DecarboN8

Place-based decarbonisation for transport

Understanding Change in Car Use over Time (UnCCUT): End of Project Report

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Summary

Reducing car use and ownership is necessary for decarbonising the UK economy. There are no plausible pathways to get to net-zero by 2050 unless the number of cars reduces. Nevertheless, in the last twenty years, car ownership has grown steadily. In this report, we explore a new and spatially detailed time series dataset about car ownership in England and Wales between 2002 and 2018. We seek places where car ownership is in decline and ask if there are any lessons that these places can teach us about how to reduce car ownership nationwide.

The analysis is based on the 34,753 LSOAs in England and Wales. For each year, we compare the number of cars registered and the resident population to calculate the number of cars per person. From this data, we know that only 220 LSOAs (0.6%) experience a decline in the number of cars per person. These areas were primarily urban and cosmopolitan, while rural areas experienced the greatest increases in car ownership.

Examination of historical aerial photography allows changes in the LSOA to be matched to changes in car ownership. Largely it was found that the most successful way to reduce car ownership was to build dense low-car housing such as flats within existing urban areas. This was often successful in increasing the resident population without increasing the number of cars and, in some cases, reducing the number of cars within the LSOA.

An exploration of changes in car ownership around new train and tram stations produced mixed results. In some cases, such as the reopening of the East London Line, car ownership declined significantly, yet the decline began before the stations opened. While in other rural locations such as the Ebbw Vale north of Cardiff, the new rail service made no difference to the rate of increase in car ownership. Overall, it appears that new stations reduce car ownership in places where car ownership is below average but have little effect on areas where car ownership is already high.

The analysis also highlighted the importance of considering key demographic groups such as children, students, and the elderly, that are less likely to own cars, so shifts in their relative proportions can skew the apparent rate of car ownership. For example, building a nursing home boosts the population without increasing car ownership. Alternatively, a new suburban housing estate results in an initial rise in both population and cars, as young couples move in. Later as the couples have children, the population increases, but the number of cars remains steady, creating the illusion of declining car ownership per person.

The report identifies several opportunities for further research and makes recommendations about how car ownership and use changes could be better understood in the future. Central to these are more data on car use (e.g. kilometres driven per year) as opposed to ownership, as it is more likely that households respond to changes by adjusting their car use rather than taking the bolder step of forgoing car ownership entirely. Secondly, that contextual time series data about population, demographics, house building, public transport and more are essential to understanding changes in car use. Further work is needed to gather and understand these changes, but would likely yield significant insight into car use and place-based decarbonisation in general.

Introduction

The surface transport sector has the largest carbon footprint of any sector of the UK economy and has made little progress towards decarbonisation over the last 20 years. More than half of all surface transport emissions come from cars, with the majority of the remaining emissions coming from road freight. While the transition to electric vehicles may help to reduce emissions from cars, it cannot completely eliminate them. High car use is also associated with a broad range of other environmental and social problems such as air pollution, congestion, road deaths, and urban sprawl. Therefore reducing car use and ownership has long been seen as a desirable outcome of transport and planning policy.

This project seeks to understand how car ownership can be reduced by investigating a new time series dataset, which records car registrations in the UK. The research explores the local trends in car ownership, with a particular focus on areas where car ownership has already declined. The goal of the work is to identify if any generalisable lessons can be learnt from places where car ownership is already declining and transferred to other locations.

Methods

This report makes use of a previously unpublished dataset acquired from the Department for Transport (DfT) which provides a count of the number of registered cars in each Lower Super Output Area (LSOAs) in England and Wales. LSOAs are small statistical neighbourhoods designed for the census by the Office for National Statistics to have a population between 1,500 and 3,000. Although the boundaries of LSOAs change slightly for each census, the DfT data has been standardised to the 2011 boundaries despite covering the period from 2001 to 2018. The DfT data were then combined with the ONS's mid-year population estimates from 2002-2018. The 2001 populations could not be used as they use the older LSOA boundary system. Thus, a spatially detailed annual dataset was compiled for the 34,753 LSOAs in England and Wales over 17 years. This dataset gives unprecedented insight into how, when, and where car ownership has changed.

A limitation of the data is that it does not distinguish between private and corporate car ownership. Therefore, there are a few LSOAs with an implausibly high number of cars. This is likely due to a company registering its fleet to a single address when in reality, the vehicles are being used across the country. It can also lead to dramatic changes in apparent car ownership if a company changes its address. Fortunately, this issue only affects a small number of LSOAs, and they have been removed from the analysis.

Selection of case study areas

Before studying why areas have experienced a decline in car ownership, it is necessary to find areas where car ownership has reduced. For this report, we focus on changes in cars per person because it is possible for the absolute number of cars to change due to increases or decreases in population. These changes in absolute numbers of cars are unlikely to provide generalisable lessons for reducing car ownership elsewhere. Conversely, a reduction in car ownership per person suggests changes in behaviours that may be replicated to reduce the UK's overall dependence on car ownership.

The first stage of case study selection was to plot and classify trends in cars per person. Figure 1 provides an example of a single LSOA in the centre of Newcastle. In this case, the population of the LSOA has increased substantially, while the number of cars has reduced slightly, resulting in a significant decline in the number of cars per person.

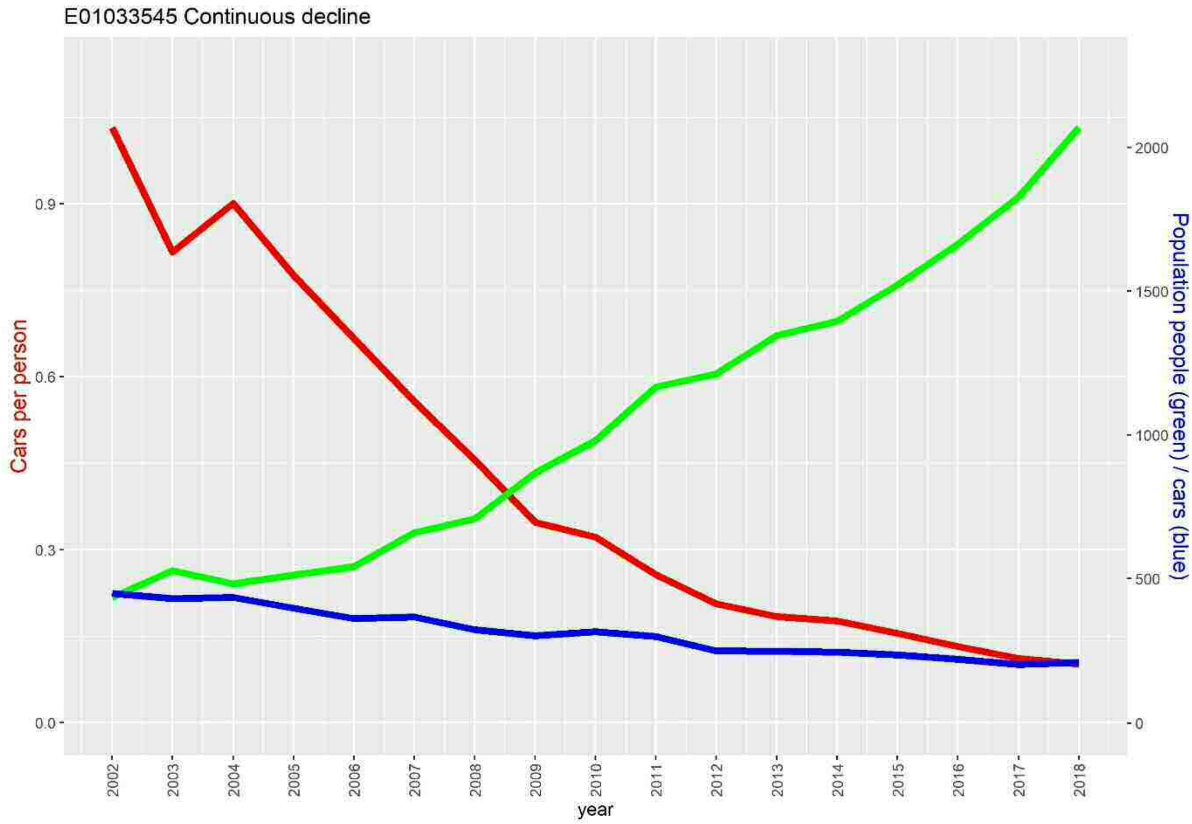

Figure 1: Example of the change between 2002 and 2018 in the population (green), number of cars (blue) and cars per person (red) for the LSOA E01033545.

It would not be practical to manually examine a graph for all 34,753 LSOAs, so several methods were devised to identify LSOAs with interesting trends in car ownership automatically.

The first approach was to break the time series data into three periods and then fit simple linear models to the population and cars per person data. This allows the calculation of the gradient of the best-fit line and the R^2 of the model. Based on the gradient of the line, the period could be classified as rising, stable, or falling, and each LSOA could be given one of twenty-seven possible three-word categorisations (e.g. falling-falling-stable) to describe the overall trends in population and car ownership. The R^2 value for each period was used to assess how linear the trends with values >0.95 being classified as linear, 0.65-0.95 slightly linear, and <0.65 non-linear. This classification was found to be helpful in identifying sudden step changes or possible errors in the data.

Step changes were also investigated by calculating the standard deviation between times t-1 and t+1. If the sum of these two standard deviations is large, it could indicate a rapid change in population or car ownership associated with an important event. For each time series, the maximum, minimum, and mean change in the standard deviation was calculated. Table 1 provides examples of the final categorisations of three LSOAs, including the descriptive labels providing an overall summary of all the statistics.

LSOA code	Population					Cars per person					Population Description	Cars per person description
	Gradient	Linear	SD change	Gradient 3-periods	Overall change	Gradient	Linear	SD change	Gradient 3-periods	Overall change		
E01000001	falling	non-linear	slight-step	falling falling rising	large	rising	non-linear	slight-step	rising steady falling	small	Falling then rising	No significant change in cars per person
E01000002	falling	non-linear	slight-step	steady steady steady	large	rising	non-linear	stepped	steady rising falling	small	Large change with no trend	No significant change in cars per person
E01000003	falling	non-linear	slight-step	steady falling rising	large	falling	non-linear	stepped	rising steady falling	small	other	No significant change in cars per person

Table 1: Example of the summary categorisation for the LSOAs

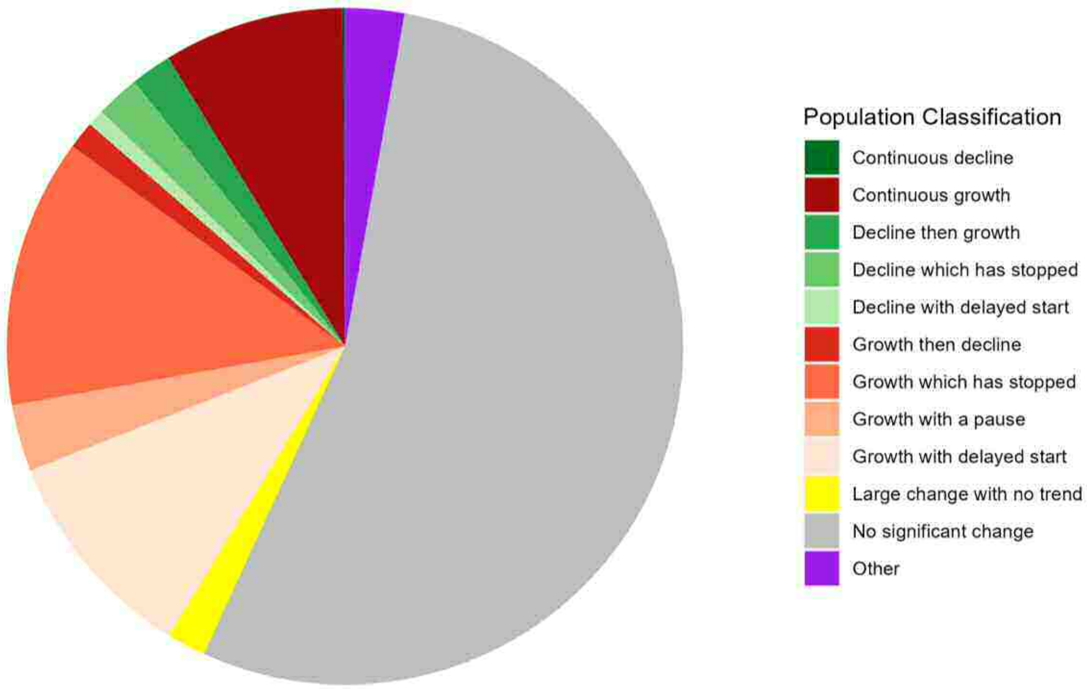

Figure 2: Distribution of population classification for LSOAs in England and Wales

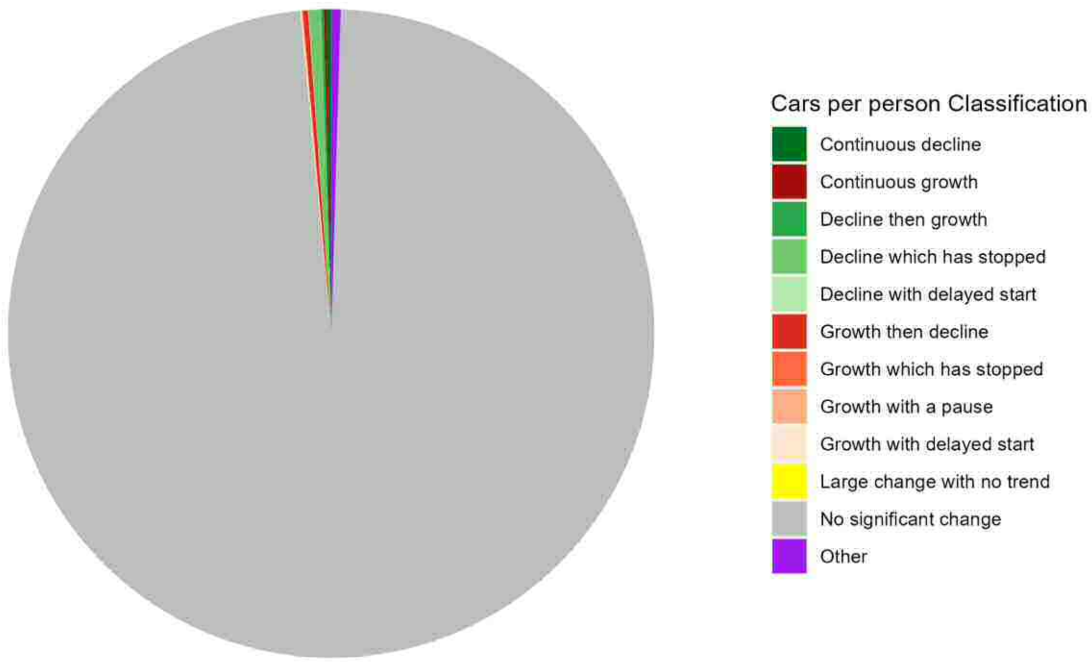

Figure 3: Distribution of car per person classifications for LSOAs in England and Wales

Figure 2 and Figure 3 show the distribution of classifications given to LSOAs for the change in populations and the number of cars per person. While slightly more than half of LSOAs have experienced no significant change in population. The remaining LSOAs have experienced a broad array of different changes. In contrast, the change in the number of cars per person has been strikingly small in the vast majority of LSOAs. For example, the LSOAs classified as “No significant change” saw a median change in cars per person of just 0.08 (16%) between their highest and lowest years. While a 16% change may appear significant, this would only be true if it represents a continuous change over time. However, the car per person data is noisy, so comparing the highest and lowest years exaggerates changes. In contrast, areas classified as having continuous growth or decline in cars per person experience changes of more than 0.5 cars per person over the same period.

Figure 4 highlights the distribution of the 692 LSOAs where a significant change in the number of cars per person was detected.

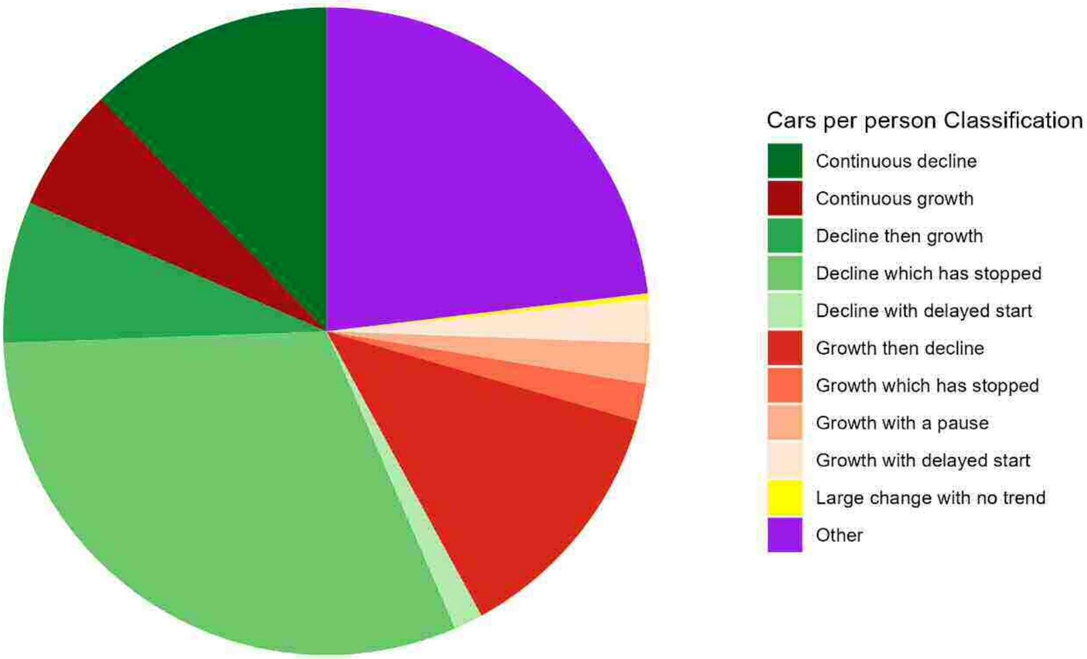

Figure 4: Distribution of car per person classifications excluding areas classified as “no significant change”

After the automatic classification of LSOAs, graphs in the style of Figure 1 were produced for each LSOA with declining cars per person. These were then manually classified into the categories shown in Table 2.

Classification	Comments	Number of LSOAs
Growing population, declining cars		33
Growing population, slowly growing cars	Population growth is faster than car growth, so there is a decline in cars per person	41
Growing population, stable cars		130
Stable population and cars		5
Stable population, declining cars		11
Error	Cases where automated classification incorrectly classified the LSOA	81

Table 2: Summary of manual classification

Excluding the “Error” category, the remaining 220 LSOAs form the case study locations for the remainder of this report.

Analysis of changes in case study locations

With the case study locations identified, it was now necessary to ascertain if any observable changes had caused the decline in car ownership. Ideally, annual statistical data about the characteristics of each LSOA could be used to identify trends which coincide with changes in car ownership. Unfortunately, very few datasets at the LSOA level of spatial resolution are updated annually—furthermore, detailed historical maps were not always available for the whole study period. Therefore we used historical aerial photography to manually look for changes in the case study areas (e.g. changes in urban form).

Google Earth provides a convenient tool to view historical aerial photography and, in the UK, has often been updated multiple times throughout the study period. Therefore, the following procedure was employed.

1. The boundaries of the case study area were loaded into Google Earth
2. Zoom to a single LSOA
3. Save an image from 2002 (or the closest available year)
4. Save an image from 2018 (or the closest available year)
5. Load images into the image difference checker[1]
6. Cross fade the images to identify changes
7. Highlight changes and save a new image
8. Record a written log of changes observed

In many cases, the changes observed in the aerial photography were ambiguous. For example, it could be seen that a building had changed, but it was unclear what the nature of that change was. In these cases, further investigation could be undertaken using Google Street View, which also provides a more limited set of historical imagery.

Figure 5 provides an example of the process of identifying the changes within the LSOA. In this case, multiple small changes have been made within the centre of Bolton. Including the construction of a block of flats and some terraced housing (highlighted in green in C) and the construction of several commercial buildings (highlighted in yellow).

[1] https://www.diffchecker.com/image-diff/

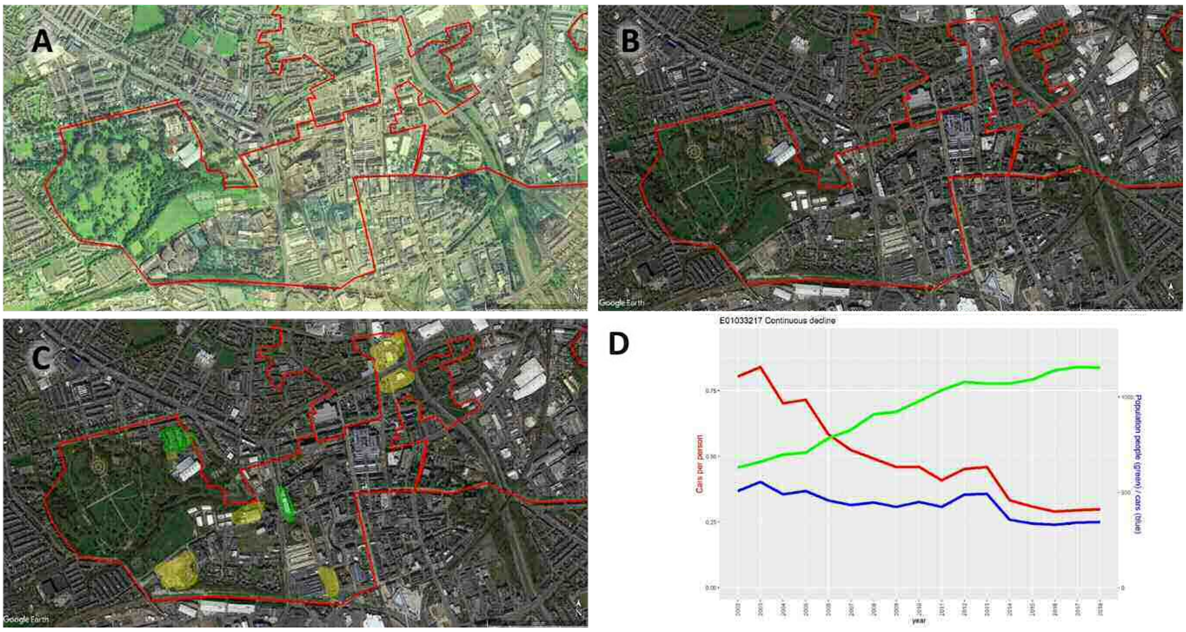

Figure 5: Example of changes identified from aerial photography for LSOA E010332173 in Bolton. Showing photo from 2002 (A) with LSOA boundary highlighted in red, photo from 2018 (B), 2018 photo changes highlighted (C), and the trends in population, number of cars and, number of cars per person (D).

Analysis of changes in public transport

To consider if changes in public transport affected car ownership, we wished to identify the locations where new or improved public transport was constructed during the study period. The National Public Transport Access Nodes (NaPTAN) dataset provides the official record of the locations of all public transport stops and includes a date-created field. However, we found significant problems with the NaPTAN data. Firstly the creation dates were unreliable, with many stops recorded with default dates (e.g. 01/01/1970). Furthermore, the NaPTAN also recorded thousands of temporary bus stops and minor changes unlikely to be relevant to this study. Due to these issues, we concluded that NaPTAN is unsuitable for this research. Therefore, we focused only on new rail stations and used Wikipedia to obtain their locations and opening dates, which were far more reliable.

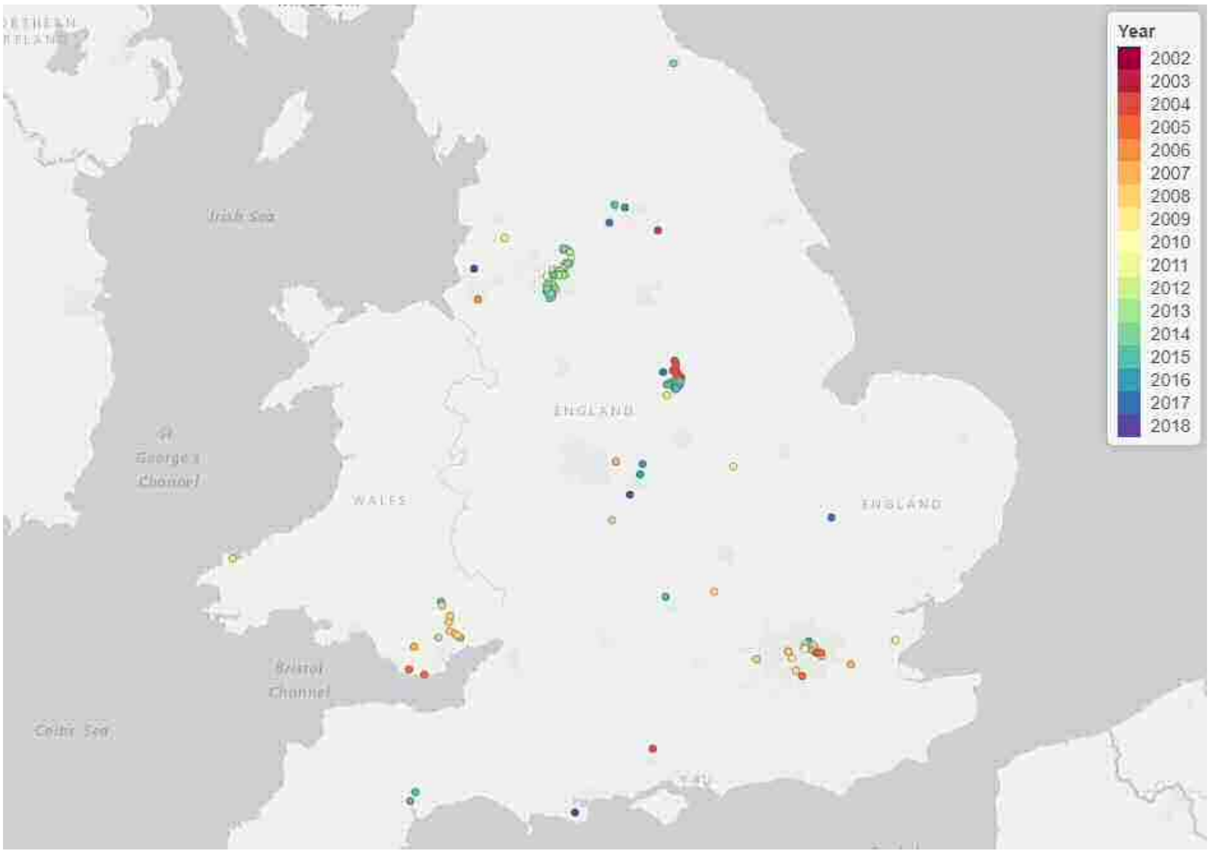

Figure 6: Map of new light and heavy rail stations in England and Wales between 2002 and 2018 coloured by year of opening.

Results & Analysis

General trends

Figure 7 and Figure 8 provide an overview of general trends in car ownership across England and Wales. Figure 7 shows the strong relationship between urbanity and lower car ownership, with larger urban areas having lower car ownership per person. Large urban areas also had a marked decline in car ownership after the recession of 2007/08 but have since recovered and often exceeded the pre-recession rates. Conversely, rural areas have maintained steady growth in car ownership for almost two decades. In Figure 8, the LSOAs are grouped by the Output Area Classifications, which combine locational and socio-economic characteristics into 24 descriptive categories. Here areas of sustained declines in car ownership can be identified, specifically “Inner city cosmopolitans” and “Cosmopolitan student neighbourhoods”. Both are groups mostly found in the centre of large cities. Interestingly “Hard pressed flat dwellers”, a group of low-income high-density neighbourhoods, have experienced significant growth in car ownership, although from a low base. This may reflect a cultural shift, with affluent and cosmopolitan neighbourhoods rejecting the car while working-class neighbourhoods maintain existing trends of increased car ownership.

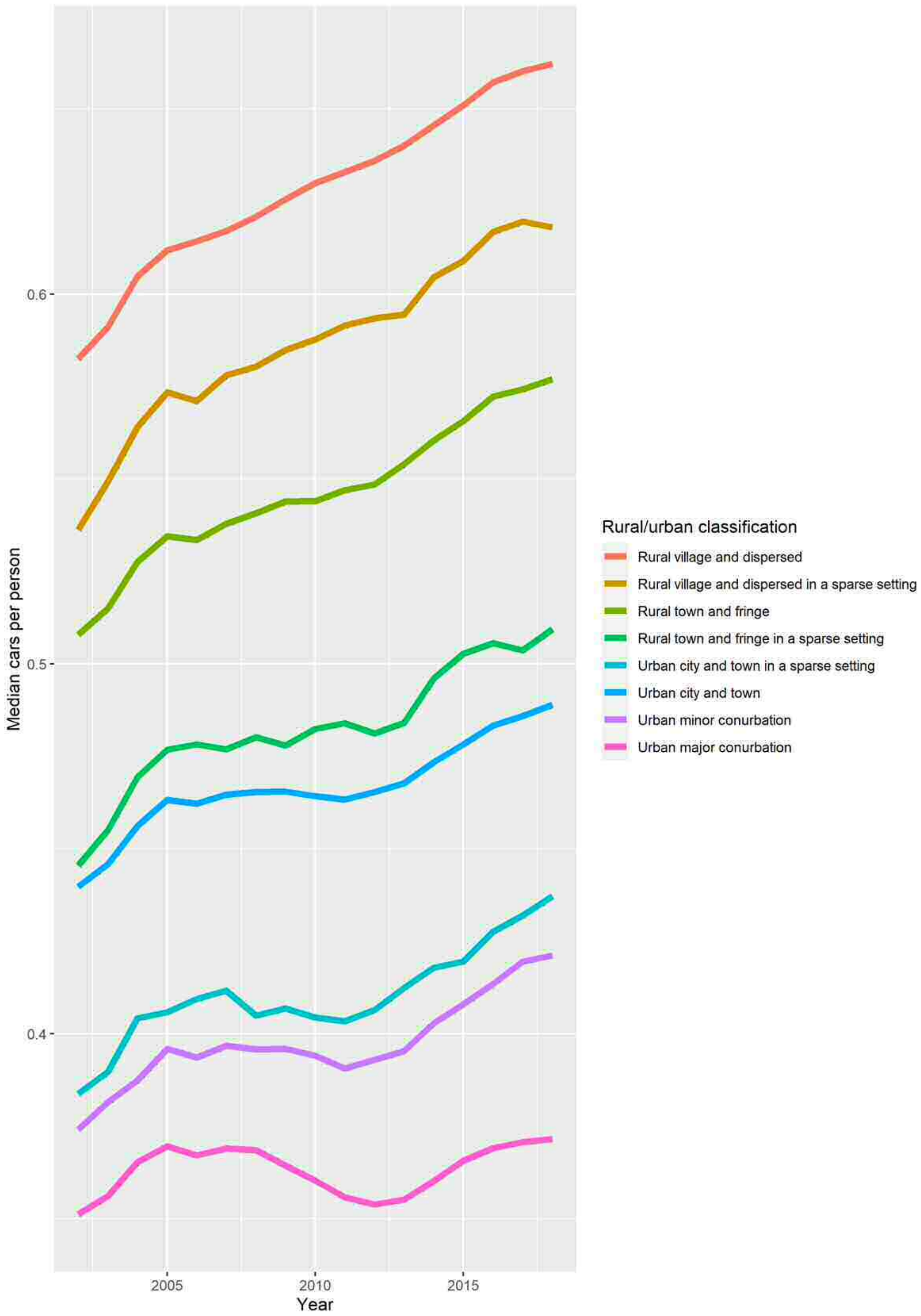

Figure 7: Trends in the median number of cars per person for LSOAs grouped by 2011 rural/urban classification

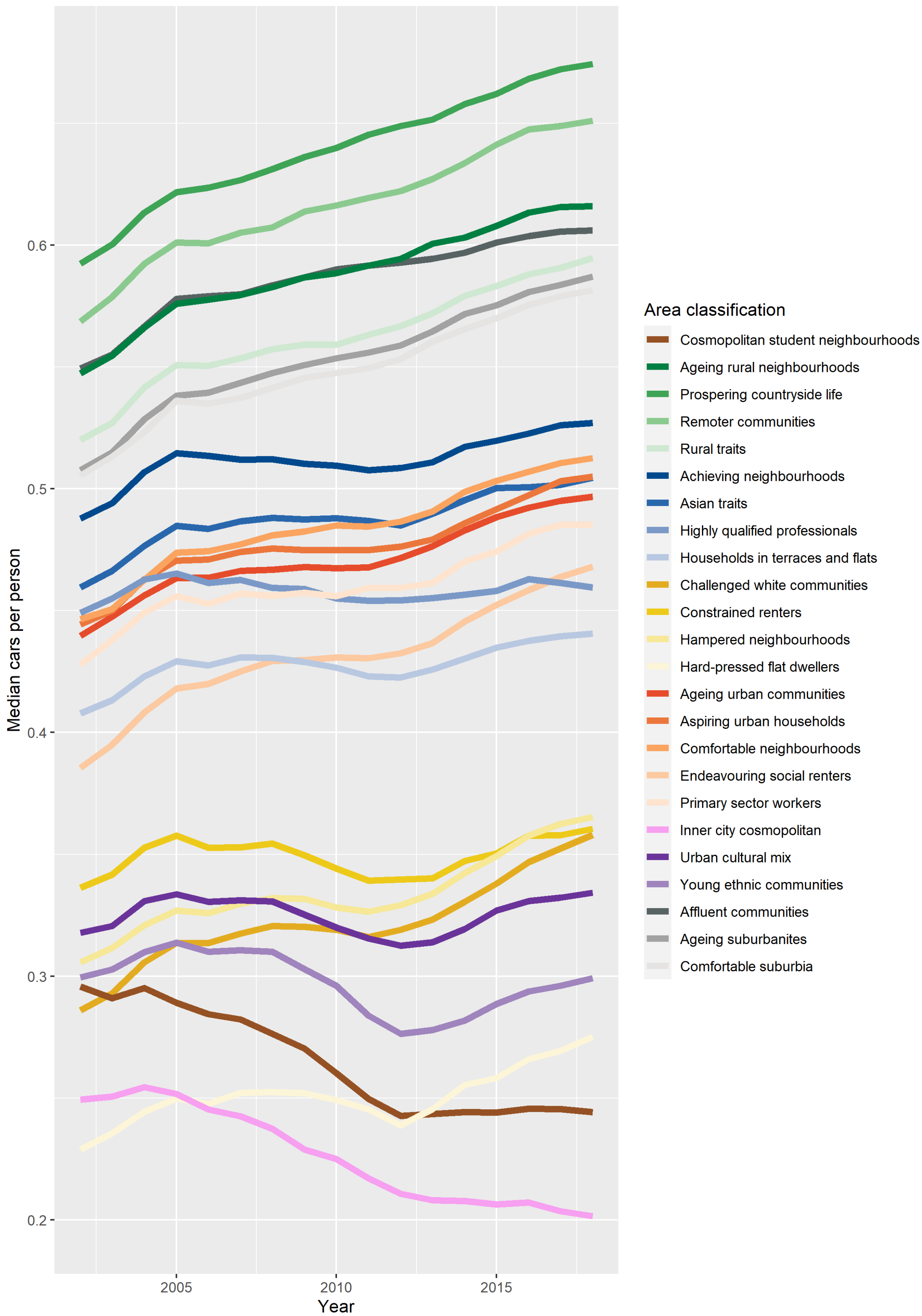

Figure 8: Trends in the median number of cars per person for LSOAs grouped by 2011 area classification

Analysis of changes in case study locations

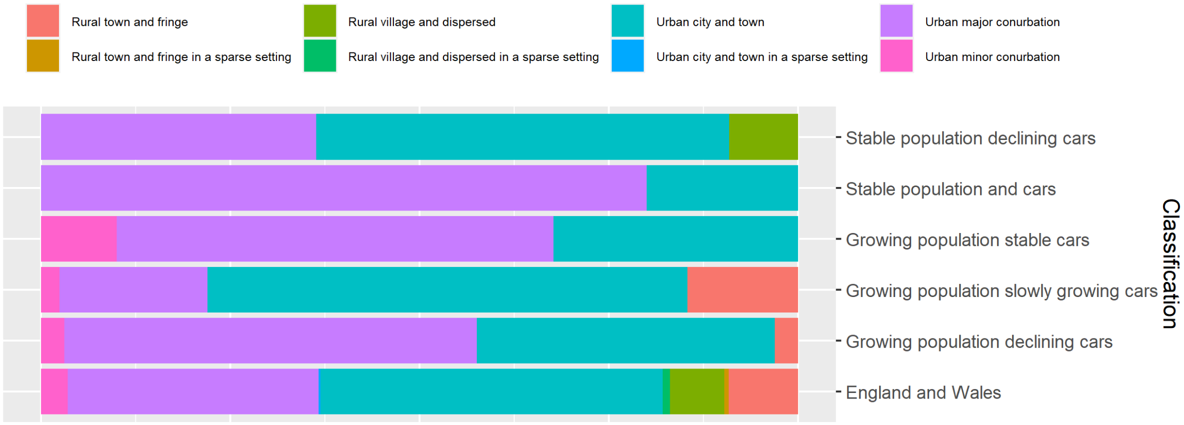

Figure 9: Distribution of Rural/Urban classifications for case study locations compared to England and Wales

Areas with a growing population and declining cars

Thirty-three LSOAs were identified as belonging to this category. Almost all are urban except for E01032626, which is a special case as a large residential care home was constructed in the LSOA. Figure 10 shows a typical example of an LSOA in Newcastle-under-Lyme. The LSOA is near the centre of the market town. Several significant changes in land use occurred between 2002 and 2018, including demolishing a supermarket and multi-storey car park to be replaced with derelict land (green). The redevelopment of an industrial site into commercial units and low-rise flats (red). The redevelopment of an industrial site into a hotel and large nursing home (blue). The partial demolition of a waste management depo and the construction of a fire station and a performing arts centre (yellow). The demolition of an industrial site and construction of a supermarket (purple).

Although the number of cars declined slightly in E01029604, it was small compared to the larger increase in population, which was the main cause of the decline in the number of cars per person. The population increase was caused by increased accommodation for groups known to be less likely to own a car (flat dwellers and nursing home residents), and there is limited evidence of broader behaviour change across the LSOA.

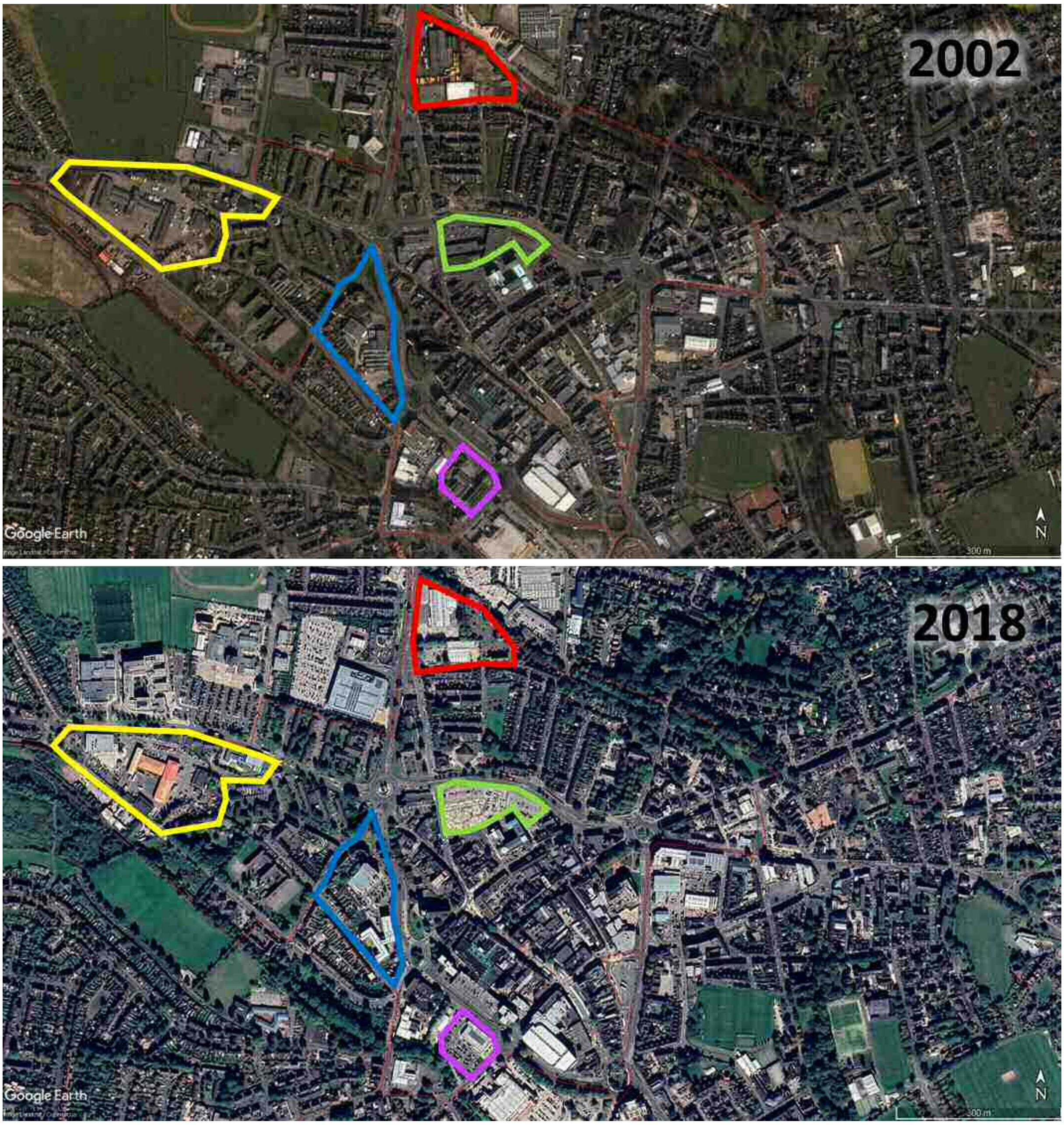

Figure 10: Comparison of E01029604 in Newcastle-under-Lyme highlighting changes in land use

Another example shown in Figure 11 is E01033104 in the centre of Hull. Where the number of cars declined from 821 in 2002 to 360 in 2018 despite the population growing from 744 to 1624, this coincided with several major redevelopments, including a major redevelopment around the station replacing derelict and light industrial buildings with a shopping centre and hotel (yellow). New offices and flats on derelict land (green). A major redevelopment of derelict and light industrial land into a mixed development of low-rise flats, townhouses, and small shops (red). The demotion of derelict buildings (blue). The conversion of police offices into flats (purple). While it is clear that the dense and walkable developments may have caused an increase in population without increasing the number of cars, it is less clear what changes caused the significant reduction in car ownership. It may have been that some of the commercial and industrial sites were the owner of a large number of vehicles. The large police offices may have been the registered location of Humberside Police's car even though few cars appear to have been on site.

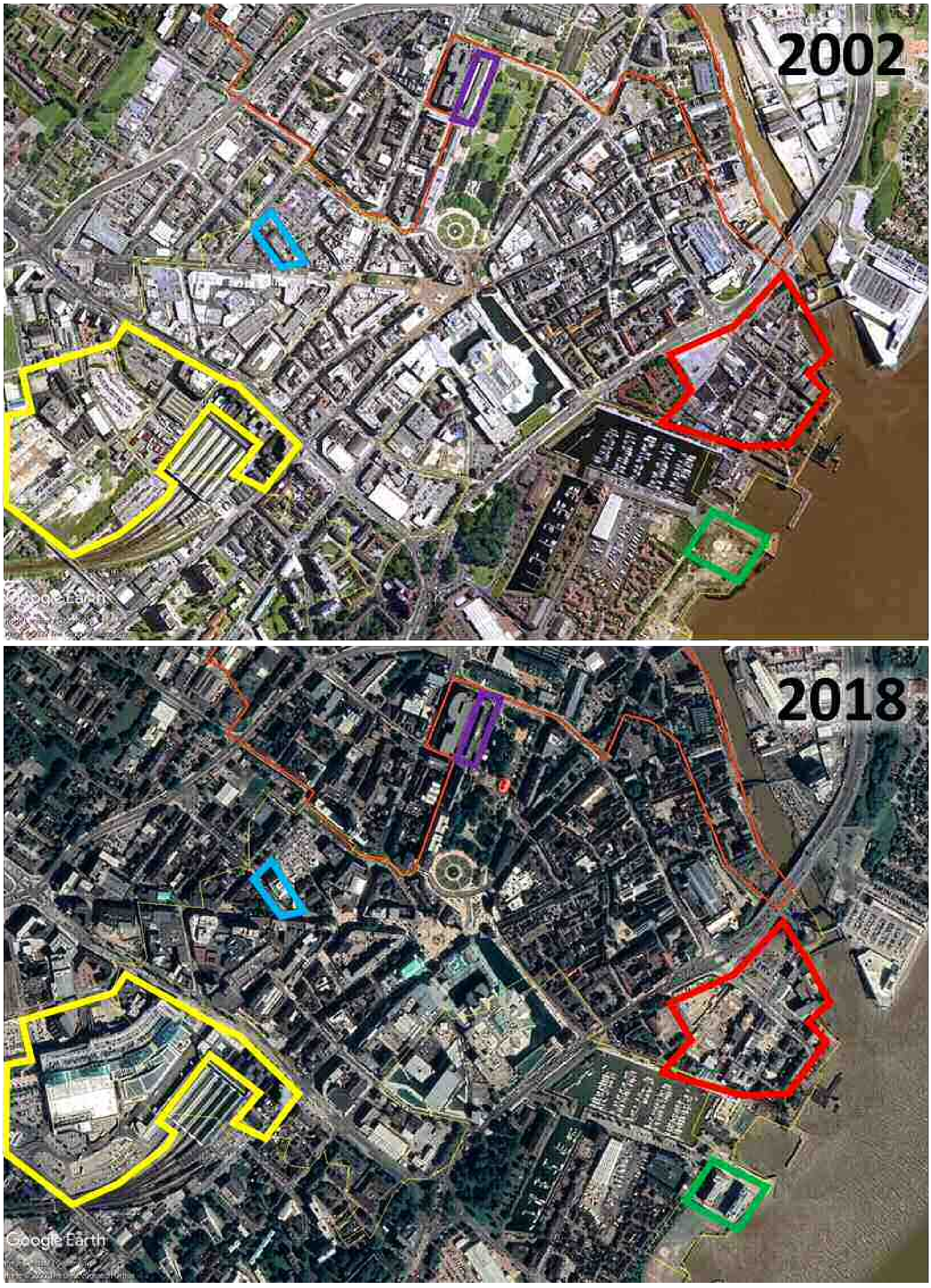

Figure 11: Comparison of E01033104 in Hull highlighting changes in land use

Areas with a growing population and stable cars

This category was the largest examined and included 130 LSOAs, all of which were urban. Many of these LSOAs had similar characteristics, such as new flats being built within existing city centres, which explains why the population is growing without an increase in the number of cars. A few LSOAs, such as E01033497 in Milton Keynes (Figure 12), were not in the city centre and had new construction, usually a mix of low-rise flats and townhouses, such as those shown in Figure 13. Although the housing was reasonably dense, it also tended to be car-focused, with large areas dedicated to parking.

It is also worth noting that the suburban LSOAs in this category often had large industrial or commercial sites within their boundaries. Therefore, a slight reduction in commercial vehicles may have hidden the increase in privately owned cars due to new housebuilding.

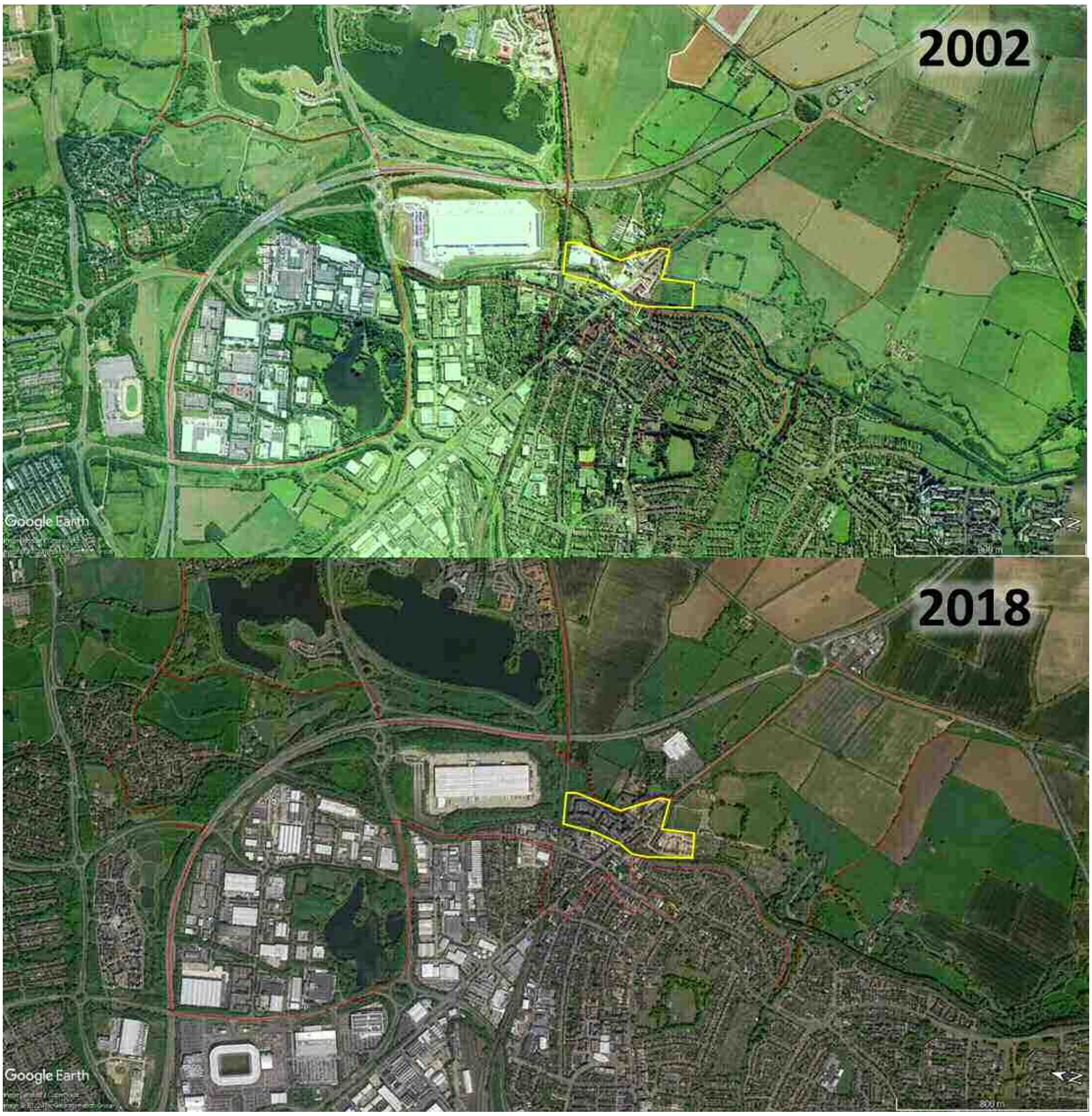

Figure 12: Comparison of E01033497 in Milton Keynes highlighting changes in land use

Figure 13: Examples of the types of new housing in E01033497 from Google street view.

Areas with a stable population and declining cars

Eleven LSOAs were identified as having stable populations and declining car ownership, most of which were urban. The only rural LSOA in this category, E01027682 near Harrogate, contains RAF Menwith Hill, a joint UK/US military base, and so may be an anomaly. The military base is the only location with any obvious changes in land use, and the decline in car registrations occurred in a single drop between 2013 and 2015, a time when the US reduced the number of troops deployed to the base[2]. It is unclear if the ONS population estimates would track the changes in US military personnel, and so a true decline in the population may have been missed.

The urban LSOAs showed a mixed picture. Several had significant redevelopment, but this was usually commercial or industrial, and so changes in car registrations may have been due to changes in the businesses within the LSOA, while others have no observed changes in land use, so the reason for their decline in car registrations is unclear. The one exception was E01010472 in Wolverhampton, where several factories were demolished around 2008/9, and the number of cars vehicles registered in the area dropped from over 3000 to under 800 around the same time. Later new housing (see Figure 14) was built on the site resulting in a flat rate of car ownership despite a rising population.

[2] https://www.stripes.com/theaters/europe/menwith-hill-lajes-schools-close-for-good-1.352059

Figure 14: New housing in LSOA E01010472 in Wolverhampton, dense but also car dominated. Yet maintains a below-average number of cars per person.

Areas with a stable population and cars

Only five LSOAs were identified in this category. Most showed limited changes, with only a few commercial developments being identified. One LSOA E01003000 in Chessington has some housebuilding, but it appears that the homes were only completed in late 2018, so the change in population and cars would not be captured by the mid-2018 data. While these areas buck the trend of rising car ownership, there are so few of them that it is likely they occur by chance.

Areas with a growing population and slowly growing cars

These areas are interesting as while they do have growth in car ownership; it is slower than the national average and so may hold some characteristics of areas that have successfully reduced car ownership. Many of these were urban areas with redevelopments of flats and houses, but several also included new housing estates built on previously rural land. For example, E01033173 in Peterborough, shown in Figure 15, gained a large suburban development between 2002 and 2006. During that time, both the population and the number of cars rose rapidly. Once housebuilding had been completed, the growth of the adult population slowed, and the number of cars stabilised. However, the child population continued to grow, and so the number of cars per person continued to decline. This suggests that the development of mostly 3-5 bed houses was largely occupied in 2006 by couples and young families who had on average 1.2 cars per household. After 2006, households increased their number of children without increasing the number of cars owned. This hypothesis conforms to observed ages within the LSOA, where the majority of adults are aged 30-50, and there has been little growth in the number of over 60s in the LSOA. A similar pattern on a smaller scale can be observed after the smaller housing development was built in 2016.

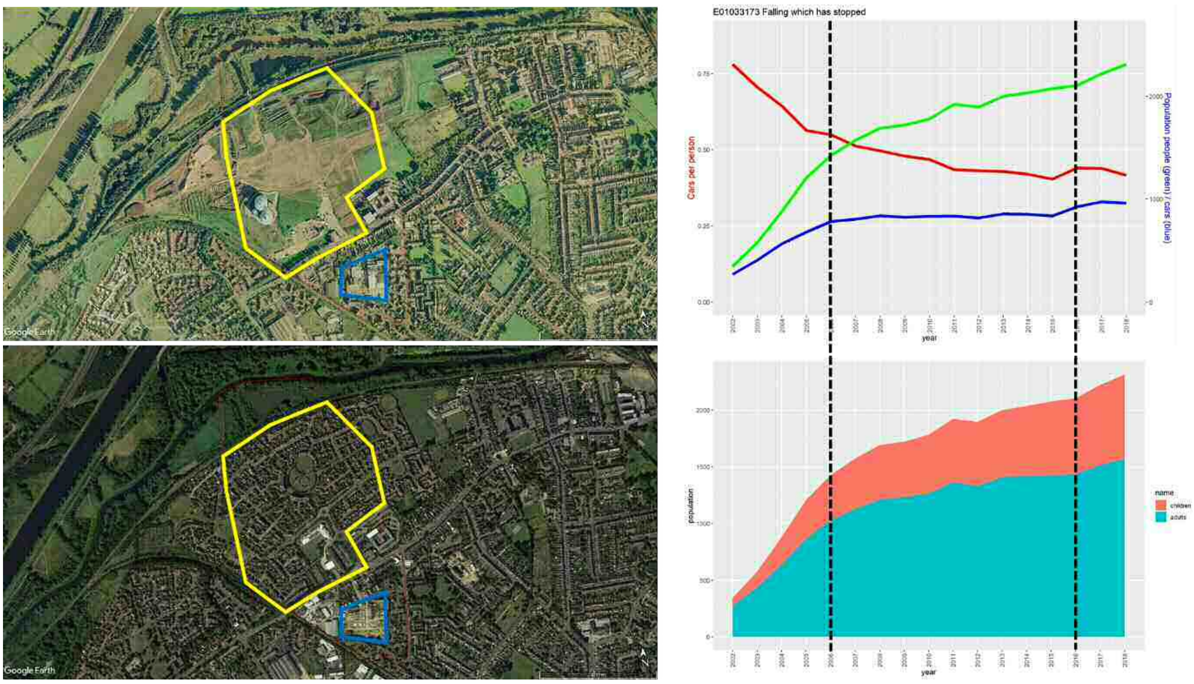

Figure 15: House building in E01033173 on two sites from 2002-2006 (yellow) and 2016-2018 (blue), and how car ownership more closely tracked the changes in adult populations (bottom right, teal) than the total population.

The demographic changes in E01033173 suggest an avenue for further research. Perhaps concentrating on cars per adult and accounting for other groups with low car ownership, such as students and the elderly.

Analysis of changes around new stations

The stations shown in Figure 6 were divided into two categories for the analysis, stations that were part of a multi-station project, such as a new tram line, and isolated stations where no other stations had opened nearby. When multiple stations have open at the same time in close proximity, it would be difficult to disentangle the relative effect of each station on car ownership, so it makes sense to study these stations collectively. For each station, the LSOAs within 500m were selected, and Figure 16 shows the mean cars per person for those LSOAs grouped by the locations of the new stations. In some cases, such as the East London Line, all stations were opened simultaneously and appeared in a single group. However, some lines, such as the Rochdale extension to the Manchester Metro link tram, were opened in stages over several years. In these cases, stations are split into separate groups based on the year the stations opened. Each time series has been adjusted relative to the opening year of the stations.

Figure 16 does not show any clear inflexion points that would suggest car ownership changed in response to the new stations. In places where car ownership declined after the stations opened (e.g. East London Line, Docklands Light Railway DLR), the decline appears to have begun several years before the stations opened. This may reflect pre-emptive changes such as new flats being constructed close to planned stations. The most evident pattern in Figure 16 is that areas with lower car ownership saw further declines in car ownership. In contrast, areas with high car ownership (such as the Ebbw Vale north of Cardiff) experienced growth in car ownership.

It is also worth considering the effect that the quality of the rail service may have on car ownership. For example, the DLR operates frequent service of up to eight trains per hour. In contrast, the Ebbw Vale line operates only one train per hour. So it is unsurprising that the Ebbw vale line is less effective at reducing car ownership.

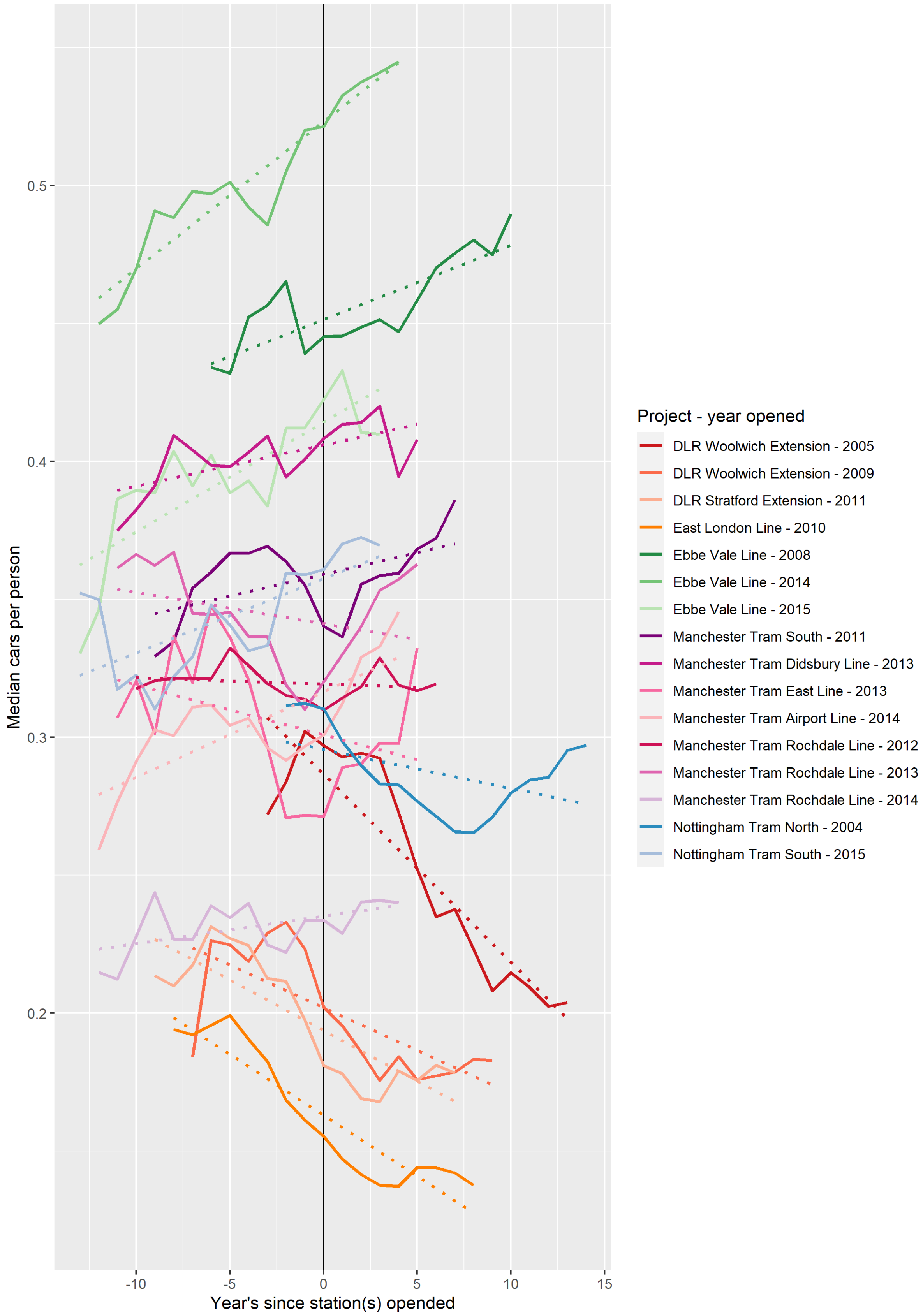

Figure 16: Change in cars per person for LSOAs within 500m of a new rail project. Linear trend lines are shown as dashed lines.

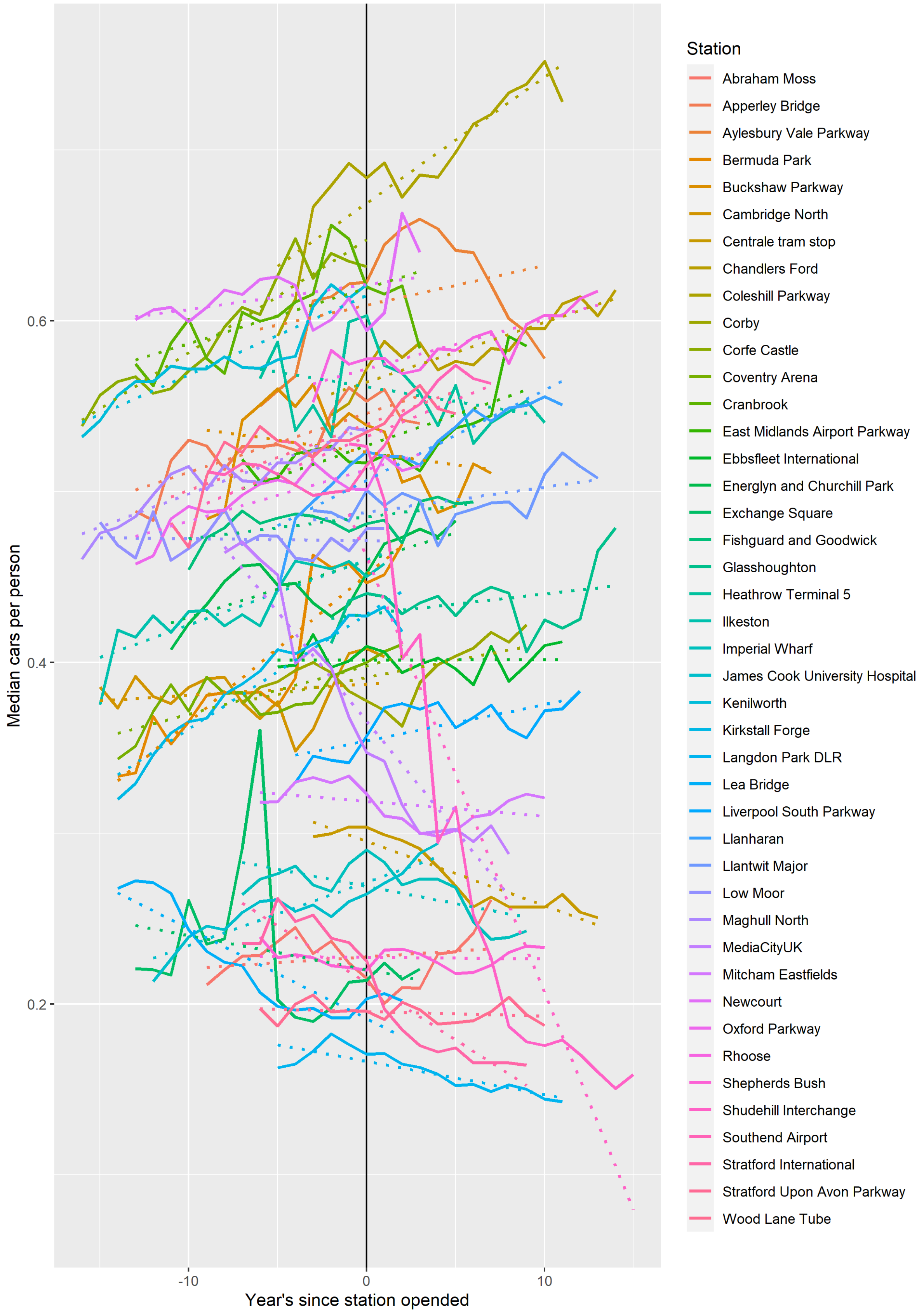

Figure 17: Change in cars per person for LSOAs within 500m of a new single station. Linear trend lines are shown as dashed lines.

Discussion

The analysis presented above has shown several consistent patterns. Firstly, there is a strong association between flats and other forms of dense urban housing and declines in car ownership. Flats do not appear to be sufficient in their own right to reduce the number of cars per person, but in combination with close proximity to existing urban centres, they usually result in rising populations without an increase in the number of cars. While there is likely an element of spatial sorting, with car-free households moving to areas that support car-free lifestyles. This observation still has important implications for place-based decarbonisation. It suggests a need to double down on existing urban areas; increasing the population within the centre of towns and cities appears to be a reliable way of encouraging people into a car-free lifestyle. Fortunately, it does not appear that the highest density tower blocks are necessary to reduce car ownership significantly. Low-rise flats, terraces, and townhouses are also effective at promoting low-car lifestyles and are likely to face less resistance from the planning system. Even relatively car-dominated developments such as the one shown in Figure 14 appear to suppress car ownership a little, perhaps as the density of housing provides a soft limit of one car per household. However, suppressing the growth in car ownership is insufficient to address the climate crisis. Therefore, more effort needs to be made to promote and build car-free housing within town and city centres. It is notable that very few mixed-used developments were identified within the case studies. While the UK does not have the strict zoning laws of the US, it is not common practice in the UK to mix residential and commercial development. For example by building flats on top of a shopping centre. This is a missed opportunity to create housing within city centres that would support viable car-free lifestyles. Another potential opportunity is car parks within town centres, which are a poor use of valuable land. Replacing urban car parks with dense car-free housing would not only increase the population within walking distance of urban centres but also reduce the attractiveness for suburbanites of driving into the centre. Figure 18 demonstrates this issue by highlighting the large amount of land dedicated to car parking in central Manchester.

Figure 18: Aerial view of the land around Manchester Piccadilly station, one of the busiest and best-connected stations in the UK. Highlighting public transport in green, car parks in red, and derelict land in orange.

Secondly, some key demographic groups such as children, students, prisoners, and the elderly are less likely to own a car, and so an increase in their population within an LSOA changes the apparent number of cars per person. This suggests the need for further research to account for these populations. While a simple disaggregation by age is possible from the existing data, it will be more complex to identify students and care home residents as they do not conform to a single age range.

However, as there are a limited number of universities and care homes, it may be possible to identify the relevant LSOAs and flag them for further investigation.

Thirdly, is the need for disaggregation of data about private and commercial vehicles. A recurring theme through the analysis of the case study areas has been that a change in the number of commercial vehicles may be the cause of or obfuscating a change in the number of cars per person. Unfortunately, the data used in this report provided no information about the types of ownership of vehicles, so it is not possible to ascertain the change in the proportion of private or commercial vehicles. If data that is more detailed were available, it would be possible to compare changes in the number of commercial vehicles with the workplace populations.

Fourthly, when considering the impact of improved public transport on car ownership, a mixed picture appears. Within existing dense urban areas with low car ownership, such as East London, new stations appear to be associated with a decline in car ownership. Yet in rural areas, such as the Ebbw Vale, car ownership appears to have been unaffected by the provision of a new rail line. Manchester, with its multiple tramlines opening during the study period, provides an interesting case study, as some lines, such as the Rochdale extension, appear to be strongly associated with decreasing car ownership, while others the reverse is true. Further study would be required to link other changes in the areas around the tram stop to identify changes due to or in anticipation of the tram opening. It would also be necessary to account for the quality of service and the price, as proximity to a station is a crude metric of access to public transport. Nottingham is also an interesting example, as it had a long period of decline in car ownership that has recently been almost completely reversed. As a mid-sized city with trams, a Local Authority controlled bus network, and nine case study LSOAs, it is a promising location for understanding how to reduce car use. So establishing what was working before 2011 and what went wrong after 2012 is important further work.

Finally, while the analysis of car ownership does provide valuable insights, it would be significantly enhanced by data about car use. Particularly when considering improvements to public transport, it may be that residents reduce their car use but do not take the more dramatic step of going completely car-free. While some authors have produced LSOA level estimates of car use[3] , comparable long time series data about car use does not yet exist.

Conclusions

This report outlined an exploratory analysis of spatiotemporal data on vehicle ownership. It found that while car ownership has grown across England and Wales as a whole, there are specific neighbourhoods where it has declined. While the evidence is mixed, it appears that densification of housing and the provision of improved public transport in urban areas are associated with a reduction in car ownership per person. It is less clear if car ownership can be reduced without an increase in an area’s population. The report also found that specific demographic groups such as students and care home residents are strongly associated with low car ownership.

Several limitations with the data have also been identified that restricted a more detailed analysis. Firstly, the lack of separation between privately and commercially owned vehicles makes it challenging to disentangle conflicting trends. At the LSOA scale, car ownership can appear to vary significantly due to a car-owning business moving into/out of an area. Separating these two types of car ownership would be useful in future work. Secondly, the lack of data on distance driven by cars

[3] www.carbon.place

means the analysis is only able to detect major changes when a person is able to change the number of cars they own. Thus, more subtle effects which may encourage people to drive less without abandoning the car entirely are undetectable. Finally, more annual data about the LSOAs would help to explain the changes observed in car ownership. While the total population of each LSOA did account for much of the change, information such as the age breakdown, number of households, land use, average income, and frequency of public transport would provide a clearer picture of when and where changes occurred. While the manual analysis of aerial and street-level photography is effective in identifying changes, it is also time-consuming and prone to error. Therefore, the research would benefit from more automatic methods to detect changes in land use.

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