Urban structure and sustainable modes' competitiveness in small and medium-sized Norwegian cities

This paper contributes novel empirical and theoretical knowledge on how built environment characteristics affect travel behaviour in small and medium-sized cities and how this differs from larger cities. The competitiveness of sustainable modes versus the private car tends to increase and commuting distances tend to decrease with proximity of dwellings and workplaces to the city centre, following similar patterns as in larger cities, although the tendencies are weaker. Car-usage tend to decrease with higher city-level densities. Relatively dense mixed-use zones outside the inner-city generate higher car shares and longer commutes compared with inner cities and in some cases also outer parts of cities. It is concluded that small and medium-sized cities aiming at improving the competitiveness of sustainable modes versus the private car can follow the same advice as larger cities–steering new urban development to central parts of cities and avoiding new development in the outer areas.

Keywords

Small and medium-sized cities; travel behavior; city-level density; distance to city center; modal split; commuting distance

1. Introduction

Reducing car dependency, car usage and traffic volumes in cities has many benefits. Among these are improved public health and well-being; reduced noise, local pollution and greenhouse gas emissions; improved urban transport systems efficiency and commute satisfaction; and more enjoyable, liveable and attractive streets, neighbourhoods and cities (Banister, 2011; Carmona et al., 2018; Chatterjee et al., 2020; European Environment Agency, 2018; Gehl, 2010; Hagen and Tennøy, 2021; Krogstad et al., 2015; Pucher and Buehler, 2010; Sallis et al., 2016; Speck, 2012; Tennøy and Hagen, 2021; UN Habitat and World Health Organization, 2020). Therefore, it is not surprising that cities of all sizes have goals related to sustainable mobility high on the agenda. In the Norwegian context, this is also inspired by the strong focus on the UN Sustainable Development Goals (UN, 2017), the national walking strategy aiming at more walkable environments and more walking (Norwegian Public Roads Administration, 2012) and the long-standing objective of zero growth in passenger road traffic volumes (total vehicle kilometres travelled by private car) in urban regions (Ministry of Local Government and Modernisation, 2012, 2014, 2017; Ministry of Transport and Communications, 2013, 2017, 2021).

Key strategies for achieving sustainable urban development goals are to develop cities through densification and transformation rather than through urban sprawl; improving conditions for travelling by public transport, bicycle and foot; and making private car use less convenient (Ministry of Local Government and Modernisation, 2017; OECD, 2018). These strategies are firmly based on previous research, but most studies have been made in the context of large cities (as we return to). Although research findings from larger cities are transferable to smaller cities to some extent, there are significant differences between them. For instance, higher proportions of trips are made by private car and lower proportions by public transport in small and medium-sized Norwegian cities compared with larger cities (Hjorthol et al., 2014). The same clear tendencies have been found in German (Reichert et al., 2016), Portuguese (Silva et al., 2021) and North American (Sidloski and Diab, 2020) cities.

This paper contributes novel knowledge to the literature on how built environment characteristics affect the competitiveness of sustainable modes versus the private car in small and medium-sized cities, strengthening the empirical knowledge base. By investigating how and with what strength mechanisms known from studies of larger cities act out and affect travel behaviour in smaller cities, it also enhances the theoretical understandings of this in small and medium-sized cities. A strength of the study is that it analyses the effects of the location of workplaces in the urban structure, as well as of dwellings. Competitiveness refers in this paper to the ability of transport modes to attract travellers at the expense of other modes.

When analysing and comparing travel behaviour in small and medium-sized cities, their role in the urban hierarchy of cities in a wider regional context must be considered, as this might affect travel patterns significantly (Aguilera and Mignot, 2004; Wiersma et al., 2016; Wolday, 2018). Smaller cities located in commuting distance from larger cities will often have higher proportions of their workforce commuting to the larger city and a weaker offering of retail and services compared with small and medium-sized cities that are the main city in their local region, where there are long distances to the nearest larger city, and where the cities are largely self-contained in terms of workplaces, workforce, retail stores and services. In the sparsely populated Norwegian context, most cities are of the latter type and not part of the polycentric interwoven urban regions that Wiersma et al. (2016) describe as common in some parts of Europe. The 20 cities included in the comparative case study in this paper are all the main city in their local region, and to a high degree, they are self-contained, for instance, in terms of workplaces and workforce. They can also be characterized as European-style cities with defined cores and relatively high overall densities, as commonly found in most parts of the developed world except from in North America and in Australia (Newman and Kenworthy, 2015; OECD, 2018). The cities in the sample vary in size from 15 000 to 980 000 inhabitants. Data from the Norwegian National Travel Survey 2013/14 and 2017/18 have been analysed together with other relevant data to answer the following research questions:

i) How do city-level densities and location of dwellings and workplaces within the urban structure affect modal splits and commuting distances in small and medium-sized Norwegian cities?
ii) How do the findings differ from what have been found in studies of larger cities?
iii) What implications might the findings have for urban planning in small and medium-sized cities aiming at improving the competitiveness of sustainable modes versus the private car?

The aim of the paper is to produce knowledge that is helpful for small and medium-sized cities aiming at more sustainable mobility by planning and developing land use in directions that improve the competitiveness of sustainable modes versus the private car. City-level densities and location of new dwellings and workplaces are strongly affected by overall municipal planning. Modal splits and commuting distances are relevant for several objectives in urban planning, such as more active transport, higher commute satisfaction and reduction of greenhouse gas emissions.

The paper is organised as follows: Section 2 describes theoretical understandings and relevant existing empirical knowledge. Section 3 describes the research design and methodology, and the findings are presented in section 4. The findings are discussed to answer the research questions in section 5. Section 6 reflects on the findings.

2. Spatial structure and travel behaviour in larger and smaller cities

A wide range of factors might affect whether, where and how people travel, relating to such elements as their personal resources, attitudes and preferences; the characteristics of the trip; the travel options; and the mobility culture in the city (Chatterjee et al., 2020; dellÓlio et al., 2011; Hägerstrand, 1970; Heinonen et al., 2021). Differences in travel time have been found to significantly affecting the competitiveness between modes of transport (Altieri et al., 2020; Downs, 2004; Goodwin, 1996; Lunke et al., 2021; Pucher et al., 2010; Redman et al., 2013). How city-level densities, overall urban structure and location of activities within the city affect the competitiveness between modes of transport have been documented and explained in previous research, mainly conducted in larger cities across the world. Key mechanisms are related to distances between activities and to the possibilities of facilitating efficient mobility solutions by different modes of transport.

Previous studies of large cities across the world (Newman and Kenworthy, 1989; 2015), in USA (Glaser and Kahn, 2010; Bento et al., 2005) and in Nordic cities (Næss, Sandberg and Røe, 1996) have found that higher city-level densities tend to influence the competitiveness between transport modes in favour of sustainable modes. Newman and Kenworthy (1989) explain that this is a result of a mix of interacting mechanisms. One is that high densities provide averagely shorter distances between activities, that allow more trips made by bicycle and foot, as well as averagely shorter car trips. Others are that higher densities enhance the potential for offering more attractive public transport services, while it reduces the potential for offering high accessibility by car (roads, parking).

Distance to the main city centre has been found to have a strong influence on travel behaviour. A substantial number of studies have found that per capita traffic volumes generated by dwellings tend to decrease with decreasing distance to the city centre. This tendency has been found in large cities in Europe (Næss, 2006; Næss et al., 2019a; Reichert et al., 2016), in South America (Zegras, 2010), North America (Bento et al., 2005; Glaser and Kahn, 2010), and in Asia (Næss, 2013). Næss et al. (2013; 2019a) explain this as a result of several interacting mechanisms. This includes that the combination of shorter distances and better public transport accessibility the closer the dwellings are located to the large concentration of workplaces, activities and amenities in the city centre, the higher proportions of trips are understood as convenient to make by sustainable modes compared with the private car. Further, that public transport accessibility to most parts of the urban region increases with proximity to the city centres, that the higher neighbourhood-level densities closer to city centres creates markets for daily services close to homes, and that accessibility by car decreases with proximity to the city centre.

Other studies have investigated the effects of location of workplaces in the urban structure on travel behaviour and traffic volumes. Studies made in the context of larger European (Aguiléra & Voisin, 2014; Schwanen, Dieleman, & Diest, 2001; Sprumont & Viti, 2018; Tennøy et al., 2014; Wolday et al., 2019), Australian (Bell, 1991) and North American (Bento et al., 2005; Yang, 2005; Hu & Schneider, 2017) cities have found strong tendencies of higher proportion of commutes made by sustainable modes and lower proportions by private car the closer to the city centre workplaces are located. Explanations for this are related to the normally better public transport accessibility and worse accessibility by car the closer to the city centre a workplace is located, and that a higher number of people live in walking and bicycling distances to a workplace the closer to the city centre it is located (due to the tendency of increased population densities closer to the city centre) (see e.g. Tennøy et al., 2014; Wolday et al, 2019). Highly specialised workplaces, drawing employees from a larger region tend, however, to concentrate in city centres and in other major public transport hubs with very good public transport accessibility from the larger region, and this might result in long commutes to these areas (Næss et al., 2019b; Tennøy et al., 2014).

The overall spatial organisation of a city also matters for competitiveness between modes. The conditions for offering competitive public transport services are better in cities where workplaces and other activities attracting many people are co-located in few zones with high densities, such as city centres, and if high proportion of dwellings are located within walking distances to main public transport stations and to daily services and amenities, compared with cities with the opposite characteristics (Næss et al., 2019a; Newman and Kenworthy, 2015). Transit-oriented development (TOD) is often understood as a strategy for facilitating the use of sustainable modes, but empirical studies have shown large variations in car usage and public transport competitiveness on TOD-related trips (Ibraeva et al., 2020). In the Norwegian context, a version of TOD called 'public transport node development' (knutepunktutvikling) is often understood as part of the strategy for reducing car dependency and achieving the zero-growth objective, but there are few empirical studies documenting transport behaviour related to this type of areas in the Norwegian context.

The absolute and relative qualities of different parts of urban transport systems also influence travel behaviour and competitiveness between modes of transport, as documented by a wide range of studies, but that we do not discuss further here (see e.g. Altieri et al., 2020; Cairns et al., 2002; Downs, 2004; Ewing and Cervero, 2010; Forsyth and Krizek, 2010; Goodwin, 1996; Heinen et al., 2010; Mogridge, 1997; Newman and Kenworthy, 2015; Noland and Lem, 2002; Pucher et al., 2010; Redman et al., 2013; Speck, 2012; Tennøy et al., 2019; Van Lierop and El-Geneidy, 2016; Walker, 2012).

There are no clear reasons why overall densities, location of activities within the urban structure and differences in absolute and relative qualities of transport systems would not affect travel behaviour through the same mechanisms within largely self-contained small and medium-sized cities as they do in larger ones. Previous studies of travel behaviour in smaller cities support this understanding. Hartoft Nielsen (2001a) investigated the relations between travel behaviour and location of dwellings in six Danish cities varying in size from 22 000 inhabitants in Herning to 1.8 million in Copenhagen. He found similar but weaker trends of increasing travel distances and proportions of trips made by car with increasing distances between dwellings and city centres in the smaller compared with the larger cities. This was also the case when Hartoft-Nielsen (2001b) investigated relations between travel behaviour and the location of workplaces in five Danish cities varying in size from 50 000 inhabitants in Vejle to 1.8 million in Copenhagen. Public transport played a modest role in the smallest cities in both studies, but the proportion of trips made by public transport was higher on commutes to centrally located workplaces in the smaller cities. Other studies of single cities in Norway and Denmark have found similar effects of distance from dwellings to city centres on car usage in cities varying in size from 17 000 inhabitants (Kongsvinger) to 213 000 inhabitants (Stavanger) (Krogstad et al., 2015; Næss and Jensen, 2004; Næss et al., 2019; Nielsen, 2002; Wolday, 2018). There are fewer studies of the effects of the location of workplaces on travel behaviour, but Strømmen (2001) found increasing car usage on commutes with increasing distances between workplaces and city centres in Trondheim (160 000 inhabitants), and Engebretsen, Næss, & Strand (2018) found the same when analysing this in four Norwegian cities. We have not found any studies outside the Nordic countries that have studied these issues in the context of smaller cities.

3. Research design, methodology and data

As mentioned above, the research was designed as a comparative case study, with Norwegian cities of various sizes as cases. This design allowed for analysing how travel behaviour varies with urban structure factors within each city, and for making comparative analyses across cities, while also considering relevant contextual factors (Flyvbjerg, 2006; Stake, 1995; Yin, 2003).

3.1 The case cities

The total sample consisted of 20 cities spread across Norway, whereof a subset of nine cities were used in more detailed analyses, see Figure 1. The 20 cities vary in size from 15 000 to 980 000 inhabitants (in 2016) in the continuous urban area (as we return to). All cities are the main cities in their local regions, and to a large degree, they are self-contained in terms of workplaces, workforce (Statistics Norway, 2021a) and most amenities, and they can be characterized as European-style cities (as discussed in section 1). The structure of 18 cities is largely monocentric, whereas the other 2 are polycentric cities or 'twin cities'. The public transport systems are largely radial in all cities, and the public transport services are far better in the larger than in the smaller cities. See Table 1 for key information about the cities.

Figure 1: Location of the 20 case cities. Darker dots indicate the 9 cities used in more detailed analyses.

In this paper, 'the cities' were defined as continuous urban areas (and not by municipal administrative borders), mainly in accordance with how Statistics Norway (2021b) defines urban settlements. That is clusters of buildings inhabited by at least 200 persons, where the distance between buildings does not exceed 50 metres[i]. Since areas with many workplaces but with few or no dwellings are excluded from urban settlements as Statistics Norway defines them, and we wanted to include such areas, we adjusted the urban areas used in our analyses accordingly. In some cases, there are unbuilt areas splitting cities into two or more urban settlements (according to Statistics Norway's definition). In those cases, the separate urban settlements were included in what we defined as the city. Data were collected at the basic statistical unit[ii] level, and we defined which units to include in our definition of the cities[iii]. Some units included large unbuilt areas (sea, rivers, forest, fields), and these areas were removed to get accurate measures of geographical space. Maps, aerial photos and knowledge of the cities were used in the manual adjustments of the urban settlements as defined by Statistics Norway so that they represented the cities in similar ways.

Table 1: Key information about the 20 case cities (continuous urban areas), sorted by population size. The nine cities where we do more detailed analyses are in italics.

Cities	Area (km^2)	Population, 2016 (no.)	Workplaces, 2016 (no.)	Density, population (pop/km2)	Density, workplaces (wp/km2)	Density, combined (pop+wp/km2)	Type of city
Oslo	268.2	978732	606900	3649	2263	5911	Monocentric
Bergen	87.5	255759	146188	2921	1670	4591	Monocentric
Stavanger/ Sandnes	79	223552	133780	2829	1693	4522	Polycentric
Trondheim	60.1	185589	105340	3088	1753	4841	Monocentric
Drammen	51.4	117132	57760	2280	1124	3404	Monocentric
Fredrikstad/ Sarpsborg	58	110836	48755	1913	841	2754	Polycentric
Kristiansand	35	79566	48546	2276	1389	3665	Monocentric
Tønsberg	32.1	61580	30917	1921	964	2885	Monocentric
Ålesund	28.2	52636	28578	1865	1013	2878	Monocentric
Arendal	31	45155	20446	1456	659	2116	Monocentric
Bodø	14.2	40433	24955	2855	1762	4617	Monocentric
Hamar	17.2	34612	21046	2016	1226	3243	Monocentric
Lillehammer	12.1	23111	15145	1910	1252	3162	Monocentric
Kongsberg	13.6	22142	14392	1624	1056	2679	Monocentric
Molde	9.1	21520	14907	2371	1643	4014	Monocentric
Harstad	11.1	21040	11490	1887	1031	2918	Monocentric
Gjøvik	12.6	20391	13908	1616	1102	2718	Monocentric
Kristiansund	8.2	18552	9797	2252	1189	3441	Monocentric
Alta	9.3	16398	9535	1763	1025	2788	Monocentric
Elverum	11.1	15041	8100	1353	729	2082	Monocentric

3.2 Defining analytical zones within each city

Each city was divided into analytical zones; city centre, inner-city and outer area, and for some cities also denser mixed-use zones, as exemplified in Figure 2 (we return to how this was done below). Only cities with 100 observations or more in each of the analytical zones (e.g. inner-city) were included in the sample of 20 cities, to ensure robustness of the analyses.

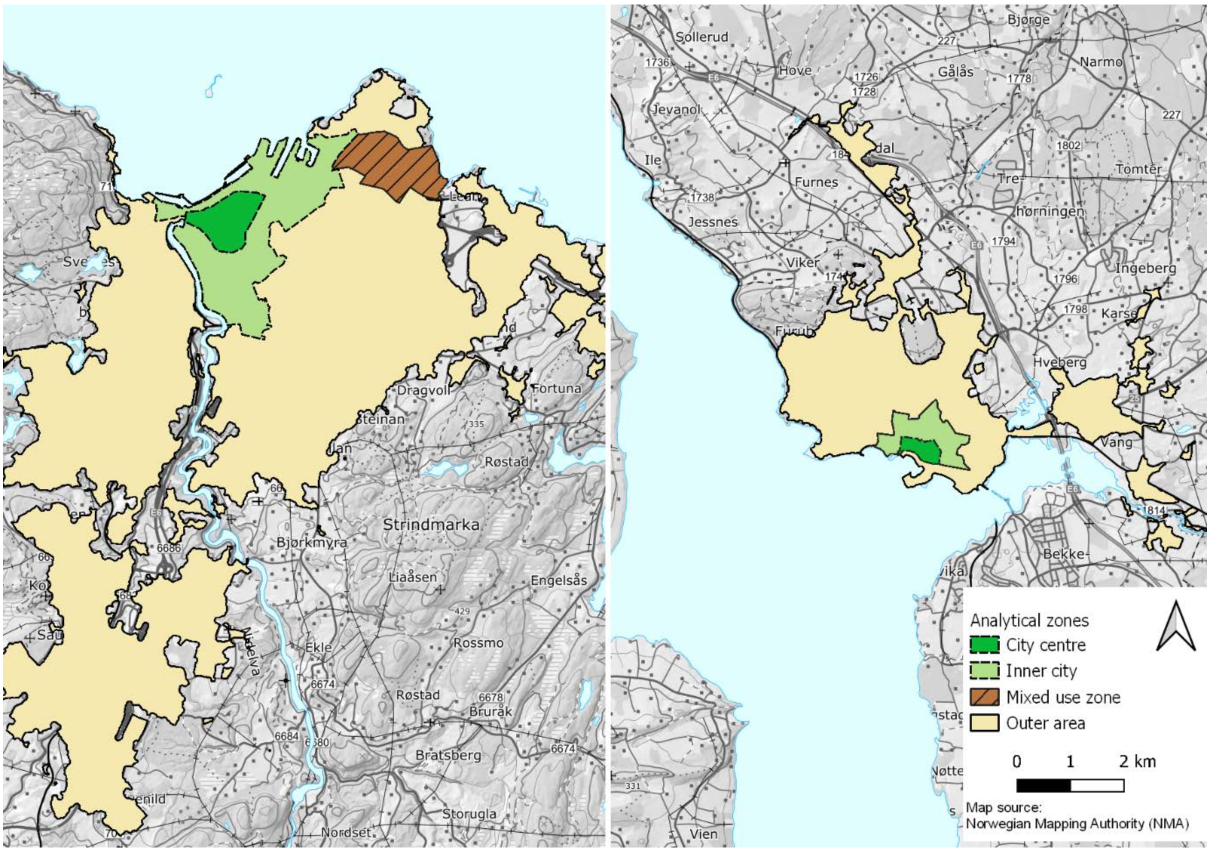

Figure 2: Illustrations of how cities are divided into the analytical zones city centre, inner-city and outer area, and for some cities mixed-use zones outside the city centres, using Trondheim (left) and Hamar (right) as examples.

Centre zones[iv] in Statistics Norway's web-based GIS maps, aerial photos, Google Street View and local knowledge were used to define what basic statistical units to include in the analytical zones 'city centre' (see examples in Figure 3). Defining what basic statistical units to include in inner cities was more complicated. Using the tools described above (and the layer 'retail trade and service area'[v] in the Statistics Norway GIS map), inner cities were defined based on proximity to the city centre, density, morphology, street pattern, and activities located there. We started by assessing the units neighbouring the basic statistical units defined as the city centre and continued outwards if they were assessed to belong to the inner-city, until we met a unit that was not assessed as belonging to the inner-city. If a basic statistical unit included a substantial part of a centre zone or a retail trade and service area (as defined by Statistics Norway), it was normally included in the inner-city, also if other parts of the unit did not fit inner-city characteristics. Basic statistical units including large workplaces such as hospitals and colleges were included, also in cases where the rest of the unit did not fit inner-city characteristics, if the distance between the workplace and the city centre did not exceed one kilometre, and if there were no large areas with only dwellings between the workplace and the rest of the inner-city. Units dominated by multi-floored city blocks were normally included in inner cities, while units dominated by detached one-family houses or rowhouses were normally not. Inner cities in smaller and larger cities are, due to this way of defining inner cities, often quite different with respect to size, densities and activities located there, as the examples in Figure 3 illustrate. Delineating the inner cities this way required much professional judgement. The shapes and sizes of the basic statistical units enhanced the inaccuracies. The same two researchers were doing the assessments of all the cities together to ensure consistent assessments. We could not define an inner-city zone in three of the smallest cities. The outer areas were defined as the basic statistical units defining the continuous urban area (see above), minus the units defined as belonging to the city centre and to the inner-city. Finally, mixed-use zones with relatively high densities and good public transport services located outside the city centres were selected and defined, using similar tools as described above.

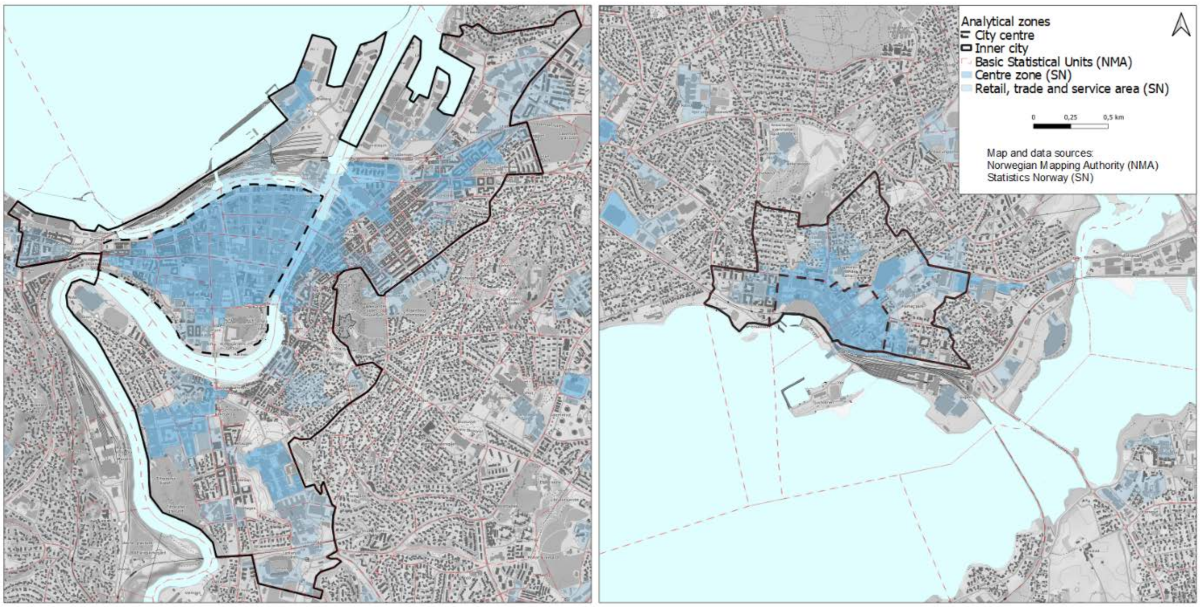

Figure 3: Examples of definitions of the city centre and the inner-city in Trondheim (left) and Hamar (right).

As an alternative to undertaking this labour-intensive work, we could have used 'distance to city centre' as a variable in the analyses. We found this was not feasible when comparing cities of different sizes because the morphology and functioning of cities varies in ways that render meaningless any comparisons, for instance, of areas located 2 kilometres from the city centre in a small versus a much larger city. A problem not solved is that the outer areas in the larger cities, and especially in Oslo, include several larger second-order centres and areas with high densities (some included in analyses of mixed-use zones described above and others not), while this is less or not the case in the smaller cities.

3.3 Data

Data were retrieved at basic statistical unit level and aggregated to the level of the continuous urban area and the analytical zones (e.g., city centre) in each city. Population statistics for 2016 were retrieved from Statistics Norway (2021b). The number of workplaces were retrieved from the Central Register of Enterprises, that includes all units in Norway with economic activity in 2016 (Statistics Norway, 2020). The geographical sizes of the analytical zones were calculated using GIS tools. Densities were calculated both as population, workplaces, and population plus workplaces per km^2 (see Table 1), and the latter factor was used in the city-level analyses (as we return to). Geo-coded data from the Norwegian National Travel Survey collected in 2013/14 and 2017/18 were used when analysing modal splits in the various cities and zones (see Hjorthol et al., 2014, for information about the survey). The data had been weighted to represent the real population. Commuting statistics at census tract level for 2015 from Statistics Norway (2016), with information about home and work addresses for a very high percentage of the employed population, were used to calculate average commuting distances (kilometres, along shortest road) to workplaces as well as to dwellings located in different analytical zones. All commutes shorter than 50 kilometres, except those with the same home and work address, were included. The distance of 50 kilometres was chosen to focus the analyses on the characteristics of each city rather than the location of cities in the larger regions.

3.4 Analyses

Modal splits for trips starting and/or ending in the continuous urban areas, as well as in the different analytical zones within each city, were calculated using Excel spreadsheets. Average commuting distances were calculated by summarizing all commutes to and from dwellings located within the various zones (continuous urban areas, city centres, etc.) and dividing them on the number of observations, and the same was done for commutes to and from workplaces located within analytical zones. These figures were used in the various analyses comparing travel behaviour across zones within cities and across cities.

First, the 20 case cities were analysed at city level, with respect to how modal splits varied with city size (population) and density of the continuous urban area (population plus workplaces/km^2). A linear regression analysis was performed to investigate the relationships between the combined population and job density in each city (independent variable) and the proportion of trips made by the different transport modes in each city (dependent variables), controlling for the effect of population size.

Second, modal splits on all daily trips to and/or from the analytical zones – city centre, inner-city and outer area – within each of the 20 cities were compared and discussed with respect to main differences and tendencies between cities. The same was done with respect to commuting distances to and from dwellings and workplaces, respectively, located in the different analytical zones.

The third analysis differentiated between trips to and from dwellings and to and from workplaces located in different analytical zones within each city. Modal splits and commuting distances were compared and discussed with respect to main differences and tendencies. When analysing modal splits on trips to and from workplaces, all commuting trips except to the basic statistical unit where the respondents lived were included. When analysing modal splits to and from dwellings, all trips starting and/or ending in the basic statistical unit where the respondents' dwellings were located were included. For these analyses, only cities with at least 100 observations for both types of trips within all analytical zones were included. These requirements affected the case selection because only the nine cities with sufficient travel survey data were included in the sample. The cities in this sample vary in size from 21 000 to 980 000 inhabitants in the continuous urban area, and they are all monocentric cities and the main city in their region. See Appendices D, E and F for supplementary information and data related to the nine cities.

The fourth analysis compared travel behaviour on trips to and from dwelling and to and from workplaces located in the mixed-use zones with travel behaviour in inner cities and outer areas in the same cities. Modal splits for the mixed-use zones were analysed in the same way as in the third analysis, see above. Relevant zones with enough respondents (100 or more observations of trips to and from workplaces within the zone) were only found in the three largest cities in our sample. See Table 2 (in section 4.5) and Appendix G for information and data related to the mixed-use zones.

4. Findings

4.1 How modal split and commuting distance vary with population size

First, to obtain an overall perspective, the interrelation between city size (population in the cities), modal split (all daily trips) and commuting distances across 20 case cities were analysed. Results from the analyses of modal splits are shown in Figure 4 (data in Appendix A).

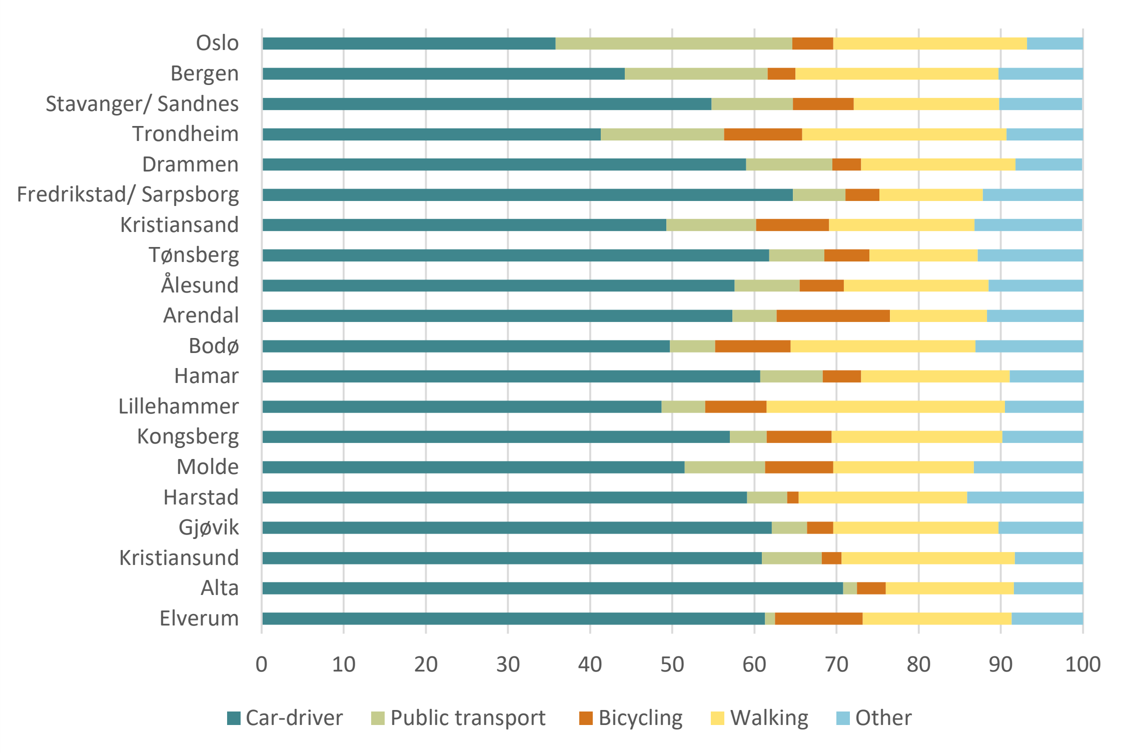

Figure 4: Modal splits (percentages) for all daily journeys starting and/or ending within the 20 cities in the sample. The cities are organised according to population size, with the largest city on top.

The figure shows a tendency of an increasing proportion of trips made by car with decreasing population size, but clear deviations from the pattern are evident. We note that the proportion of trips made by car is clearly lower in three of the largest cities (Oslo, Bergen and Trondheim), car shares are high for their city size in the two polycentric/twin cities Sandnes/Stavanger and Fredrikstad/Sarpsborg and the proportions of trips made by car are between 55 and 65 per cent in 12 of the cities. As expected, the data show a clear tendency of increasing proportions of trips made by public transport with increasing population size. They confirm the significantly stronger role public transport plays in a metropolitan area like Oslo compared with medium-sized cities like Bergen and Trondheim and show that public transport plays a rather marginal role in many smaller cities. The proportion of trips made on foot shows a weak tendency to increase with population size, whereas the proportion of trips made by bicycles shows no systematic variation.

Analyses of commuting data showed a tendency of shorter commutes (kilometres) on average to and from dwellings as well as workplaces in smaller cities compared with larger cities, but with clear deviations from the pattern, see results in Figure 5 (data in Appendix A). Such deviations indicate the importance of the local context of each city. The figure shows overall shorter commuting distances to and from dwellings located within the cities compared with commuting distances to and from workplaces. This is because those who live in the cities (here the continuous urban areas) tend to commute to workplaces located there, while workplaces tend to also attract employees living outside the continuous urban area, with averagely longer commutes.

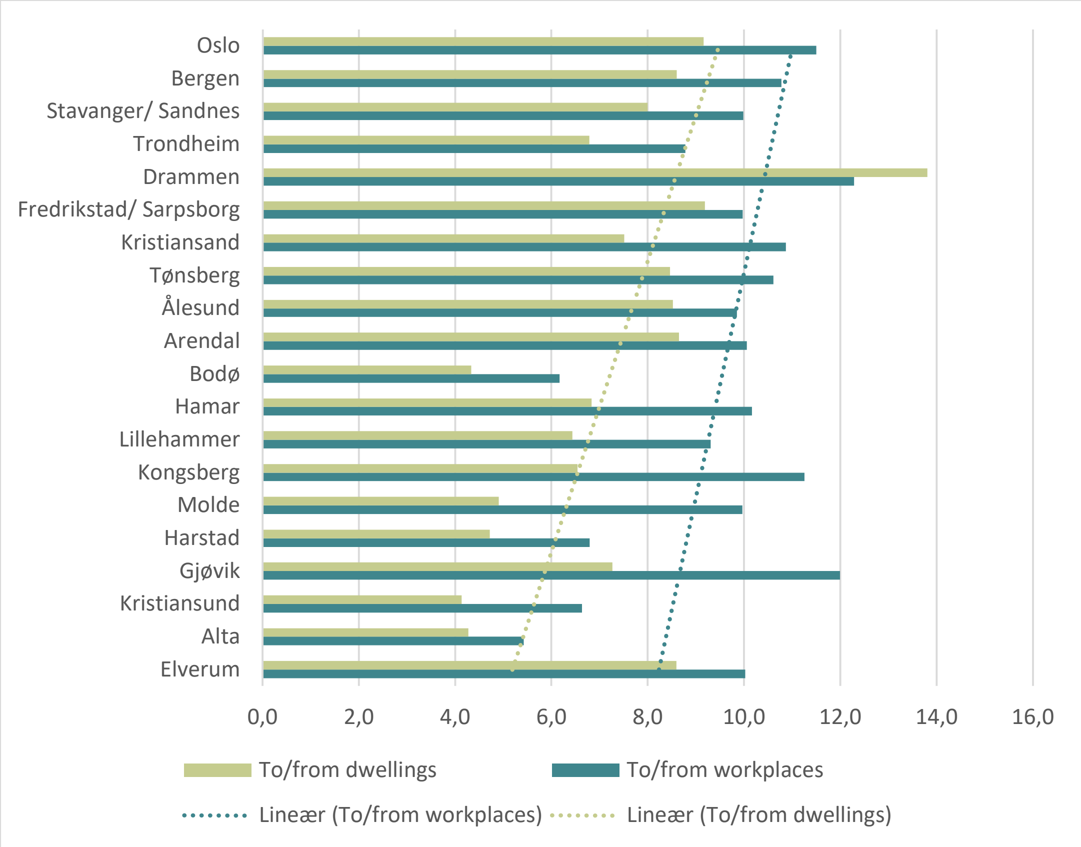

Figure 5: Commuting distances (one way and in kilometres) on commutes to and from dwellings and workplaces located in the 20 case cities. The cities are organised according to population size, with the largest city on top.

4.2 How modal splits and commuting distances vary with overall combined densities

The interrelations between overall densities and modal splits in the 20 cities were analysed (data in Appendix A). The results in Figure 6 show clear tendencies where higher combined overall city densities (population and workplaces/km^2) correlate with lower proportions of trips made as car-driver and higher proportions of trips made by public transport and foot. The same tendencies persist when analysing population and workplace densities separately and when Oslo is excluded from the analysis. Linear regression analyses on the same data confirmed the strong association between the combined density and mode usage even after accounting for differences in city size (see results in Appendix C).

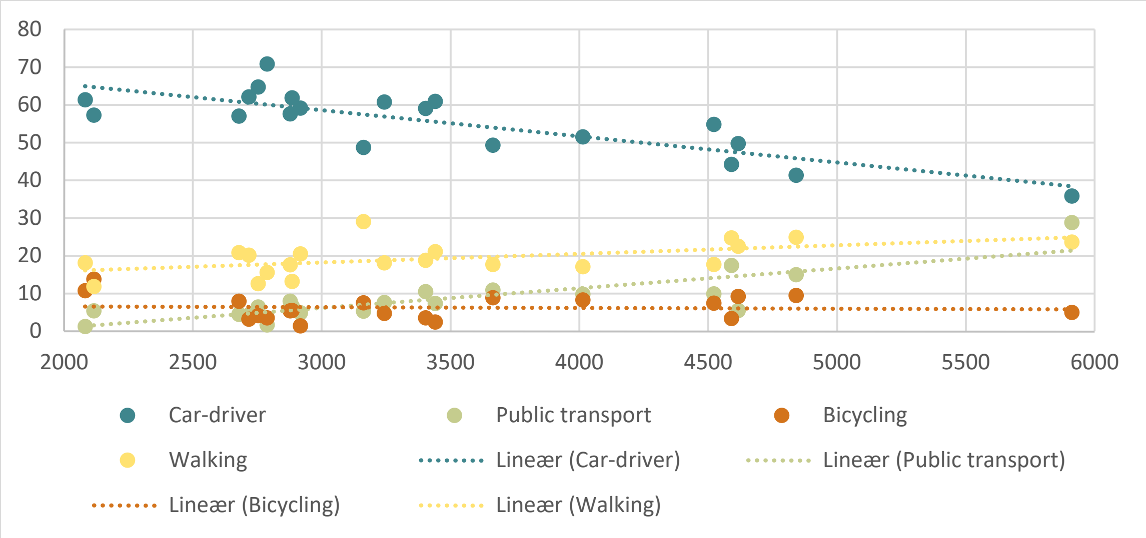

Figure 6: Modal splits versus city densities in the 20 case cities of various sizes. Percentages, of all daily journeys starting and/or ending within the cities made by different modes on the y-axis, and densities (population plus workplaces per km^2) on the x-axis.

Analyses of commuting data showed no clear tendencies of average commuting distances with overall combined densities, see Figure 7 (data in Appendix A).

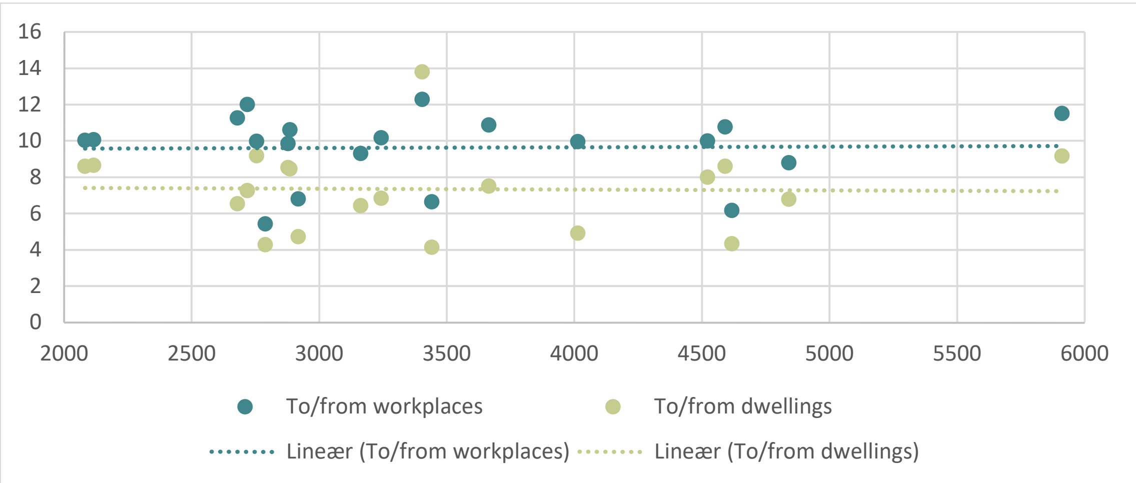

Figure 7: Commuting distances versus city densities in the 20 case cities of various sizes. Commuting distances (one way and in kilometres) on commutes to and from dwellings and workplaces located in the different cities on the y-axis, and densities (population plus workplaces per km^2) on the x-axis.

4.3 Modal split on all daily journeys to and from different parts of the cities

Distance to city centre has been found to strongly affect the modal split, as described in section 2. Analyses were carried out to investigate how the modal split varied on trips that started and/or ended in the analytical zones (city centres, inner cities and outer areas) within the 20 case cities. See results for the 10 largest cities in Figure 8 (data in Appendix B).

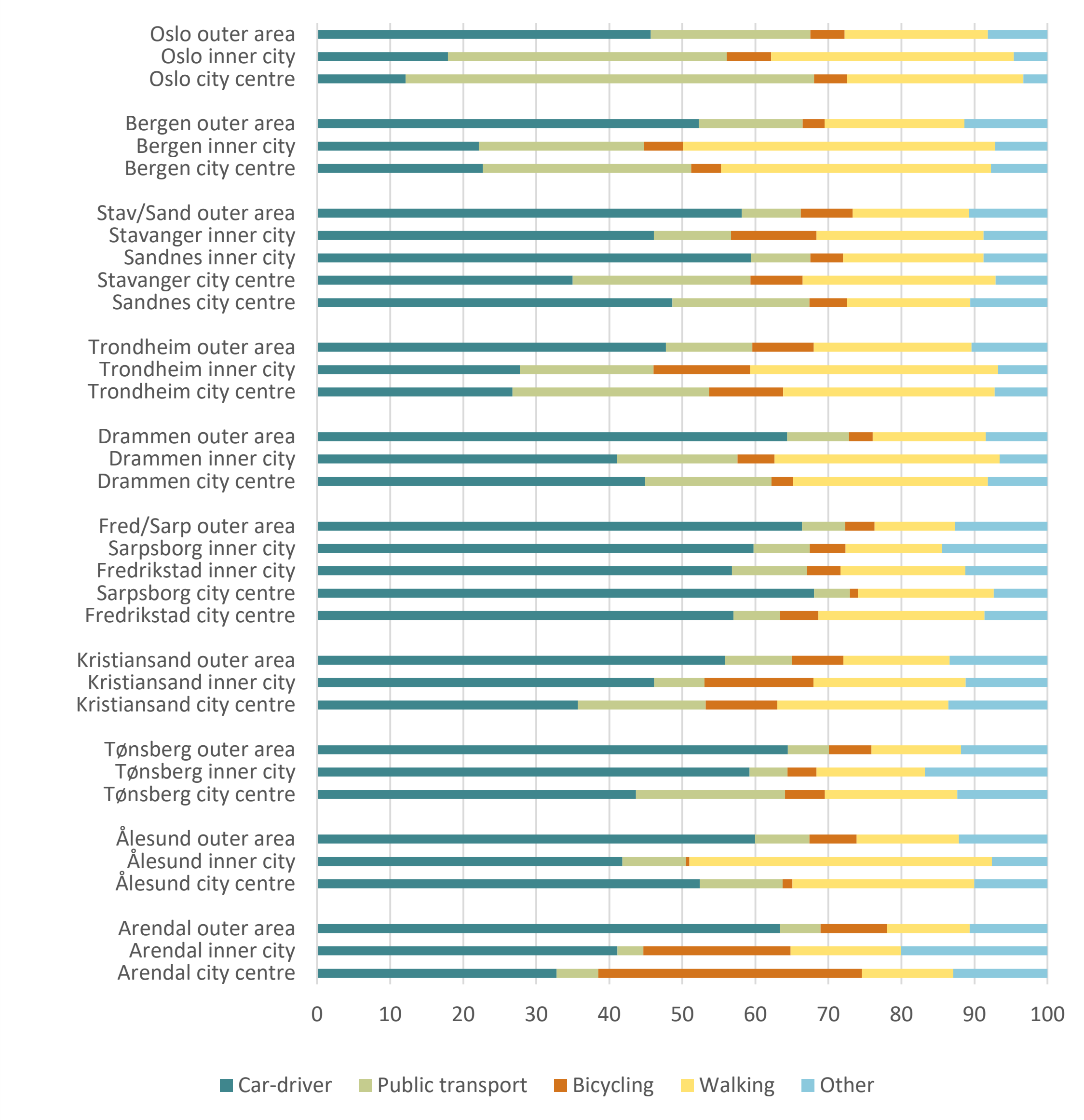

Figure 8: Modal splits (percentages) for all daily journeys starting and/or ending within different analytical zones of the 10 largest cities in the sample. The cities are organised according to population size, with the largest city on top.

Comparison of modal splits on all trips (daily journeys) starting and/or ending in different analytical zones of the cities shows that the private car competes significantly better than sustainable modes of transport on trips to and from the outer areas compared with city centres and inner cities in most cities. The exceptions are Sandnes and Sarpsborg (both part of twin cities), where the highest car shares are found on trips to and from the inner-city and the city centre, respectively. In the largest city Oslo, public transport competes better the closer to the city centre the origins and destinations are located. The same pattern is found in the relatively large (in our sample) cities of Bergen, Stavanger/Sandnes and Trondheim, as well as in the smaller cities of Drammen and Ålesund, but the tendencies are weaker and the public transport shares generally lower. Public transport also competes significantly better on trips to and from the city centre than to other parts of the city in Kristiansand and Tønsberg, but here, the results show somewhat higher public transport shares on trips to and from the outer area compared with the inner-city. In Arendal and Fredrikstad/Sarpsborg, there are no clear tendencies. In all cities, the proportions of trips made on foot are lower in outer areas than in inner cities and city centres. Bicycle shares vary rather unsystematically across cities and zones.

Turning to the 10 smallest case cities (see Figure 9; data in Appendix B), the proportion of trips made as car drivers is higher on trips starting and/or ending in the outer areas compared with city centres and inner cities in 8 of the 10 cities. In two cities (Bodø and Lillehammer), car shares are somewhat higher on trips to and from the inner-city compared with the outer area. Car shares are higher on trips to and from the city centre compared with the inner-city in two cities (Kongsberg and Gjøvik). The proportion of trips made by public transport is too low to be included in the discussions in the two smallest cities. Among the remaining eight cities, the expected pattern with the highest public transport shares in the city centre, followed by the inner-city and the outer area, is found only in Kongsberg and Harstad. Public transport shares are highest on trips to and from the city centre in five cities, to the inner-city in two cities and to the outer area in one city (Lillehammer). In all cities but Elverum, the proportions of trips made on foot are higher on trips to and/or from the city centre and inner-city compared with the outer area. Again, it is hard to see any clear patterns when it comes to bicycling.

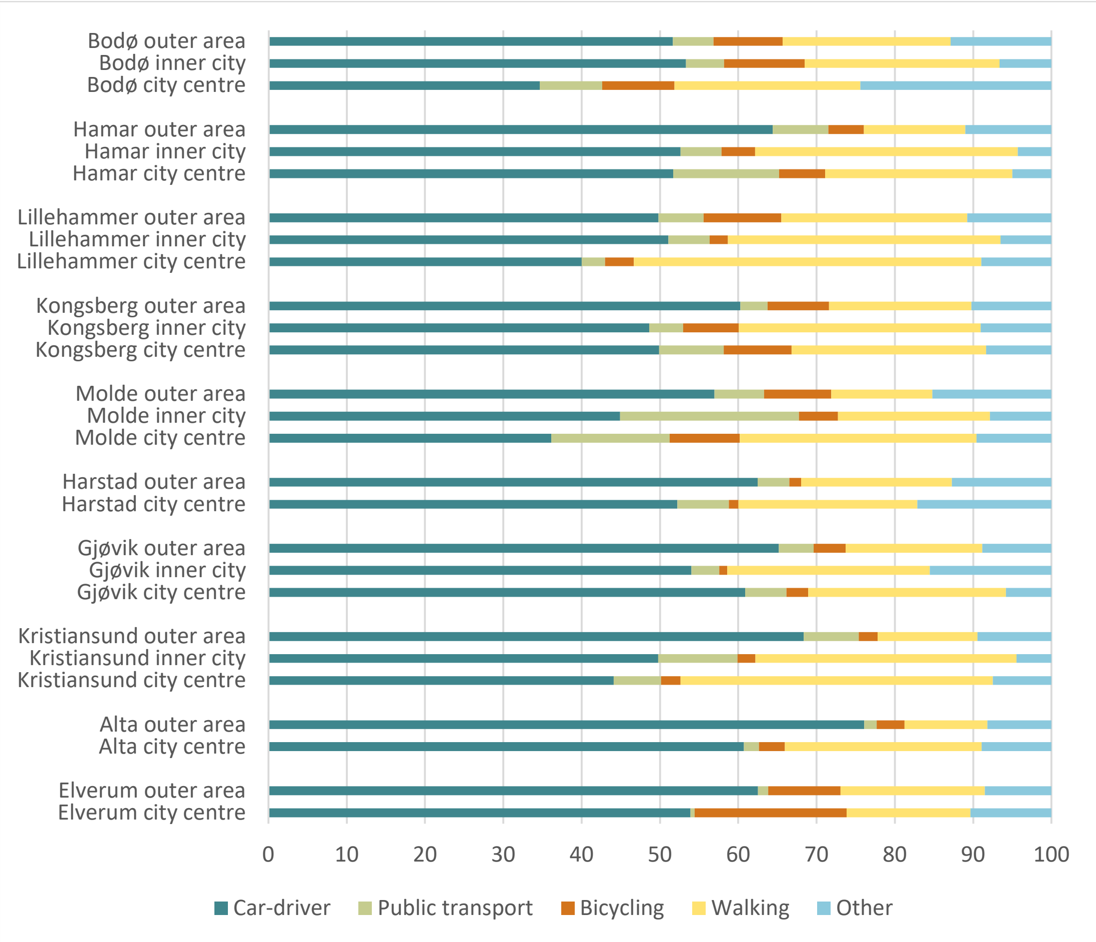

Figure 9: Modal splits (percentages) for all daily journeys starting and/or ending within different analytical zones of the 10 smallest cities in the sample. The cities are organised according to population size, with the largest city on top.

To summarize, there are clear tendencies across cities that the private car competes better on trips starting and/or ending in the outer areas, while sustainable modes of transport compete better on trips starting and/or ending in the city centre and the inner-city. This tendency is stronger and more consistent among the larger cities compared with the smaller cities.

Analyses of commuting distances were also conducted. They showed that commutes to and from workplaces, as well as dwellings located in city centres and inner cities, were shorter than to workplaces and dwellings located in the outer areas in most cities (data in Appendix B).

4.4 Differentiating between trips to and from workplaces and dwellings

For nine of the case cities, travel survey data had enough observations to allow analyses differentiating between trips to and from dwellings and to and from workplaces located in different analytical zones in the cities. The results of the analyses of modal splits on trips to and from dwellings are shown in Figure 10 (data in Appendix F). The proportion of trips made as car drivers are significantly lower on trips starting and/or ending in dwellings located in the city centre and the inner-city compared with dwellings located in the outer area in all but one city (Bodø). We exclude Harstad from the discussions here because the high percentage of 'other' indicates problems with the data. The pattern found in Oslo, with higher public transport shares on trips to and from dwellings located in the city centre, followed by the inner-city and the outer area, is only found in two of the smaller cities (Trondheim and Drammen). The highest public transport shares are found on trips starting and/or ending in dwellings located in the city centre in five cities, but in general, the variation in the proportion of trips made using public transport with the location of dwellings is small and rather unsystematic. The proportions of trips made on foot to and from dwellings located in city centres and inner cities are very high in most cities and significantly higher than what is found in the outer area.

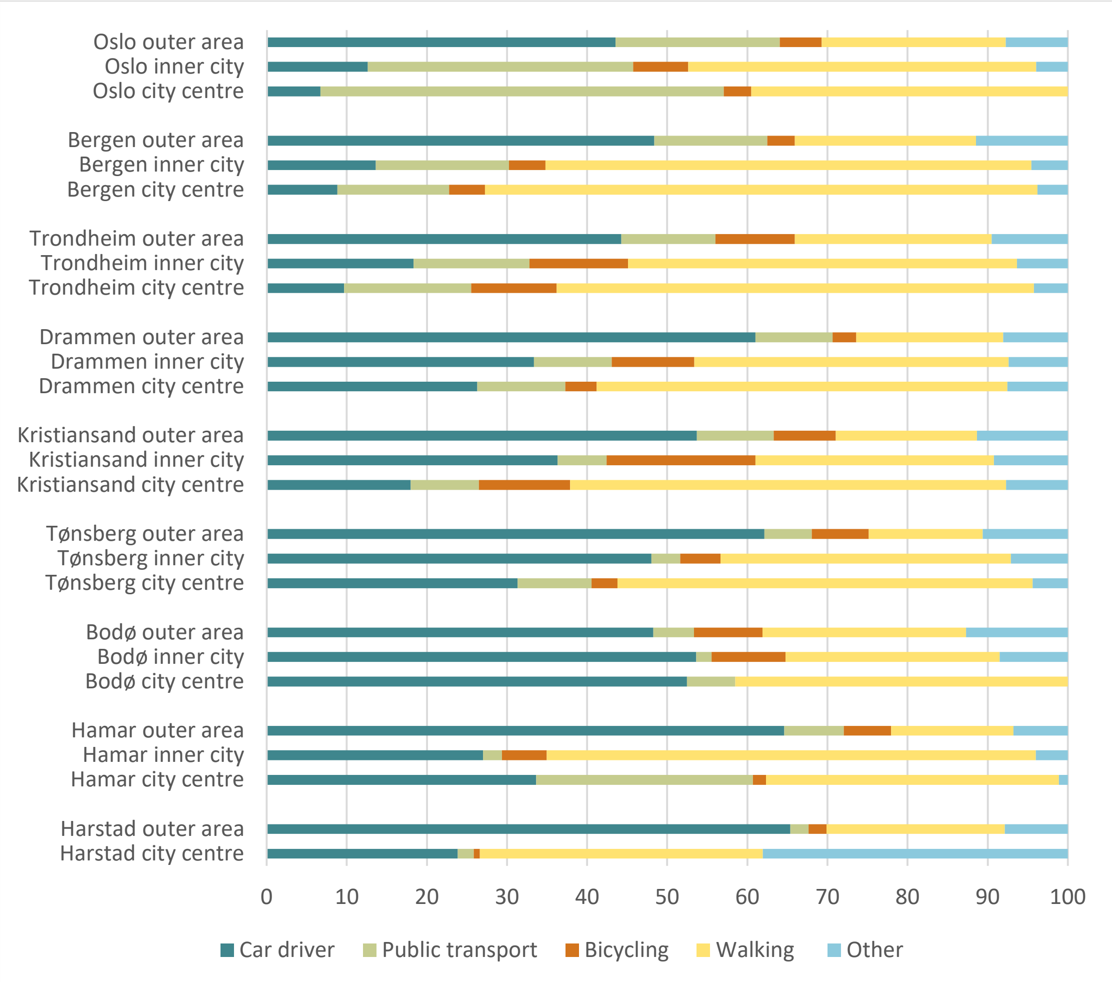

Figure 10: Modal splits (percentages) for trips starting and/or ending in own dwelling, for dwellings located in different analytical zones of the cities. The cities are organised according to population size, with the largest city on top.

Analyses of commuting distances to and from dwellings located in different analytical zones of the nine cities showed shorter commutes on average to and from dwellings located in city centres and inner cities compared with dwellings located in outer areas in all cities but one (see

Figure 11; data in Appendix F). Drammen stands out with less variation in commuting distances and with significantly longer commutes than the other cities. Commuting data from Statistics Norway (2021a) shows that Drammen also stands out with a higher proportion of the workforce commuting out of Drammen municipality (47%), with only a modest part (14%) going to the neighbouring municipalities and 14 per cent to Oslo (about 45 kilometres away; see Appendix E for data). The proportions commuting out of the municipality and to municipalities other than their neighbours (that in many cases is part of the city as defined here) are significantly lower in the other eight cities. It is interesting to note the very short commutes on average among city-centre and inner-city dwellers in Bodø in light of the high proportion of trips made by car to and from dwellings located in the same areas.

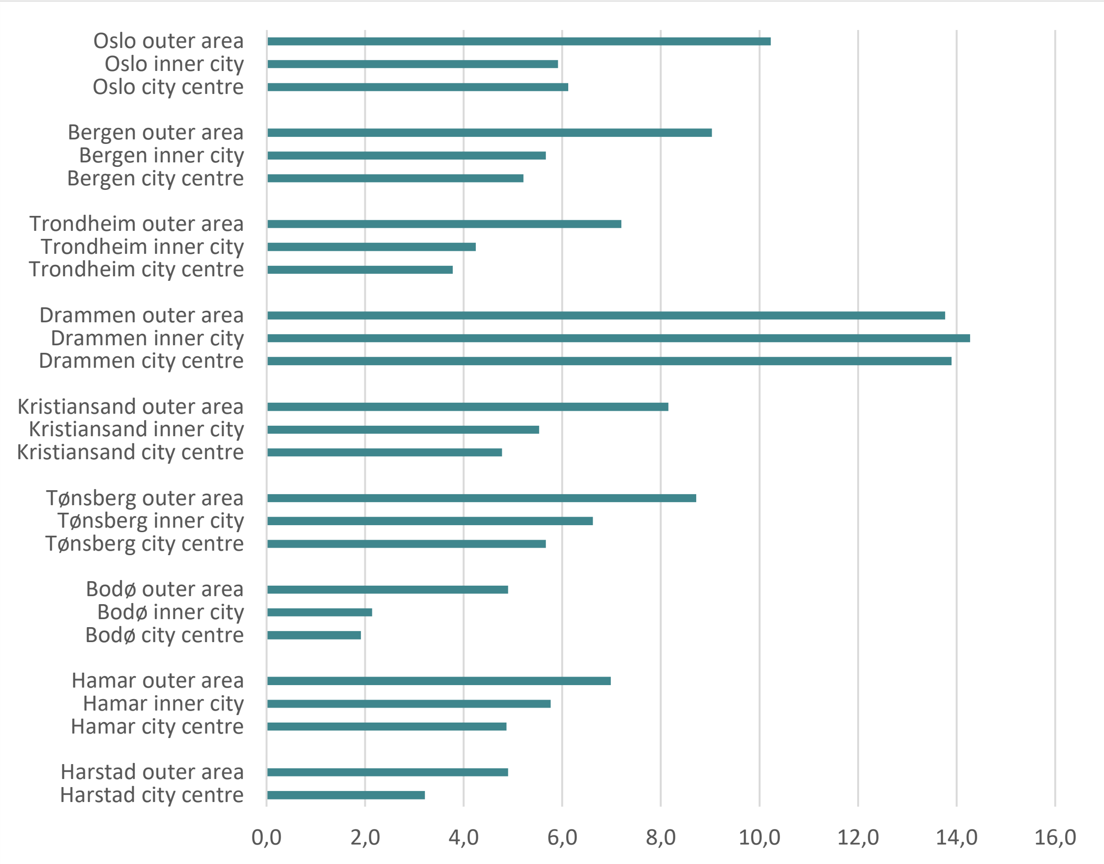

Figure 11: Commuting distances (one way and in kilometres) on commutes to and from dwellings located in different analytical zones of nine cities. The cities are organised according to population size, with the largest city on top.

The analyses also show that the competitiveness of sustainable modes is stronger on commutes starting and/or ending in workplaces located in city centres and inner cities compared with workplaces located in the outer area (see results in Figure 12; data in Appendix F). The proportions of commutes made as car drivers are lowest to workplaces located in the city centre and highest to those located in the outer areas in all cities but Drammen, where car shares are lowest to workplaces located in the inner-city. (Bodø is excluded due to a high proportion of 'others', indicating problems with the data). The proportions of commutes made by public transport are highest to workplaces located in city centres in all cities. In the four largest cities, public transport shares are higher to workplaces located in the inner-city than to those located in the outer areas, while the opposite is the case in three of the smaller cities (Kristiansand, Tønsberg, Hamar). In all cities (Bodø excluded), the proportions of commutes made on foot are highest to workplaces located in the city centre and inner-city.

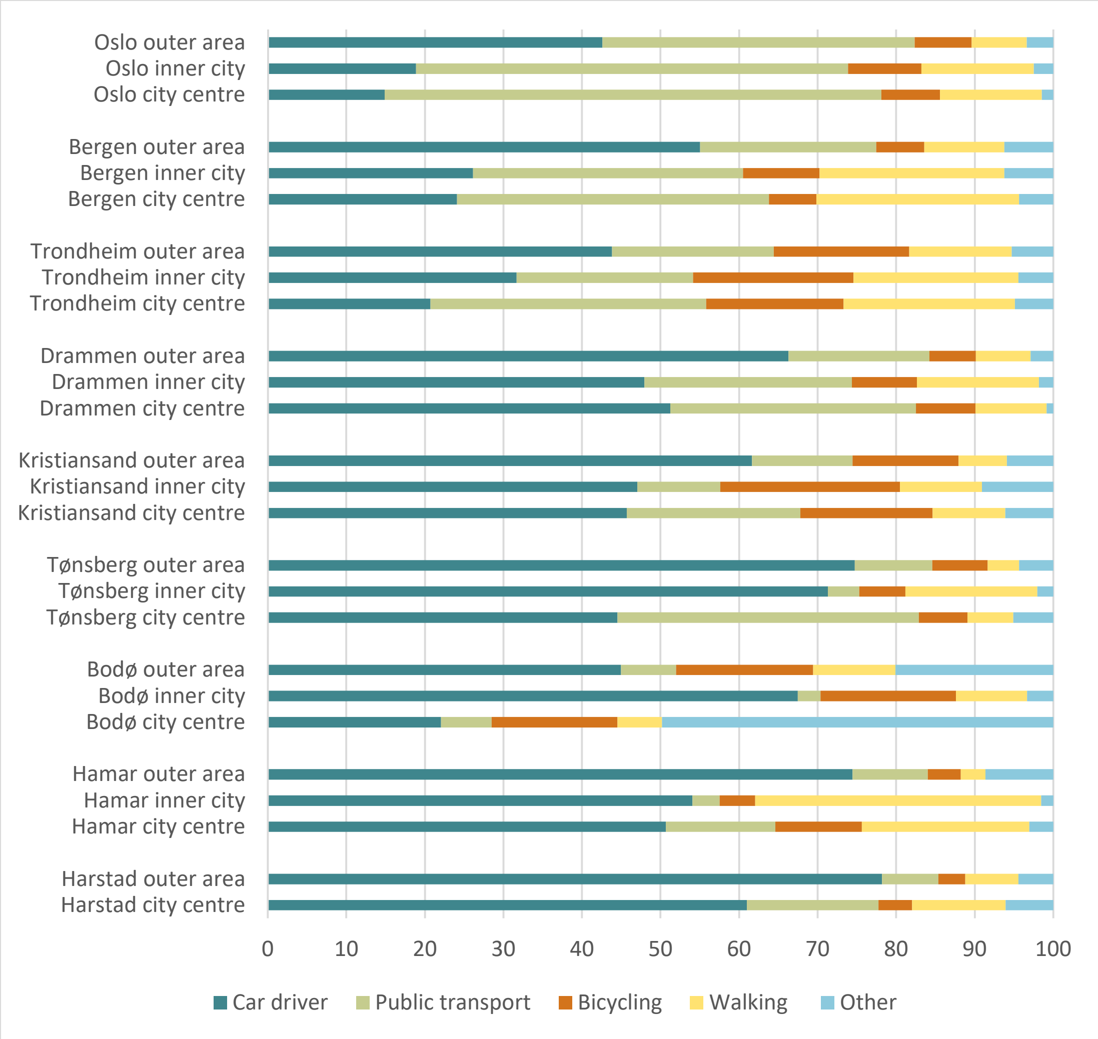

Figure 12: Modal splits (percentages) on commutes starting and/or ending in workplaces located in different analytical zones of the cities. The cities are organised according to population size, with the largest city on top.

Turning to average commuting distances, Figure 13 (data in Appendix F) shows only modest differences in commuting distances to workplaces located in different analytical zones of the cities. The variations are rather unsystematic but exhibit a weak trend of shorter commutes to centrally located workplaces.

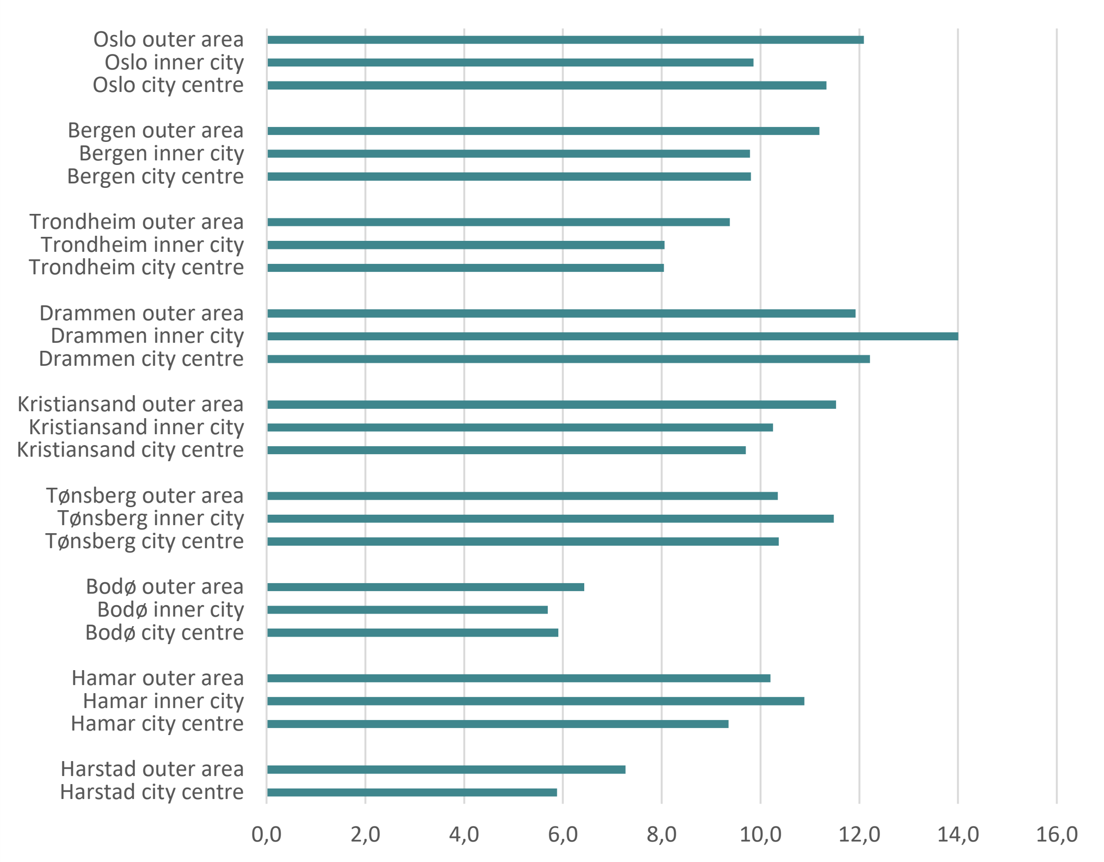

Figure 13: Commuting distances (one way and in kilometres) on commutes to and from in workplaces located in different analytical zones of nine cities. The cities are organised according to population size, with the largest city on top.

Drammen stands out again, with the longest commutes to workplaces located in the city. This can be explained by the high proportion of people who work in Drammen but live in other municipalities (52%; see Appendix E). Tønsberg and Hamar also have high proportions of people who work there but live in other municipalities, mainly in neighbour municipalities, that might affect the commute distances to workplaces located in these cities.

4.5 Modal splits and commuting distances related to concentrated mixed-use zones

Travel behaviour related to relatively dense mixed-use zones in three cities were analysed. The mixed-use zones differ from each other, for instance, with respect to density, number of workplaces and inhabitants, population/workplace ratio, distance to city centre and public transport services (which we have data for, see Table 2), and with respect to, for instance, parking accessibility and walkability, for which we do not have data. All zones have a lower population/workplace ratio than the outer area in the same cities. The key point here is to compare travel behaviour related to these zones to what is found in inner cities and in the outer areas in the same cities.

Table 2: Key characteristics of the investigated mixed-use zones and the inner-city (IC) and outer areas (OA) in the same cities.

City/zone	Population/ workplace ratio	Area, km²	Pop. 2016	Workpl. 2016	Combined densities*	Dist. to city centre, km, along road	Public transport services
Oslo							

Oslo OA	2.3	225.9	660375	287579	4196	-	-
Oslo IC	1.6	16.5	204804	127696	20213	-	-
Løren/Økern	1.1	2	10781	9737	10522	4	Subway, bus
Storo	0.9	2.1	15341	17640	15557	5	Subway, tram, bus
Bryn	0.5	2.9	10151	21971	11077	4	Train, subway, bus
Skøyen	0.3	1.2	5140	19133	20570	5	Train, tram, bus
Bergen							
Bergen OA	2.9	66.8	188596	64284	3784	-	-
Bergen IC	1.1	2.4	18984	16682	15043	-	-
Åsane	1.6	4	8846	5512	3554	14	Bus
Nestun	1.5	4.2	8510	5742	3385	10	Light rail, bus
Danmarksplass	0.5	1	3179	6120	9455	2	Light rail, bus
Sandsli/ Kokstad	0.1	3.3	1848	12622	4425	15	Light rail (since April 2017), bus
Trondheim							
Trondheim OA	3.5	42	136397	38532	4169	-	-
Trondheim IC	0.7	5.5	18660	28679	8557	-	-
Lade	0.4	1.6	1985	4788	4342	4	Bus

* Combined densities = (Population + workplaces)/ km^2.

Analyses of modal splits on trips starting and/or ending in dwellings located in the investigated mixed-use zones show lower proportions of trips made as car drivers and higher proportions of trips made as public transport passengers compared with the outer areas in Oslo and Trondheim, while this varies in Bergen (see Figure 14, data in Appendix G). On trips to and from dwellings located in Åsane and Nestun, quite distant from the Bergen city centre, public transport shares are lower, and car-driver shares about the same as in the outer area. Walking shares are higher than in the outer area in all zones but Åsane. Compared with inner cities, car-driver shares are higher, and walking shares lower in all zones, whereas whether public transport shares are higher or lower varies.

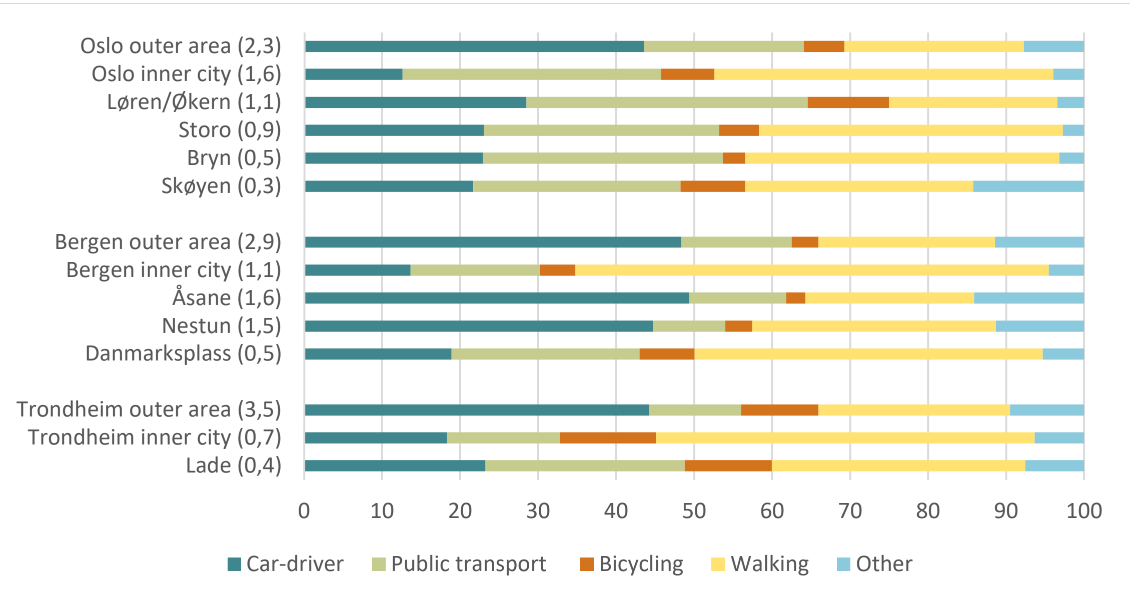

Figure 14: Modal splits (percentages) on trips starting and/or ending in dwellings located in concentrated mixed-use zones compared with the inner cities and the outer areas in Trondheim, Bergen and Oslo. Population/workplace ratios in brackets.

Analyses of modal splits on commutes starting and/or ending in workplaces located in the mixed-use zones show that it varies whether car shares are higher or lower in the investigated zones compared with the outer areas (see Figure 15; data in Appendix G). Car shares are higher on commutes to workplaces located in Løren/Økern in Oslo (which is more detached from the inner-city than the other zones in Oslo), in Åsane and Sandsli/Kokstad in Bergen (both located quite far from the city centre) and in Lade in Trondheim, whereas they are lower in the other zones. It also varies whether proportions of trips made by public transport, bicycle and foot are higher or lower on commutes to the zones compared with the outer area. Compared with inner cities, car-driver shares are significantly higher and public-transport shares lower on commutes to workplaces located in all mixed-use zones. Furthermore, in all but one zone (Storo in Oslo), the proportion of commutes made on foot is lower.

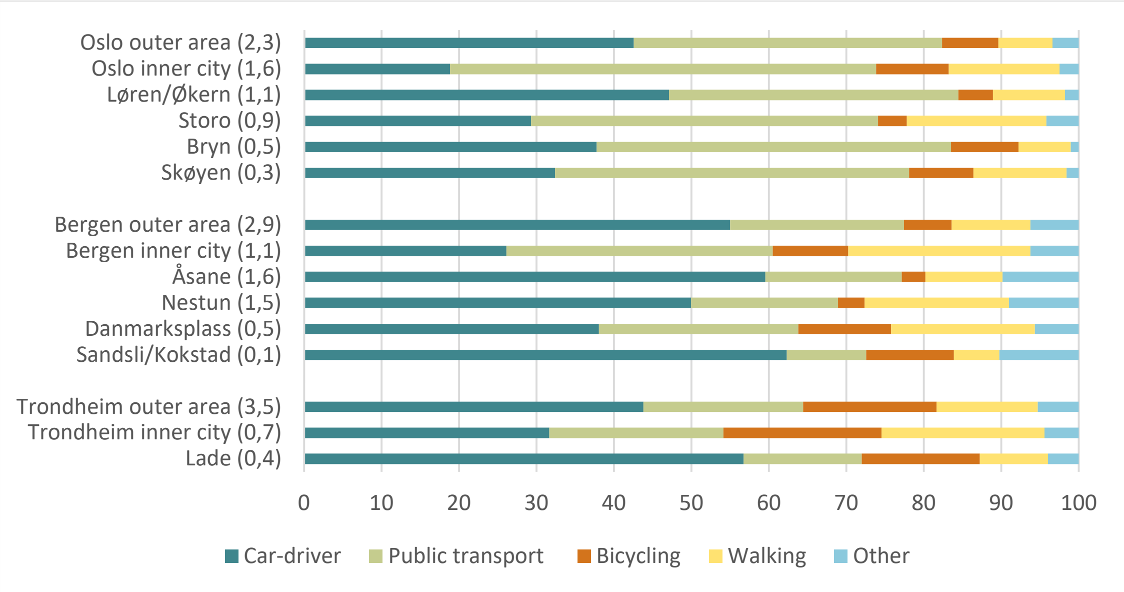

Figure 15: Modal splits (percentages) on commutes starting and/or ending in workplaces located in concentrated mixed-use zones compared with the inner cities and the outer areas in Trondheim, Bergen and Oslo. Population/workplace ratio in brackets.

In all cities, commutes are similar or longer to workplaces located in the mixed-use zones compared with those located in the outer area (except Storo in Oslo), while they are similar or shorter to and from dwellings located within the zones (except Åsane in Bergen; see Figure 16). Compared with inner cities, commutes to and from workplaces and dwellings located in the mixed-use zones are longer.

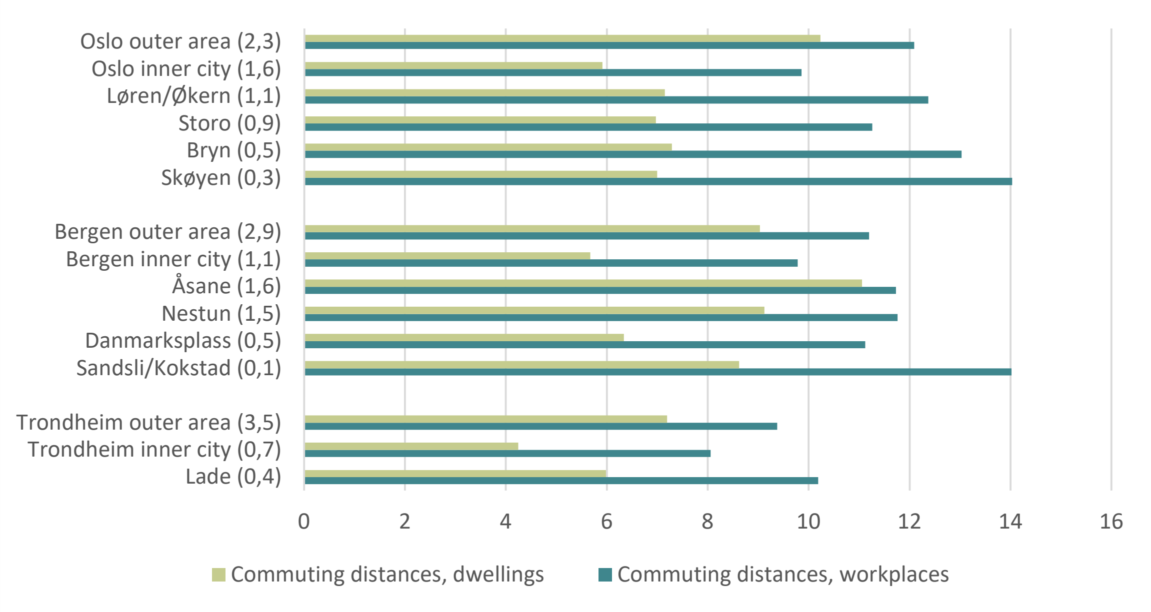

Figure 16: Commuting distances (one way and in kilometres) on commutes to and from dwellings and workplaces, respectively, located in concentrated mixed-use zones compared with commuting distances to and from the inner cities and the outer areas. Includes commutes shorter than 50 km.

5. Discussion

5.1 Differences between smaller and larger cities

Research conducted in the context of large cities across the world have documented how and to what extent city level densities and location of activities within the urban structure affect travel behaviour, as described in section 2. Section 4 has presented results from analyses of these interrelations in 20 Norwegian cities varying in size from 15 000 to 980 000 inhabitants. Based on these results, we discuss how the investigated interrelations differ between larger and smaller cities, and what implications the findings might have for urban planning in small and medium-sized cities aiming at improving the competitiveness of sustainable modes versus the private car. The overall finding is that the tendencies are similar, but weaker, in smaller cities compared with larger cities.

The initial comparisons of variation in travel behaviour between the cities in our study showed, as expected, clear tendencies of increasing proportions of trips made by car and decreasing proportions of trips made by public transport and on foot with decreasing population size. The findings confirmed the significantly stronger role public transport plays in a metropolitan area like Oslo compared with the smaller cities, and the significantly stronger role the private car plays in smaller compared with larger cities. They also displayed a tendency of shorter commutes on average to and from dwellings and workplaces with decreasing city size.

Previous studies of large cities across the world (Newman and Kenworthy, 1998; 2015) and across Nordic cities (Næss, Sandberg and Røe, 1996) have found that city-level densities tend to influence travel behaviour. The same tendency, where higher city-level densities correlated with lower proportions of trips made as car-driver and with higher proportions of trips made by sustainable modes was found when analysing this across the 20 case cities, also when excluding the metropolitan city Oslo from the analyses and when controlling for the effect of city size. Analyses displayed no clear effects of combined city level densities on commute distances.

Proximity to the city centre has been found to have a strong influence on travel behaviour in studies of larger cities (Ewing and Cervero, 2010). This was also found in the analyses of 20 cities in this study, with results displaying clear tendencies of lower proportions of all daily trips made by private car and higher proportions made by sustainable modes on trips starting and/or ending in city centres and inner cities compared with the outer areas. These tendencies were stronger and more consistent among the larger cities in the sample compared with the smaller ones. A substantial number of studies made in the context of large cities across the world (e.g. Bento et al., 2005; Næss et al. 2019a; Zegras, 2010) and a more modest number of studies in smaller Nordic cities (e.g. Hartoft-Nielsen, 2001a; Nielsen, 2002) have found that dwellings tend to generate less traffic the closer to the city centre the dwellings are located. This was also found in the more detailed analyses of 9 of the case cities, where separate analyses of effects of locations of dwellings and of workplaces were conducted. The results revealed clear and strong tendencies of lower proportions of trips made as car drivers on trips starting and/or ending in dwellings located in city centres and inner cities compared with those located in the outer areas, and significantly shorter commutes. The proportions of trips made on foot to and from centrally located dwellings were very high in most cities and significantly higher than what was found in the outer areas. Key explanations may be the combinations of significantly shorter commutes by those inhabiting dwellings located in city centres and inner cities and high densities (population plus workplaces) that creates markets for services and amenities close to dwellings. The better public transport accessibility to and from city centres may explain why city centre dwellers tend to choose public transport on longer trips more often than others do.

Previous studies have also found that centrally located workplaces tend to generate less traffic compared with workplaces located in outer areas of larger cities in different parts of the world (e.g. Aguiléra & Voisin, 2014; Hu and Schneider, 2017; Tennøy et al., 2014), as well as in smaller Nordic cities (e.g. Hartoft-Nielsen, 2001b; Strømmen, 2001). The systematic comparison of travel behaviour on commutes to workplaces located in different parts of 9 case cities in this study revealed the same tendency across cities of different sizes, towards lower proportions of commutes made as car drivers and higher proportions by sustainable modes, to centrally located workplaces compared with those located in the outer areas. A weak tendency towards on average shorter commutes to centrally located workplaces was also found. This might be surprising, because highly specialised office workplaces attracting employees from a large geographical area are often located in the most central areas, and thus, one might expect longer commutes to city centres (Tennøy et al., 2014; Næss et al., 2019b). The explanation is probably that an even higher proportion of employees lives rather close to workplaces located in city centres and inner cities, as indicated by findings concerning dwelling-related commutes.

Finally, travel behaviour related to relatively dense mixed-use zones with relatively good public transport accessibility was analysed and compared to inner cities and outer areas in the same cities. It is often assumed that locating new dwellings and workplaces in such zones will help reducing traffic volumes in the cities. This form of urban development is often termed 'public transport node development', and it could be understood as a form of transit-oriented development (TOD). While a review by Ibraeva et al. (2020) found that empirical studies display large variations with respect to how sustainable TOD-related trips are, there are no systematic studies of Norwegian 'public transport node development'. The results from this study showed that dwellings and workplaces located in the investigated zones generate higher car-shares and longer commutes compared with inner cities, whereas this varies with the location of the different zones when compared with outer areas. Zones located rather close to the city centre and connected to the inner-city structure tend to generate more sustainable travel patterns compared with those with opposite characteristics.

5.2 Implications for urban planning in small and medium-sized cities

The findings from this study suggest that small and medium-sized cities aiming at improving the competitiveness of sustainable modes versus the private car safely can follow the same land use development strategies as recommended for larger cities, that is, to steer development of new dwellings and workplaces to city centres and inner cities rather than to outer parts of the cities. Urban development in denser mixed-use zones outside the inner-city cannot be recommended, because dwellings and workplaces located there tend to generate higher proportions of trips made by car and longer commutes compared with inner-city locations. In some of these zones, the proportion of trips made by car was higher also compared with the outer areas. It is worth noting that the data presented in this paper is a snapshot of the situation. Some of the investigated zones are still evolving, and it would be interesting to follow up with longitudinal analyses of whether further densification, improved walkability and reduced car accessibility eventually will result in more sustainable travel patterns.

Other interventions to change the relative competitiveness between modes may also be necessary. The significant variation in the proportion of trips made by public transport also among the smaller cities may indicate that public transport competitiveness can increase if services are improved, which has been demonstrated in several smaller Norwegian cities (Engebretsen et al., 2017; Nielsen, 2016; Norconsult AS, 2017). The low proportion of trips made by bicycle in Norwegian cities indicates a large potential for transfer from the private car to bicycle, which may be strongly enhanced by the introduction of e-bikes. Walking is an important mode in cities of all sizes, but many short trips are made by car (Hjorthol et al., 2014). The proportion of trips made on foot might increase if the built environment becomes more walkable, and by bicycle if proper infrastructure is offered (Forsyth and Krizek, 2010; Krogstad et al., 2015; Pucher et al., 2010). This would require changes in prioritisation between walking, bicycling and car traffic, with less space allocated to driving and parking cars; lower traffic volumes and speed; and more welcoming environments for those walking and bicycling, which might also reduce the accessibility by car.

Changes like these may, however, meet resistance in smaller cities and outer parts of larger cities where car ownership[vi] and car-usage is the norm and a habit, and where this influences attitudes towards interventions affecting car accessibility (Anable, 2005; Heinonen et al., 2021; Klinger et al., 2013; Prillwitz and Barr, 2011). These studies found, however, that attitudes, travel behaviour, and even mobility cultures are dynamic and might change if circumstances are altered. This has also been exemplified in studies documenting how employees' travel behaviour changed after their workplaces were relocated, and the conditions for commute mode choices were changed (Tennøy et al., 2014). For instance, Meland (2002) found that car-usage on commutes decreased from 63 percent to 20 percent when governmental offices were relocated from less central locations in Trondheim to a centrally located office. Cities that find ways of steering new land-use development to locations that reduce car dependency and car-usage, and reallocating space and resources to other modes than the private car, could contribute to the achievement of goals related not only to reduced traffic volumes and lower greenhouse gas emissions but also to more people-friendly, healthy and attractive cities.

5.3 Weaknesses of data and methodology

Despite efforts to produce robust datasets, the datasets in this study have weaknesses. The most important are the definition of zones, which is hard to make exact and comparable across cities, and the travel survey data, where the number of observations is as low as 100 for some zones. These weaknesses affect the accuracy of modal splits on trips to and from the analytical zones in each city. When analysing modal splits, trips other than those made by public transport, bicycle, foot or driving cars were defined as 'other' (including trips made as car passengers, by motorbike boat, and when respondents answered 'other'). The 'other' category also includes trips where the mode is unknown. In a few cases, high proportions of trips are classified as 'other', and those cases were excluded from that specific analysis.

6. Concluding remarks

The paper contributes novel empirical knowledge to the literature on the relations between built environment characteristics and travel behaviour in largely self-contained small and medium-sized cities. Moreover, it has investigated how mechanisms known from studies of larger cities act out and affect travel behaviour in cities of different sizes to enhance the theoretical understanding of this phenomenon in small and medium-sized cities. The key finding is that the tendencies are similar, but weaker, in smaller cities compared with larger cities. Limited attention has been paid to smaller cities in previous research, and the study and findings strengthen the empirical and theoretical knowledge base.

We believe the findings may be useful in planning of small and medium-sized cities aiming at improving the competitiveness of sustainable modes versus the private car. By researching the effects on modal splits and commuting distances, the findings may also be relevant in planning discussions beyond traffic volumes and greenhouse gas emissions, such as in discussions on more active transport, higher commute satisfaction and more liveable and inclusive neighbourhoods and cities. These are relevant issues when aiming at achieving several of the UN (2017) Sustainable Development Goals, such as Sustainable cities and communities (no. 11), Good health and well-being (no. 3), Reduced inequalities (no. 10) and Climate action (no. 13).

The results are in line with theory and previous empirical findings related to large cities, as well as with previous empirical studies of small and medium-sized cities (as discussed in section 2). We consider the results to be relevant to small and medium-sized cities that are relatively self-contained 'regional cities', that have relatively high overall densities and defined cores, as commonly found in most parts of the developed world except from in North America and Australia (OECD, 2018). There is a need for more research made in the context of smaller cities of similar, as well as different types, as the ones studied here.

Appendices

Appendix A: Modal splits (all daily trips) and commuting distances in 20 cities, sorted by population size

	Area and population		Modal split, all daily journeys, 2013/14 and 2017/18 (%)					Commuting distances (one way, kilometres)	
Cities	Area (km^2)	Population, 2016	Car-driver	Public transport	Bicycling	Walking	Other	To/from workplaces	To/from dwellings
Oslo	268.2	978732	35.8	28.8	5	23.6	6.8	11.5	9.2
Bergen	87.5	255759	44.2	17.4	3.4	24.7	10.3	10.8	8.6
Stavanger/ Sandnes	79	223552	54.8	9.9	7.4	17.7	10.1	10.0	8.0
Trondheim	60.1	185589	41.3	15	9.5	24.9	9.3	8.8	6.8
Drammen	51.4	117132	59	10.5	3.5	18.8	8.1	12.3	13.8
Fredrikstad/ Sarpsborg	58	110836	64.7	6.4	4.1	12.6	12.2	10.0	9.2
Kristiansand	35	79566	49.3	10.9	8.9	17.7	13.1	10.9	7.5
Tønsberg	32.1	61580	61.8	6.7	5.5	13.2	12.8	10.6	8.5
Ålesund	28.2	52636	57.6	7.9	5.4	17.6	11.5	9.9	8.5
Arendal	31	45155	57.3	5.4	13.8	11.8	11.8	10.1	8.7
Bodø	14.2	40433	49.7	5.5	9.2	22.5	13.1	6.2	4.3
Hamar	17.2	34612	60.7	7.6	4.7	18.1	9	10.2	6.8
Lillehammer	12.1	23111	48.7	5.3	7.5	29	9.6	9.3	6.4
Kongsberg	13.6	22142	57	4.5	7.9	20.8	9.8	11.3	6.5
Molde	9.1	21520	51.5	9.8	8.3	17.1	13.3	10.0	4.9
Harstad	11.1	21040	59.1	4.9	1.4	20.5	14.2	6.8	4.7
Gjøvik	12.6	20391	62.1	4.3	3.2	20.1	10.3	12.0	7.3
Kristiansund	8.2	18552	60.9	7.3	2.4	21.1	8.3	6.6	4.1
Alta	9.3	16398	70.8	1.7	3.5	15.6	8.4	5.4	4.3
Elverum	11.1	15041	61.3	1.2	10.7	18.1	8.7	10.0	8.6

Appendix B: Modal splits (all daily journeys) and commuting distances in different analytical zones of 20 cities, organised from largest to smallest city

	Modal splits (%)					Commuting distances, km	
Cities	Car-driver	Public transport	Bicycling	Walking	Other	To/from dwellings	To/from workplaces
Oslo outer area	45.7	21.9	4.7	19.6	8.1	10.2	12.1
Oslo inner-city	17.9	38.2	6.1	33.2	4.6	5.9	9.9
Oslo city centre	12.1	55.9	4.5	24.2	3.3	6.1	11.3
Bergen outer area	52.3	14.2	3.0	19.2	11.4	9.0	11.2
Bergen inner-city	22.1	22.6	5.3	42.8	7.1	5.7	9.8
Bergen city centre	22.7	28.5	4.1	37.0	7.7	5.2	9.8
Stav/Sand outer area	58.1	8.1	7.1	16.0	10.7	8.1	10.4
Stavanger inner-city	46.1	10.6	11.7	22.9	8.8	6.6	9.3

Sandnes inner-city	59.4	8.1	4.5	19.2	8.8	8.5	8.6
Stavanger city centre	35.0	24.3	7.1	26.4	7.1	6.6	8.1
Sandnes city centre	48.6	18.8	5.1	16.9	10.6	8.3	8.8
Trondheim outer area	47.7	11.9	8.4	21.6	10.4	7.2	9.4
Trondheim inner-city	27.8	18.3	13.2	33.9	6.8	4.2	8.1
Trondheim city centre	26.7	26.9	10.1	29.0	7.2	3.8	8.0
Drammen outer area	64.4	8.5	3.2	15.5	8.5	13.8	11.9
Drammen inner-city	41.1	16.5	5.1	30.8	6.6	14.3	14.0
Drammen city centre	44.9	17.3	2.9	26.7	8.1	13.9	12.2
Fred/Sarp outer area	66.4	5.9	4.0	11.1	12.6	9.3	10.0
Sarpsborg inner-city	59.7	7.7	4.9	13.2	14.4	8.3	10.2
Fredrikstad inner-city	56.8	10.3	4.6	17.1	11.2	7.6	9.7
Sarpsborg city centre	68.0	4.9	1.1	18.6	7.3	8.3	10.9
Fredrikstad city centre	57.0	6.4	5.3	22.7	8.6	7.5	8.8
Kristiansand outer area	55.8	9.2	7.0	14.6	13.4	8.2	11.5
Kristiansand inner-city	46.1	6.9	14.9	20.8	11.2	5.5	10.3
Kristiansand city centre	35.7	17.5	9.8	23.4	13.6	4.8	9.7
Tønsberg outer area	64.5	5.6	5.8	12.3	11.8	8.7	10.3
Tønsberg inner-city	59.2	5.2	4.0	14.8	16.8	6.6	11.5
Tønsberg city centre	43.6	20.4	5.4	18.1	12.3	5.7	10.4
Ålesund outer area	60.0	7.5	6.5	14.0	12.1	8.5	9.5
Ålesund inner-city	41.8	8.7	0.5	41.4	7.6	8.4	10.5
Ålesund city centre	52.4	11.3	1.4	24.9	10.0	8.8	10.8
Arendal outer area	63.4	5.5	9.2	11.3	10.7	8.9	10.2
Arendal inner-city	41.1	3.5	20.2	15.1	20.0	5.6	10.6
Arendal city centre	32.8	5.7	36.1	12.5	12.9	3.8	9.4
Bodø outer area	51.7	5.2	8.8	21.4	12.9	4.9	6.4
Bodø inner-city	53.3	4.9	10.3	24.9	6.6	2.1	5.7
Bodø city centre	34.7	8.0	9.2	23.7	24.4	1.9	5.9
Hamar outer area	64.4	7.1	4.5	12.9	11.0	7.0	10.2
Hamar inner-city	52.6	5.2	4.3	33.5	4.3	5.8	10.9
Hamar city centre	51.7	13.5	5.9	23.9	5.0	4.9	9.4
Lillehammer outer area	49.8	5.8	9.9	23.7	10.8	6.6	9.8
Lillehammer inner-city	51.1	5.2	2.3	34.8	6.5	4.8	9.2
Lillehammer city centre	40.0	3.0	3.7	44.4	8.9	4.8	7.9
Kongsberg outer area	60.3	3.5	7.8	18.2	10.2	6.7	11.6
Kongsberg inner-city	48.6	4.4	7.1	30.9	9.0	4.4	9.2
Kongsberg city centre	49.9	8.2	8.7	24.8	8.3	4.8	10.4
Molde outer area	57.0	6.3	8.6	12.9	15.2	5.1	10.5
Molde inner-city	44.9	22.8	5.0	19.4	7.9	3.6	9.3
Molde city centre	36.1	15.1	8.9	30.2	9.6	3.4	8.8
Harstad outer area	62.5	4.1	1.5	19.3	12.7	4.9	7.3
Harstad city centre	52.2	6.6	1.2	22.8	17.1	3.2	5.9
Gjøvik outer area	65.2	4.5	4.1	17.5	8.8	7.3	12.0
Gjøvik inner-city	54.0	3.6	1.0	25.9	15.5	6.5	12.0
Gjøvik city centre	60.9	5.3	2.8	25.3	5.8	6.8	11.8

Kristiansund outer area	68.4	7.0	2.4	12.8	9.4	4.3	6.9
Kristiansund inner-city	49.8	10.1	2.3	33.3	4.5	3.5	6.4
Kristiansund city centre	44.1	6.0	2.5	39.9	7.5	3.4	6.2
Alta outer area	76.1	1.6	3.6	10.6	8.2	4.4	5.3
Alta city centre	60.7	1.9	3.3	25.1	8.9	1.9	5.6
Elverum outer area	62.5	1.3	9.3	18.4	8.5	8.7	10.2
Elverum city centre	53.9	0.5	19.4	15.8	10.3	5.9	9.0

Appendix C: Linear regression of effect of combined density on usage of different modes of transport controlling for population size, 20 cities

	All cities taken together		**Oslo excluded**		**Cities with population <=200 000**	
	Coef.	P-value	Coef.	P-value	Coef.	P-value
Car-driver						
Combined density	-0.006	0.003	-0.006	0.008	-0.006	0.008
population2016	-5.58e-06	0.496	-6.37e-06	0.781	-0.00002	0.599
Constant	76.991	0.000	76.933	0.000	77.62518	0.000
n	*20*		*19*		*17*	
Adj R-sq.	*0.6286*		*0.4715*		*0.4397*	
Public transport						
Combined density	.0025018	0.004	.0019661	0.028	.0020209	0.011
population2016	.0000175	0.000	.00003	0.005	.0000403	0.003
Constant	-2.158013	0.377	-1.22573	0.615	-1.78548	0.398
N	*20*		*19*		*17*	
Adj R-sq.	*0.8675*		*0.7137*		*0.7055*	
Biking						
Combined density	.0000626	0.956	.0000634	0.961	8.20e-07	1.000
population2016	-1.65e-06	0.754	-1.67e-06	0.910	8.38e-06	0.704
Constant	6.24145	0.096	6.24005	0.118	6.001951	0.151
N	*20*		*19*		*17*	
Adj R-sq.	*-0.1069*		*-0.1240*		*-0.1273*	
Walking						
Combined density	.0029715	0.033	.0034545	0.030	.0035549	0.028
population2016	-4.41e-06	0.468	-.0000157	0.352	-.0000258	0.292
Constant	9.505949	0.031	8.665253	0.059	8.804567	0.060
n	*20*		*19*		*17*	
Adj R-sq.	*0.2152*		*0.1920*		*0.1987*	

Appendix D: Population, workplaces and densities in different parts of 9 cities

	Size (km²)	**Popu-lation, 2016**	**Density, Popu-lation/**	**Work-places, 2016**	**Density, Work places/**	**Population + workplaces**	**Combined density, pop+wp/ km²**

			km², 2016		km², 2016		
Oslo city centre	1.96	2095	1069	104104	53114	106199	54183
Oslo inner-city	16.45	204804	12450	127696	7763	332500	20213
Oslo outer area	225.91	660375	2923	287579	1273	947954	4196
Bergen city centre	1.33	9371	7045	28954	21767	38325	28811
Bergen inner-city	2.37	18984	8007	16682	7036	35666	15043
Bergen outer area	66.83	188596	2822	64284	962	252880	3784
Trondheim city centre	0.97	4441	4562	20809	21375	25250	25937
Trondheim inner-city	5.53	18660	3373	28679	5184	47339	8557
Trondheim outer area	41.96	136397	3251	38532	918	174929	4169
Drammen city centre	1.74	2653	1525	6586	3785	9239	5310
Drammen inner-city	2.87	7896	2751	8806	3068	16702	5819
Drammen outer area	37.89	81390	2148	37638	993	119028	3141
Kristiansand city centre	2.04	6665	3267	14550	7132	21215	10399
Kristiansand inner-city	3.71	10959	2954	5437	1466	16396	4420
Kristiansand outer area	17.85	43041	2412	20154	1129	63195	3541
Tønsberg city centre	0.33	1012	3095	4649	14217	5661	17312
Tønsberg inner-city	2.09	5750	2757	6770	3246	12520	6003
Tønsberg outer area	22.66	41225	1819	14248	629	55473	2448
Bodø city centre	0.30	751	2541	4750	16075	5501	18616
Bodø inner-city	1.47	7535	5125	5214	3547	12749	8672
Bodø outer area	10.04	27026	2692	9263	923	36289	3614
Hamar city centre	1.55	833	537	4718	3044	5551	3581
Hamar inner-city	1.71	3096	1811	4073	2382	7169	4192
Hamar outer area	11.88	26336	2218	11555	973	37891	3191
Harstad city centre	0.70	2468	3537	4190	6004	6658	9541
Harstad outer area	8.17	14367	1758	6578	805	20945	2563

Appendix E: Commutes in and out of 9 cities (2017)

Source: Statistics Norway, table 03321

Proportion of employed inhabitants working within own municipality		
Municipality	Proportion	Comments
Oslo	0.82	Commuting mainly to neighbour municipalities
Bergen	0.88	Commuting mainly to neighbour municipalities and to cities located in other parts of Norway

Trondheim	0.88	Commuting mainly to neighbour municipalities and to cities located in other parts of Norway
Drammen	0.53	Commuting to neighbour municipalities (14%), but also more distant, e.g., 14% to Oslo
Kristiansand	0.81	Commuting mainly to neighbour municipalities
Tønsberg	0.60	Commuting mainly to neighbour municipalities
Bodø	0.90	Commuting mainly to neighbour municipalities
Hamar	0.61	Commuting mainly to neighbour municipalities
Harstad	0.86	Commuting mainly to neighbour municipalities
Proportion of jobs within the municipality occupied by inhabitants in the municipality		
Municipality	Proportion	Comments
Oslo	0.63	Many commuting in from neighbour municipalities (16%), but also from more distant municipalities and from cities elsewhere in Norway
Bergen	0.77	Many commuting in from neighbour municipalities (14%), but also from more distant municipalities
Trondheim	0.76	Many commuting in from neighbour municipalities (12%), but also from more distant municipalities
Drammen	0.48	Many commuting in from neighbour municipalities (26%), but also from more distant municipalities
Kristiansand	0.71	Many commuting in from neighbour municipalities (17%), but also from more distant municipalities
Tønsberg	0.47	Mainly commuting in from neighbour municipalities (38%), but also from more distant municipalities
Bodø	0.88	Commuting in from neighbour municipalities, but also from larger cities elsewhere in Norway
Hamar	0.46	Mainly commuting in from neighbour municipalities (41%), but also from more distant municipalities
Harstad	0.86	Many commuting in from neighbour municipalities (7%), but also from more distant municipalities

Appendix F: Modal splits and commuting distances, to and from dwellings and to and from workplaces in 9 cities

City and area	Modal shares, trips to/from dwellings located in different parts of the cities (%)						Modal shares, trips to/from workplaces located in different parts of the cities (%)						Commuting distances, km	
	Car-driver	Public trans	Bicycle	Walk	Other	Tot	Car-driver	Public trans	Bicycle	Walk	Other	Tot	Dwellings	Workpl.
Oslo outer area	43.6	20.5	5.2	23.0	7.8	100	42.6	39.8	7.2	7.0	3.4	100	10.2	12.1
Oslo inner-city	12.6	33.1	6.9	43.4	3.9	100	18.9	55.0	9.3	14.3	2.5	100	5.9	9.9
Oslo city centre	6.7	50.4	3.4	39.5	0.0	100	14.9	63.2	7.5	13.0	1.5	100	6.1	11.3
Bergen outer area	48.4	14.1	3.4	22.6	11.5	100	55.0	22.4	6.1	10.2	6.2	100	9.0	11.2
Bergen inner-city	13.6	16.6	4.6	60.7	4.5	100	26.1	34.4	9.8	23.5	6.2	100	5.7	9.8
Bergen city centre	8.8	13.9	4.5	69.0	3.8	100	24.1	39.7	6.1	25.8	4.4	100	5.2	9.8
Trondheim outer area	44.3	11.7	9.9	24.6	9.5	100	43.8	20.6	17.3	13.1	5.3	100	7.2	9.4
Trondheim inner-city	18.3	14.5	12.3	48.6	6.3	100	31.7	22.5	20.4	21.0	4.4	100	4.2	8.1
Trondheim city centre	9.7	15.8	10.7	59.6	4.2	100	20.7	35.1	17.5	21.8	4.9	100	3.8	8.0
Drammen outer area	61.0	9.6	3.0	18.4	8.1	100	66.3	17.9	5.9	7.0	2.9	100	13.8	11.9
Drammen inner-city	33.4	9.7	10.3	39.2	7.4	100	48.0	26.4	8.3	15.5	1.8	100	14.3	14.0
Drammen city centre	26.3	11.0	3.9	51.3	7.5	100	51.3	31.3	7.6	9.1	0.8	100	13.9	12.2
Kristiansand outer area	53.7	9.6	7.8	17.6	11.3	100	61.7	12.8	13.5	6.2	5.9	100	8.2	11.5
Kristiansand inner-city	36.3	6.1	18.6	29.7	9.2	100	47.1	10.5	22.9	10.5	9.1	100	5.5	10.3
Kristiansand city centre	18.0	8.5	11.4	54.4	7.7	100	45.7	22.1	16.8	9.3	6.1	100	4.8	9.7
Tønsberg outer area	62.1	5.9	7.1	14.2	10.6	100	74.7	9.9	7.0	4.0	4.4	100	8.7	10.3
Tønsberg inner-city	48.0	3.6	5.0	36.3	7.1	100	71.3	4.0	5.9	16.8	2.0	100	6.6	11.5
Tønsberg city centre	31.3	9.2	3.2	51.8	4.4	100	44.5	38.3	6.2	5.8	5.1	100	5.7	10.4
Bodø outer area	48.3	5.1	8.5	25.4	12.7	100	45.0	7.0	17.4	10.5	20.1	100	4.9	6.4
Bodø inner-city	53.6	1.9	9.2	26.7	8.5	100	67.5	2.9	17.2	9.0	3.4	100	2.1	5.7
Bodø city centre	52.5	6.0	0.0	41.5	0.0	100	22.1	6.4	16.0	5.6	49.8	100	1.9	5.9
Hamar outer area	64.6	7.4	5.9	15.3	6.8	100	74.4	9.6	4.2	3.1	8.6	100	7.0	10.2
Hamar inner-city	27.0	2.3	5.6	61.1	4.0	100	54.1	3.5	4.5	36.4	1.6	100	5.8	10.9
Hamar city centre	33.6	27.0	1.7	36.5	1.1	100	50.7	13.9	11.0	21.3	3.1	100	4.9	9.4
Harstad outer area	65.4	2.3	2.3	22.2	7.9	100	78.2	7.2	3.4	6.7	4.4	100	4.9	7.3

Harstad city centre	23.8	2.0	0.8	35.3	38.1	100	61.0	16.7	4.3	11.9	6.1	100	3.2	5.9

Appendix G: Modal splits and commuting distances, to and from dwellings and to and from workplaces in concentrated mixed-use ones

	Modal splits on trips to and from workplaces (%)						**Modal splits on trips to and from dwellings (%)**						**Commuting distances, km**	
City and area	Car-driver	Public trans	Bicycle	Walk	Other	Tot	Car-driver	Public trans	Bicycle	Walk	Other	Total	Work-places	Dwellings
Trondheim														
Lade (0,4)	56.7	15.2	15.2	8.8	4.0	100	23.3	25.5	11.2	32.5	7.5	100	10.2	6.0
Trondheim inner-city (0,7)	31.7	22.5	20.4	21.0	4.4	100	18.3	14.5	12.3	48.6	6.3	100	8.1	4.2
Trondheim outer area (3,5)	43.8	20.6	17.3	13.1	5.3	100	44.3	11.7	9.9	24.6	9.5	100	9.4	7.2
Bergen														
Sandsli/Kokstad (0,1)	62.3	10.2	11.3	5.8	10.3	100	-	-	-	-	-	-	14.0	8.6
Danmarksplass (0,5)	38.0	25.8	12.0	18.5	5.7	100	18.9	24.1	7.1	44.6	5.3	100	11.1	6.3
Nestun (1,5)	49.9	19.0	3.4	18.6	9.0	100	44.7	9.3	3.4	31.2	11.3	100	11.8	9.1
Åsane (1,6)	59.5	17.6	3.1	10.0	9.8	100	49.4	12.5	2.5	21.6	14.1	100	11.7	11.1
Bergen inner-city (1,1)	26.1	34.4	9.8	23.5	6.2	100	13.6	16.6	4.6	60.7	4.5	100	9.8	5.7
Bergen outer area (2,9)	55.0	22.4	6.1	10.2	6.2	100	48.4	14.1	3.4	22.6	11.5	100	11.2	9.0
Oslo														
Skøyen (0,3)	32.4	45.7	8.3	12.0	1.6	100	21.7	26.6	8.3	29.2	14.2	100	14.0	7.0
Bryn (0,5)	37.8	45.7	8.7	6.7	1.0	100	22.9	30.7	2.9	40.3	3.2	100	13.0	7.3
Storo (0,9)	29.3	44.8	3.7	18.0	4.2	100	23.0	30.2	5.1	39.0	2.7	100	11.3	7.0
Løren/Økern (1,1)	47.1	37.4	4.4	9.3	1.8	100	28.5	36.0	10.4	21.6	3.4	100	12.4	7.2
Oslo inner-city (1,6)	18.9	55.0	9.3	14.3	2.5	100	12.6	33.1	6.9	43.4	3.9	100	9.9	5.9
Oslo outer area (2,3)	42.6	39.8	7.2	7.0	3.4	100	43.6	20.5	5.2	23.0	7.8	100	12.1	10.2

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[i] Statistics Norway, definition of urban settlement: https://www.ssb.no/en/befolkning/folketall/statistikk/tettsteders-befolkning-og-areal

[ii] SN's definition of statistical basic statistical unit[ii]: *'There are about 14 000 basic statistical units and 1550 statistical tracts in Norway. The purpose of dividing the municipalities in basic statistical units was to establish small, stable and geographical units that can give a flexible basis for the work with and the presentation of regional statistics for statistical, analytical and planning purposes. The basic statistical units are designed to be as stable as possible for a reasonable time period, and the units shall be geographically coherent. One main principle is that basic statistical units shall be as homogeneous as possible with respect to e.g., communication and building structure. The statistical tract is an intermediate level between municipality and basic statistical unit'.*

[iii] The list of basic statistical units included in the continuous urban settlements and the analytical zones can be retrieved from the authors for reproduction and comparability of the study.

[iv] Statistics Norway's definition of 'centre zones'[iv]: *'1. A centre zone consists of one or more centre kernels and a 100-metre zone around them. 2. A centre kernel is an area with at least 4 different main types of economic activity with centre functions. In addition to detail trade, governmental administration or health and social services or social and personal services must be present. The distance among enterprises must not be more than 50 meters. At least 50 employees (in businesses with centre functions) in the centre zone'.*

[v] Retail trade and service areas are defined as: *'Areas with concentration of businesses of a selected set of industries. The selection is based on transport generating properties. The retail trade and service area is delimitated just as the centre zones, but the maximum distance between businesses is 100 m. There are no criteria for diversity of industries either. It has, however, to be at least 3 businesses and at least 50 employees[v]'.*

[vi] Data from the Norwegian National Travel Survey from 2013/14 suggest that this is the case in Norwegian cities, with far higher proportions of the population living in households without access to a private car in the larger city municipalities (32% in Oslo, 12–22% in the next three largest cities) compared with their neighbouring municipalities (6–9%) and the smaller cities (6–9%) (Hjorthol et al., 2014).