciousness, energy costs (Fox, 1995, Nilsson and Kuller, 2000) as well as chosen lifestyles, personal preferences, worldviews and attitudes (Anable, 2005). Anable argues that classifications used to segment populations based on demographic variables or simple behavioural measures commonly used in transport research "may oversimplify the structure of the market" (ibid).

The research described in this paper addresses these issues and contributes to the debate on what factors influence personal travel activity.

Research Methodology

OVERALL APPROACH

The research was based around a major survey of the population of Oxfordshire, a County located just West of London in the South East of England, using a number of survey techniques, to measure, evaluate and analyse GHG emissions from personal travel activity. The empirical research methodology employs three stages of data collection, preparation and analysis. First, an innovative household survey technique based on weekly and annual estimates of day-to-day and casual travel activity were used to collect the data required to measure the key determinants of greenhouse gas emissions from travel over a 12-month period. The survey was designed and developed in two formats: a postal paper-and-pen survey as well as a web-based survey. A multi-method approach was used to validate internally and improve accuracy of the final outputs. This was further augmented by secondary data from national and local sources. Secondly, an evaluation and calculation tool was developed in a series of inter-linked spreadsheets and databases. This was designed to incorporate travel activity data with emission rates for each GHG pollutant for a range of transport modes, vehicle characteristics, travel characteristics, times of day and operating conditions. All quantitative survey data were input via the web-based survey interface into a single survey database to ensure consistency between the two survey formats. Secondary data were collected for this stage on local emissions factors, fuel lifecycle emissions, public transport vehicle fleet and passenger loadings. Thirdly, the travel activity data were translated into emissions profiles, analysed at the individual and household levels and aggregated to higher levels. This included validation in terms of comparison with more aggregate datasets and national statistics.

SURVEY DESIGN AND ADMINISTRATION

Design and sampling

The survey built on previous work (in particular Anable et al., 1997, Brög et al., 2004) and was designed to collect information from three study groups: the household, the individual and (if applicable) the driver of a car or motorcycle. Within each of the study groups, examination was made of how household location, structure, income, occupation, age, gender, vehicle ownership and choice of transport mode may affect travel emissions.

Two versions of the survey questionnaire were developed, piloted and then employed on a larger scale: a postal paper-and-pen version and a web-based version. The mailed out paper-and-pen questionnaire included a *Household Form*, a maximum of five *Person Forms* and five *Vehicle Forms*. The *Household Form* mainly requested details of the socio-economic background of the household members. It also collected simple accessibility data by asking respondents how long it takes them to access key services and opportunities such as employment, primary and secondary schools, further and higher education,

local stores, larger supermarkets, shopping and commercial centres, sports and leisure facilities, railway stations and local bus stops. For local bus stops, weekday, Saturday and Sunday bus frequencies were also requested. The *Person Forms* requested details on regular daily/weekly travel and irregular travel by non-private transport modes over a period of 12 months during 2004/05. The *Vehicle Forms* collected vehicle-specific data (such as fuel type and recorded, estimated or guessed annual distance travelled) as well as vehicle use data for each driver in the household. Respondents were asked to give details on all private travel activity (distance travelled, duration, trips) over a period of 12 months. The web-based version can still be accessed at www.tsu.ox.ac.uk/research/oxontravel (guest login: oxontravel, password: onthemove).

Administration and responses

The postal, pen-and-paper questionnaires were sent out to 900 randomly selected, non-commercial and private addresses in Oxfordshire. To stimulate higher response rates, it was administered with pre-paid return envelopes and a prize draw. Reminder procedures were used to chase non-respondents after two weeks of the initial mail-out. Overall, the postal survey was administered and the responses chased and collected over an 18-week period in early to mid 2005. For the web-based survey, a total of 532 emails were sent to individuals inviting them to participate in the survey. The sampling frame was based on email addresses on mailing lists provided by departmental administrators, including university members living in Oxfordshire.

EMISSIONS EVALUATION

The GHG emissions evaluation tool uses a number of techniques and data sources. For travel by private motorised travel and air travel, the survey questionnaires collect data to a high level of detail. For car travel, the tool employs four alternative techniques to derive GHG emissions (*Table 1*). Car method A, for example, calculates emissions from equations relating pollutant emissions to fuel type, engine size, age, trip lengths and average speeds based on the set of speed-emission equations developed by the Transport Research Laboratory (Barlow et al., 2001) and others. Excess emissions from cold starts are also included (taking into account the shares of urban vs. non-urban driving) as are fuel life-cycle emissions based on the most recent work by CONCAWE (2006).

The main method for bus, rail, taxi and ferry travel was based on transport activity (split into day-to-day and casual travel, with an indication of peak or off-peak travel), vehicle emissions factors and passenger loadings per vehicle. Two alternative techniques and sources of data were used to compare national and local averages based on differences in emissions factors and occupancy rates.

For air travel, three alternative techniques are used, all newly developed and based on the travel activity approach (one on trip distance, one on stated trip duration and one on calculated trip duration). Total annual emissions are derived using a two-step approach. First, top level travel activity indicators (passenger-km, time spent in the air) are derived from data collected in the surveys for each flight (both directions, including stopovers). Secondly, the travel indicators are multiplied by emissions factors based on distance-emissions curves developed in this

Table 1: The four alternative methods for calculating emissions from car travel

	<i>Method</i>	<i>Description</i>	<i>Main relationship</i>	<i>Main disaggregation</i>
A	Transport activity and disaggregate average emissions factors (reference method)	Based on travel activity data collected in the surveys and emissions factors disaggregated by fuel type, engine size, Euro band and average speed.	emissions = emissions factor x transport activity (km, hours) (Cars: plus excess emissions from cold starts)	2 propulsion technologies 3 fuel types 3 engine sizes 6 Euro standards 3 road types/speeds (Cars: 3 trip lengths)
B	Transport activity and 'official' vehicle specific emissions factors	Based on travel activity data collected in the surveys matched with vehicle specific fuel use and emissions data for each make, model, fuel type and engine size	emissions = <i>f(car make, model, fuel, engine size, first year of registration)</i> taking figures from 'official' databases, depending on first year of registration	1000's of combinations of vehicle make & model, fuel type, engine size and first year of registration 2 road types (urban/extra-urban)
C	Fuel consumption	Direct conversion of fuel use to emissions via carbon balance	emissions = <i>f(fuel consumption and type)</i> (carbon balance)	3 fuel types: petrol, diesel, 'other' (LPG, etc.)
D	Fuel expenditure	Direct conversion of fuel purchase and fuel type to fuel use and emissions via carbon balance	emissions = <i>f(fuel expenditure, price and type)</i> (carbon balance)	3 fuel types: petrol, diesel, 'other' (LPG, etc.)

research. These distance-emissions curves were derived from average-weighted fuel consumptions of the most common aircraft types obtained from EEA (2005), which were further split into two distance classes (short-haul and long-haul). As the total distance includes all legs of a journey (single or return-out and return-back), so do the emissions totals include all legs, independent of where the aircraft was refuelled. In addition, the methodology takes account of the most important factors influencing fuel consumption, including the number of take-offs per trip, average passenger loadings, cargo factors, detours and holding patterns obtained from a number of sources (e.g. DLR, 2000, AEA, 2002, CAA, 2006).

The above emissions evaluation techniques were developed in the evaluation tool, which consists of a series of interlinked spreadsheets and allows for a transparent analysis of outputs as a function of survey inputs, external data and model assumptions.

Results

THE SURVEY SAMPLE

The paper-and-pen survey achieved a response of 171 out of 900 completed household returns (19%), providing 339 individual travel profiles. In addition, the web-based survey achieved a response of 117 out of 532 completed individual returns. This provided a total sample size of 456 individuals living at 278 addresses. Of these, 72% of individuals held a driving licence, 59% drove cars and/or motorcycles, 59% made at least one flight over the year, 69% had used buses or coaches, 46% taxis, 52% rail and 15% ferry. Some 20% of respondents drove but didn't fly, while incidentally the same number (but not necessarily the same sub-sample) of respondents didn't drive but flew at least once. 39% did both, 21% did neither.

The comparison of the socio-economic composition of the sample with UK Census data (ONS, 2001) showed that the sample was representative of the County population in terms of age structure, gender and economic activity. Despite the high degree of accuracy of representation, the results were corrected for response bias by gender, age and economic activity. Some caution with regard to the lower car ownership levels of the

sample as compared to the County as a whole may have to be exercised.

VALIDATION AND KEY METHODOLOGICAL ISSUES

The integrity of the data collected was assessed as part of the validation exercise. Whilst the validation procedures have been unable to assess conclusively the accuracy of the data in so far as it is a true reflection of individual emissions from travel activity, the following conclusions can be drawn. As the survey used separate forms pertaining to each vehicle used in the household, supplemented by separate forms for each individual to break down their journey profiles, there was no clear indication of any double counting effects amongst drivers of cars or motorcycles when two people drove the same vehicle. However, the danger remains of creating an overly complex and time-consuming exercise which runs counter to the overall objective of designing an efficient and cost-effective survey to be carried out annually without detailed instruction.

The use of any documented evidence to record distance travelled, and any other pieces of information requested, produces considerably better results. Also, by asking respondents how accurate their estimates of the distance travelled by car or motorcycle are, an assessment of confidence levels was performed, thus keeping uncertainty to a minimum. This confidence level feeds directly into the uncertainty analysis.

By investigating the multi-method approach used for car and air travel, the following can be concluded. First, methods A (based on travel activity and disaggregate emissions factors, see Table 1) and B (based on 'official' vehicle-specific fuel consumption and emissions figures) for car travel produced remarkably similar results overall. However, emissions varied considerably on a case by case basis, revealing how different approaches can lead to different results at the disaggregate level. Given the uncertainty in individual emissions totals, however, both methods produce largely similar results. Method A, however, is more disaggregate and leaves room for patterns to emerge relating to disproportionate usage of different road types and trip lengths. The emissions factor database for method A is also more complete and is used by local authorities in the UK for air quality management and planning. Method B provides one distinct advantage in that vehicle-specific emissions factors are

used, as opposed to the more general emissions categories (by fuel type, engine size and vehicle age) used in method A.

For air travel, overall distance and duration estimates between the three tested methods E (distance based), F (based on stated duration) and G (based on calculated duration) can, at least at the sample level, be used interchangeably as the key parameters determining emissions from air travel.

Further aggregation of the results to national levels (England, UK) and comparison with national statistics provided a good match at the aggregate level (emissions, miles travelled, by mode), thus giving confidence in the integrity and relevance of the conclusions drawn. This comes with a word of caution. Travel patterns vary according to demographics, socio-economic aspects (e.g. gender, income, age, economic activity), ethnicity and culture (e.g. Banister and Banister, 1995, Carlsson-Kanyama and Linden, 1999, Stead, 1999, Cameron et al., 2003, Best and Lanzendorf, 2005). They also vary according to environmental consciousness, energy costs (Fox, 1995, Nilsson and Kuller, 2000) as well as chosen lifestyles, personal preferences, worldviews and attitudes (Anable, 2005). Yet, when accounting for the dominant factors, evidence by e.g. Timmermans et al. (2003) has shown that location does not add significantly to explaining the variation in travel patterns amongst the population.

AREA-WIDE TRAVEL EMISSIONS PROFILES

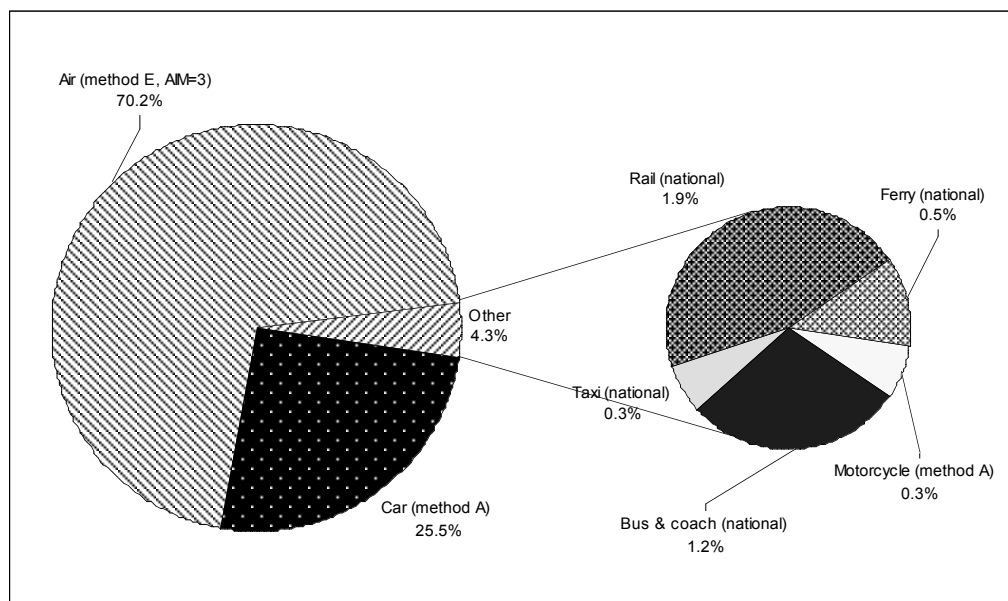
The achieved sample size allowed for a distinction to be made between a number of geographical area types whilst ensuring statistically significant results for each. Four geographical area types based on built-up/non-built area and population characteristics were defined for the analysis, including large urban (built-up, population 100-250 k, e.g. Oxford City), medium urban (built-up, population 25-100 k), small urban (built-up, population 10-25 k) and rural (non built-up, population <10 k) areas.

Travel activity

Overall, travel by air and car dominates total distance travelled, accounting for 77 % of total annual kilometres. For air travel, the flying individuals (59 % of the sample) averaged about 17,400 kilometres, 24 hours in the air and 5.4 landing and take-offs (LTO) per person p.a. When looking solely at location, i.e. ignoring personal characteristics such as age and income, respondents living in medium and large urban areas travelled less by car and air (73 %) than respondents living in small and rural areas (87 %). Specifically, the distances travelled by car by Oxford residents were 27 % lower than the sample average while residents in rural areas travelled on average 46 % further than the sample average. Conversely, Oxford residents travelled 31 % further by air than the sample average, whereas the distances travelled by air of residents in small urban and rural areas were 23 % and 30 % lower than the sample average. For respondents living in large and medium urban areas, travel by public transport (rail, bus, coach, taxi) was significantly higher than the national average, reflecting the location of Oxford City and its surrounding towns in London's commuter belt and, for UK standards, the good provision of public transport services in central Oxfordshire.

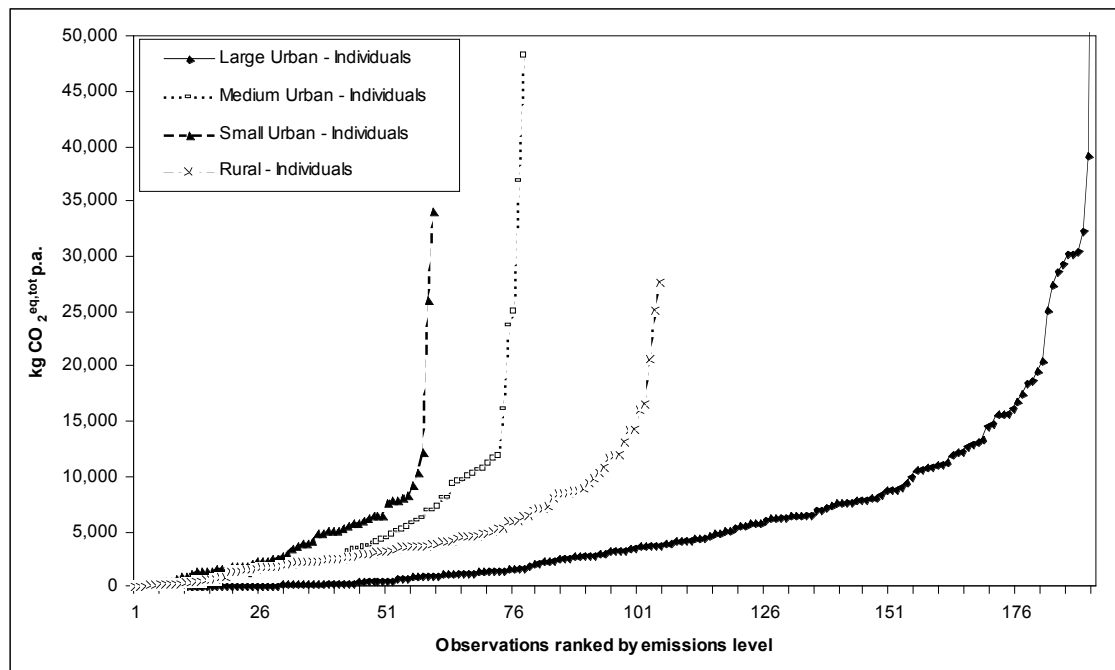
Travel emissions

This travel activity translated into total GHG emissions of 5.2 tonnes of CO₂ equivalent (tCO₂^{eq,tot}) per person per year (all modes, method A for car, method E for air, central AIM value of 3). Figure 1 provides the modal breakdown of this total (central AIM value), suggesting that private travel by car (25.5 %) and air (70.2 %) dominate GHG emissions from personal travel activity. After accounting for the different approaches, this largely confirms results of other work, namely that of Hillman and Fawcett (2004), ONS (2004) and DfT (2006). Emissions from air travel are the exception, where averages per person were significantly higher than e.g. in the ONS (2004) study. The variations can be explained by a combination of differences in



Base: all 456 individual responses. Note: 'national' depicts national average emissions and load factors.

Figure 1: Average CO₂eq, tot emissions per person by mode of transport (AIM=3, central value)



Base: 434 respondents who produced any emissions at all (i.e. 22 excluding non-travellers).
 Note: an outlier of a respondent in large urban areas (>90,000 tCO₂eq,tot p.a.) is not shown.

Figure 2: Individual GHG emissions from all travel activity by area type, ranked by emissions totals

accounting methods (e.g. this research accounts for both directions of a return flight, detours from the 'as-the-crow-flies' route, taxiing, cargo factor), emissions data sources and methods, local vs. regional variations (higher share in the sample of younger residents living in Oxford, e.g. a higher share of 19-35 old overseas students who tend to fly significantly more than the average person, as demonstrated later), and better than average access by car and public transport to major international airports.

Again, when ignoring other factors influencing travel patterns such as income and age, GHG emissions varied considerably by geographical area, providing some important findings. First, average emissions from residents living in large urban areas (Oxford City) were 16 % higher than the sample average, whereas emissions were lower (between -10 % and -18 %) for other areas. In particular, emissions from air, bus/coach, rail and taxi travel were disproportionately higher for residents in large urban areas than the sample average, while conversely they were responsible for 26 % lower emissions from car travel. This can be explained by a combination of good accessibility to public transport and airports as well as the effects of local transport policy, which largely restricts access to the city centre for private car (but not taxi) travel. Interestingly, residents in rural areas are responsible for 41 % higher than average emissions from car but 29 % lower than average emissions from air travel.

Secondly, the 3.5 % (central AIM value) share of the total from land-based public transport (bus, coach, minibuss, rail and taxi) suggests that these modes can be considered insignificant overall. Even when ignoring non-CO₂ effects of aviation (i.e. AIM=1), the share of the total of these modes is only 6.1 %. Although demonstrating the highest GHG emissions rates per

passenger-km, average emissions from travel by ferry are below 1 % independent of the value for the AIM factor.

Respondents were further ranked (smallest first, i.e. rank 1 for lowest emitter) according to GHG emissions levels. For emissions from all travel, Figure 4 shows an unequal distribution between individuals. This suggests that a large proportion of the population produce similar travel and CO₂ emissions profiles, whilst a few are responsible for a disproportionately large share of the total. In further analysis, the shape of the emissions ranking curve was found to be similar regardless of the area type or mode of travel. Specifically, the car emissions profile of residents living in rural areas is similar to the profile of residents living in large urban areas, except for the highest emitters.

TRAVEL EMISSIONS PROFILES BY SOCIO-DEMOGRAPHIC AND OTHER PERSONAL CHARACTERISTICS

When the analysis of emission profiles moves from the area level to individuals and households, the scale of the disparities in travel and emissions becomes even clearer. In addition to the continuous distribution of emissions, the results were reduced so as to rank each individual or household according to where they lie in a scale of 'high' or 'low' polluters across the transport modes. Emissions were ranked and grouped into emissions quintiles and deciles, that is, into groups of a fifth and a tenth of the total case base each.

Overall, GHG emissions appear to be unequally distributed amongst the population. It is a minority of users, travelling comparatively long distances, who account for the differences between high and low quintiles. 61 % of emissions were produced from respondents in the highest *emissions quintile* (20 %), but only less than 1 % of emissions were generated

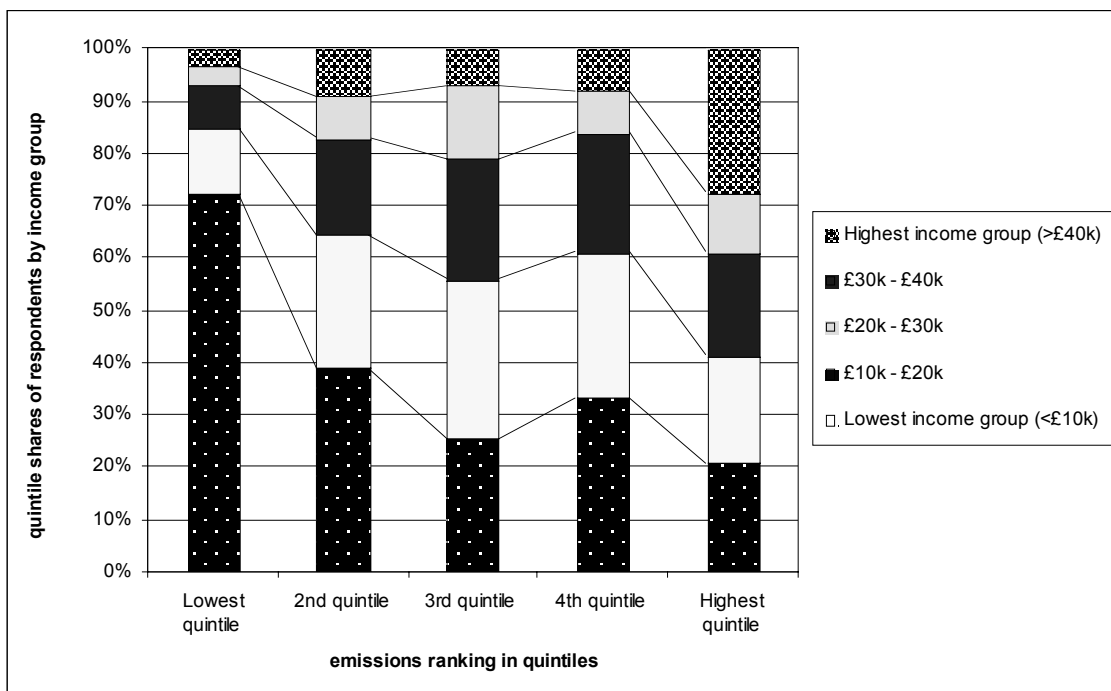
from respondents in the lowest emissions quintile, implying a 'high-over-low' factor of 90. The corresponding average GHG emissions from all travel activity were 16.6 tCO₂^{eq,tot} per person p.a. in the highest quintile, and 0.19 tCO₂^{eq,tot} per person p.a. in the lowest quintile. Similarly, the top *emissions decile* (10 %) of the sample are responsible for 43 % and the bottom emissions decile of the respondents only 0.1 % of the CO₂^{eq,tot} resulting from all travel in this research. When compared to the sample as a whole, respondents in the top emissions decile were typically in their 30s and 40s, in full-time work or at university and earning £ 30 k or more. Almost all of the respondents in the top emissions decile flew regularly, undertaking on average 12.7 LTOs and flying 53,861 km per year. In terms of total distance travelled, this is more than 5 times the sample average (10,249 km p.a.) and, astoundingly, 30 % more than the circumference of the earth. 72 % of the respondents in the top emissions decile drove a car an average of 13,570 driver-km per year (or 37 km a day) – i.e. 2.4 times the UK national average of 5,582 km taken from ONS (2005). In contrast, respondents in the lowest impact decile were typically women, children (aged 6-17 years) or residents older than 75 years, not economically active residents, non-car drivers and residents on low income of less than £ 10k p.a.

These revelations are significant for the realisation that intervention must be particularly aimed at a minority of the population in order to be effective. It is also key to the realistic setting of targets. Above all, it is the composition of both the specific travel related causes of these highest emissions levels and the people producing them that are important contributions to the literature to be gained from this work.

So who the high and low emitters? Part of the answer is provided by segmenting the population according to socio-demographic and other factors such as car ownership. To assess the significance and degree of confidence of the analysis, chi-

square tests were performed in order to find out whether or not there is a relationship between socio-economic characteristics (as defined by bands of income, age, gender, etc.) and emissions levels (as defined by income quintiles) and, if so, how strong the relationship is. This was further augmented by performing stepwise, log-linear regression analyses between the log normal of emissions (dependent variable) and dummy-coded variables such as income, age, accessibility to public transport and car ownership (independent variables). The detailed description of this somewhat lengthy analysis goes beyond the scope of this paper and is described elsewhere (Brand, 2006). This analysis provides strong evidence on the connection between GHG emissions and:

- **Income:** in terms of GHG emissions from all travel, more than a quarter of the respondents in the highest emissions quintile were in the highest income group (>£ 40 k per person p.a.), while about three-quarters of the respondents in the lowest emissions quintile were in the lowest income group (<£ 10k per person p.a.) (Figure 3). Respondents in the highest income group produced on average 3.5 times the annual emissions level of respondents in lowest income group. This disproportionality was significant (chi square test, $p < 0.05$) for 'all travel', car, rail and taxi, while the link between air travel emissions and income was found to be relatively weak for the flyers (59 % of the population) but highly significant ($p < 0.01$) for the sample as a whole;
- **Economic activity:** about three-quarters of those in the top emission quintile were in work, whilst about four-fifths of those in the lowest emissions quintile were not. The relationship was highly significant ($p < 0.01$) for emissions from 'all travel', car and rail. Emissions from rail travel provide the strongest of these links, likely to be rooted in good accessibility to rail services for many respondents and the



Base: 434 respondents who produced any emissions at all and provided information on income.

Figure 3: Composition of survey responses by emissions quintile and income group (all travel).

relatively high share of regular rail users (commuters). As with income, air travel emissions showed only weak links to working status of the flyers but a highly significant relationship with all respondents;

- **Gender and travel by private vehicles:** for car travel, two-thirds of respondents in the highest emissions quintile were male, while equally two-thirds of respondents in the lowest emissions quintile were female. The men in the highest car emissions quintile were predominantly in full-time employment, aged between 36 to 65 years, with income of £ 20 k or more and living in households with higher than average car availability. Motorcycle travel was 100 % dominated by men. Interestingly, the link between gender and GHG emissions was not significant for any other mode of travel;
- **Gender, other socio-economic factors and emissions from all travel:** multivariate analysis showed gender and working status had a highly significant influence ($p < 0.01$) on emissions levels from 'all travel' and car travel. Also, a quarter of respondents in the lowest emissions quintile were women in retirement age, while equally a third of respondents in the highest emissions quintile were men between 36 and 65 years of age;
- **Age:** even though the 36-65 year olds comprised only about two-fifths of the respondents, they were responsible for more than half of the total GHG emissions and producing on average 3.6 and 2.6 times the annual emissions level of the respondents in retirement age (>65 years) and children (18 years or younger) respectively. Two-thirds of respondents in the highest emissions quintile (all travel) were between 36 and 65 year old, while two-fifths of respondents in the lowest emissions quintile were 66 years or older. The association between age and emissions levels was highly significant ($p < 0.01$) for 'all travel', car, rail and, crucially, air travel. It was also significant ($p < 0.05$) for travel by bus & coach;
- **Household composition and size:** overall, individual averages compared well with published sources. Single person households showed the highest average emissions levels per individual (16% higher than the sample-household average), mainly because of higher than average emissions from air travel. Households with three individuals showed the lowest average emissions level per person, yet the highest contribution from car travel, which was concluded to be due to differences in household composition (presence of children) and associated car use. While households with children are associated with higher distances travelled per driver than households without children (e.g. Best and Lanzendorf, 2005), this is outweighed by the increase in children;
- **Car availability,** which showed strong relationship with emissions. Overall, households with access to two cars or more produced about 75 % higher emissions levels per household than the sample average and more than twice the figure for households owning only one car. Similarly, emissions from car travel were highest from households with access to two cars or more at about twice the sample average;

- **Car ownership (company car vs. private car):** for personal usage, company cars were driven about 50 % further than private cars, with even higher distances travelled on business in company cars. As found in other research (e.g. Hughes, 1994, ONS, 2005), the company cars in this sample were significantly younger and larger (in terms of engine size) than the average car fleet.

Discussion

Cross-modal, socio-economic group and location-specific emissions data for individuals and households seldom exist together. The methodology and tool tested here is an example of the type of adaptable, multi-output yet potentially policy-specific method which needs to be developed further and employed nationally if the measurement and influencing of travel activity and associated GHG emissions are to become a serious and effective component of policy development and assessment. The results have highlighted implications for policy and strategy development, which are discussed next.

INSIGHTS FOR POLICY

The differences that exist between the general population and subgroups within the population have far-reaching consequences for the development of transport, energy and environmental policies. Indicators of travel and emissions were identified, such as those characteristics indicative of higher income, being in work, being female in pensionable age, middle age, small household size, higher car availability and the presence of a company car.

Climate change mitigation policy should focus primarily on car and air travel. Particular attention should be paid to air which, when non-CO₂ climate effects are included via a multiplier, can account for 56 % (low), 70 % (central) or 76 % (high) of passenger transport GHG emissions at the individual level.

Overall, household location influences GHG emissions production. However, when accounting for socio-economic and other factors, the evidence derived in the statistical and regression analyses (reported elsewhere e.g. Brand, 2006) suggests that location does not influence travel activity and GHG emissions significantly. This result contributes to the literature on the linkages between travel activity, emissions generation and their underlying influences (e.g. Carlsson-Kanyama and Linden, 1999, Timmermans et al., 2003, Cameron et al., 2004). Residents in large urban areas may experience more difficulties in meeting any future caps on personal GHG emissions (e.g. as part of carbon cap-and-trading) – yet alternatives to the car are generally available, so the scale of any equity impacts will be lower. However, regular flying will most certainly pose a challenge to meeting carbon caps. The respondents in the top emissions decile produced 19.1 tCO₂^{eq,tot} per person per year (central AIM value) from flying alone. This has important implications for any future Personal Carbon Allowance (PCA) scheme, where allowances would be reduced year on year to a 'safe' level in terms of climate change. This 'safe' level is estimated to be around 3-4 tCO₂^{eq,tot} per capita p.a. in 2050 (Meinshausen, 2006). Thus the top 10 % emitters of the population may use up their future annual carbon allowance in a couple of months unless they flew less or bought carbon allowances at prices that are expected to increase considerably by 2050, espe-

cially if the UK Government decided to (artificially) align price with the expected increase in the social cost of carbon (Watkiss et al., 2005) by limiting carbon supply. Furthermore, as people in practice have limited manoeuvring space regarding where they can afford to live, this in turn will affect the feasibility of PCA based policy instruments for transport.

Broadly based on, and positioned at opposite ends of, the environmentalist's view of the world (O'Riordan, 1976), carbon pricing (technocentric) and cap-and-trading (ecocentric) of carbon emissions are two of the main policies to tackle CO₂ emissions and believed to have great potential to meet reduction targets cost-effectively. Following the recent UK Energy Review, PCAs are currently being investigated by the UK government to combat rising domestic emissions (DEFRA, 2006b). The debate continues as to what approach to use, and who to include. For instance, the aviation sector is largely excluded from both fuel taxation *and* emissions trading, suggesting something must be done sooner rather than later to curb the rising demand and its effects on climate change. Also, prices would have to go up considerably to have a restraining effect on demand, mainly because of the inelasticity of air travel demand (Cairns and Newson, 2006).

As the 'nearly exponential' shape of the curve ranking respondents by their emissions level is surprisingly similar when compared between modes, location and unit of analysis, policy needs to be targeted at the gross polluters, i.e. certain subgroups of the population who are responsible for a disproportionately large share of total emissions. Policy has to seek out these differences, identify the causes and target these causes directly. The following section briefly explores how this could be done.

POTENTIAL USES OF THE METHODOLOGY AND EVALUATION TOOL

The methodology and tool could potentially be used for developing policy and strategies and assessing the likely effects of these in impact and longitudinal studies. An important application would be to assess the climate change and emissions impacts of interventions aimed at changing people's travel behaviour (Cairns et al., 2004, Anable et al., 2005). In addition, the methodology could potentially be employed in awareness raising, informing, advising and giving feedback on travel activity and emissions at the household and individual levels. One option is to notify participants whether they fall into the highest or lowest emissions quintiles. An attempt has been made at designing a one-page *Household GHG Emissions Report*, shown in *Figure 4* for a five-person household drawn from the sample. The top half gives feedback on where the household falls in terms of GHG emissions quintiles of all five-person households in the UK. The bottom half gives more detail on individual travel activity and emissions totals and modal contributions to these totals. It further provides some 'expert advice' and 'personalised suggestions' on how to reduce emissions in the future.

The potential for a predictive model of aggregate emissions and personal travel activity based on personal characteristics influencing emissions was investigated. Multiple regression analyses were performed in parallel work (Brand, 2006), showing there are significant relationships between outcomes (emissions, travel activity) and predictors (socio-economic and other factors). However, the regression models explained only up to two-fifths of the variation in outcomes, and only a relatively

small number of categorical independent variables were significant for each model. Thus, other factors such as attitudes, life-style and personal circumstances are likely to play an important role in explaining the other variations. This suggests that there is a need for an alternative or complimentary segmentation of the personal travel market, for example by segmenting the population into potential 'mode switchers' via cluster analysis as performed by Anable (2005).

The potential for a detailed 'household carbon end-use model' for household and transport energy use and GHG emissions was identified. Although this paper focuses solely on transport, broader based PCAs for households could be explored first, instead of focusing on transport only. The size and quality of the home, the kind of heating, as well as food choices also greatly contribute to the overall attributable carbon budget of a household. Arguably, handling transport separately may risk hitting the households harder than necessary. On the other hand it could be studied whether for transport a supply side approach could achieve the same reductions with less hassle. (See *Figure 4* overleaf)

Conclusions and outlook

This research contributes to the literature primarily by providing an innovative assessment framework and evaluation tool for cross-modal travel emissions profiling at the personal and household levels, thus providing a more complete yet cost-effective assessment of travel emissions. It fills the knowledge gap of limited geographical and modal coverage of travel emissions profiles. It further contributes to the debate and search for an accepted methodology for auditing GHG emissions from all personal travel and the elaboration of PCA methods with special reference to transport. The research has produced a rich and extensive dataset providing an improved understanding of the overall extent and composition of GHG emissions from personal travel within a 12-month timeframe. This disaggregate dataset did not exist before. A number of important policy implications have been identified, including effectiveness and equity issues as well as issues of scale and practicality. The research further contributes to the growing body of transport research focussing on changing travel behaviour rather than relying on technology to fix the climate change problem. By providing insights into the demographic and socio-economic profile of travel emissions, this work gives clues to who is polluting the most and who is likely to be affected most by these policies. It identified and discussed four potential uses of the methodology and tool and provides prototype tools for the measurement, influencing and forecasting of GHG emissions at the disaggregate levels that did not exist before.

This research provides a methodology and tool that does not claim to be the ultimate in GHG emissions measurement and analysis at the disaggregate level – the research can be considered as work in progress. Also, even though the case study was representative of a regional population and includes travelling abroad, it risks having representation biases as it draws on one county only. The areas for further research are briefly summarised here. First, the tool employed a number of alternative methods and calculation techniques, some of which have been found to be incomplete or too resource-consuming. Further work could focus on the one or two methods that have proved

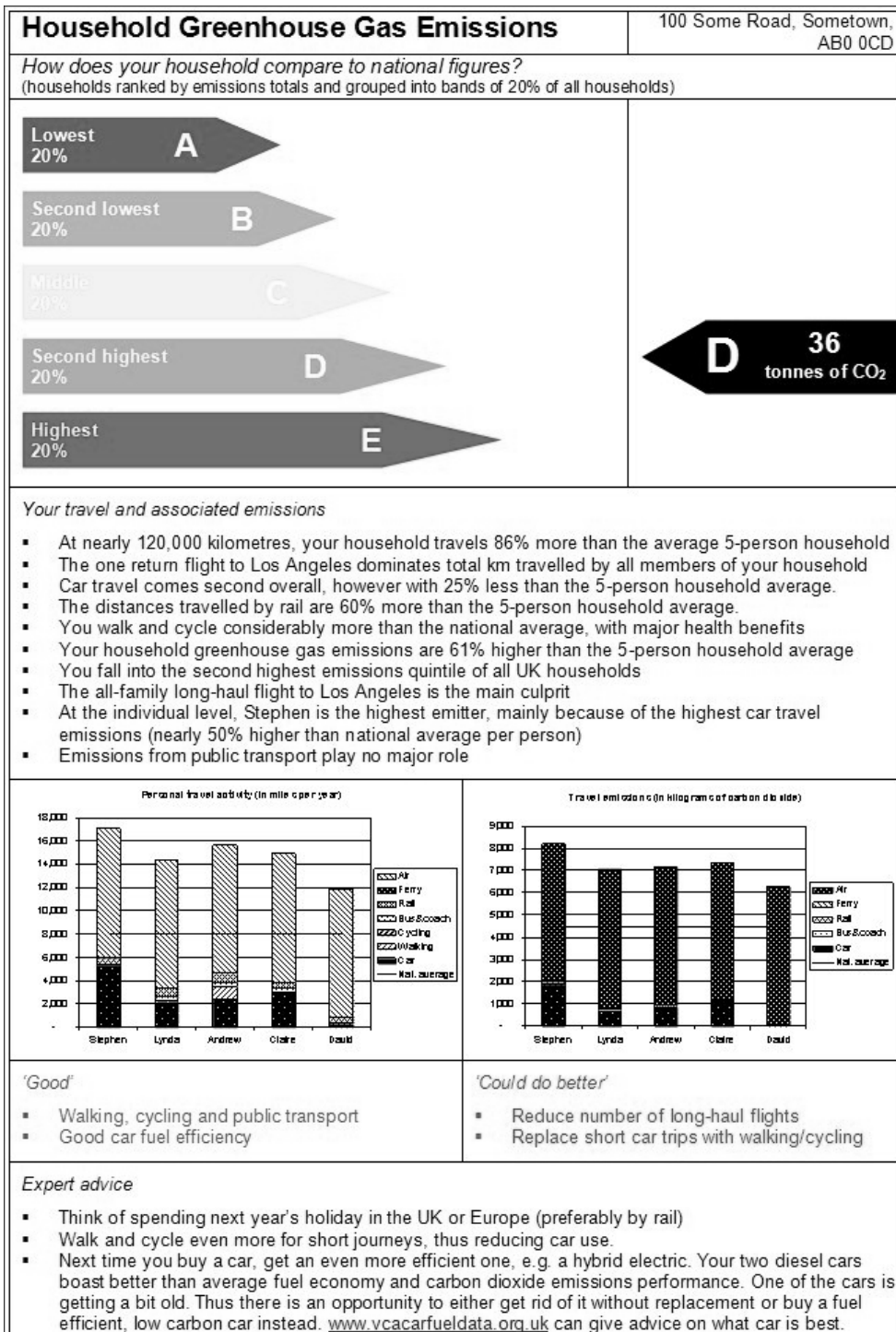


Figure 4: Prototype 'Household GHG Emissions Report' for feedback and advice

to be most promising and accurate in providing emissions profiles at all levels of analysis. Secondly, in earlier research Banister (1993) concluded that settlement size together with the availability of local facilities, services and employment, are the key determinants of travel and energy consumption. This conclusion could be tested and scrutinised by linking household location data and the Accession[®] accessibility planning tool (MVA, 2006) already used by some LAs (e.g. Oxfordshire County Council, 2005). Thirdly, the methodology could easily be extended to all personal carbon emissions, thus integrating travel and domestic energy use. One interesting application

of such a tool would be to accurately assess the 'before' and 'after' effects of home working amongst large scale employers on overall carbon emissions. The UKERC Demand Reduction Theme at Oxford University are currently developing a detailed web-based household and individual carbon calculator, which will build on the experience gained from this work (ECI, 2006). Fourthly, the aggregate forecasting model could be developed further, for example for each mode and/or population group based on personal characteristics or, alternatively, attitudinal and lifestyle factors. The latter would require a change in survey design and content with the view to elicit attitudinal factors

and willingness to change as suggested by Anable (2005). This could then be validated by repeating the surveys and running the model in a time series year on year. Finally, there is an opportunity to incorporate elements of the survey and emissions evaluation methods explored here into more established travel survey methods such as travel diaries. Travel emissions diaries would be able to assess and evaluate policy aimed at changing daily travel behaviour. Additional data would need to be collected on less regular, casual travel such as annual holidays, visiting family and friends. Other elements of this research may be incorporated, e.g. survey questions on private vehicle technology (make/model, fuel type, engine size, etc.), records of annual distance travelled and fuel use, and household income.

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