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NET ZERO TRANSPORT

Methodological Appendix

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About this paper

This is the Methodological Appendix to the research paper Net Zero Transport: the role of spatial planning and place-based solutions, which was carried out by a research consortium led by LDA Design with City Science and Vectos.

Contents

1. Modelling carbon

Human settlements are naturally open systems with no fixed boundary. This is especially true for transport emissions which derive from the flows of people and goods, often between settlements. Many of these flows can occur cross traditional administrative boundaries or even country borders.

Defining an approach to accounting for GHG emissions therefore presents a series of challenges. In particular, there are three common methodological challenges that need to be considered in determining an appropriate approach:

- **System Boundary Problem (Box 1):** People come and go with settlements changing over the long-term and even at different times of the day. Estimates of GHG emissions can therefore vary significantly depending on the choice of system boundary applied. One of the key challenges therefore is in defining and delineating the exact boundaries of settlements.
- **Accounting Scope (Box 2):** Once a settlement boundary has been chosen, the emissions associated with the settlement do not all take place within that boundary. This is particularly the case with transport where residents create activity that generates GHG emissions beyond the settlement's own boundary, while the region itself acts as attractor for other GHG-generating activities such as employment, commerce or use of energy produced elsewhere. The accounting scope is commonly referred to by the terminology – Scope 1, Scope 2 and Scope 3.
- **Calculation Method:** Significant differences can result from the choice of calculation method. Differences could result, for example, from simple choices such as the difference between a top-down allocation of terrestrial carbon emissions vs. a bottom-up approach to emissions calculations. Different modelling approaches will also yield different results. Other differences include emissions factors used, methods for infilling missing data and methods used for calculating indirect emissions (Heijungs and Suh, 2010; Ibrahimet al. 2012).

Box 1 | What is urban? The system boundary problem

Any empirical analysis of urban and rural areas, as well as human settlements, requires clear delineation of physical boundaries. However, it is not a trivial or unambiguous task to determine where a city, an urban area, or human settlement physically begins and ends. In the literature, there are a number of methods to establish the boundaries of a city or urban area Elliot, 1987; Buisseret, 1998; Churchill, 2004). Three common types of boundaries include:

- Administrative boundaries, which refer to the territorial or political boundaries of a city (Hartshorne, 1933; Aguilar and Ward, 2003).
- Functional boundaries, which are delineated according to connections or interactions between areas, such as economic activity, per capita income, or commuting zone (Brown and Holmes, 1971; Douglass, 2000; Hidle et al., 2009).
- Morphological boundaries, which are based on the form or structure of land use, land cover, or the built environment. This is the dominant approach when satellite images are used to delineate urban areas (Benediktsson et al., 2003; Rashed et al., 2003)

What approach is chosen will often depend on the particular research question under consideration. The choice of the physical boundaries can have a substantial influence on the results of the analysis. For example, the Global Energy Assessment (GEA) (GEA, 2012) estimates global urban energy consumption between 180-250 EJ/yr depending on the particular choice of the physical delineation between rural and urban areas. Similarly, depending on the choice of different administrative, morphological, and functional boundaries, between 37% and 86% in buildings and industry, and 37% to 77% of mobile diesel and gasoline consumption can be attributed in urban areas (Parshall et al., 2010). Thus, any empirical evidence is dependent on the particular boundary choice mode in the respective analysis.

Reproduced from IPCC, Fifth Assessment, Chapter 12 (Seto K. C., 2014)

1.1. Use of Data and Carbon Tool in this Study

1.1.1. Disaggregation of Carbon

In this study we made use of a disaggregation model based on the UK Territorial Emissions table for Local Authorities published by BEIS. This data covers a basket of six greenhouse gases which contribute to global warming. These include Carbon Dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulphur hexafluoride (SF_6). In accordance with international reporting and carbon trading protocols, each of these gases is weighted by its global warming potential (GWP), so that total greenhouse gas emissions can be reported on a consistent basis (in terms of CO_2 equivalent units). Our model uses the secondary table provided which covers emissions deemed to be “within the scope of influence” of Local Authorities. This table excludes emissions for trunk roads, railways and sites within the EU ETS. We use the secondary table in order to remove motorways and large industrial sites which could adversely impact the perceived carbon for smaller settlements, however this choice may also underestimate carbon for larger settlements where the strategic road network is used by a larger proportion of residents for day-to-day activities.

The disaggregation model firstly allocates terrestrial emissions to each of the typologies examined in this study. For some places (e.g. the Wotton City-Region Polycentric Conurbation) this requires aggregation of Local Authority data, while for others (e.g. Ebsham, the smallest typology) this requires disaggregating emissions data. In these cases the relevant local authority data was used and local emissions disaggregated on the basis of population. The model then uses trip purpose and mode share data drawn from the National Travel Survey (NTS) and 2011 Census Journey to Work and regional road traffic data from the Department for Transport. The model utilises an in-depth analysis of OD trip patterns to establish commuting behaviours and carbon and then uses relationships observed within the NTS to allocate carbon across all purposes and modes. The results (for personal trips) were validated against a similar exercise undertaken by the DfT in 2008 (Barrett, 2008). The impact of vehicle emission assumptions on the model were also validated using emission factors in DfT's WebTAG.

As with any model of carbon, the model has a number of limitations. The following limitations may have a particular impact on some of the observations in the research:

- **Sample Size:** The NTS sample size is especially useful for national-level observations but the survey was not designed for disaggregation to the level of built-up areas in the UK. While our method makes use of local data and nationally-observed relationships, there is no guarantee these relationships persist at the localised level. In particular, the method applies nationally observed purpose splits to all typologies which does not capture any localised differences in trip purpose. For example, it is expected that there is likely to be a strong income driver for the types of activities undertaken which could lead to regional differences in journey purposes being under-represented.
- **Data Sources:** Each individual data source has its own limitations, for example the NTS excludes people not living in households such as students and tourists, the Van split between personal and non-personal trip types is undertaken based a national source without regional variation etc. Each of these steps may mask regional differences that will not have been picked up by this study.
- **Carbon Data:** Our method seeks to reconcile nationally recognised carbon data with a bottom-up analysis such that it can be used by Local Authorities. However, the local authority dataset is itself a model, which we then disaggregate further for smaller settlements. The current disaggregation approach (by population) may disguise some of the larger differences in trip lengths at the aggregate level. These are captured in the underlying analysis but a full regional model of transport movements for a potentially more appropriate carbon disaggregation was beyond the scope of this study.
- **Freight:** While freight patterns were reviewed in independent national models, the disaggregation of freight carbon uses the vehicle mile split drawn from DfT statistics at regional level. This split is applied proportionately to vehicle miles in each geography. This is again likely to limit the regional variations. In freight in particular, further high-quality data would be beneficial to improve the analysis.

1.1.2. Modelling the impact of Carbon Interventions

Having developed a carbon disaggregation for each typology we then apply a series of interventions. The underlying research that feeds into the assumptions for modelling the impact of each intervention is set out in section 0.

The carbon impact model uses a hierarchical (ordered) attribution of carbon emissions. This is important to note, as the ordering of the interventions impacts the size / scale of the carbon benefit attributed. For example, imagine a town that produces 100 units of transport carbon. If transport demand was first reduced by 50% and then 50% of the remaining travel served by zero carbon modes, demand reduction would be attributed 50 units of benefit and mode shift 25. If this ordering was reversed, mode shift would be attributed 50 units and demand reduction 25.

Our chosen hierarchy is based on the SAM framework which prioritises interventions that substitute (avoid) trips first, shift modes second and finally switch fuels. As a result of initial substitution (trip avoidance), mode-shift impacts may appear reduced. After all interventions have been "exhausted", fuel switching is then applied to all residual carbon.

Each typology also includes a "do nothing" carbon increase. This is the carbon increase that would be expected if we were to assume that new developments were built with no change in the intensity of current transport carbon i.e. all new developments induce new travel demand and no measures are taken either locally or nationally to reduce emissions. Housing projections in each case are taken from the ONS housing forecasts and, as a result, do not reflect potential local increases from national housing targets outlined in the planning white paper.

Finally, carbon impacts are presented in the following categories – Do nothing increase in carbon, zero-carbon developments (which combine interventions to ensure new developments add no carbon), substitute trips, shift modes, switch fuels. For the workshops, in total 40 interventions were individually modelled based on the available academic evidence and real-world evidence presented in section 0. Naturally, this evidence was converted into a series of assumptions. Many of the assumptions represent a balance between ambition and evidence. The assumptions for the final pathways are presented in Section 3.

Allocation of individual measures is highly complex in a range of areas but in particular attribution of different interventions (enablers vs. deterrents) within the shift-mode category and attribution of vehicle-based vs. infrastructure-based interventions within the switch-fuels category. To simplify this, in the mode-shift category, we first present the impact of mode-shift in line with a UK benchmark, then we present the further impact of mode-shift beyond the UK experience to date without attribution. For switch-fuels we present the interventions by vehicle group – freight, private vehicles and public transport.

1.1.3. Understanding Current Emissions Profiles

Despite the limitations, the model enables us to make some broad conclusions about transport carbon, in particular with regards to mode and purpose. We start by discussing the broad observations and then identify Typology-specific observations through further analysis of commuting data.

Personal Trips:

To disaggregate carbon by journey purpose, the model draws on data from the National Travel survey including trips, average trip lengths (Figure 1), trip modes (Figure 2) and occupancies enabling us to calculate vehicle miles and carbon emissions by purpose. The carbon split for personal travel is presented in

Figure 1: Average trip lengths by purpose and mode . Data from previous analysis by the DfT (Barrett, 2008) is included for comparison. The overall split for personal travel by purpose appears relatively consistent, however as discussed above, this may be a limitation of the data input to the model being more appropriate for national analysis.

Table 1: Estimated CO_2 emissions from all modes of passenger transport by journey purpose. DfT Source - Barrett, 2008

	DfT Analysis (2008)	Base Model (NTS Only)	Wotton City-Region (Polycentric Conurbation)	Castlemore (Unicentric Regional Centre)	Stoneborough (Regeneration Town)	Ebsham & Monteshire (Growing County)
Commuting	24%	22.9%	22.9%	22.8%	23.2%	22.9%
Business	13%	9.7%	9.7%	9.7%	9.6%	9.6%
Education	4%	3.6%	3.6%	3.4%	3.9%	3.4%
Shopping	14%	10.8%	10.8%	10.8%	10.8%	10.8%
Other Escort	8%	7.6%	7.6%	7.7%	7.3%	7.5%
Personal business	8%	7.9%	7.9%	8.0%	7.9%	8.0%
Leisure	30%	37.4%	37.4%	37.5%	37.3%	37.6%
Other	0%	0.1%	0.1%	0.1%	0.1%	0.1%
	100%	**100%**	**100%**	**100%**	**100%**	**100%**

Figure 1: Average trip lengths by purpose and mode

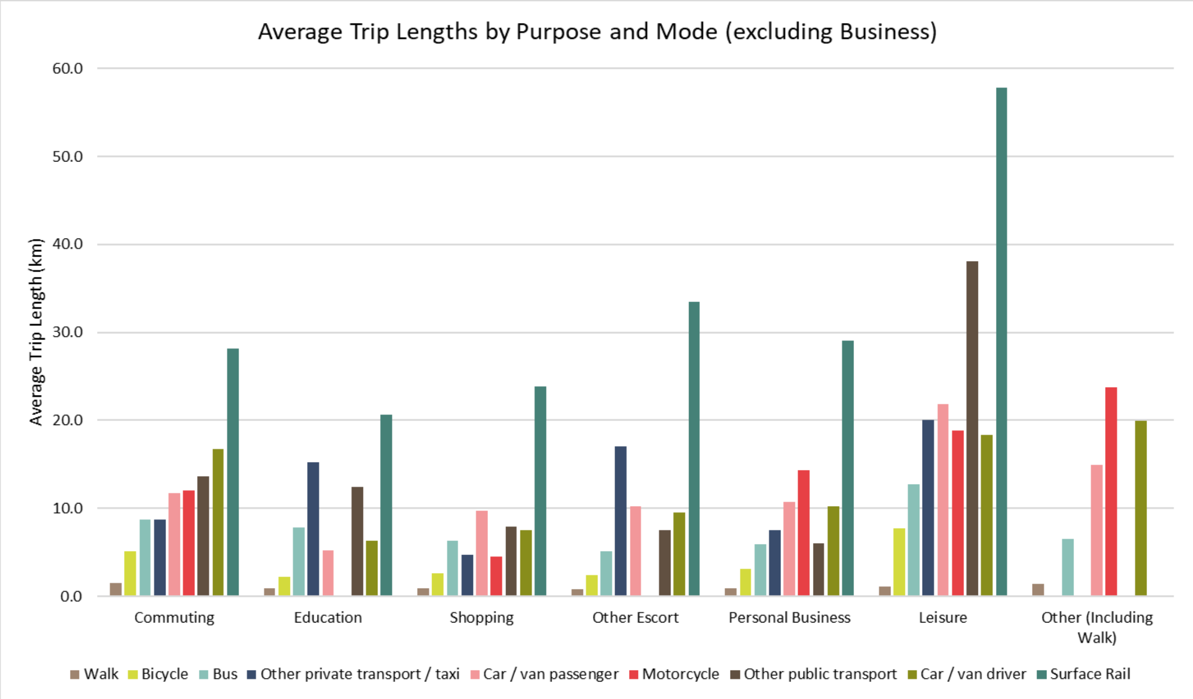


Figure 2: Average mode share by purpose

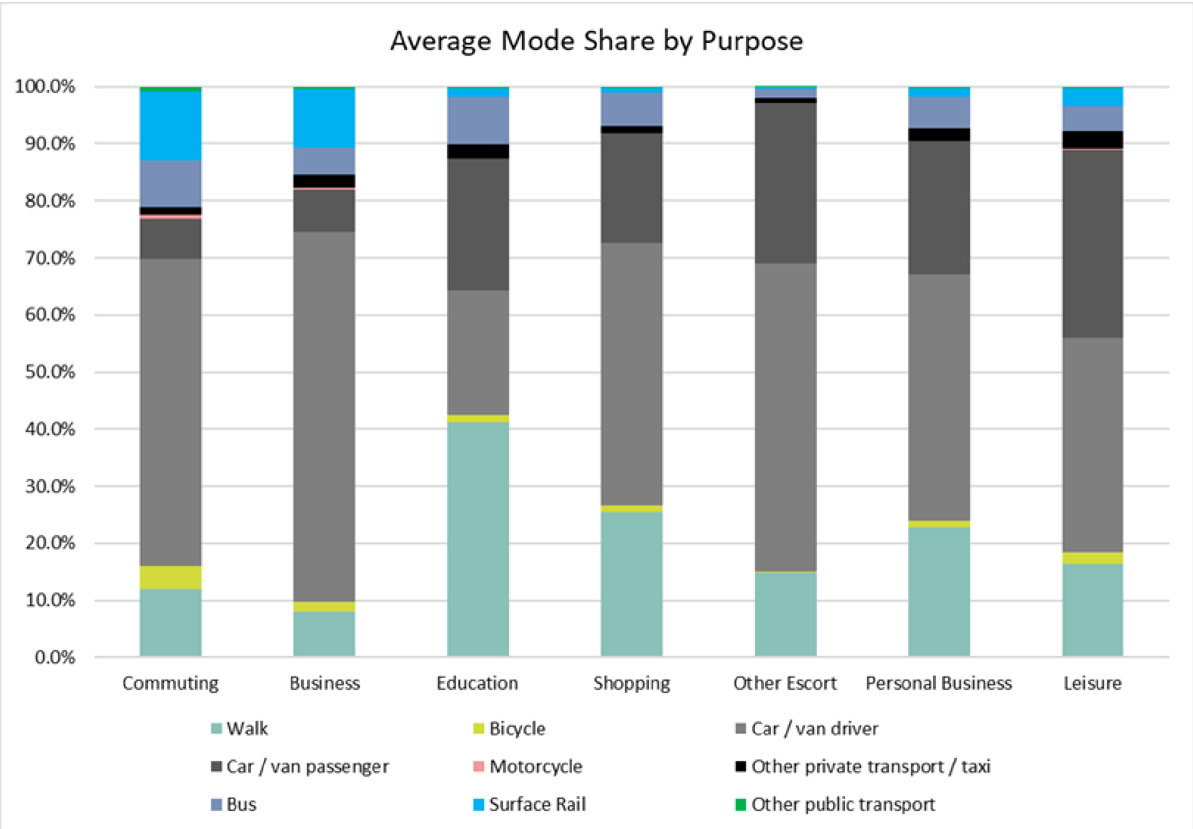
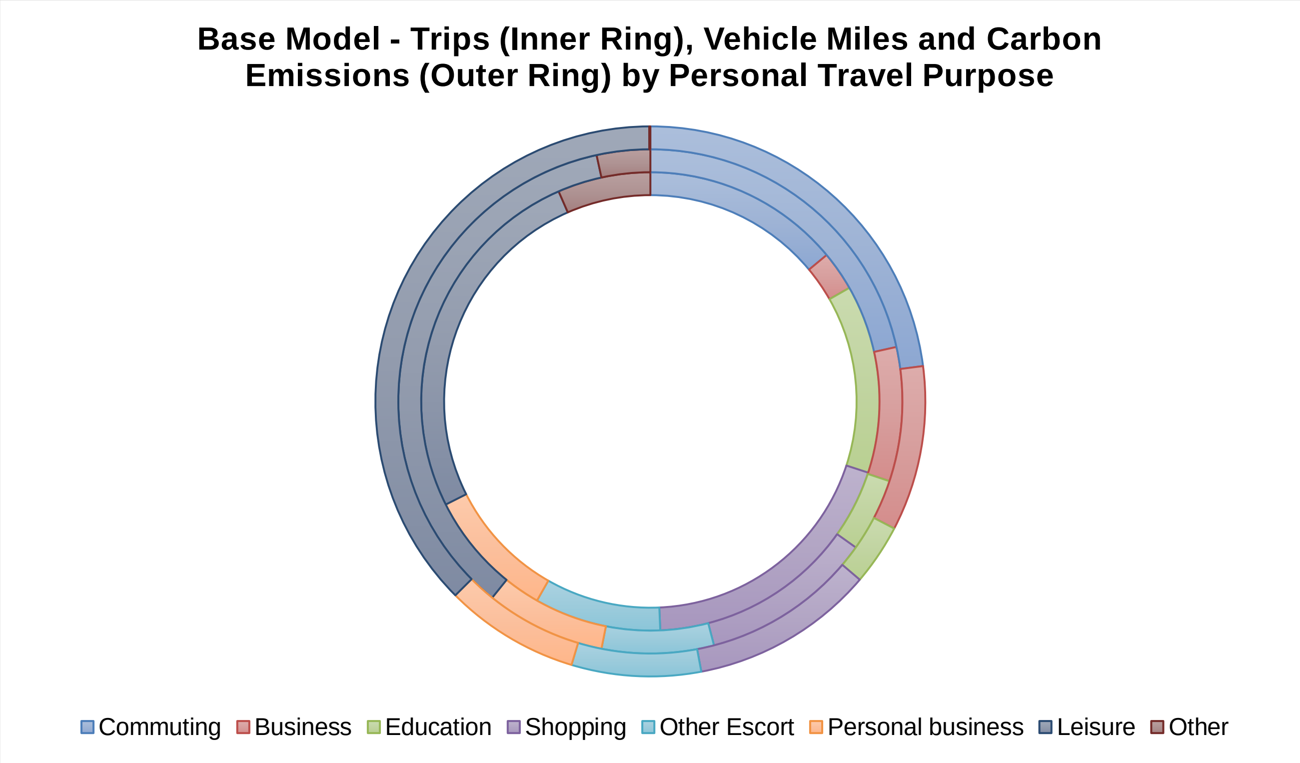


Figure 3 shows the difference between the share of trips, vehicle miles and carbon emissions by purpose at the national level for personal trips. From this we can see for example that commuting accounts for 14% of personal trips, 22% of personal vehicle miles and 23% of carbon emissions while Leisure purposes account for 26% of personal trips, 36% of personal vehicle miles and 37%

of carbon emissions. Overall, ~70% of carbon emissions derive from commuting, business and leisure trips. These trips are also those with longer average trip lengths.

Figure 3: Difference between trips, vehicle miles and carbon emission share (Source: NTS)

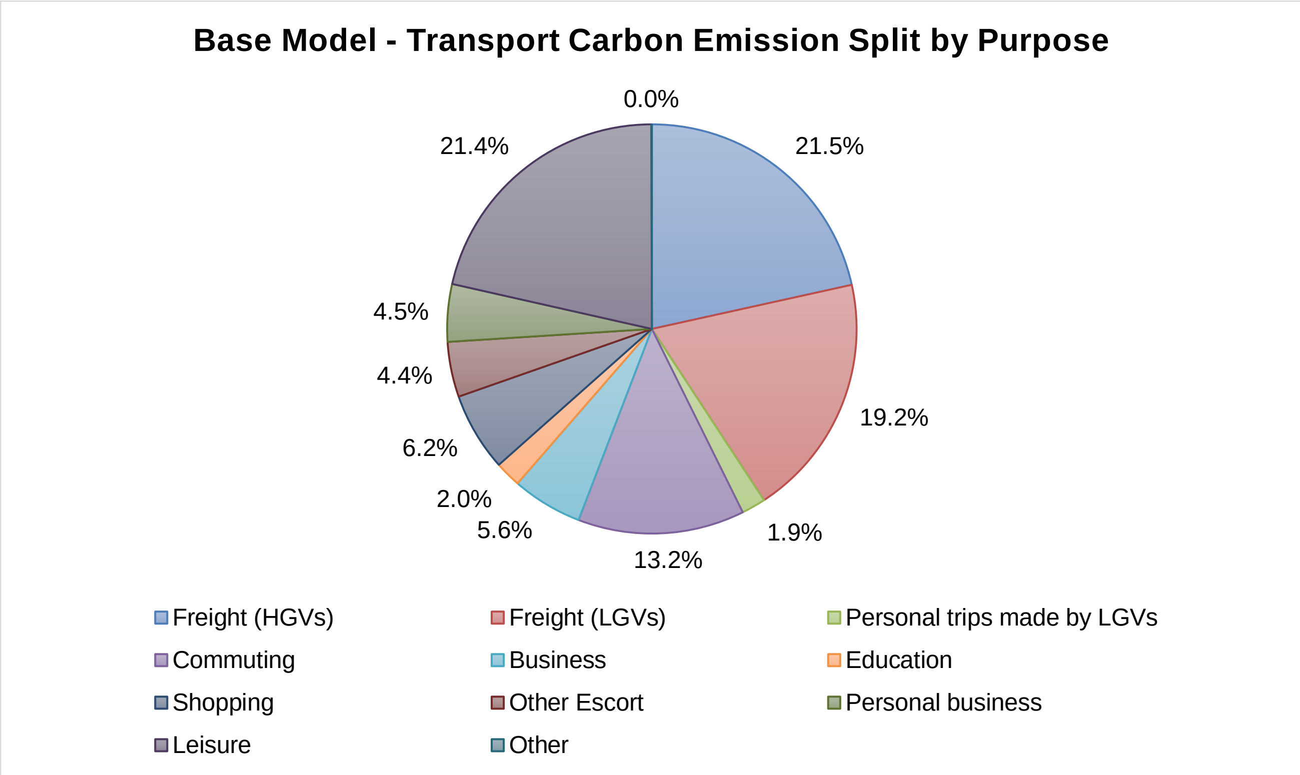


Total Trips: Error! Reference source not found. and Figure 4 set out the split for each typology including Freight trips. It can be seen that freight accounts for between 30%-33% of total emissions in each typology. Addressing the decarbonisation of freight will require considerable new understanding for local freight movements and their drivers.

Table 2: Estimated road transport CO_2 emissions split by typology

	Wotton City-Region (Polycentric Conurbation)	Castlemore (Unicentric Regional Centre)	Stoneborough (Regeneration Town)	Ebsham & Monteshire (Growing County)
Freight (HGVs)	16.6%	15.9%	14.9%	17.0%
Freight (LGVs)	14.8%	16.4%	15.2%	15.9%
Personal trips made by LGVs	1.5%	1.6%	1.5%	1.6%
Commuting	15.4%	15.1%	15.9%	15.0%
Business	6.5%	6.4%	6.5%	6.3%
Education	2.4%	2.2%	2.7%	2.2%
Shopping	7.3%	7.1%	7.4%	7.1%
Other Escort	5.1%	5.1%	5.0%	4.9%
Personal business	5.3%	5.3%	5.4%	5.2%
Leisure	25.1%	24.8%	25.5%	24.6%
Other	0.0%	0.0%	0.0%	0.0%
	100%	**100%**	**100%**	**100%**

Figure 4: Transport Carbon Emission Disaggregation by Purpose



Local Movements: Figure 5 - Figure 8 show the detailed picture of trips and vehicle kilometers travelled for each of the typologies by distance derived from Journey to Work data from the 2011 census. Since vehicle miles are a key driver of carbon, this analysis can help us understand the broad travel footprint of each of the typologies. For example, in Typology 1 (the Wotton City-Region), the majority of trips are in the 0-40 km range with the majority of vehicle miles recorded below 60 kms. In contrast, as we move down to Typology 4, trips are much more geographically dispersed with many trips being greater than 40 km. The majority of vehicle miles (over 80%) for typology 4 are actually generated more than 20 kms away from the settlement itself! Addressing longer distance trips is one of the key factors our interventions need to consider.

Figure 5: Typology 1: Polycentric Conurbation (the Wotton City-Region) - trip number (left) and vehicle miles (right) by distance

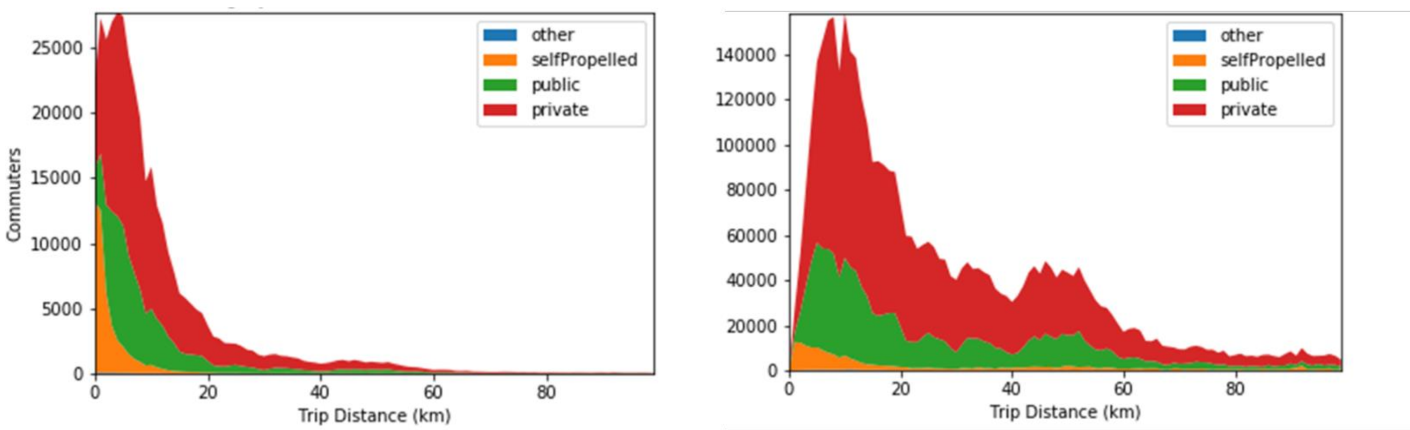


Figure 6: Typology 2: Unicentric Conurbation (Castlemore) - trip number (left) and vehicle miles (right) by distance

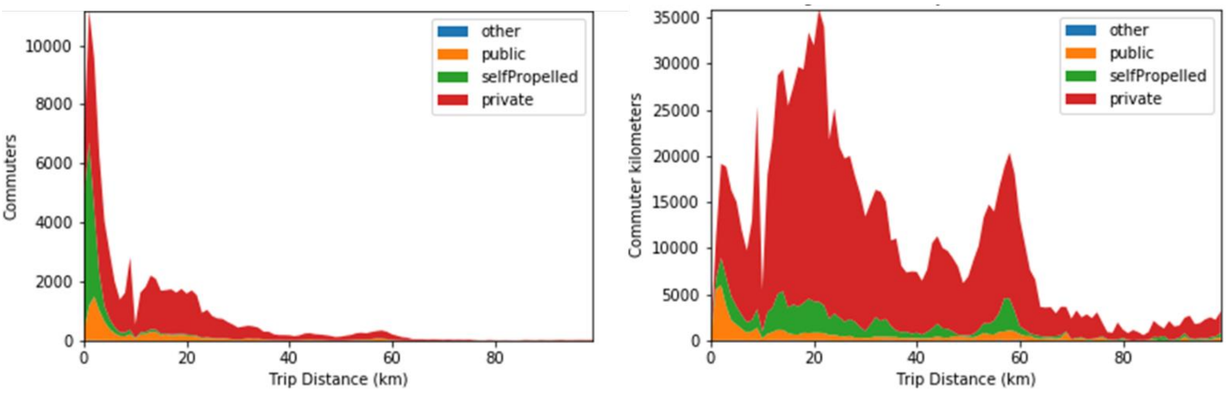


Figure 7: Typology 3: Regeneration Town (Stoneborough) - trip number (left) and vehicle miles (right) by distance

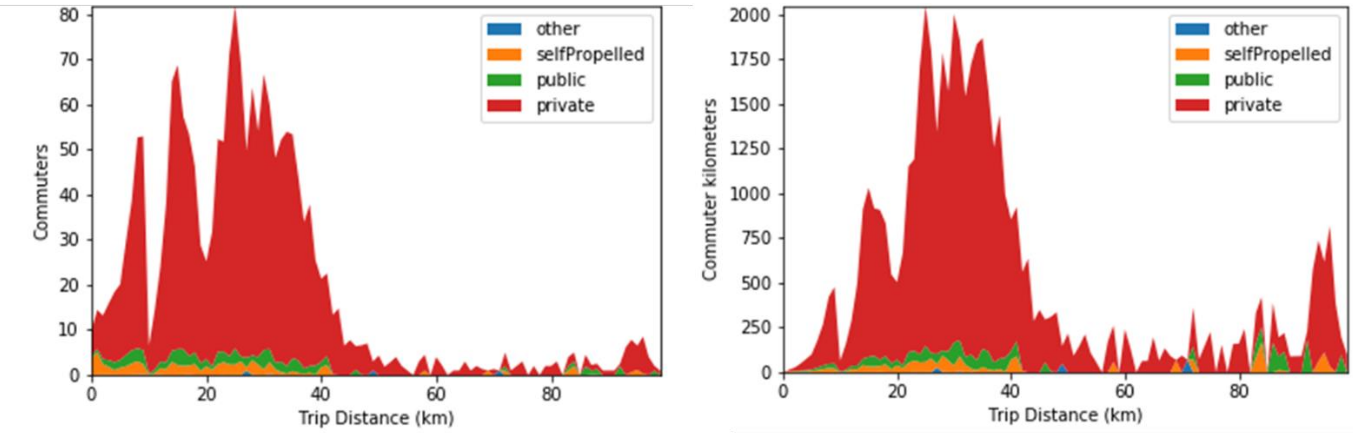


Figure 8: Typology 4: Growing County (Ebsham and Monteshire) - trip number (left) and vehicle miles (right) by distance

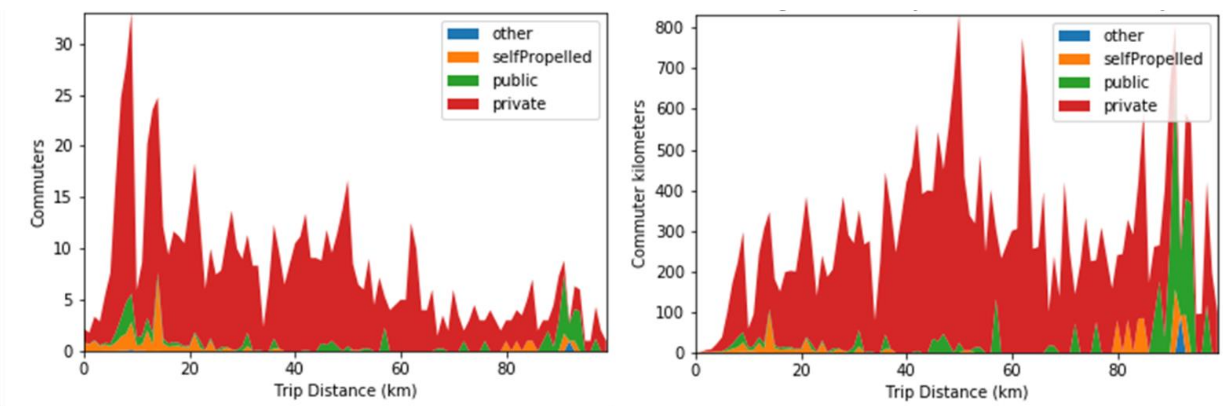


Table 3 summarises these charts into the average daily commuting vehicle km for each typology, presenting these on a per capita basis. This offers an indication of the likely trends in per capita carbon emissions for each typology. The table clearly shows that the vehicle kilometres for private vehicles increase as the size of the settlement gets smaller.

Table 3: Average daily commuting vehicle km per capita by mode and typology

Typology	Private Vehicle km / capita	Public Transport Vehicle km / capita	Active Travel Vehicle km / capita
Typology 1 (Largest)	0.6	0.3	0.1
Typology 2	3.4	0.9	0.7
Typology 3	5.9	0.5	0.6
Typology 4 (Smallest)	6.1	1.4	0.7

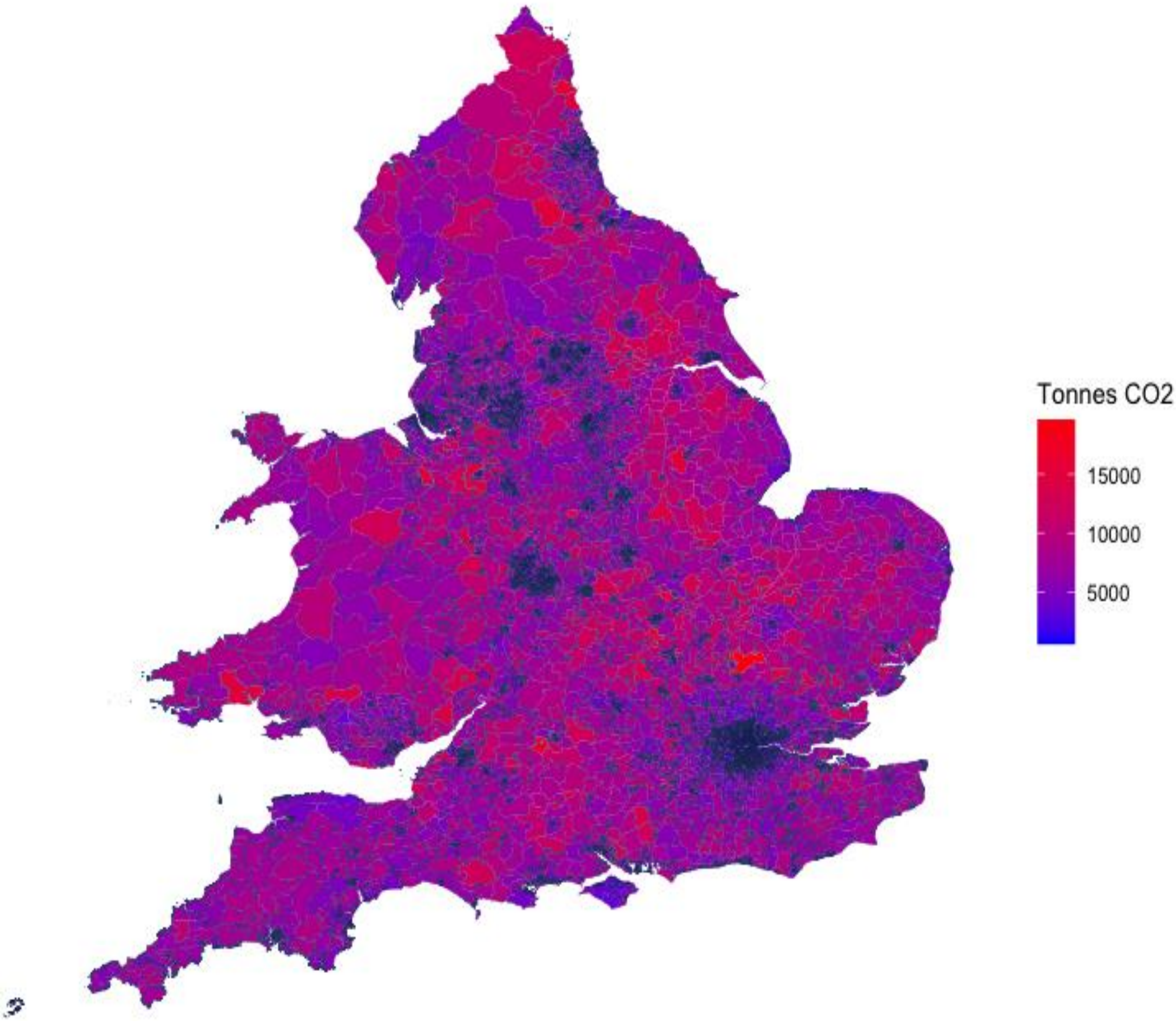
1.1.4. Carbon Emissions and Urban Form

The RTPI previously reviewed the evidence linking settlement patterns, urban form and sustainability (RTPI, 2018). The UK is one of the most densely populated countries in Europe with 13% of land built-up. Most of the UK's settlements have largely concentric densities (high-density inner areas; medium density outer-central areas; low-density suburbs), with many being belted by protected land (Williams K. , 2014). The traditional development pattern in many English settlements is for larger settlements to be surrounded a "patchwork of smaller towns, villages and hamlets separated by open land". The majority of places settlements are of low density with around 84% of the English population estimated to live in some form of suburb (RTPI, 2018).

Urban form has a clear impact on overall carbon of different typologies for settlement. An extensive body of evidence has explored the relationship between urban form and greenhouse gas emissions with the majority focusing on broad energy use across all purposes. While there are limited studies focusing solely on transport some general drivers have been identified. Key drivers identified for total carbon include density, land use mix, connectivity and accessibility (Seto, 2014; Creutzig, 2015; Williams, 2013). However, emissions of individual settlements are also charaterised by unique, place-specific combinations of factors, in particular income (Baiocchi, 2015) and other potential factors such as fuel mix, distance to nearest larger settlements and effectiveness of regional services (O'Regan, 2009). Previous analysis of human settlements in the UK finds that very high income households in low-density settlements with large houses are likely to exhibit the highest household total carbon emissions (Baiocchi, 2015). In contrast, large and compact settlement patterns tend to make more efficient use of infrastructure networks (RTPI, 2018) and as a result should minimise per capita carbon. However, the scope of carbon emissions reviewed is also likely to play a significant factor with some evidence that consumption-based CO_2 emissions may be higher in urban areas with socio-economic determinants such as income, education and car-ownership key drivers (Minx, 2013).

A holistic analysis of transport carbon in the UK has not previously been undertaken. To address this, we use a mixed effects linear model to estimate the effects of fixed socioeconomic factors and random geographically related factors at MSOA-level. The analysis addresses transport carbon from commuting only with data drawn from the ONS 2011 Census JTW tables. Using this mode, population, average income and economic activity indicators all significantly predicted commuting carbon. Geographical factors at MSOA and LA level were also significant predictors.

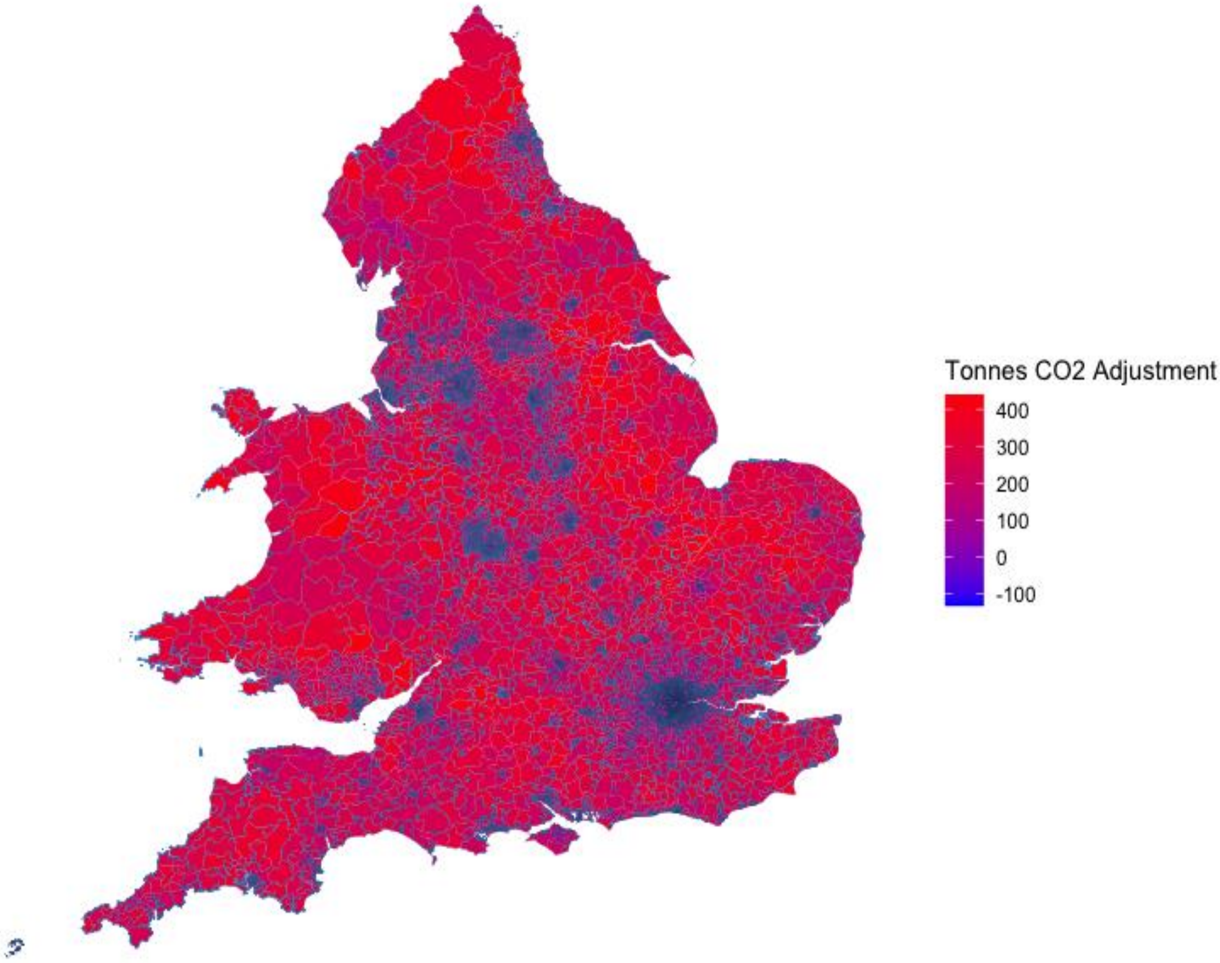
Figure 9: Carbon Footprint of Commuting in the UK (Source: City Science estimates, ONS Census JTW 2011)



Overall, the model predicted 61% of the variance in carbon emissions at the MSOA level. The pattern of MSOA factors is clearly very geographically dependent with large cities tending to have much lower-than-expected commuting carbon footprints. Rural areas with good access to the transport network are seen to have the highest carbon footprints (

Figure *10*). Greenfield sites with good access to the road transport network are often very attractive sites, but the implications of this initial model imply that these are likely to generate the highest commuting carbon footprints.

Figure 10: Modelled MSOA factors for transport carbon (Source: City Science estimates, ONS Census 2011)



2. Summary of interventions considered

For each typology over 40 individual interventions were considered and their potential impacts modelled. Interventions were grouped using the SAM framework. The research that underpins the treatment of the interventions in the subsequent carbon estimation is outlined below.

2.1. Substitute Trips

Land Use Planning

Mixed use developments meeting greater range of local needs

For a development to be truly low carbon, the strategic location, land use mix and access to transport options need to be right (Campbell, 2020). Previous research regarding the impact of built environment on travel behaviour has reported mixed findings, with some studies observing statistically significant effects while others not (Zhang, 2012). The reasons for these different conclusions are not known and this gap has made it difficult for decision makers to evaluate land use plans and policies according to their impact on vehicle miles travelled (VMT), and as a result their carbon impacts. Development 'compactness' is usually defined by 'D-variables' - density, diversity, design, destination accessibility, and distance to public transport. A body of evidence suggests that compact settlements encourage reduced driving, but that the effects can be small, depending on the D-variable observed (Stevens, 2016). Previous US studies have modelled the carbon impacts of compact developments assessing the impacts against a future 'business as usual' baselines (Burchell et al., 2002; Ewing, 2007). These studies indicate that Carbon emissions could be reduced by between 4%-10% against a future baseline. However, since the baselines in these studies assume significant development, there is a risk that absolute carbon emissions increase. In this study, we take the view that to secure net zero, all new developments need be net zero by design to mitigate against any residual carbon. Achieving this will likely involve a combination of land-use planning, transit-oriented development, and restrictions to private vehicles.

Local amenities within short walk and cycle (15-minute neighbourhood)

The concept of the "15-minute neighbourhood" (also referred to as the "15-minute city" and "20-minute neighbourhood") aims to reduce the need to travel by ensuring that all services and activities fundamental to well-being are provided within a short walking or cycling distance. This concept essentially aims to achieve mixed use, but through retrofit of existing settlements. As a planning concept the 15-minute neighbourhood is growing in popularity and was generally embraced by participants in this study. A meta-analysis of 36 studies of the relationship between development compactness and vehicle miles, identifies that distance to the centre (or 'downtown') has an elasticity of -0.63 – i.e. a 1% reduction in distance to the centre, would reduce Vehicle Miles by 0.63% (Stevens, 2016). This adds promise to concept that greater proximity could reduce vehicle miles. However, since implementations of 20-minute neighbourhoods are at an early-stage, further empirical research on their successes and carbon impacts is needed. For the purposes of this study we estimate the potential impacts by considering the potential to reduce vehicle miles or switch individual trips by purpose, considering the context of each individual typology. It is important to note that in less populous typologies (e.g. Typology 4), questions of cost-effectiveness, viability and the role of the state will need to be addressed.

Recreation space embedded in neighbourhoods

Increased space for leisure, in particular recreational space, is expected to impact carbon in the following ways – 1) providing a modest reduction in the need to travel for a sub-set of leisure trips, 2) replacing car dominant design, in some cases restricting access and reducing the convenience of driving and 3) increasing the natural carbon sinks in the built environment. In our modelling, we do not consider recreation space explicitly, rather addressing the effects as part of the 20-minute neighbourhood or traffic restrictions. We do not consider the impact of carbon sinks.

Co-Working Spaces (local, in new developments / disused shops)

At the peak of the COVID-19 pandemic, 49% of workers were working from home (ONS, 2020). It has therefore been suggested that Co-Working spaces could encourage more people to work in their local area on a permanent basis. While it is unlikely that co-working space is a necessary condition to support increased local working over the long-term, it is seen as likely to be an attractive option in supporting reduced need for travel, potentially encouraging workers with a lower propensity to work from home to reduce their commuting distances. At the same time, however the intervention may also induce some local trips to a shared space that would otherwise work from home. As an emerging area, more formal research will be needed. In the next section we consider the broader impacts of digital technology and home working on carbon emissions.

IT Infrastructure

Home working (Superfast broadband and house design to allow for work space)

The Code for Sustainable Homes provided credits for a home office recognising the potential role of home working on reducing the need to commute (CLG Communities and Local Government, 2010). The potential role of digital technology in transport planning to achieve accessibility outcomes had been noted well before the COVID-19 pandemic (Lyons, 2016). Prior to COVID-19 there had been some work on the impacts of 'telecommuting' but 2020 has revealed the full potential of home working as an alternative to office-based work. In fact, at the peak of the COVID-19 pandemic, 49% of workers were working from home (ONS, 2020). A systematic review of 39 empirical studies was recently undertaken to provide an up-to-date state of knowledge with regards to the energy (and carbon) impacts of home-working (Hook, 2020). The 39 papers reviewed vary in their conclusions with some suggesting teleworking could reduce emissions by up to 77%, while others suggest emissions may increase. While many studies identify the potential benefits from reduced commuting, other factors may reduce the overall carbon benefits if unmanaged – for example, impacts of increases in home energy consumption or unpredictable increases in non-work travel. It is also generally found that workers are more inclined to accept a job that is located farther away from home if they have the ability to work from home one day a week or more (de Vos, 2018). With studies suggesting possible increased distances of between 2.3-10.7 miles, if uncontrolled, longer-term land-use effects could induce sprawl and result in higher carbon for non-commuting journeys (Helminen, 2007; De Abreu, 2017). To realise carbon benefits then, home working likely needs to be combined with other land-use and energy efficiency measures to mitigate potential unintended consequences.

Impact of Digital on other Journey Purposes

Once we consider the potential benefits of home working on carbon emissions, it is then natural to consider its potential role on other purposes. A range of services are increasingly being delivered through digital means including elements of further and higher education and some health and GP services. We can explore the potential impacts of these advances by applying potential impacts to the carbon emissions by purpose (see section 1.1.3). Overall, the impacts are likely to be less than for commuting given the lower carbon contribution. However, additional efforts to minimise the need for travel across other purposes could also be an important consideration to mitigate the potential rebound effects of home working noted above.

Home Deliveries

Another area where digital technology is having a significant impact is in our shopping habits. Home supermarket retail reached 20% of the total market share in June 2020 (Kantar, 2020) and the online share of total retail sales reached 32.8% (ONS, 2020). There is general agreement that online shopping is beneficial from a carbon perspective with store based ('bricks-and-mortar') retail systems likely to have lower emissions in only a small number of contexts (Smidflet Rosqvist, 2016; Al-Mulali, 2015; Weber, 2010; Van Loon, 2014; Carling, 2015). However, again there are complex effects that need to be considered, in particular shopping behaviour and rebound effects such as use of time-saved to conduct more travel.

While overall there is evidence that home deliveries are beneficial, the impacts likely vary by location and purpose. For example in our Typology 4: Ebsham and Monteshire (Growing County), distances to the nearest supermarket are high (5-6 miles). Reducing these car trips and replacing with an optimised route is likely to be beneficial. But with multiple operators and limited sharing of commercial data, it is difficult to monitor, let alone guarantee these benefits. Specific behavioural impacts also matter including the degree to which online shoppers attend traditional retail outlets in their buying decision (Weideli, 2013); whether the delivery is itself successful first time; and the returns policy of the retailer, in particular in relation to 'fast fashion' (Edwards, 2009). Similarly, the delivery mode has an impact in particular where the long-haul leg is by air (Van Loon, 2014). In some city centres, online retail is also having a significant impact on traffic volumes (Jamshid, 2016) with wider potential implications on traffic speeds and emissions. These latter effects are likely to be most acute in our Typology 1: Polycentric Conurbation (the Wotton City-Region).

Logistics Infrastructure

Micro-consolidation - Cargo bike / Electric Vehicle last mile delivery:

Micro-consolidation refers to interventions that seek to replace last-mile deliveries with low carbon options. These could include cargo bikes, e-cargo bikes or electric vehicles. Delivery services by LGVs have been claimed to account for 29% of LGV miles (Cherrett, 2019; DfT, 2009)[1] however,

[1] The original source for this figure is believed to be the Van Activity Baseline Survey 2008. Given the changes to LGV activity over that period it is recommended that more up-to-date studies on LGV activity are undertaken.

there is limited data on the split between "depot to town" and "within town" legs of the journey. A number of studies have sought to estimate the potential for cargo-bikes/e-cargo bikes to replace motorised trips within city centres with potential impacts ranging between 14% to 55% (Schliwa, 2015; Gruber, 2013; Browne, 2011). Using these values and depending on the impacts assumed, the carbon impacts could therefore be between 4% and 16% of current carbon associated with LGVs. However, given recent increases in LGV miles, further research should be undertaken to validate movement data and constraints to realising this potential.

In addition to mode shift of vehicles, consolidation (combining multiple servicing or delivery vehicle movements into fewer, larger consignments) can also have beneficial impacts. Evaluation of Freight Consolidation Demonstrator Projects in London found positive impacts on trips and vehicle miles, in projects where data on vehicle mileage was available (TfL, 2019) – for example the Camden Freight Consolidation Centre demonstrator claims a 66% reduction in vehicle miles[2]. In urban areas then, combined with mode shifting, consolidation has high potential. Research on the impact of consolidation approaches in more rural typologies is limited.

Flexible pick up / drop off points for home deliveries:

In addition to consolidation and mode-shift, flexible pick up / drop off points could be introduced for home deliveries. Parcel pickup points would reduce the very final portion of the trip to a walking trip instead of taking the goods directly to the customer's door. Since a single drop-off can be made instead of multiple, it can potentially save multiple short trip-legs. However, if cargo bikes are already implemented the introduction of pick-up points will have limited additional carbon impact. From an operational perspective such facilities may improve fleet optimisation opportunities reducing delivery times and costs, and, as a result, may help to make cycle-based deliveries more viable for certain goods.

Negative Carbon Developments

Negative carbon developments bring together all demand reduction, mode shift and fuel switching interventions to ensure that new developments have no net carbon impact. This is important since until our systems are at a net zero position, every new development will create a net generation of carbon unless this is managed. It is envisaged that this would be achieved through a number of approaches including restraint on private vehicles – for example eliminating parking within the development itself. But successfully achieving this will also require greater integration between transport and land-use planning, increased density, improved facilities that better cater for the full range of needs of residents, long-term support for alternative sustainable modes to and from these new developments, on-site generation and charging infrastructure and improvements to wider networks to enable connectivity.

[2] Note the underlying data supporting this was not reviewed as part of the evaluation.

2.2. Shift Modes

Incentives vs Deterrents

The interventions that follow consist of those designed to shift use away from the private car to either public transport or active modes. These interventions naturally comprise both carrots (enablers of alternative modes) and sticks (deterrents to the private car). The majority of studies focus on interventions aimed at enabling active travel rather than deterring driving and there are limited studies covering both effects simultaneously. Literature reviews find that interventions aimed at enabling active travel have modest impacts - up to 5% at best (Piatkowski, 2017). However, often schemes will involve both enablers and deterrents, in particular many of the best practice examples reviewed in this study. The question then emerges of how to attribute change between each of the measures.

Two UK examples were widely cited through our workshops that help articulate the challenge from a carbon impact perspective – Milton Keynes and Cambridge. In the words of one workshop participant "Milton Keynes has great cycle infrastructure but everyone drives, whereas Cambridge doesn't have that good infrastructure but it is difficult to drive and so everyone cycles". Comments such as this were widespread and suggest that making it less convenient to drive is a likely to be a critical factor in promoting adoption of more sustainable modes. Case studies cited for success in active travel such as Houten or Ghent often impose traffic restrictions in the central core (Foletta, 2011). The few studies that cover the subject suggest that deterrents may in fact be more powerful than enablers (Piatkowski, 2017; Petronuff, 2015). One study in particular reviews travel plans across two similar hospitals, one using only enablers and the other combining enablers with deterrents. The impact of the plans were 5% (enablers alone) and 42% (enablers and deterrents) respectively, indicating a 37% difference in impact when combining enablers with deterrents (Petronuff, 2015).

For the purposes of the modelling in this study, we assume that both enablers and deterrents need to be in place to achieve maximum impact on mode share – for simplicity we split the impacts. However, it may be that much can be achieved with deterrents alone. It is often the case that practitioners want to ensure alternatives to the private car exist, before measures perceived as taking mobility away are introduced. However, two points should be made: 1) it is not clear that new infrastructure will achieve sufficient scale to provide suitable alternatives within the timeframe needed to address the climate emergency, and 2) some deterrents in particular could provide new revenue through which to fund improved alternatives. The role of deterrents therefore needs to be strongly considered - this is an area where we recommend further research.

Street Design and Access Restrictions

We commence this section by looking at street design and access restrictions.

Congestion Charging Zone

Congestion Charging impacts differ 1) over time and 2) depending on the make-up of the place. ITF published useful analysis on the long-term effects of congestion charging in Sweden (OECD/ITF, 2015). In Stockholm, where good public transport is available, congestion charging has been more successful (both in terms of price elasticity and public support) compared to Gothenburg where reactions have been lower.

Parking Restrictions

Parking restrictions refer to any price differentials or controls on parking number or access. Restrictions could cover certain vehicle types (e.g. higher emissions vehicles or SUVs) to the outright closure of certain car parks. Parking charges can also be increased as a disincentive to car-based travel. Parking charges have been shown to have a fairly low price elasticity, meaning that prices can be increased significantly before behaviour change is material. A review of 50 studies shows that observed price elasticities range from -0.02 to -2.40 (Lehner, 2018). Lehner suggests a baseline price elasticity for commuting trips of -0.52 which suggests that a 1% increase prices leads to a 0.52% decrease in occupancy. Such an elasticity means that in many cases, price increases can raise additional revenue which could be recycled into alternative modes.

20 mph zones

20 mph zones can be implemented through speed limits or, using design through the introduction of traffic calming measures (e.g. speed humps and chicanes). Reduced speed limits can impact carbon in the following ways: 1) reducing the risk of road accidents making it more attractive to walk and cycle; 2) increasing journey times and reducing convenience for car-based journeys; and 3) speed changes will also impact driving behaviour and vehicle performance with impacts on fuel efficiency, braking and idling.

With regards to road safety, it is expected that there is a 6% reduction in collisions for every 1mph reduced (Welsh 20mph Task Force, 2020). 20mph zones are widely believed to lead to a five-fold reduction in mortality risk. An evaluation of 12 case studies in the UK showed 20 mph zones resulted in significant speed reductions with 47%-65% compliance with the limit. The majority of residents perceive the 20mph limits to be beneficial for cyclists and pedestrians, but evidence to date from these case studies shows no significant change in collisions and casualties (Atkins, 2018).

With regards to journey times, the Atkins evaluation estimated that journey times for private vehicles increased by 3% in residential areas and 5% in city centre areas following introduction of the 20 mph zones. However, the majority of residents (about two-thirds) and non-resident drivers (just over half) have not noticed a reduction in the speed of vehicles. These case studies also show small (but significant) increase in the proportion of residents stating that they have increased their active modes (5% for cycling and 2% for walking), with a significant minority (16% and 9% respectively) saying that it is more likely they will walk or cycle rather than using the car (Atkins, 2018).

With regards to fuel efficiency, NICE Guidance suggests that ensuring motorists drive steadily at the optimum speed can help reduce stop–go driving and so improve fuel consumption as well as reducing congestion and air pollution (NICE, 2017). While there are some concerns that lower speeds might reduce fuel efficiency, research in London shows no net negative impact on emissions from 20mph zones (TfL, 2018). Some studies even report that a 30km/h zone could improve fuel efficiency overall by 12% (Transform Scotland, 2017).

Low Traffic Neighbourhoods - Active travel priority

An alternative or complementary approach to 20mph zones is the introduction of Low Traffic Neighbourhoods. Low Traffic Neighbourhoods are groups of residential streets bordered by main or “distributor” roads where “through” motor vehicle traffic is discouraged or removed (Living Streets, 2020). A recent analysis of the People and Places survey covering areas of Outer London and associated LTNs suggests that LTNs make a difference to car ownership, with residents becoming 20% less likely to own a car as time goes on. There is also evidence that LTNs are more likely to see increased active travel (Aldred, 2020).

Street space reallocation from car to active and Public Transport

Reallocation of road space could significantly increase the attractiveness of alternatives to the private car, but road space reallocation schemes are often controversial. Research has often focused on the key areas of contention – namely the effects on dispersed traffic and congestion and economic impacts. Research often finds that on both fronts the impacts are far less serious than predicted (Cairns, 2002; Fleming, 2013; Living Streets, 2018).

With respect to the effect on road users, evidence across over 70 case studies demonstrates that detractors often overestimate the negative impacts and that in fact significant reductions in traffic can be observed. More recently, research has turned to addressing the economic push-back with a range of studies bringing together individual case studies where reported increases in footfall or retail sales have been observed. Studies demonstrate that sustainable transport users can often account for a large proportion of the total expenditure in shopping areas (Fleming, 2013), that reallocation schemes often result in a significant increase in both footfall and sales (Natural Economy Northwest, 2009; Ryder, 2020; Living Streets, 2018).

Car Free Zones

A further measure to enable mode shift, by increasing the attractiveness of sustainable modes, while deterring driving, is the development of car free zones. Examples include pedestrianisation schemes or car free development. In a similar manner to interventions discussed above car free zones often meet with contention and perceptions that they could impact negatively on congestion and re-routing behaviour. Car free zones are increasingly popular in larger cities where they are likely to have direct and indirect health benefits, but the exact magnitude and potential conflicting effects are as yet unclear (Nieuwenhuijsen, 2016). Much will depend on the precise implementation and the alternatives available. However, to avoid the continuous increase in commuting-related CO_2 emissions, restrictions on car use is seen as one of the most important traffic demand management measures (Wang, 2019).

Fiscal Measures

Workplace Parking Levy

A Workplace Parking Levy (WPL) is a mechanism to restrict car use and raise funds to invest in public transport services. Workplace Parking Levies can be an effective mechanism to target pricing interventions towards commuter journeys. Examples of implementations in the UK include Nottingham, where the WPL is believed to have contributed to additional investment in public transport modes. In addition to the revenue raising potential, research by Loughborough University suggests that WPLs can also provide a strong influence on mode shift – their study of the Nottingham WPL suggests that 8.6% of commuters switched their behaviour following implementation of the WPL with 50% of these citing WPL as an "important" factor (Dale, 2019).

Fuel Tax

As with parking charges there have been a number of studies to investigate the effects (price elasticity) of fuel costs. Whether or not a car trip will be avoided in response to prices changes depends on a range of factors of which price is only one. However, studies trying to separate the impact of price report elasticities ranging from -0.93 to +0.09 (Hössinger., 2017). Some reports indicate that price elasticities change over time and in some contexts have fallen in recent decades (EIA, 2014). To give an example, a price elasticity of -0.1, would imply that a 10% price increase in cost would result in a 1% reduction in travel demand (which we can represent as vehicle miles). In a UK context, let's assume we were to normalise Fuel Duty, hiking it to 65p/litre. The effect would be to add 7.05p to the pump price of petrol (113.29 via BEIS weekly fuel prices at the time of writing). At current prices this would equate to a 6% increase on Petrol and Diesel. If the -0.1 price elasticity holds, then we would assume travel demand would reduce by 0.7%. On it’s own, it might not have a significant impact on travel, but that’s not to say fuel taxes do not have an important role to play.

Firstly, fuel taxes could have a significant role in revenue raising to fund the transition to more sustainable modes. Data from the Office for Budget Responsibility (

Figure *11*) demonstrate the potential impact with previous forecasts based on fuel duty rising in line with inflation suggesting an additional £9bn of annual revenue (Office of Budget Responsibility, 2019). But central policies, including taxation policy, also play a critical role in managing the relative costs between modes. Consider the divergence in travel costs for public and private transport modes since 1987 (Figure 12). Increases to the cost of driving have trailed RPI over that period while the cost of using trains has increased by 300% and buses by over 350% (Dempsey, 2018). If it is cheaper to drive for the majority of long-distance trips, it should come as no surprise that the driving is then the preferred mode. Deterring long-distance travel at a national level will likely require some kind of pricing regime – a pricing regime for private cars that scales according to distance, while offering subsidies for public transport might offer the best disincentive against longer-distance travel by private car.

Figure 11: Previous Forecasts for Tax Income from Fuel Duty, Office for Budget Responsibility

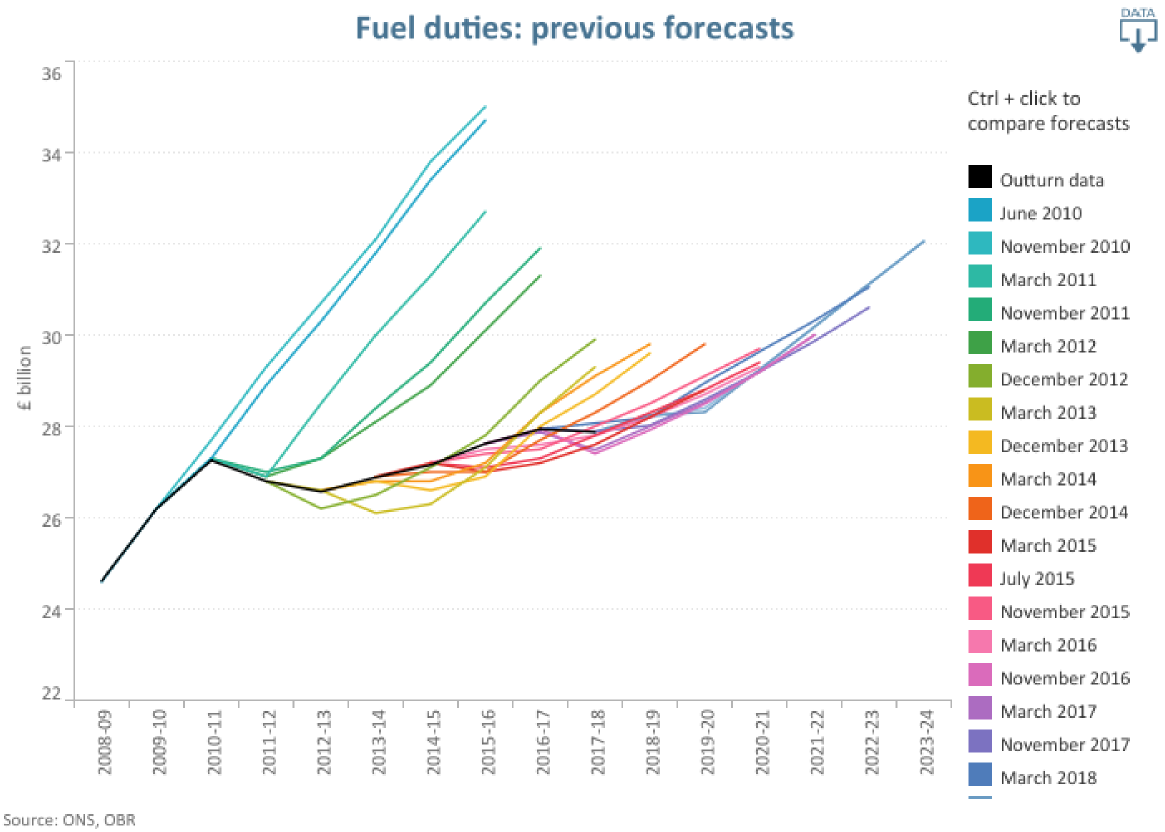
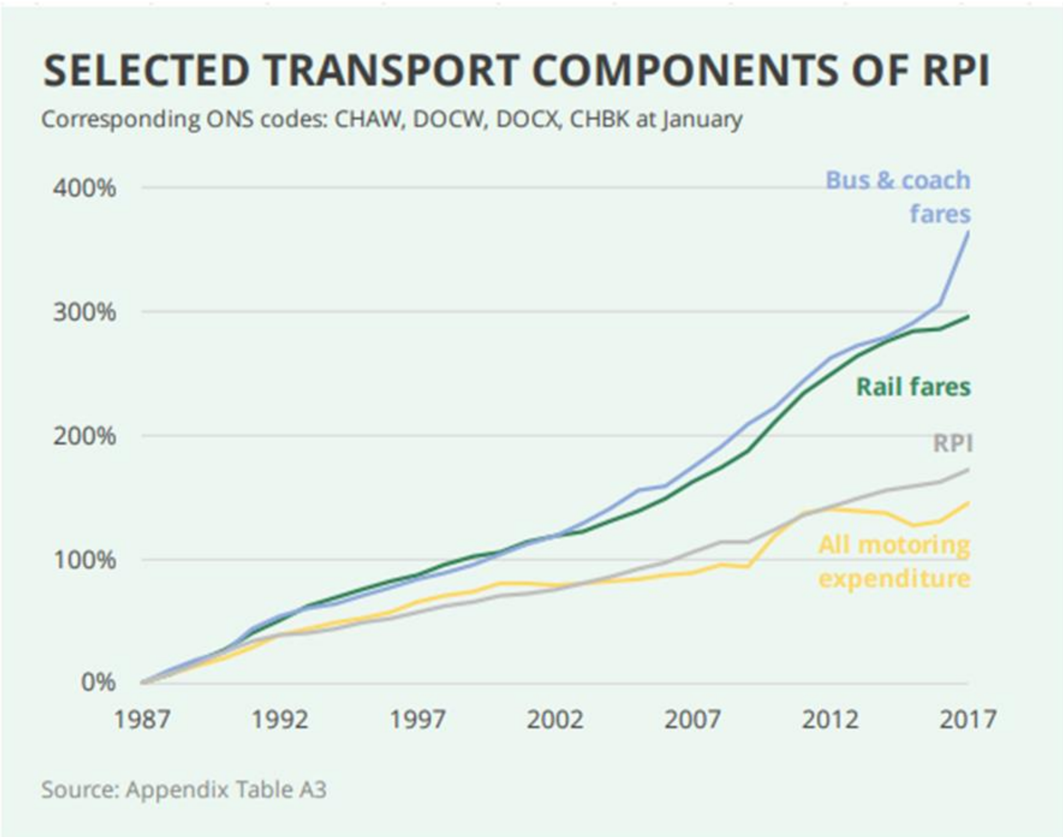


Figure 12: Transport Cost Evolution by Mode Compared to RPI, Source – Dempsey, 2018



Cycling Infrastructure – Genuine Connected Network

Joining up cycling infrastructure, ensuring direct routes between key sites, linking cycling networks to public transport networks and extending the number places that are cyclable are clearly welcome. There is good evidence that safe, separated cycling infrastructure is likely to be among the key influencing factors of cycling propensity (Wardman, 2007; Hirst, 2020). Ongoing operational and maintenance costs of cycle infrastructure are also significantly lower than for any other form of infrastructure (National Infrastructure Commission, 2018). However, as discussed in section **Error! Reference source not found.** above, it is rare to find best practice examples that rely solely on infrastructure alone. An evaluation of Connect2 in Cardiff notes the potential for active travel to replace short car trips and reduce carbon (4.9% for personal trips), but also notes that the scheme in question was unlikely to promote a significant change in travel behaviour on its own (Neves, 2015). Studies of European best practice conclude that “the key to achieving high levels of cycling appears to be the provision of separate cycling facilities along heavily travelled roads and at intersections” (Pucher, 2008) but also adds that calming measures are also needed.

Our purpose is not to present an argument that genuine connected cycling networks are not important – they are. But we do think it important to challenge the notion that they are sufficient. If we are truly going to change our places then we need active travel to be the priority – that means making it more convenient than the private car. Milton Keynes is a great example - Milton Keynes has 300 km of cycleways known as the ‘redways’, nearly all of which are segregated from cars. As a result, it could be described as ‘infrastructure rich’ compare to many UK towns. However, despite this plentiful infrastructure, the commuter mode share for cycling within the city is only 4.2% while cars account for 75% of commuter journeys (National Infrastructure Commission, 2018). In its 2018 report promoting investment in cycling infrastructure across the Ox-Cam arc, the NIC fatalistically states “the car clearly is, and will remain, Milton Keynes’ dominant mode”. In contrast it is clear from studies of European best practice that many areas where cycling is a success (the Netherlands, Denmark and Germany) make driving expensive and inconvenient in city centres. This is an important take home message for places that really want car dominance to end.

Walking Infrastructure – Genuine Connected Network

“A walkable environment is a crucial factor for promoting active transportation” (Kim, 2020). Numerous studies have sought to develop metrics to evaluate the quality of the built environment for pedestrians with various definitions of “walkability” (Humberto, et al., 2019). Walkability can generally be considered a measure of how friendly an area is for walking. At this local level, measures of walkability are influenced by a range of factors such as network quality itself, traffic speeds/restrictions, climate, built environment, density, safety, community, aesthetics and experience, greenspace, on-street facilities among others (Tight, 2018; Zuniga-Teran, 2017). Walkability studies broadly focus on three core areas: 1) examining the relationship between walking behaviour and the physical or built environment; 2) exploration of the importance of individual perspectives and perceptions; and 3) framing walkability in more general terms of quality of life (Blecic, 2020). As we have seen with cycling, there is the sense that appropriate packages of measures, tailored to the circumstances and context of a location, have the potential to be more effective than single measures (Tight, 2018).

A number of studies have shown that aggregate measures of walkability and the individual components can be good predictors of propensity to walk with individuals being seen as more likely to walk in neighbourhoods with higher walkability (Liao B. v., 2019; Zuniga-Teran, 2017; Kartschmit, 2020; Humberto et al., 2019). For example, one study found that the odds of walking were almost 3.5x higher when the Walk Score for the trip origin was "Walker's Paradise" compared to less walkable neighbourhoods (Duncan, et al., 2016), another found that every one-point increase in the Walkability Score was associated with 1.5%-1.8% higher odds of active transportation for certain journey purposes (Kim, 2020).

Different studies expose different elements supporting walking. For example, in one study categories such as traffic safety, experience, and greenspace showed a strong influence, especially for recreational walking, while in another proximity to services such as supermarkets, daily goods stores, cafeterias and high urban density were found to be significant (Zuniga-Teran, 2017; Liao, 2020). Others have found the relationship between car ownership and walking propensity to be very strong, suggesting that highly car-dependent neighbourhoods discourage walking (Habib, 2011). This links to findings on the related area of severance – usually defined as the separation of local communities by transport infrastructure, in particular road traffic. A literature review on severance by Jacobsen et al. identified a consistent inverse correlation between traffic volumes and speeds and levels of walking and cycling (Anciaes, 2014).

Studies also suggest that individuals or groups are likely to experience the environment differently, exhibiting different propensities to walk based on changes in the external environment. For example, conditions for walkability may not be the same for all age groups (Lioa B. v., 2019; Kim, 2020), genders (Kim, 2020) and physical abilities (Kartschmit, 2020).

Electric Bikes

In addition to cycling and walking electric bikes also offer great potential, in particular to extend distances and accessibility to key locations. Research by CREDS suggests that e-bikes could offer significant (up to 50%) carbon saving potential if they were to replace all car trips in the UK (Philips, 2020). Whole life carbon of an e-bike is estimated at 22g/km vs. electric cars at 104g/km meaning that transition to an e-bike fleet could make more carbon sense than transition to electric vehicles. However, there are limited real-world examples where e-bikes have yet provided a significant mode share. The replacement effects are also not known (e.g. how much will e-bikes replace bus journeys for example).

While these implementation questions are not fully known, it cannot be ignored that each person using an e-bike to replace all the car journeys could be able to save 0.7 tonnes CO_2 per annum (Philips, 2020). This raises an important point about the role of vehicles in the transition to net zero. Recent research into SUVs for example, suggests that SUVs have been the second largest contributor to the increase in global carbon emissions from 2010 to 2018 and yet, today, almost half of all cars sold in the United States and one-third of the cars sold in Europe are SUVs (Cozzi, 2019). This demonstrates the need to promote smaller, functional electric vehicles that simply require less energy but can address some of the limitations of fully self-propelled vehicles.

Modern Public Transport

Bus Rapid Transit

BRT could attract significantly private vehicle users to change mode choice and can attract many passengers if travel time reductions are sufficiently high. A review of 86 international projects finds modal shifts away from private cars of between 0% and 50% with the majority of schemes reviewed delivering double digit percentage shifts away from private cars (Ingvardson, 2018). Both travel time and travel cost ultimately affect the mode choice, but travel time is likely to have a highly significant effect on car users' switching to BRT (Satiennam, 2016).

In reality, for most places in the UK, full BRT is unlikely to be needed, but improved bus services with greater frequencies and reliability, supported through dedicated lanes could have a meaningful, but cost-effective impact. In addition, as we have seen with many of the other mode shift interventions, the benefits are likely to be enhanced through wider traffic restrictions. For example, the efficiency of public transport systems can be increased simply and cost-effectively through a range of constraints on private vehicles such as reduced number of lanes, parking restrictions, and limited access (La Branche, 2011) and in many cases schemes could be enhanced by combining measures. For example, a modelling exercise in Lille covering multiple strategies for CO_2 reduction finds that combining significant increases in parking tariffs and tolls combined with travel time improvements for public transport is likely to be the most effective scenario (Hammadou, 2015).

Other Public Transport Measures

Other measures to afford priority include bus priority at junctions, transport hubs and greater integration with first and last mile connectivity. Previous work by City Science indicated that up to 48% of vehicular trips could be replaced by first- and last-mile shuttles, through the reallocation of a small amount of road space to shuttles, cycles or e-bikes (City Science, 2017). Integration of public transport and active transport networks is therefore key to providing an attractive all round transport offer and genuine alternative to the private car. In the final section, we briefly review the potential for shared mobility.

Shared Mobility

Car Share (club)

Car clubs can be introduced to offer the service of a car to those who can eliminate a car from their lives but want residual access to a car, for occasions when they may need it. Estimates suggest that each round trip car club vehicle put on the street can replace 10.5 privately owned vehicles (Marsden G. A., 2019). However, to dates car clubs often operate in central urban areas where there is a good mix of alternative transport options and suitable density to achieve service viability. It is unclear the extent to which car clubs are complementary rather than a solution which itself provides direct effects. Some authors have estimated that between 20%-50% of members could give up their car as a result of joining a car club (Cairns S, 2004). There is certainly strong evidence that if someone gives up their vehicle when joining a car club, they are likely to significantly reduce their vehicle miles, but changes to car ownership may also require a range of other external factors to be in place. Car clubs can also be electric, which, as well as offering zero tailpipe emissions, may enable users who have never tried an electric vehicle to use one – this in turn could help in promoting the transition to low carbon vehicles.

Car Pooling

Car Pooling or Ride-sharing enables users to share a trip from a common origin, to a common destination or for a particular leg of a journey. By combining multiple users into a single trip that would otherwise be undertaking the journey as sole occupants, car-pooling has strong potential to reduce vehicle miles and, as a result, carbon. Studies of employment sites that have implemented car pooling demonstrate that the intervention can reduce vehicle miles by users in the region of 4%-6%. When evaluated regionally, impacts can be in the region of 1%-1.6% (Shaheen, 2018). However, it is also worth noting the potential when financial disincentives to single-occupancy trips are introduced – research during the 1970s energy crisis indicated that car pooling enabled a reduction of vehicle miles by 23% due to the significant additional financial incentive to share (Shaheen, 2018). This suggests again that a coordinated approach that combines the intervention with wider deterrents might be the most effective way to induce uptake.

Bike Share

Bike sharing systems are highly flexible and can provide users access to a bike from multiple locations. Implementations can be “docked” with fixed locations for pick-up/drop-off or “dockless” potentially providing more freedom and flexibility. Bike sharing has universally been observed to reduce personal driving and taxi use, especially for short trips (Ma, 2020). Mode-shift changes as a result of bike sharing are reported to range from 0.3%-21% within the affected areas (Ma, 2020). Bike sharing also has the potential to increase public transit trips - where bike-sharing and public transport are integrated this has been shown to strengthen the benefits of both modes. The effects of bike sharing may also vary by implementation location with one study finding that bike-share is more likely to act as a substitute for public transport trips in larger, more dense cities while serving an important first/last mile function in small to medium size and less denser cities. The full benefits towards overall mode shift away from private vehicles are therefore likely to depend on the presence of, and integration with Public Transport (Ma, 2020).

E-Scooters

One final mode receiving significant attention currently is e-scooters. E-scooters offer an alternative for short trips and are likely to be particularly suited to the first- and last-mile of trips when integrated with public transport. Data from trials is still emerging, but there is emerging evidence that e-scooters can help shift trips away from private vehicles, but may also shift modes away from walking with a lower shift from public transport and cycling (London Cycling Campaign, 2020). Analysis of trials in Portland confirm these broad trends, with mode shift being most notable away from walking, single occupancy vehicles and ride hailing (PBOT, 2018).

2.3. Switch Fuels

Finally, we consider the need for fuel switching. This naturally involves a concurrent replacement of the existing fleet with electric or hydrogen vehicles, the provision of new re-fuelling or re-charging infrastructure and necessary changes to grid capacity and fuel mix to ensure the system can be effectively powered over the long-term by renewable energy. This in itself is no easy undertaking with many issues to consider across different vehicle types.

In the market for private vehicles one of the key concerns is that approximately a third of households do not have off-street parking to install a home chargepoint (Energy Savings Trust, 2019). This will naturally require increased provision of public charge points or cost- and time-effective re-charging points at convenient locations.

The transition to electric buses involves many challenges noted by participants in our workshops and confirmed through this research, in particular concerns over limitations of power and range. Challenges include confusion about the most appropriate technology, grid instability and limitations for charging at stations, disjointed e-bus market place, combined with a range of financial and institutional barriers (Sclar, 2019).

Similarly the transition to zero carbon freight also faces considerable challenge due to confusion over competing technologies including Large-battery electric vehicles, Hydrogen fuel cells, Biofuels, synthetic fuels, of electric road systems such as overhead conductive transmission (Ainalis, 2020). A clear direction of travel is needed to support roll-out and uptake of the technology most likely to deliver within the decarbonisation time frame.

Finally, the transition to zero carbon vehicles across all modes will also likely need to be supported by incentives and restrictions. While some local authorities have programmes to support zero emission fuel adoption, there are currently limited powers or direction to support accelerated transitions for those places aspiring to achieve net zero faster.

3. Assumptions and targets used in carbon modelling of pathways for each place typology

Category	Intervention	Assumptions / targets used in proposed pathway
Negative Carbon Developments	Negative Carbon Developments	Full offset of all new developments. Effectively requires all new developments to zero carbon by design with independently verified carbon modelling a key determinant of whether or not they are allowed to go ahead.
Substitute Trips	Home Working	The equivalent of 30% of commuting trips can be avoided over the long-term.
	Co-Working Spaces	An additional 2.5% uptake is enabled for commuting purposes, reducing the commuting distance by the difference between the long- and short- distance average.
	Replace 'Personal Business' with Digital Services	The equivalent of 30% personal business trips can be avoided over the long-term.
	Replace 'Leisure' Trips / Other Escort with Digital Services	The equivalent of 2.5% of leisure and other escort trips (or miles) can be removed.
	Local amenities within 15 minute walk/cycle	Vehicle miles can be reduced by an additional 20% across other escort, personal business and leisure trips.
	Micro-Consolidation	LGV delivery miles can be reduced by 30%.
Shift Modes	Active Travel Mode Share (UK Benchmark)	UK "benchmark" seeks 50% active modes for short-distance trips and 11% share for longer-distance trips. This is the same across all typologies.
	Public Transport Mode Share (UK Benchmark)	Public transport mode share for the Polycentric conurbation achieves 43% for short- and long-distance trips. For other typologies public transport share achieves 15%.
	Additional Public Transport Target	Public transport is mode share is extended to 50% of longer-distance trips in the Polycentric conurbation and 40% of short- and long-distance trips in all other typologies.

Switch Fuels	Private Vehicles	Residual carbon emissions to the 80% 2030 target can be achieved through fuel switching. Private vehicle share is allocated on the basis of residual private vehicle emissions following all previous interventions.
	Public Transport	Residual carbon emissions to the 80% 2030 target can be achieved through fuel switching. Public Transport share is allocated on the basis of residual public transport emissions following all previous interventions.
	Freight	Residual carbon emissions to the 80% 2030 target can be achieved through fuel switching. Freight share is allocated on the basis of residual freight emissions following all previous interventions.

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