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A disaggregate analysis of 'excess' car travel and its role in decarbonisation

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ABSTRACT

This paper measures 'excess' car travel for its role in decarbonisation. On average, each English adult travels around 5,680 miles a year and emits 1,006 kg of CO_2. However, the top 5% 'excess' car users travel 4.8 times and emit 5.7 times the national average. Four binary logistic regression analyses were used to model the probability that people with specified characteristics belong to the 'excess' mileage and emitter groups. Results indicated that gender, employment and socio-economic status, household income (higher quintiles), company car availability, residential location and local population density were highly significant correlates of this 'excess' travel mileage. Multiple car ownership, business travel by car, multiple international flight frequencies and ownership of larger and diesel cars were positively associated with excess travel and emissions. A mileage rationing scheme targeting the top 20% users can cut emissions substantially (by 26%) compared to targeting 'excess' (top 5%) users only.

1. Introduction

High levels of carbon emissions generated by the wealthier sectors of the population have been the focus of substantial academic and non-academic attention in recent years (Büchs and Mattioli 2021, Brand and Preston 2010, Yang et al., 2017). Understanding the unequal distribution of carbon emissions relating to personal travel and the associated carbon emissions is not only important from the transport equity perspective, but also in terms of decarbonisation.

Passenger travel is one of the largest carbon emitting sectors of the economy in highly motorized countries, e.g. around 20% of US carbon emissions are from passenger transport, while the share is around 16% for UK domestic emissions (Department for Transport 2021). Despite the urgency expressed in the recent COP26 to drastically cut emissions, decarbonising the transport sector remains difficult and slow (Climate Change Commission, 2018; BEIS, 2019). Most transport policies in highly motorized countries support hypermobility, prioritising the trilogy of distance, speed and time over safety, access and energy reduction (Banister 2011). Similarly, land use or housing policies tend not to actively seek to reduce car dependence or car based hypermobility, which could potentially reduce carbon emissions.

Büchs et al. (2021) suggest the need to address the overconsumption of transport related energy use or carbon emissions in order to

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achieve fairness in decarbonising personal travel. In this paper, we define the concept of excess travel consumption as that which is viewed as 'unnecessary' (e.g. Frost et al, 1998; Hamilton and Röell, 1982; Ma and Banister, 2006). However, a key challenge is to determine exactly who precisely the excess travellers are. This is important in order to evaluate whether personal behaviours and/or locational circumstances are amenable to behaviour change polices to reduce excess travel, energy consumption and carbon emissions. This paper addresses this issue by:

1. Quantifying excessive car use: how much more do high-end consumers travel and for what purposes?
2. Identifying the excess users and emitters: what are the socio-economic and spatial characteristics of excess users and emitters?
3. Identifying the key determinants: how do the individual, household and vehicle level attributes (social, economic, spatial and technological characteristics) shape car mobility and emissions among excess users?
4. Limiting the excess: would mileage or emission rationing at the top end of the distribution provide significant reductions in overall car mileage and related carbon emissions?

We contribute to existing knowledge by developing disaggregated models of individuals' excess car travel and associated emissions using the National Travel Survey (NTS) for England[1], which we use as an exemplar of the approach. This data is used to identify who the high-consuming car travellers are, based on their annual mileage and socio-economic determinants such as income, age, gender, ethnicity, car ownership, household composition, etc.

Specifically, we identify the likelihood of individuals belonging to the 'excess' users and emitter groups (defined here as falling within the top 5% of mileage or emissions) according to these socio-economic factors. We compare this 'excess' group to the 'high-end' group, defined here as the remainder of the top 20%, to investigate the potential social effects of limiting 'excess' and/or 'high-end' travel. Given our use of NTS data, which is available in most industrialized countries, our approach can be replicated to understand excess travel and its correlates in those countries, too.

The paper first provides a summary of the relevant research literature (Section 2), covering both transport and wider consumption-related disciplines. It then describes the main methods for this research (Section 3), including data description and model development. In Section 4, we present the main research findings, and discuss our conclusions and their policy implications in Section 5.

2. Literature review – Exploring theories and studies of excessive consumption

A review of the literature relating to overconsumption across a wide range of disciplines provides a high-level understanding of how excessive consumption has been conceptualised, measured, and examined. Across multiple disciplines and sectors 'excess' consumption is defined as a problem, particularly in terms of resource scarcity and planetary survival e.g. food, water, electricity, heating consumption, as well as transportation (e.g. Herring 2006; Moisander, 2007; Muller, 2008; Büchs and Schnepf, 2013). Overconsumption is perceived as a moral, philosophical, environmental and societal problem, believed to not only threaten resource sustainability, contributing to their scarcity, but also to deny less advantaged populations access to such resources (Straughan and Roberts, 1999; Wu, et al. 2010; Galvin and Sunikka-Blank, 2018; Bianco et al, 2019; Büchs et al., 2018). This is therefore an issue which should be addressed by public policy.

The problem of excessive consumption is also generally recognised as being on the rise, particularly in rich countries, triggered by the increased affordability of superfluous consumer items. Gou et al. (2017) show that the 'excess' is driven by value-judgements associated with higher living standards and quality of life expectations, which in turn are driven by the social or economic standings of individuals. These escalating consumer demands are also evident within the transport context.

The issues of mobility, inequality and hyper mobility are well documented, particularly in relation to sustainable mobility and urban contexts (e.g. Ko et al., 2011; Brand and Preston, 2010; Schwanen et al., 2012; Brand et al., 2013), in terms of what is needed to promote behaviour changes, modal shifts, reduced travel and smarter choices (Anable, 2005; Gordon and Richardson, 1989; Breheny, 1995; Banister, et al. 1997). Many studies of 'excess' travel have focused on the impacts and outcomes of excessive car mileage, for example, degradation of the urban realm, increased traffic-related pollution and emissions.

Spatial structure and degrees of urbanisation also play important roles in shaping excess travel. The residents of large and dense urban areas undertake less overall travel than those from small, less dense and rural settlements. Overall, excess travel is significantly associated with the lack of spatial proximity to desired facilities and access to local public transport (Banister et al. 1997; Boussauw et al., 2012; Stead 2001). As Handy et al. (2005) note, the distinction between driving (travel) by choice and driving (travel) by necessity is not entirely clear-cut: each individual has her/his own set of minimum requirements, given her/his own activity needs and capability constraints, which are not always readily observable.

Contextual and demographic factors such as the age structure of the population, gender assigned roles and household compositions, levels of household income and financial stability, and home locations, significantly contribute, both directly and indirectly, to people's energy consumption behaviours (Petrovic et al., 2017). Human consumption is also driven by human agency factors such as individualized choice, preferences, attitudes and social relations; and wider structural factors including the physical infrastructures and institutions that govern our lives; as well as by the prevailing economic and social trends. Consumers in higher-income countries and higher-income consumers in general tend to consume more goods and services overall (Csutora 2012), but this is rapidly changing

[1] Under the devolved governmental responsibilities of the UK, the NTS does not include a sample for Wales, Scotland and Northern Ireland.

with many less developed countries ‘catching up’ in their consumer demands. This is both as a result of lifestyle choices, but also as a function of changing social norms around consumerism which are embedded within increasingly globalised cultural values, for example, car ownership is increasingly viewed as a necessity worldwide.

Empirically, much of the early research on excess travel consumption was exploratory (e.g. Anable et al, 2012; Anable 2005; Brand and Boardman 2008; Brand and Preston, 2010; Ko et al., 2011; Schwanen et al., 2012; Brand et al., 2013). More recently, it has also included GIS-based spatial analyses of the distribution of consumption patterns geographically and demographically, with some clustered segmentation and regression models to identify user types (e.g. Büchs et al., 2018; Chatterton et al., 2016; 2018).

There has been a strong focus on commuter travel particularly in the UK (Hamilton, 1982; Frost, Linneker and Spence, 1998; Ma and Banister, 2006; Barr et al., 2010) and the US contexts (Kim, 1995; O'Kelly and Lee, 2005; Yang, 2008; Fan et al., 2011), which provides only a partial picture of *overall* travel consumption. These studies tend to measure the difference between the actual commute lengths and theoretical minimum achievable journey distances through linear programming and statistical analyses for various metropolitan areas to estimate ‘excess’ (Ma and Banister, 2006). As such, this approach mainly considers excess travel as a function of residential, and workplace locations and transport networks, which individuals ‘should’ optimize through more rational (and thus optimal) location choices.

Some of the studies have used various social factors to explain excess travel, for example, the transaction costs of moving jobs or housing (Hamilton, 1982; Giuliano and Small, 1993; Levinson, 1998), neighbourhood amenity (Ma and Banister, 2006), rapid job turnover (Giuliano and Small, 1993), imperfect labour market information (Rouwendal, 1998), and the increasing importance of non-work trips (Hamilton, 1982; Giuliano and Small, 1993). High land use density, retail accessibility and street connectivity are associated with decreases in both required and excess travel distances. Ma and Banister (2006) observes that the estimates of what constitutes excess travel within these studies differ widely, between 15 and 87% of total commuting distance travelled or time spent, and there are contentions relating to methodological and contextual circumstances. A substantial component of excessive travel remains statistically unexplained due to the complexity of travel behaviour combined with the inherently unequal social distributions of travel resources embedded within transportation systems.

A second strand of excess travel research has sought to measure disparities between high-end and average or low-end user populations (e.g. Büchs and Schnepf, 2013; Ko et al., 2011; Anable et al, 2012; Anable 2005; Brand and Boardman 2008; Brand and Preston, 2010; Brand et al., 2013; Chatterton et al., 2018). This approach identifies high-end users as ‘excess’ travellers, who although fewer in number, have a disproportionally high contribution to overall mobility consumption (both in terms of mileage and emissions). These analyses include non-work-based journeys to provide a more comprehensive spectrum of journey purposes (Mattioli and Anable, 2017; Horner and O'Kelly, 2007; Kanaroglou et al., 2015; Chatterton et al., 2018); it also considers the impact of personal and social preference, choice and lifestyle as important determinants of mobility routines (Brand and Preston, 2010; Ko et al., 2011; Brand et al., 2013; Galvin, 2015; Chatterton et al., 2018).

A further research development has been the examination of how cross-national mobility shapes domestic mobility behaviours and expectations (Frändberg and Vilhelmson, 2003; Scheiner and Holz-Rau, 2012; Circella et al., 2016). Some of these studies have also sought to improve model predictions through additional explanatory variables such as overseas flights and emission impacts on their model calculations, which are not traditionally incorporated within the national estimates (e.g., Barr et al. 2010; Büchs and Schnepf, 2013; Buchs et al., 2021; Chatterton et al. 2016; 2018; Mattioli and Scheiner, 2019; Owen and Barrett, 2020).

The literature cited above shows that overconsumption and excess travel have been active research area recently. New methods have been adopted in identifying and explaining excess travel as countries and regions increase their attention towards limiting transport emissions for wider policy objectives, such as environmental sustainability and climate change. However, there is still a need for a robust estimation and explanation of the phenomenon by taking into account a wider set of socioeconomic, spatial and travel characteristics (e.g., fuel and vehicle details). The paper addresses this gap and takes the issue further by examining the potential impacts of limiting the excess travel on emissions and mileage levels, using national travel survey (NTS) data.

3. Data description and methods

3.1. Data

The NTS is an annual national survey of English residents recording personal domestic travel by all modes of transport, including cycling and walking. Each year, the survey notes personal and household sociodemographic information along with trip attributes, household vehicle and fuel details. Our research used Special Access versions of the data, which provided additional disaggregation of important variables such as income, location and vehicle details, which are not available from publicly available sources. We pooled data for the three years from 2015 to 2017 (Department for Transport., 2019) to generate a significant sample size for detailed analysis and to provide a more reliable ‘broader’ snapshot of excess travel. Pooling the studies together also allowed us to avoid any discrepancies that may have occurred in one particular year. The three years' data (2015–17) includes a weighted sample of 46,603 travel diary respondents, of whom 5,764 respondents did not report making any trip by car in the diary week.

On average, each English resident travels 6,500 miles overall a year (953 trips), of which car-based travel accounts for nearly 79% of the mileage (5,680 miles) and 76% of all the trips (Department for Transport, 2018). For a comparison, the distance travelled is substantially less compared to the Californian average (12,800 miles), but the modal share for car-based travel (77%) is similar (Eisenmann and Buehler 2018). However, Germans travel an average of 8,200 miles a year, but the modal share for car use is only 55% (Eisenmann and Buehler 2018). This shows that, whilst both Californians and Germans cover more mileage than English residents, personal travel is more heavily car oriented in both the UK and in the US (California), and Germans are significantly less car reliant.

For this research, the NTS trip dataset was reorganised into a person level dataset in which each record represents one person. The final dataset measured total yearly car mileage and resulting CO_2 emissions by each survey respondent aged 17 and over (N = 34,185). The total annual car mileage for each respondent was derived from unweighted travel diary data, which included car driver and passenger miles. The unweighted results were validated against the published official statistics (Department for Transport, 2018). Relevant socio-economic, spatial and vehicle holding data were collated and attached to the individual records. Table 1 presents the summary statistics of the sample. The study excludes individuals aged 16 and under, as this age group cannot hold a driver's licence and so do not travel independently by car.

In terms of the emissions models, NTS provides emissions data for around 90% of household car trip stages, this is derived from the emission register of the Driver & Vehicle Licensing Agency (DVLA) matched to vehicle registration number. In our models, emission factors were generated for the remaining 10% of trip stages, using a regression model based on vehicle type, age, fuel type and engine capacity, in accordance with Mattioli et al. (2018). For non-household cars, CO_2 values were obtained from the 'UK Government conversion factors for Company Reporting' (DECC, 2017), based on the car engine size and fuel type. Where such details were missing in the survey dataset, an average emission factor based on unknown engine size and fuel type was used.

Emissions from individual trips were divided by the vehicle occupancy and aggregated over the travel diary to calculate *personal* emissions. Total miles were attributed to each traveller individually. This means that if two individuals took the a car trip together, they would share the emissions of that trip (half each) but their personal travel miles would be the total mileage of the trip.

Some limitations in the data remain in the context of this study. For example, where a person used more than one car for their travel activities, only the most regularly used vehicle details can be identified. For some respondents, various car attributes (e.g. engine size) were also missing, and for them, average car specifications were used. In addition, the NTS does not capture international personal travel trips, or trips by non-UK residents (DfT, 2019), so these are missing from the datasets and our models. Furthermore, domestic flights recorded in the NTS do not include trip purpose or trip length information, which could have been important in predicting extreme domestic mobility overall. Travel within Northern Ireland is also only partially measured and so was not included within our analysis due to these data gaps. It is important to reiterate that the analysis covers *domestic* travel by *English* residents only.

Table 1
Summary statistics of the sample.

	% respondents
Male	47.5
Having a degree qualification	18.0
Full time workers	44.7
Working in Managerial and professional occupations	35.6
From Non-White ethnicity	11.0
Having a valid full driving license	76.0
Having a 'Blue badge' for car	5.1
Having Car Engine Size > 1500	58.9
Using petrol as main fuel	42.7
Frequency of. of international flights	
No flights	50.0
Only one	23.0
More than one	27.0
Freq. of domestic flights	
No or one	92.0
Two	5.8
More than two	2.2
Weekly train travel frequency	
Once or less	40.0
Once or twice	21.0
Twice or more	39.0
By Age group	
17–25	11.0
26–45	31.0
46–64	32.0
64+	26.0
By household cars owned	
0	16.0
1	40.0
2	33.0
2+	11.0

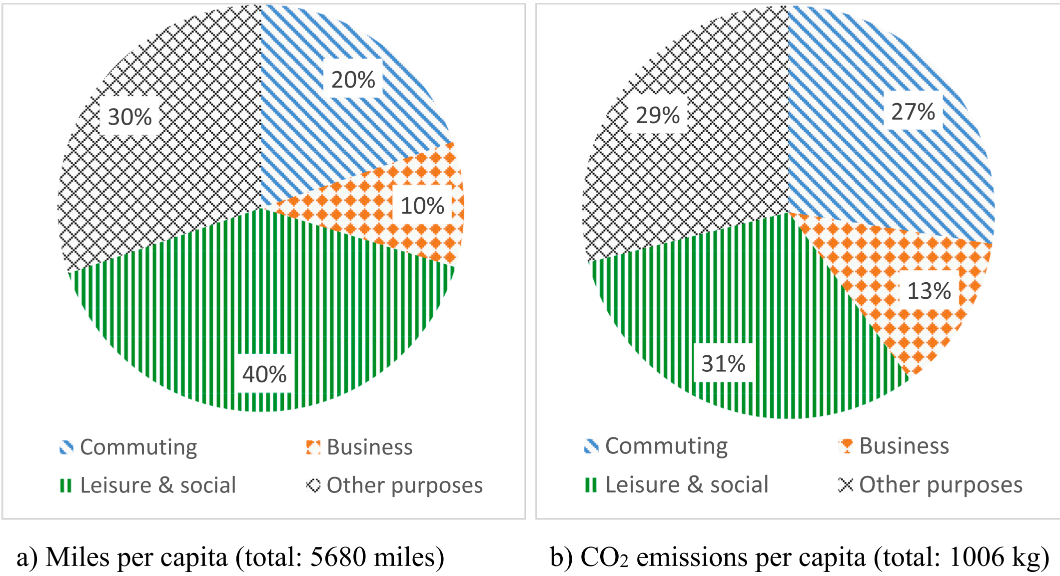

Fig. 1. Share of annual per capita passenger car miles and car CO_2 emissions in England (NTS 2015-17, England residents > 16 years age only). a) Miles per capita (total: 5680 miles). b) CO_2 emissions per capita (total: 1006 kg).

3.2. Descriptive data analysis

On average each English resident, aged 17 and over, travelled 5,680 person-miles by car per year[2], and emitted 1,006 kg of CO_2 per capita showing that each car person-mile produced approximately 0.18 kg of CO_2. As shown in Fig. 1, commuting represented 20% of all car travel miles per capita but produced 27% of total CO_2 emissions. Business travel accounted for 10% of mileage and 13% of total CO_2 emissions. Taken together, business travel and communing were responsible for around 30% of person-miles and 40% of emissions, confirming that these trips are generally more carbon intensive than other trips (Brand and Preston, 2010).

Nevertheless, leisure and social travel significantly contributed around 40% of all domestic personal car miles, but was responsible for only 31% of per capita emissions. This is largely due to the relatively higher vehicle occupancy of leisure and social travel, which reduces per capita emissions. Other purpose travel, e.g. escort and shopping trips, contribute the remaining 30% of mileage and emissions per capita. Taken together this often perceived 'non-essential' travel accounts for 70% of the total mileage and 60% of emissions.

As shown in Table 2, the average annual car mileage per capita and emissions for men are 30 to 50% higher than for women (as drivers and passengers). People in the middle years of their lives (24–64 years) travel significantly more than the younger and older groups recording higher emissions. Full-time workers' travel and CO_2 emissions are roughly a quarter higher than for part-time workers, and two to three times higher than the economically inactive population confirming the effect of employment status on car travel.

Households in the lowest income quintile were responsible for 40% less car mileage and 50% less emissions than the national average. Those from the fourth- and fifth-income quintiles reported up to 1.4 times higher mileage and 1.5 times more CO_2 emissions compared to the national average. These values are more than double those for the lowest quintile, confirming that affordability may be a major reason for high car mileage and emissions amongst richer households (Anable *et. al.,* 2012). People living in rural and small urban areas travel up to three times farther than the residents of large cities or metropolitan regions where there is a greater density of activity destinations and supply of public transport services (Ma and Banister, 2006).

As demonstrated in Table 3, individuals with company cars drive (and emit) more than double the mileage of private vehicle owners. People driving vehicles with larger engines also travel more miles (and emit) more than those with small engines, as do those with diesel engines and with newer cars. Newer vehicles are also used to undertake more travel than old vehicles. Generally, a new car is used for 1.5 times longer distances than old ones. However, newer vehicles drive an average 6.6 miles per 1 kg of CO_2 emissions whereas cars >10 years old could emit the same amount of CO_2 in only 4.7 miles. As such, emissions from older cars can be higher than from newer ones, despite the mileage being lower. This shows that, in order to reduce emissions, it is necessary to reduce car mileage

[2] DfT reports estimated annual per capita car mileage at around 7,900 miles for year 2015–2017 (Table NTS0901). This figure excludes non drivers and is a self-estimated mileage by the travelers. Whereas our value of 5,680 miles per capita comes from travel diary data of all respondents above 16 years age and includes nearly 13% respondents who did not report any car travel during the survey period.

Table 2
Annual average car miles and associated CO_2 emissions per capita in England by demographics (NTS 2015–17: England residents > 16 years age only, N = 34,185).

	Miles	CO_2
All trips	5680	1006
Gender		
Male	6368	1232
Female	5055	802
Age		
17–25 years	4022	782
26–45 years	6171	1169
46–64 years	6849	1248
65 years plus	4321	600
Economic status		
Full-time workers	7230	1447
Part-time workers	5852	942
Economically inactive	3913	545
Household income Quintile		
First (lowest)	3307	536
Second	4309	695
Third	5658	1002
Fourth	6740	1255
Fifth (top)	7994	1465
Residential location		
Metropolitan	3621	664
Large urban	5341	980
Medium and small urban	6195	1090
Rural	8680	1481

Table 3
Annual average car miles and CO_2 emissions per capita in England by vehicle details (NTS 2015–17: England residents > 16 years age only, N = 34,185).

	Miles	CO_2
Car ownership		
Personal car	5443	965
Company car	13,100	2307
Petrol as Fuel type		
Yes	5917	1100
No	8512	1462
Engine size		
Up to 1500 cc	6004	968
Above 1500 cc	6804	1251
Car age		
<3 years	8453	1279
3 to 10 years	6141	1066
Above 10 years	5787	1242

Table 4
Annual average car miles and CO_2 emissions per capita in England by yearly frequency of train and air travel (NTS 2015–17: England residents > 16 years age only, N = 34,185).

	Miles	CO_2
Surface rail trips taken		
Once or less	4848	849
Once or twice	6352	1141
Twice or more	6092	1081
Domestic flights taken		
Once or less	5478	967
1–2 flights	7760	1418
>2 flights	8607	1592
International flights taken		
Didn't fly	4624	808
1–2 flights	6260	1123
>2 flights	7131	1273

but also to improve vehicles carbon or energy efficiency (Docherty *et. al.*, 2021).

The *average* car miles travelled tend to increase for those who fly more frequently (Table 4). However, air travel is highly unequal as the top income quintile (i.e. 20%) in the UK is responsible for 42% of all annual flights (Büchs and Mattioli, 2021). This means that wealthier households are more likely both to travel more by car as well as fly more frequently.

3.3. Car mobility and emissions of high-end travellers

Differences in the distribution of car travel in terms of journey distances and for different types of journeys have significant implications for overall energy consumption levels, which is often masked when only considering averages (Anable, 2005). Fig. 2 shows the annual car miles travelled across five mileage-based quintiles and different sub-groups of the top quintile such as 10%, 5%, 2% and 1%. It demonstrates that individuals in the lowest quintile travel <300 miles per capita per year and even those in the fourth mileage quintile travel close to the national average. However, individuals in the top quintile (20%) of total travel distances are responsible for three times as much annual mileage as the national average.

At the high-end of car mobility, the amount of car travel increases for every purpose. The top 10% travel around 22,000 car miles per year (3.9 times the national average), whereas the top 5% (excess) travellers are responsible for 27,500 annual car miles per capita (4.8 times the national average) which increases to 40,280 miles per capita (7 times the national average) amongst the top 1%. Within this group the proportion of business travel increases more than any other journey purpose, suggesting that car travel remains the favoured option for business travel in England rather than rail or flying (Chatterton et al., 2018). The journey purpose splits show that the share of non-work-related car mileage gradually increases from 32% to 42% across the mileage quintiles, suggesting that personal choice plays a significant role in mobility behaviour along with travel needs as reported by Anable (2005). Another important observation is that the share of miscellaneous or other purpose trips, which includes shopping and caring responsibilities, drops rapidly as car mileage increases showing that high car users are unlikely to travel long distances for these activities.

Fig. 3 shows that car emissions also exhibit a similar pattern across emission based groups. On a per capita basis, the top 20% *emitters* produce nearly 3.2 times as much CO_2 as the national average, the top 5% emit 5.7 times as much, while the top 2% and 1% emit 7.7 and 9.3 times as much CO_2, respectively. The share of emissions for leisure, social and other purposes drops, whereas the share for business and commuting increases from 10% to 40% between the first and fifth income quintiles and to 68% amongst the top 1% emitters.

3.4. Econometric model development

Based on the preliminary descriptive analysis of individual annual mileage records, we define the top 5% car travellers as the 'excess' car use group compared to the remaining 95% of the sample. Similarly, the top 5% emitters are also identified as 'excess' emitters from car travel. The specific cut-off points were chosen following previous research by the study team to determine the most effective ways of rationing car use based on different levels of total annual miles travelled (Lucas et al., 2021).

Two binary logistic regression models were developed to predict the likelihood of each person belonging to the 'excess' group for both car mileage and car emissions. These models attempt to identify the characteristics that distinguish excess car travellers and emitters from the rest of the population. The key socio-demographic/economic factors associated with this likelihood were identified through widely published literature (e.g. Anable 2005; Brand et al., 2013; Levinson, 1998; Ma and Banister, 2006). We also included some explanatory variables that have not traditionally been measured in previous studies, such as ethnicity, the frequency of domestic and international air trips, the share of business-related car mileage and total rail mileage compared to all respondents. These variables highlighted the influence of traditionally overlooked factors in car travel behaviour research. Due to missing data for some variables, the models are run on 34,119 observations, instead of 34,185.

Two further binary logistics models were conducted to differentiate the excess users and emitters (top 5%) from high users and

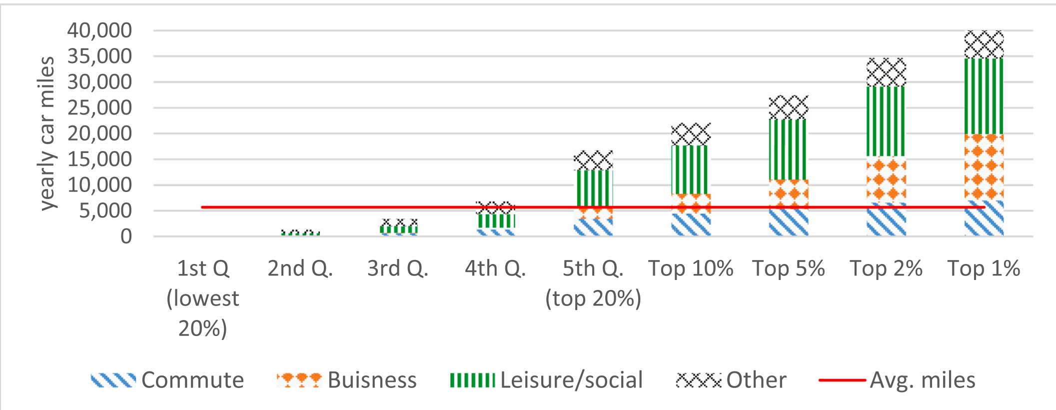

Fig. 2. Annual per capita car miles by mileage groups in England (NTS 2015–17: England residents > 16 years age only).

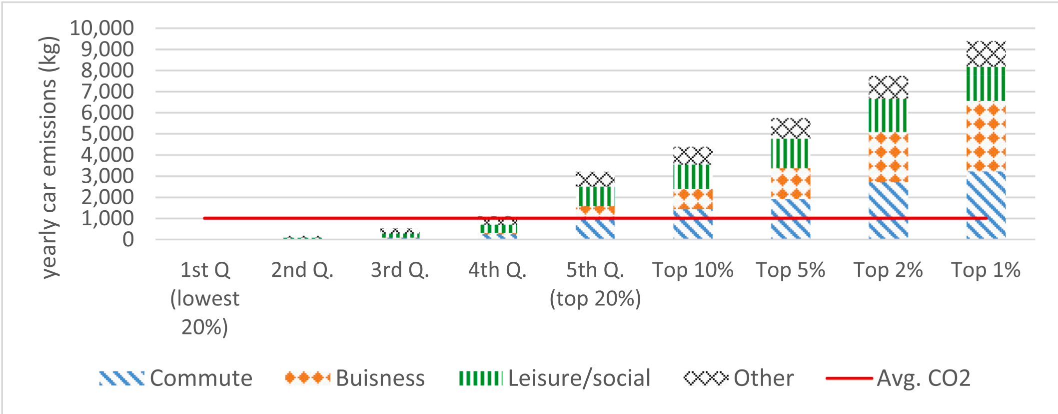

Fig. 3. Annual per capita CO_2 emissions by emission groups in England (NTS 2015–17: England residents > 16 years age only).

emitters (i.e. the rest of the top 20%). We use these models to determine the social groups that might be affected if different mileage and emissions (using cut-off points) are used to ration travel (see 4.3). This technique would be useful for policy makers when thinking about targetted policy measures. It is important to mention that the model results present statistical associations with explanatory factors, but do not necessarily confirm causality (Aneshensel, 2012).

4. Model results

4.1. *Characteristics of excess car travellers*

Table 5 presents the binary logistic model results for the excess car travellers (Model 1) and emitters (Model 2). At a 95% significance level, both models confirm the highly significant role of gender, employment and socio-economic status, household income (higher quintiles only), residential location and local population density in predicting the likelihood of a person being in the excess group. Having higher household income, living in small settlements and rural locations, and company car availability also positively associate with the probability of being an excess user and emitter. Multiple car ownership, business travel by car, the use of non-petrol and bigger cars were also positively linked with the excess (top 5%) of emissions and mileage. Other influential factors, significant to a lesser extent, were age (over 65s only), educational attainment and vehicle age. Being elderly, outside full-time employment, or in non-professional work, being a rail user, using older and petrol-fuelled cars were all negatively associated with excess car travel.

A detailed breakdown of the individual variables' effect on the likelihood of being an excess car user or emitters is now discussed in the following sections.

4.1.1. *Socio-economic factors*

Household income is the most important socio-economic factor in the excess mileage and emission models. Respondents from the top quintile were 70% more likely to be excess travellers and almost twice as likely to be excess emitters. Respondents from the fourth-income quintile were also 42% and 62% more likely to be in the excess traveller and emitter groups respectively compared with those in the lowest quintile. For emissions, being in the third income quintile also increases the likelihood to be in the excess group. Part-time workers and economically inactive respondents were nearly a quarter less likely to be among the excess mileage group and half as likely to be in the excess emission group, compared to full-time workers. The likelihood of being an excess car traveller was also nearly a third lower for those in intermediate occupations, manual work or those who never worked compared to professional or managerial workers in both models. This is associated with the finding that people with a degree-level qualification were almost one-fifth more likely to be in the 'excess' mileage and emission groups, compared to those without a degree, in line with previous findings from Brand et al., (2013) for high car use among graduates and professional workers.

Whilst controlling for other variables in the statistical model, women are 30% and 50% less likely to be excess travellers and emitters respectively compared to men, suggesting a strong gender effect which is reported in mobility behaviour studies as well (Scheiner and Holz-Rau, 2012; Galvin, 2015). Perhaps more surprisingly, individuals from non-white ethnic backgrounds were barely more likely to be in the excess mileage group, but 55% more likely to be in the excess emissions group. This finding perhaps reflects the differences in the emissions of vehicles types or levels of occupancy.

The likelihood of being an excess traveller or emitter was significantly lower for elderly respondents who were 30% and 70% less likely to be excess travellers and emitters compared to the reference age group of 26- to 45-year-old car travellers. Similarly, older adults (46–64 years) were 30% less likely to be excess emitters than the same reference group.

Household structure also showed a significant effect on excess travel as single adult households were twice as likely to be excessive emitters but no more likely to be among the excess mileage group compared to two-adult households as the reference group. The apparent discrepancy possibly arises because single individuals cannot share trip-based activities such as shopping and have lower vehicle occupancy rates than families. People living in households with two adults and children were a third less likely to be in the

Table 5
Logistic regression results of yearly car miles and CO_2 emissions per capita in England among excess car travellers and emitters (Source: NTS 2015–17, England residents > 16 years age, N = 34,119).

	Model 1: Car mileage: excess vs. rest				Model 2: CO_2: excess: vs. the rest			
	Coef.	Odds Ratio	Z	Sig.	Coef.	Odds Ratio	Z	Sig.
Demographic effect								
Gender: Ref. Male								
Female	**−0.38**	**0.69**	**−6.45**	***	**−0.72**	**0.49**	**−11.37**	***
Age: Ref. 26 to 45								
17–25	0.07	1.07	0.6		0	1	0.03	
46–64	−0.02	0.98	−0.29		**−0.38**	**0.69**	**−5.74**	***
65 and more	−0.37	0.69	−3.2	**	**−1.16**	**0.31**	**−8.04**	***
Ethnicity: Ref. white								
Non white	0.17	1.19	1.58		**0.44**	**1.55**	**4.4**	***
HH structure: Ref: 2 adults								
Single adult	0.01	1.01	0.05		**0.7**	**2.01**	**6.91**	***
3 adults or more	−0.21	0.81	−2.33	**	0.16	1.18	1.87	
Single parent family	−0.58	0.56	−1.8		−0.35	0.7	−1.13	
2 adults, with children	−0.05	0.95	−0.7		**−0.43**	**0.65**	**−5.24**	***
> 2 adults, with children	0.13	1.14	1.23		−0.02	0.98	−0.21	
The effects of economic conditions								
Education: Ref: No degree								
Yes	0.17	1.19	2.77	**	0.2	1.23	3.17	**
Employment status: Ref. Full time worker								
Part-time work	−0.3	0.74	−3.46	**	**−0.66**	**0.52**	**−6.64**	***
Economically inactive	−0.27	0.77	−2.82	**	**−0.87**	**0.42**	**−7.48**	***
Socioeconomic status: Ref. Professionals & managers								
Intermediate occupations and small employers	**−0.43**	**0.65**	**−5.66**	***	**−0.49**	**0.61**	**−6.2**	***
Routine and manual occupations	**−0.44**	**0.64**	**−5.64**	***	**−0.33**	**0.72**	**−4.25**	***
Never worked and long-term unemployed	−0.54	0.58	−2.07	**	−0.85	0.43	−2	**
Not classified (including students)	0.14	1.15	1.2		0.17	1.18	1.47	
Household income: Ref. 1st Quintile								
2nd	0.08	1.09	0.66		0.19	1.2	1.3	
3rd	0.14	1.15	1.17		0.34	1.4	2.59	**
4th	0.35	1.42	3.02	**	**0.48**	**1.62**	**3.78**	***
5th	**0.52**	**1.69**	**4.53**	***	**0.67**	**1.95**	**5.18**	***
Flying, business travel and train journeys								
Overseas flights: Ref. Zero								
One flight	0.06	1.06	0.78		0.06	1.06	0.82	
Twice or more	**0.26**	**1.3**	**3.92**	***	0.13	1.14	1.97	**
Domestic flights: Ref. Zero								
1–2 flights	0.17	1.19	1.9		0.19	1.21	2.02	**
Twice or more	0.02	1.02	0.12		0.09	1.1	0.68	
Rail miles: Ref. Low, below 600								
Medium, 50–95%, 600–3300	−0.17	0.84	−1.08		−0.33	0.72	−1.91	
High, >95, Above 3300	**−0.65**	**0.52**	**−5.34**	***	**−0.79**	**0.45**	**−6.27**	***
Business miles: Ref. Low, below 10%								
10–25%	**0.52**	**1.68**	**4.2**	***	**0.75**	**2.11**	**6.38**	***
25–50%	**0.86**	**2.37**	**8.15**	***	**0.88**	**2.41**	**8.33**	***
50–75%	**1.13**	**3.08**	**10.19**	***	**1.4**	**4.04**	**13.13**	***
75–100%	**1.64**	**5.13**	**15.82**	***	**1.92**	**6.85**	**19.02**	***
Car ownership and driving ability								
Full driving license: Ref: Yes								
No	**−0.61**	**0.55**	**−4.38**	***	**−1.52**	**0.22**	**−7.22**	***
Household car ownership: Ref. 1 Car HH								
0 Car	0.1	1.1	0.38		−0.09	0.92	−0.28	
2 Cars	0.21	1.23	2.98	**	**0.29**	**1.34**	**3.86**	***
2 + Cars	0.3	1.35	3.07	**	**0.47**	**1.61**	**4.75**	***
Company Car use: Ref. No								
Yes	**0.39**	**1.48**	**4.08**	***	**0.4**	**1.49**	**3.86**	***
Car with blue badge: Ref. No								
Yes	−0.37	0.69	−1.82		−0.7	0.5	−2.23	**
Residential location and area type								
Household area type: Ref. Large Urban Areas (>250,000 pop)								
London Boroughs	−0.2	0.82	−0.98		0.11	1.12	0.49	
Metropolitan built-up areas	−0.17	0.84	−1.42		0.09	1.09	0.72	
Medium urban (25 k to 250 k population)	0.11	1.11	1.13		0.12	1.13	1.26	
Small/medium urban (10 k to 25 k population)	0.27	1.31	2.24	**	0.22	1.25	1.76	
Small urban (3 k to 10 k population)	**0.43**	**1.54**	**3.69**	***	0.39	1.48	3.27	**
Rural	**0.5**	**1.65**	**5.11**	***	**0.44**	**1.56**	**4.37**	***
Household region: Ref. North East								

(*continued on next page*)

Table 5 (*continued*)

	Model 1: Car mileage: excess vs. rest				Model 2: CO_2: excess: vs. the rest			
	Coef.	Odds Ratio	Z	Sig.	Coef.	Odds Ratio	Z	Sig.
North West	0.06	1.06	0.37		0.31	1.36	1.78	
Yorkshire and the Humber	0.21	1.24	1.39		**0.63**	**1.88**	**3.6**	***
East Midlands	0.22	1.25	1.45		0.57	1.76	3.18	**
West Midlands	0.31	1.36	2.02	**	0.49	1.63	2.76	**
East of England	0.18	1.2	1.24		**0.71**	**2.03**	**4.13**	***
London								
South East	0.25	1.29	1.78		**0.73**	**2.07**	**4.38**	***
South West	0.34	1.41	2.29	**	**0.88**	**2.4**	**5.1**	***
Population density	−0.01	0.99	−2.78	**	−0.01	0.99	−3.01	**
<u>Vehicle details and fuel type</u>								
vehicle fuel type: Ref: Petrol								
No	**0.51**	**1.67**	**7.83**	***	0.17	1.18	2.57	**
Don't Know	0.01	1.01	0.06		−0.58	0.56	−2.45	**
vehicle engine size: Ref: Below 1500								
>1500	0.2	1.23	2.81	**	**0.66**	**1.94**	**8.59**	***
Don't Know	**−3.75**	**0.02**	**−4.72**	***	**−2.57**	**0.08**	**−3.78**	***
vehicle age: Ref: 3 to 10 years								
Below 3	0.12	1.13	1.83		**−0.26**	**0.77**	**−3.52**	***
Above 10	−0.24	0.78	−3.28	**	0.16	1.18	2.42	**
Don't know	0.3	1.35	0.9		0.56	1.75	1.79	
Model Constant	**−3.55**	**0.03**	**−16.39**	***	**−3.86**	**0.02**	**−15.96**	***
Number of obs.	34,119				34,119			
LR $chi^2(58)$	2577				3620.77			
Prob > chi^2	<0.001				<0.001			
Pseudo R^2	0.19				0.267			
Log likelihood	−5488				−4969			

*** statistically significant at 99% confidence level.
** statistically significant at 95% confidence level.

excess emission groups for the same reasons. Perhaps unsurprisingly, individuals without a driving licence were half as likely to be in the high-mileage group and 80% less likely to be excessive emitters than those with a license due to this restriction on their mobility. Disabled 'blue badge' holders were also at least half as likely to be in the 'excess' emitters group, but disability had no significant effect on excess mileage.

4.1.2. Spatial effects

Generally, personal mileage by car, and associated CO_2 emissions, increase up to 1.6 times for residents living in settlements with a population of <25,000. Compared to the reference group of 'large urban areas' (area with population >250,000), small urban and rural residents were 1.5 to 1.6 times more likely to be the 'excess' car milers or emitters groups respectively. This finding implies that the dispersal of activity locations and residential remoteness are both heavily associated with high car use, in line with similar findings in other studies (Breheny, 1995; Ma and Banister, 2006; Banister et al., 1997). The residents of London or metropolitan cities were not significantly different to the reference group.

Controlling for settlement size in the statistical analysis, only residents from the West Midlands and South West regions were significantly more likely to be excess travellers. Compared to the North East, all regions, except North West and London, were more likely to be in the excess emitters groups. Additionally, the population density exhibits a statistically significant negative association with excess travel across all English regions. Increasing population density has previously been widely advocated as a remedy to reduce travel miles (e.g. Banister et al., 1997; Cervero and Murakami, 2010; Liu and Shen, 2011), but this evidence shows relatively small gains in the context of already mature urban morphologies such as the UK.

4.1.3. Association with vehicle characteristics

Belonging to a household with multiple cars is associated with a higher likelihood of being in the excess mileage or emissions groups. A particularly stark finding was that access to a company car increases the likelihood of being in the excess group by almost half. This suggests that company car drivers are more involved in long distance travel for business purposes and/or their travel costs are not a disincentive. This corresponds to the finding that business travel is strongly associated with high car use; and those with relatively high business mileage were more likely to be in the excess group.

After controlling for social factors such as income and user demographics, the owners of diesel and larger engine vehicles were significantly more likely to be in the excess group. Although non-petrol car owners are 67% more likely to be in excess mileage category, they are only 18% more likely to be in the excess emitter category due to the higher fuel economy of diesel vehicles (Schipper and Fulton, 2009). Vehicle age exhibits a negative association with the likelihood of being an excess traveller but a positive association with being an excess emitter. The use of new cars (<3 years old) increased the chances of being excess travellers (at a 10% significance level), but significantly decreased the probability of being classified as excess emitters.

4.1.4. Flying and train travel

Only flight frequency, not mileage, is recorded in the NTS. Results show that there is a significant positive association between taking multiple international flights and the likelihood of being among the excess car mileage and emissions groups.[3] For domestic flights, however, the relationship is less clear, with those taking 1–2 trips a year being associated with the excess emissions group. High rail usage (>3,300 miles a year) showed a strong negative association with both excess car mileage and emissions.

4.2. Comparing excess users (top 5%) vs. high-end users (top 20%)

Table 6 presents the next pair of statistical models that identify the characteristics to distinguish *excess* car travellers and emitters (top 5%) from the rest of the *high-end users* and emitters (i.e. the remainder of the top 20% sample). The main motivation for this is to test if different population groups could be affected by imposing rationing policies at different mileage cut-off points, as discussed further in Section 4.3.

The model results show that the excess travellers and emitters are very similar in their social characteristics to the high-end consumers. Being female, in the older age categories, of white ethnicity, high rail mileage and in part-time employment all decrease the likelihood of being in the excess group compared with the high group. Similarly, having two or more overseas flights in the preceding year, high business mileage, rural residence, company car use, newer cars and higher engine capacity were positively associated with being in the excess group relative to the high group. Single parent households were less likely to be in the excess mileage group, but no less likely to be in the excess *emitter* group – potentially due to the cumulative effects of being female, in single adult households and lone parenthood, in line with the research by Sunikka-Blank and Galvin (2021). Single adults were also a third more likely to be excess emitters compared to high emitters. However, the model fit of these two regressions are not as strong compared to Model 1, partly due to smaller sample sizes.

Having a driving license did not have a significant effect but having a degree did have a significant impact on being in the excess emitter group. In comparison to the North East, other regions showed a significant positive association with excess emissions. Household area type did not significantly correlate in this model, with the exception of rural areas, a potential concentration of excess emitters were predicted in remote locations. Similarly, only the top income quintile was more likely to record excessive mileage and the top two quintiles were more likely to record excessive emissions, suggesting a strong income effect in car use only occurs for the richest households.

The significance of many ‘excess’ variables in the top 20% ‘high’ subsample reconfirms their importance in shaping excess travel at all levels and mileage cut-offs points. The findings of this comparative analysis also raise questions about the most appropriate cut-off point when targeting the issue of excess car use in those sectors of the population, journeys and vehicle use that are most excessive. To frame this question, we generated a simple way to identify excess car travel through a mileage and carbon emissions rationing approach, which is discussed in the following section.

4.3. Mileage and emission rationing across different cut-off points

Table 7 presents the expected changes to average per capita car mileage and emissions using different *mileage* cut off points. It shows that if we set a per capita cut-off of 30,000 miles per annum, we can reduce overall mileage and emissions by up to 2%, whereas if this is set at 20,000 miles there is a 6.6% reduction. Limiting only the top 5% excess users to this cut-off point would decrease overall car miles and emissions by 6.9%, whereas limiting all of the top 20% high car mileage group would results in a reduction of nearly 26%.

Table 8 presents the per capita changes in car-based CO_2 emissions resulting from the hypothetical rationing of *emissions* at different cut-off points. For example, if everyone emits below 7000 kg CO_2 per annum, per capita emissions would be decreased by nearly 2.4 percent, but if the cut-off is 5000 kg, there is a 5.6% overall reduction, with a relatively lower percentage reduction in miles per capita.

This analysis implies that whether we target excess mileage or emissions, the gains remain relatively low unless and until a mileage or emission cut-off is lowered substantially or a substantial share of the population is subjected to a budget. For example, targeting the top quintile of emitters (high emitters) for the carbon budget could reduce emissions by almost 32% and mileage by 26%, as compared to only 10% reduction in emissions and 7% in mileage for cut-off at the top 5% level (excess emitters and travellers). More importantly, for reducing carbon emissions targeting excess or high emitters directly work better than targeting excess or high mileage users.

5. Conclusions and policy implications

By using a pooled dataset of England’s National Travel Survey (for years 2015 to 2017) our research explored the associations between excess mileage and emissions and the sociodemographic and vehicle characteristics of the adult diary respondents, through four binary logistic regression models. The analysis demonstrated that ‘excess’ car users emit up to 4.8 times that of the average population. Men, professionals, full time employed and those with company cars were more likely to be excess travellers than women, part time workers, semi-skilled professions, disabled and those without driving licenses. Having a higher household income, higher

[3] There is some literature on the positive relationship between urban density (so, potentially low car travel) and long distance travel (mostly flying), but a recent review suggests that the issue is yet to be settled (Czepkiewicz et al. 2018). Mattioli et al (2021) also reported no rebound effect (larger flying frequency by those without car) in the UK, indicating our results are not implausible.

Table 6
Logistic regression results of yearly car miles and CO_2 emissions per capita in England among excess travellers vs high travellers sub sample (Source: NTS 2015–17, England residents > 16 years age, N = 6830).

	Model 3: Car mileage: excess vs. high				Model 4: CO_2: excess vs. high			
	Coef.	Odds Ratio	z	Sig.	Coef.	Odds Ratio	z	Sig.
Demographic effect								
Gender: Ref. Male								
Female	**−0.27**	**0.76**	**−4.2**	***	**−0.53**	**0.59**	**−7.64**	***
Age: Ref. 26 to 45								
17–25	0.08	1.08	0.58		−0.06	0.94	−0.47	
46–64	−0.04	0.96	−0.5		**−0.33**	**0.72**	**−4.59**	***
65 and more	−0.21	0.81	−1.66	*	**−0.71**	**0.49**	**−4.56**	***
Ethnicity: Ref. white								
Non white	0.13	1.13	1.04		**0.41**	**1.51**	**3.63**	***
HH structure: Ref: 2 adults								
Single adult	−0.15	0.86	−1.27		0.28	1.33	2.56	**
3 adults or more	−0.23	0.8	−2.3	**	0.11	1.12	1.2	
Single parent family	−0.77	0.46	−2.25	**	−0.31	0.73	−0.92	
2 adults, with children	−0.11	0.9	−1.28		−0.28	0.76	−3.14	**
> 2 adults, with children	0.06	1.06	0.52		−0.02	0.98	−0.17	
The effects of economic conditions								
Education: Ref: No degree								
Yes	0.08	1.09	1.21		0.17	1.19	2.49	**
Employment status: Ref. Full time worker								
Part-time work	−0.27	0.76	−2.87	**	**−0.5**	**0.6**	**−4.7**	***
Economically inactive	−0.01	0.99	−0.05		−0.34	0.71	−2.66	**
Socioeconomic status: Ref. Professionals & managers								
Intermediate occupations and small employers	−0.15	0.86	−1.79		−0.21	0.81	−2.47	**
Routine and manual occupations	−0.17	0.85	−1.94		−0.11	0.9	−1.25	
Never worked and long-term unemployed	−0.21	0.81	−0.7		−0.57	0.57	−1.26	
Not classified (including students)	0.34	1.41	2.65	**	*0.27*	*1.31*	*2.15*	**
Household income: Ref. 1st Quintile								
2nd	0.04	1.04	0.31		0.12	1.13	0.77	
3rd	−0.02	0.98	−0.15		0.21	1.23	1.47	
4th	0.11	1.12	0.87		0.29	1.34	2.1	**
5th	0.28	1.32	2.22	**	**0.49**	**1.63**	**3.49**	***
Flying, business travel and train journeys								
Overseas flights: Ref. Zero								
One flight	−0.01	0.99	−0.09		0.02	1.02	0.31	
Twice or more	0.18	1.2	2.51	**	0.07	1.08	0.99	
Domestic flights: Ref. Zero								
1–2 flights	0.18	1.2	1.79		0.21	1.23	2.01	**
Twice or more	−0.04	0.96	−0.25		0.07	1.07	0.48	
Rail miles: Ref. Low, below 600								
Medium, 50–95%, 600–3300	−0.07	0.93	−0.4		−0.26	0.77	−1.39	
High, >95, Above 3300	−0.26	0.77	−1.93		−0.29	0.75	−2.03	**
Business miles: Ref. Low, below 10%								
10–25%	0.11	1.11	0.8		0.37	1.45	2.92	**
25–50%	0.5	1.65	4.34	***	0.45	1.56	3.93	***
50–75%	0.63	1.87	5.16	***	0.86	2.37	7.43	***
75–100%	0.98	2.67	8.49	***	1.28	3.6	11.44	***
Car ownership and driving ability								
Full driving license: Ref: Yes								
No	0.29	1.34	1.77		−0.2	0.82	−0.82	
Household car ownership: Ref. 1 Car HH								
0 Car	0.11	1.12	0.35		−0.01	0.99	−0.01	
2 Cars	−0.02	0.98	−0.22		−0.03	0.97	−0.38	
2 + Cars	0.09	1.1	0.85		0.1	1.1	0.88	
Company Car use: Ref. No								
Yes	0.33	1.39	3.09	**	0.34	1.4	3	**
Car with blue badge: Ref. No								
Yes	−0.09	0.92	−0.39		−0.56	0.57	−1.68	
Residential location and area type								
Household area type: Ref. Large Urban Areas (>250,000 pop)								
London Boroughs	−0.07	0.93	−0.33		0.39	1.48	1.63	
Metropolitan built-up areas	−0.12	0.89	−0.88		0.07	1.08	0.55	
Medium urban (25 k to 250 k population)	−0.01	0.99	−0.14		0.07	1.08	0.72	
Small/medium urban (10 k to 20 k population)	0.03	1.04	0.26		0.11	1.12	0.8	
Small urban (3 k to 10 k population)	0.14	1.16	1.12		0.2	1.22	1.5	
Rural	0.16	1.17	1.41		0.22	1.25	1.97	**
Household region: Ref. North East								

(*continued on next page*)

Table 6 (*continued*)

	Model 3: Car mileage: excess vs. high				Model 4: CO_2: excess vs. high			
	Coef.	Odds Ratio	z	Sig.	Coef.	Odds Ratio	z	Sig.
North West	−0.01	0.99	−0.05		0.44	1.56	2.37	**
Yorkshire and the Humber	0.13	1.14	0.76		0.59	1.8	3.13	**
East Midlands	0.08	1.09	0.48		0.57	1.76	2.98	**
West Midlands	0.1	1.11	0.61		0.49	1.63	2.57	**
East of England	0.08	1.08	0.46		**0.68**	**1.98**	**3.75**	***
London								
South East	0.15	1.16	0.92		**0.73**	**2.07**	**4.12**	***
South West	0.25	1.28	1.49		**0.82**	**2.28**	**4.48**	***
Population density	0	1	−0.29		0	1	−0.37	
Vehicle details and fuel type								
vehicle fuel type: Ref: Petrol								
No	**0.32**	**1.37**	**4.45**	***	0.13	1.14	1.92	
Don't Know	0.59	1.81	2.26	**	0.07	1.08	0.27	
vehicle engine size: Ref: Below 1500								
>1500	0.15	1.16	1.91		**0.46**	**1.58**	**5.46**	***
Don't Know	0.8	2.22	0.63		0.54	1.72	0.66	
vehicle age: Ref: 3 to 10 years								
Below 3	0.07	1.07	0.99		−0.17	0.84	−2.1	**
Above 10	−0.04	0.96	−0.55		0.14	1.15	1.95	*
Don't know	0.82	2.26	2.08	**	0.75	2.12	2.18	**
Model Constant	**−1.67**	**0.19**	**−6.96**	***	**−2.34**	**0.1**	**−8.98**	***
Model Specifications								
Number of obs.	6830				6827			
LR $chi^2(58)$	459.47				767.04			
Prob > chi^2	<0.001				<0.001			
Pseudo R^2	0.06				0.1			
Log likelihood	−3610				−3457			

*** statistically significant at 99% confidence level.
* * statistically significant at 95% confidence level.

Table 7
'Excess' car travel defined by mileage and the effects of imposing mileage rationing in England (Source: NTS, 2015–17, England only, Above 16 years old).

Excess Cut off value	Current avg. miles of those above cut-off	Expected Avg. of whole sample after cut-off	% reduction in miles	% reduction in CO_2
By absolute miles				
30,000	38,206	5573	1.86%	1.85%
25,000	32,931	5482	3.47%	3.48%
20,000	27,847	5305	6.58%	6.58%
By % miles				
Top 1% (32,133)	40,278	5600	1.43%	1.43%
Top 2% (26,695)	34,666	5520	2.80%	2.80%
Top 5% (19,630)	27,466	5287	6.90%	6.90%
Top 10% (14,234)	22,034	4900	13.71%	13.75%
Top 20% (9,380)	16,737	4,207	25.91%	26.00%

Table 8
'Excess' car travel defined by CO_2 emission and the effects of imposing CO_2 emissions rationing in England (Source: NTS, 2015-17, England only, Above 16 years old).

Excess Cut off value	Current avg. CO_2 of those above cut-off	expected Avg. CO_2 of whole sample after cut-off	% reduction in miles	% reduction in CO_2
By absolute emissions (kg)				
7000	9385	982	1.34%	2.36%
6000	8395	970	2.15%	3.60%
5000	7242	950	3.48%	5.55%
By % emissions				
Top 1% (7000 kg)	9385	982	1.34%	2.36%
Top 2% (5435 kg)	7740	960	2.81%	4.58%
Top 5% (3682 kg)	5742	903	6.93%	10.24%
Top 10% (2580 kg)	4387	826	13.11%	17.95%
Top 20% (1594 kg)	3201	685	25.45%	31.94%

education, frequent overseas flying, undertaking business travel and rural residence also showed a positive association with excess mileage and emissions. The use of non-petrol (primarily diesel), larger and newer cars was also positively associated with excess car travel. A comparison between high mileage/emitters and excess mileage/emitters generally reinforces the significance of these variables. While our results are specific to England, we expect that many of the findings regarding the socio-economic correlates of 'excess' mileage and emission will likely hold for similar industrialized economies in Europe. The exact quantitative relationship, naturally, will vary and is a matter of empirical investigation.

Our analysis shows that a mileage rationing scheme targeting only excess (top 5%) car travellers would have a relatively small impact on reducing overall carbon emissions from travel, i.e. only 7% of emissions are reduced. However, targeting all the high end travellers (top 20%) would offer a substantially greater reduction of a 26% cut in total emissions. This shows that, contrary to popular belief within the previous literature, targeting the top 1–5% of travellers alone would not be a very effective way to achieve *farther and faster reductions* in CO_2 emissions.

Our analysis suggests, therefore, that a multi-pronged policy approach is needed to reduce car use for specific journey purposes e.g. business travel and particularly the company car use that is associated with this; and high-mileage leisure travel, for example for holidays and car-dependent weekend breaks. As the results demonstrate, both excess and high-end car users are more likely to be high-income professionals in full-time employment, which suggests that they will likely have more resources to acquire new, potentially expensive low-carbon technologies, such as hybrid-electric, battery electric and hydrogen fuel-cell vehicles. However, this uptake will not necessarily solve the problem of their over-consumption of travel-related energy because this group also tend to opt for larger cars with heavier engines, which are less energy efficient. This indicates that directly addressing high carbon emissions and not high mileage is a more effective approach to reduce the carbon emissions from domestic travel overall.

The findings call for a wide range of structural changes in the way we live, the way our cities have been organised and how we travel around. The shift of our development policies from a mobility to accessibility perspective could be a fundamental way of reducing the overall need to travel. Economic disincentives for carbon intensive mobility for certain travel purposes, e.g. business trips, could be a useful policy option. Recent qualitative research has shown that people view economic support as a better policy option than fines and other negative economic sanctions (Cass et al., 2022).

Our analysis has shown that the average per capita mileage of the high-end car use group (i.e. top 20%) increases with income levels, and income tax is perhaps a more progressive way to redistribute the cost of providing alternative solutions (Owen and Barrett, 2020). In terms of incentivising reduced travel, during the pandemic, many high-income professionals became used to working from home and so employment policies to embed this practice could be particularly effective in reducing their excessive commuting and business trips. Since the pandemic, there has also been an increase in walking and cycling (Docherty et al., 2021), and so public investment in infrastructure to capture this modal shift could be another potential way forward. However, these strategies are unlikely to provide an effective substitute for the high-end consumers because of their demand for long distance business trips and their preferences for multiple overseas leisure trips.

Finally, the allocation of carbon allowances and restricted budgets have been suggested as another possible way forward to ration overconsumption of energy (Wadud, 2011; Wadud, et al., 2008; Wadud, 2007). Potentially, these could be administratively burdensome and difficult to allocate fairly according to people's basic travel needs and capabilities, which could lead to further inequalities in their distribution and uptake. Further research is necessary on the distributional impact of such carbon budgets or allowances. Any allowance would also need to go beyond the transport sector to all other areas of domestic energy consumption in order to avoid substitution and rebound effects (Wadud and Chintakayala, 2019). Well-known technical solutions such as improving vehicle efficiencies or regulations such as limiting vehicle engine power, vehicle sizes or electrification will also reduce overall emissions, but will be even more effective in curtailing excess emissions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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