

Article

Travel Behaviour and Carbon Emissions of Residents of Public Housing Areas in Aotearoa, New Zealand

Michael Keall ^{1,*}, Ralph Chapman ², Keren Love ³, Guy Penny ⁴, Edward Randal ¹ and Philippa Howden-Chapman ¹

¹ Te Tari Hauora Tūmatanui Department of Public Health, University of Otago, Wellington 6021, New Zealand; edward.randal@otago.ac.nz (E.R.); philippa.howden-chapman@otago.ac.nz (P.H.-C.)

² School of Geography, Environment and Earth Sciences, Te Herenga Waka Victoria University of Wellington, Wellington 6140, New Zealand; ralph.b.chapman@gmail.com

³ Wellington City Council, Wellington 6140, New Zealand; kerenlove@outlook.co.nz

⁴ EMPlan Services Ltd., Auckland 1041, New Zealand; guypenny@emplanservices.co.nz

* Correspondence: michael.keall@otago.ac.nz

Abstract

Public housing tenants in many countries have multiple challenges, often including socio-economic disadvantage, family health and disability limitations, and compromised potential to earn income. An understanding of this group's travel behaviours is particularly salient when policies to limit carbon emissions are being considered because such policies can exacerbate transport inequities. The current study makes use of an ongoing national travel survey in New Zealand that uses in-person interviews. We studied travel behaviours from neighbourhoods with mostly public housing tenants compared to other areas with no, or low numbers of, public housing tenants. Respondents from public-housing-intensive areas tended to be younger, have lower incomes, have more dependent children, have fewer household vehicles, and reside in areas with the highest levels of socioeconomic deprivation, all features that are known to affect travel patterns. The public-housing-intensive areas had a much higher proportion of trips made as passengers and hence higher levels of car occupancy than people living in other areas. The distance driven per person was less than half that of other areas, as were carbon emissions per person arising from private vehicle travel. Public housing providers and transport planners need to collaborate so that public housing is close to public transport and active transport facilities to allow tenants ready access. Public housing tenants are likely to suffer aspects of transport poverty, and where policies designed to limit carbon emissions increase the price of fossil-fuelled private car travel, other affordable and accessible transport options need to be available.

Keywords: public housing; social housing; wellbeing; transport equity; carbon emissions; sustainable transport; Māori wellbeing; accessibility; health



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1. Introduction

Public housing is typically owned by a government agency or a charitable organisation and is provided to people who have very low incomes. For these tenants, the cost of transport is therefore very important. They may also have other characteristics contributing to their eligibility for public housing (for example, having disabilities or caring for disabled family members) that constrain transport choice. Understanding actual travel undertaken by public housing tenants, shaped by their transport needs and constraints on travel, is important to predict the potential impacts of transport and climate change policy. For

example, petrol prices can be increased by taxation to motivate reduced car travel and consequent emissions, but this measure could also widen socioeconomic disparities [1]. Such understanding is also important for determining appropriate locations for public housing development (including access to transport) and for guiding public transport (PT) provision that can serve such development.

Various studies have looked at mode choice in relation to income level, particularly lower income. A Canadian study concluded that trips to work are more likely to be taken by PT by people on lower incomes if that trip happens within the municipality of residence [2]. However, the authors also found strong geographical differences for the areas they studied and warned against over-generalising the factors behind the mode choice of people on lower incomes. Important factors motivating private car use were geographical location and parental responsibilities, with the latter increasing dependence on private cars [2]. Distances travelled by people on lower incomes are also very context dependent. In Aotearoa New Zealand (A-NZ), people on lower incomes were found to travel substantially less than people on higher incomes [3]. In the city of Wuhu (China), low-income people travelled greater distances per day by bus than higher-income people, benefitting from a government subsidy for such travel, but needed to travel greater distances from homes in the periphery of the city to the city centre to access employment [4]. In rural Ireland, people without a private car tended to make a much greater proportion of trips via different modes (car passenger, bus, pedestrian) and undertake fewer recreational activities [5]. Generally, in the absence of frequent and reliable PT, access to a private car is clearly important for mobility; however, in car-oriented communities, disadvantaged groups tend to bear a higher share of transport-related costs and enjoy a lower proportion of the benefits [6].

Limiting carbon emissions motivates substantial policy effort internationally. Transport policy designed to reduce carbon emissions can make use of market mechanisms to reduce demand for private car transport [7]. However, such policies can have a greater impact on people without feasible transport alternatives to enable them to avoid the costs imposed by new policies. Therefore, an important consideration in developing such policies is their impact on different socioeconomic groups, which needs to be informed by analysis of travel patterns and consequent carbon emissions. A recent analysis from A-NZ found that those residing in the most affluent areas emitted almost 80% more carbon per person from household travel than those in the most deprived areas [3]. The authors concluded that transport policy aiming to reduce emissions should also aim to avoid increasing inequities; such inequities could increase if barriers for different socioeconomic groups to change to lower-emitting modes were not addressed in the policy [3]. Electric vehicles can also lower emissions when electricity generation produces little carbon (as in A-NZ), and encouraging uptake has been proposed as an important strategy for lowering emissions (for example, in A-NZ by the Climate Change Commission [8]), but the current high price of such vehicles poses a barrier for people on low incomes.

Changing to lower-emitting modes is difficult in A-NZ and in many highly motorised countries where urban form has been developed with an assumption that private cars would be the primary transport mode used. A-NZ has one of the highest rates of car ownership in the world, with approximately 0.8 cars per capita and 1.3 cars per driving-age adult [9]. Nevertheless, even in A-NZ conditions, modest investment in providing suitable walking and cycling infrastructure can increase non-motorised mode share [10,11], and the conjunction of more compact urban form with good PT provision “can generally lower combined housing and transport costs, which is significant for many lower income or middle income households” [12]. Challenging often car-oriented US city norms, a travel demand model developed for Sacramento, California, indicated that PT improvements would provide net overall benefits greater than providing households with cars [13].

Internationally, public housing availability and related eligibility criteria vary considerably across countries. In A-NZ, public and community housing together make up less than 4% of the nation's housing stock. The scarcity of such housing and its needs-based provision mean that A-NZ's tenants are in relatively worse socioeconomic circumstances than typical public housing tenants in countries with much more available public housing, e.g., Denmark, Austria, and The Netherlands [14].

The history of each country also affects patterns of disadvantage. A-NZ was a colony of the UK from 1841 to 1907, and the colonised Māori remain disadvantaged, with persistent adverse impacts from the current transport system in terms of road injury, exposure to air pollution, and physical inactivity [15]. The Housing New Zealand Corporation was the A-NZ government body responsible for public housing between 1974 and 2019; its roles and functions were expanded under the Crown Agency, Kāinga Ora, from 2019. Kāinga Ora—Homes and Communities is currently A-NZ's largest single provider of housing, owning and maintaining 75,000 public houses as of September 2024, housing approximately 191,000 people who qualify for public housing based on socioeconomic criteria, such as lack of income and limited capacity to earn income [16]. The ongoing impacts of colonisation are evident in the disproportionate number of Māori and Pacific Island people that make up public housing tenants—36% and 26%, respectively, despite being 18% and 9% of A-NZ's population [17,18].

Transport ideally supports people's wellbeing by enabling both essential and discretionary activity, which is in turn shaped by culture [19]. As outlined in the wellbeing frameworks for Māori [20] and for Pacific peoples [21], transport plays a key role in Māori and Pacific cultures by enabling social connections within and between large intergenerational families. Both Māori and Pacific peoples in A-NZ suffer from aspects of transport poverty (disadvantage due to lack of transport access and/or affordability) compared to other people. For example, in the NZ Health Survey, both Māori and Pacific respondents reported more than double the European rate of not being able to access treatment from a family doctor (GP) because of transport barriers (2.1% of Europeans; 5.5% of Māori; 4.8% of Pacific) [22]. More generally, a review of studies internationally concluded that public housing with easy walking and low-cost PT providing access to amenities enhances public housing tenants' wellbeing via employment and social connection opportunities, together with physical and mental health benefits [23].

Within the A-NZ context, the aim of the current analysis is to look at transport patterns and consequent private motor vehicle carbon emissions for residents of areas with high concentrations of public housing tenants. These tenants have circumstances that predispose them to transport poverty, including very low incomes, together with personal disability or carer responsibilities. Knowing how public housing tenants' travel behaviours vary from those of other people can guide the delivery of new housing (particularly its location with respect to transport infrastructure) and shed light on the potential consequences of proposed new transport policy, particularly policy that attempts to generate mode shift.

2. Materials and Methods

2.1. New Zealand Household Travel Survey

The New Zealand Household Travel Survey (NZTS) [24] has been conducted annually since 2003 by Te Manatū Waka/Ministry of Transport to collect travel data across A-NZ throughout the year. Each year, randomly sampled households complete a travel log diary, and interviewers conduct face-to-face interviews with each household member. From 2003 to 2010, two days of detailed travel behaviour were recorded for each participant, supplemented by more general questions around travel behaviour. From mid-2015 to mid-2018, seven days of detailed travel were reported for each respondent, preceded by

a gap when no travel data were collected (12 months from mid-2014 to mid-2015), but the survey reverted to two-day reporting after 2018. For the current study, the Ministry of Transport provided NZTS data for the period from mid-2013 to early 2020. Later in the year 2020, constraints on travel related to measures and behaviours in response to the spread of COVID were experienced in A-NZ and many other countries. This period was excluded from the current analysis, as very little data were collected, and travel occurring over this period was not representative of usual travel behaviour.

Meshblocks served as the primary sampling units for the NZTS, sampled randomly with probability proportional to size. Meshblocks are geographical units of varying sizes (roughly equivalent to city blocks, consisting of about 110 people in urban areas). Households were randomly selected by choosing every n th household (e.g., commonly $n = 7$) from a randomised list within the selected meshblocks, and all members of the chosen households were surveyed where possible [24]. While response rates are not published for particular years, in the past, they have been reported as ranging from 65% to 70% [24]. Response rates occur at two stages of surveying—at the household level and then at the occupant level. For example, in 2016, 67% of households supplied detailed travel information for at least one household member, although only 37% of households provided comprehensive information for all usual residents [11].

For estimated means and totals from the survey data reported, 95% confidence intervals were calculated using SAS[®] (version 9.4, SAS Institute Inc., Cary, NC, USA) procedures SURVEYFREQ and SURVEYMEANS. These procedures incorporated the complex survey design features (stratification, clustering, and weighting) into the estimation of the standard errors.

2.2. Identifying Areas with High Concentration of Kāinga Ora Residents

A-NZ has a well-established system for statistical analysis of official data for individuals: the Integrated Data Infrastructure (IDI), a collection of linked de-identified microdata from different government agencies, surveys, and censuses [25]. These include tenancy and public housing information for people who lived in public housing from 2016 to 2023. Travel survey data from the NZTS data do not include information that would allow Kāinga Ora houses to be identified, so for the current analysis, we made use of an ecological approach involving a comparison of travel behaviours of people living in meshblocks where there were high concentrations of Kāinga Ora tenants. These were termed “Kāinga Ora intensive”, or as shorthand, “KO50” meshblocks, defined as areas where at least 50% of the population of the meshblock were Kāinga Ora tenants at the time of the 2013 population Census and/or the time of the 2018 population Census. For privacy reasons, and because such a match is impossible given the protocols protecting the IDI data, we were unable to link particular addresses surveyed in the NZTS to data in the IDI. To classify respondents according to an area-level socioeconomic measure, we also reported travel according to levels of NZDep [26], which is classified in quintiles, with the lowest level of socioeconomic deprivation (the least deprived 20% of people) being quintile 1.

2.3. Calculating Carbon Emissions for Private Motor Vehicle Travel

The NZTS data has trip distances derived from geocoding trip origins and destinations and linking these by the road network or other network appropriate to the mode used. From these distances, we calculated carbon dioxide (“carbon”) emissions per km driven based on factors provided by the Ministry for the Environment. These factors represent average carbon emissions per km driven according to type of vehicle, vehicle age, fuel type, and engine capacity [27]. Vehicle details provided in the NZTS were used to specify emissions factors, although average emissions aggregated across categories were assumed

for vehicles where any specific detail (type of vehicle, vehicle age, fuel type, and engine capacity) was missing. There were high proportions of missing values for the age of the vehicle: 50% of vehicle ages were missing for the KO-intensive meshblocks and 25% for the remainder of the country. To calculate carbon emissions for vehicles with missing age, some imputation was therefore necessary: we used the SAS procedure SURVEYIMPUTE (SAS® version 9.4, SAS Institute Inc.) to apply hot deck imputation within classes. For each missing value of vehicle year and/or vehicle engine capacity, classes (or donor cells) were defined as being in the same geographical stratum (as used for the travel survey), year of surveying, and from an area defined as a KO-intensive meshblock or not. For each missing value, one non-missing value within the same cell was selected randomly and attributed to the record with missing values. A-NZ's electricity generation is largely via renewable sources (e.g., 87% in 2022 [28]), but the remainder of electricity generation does emit carbon, so electric vehicles were accordingly estimated to generate some carbon per unit of distance travelled.

Estimated carbon emissions were presented according to the purpose of the driver's trip, with the exception of trips where the driver specifically drove a passenger to their destination (so the passenger's travel purpose was the underlying purpose for the travel). To more accurately classify emissions according to the purpose motivating the trip, for the analysis of carbon emissions, we reclassified such driver trips using the purposes of their passengers' travel. For example, where a child is given a lift to school as a passenger, the resultant trip's carbon emissions were allocated to "study/education" rather than using the driver's original trip purpose as recorded in the survey ("accompanying someone"). We conducted Rao–Scott chi-square tests looking at differences in trip distribution for KO-intensive meshblocks vs. other meshblocks in terms of trip purpose and trip mode. These tests adjust the standard Pearson chi-square statistic using the sample design information (strata, clusters, and weights) to account for complex survey designs.

Carbon emissions per person for the KO-intensive areas (KO50) and the remainder (non-KO50) were calculated by first calculating total emissions from drivers' trips (as every motorised trip has a vehicle with a driver) and then dividing this total by the number of people in these areas and also the total number of people aged 18 and over. In addition to comparing carbon emissions from private motor vehicle travel, our analysis also aims to show how the travel of people in KO-intensive areas differs in terms of quantity of driving, trip purposes, and mode share.

3. Results

Table 1 summarises the population surveyed in the NZTS according to whether they were living in meshblocks with 50% or more public housing tenants (KO50) or not (non-KO50). Percentages shown are based on weighted counts to account for different selection probabilities of meshblocks sampled with probability proportional to size. The population in the KO50 areas was generally younger—45.6% were under 25, compared to 30.5% for the non-KO50 residents. There was a much smaller proportion with European ethnicity—18.4% compared to 73.5% for the non-KO50 areas. KO50 respondents tended to have lower income, more dependent children, fewer household vehicles, and residence in areas with the highest levels of socioeconomic deprivation (Table 1). The sampling rate per time period shows that a slightly higher proportion of the KO50 people were surveyed in the latter four years compared to the non-KO50 people. The participants represented in Table 1 are summarised mostly at the person level, but the last three categories (household vehicles, household bicycles, and deprivation level) have percentages at the household level, which is indicated in the row heading with the word "households" in brackets. The final row

shows the sum of the weights applied at the person level, showing how many people in aggregate (across all years) are represented by the weighted sample.

Table 1. Characteristics of participants surveyed in the NZTS from mid-2012 to early 2020 according to whether they were in meshblocks with 50% or more public housing tenants (KO50) or not (non-KO50). Percentages are based on weighted counts to account for different selection probabilities.

	KO50 n (People) = 285	Non-KO50 n (People) = 38,289
Time period (survey years)		
2012 to 2016	38.9%	41.2%
2016 to 2020	61.1%	58.8%
Gender		
Female	52.7%	50.7%
Male	47.3%	49.3%
Age group		
0–14	31.0%	18.8%
15–24	14.6%	11.7%
25–34	17.2%	15.0%
35–44	9.7%	14.2%
45–54	11.4%	13.6%
55–64	9.5%	11.7%
65+	6.6%	15.0%
Self-identified ethnicity (respondents may select more than one)		
European	18.4%	73.5%
Māori	27.0%	10.7%
Pacific peoples	49.5%	5.4%
Other	18.7%	13.9%
Income ranges (16+-year-old respondents only)		
Under \$10,000	25%	12%
\$10,001–\$30,000	22%	20%
\$30,001–\$50,000	14%	14%
\$50,001–\$70,000	7%	11%
\$70,000+	3%	13%
Do not know / object to state	30%	30%
Household type		
Person living alone	8.3%	12.2%
Couple only	9.5%	21.6%
Other adults only	7.7%	7.0%
Family with children	49.8%	39.9%
Family with adults only	10.7%	13.7%
Single adult living with children	10.5%	4.8%
Other	3.6%	0.9%
Children (age < 18) in household	60.3%	44.7%

Table 1. Cont.

	KO50 n (People) = 285	Non-KO50 n (People) = 38,289
Number of household vehicles (households)		
0	17.0%	6.8%
1	50.3%	40.4%
2	21.2%	38.2%
3+	11.5%	14.6%
Number of household bicycles * (households)		
0	74.5%	55.0%
1	13.7%	15.7%
2	5.9%	13.6%
3+	5.9%	15.7%
Socioeconomic deprivation quintile (households)		
1 (low deprivation)	0%	19%
2	0%	21%
3	0%	22%
4	2%	20%
5 (high deprivation)	98%	18%
Total number of weighted individuals		
Sum of weights	242,319	32,640,000

* Number of bicycles in working order kept at this household (includes children's bikes but excludes tricycles).

Figure 1 shows total annual carbon emissions per person, distance driven (in private passenger motor vehicles) per person and emissions per km driven (a measure of the fuel efficiency of the vehicles used), as estimated from driving trips in the NZTS. As explained above, the per-person measures are total distance driven or total emissions from household vehicles driven divided by the total number of residents. Distance driven and carbon emissions from private car travel are also presented per person aged 18 and over to give an indication of the mobility and driving emissions of the age group eligible to drive. Distance driven, carbon emissions from driving, and emissions per km driven are also shown for Māori in KO-intensive areas and elsewhere. The carbon emitted per person in the KO-intensive meshblocks was less than half that for the remainder of A-NZ, mainly because non-KO-intensive households drove considerably more distance. Per adult aged 18 and over, there was less of a contrast, with the per-adult KO-intensive driving distance averaging just over half that of the non-KO-intensive residents. However, per km driven (Figure 1), emissions were similar for the two groups (KO and non-KO-intensive areas). Mainly because their cars were older (as shown in Figure 2), 6% more carbon per km was emitted by residents of the KO-intensive meshblocks. In terms of distance driven per person and emissions per person from driving, Māori had lower levels than all ethnicities combined. However, Māori emissions per person per km driven in non-KO-intensive meshblocks were higher than those for all ethnicities. This may be due to Māori driving older, larger, less fuel-efficient vehicles on average that are capable of accommodating more passengers. This latter aspect is an important characteristic of Māori culture, reflecting a sharing of resources within families and communities and vehicle affordability [29]. Although the proportion of private passenger vehicles that is electric is growing over time, in the data analysed, only 0.17% of surveyed driver trips in the non-KO-intensive areas were by purely electric vehicles and 0% of the KO-intensive driver trips.

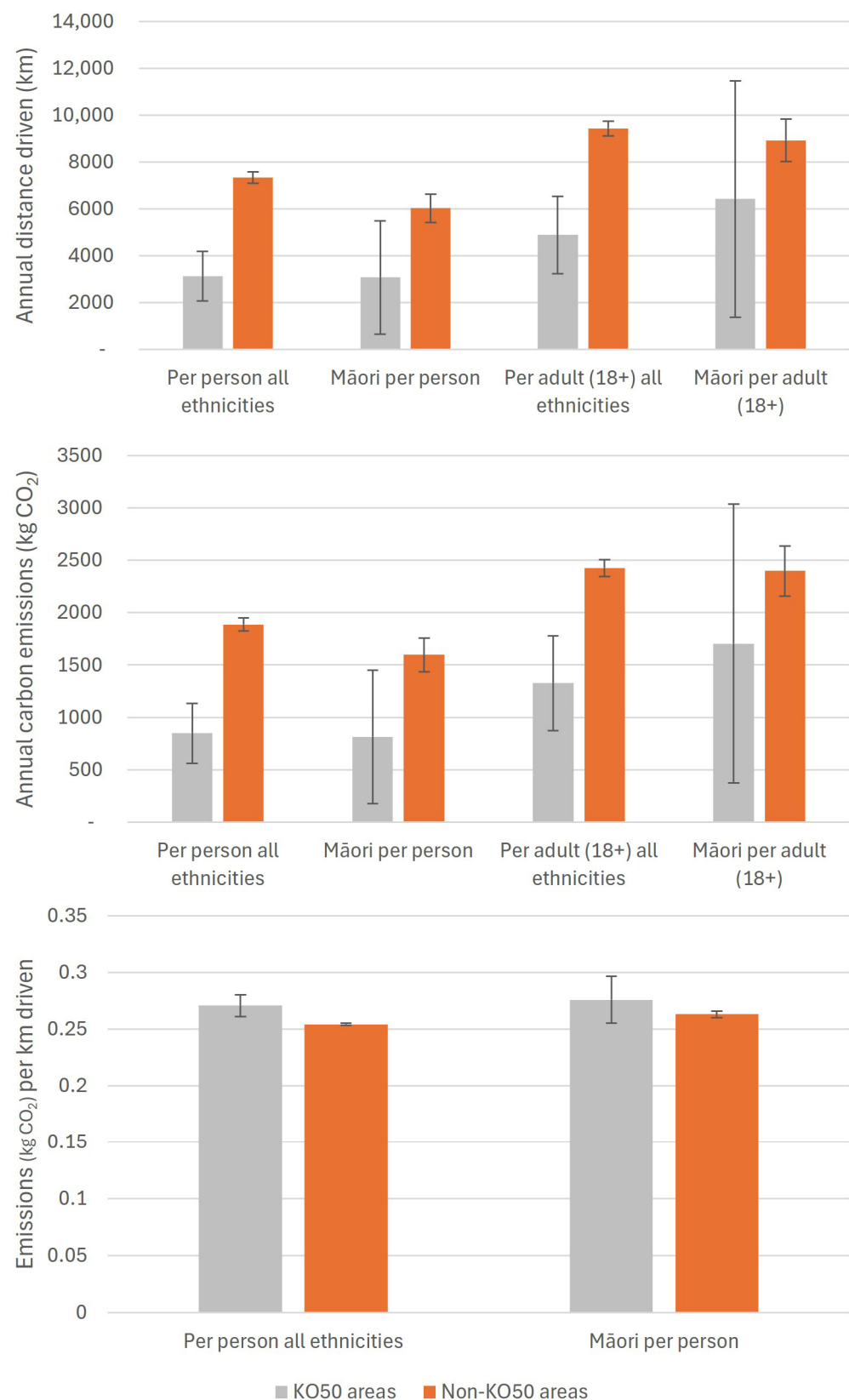


Figure 1. Total annual private motor vehicle distance travelled (data from mid-2012 to early 2020) and annual carbon emissions (kg CO₂) from driving per person and per adult (age 18+) according to area of residence (NZTS) and ethnicity, with 95% confidence bars.

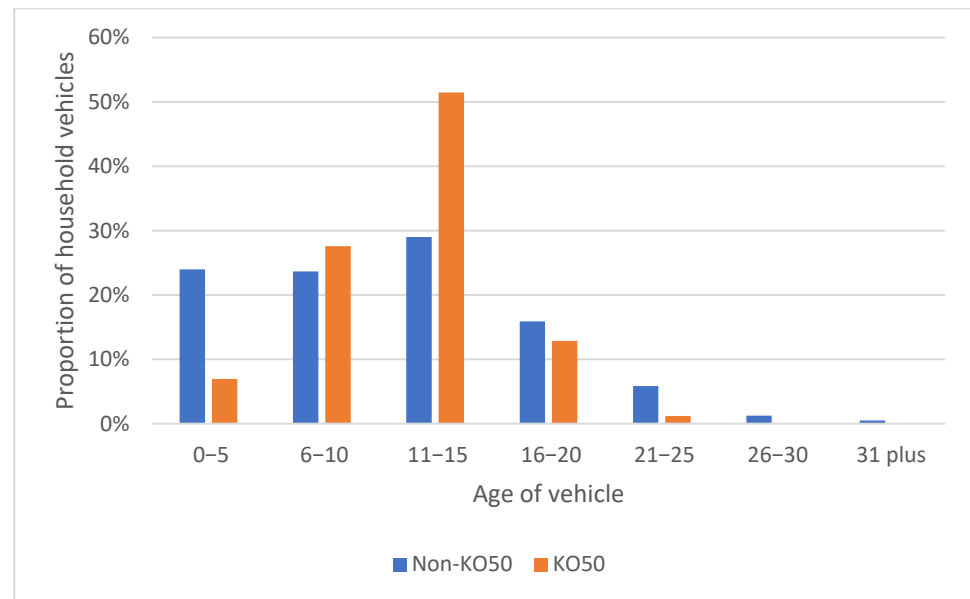


Figure 2. Proportion of household vehicles according to age (years since manufacture) for KO-intensive areas (KO50) vs. the rest, with imputation of vehicle age when missing (see text).

Figure 2 shows the estimated age distribution of the vehicles driven. This shows that only a small proportion of the KO-intensive vehicles were recently manufactured (5 years old or less), and a much higher proportion of vehicles were 11–15 years old. Hot deck substitution of missing values was conducted within cells defined by KO50 or not, year of survey, and geographical area. The graph shows a similar pattern when the imputed values are excluded. The Rao–Scott chi-square was highly significant ($p < 0.0001$), showing the differences in terms of vehicle ages analysed could not feasibly have arisen by chance.

Figure 3 shows carbon emissions per person generated by residents of KO-intensive areas and others by the purpose of the trip. In Figure 3, the purpose “went home” refers to all travel where the prior purpose of the travel was completed and the person was returning home. This is less than half of all trips, as once a person leaves their home, subsequent trips can be chained together, achieving more than one purpose (e.g., go to work—“went to work”—and then go to the supermarket—“shopping”—before returning home). The data in Figure 3 are for drivers only. Residents of KO-intensive meshblocks have a much higher rate of non-driver trips (viz., passenger, walking, cycling, and PT—Figure 4 below). Where there are multiple occupants of a vehicle and all occupants share the same trip purpose, the carbon generated by that trip attributed to this purpose is logically shared between the occupants. Some purposes would have been underrepresented where the driver was making the trip for the sole sake of the passenger (in the survey, the trip purpose was classified as “accompanied someone”). As explained above, to more correctly identify the trip purpose motivating the travel, the passenger’s trip purpose was used in these cases. A graph of distance driven would show a very similar pattern to the carbon emissions represented in Figure 3, as carbon emissions per distance driven were similar for both groups (see Figure 1). Rao–Scott chi-square tests looking at differences in trip distribution for KO-intensive meshblocks vs. other meshblocks in terms of trip purpose and trip mode were highly statistically significant ($p < 0.0001$).

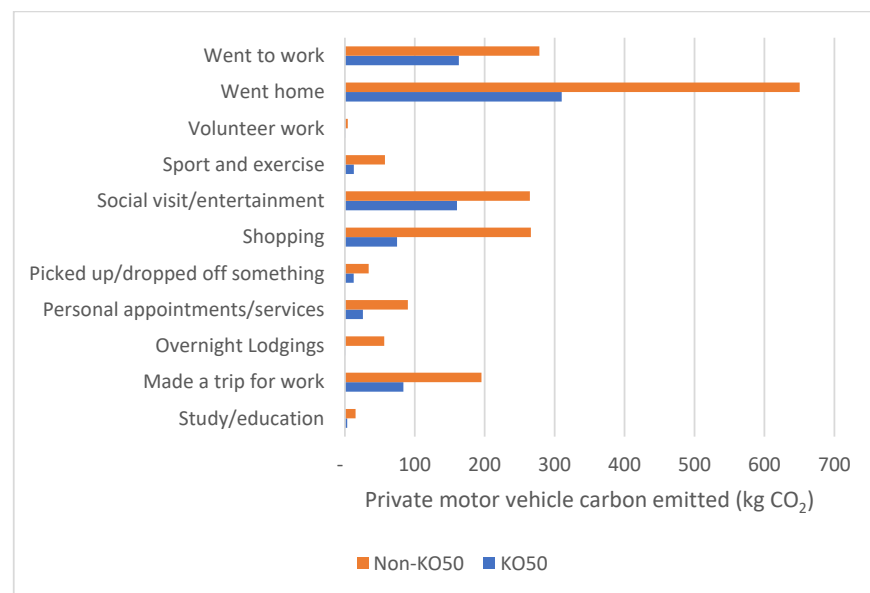


Figure 3. Amount of private motor vehicle travel carbon emitted (annual, kg CO₂) per person in KO-intensive areas (KO50) and other areas (Non-KO50) according to purpose of trip.

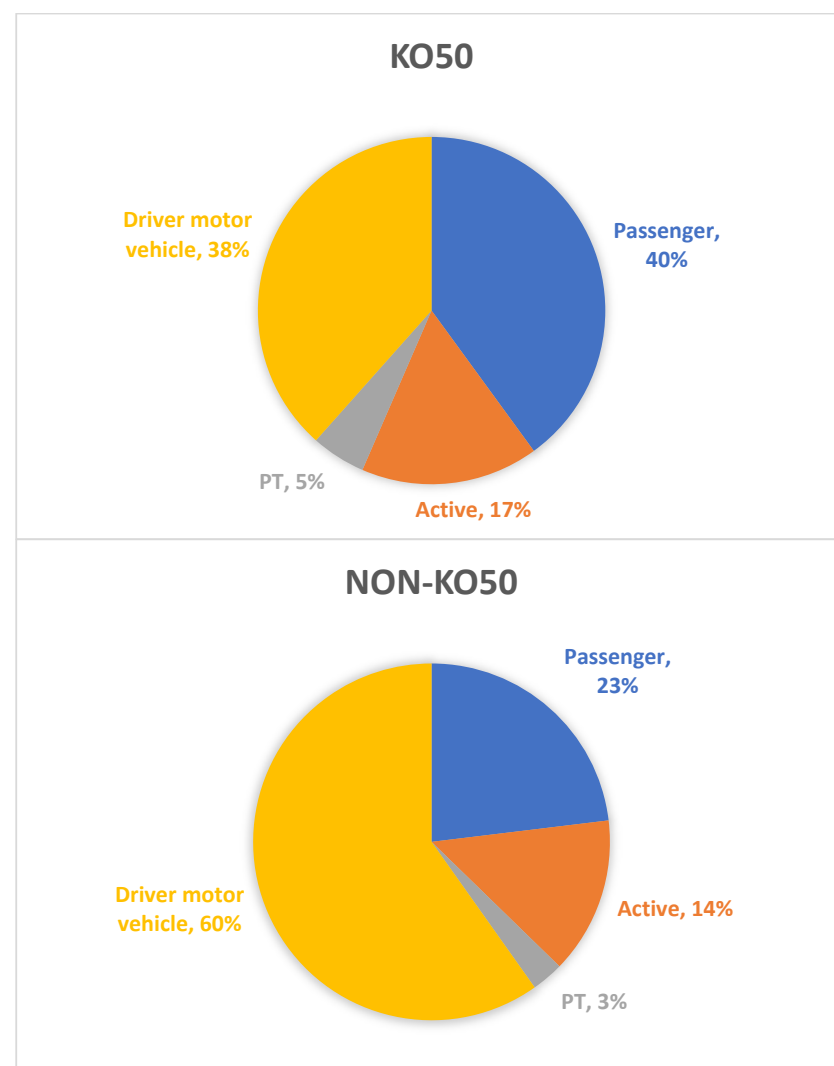


Figure 4. Estimated proportion of all trips made according to travel mode for KO-intensive mesh-blocks (KO50) and all other areas (Non-KO50).

Figure 4 shows the estimated proportion of all trips made according to travel mode for KO-intensive meshblocks (KO50) and all other areas (non-KO50). Cycling and walking are presented combined as “active” modes, as cycling is rare in the data, and counts are not high enough to support the presentation of estimates separately for the KO-intensive meshblocks (only 17 trips across all the years surveyed).

Table 2 provides a comparison between KO50 resident drivers and drivers in other areas in terms of the proportion of driving trips made for specified purposes. This shows that taking other people in your car (“accompanied someone”) was the highest prevalence purpose for KO50 residents compared to all other respondents, as indicated by the ratio (1.66) in the final column. The higher proportion of driving trips to work for KO50 (Table 2) reflects low levels of travel for discretionary purposes. For example, proportionally much less driving was done for shopping or personal appointments among residents of KO-intensive areas. Shopping trips and trips to schools and other places of education for KO50 residents were on average much shorter (shopping: 4 km; schools: 3 km on average) than for other respondents (shopping: 7 km; schools: 5 km on average), indicating that shopping and education were generally more local. Trip distances to work were, on average, similar for KO50 residents as for other people (around 10 km). There were no trips at all to holiday accommodation for the KO50 respondents, compared to 1% of all driving trips for the non-KO50 residents.

Table 2. Comparison of the proportion of driving trips made by trip purpose for KO50 residents compared to residents of other areas (non-KO50). Figures greater than 1 in the RH column indicate a higher proportion for KO50 resident drivers.

Trip Purpose	Proportion of Trips for KO50 Residents	Proportion of Trips for Non-KO50 Residents	Ratio of Trip Proportions, KO50/Non-KO50 (95% CI)
Accompanied someone	14%	8%	1.66 (1.11, 2.48)
Went to work	13%	12%	1.11 (0.75, 1.65)
Went home	35%	31%	1.11 (0.97, 1.26)
Study/education	1%	1%	1.09 (0.27, 4.44)
Picked up/dropped off something	2%	2%	0.99 (0.38, 2.63)
Social visit/entertainment	11%	11%	0.98 (0.68, 1.41)
Shopping	15%	18%	0.82 (0.62, 1.09)
Made a trip for work	6%	8%	0.76 (0.25, 2.33)
Sport and exercise	1%	3%	0.54 (0.21, 1.39)
Personal appointments/services	2%	5%	0.45 (0.22, 0.89)
Volunteer work	0%	0%	0.19 (0.01, 2.48)
Overnight lodgings	0%	1%	(not calculable)
Total	100%	100%	

4. Discussion

4.1. Generalisability

Aspects of our analysis are likely to be relevant to other countries, particularly the greater prevalence of public and active transport use in public-housing-intensive areas and the low carbon emissions of public housing residents. Low levels of emissions arise from constrained discretionary travel behaviours (see Table 2), which in turn is related to

low incomes that motivate less expenditure on travel and often personal disabilities or caring responsibilities.

Other aspects may be related to the A-NZ setting. Due in part to A-NZ's largely car-dependent society and lack of easily accessible PT in many areas, access to cars is important for the wellbeing of public housing residents. For Māori and Pacific Island people, who collectively make up around two-thirds of public housing residents, cars can serve as a means for shared mobility for (often) large intergenerational families [30] while also providing opportunities for social connection amongst the vehicle occupants, including the strengthening of knowledge of tikanga (Māori traditions) and whakapapa (genealogy) [29]. The high proportion of trips made as passengers, shown in Figure 4, for the Kāinga Ora-intensive areas, arising partly because of the higher proportion of households with children (Table 1), shows that public housing residents generally have higher levels of car occupancy than people living in other areas, which has also been found for Māori in the general population, which is likely motivated by cultural and socioeconomic factors [31]. Specific to Māori in public housing, Russell et al. [32] highlighted the important role transport plays in creating a home and in establishing and maintaining social connections, as also emphasised in a wellbeing model developed for Māori, the Whakawhanaungatanga model [20]. Reflecting on attempts to provide transport solutions for Māori public housing tenants, Russell et al. [32] concluded that successful transport systems for Indigenous populations require their involvement in policy-making at a fundamental level.

4.2. Constraints on Travel

Data from the current study showing relatively low car use rates for public-housing-intensive areas, together with much lower rates of travel, particularly for discretionary purposes, are consistent with transport poverty. Transport poverty has been shown to be negatively correlated with subjective wellbeing in Australian longitudinal data analysis [33]. An important aspect that we could not examine with the current data was the impact of transport-related social exclusion [34] on the wellbeing of the residents of public-housing-intensive areas. Although it is likely that residents' travel (and hence opportunities for meeting social, cultural, and economic needs) analysed here would have been constrained by the same factors that made most of them eligible for public housing (namely, low income, limited ability to earn income, and disability or caring responsibilities), the specific role of these factors in the transport patterns we found is unknown. With car-dominant transport systems, such as in A-NZ (characterised by sprawling urban centres often poorly served by PT), wellbeing can be compromised by "forced car ownership" [35], where the lack of viable alternatives to private car transport compels people to own and operate a car. The expense of vehicle ownership, upkeep, and fuel costs diverts scarce income from other necessary expenditures (such as rent, mortgage, household maintenance, energy bills, and food), compounded by vulnerability to fuel price increases, leading to detrimental effects on wellbeing [35]. Research from Scotland found examples where urban regeneration policies were failing to foster transport mobility and accessibility for economically disadvantaged communities, effectively promoting forced car ownership and reinforcing economic and social disadvantage [36].

Table 1 shows that around 17% of the public-housing-intensive area households had no private car, compared to under 7% of other households, which may be another symptom of transport poverty when other modes of transport are not available to serve necessary purposes. Around three-quarters of the households in public-housing-intensive areas had no access to bicycles, compared to just over half of other households. Despite this, our analysis of trip mode share showed that people in public-housing-intensive areas made greater use of active travel than people in other areas.

Our results for PT use, which was higher in KO-intensive areas, suggest that ready access to PT is important to provide transport access for public housing residents. However, household and cultural characteristics can affect the uptake of PT. Thompson [37] found that travelling with children or other people was a barrier to using sustainable modes of transport for Pacific people who are public housing residents. Regarding employment, improved access to PT has been proposed as a means to improve employment access and hence reduce poverty; however, research conducted to support this idea is still emerging [38,39].

4.3. Implications for Climate Change Policy

One objective of the current analysis was to gain some insight into the effects of policies to reduce carbon emissions, which could potentially include additional charges (via an Emissions Trading System) or taxes on petrol. In terms of vulnerability to increased petrol prices, an Australian study found that low-income, car-dependent outer suburbs of cities are likely to be most adversely affected [40]. Mattioli et al. [41] concluded that policies that increased petrol prices may help motivate longer-term measures to reduce carbon emissions (such as more compact urban form) but can cause hardship for certain sectors of the population in the short term; a solution to hardship consequences would be to ensure that those with limited financial means have affordable and accessible alternatives to fossil fuel-based private transport, including PT, access to cycling and pedestrian infrastructure, and electric vehicle sharing.

4.4. Limitations and Sensitivity Analyses

A limitation of our analysis was the small sample size for estimating travel in the public-housing-intensive areas. This meant that some travel behaviours were too rare to be usefully compared between the areas studied, most notably cycling. A study of English National Travel Survey data found that cycling for transport was less common for people in lower-income households than in higher-income households, particularly commuting by bicycle [42], although the study did not find notable differences for leisure cycling. An A-NZ study of the mode shift associated with a programme of active travel infrastructure provision and promotion in two small cities found that Māori increased their active travel rates considerably more than non-Māori, as did members of households with below-median income [11]. Two factors behind the success of that programme for Māori were identified as greater proximity to the new infrastructure and the way that the new infrastructure encompassed sites of cultural significance [11]. The study therefore highlighted some mechanisms that can lead to greater uptake (with concomitant health benefits [43] from the physical activity involved) for these groups who suffer health inequities.

One way of increasing the sample size of the groups is to look at meshblocks with less than 50% public housing residents. As a sensitivity analysis, we also looked at KO30 respondents (those where the meshblock had at least 30% of residents being public housing tenants) and KO10 respondents (as above but at least 10%). The comparison group for KO30 respondents included residents of meshblocks where less than 30% of residents were public housing tenants. The comparison meshblocks for the KO10 groups were those with less than 10% of residents as public housing tenants. As expected, the less intensive public housing meshblocks became gradually more similar to their respective comparison groups. The proportion of respondents with annual incomes of \$35,000 and above increased from 25% for the KO50 respondents to 37% for the KO30 respondents and 41% for the KO10 respondents. The comparative proportion for the comparison groups was 51% for all three groups. Using these same definitions of groups, we also compared total carbon emissions from private motor vehicle usage. As shown in Figure 1, emissions

per person per year (kg CO₂) for KO50 residents were 45% those of non-KO50 residents (848 kg/1887 kg). For KO30 residents, their emissions were 59% of their comparison group; for KO10 residents, their emissions were 70% of their comparison group. These results indicate that the groups became more similar to their comparison groups as the proportion of public housing was reduced, as might be expected. Although the converse might also be expected (that emissions per person fall further when the proportion of public housing increases above 50%), for data confidentiality reasons, we could not examine this aspect.

4.5. Imputation for Missing Values

Some imputations were necessary to calculate carbon emissions specific to the vehicles driven in the survey. In the NZTS, details of vehicles driven were available for vehicles owned or usually parked outside the home of the respondents. Although a smaller proportion of driver trips in KO-intensive meshblocks was in a vehicle owned by a household member (60% vs. 76% for the rest of A-NZ), there was additionally a high number of missing values for the owner of KO-intensive vehicles driven. As outlined in Section 2, multiple imputation was used for these missing values, a process that is better than no imputation, as it averts some aspects of bias (by using similar donors for the missing values) but not all bias. Similarly, there is some additional variability introduced by multiple imputation, but this variability was quite small in this case. For total carbon emissions from driving, the sample standard deviation of a small number of repeated imputations was only 0.02% of the average across these imputations. As with all surveys, non-response will also generate some bias, which is difficult to quantify but can lead to an underestimation of travel [44]. Other limitations include the use of ecological classification of participants, the changed survey methodology (7-day diary) for two of the years studied, mid-2015 to mid-2018, and the relatively small sample of the KO-intensive participants, which meant that the study needed to encompass data over an extended period (10 years).

As described in Section 2, carbon emissions were mostly estimated according to the purpose of the driver's trip, with the exception of trips where the driver drove a passenger to their destination. As the passenger's travel purpose was the underlying purpose for the travel, this purpose was presumed for such trips in our analysis; these trips made up 9% of the estimated total carbon emissions for the KO-intensive meshblocks and 6% for the rest. There was some potential for the emissions to be misallocated in these cases if the driver and the passenger were from different areas (one from a KO-intensive area; the other from elsewhere), so we checked the NZTS data, looking at whether the driver was from the same household as the passenger. We found this was true for 90% of trips in both the KO-intensive areas and the other areas, so the potential for misclassification was small.

4.6. Carbon Emissions per Person

Our estimate of carbon emissions per person from light passenger vehicles is consistent with a figure derived from official 2017 estimates. A-NZ's gross 2017 emissions per person were 7.7 tonnes, of which road transport constituted 43% [45], and 55.9% of 2017 road transport emissions were from light passenger vehicles [46]. Multiplying these together, the 2017 estimate of emissions per person from light passenger vehicles using these official figures was 1851 kg. This is consistent with our overall estimate of 1879 kg per person annually for the period from 2012 to early 2020. A-NZ's rate of carbon dioxide (equivalent) emitted per person from road transport has been assessed as higher than countries such as Iceland, Ireland, Germany, and the UK but similar to that of Australia and Canada [45].

To meet commitments under the Paris Agreement, the A-NZ Ministry of Transport aimed to reduce transport emissions by 41% by 2035 [47]. Clearly, if the entire population were to adopt the transport patterns of the KO50 residents, this reduction could be

achieved, cutting carbon emissions by more than half. However, with the current private car-dominated configuration of the transport system, much necessary travel would need to be curtailed, consistent with transport poverty suffered by the KO50 residents as shown in this analysis. The Ministry also aimed to improve PT provision and active transport infrastructure, along with promoting electric vehicles to avert undesirable mobility constraints that could accompany reduced transport carbon emissions [47].

5. Conclusions

From our analysis of A-NZ public housing tenants, it is clear that their travel is highly constrained. The high proportion of Māori and Pacific people in public housing also means there are additional cultural necessities for transport availability to maintain connections with family and tribal links, which are important for individual and community wellbeing. Public housing providers need to give priority to locating public housing where PT and active modes of transport allow tenants ready access to their principal destinations, including shopping, social visits, and entertainment. Conversely, PT providers need to favour proximity to major public housing developments when deciding on locations for PT routes and nodes. The group we studied is likely to suffer aspects of transport poverty and generally drive cars only when this is necessary, often maximising the use of the car by carrying passengers. Where policies designed to limit carbon emissions increase the price of fossil-fuelled private car travel, other affordable and accessible transport options need to be facilitated in consultation with tenants and their representatives.

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