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Working Papers in Real Estate & Planning 05/11

Business parks and town centre workplaces in England: a comparative analysis of commuting-related energy consumption

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Abstract

To fully appreciate the environmental impact of a workplace the transport-related carbon dioxide (CO_2) emissions resulting from its location should be considered in addition to the emissions that result from the occupation of the building itself. Since the first one was built in the early 1980s, business parks have become a significant workplace location for service-sector workers; a sector of the economy that grew rapidly at that time as the UK manufacturing output declined and the employment base shifted to retail services and de-regulated financial services. This paper examines the transport-related CO_2 emissions associated with these workplace locations in comparison to town and city centre locations. Using 2001 Census Special Workplace Statistics which record people's residence, usual workplace and mode of transport between them, distance travelled and mode of travel were calculated for a sample of city centre and out-of-town office locations. The results reveal the extent of the difference between transport-related CO_2 emitted by commuters to out-of-town and city centre locations. The implications that these findings have for monitoring the environmental performance of workplaces are discussed.

1. Introduction

Twice as much land is devoted to roads in England than to dwellings (Office for National Statistics, 2005). Transport activity accounts for over a quarter of UK CO_2 emission and is rising faster than any other sector of the economy (Sustainable Development Commission, 2009). Over the past half century widespread use of the car as a means of transport for workers in a predominantly service-based economy has freed households and businesses from the need to locate close to public transport nodes. Instead they have been able to decentralise to suburban, edge and out-of-town locations where land is cheaper and development is usually quicker and cheaper as a result of fewer constraints relating to ownership, planning and previous uses. By purchasing land at low cost, building cheaply and letting at rents comparable to nearby urban locations, developers have been able to reap increased profit at lower risk relative to brownfield sites in town and city centres. Business occupiers, when deciding to locate at edge and out-of-town locations, have been able to externalise at least some of the transport-related costs associated with a city centre location. Furthermore, homeowners, faced with considerable house price inflation, have tended to decentralise to suburban and extra-urban locations because travel costs have not inflated to the same extent. In effect, rising housing costs have been traded off against travel costs at an increasing rate, thus extending the distances people are prepared to commute. Assuming a monocentric urban layout, as workers and workplaces decentralise, distances between them will increase. A consequence of this is an environmental cost in the form of increased CO_2 emission.

These trends are borne out in travel data collected by the Government and summarised in van de Wetering and Wyatt (2010). Three quarters of households now have access to at least one car and the average distance people travel annually was 6,775 miles in 2009 (Department for

Transport, 2010). This is an increase of 50 per cent since the early 1970s and is comparable to the USA where vehicle miles travelled per household increased by nearly 50 per cent between 1970 and 2005. In terms of journeys to work, in Britain 73 per cent of all commuting miles travelled were made by car (Department for Transport, 2010) and, again, this is proportion comparable to the United States where approximately 76 per cent of workers drive alone by car to work (Horner, 2004). Car-based commuting has significant implications for the environmental performance of office space due to the high levels of CO_2 emitted compared to public transport. Whereas UK carbon emissions as a whole fell by 6 per cent between 1990 and 2005, transport-related emissions rose by 11 per cent with road transport accounts for 93% of transport emissions by source (excluding the UK's share of international aviation and shipping) (Commission for Integrated Transport, 2007).

Travel to and from a workplace generates CO_2 emissions and these commuting-related emissions are a function of (a) the location of the workplace relative to the location of the workforce, (b) the availability and cost of transport modes and (c) frequency of visits, which depends on the requirement for the workforce to be physically present. In terms of cost, each mode has a mix of economic, social and environmental costs and differs in terms of the extent to which these costs are externalised by the firm. Other things equal, workplace locations that require workers to commute by car will generate more emissions than locations that are easily accessible via public transport and locations that require shorter commutes will be more CO_2 efficient than those that require long distance commutes.

Since the first one was built in the early 1980s, business parks have become a significant workplace location for service-sector workers; a sector of the economy that grew rapidly at that time as the UK manufacturing output declined and the employment base shifted to retail services and de-regulated financial services. This paper examines the transport-related CO_2 emissions associated with these workplaces in comparison to town and city centre locations and is structured as follows. Following this introduction Section Two reviews literature relating to the location of economic enterprises and the way in which workers interact with them. The focus is on the energy consumption and CO_2 emission that results from the way in which workers travel to and from their workplace locations. Section Three describes the data and methods used to estimate the number of commuters, the distances that they travel and the resultant CO_2 emitted. Section Four presents the findings at the national and workplace-specific levels before Section Five offers some concluding comments and suggestions for further work.

2. Literature Review

Investigation of the cost of locating economic activities in specific locations began with the seminal works of Ricardo (1817) and von Thűnen (Hall, 1966) in the nineteenth century who recognised that certain agricultural locations (near market, material or labour supply for example) bear lower transport costs than other locations. Haig (1926) applied these theories to urban land use and argued that transport cost was a payment to overcome ‘friction of space’. A key development in research that sought to integrate issues relating to urban form with travel behaviour and, more specifically, commuting behaviour was the publication of Hamilton’s paper on *excess commuting* (Hamilton, 1982), a term used to describe the non-optimal commuting time and/or distance resulting from the spatial arrangement of dwellings and workplaces in an urban area (White, 1988). Horner (2002) provides a summary of the excess commuting literature that followed and places the debate in the context of wider concerns relating to urban sprawl and sustainability. But whereas in the US sprawl is a key concern, in the UK higher density urban environments and a more defined urban / rural boundary have led to a research emphasis that includes mode of travel as well as travel times and distances. For example, research has examined the relationship between urban size, travel demand and energy use (Banister, 1992) and results showed a higher level of car use in rural areas, and the car was the dominant mode of domestic passenger transport, accounting for 48% journeys and 90% energy consumption. Breheny (1993) also found rural areas had the highest transport-related energy consumption levels.

Banister and Banister (1994) used work-travel data from 1981 census and found that the commuter hinterland around London had the highest fuel use levels, followed by large metropolitan areas, and that the physical characteristics of urban settlements (size, availability of facilities and services, and public transport provision) are important too. This basic relationship is modified, however, by two influences: the socio-economic characteristics of the population, which can influence the frequency and length of trips as well as mode of travel, and location of each settlement in relation to other large urban areas. Breheny (1990) considered the issue of urban self-containment and energy use and found new towns to be more self-contained regarding work-related travel and larger ones to be more so than smaller ones. Breheny (1993) also investigated counter-urbanisation and energy use and found that areas of population growth were associated with high energy consumption rates per head: as people move into new areas their demand travel increases and this leads to higher energy consumption. Titheridge and Hall (2006) found that new growth centres in south-east England that had poor access to the rail network led to increased car use in the region. Population density has been shown to be strongly positively associated with vehicle miles travelled per capita but the effect is moderated by traffic-inducing effects of increased density.

Accessibility of basic employment, urban size and rail transit supplies and usage were found to have relatively modest effects (Cervero and Murakami, 2010).

Empirical studies of commuting activity at the intra-urban scale point to decentralized commercial activity as a contributory factor to higher levels of commuting. Cervero (1988) found that office decentralisation in North America led to longer journey distances and greater use of private vehicles, although these findings were contested (see Gordon *et al*, 1991 for example). In the UK, Frost *et al* (1997) found that work-travel had increased due to greater travel distances as a result of counter-urbanisation and other decentralisation trends. They found that car-based commuting dominated work-travel in London, Birmingham and Manchester and there had been a large increase during the 1980s. The high level of energy consumption per person kilometre that car-based commuting produces meant that it dominated work-travel energy consumption from these three cities. Frost *et al* argued that a centralised compact city should reduce travel due to shorter journeys and increased public transport use but retail, office and leisure uses have decentralised: "[t]he already considerable separation of workplaces and residences in urban systems seems to be increasing..." (p2). McQuaid *et al* (2004) argued that transport developments have increased the accessibility of suburban and exurban locations relative to city centre locations. This has moved the accessibility-to-cost ratio in favour of out-of-town business locations.

Analysis of commuter flows in England and Wales has been undertaken using census data. Nielsen and Hovgesen (2007) mapped the origin-destination commuting flows using data from the 1991 and 2001 censuses. Their study was at a fairly small scale and illustrated how, over the decade, the main commuter corridor between London and Manchester had widened. They suggested that this was a result of decentralisation of population and jobs and increased commuting distances. Hincks and Wong (2010) investigated the spatial interaction between housing and labour markets in north-west England by analysing commuting flows. They found that the majority of housing market areas (HMAs) intersected two or more travel-to-work areas (TTWAs) suggesting complex outward commuting. Similarly there were dual and multiple HMAs serving single TTWAs, so TTWAs attract significant inflows of commuters from a range of HMAs. Hincks and Wong argued that intersections were indicative of potential travel-to-work relationships and suggested that "...since population and jobs have decentralised, many of the work-trips are now between non-urban residential and workplace locations..." and "...commuting tends to be shorter in urban areas whilst commuting to non-urban locations tends to be longer distance" (p644). They also found that commuting patterns have diversified and length increased with the majority of workers travelling to workplaces outside the CBD. Hincks and Wong concluded that "the fragmentation of housing and labour market issues in national and regional policy frameworks has to be addressed in order to achieve the objectives of developing sustainable communities" (p645).

Increasingly, and particularly when planning permission is being sought for the development of large workplace locations, local planning authorities stipulate that a package of measures, known as a travel plan, is put in place to encourage staff to use alternatives to single-occupancy car-use. The plan might include a car sharing scheme, cycling facilities, a dedicated bus service or restricted car-parking allocations. It might also promote flexible-working practices such as remote access and video-conferencing. The travel plan usually includes a survey of commuting modes used by staff before and after a certain date relevant to the planning permission. By examining the results from six travel plans Rye (2002) found evidence to suggest that they encourage a reduction in the number of employees commuting to work alone by car at the site level, although there may be little effect on congestion levels in overall terms as journeys saved may be replaced by those suppressed by previously high congestion. Since that time, the UK Department for Transport has published a sample of travel plans from a range of organisations on its web-site[1]. Focussing on office workplaces, Table 1 shows the results of the latest surveys undertaken by these organisations. The substantial difference in travel behaviour between in-town and out-of-town workplaces is clear: on average 83 per cent of employees commute by car to out-of-town workplaces, in-town the average is 44 per cent. The key question as far as this paper is concerned is what impact does this have on CO_2 emission?

Method

To estimate annual CO_2 emissions per person for each transport mode, three inputs are required: the proportion of workers that travel by each mode, the distance that they travel and the CO_2 emissions of each mode per kilometre. Commuting travel modes and distances travelled can be obtained from national statistics. Two types of data are required: the locations of residences and workplaces and the volume and mode of travel between them. The decennial census of population records the location of people's usual workplaces and the usual mode of transport to those workplaces. The data were derived from questions on the 2001 census form relating to place of usual residence and the place of work for the respondent's main job. The data have thus been derived from a 100% sample and include imputed households where responses were not obtained. The relevant question on the census form was: "what is the address of the place where you work in your main job?" 'Main' job was defined on the census form as the workplace attended last week (assuming the respondent was in work that week). Together with each respondent's home address, this allows the

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[1] http://webarchive.nationalarchives.gov.uk/+/http://www.dft.gov.uk/pgr/sustainable/travelplans/work/casestudy/

construction of origin and destination points for work-related travel, including home-workers. Where workplace locations were unknown, these were also imputed. The question relating to mode of travel asks the respondents to indicate the mode used for the longest part of the 'usual' work journey, which may not necessarily have been the mode used in the last week. The census day is conventionally a Sunday and this may affect the origin-destination and mode of travel data because a weekend home location may differ from a mid-week residence. Consequently it is not possible to unravel responses that inadvertently confuse first and second homes, split mode commuting, multiple workplace destinations and so on. It is assumed, however, that the majority of commuters display a regularised pattern of weekly commuting behaviour and that this is reflected in the census data sample.

These 'interaction' data are published as Census Workplace Statistics (Office for National Statistics, 2001) and report journey-to-work flows within and between various levels of administrative and electoral geographical areas including local authorities, wards (administrative boundaries delineating electoral districts, of which there are approximately 9,000 in England and Wales) and census output areas (the smallest geographical area for which census data are published, numbering approximately 80,000 in England and Wales). The data do not take account of periods when people may not be travelling because they are on holiday, off sick, working at home[2] for part of the week or attending meetings away from the workplace. Work-travel behaviour involves more complex interactions than simply journeying to and from work. Sometimes people work at home but sometimes they travel long distances to meet clients. The data are therefore a proxy for actual travel flows and tend to over-estimate activity at centres of employment. Only full-time workers were selected for this study, part-time workers and students were not included in the analysis. The data may,

[2] Home-working may reduce transport usage but increase domestic energy use and reduce the energy efficiency of existing workplaces.

therefore, under-represent the actual flows but it was felt that excluding part-time workers would counter-balance those full-time workers who do not commute to their usual place of work every day of the week. Although the interaction data can be classified by mode of transport and by employment type, both cannot be done simultaneously. Consequently it is not possible to select only office-based workers and investigate their mode of travel. This is a constraint of the web-site from which the data are obtained. Because the focus of this investigation is carbon emission it was essential that mode of travel was selected as the classification scheme for commuting behaviour. Travel mode is categorised as working at home, walking, cycling, travelling by bus, train, underground, taxi, car (as driver or passenger), motorbike or other.

Commuter origins (people's residences) were mapped at local authority level for the 354 local authority areas in England. Commuter destinations were the wards in which the workplace locations were located[3]. In order to differentiate city centre from out-of-town commuter destinations, a sample of workplace locations was constructed as follows. The UK Government (Department for Communities and Local Government)[4] publishes boundaries and statistics for consistently defined 'Areas of Town Centre Activity' for the years 1999-2004. These data identify and describe the central cores of 1,500 town and city centres and 700 'retail cores' (typically out-of-town retail and leisure destinations) in England. The areas are defined using data on employment, net internal floor-space and rateable value. Employment data is sourced from the Annual Business Inquiry at the individual person level and include full-time and part-time employees. Floor-space and rateable value data are sourced from the Valuation Office Agency. 2001 statistics were selected to coincide with the

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[3] For queries involving aggregation of geographies to different levels, for any pair of areas with different geographies, the internal flow is the flow that takes place within the smaller area.
[4] http://www.communities.gov.uk/publications/corporate/statistics/retailcores19992004

2001 census work-place statistic, the retail cores were removed and, in order to focus on the larger towns and cities, those less than 40 hectares were removed. This excludes places like Truro (39.75 hectares) and Tooting (39.5 hectares) but includes Farnham (40 hectares) and Solihull (40.25 hectares). 141 wards contain a centroid[5] from the 2001 town centre polygons as defined above (i.e. not a retail core and greater than 40 hectares in size). One of the centroids was central London and this destination has been treated separately for analysis purposes. That leaves 140 wards for non-London in-town workplaces. London workplace destination wards were selected as those which had their centroid in the central London town centre polygon; there were 95 such wards. The city and town workplace locations are shown as red dots in Figure 1. London workplaces are shown as grey dots.

Out-of-town office work-place locations were sampled from businessparks.net[6]. As of September 2010, 153 business parks were listed ranging from 9,290 to 6,900,000 square metres with an average size of 100,000 square metres. In order to geographically locate these business parks, their postcodes needed to be matched to the National Statistics Postcode Directory which records the spatial coordinates of the centroid of each UK postcode. Postcodes could not be found for 14 business parks and no match could be found for six business parks. These matching errors and omissions appeared to be due, at least in part, to the fact that some of the business parks were either under construction or had planning permission but construction had not yet begun. With the remaining business parks spatially referenced to their postcode centroids, a point-in-polygon GIS routine was used to determine which census ward each business park was located in. Because there can be more than one business park in a ward, after the matching process was complete, there were 105 wards

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[5] Hawth's Tools (http://www.spatialecology.com/htools/tooldesc.php) were used to calculate the coordinates of the centre points of the of the 141 town centre polygons, 354 local authority polygons (the commuter origins) and the 341 ward polygons (the commuter destinations)

[6] http://www2.businessparks.net/

containing one or more business parks, the locations of which are shown in blue in Figure 1. Figure 2 is a composite illustration of town and city centre workplaces. The grey shaded areas are the town centres (as defined by CLG) and the light grey polygons that surround them delineate the ward boundaries for these centres. The locations of the business parks are indicated by triangles. The way in which the business park wards (dark grey polygons) relate to the extent of urban areas as defined by the Ordnance Survey can be seen clearly in the towns and cities in Yorkshire.

A further methodological issue was the estimation of travel-related CO_2 emissions and some work has been undertaken in this area. Frost *et al* (1997) used energy consumption figures, rather than CO_2 emission, to calculate work-travel energy consumption. Per kilometre estimates of energy consumption for each vehicle type were adjusted for seating capacity and average occupancy to derive a standardised energy consumption estimate per person kilometre. So car travel consumed 2.5 mega joules per person kilometre while train travel was 0.31, light rail was 0.28 and bus travel was 0.25MJ/person km. Work-travel energy consumption is equal to person kilometres travelled by each mode multiplied by the standardised energy consumption value per person kilometre for that mode. Mackay (2008) adopted a similar but more simplified approach that focused on car-based commuting only. He assumed commuters travelled 50 kilometres per day and that the distance that could be travelled per unit of fuel was 12 kilometres per litre. Daily energy consumption was calculated as distance travelled divided by distance per unit of fuel, multiplied by energy per unit of fuel. Energy per unit of fuel is 10 kilowatt hours per litre so daily commuting energy amounted to 40 kilowatt hours per day. Mackay (2008) argued that this represents around one third of our total daily energy consumption. The focus of this paper is CO_2 emission, which is related to energy consumption but uses different metrics. Figures reporting CO_2 emission per kilometre of each mode of travel are available from the National Atmospheric Emissions Inventory (AEA, 2009) and these are summarised in Table 2. These emissions figures were compared with figures published by the UK Department for Transport[7]. In order to link modes of travel defined in the census workplace statistics to the modal classification used by the National Atmospheric Emissions Inventory, the Department for the Environment, Farming and Rural Affairs and the Department of Energy and Climate Change, walking and cycling were combined (because neither emits CO_2), and car driver and taxi modes were combined.

Results

The first stage of the analysis examined the relative performance of each workplace type; town centres, business parks and London. The distances between each residence origin (represented by centroids of local authority districts) and each workplace destination (represented by the centroid of the ward in which each workplace is located) were calculated using a Geographical Information System. Then, separately for each mode, the number of commuters from each origin to each destination was recorded. Part (a) of Table 3 shows the number and proportion of commuters to each of the three workplace types classified by mode of transport. The numbers for each transport mode are calculated by summing the number of commuters, *C*, from each origin, *i*, to each workplace destination, *j*, and then summing these figures for all origin-destination combinations to produce a total for each workplace type. This calculation is shown in equation [1].

[1]

[7] http://www.transportdirect.info/Web2/Downloads/TransportDirectCO2Data.pdf

Clearly a substantial proportion of London's workforce commutes on the underground rail network. This is why London has been treated separately from other towns and cities in the UK. Interestingly the same cannot be said for bus patronage which is comparable to business parks and lower than for other town centres. It would seem that the underground network takes the place of not only car commuters in London but bus passengers too. Around half (52 per cent) of commuters to towns and cities travel by car whereas 72 per cent of commuters to business parks travel by car. Lift-sharing seems to be more popular outside London, with no difference for town centre or out-of-town locations.

Part (b) of Table 3 shows the total vehicle kilometres travelled (VKT) to each of the workplace types categorised by travel mode. These figures are derived from the distances and numbers of commuters described above. For each travel mode the number of commuters from each commuter origin is multiplied by the distance, *D*, to each workplace. These are summed to produce a total VKT by commuters to each destination, categorised by mode, as shown in equation [2].

[2]

It is interesting to compare the figures from part (b) of Table 3 with the corresponding figures in part (a). Focusing on the underground and train modes for London, while approximately one third of commuters patronise each mode, the distances travelled by train are far greater, as expected. Interestingly, as far as CO_2 emission is concerned, around half of commuters to towns and cities (excluding London) travel alone by car. For London it is much lower (13 per cent) but for business parks it is 72 per cent. All of these percentages increase when the commuting distances are examined, revealing the longer journeys made by car relative to other modes of travel. For business parks in particular, 81 per cent of commuter miles are completed in single-occupancy cars. Since walking and cycling emit negligible CO_2 these distances are not used in subsequent calculations.

Examination of the outlier origin-destination distances and travel modes reveals some anomalies. There are, for example, three commuters from Bromley who work on a business park in Leeds and state their travel mode as underground. There may be several reasons for this; the inability of the census form to record mixed mode journeys, workers choosing to live a long distance from their place of work and commuting from a secondary residence during the working week, or incorrectly documented journey details on the census forms. Given the sample size used in this study, these anomalies should not influence the overall results unduly. The short distance measures should be treated with caution because of the possibility that they form part of mixed-mode journeys.

Part (c) of Table 3 shows the total distance travelled using each mode of transport weighted by the number of commuters using that mode (equation [2] divided by the equation [1], as shown in equation [3]).

$$\frac{\qquad}{\qquad} \qquad [3]$$

These figures shift the focus away from the work-place types and on to the commuters. This is an intermediate step towards the calculation of CO_2 emissions per commuter. It is interesting to note the long journeys that London commuters take by train and by car. The results show that, although only 13 per cent of London commuters travel to work by car, they travel long distances on average. In overall terms commuters to towns and cities travel the shortest distances, followed by business parks and then London, but noting that 76 per cent of London commuters travel using public transport. The variances around mean VKT by each travel mode are not homogeneous for the three workplace types so this precludes an ANOVA. However a non-parametric independent samples test of median VKT by each travel mode[8] reveals that these are significantly different for London, towns, and business parks.

Table 4 expresses commuting activity for each of the workplace types in terms of CO_2 emission per commuter and classified by travel mode. The table shows daily and annual emissions. For train and bus travel the results are broadly comparable across the workplace types; each commuter emits approximately one tonne of CO_2 per annum when travelling by train and around half of that figure in the case of bus travel. For single-occupancy car travel, the longer distances travelled by London commuters translate to high CO_2 emissions, as does the high proportion of shared car travel. Although car-sharing is regarded as energy efficient, if the distances travelled are long then the CO_2 emission will be high.

The total VKT by each mode for each destination was multiplied by the relevant per kilometre CO_2 emissions metric from Table 2 and then summed for all modes to produce a total CO_2 emissions figure for each workplace. This produced a single composite measure of emissions for each destination which was divided by the total number of commuters to arrive at a daily average CO_2 emissions figure per person for each workplace type. The average for towns is 4.65 kg CO_2 per person per day, for business parks it is 6.64 kg CO_2 per person per day and for London it is 3.76 kg CO_2 per person per day. The standard deviations for each workplace are illustrated geographically in Figure 3. The low level of emissions from workplaces in Greater London is clear to see, as is the high level of emissions from

[8] Underground travel was excluded from this analysis as it is not relevant to business parks and taxi commuting was excluded due to the small sample size.

workplaces to the west of London and stretching out along the M4 corridor. Figure 4 focuses on this region in particular; town centre workplaces are represented by triangles, business parks by squares and London destinations by circles. At this scale the difference in emissions between London, provincial town centres and business park workplaces is plainly evident with two exceptions; Basingstoke and Farnham.

Average annual emissions per person can be calculated by multiplying the daily figures by 230 days (5 days a week for 46 weeks a year). This results in 1,070 kg CO_2 for towns, 1,527 kg CO_2 for business parks and 865 kg CO_2 for London. This is a way of aggregating the various modes to provide an annualised composite result for each workplace type. It shows that, on average, business parks are responsible for 43 per cent more commuting-related emissions than town centres and 77 per cent more than London. At the time of the 2001 census, UK annual CO_2 emissions per capita averaged 9.57 tonnes between 1997 and 2006 (US Energy Information Administration, 2006) so the significant contribution that commuting activity makes to that total is evident.

Four factors which are not captured by this analysis should be noted. First, it does not reflect the lifecycle of carbon costs of travel modes; the manufacture, lifespan and disposal of vehicles, fuel creation and delivery for example. Second, emissions are influenced by operating conditions and speeds so CO_2 produced by those commuting in denser, more congested locations such as London are probably under-estimated. Third, compared to other modes, rail travel is more likely to be a part of mixed-mode journeys and therefore emissions will be a function of these supplementary modes too. Fourth, non-commuting trips made by workers, whether to meet clients, run personal errands or travel off-site for lunch, are more likely to be made by car in the case of business parks simply due to the lack of retail and leisure facilities on-site and the distance from the park to retail and leisure centres.

Conclusions

This research has used origin-destination commuting data from the last national population census in England to examine whether commuting behaviour differs between town centres, business parks and London workplaces. The results show that there is a significant difference both in terms of mode of travel and distance travelled. This behaviour has implications for CO_2 emissions that result from commuting activity due to the heavy reliance on private, single-occupancy vehicles by business park workers.

The extent to which a property generates and relies upon carbon-based transport is significant to its environmental performance. "Organisations in out-of-town locations are likely to have more difficulty in achieving low levels of car use" (Department for Transport, 2005). It is, therefore, important to consider environmental performance beyond the operation of the building itself. This may lead to a re-evaluation of the role of out-of-town locations in the light of their growing contribution to CO_2 emissions based on their generation of individual car movements. In the future, increasing objections to road-building, out-of-town development and unrestrained vehicle use may influence the location and use of buildings and locations that generate increased road traffic may fall out of favour. The use of census data could help test the commuting-related CO_2 emission from proposed development schemes, perhaps as part of the sequential testing for development locations, as well as informing forward planning with regard to workplace locations. Haig (1926) used the phrase 'friction of space' to describe the way occupiers seek to minimise economic transport costs when choosing a location. A similar notion might be used to describe how occupiers and planners may seek to minimise the environmental and social costs of work-related travel.

The results have implications for the way in which commuting relating CO_2 emissions are handled by eco-labelling schemes such as BREEAM. At the moment BREEAM handles location-related environmental performance by recording the number and proximity of public transport nodes and provision of cycle parking. These, it is argued, do not reflect actual travel behaviour: a bus stop that serves a business park with an hourly service throughout the day or even the provision of a dedicated shuttle bus by the occupier or park operator does not necessarily mean that workers will switch from car-based to commuting, particularly if their residences are widely dispersed. A shuttle bus to the nearest station can mean a multi-mode commute which is long and the length of such journeys is a major disincentive and is not factored into BREEAM. Mandatory energy certification of real estate in England takes form of Energy Performance Certificates and, at the moment, these take no account of commuting-related energy consumption, nor does the recently launched Carbon Reduction Commitment (CRC) Energy Efficiency Scheme.

Further research will look more closely at the proximity of workplaces to public transport nodes, investigate the origin geography at ward level and examine the relationship with travel-to-work areas. Also, network distances will be constructed instead of straight line distances and an attempt will be made to normalise the commuting data for occupation type. These enhancements will be used to construct and test models that attempt to predict variation in CO_2 estimates per worker as a function of workplace type, location or travel mode, controlling for other variables such as workplace density.

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Table 1: Travel plan surveys of commuting behaviour (Source DfT)

Organisation	Location	Car	Bus	Train	Walk	Bicycle	Motor-bike	other
Agilent Technologies	out-of-town	78.40%	0.70%	13.00%	4.00%	2.20%	1.80%	-
Andersons	in-town	23.00%	23.00%	29.00%	19.00%	6.00%	-	-
Astra Zeneca	out-of-town	91.40%	7.00%	-	-	2.00%	-	-
BP Business Centre	out-of-town	73.40%	15.10%	5.70%	5.10%	0.70%	-	
Bristol & West	in-town	36.00%	36.00%	13.00%	9.00%	6.00%	2.00%	-
Bucks County Council	in-town	65.00%	10.20%	3.60%	16.90%	3.20%	0.40%	-
Computer Associates	out-of-town	92.00%	1.00%	4.00%	1.00%	1.00%	1.00%	-
DAS	in-town	50.00%	25.00%	9.00%	10.00%	4.00%	2.00%	-
Orange (North Bristol)	out-of-town	86.00%	7.00%	-	4.00%	2.00%	2.00%	-
Orange (Temple Point)	in-town	31.00%	22.00%	16.00%	13.00%	9.00%	8.00%	1.00%
Pfizer	out-of-town	79.20%	11.80%	0.30%	1.40%	5.20%	2.00%	-
Government Office for the East Midlands	in-town	38.00%	50.50%	2.00%	9.00%	1.00%	-	-
Marks and Spencer Financial Services	out-of-town	89.00%	3.00%	2.00%	2.00%	3.00%	1.00%	-
Stockley Park Consortium	out-of-town	84.00%	12.00%	1.00%	2.00%	1.00%	-	
Boots	out-of-town	69.40%	17.60%	-	5.90%	7.10%	-	
University of Bristol	in-town	41.50%	13.50%	2.70%	22.90%	8.40%	1.90%	-
Wycombe District Council	in-town	69.00%	5.00%	3.00%	6.00%	5.00%	2.00%	-

Table 2: Transport CO_2 emissions by mode of travel ($kgCO_2/km$)

Source	Car driver (inc taxi)	Car Passenger	Train	Motor-cycle	Walk/ bike	Bus	Underground
AEA (2009)	0.20282	0.10141	0.07305	0.11606	0	0.10351	0.065
DfT (2009)	0.1276-0.257	0.063-0.1288	0.0577	-	0	0.1035	0.0780

NB: Other GHGs have not been converted to CO2 in these figs.

Table 3: Numbers of commuters and distances travelled by commuters

	(a) Commuters						(b) Distance (number of commuters x kilometres travelled)						(c) Round-trip distance travelled per commuter (km)		
	Number			Percentage			Distance (km)			Percentage					
	Towns	BParks	London	Towns	BParks	London	Towns	BParks	London	Towns	BParks	London	Towns	BParks	London
Under-ground	97,204	6,080	434,299	5%	1%	32%	2,552,898	223,868	10,788,342	4%	1%	18%	26	37	25
Train	156,043	15,312	469,843	8%	2%	34%	8,881,222	931,210	32,172,364	14%	4%	54%	57	61	68
Bus	272,844	47,506	104,991	14%	7%	8%	5,311,812	942,550	2,409,372	8%	4%	4%	19	20	23
Taxi	8,843	2,089	6,482	0%	0%	0%	171,010	62,602	145,110	0%	0%	0%	19	30	22
Car	1,002,598	465,685	183,532	52%	72%	13%	37,885,672	20,286,370	10,266,000	60%	81%	17%	38	44	56
Car-pass	109,676	37,236	14,000	6%	6%	1%	2,792,346	1,013,254	749,748	4%	4%	1%	25	27	54
Motor-bike	22,937	7,973	27,170	1%	1%	2%	674,638	253,312	912,252	1%	1%	2%	29	32	34
Bike	52,987	15,023	31,973	3%	2%	2%	875,092	278,968	596,882	1%	1%	1%	17	19	19
Walk	162,139	26,107	66,316	8%	4%	5%	2,900,570	494,826	1,175,502	5%	2%	2%	18	19	18
Home	32,337	24,388	28,463	2%	4%	2%	279,124	332,072	115,830	0%	1%	0%	9	14	4
Other	7,027	1,619	4,458	0%	0%	0%	924,580	140,988	419,256	1%	1%	1%	132	87	94
TOTAL	1,924,635	649,018	1,371,527	100%	100%	100%	63,248,964	24,960,020	59,750,658	100%	100%	100%	33	38	44

Table 4: CO_2 emissions per commuter

Transport mode	**Round-trip distance travelled per commuter (km)**			**CO_2 emission ($kgCO_2/km$)**	**CO_2 emission ($kg CO_2$/commuter/day)**			**CO_2 emission ($kg CO_2$/commuter/year*)**		
	Towns	**Business Parks**	**London**		**Towns**	**Business Parks**	**London**	**Towns**	**Business Parks**	**London**
Underground	26	37	25	0.06500	1.71	2.39	1.61	393	550	371
Train	57	61	68	0.07305	4.16	4.44	5.00	956	1,022	1,150
Bus	19	20	23	0.10351	2.02	2.05	2.38	463	472	546
Taxi	19	30	22	0.20282	3.92	6.08	4.54	902	1,398	1,044
Car	38	44	56	0.20282	7.66	8.84	11.34	1,763	2,032	2,609
Car-pass	25	27	54	0.10141	2.58	2.76	5.43	594	635	1,249
Motor-bike	29	32	34	0.11606	3.41	3.69	3.90	785	848	896
All modes					4.65	6.64	3.76	1,070	1,527	865

*assuming workers commute for 46 weeks per annum and five days per week

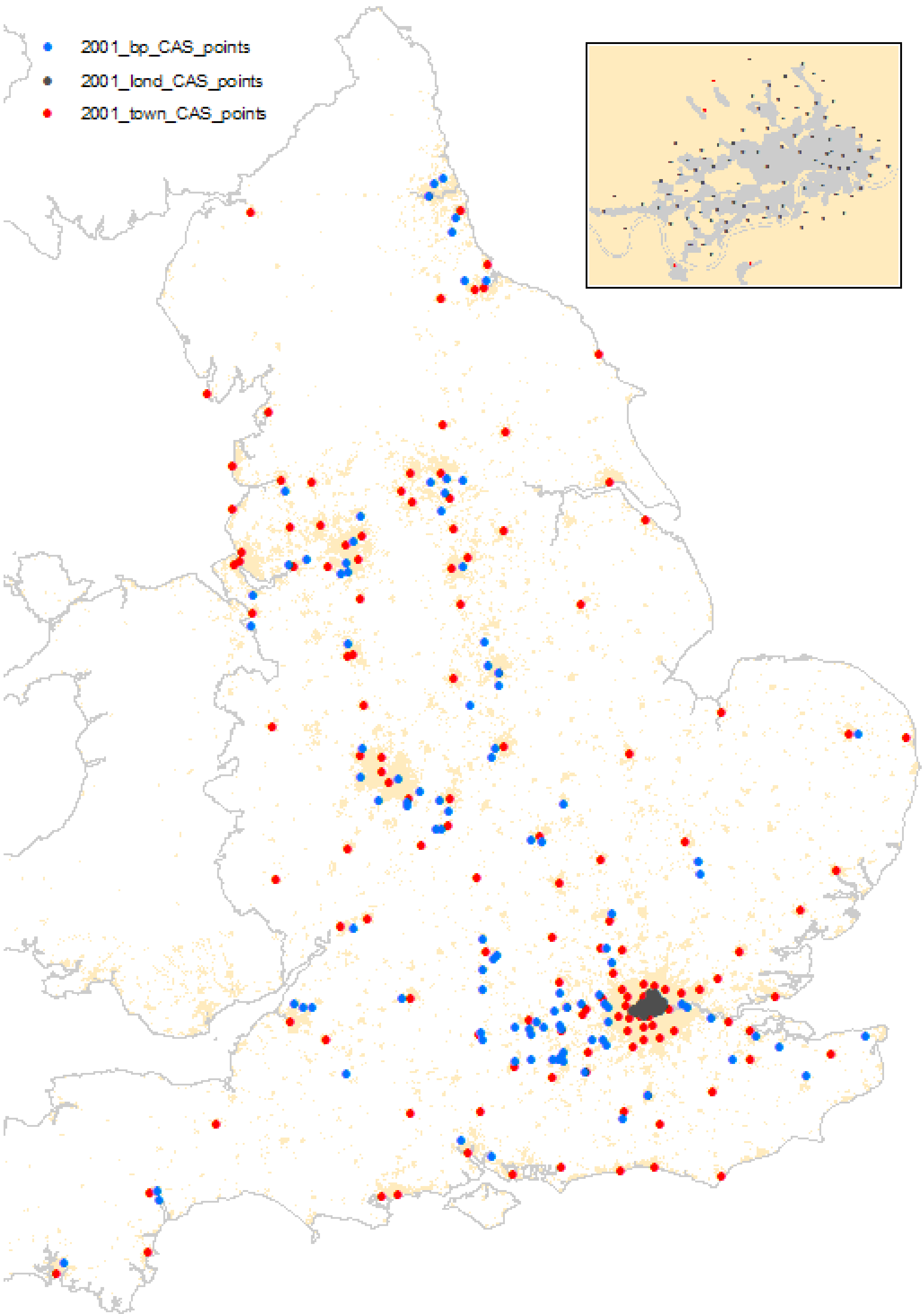

Figure 1: Workplace locations

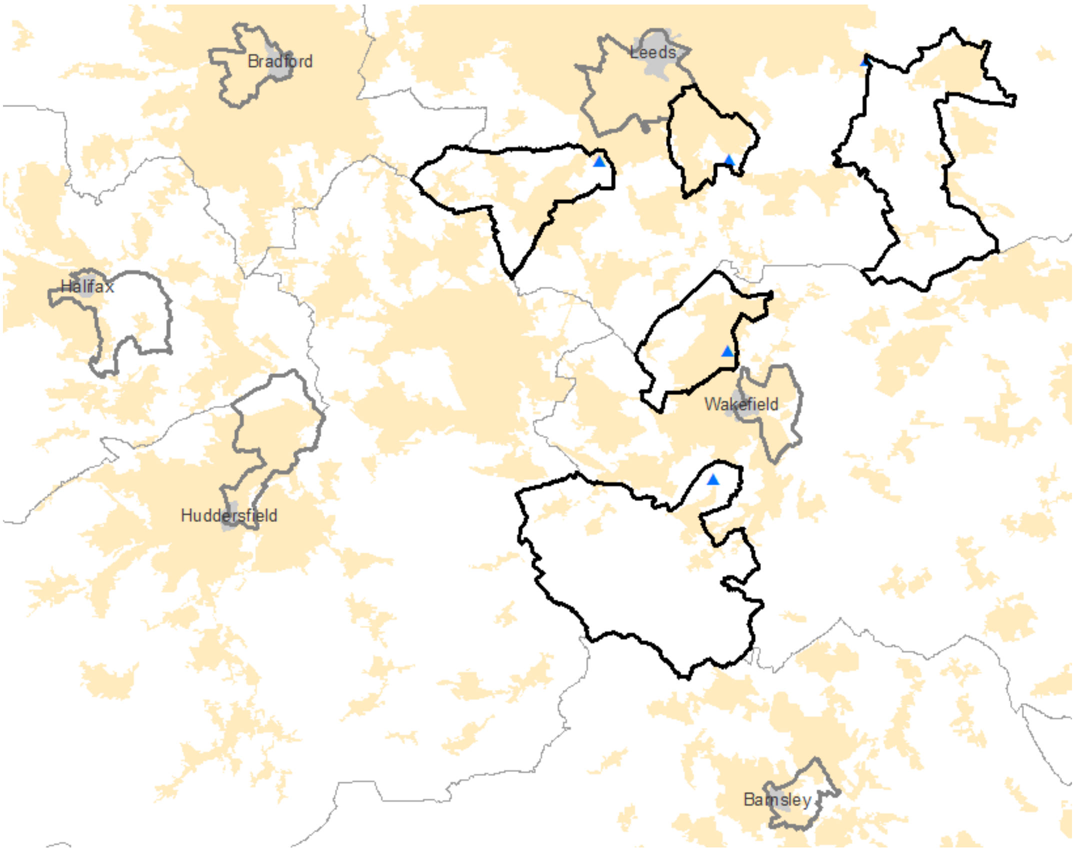

Figure 2: Town/city centre (light grey) and business park (dark grey) workplace locations in Yorkshire, UK

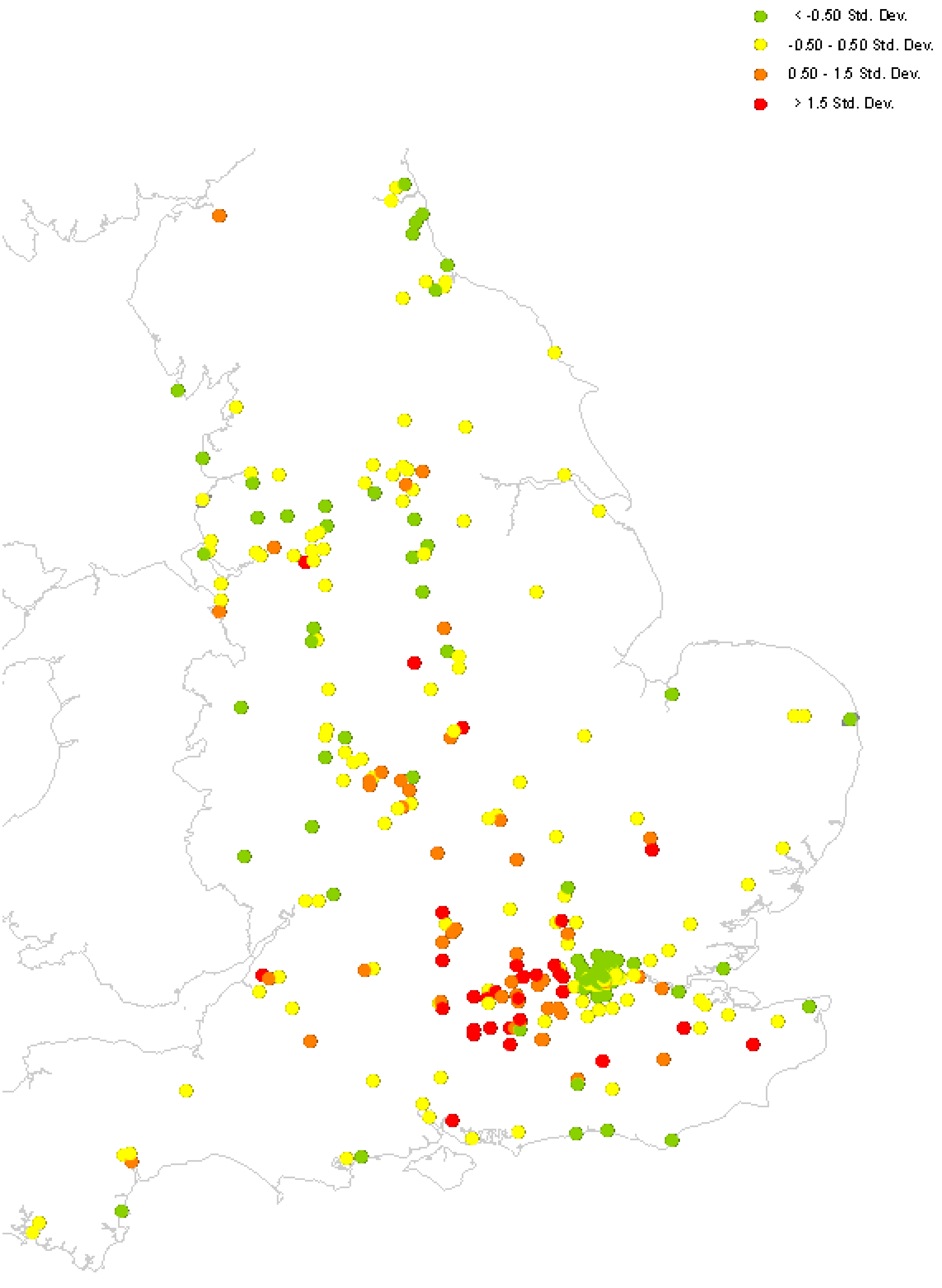

Figure 3: Standard deviations of CO_2 emissions per person from all workplaces

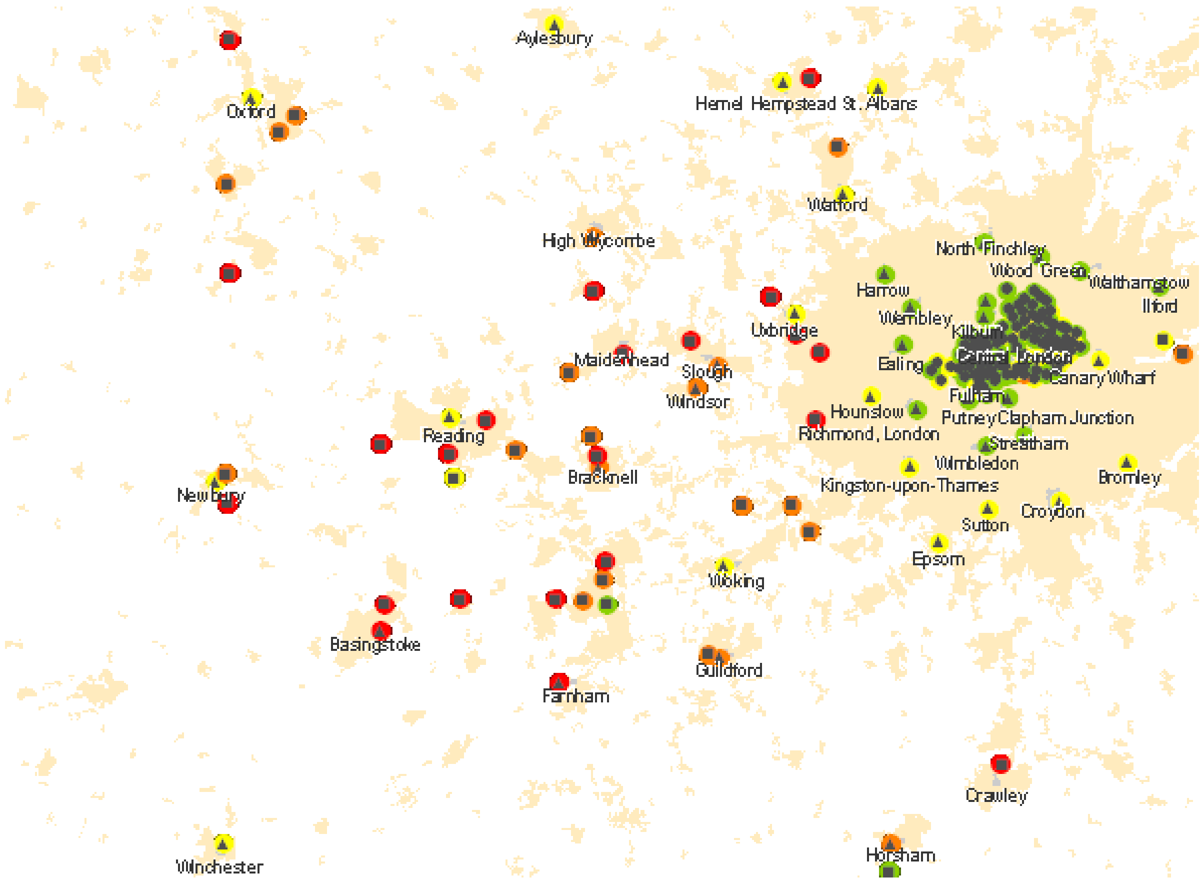

Figure 4: CO_2 emissions from town centre (triangles), business park (squares) and London (circles) workplaces in central southern England