Supplementary Materials

Table S1. Postal code area characteristics.

ID	Name	Area (ha)	Floor area (ha)*	Number of dwellings*	Number of residents*	Number of jobs*	Dwelling floor area (ha)*	Workplace floor area (ha)*	Amenities floor area (ha)*	Land use mix entropy*	Number of intersections*	DMA-score*	DMA-class
1	City center	168	98	5754	7362	12792	32	25	21	0.98	289	16.39	3
2	Kontinkangas	105	26	568	803	7926	3	9	12	0.89	144	8.80	3
3	Raksila	224	49	3874	5802	4162	22	9	9	0.90	281	6.74	3
4	Tuira	190	47	5750	8025	2367	31	2	3	0.47	254	6.50	3
5	Heinäpää	241	55	4166	5641	4350	22	13	4	0.83	196	5.35	3
6	Karjasilta	158	28	1845	2995	2663	12	4	6	0.92	156	5.12	3
7	Värttö-Maikkula	402	47	3847	7273	1804	30	5	4	0.62	397	2.52	2
8	Välivainio	228	28	2582	4192	1551	16	3	3	0.67	177	2.50	2
9	Kaukovainio	354	41	4083	6788	1864	25	6	3	0.68	231	2.19	2
10	Taskila-Toppila	372	40	2777	4867	1254	18	8	4	0.84	225	2.05	2
11	Kaijonharju-Linnanmaa	560	56	4235	7070	3055	26	18	5	0.85	303	1.97	2
12	Höyhtyä	290	33	3390	6136	979	23	1	2	0.44	235	1.58	2
13	Koskela	158	17	1761	3156	390	13	0	1	0.32	134	0.94	2
14	Äimärautio (incl. Metsokangas)	1373	72	2768	6188	6760	24	12	11	0.93	613	0.90	2
15	Pyykösjärvi-Puolivälinkangas	228	24	2447	4649	304	18	1	1	0.26	169	0.41	2
16	Hietasaari	419	11	563	1033	524	4	2	2	0.95	173	0.27	1
17	Haapalehto	843	55	4638	10210	1456	40	3	3	0.41	634	-0.05	1
18	Rajakylä	344	28	2320	4724	588	19	1	2	0.39	211	-0.11	1
19	Teknologiakylä	102	12	1	2	4645	0	11	0	0.04	47	-0.20	1
20	Pateniemi	1033	48	3515	8705	718	33	4	2	0.45	561	-0.90	1
21	Iinatti	933	40	3066	6843	1366	26	4	2	0.50	409	-0.96	1
22	Kaakkuri	1007	28	1841	4769	1035	17	2	3	0.59	455	-0.97	1
23	Haukipudas center	4371	52	3107	7488	3061	28	10	6	0.81	781	-1.05	1
24	Martinniemi	1098	12	881	2103	342	8	2	0	0.63	287	-1.64	1

25	Sanginsuu	14467	7	296	737	647	3	2	0	0.77	403	-1.83	1
26	Oulunsalo center	5264	46	2882	7984	2259	29	6	3	0.65	746	-1.85	1
27	Yli-Ii center	38293	9	576	1479	470	5	1	1	0.73	553	-2.03	1
28	Rusko-Heikinharju	1571	53	288	644	9247	2	35	3	0.45	344	-2.09	1
29	Kello	6490	21	1193	3257	813	13	3	1	0.65	688	-2.10	1
30	Haukipudas station area	11774	12	645	1974	498	7	3	0	0.67	370	-2.24	1
31	Ylikiiminki center	100786	22	1370	3486	939	13	3	2	0.66	1074	-2.33	1
32	Jääli	4387	28	1906	4936	905	19	2	2	0.51	496	-2.58	1
33	Kiiminki center	35255	35	2253	6077	1439	23	2	3	0.56	1151	-2.67	1
34	Kuivasjärvi	2773	41	3115	8434	751	33	2	2	0.37	480	-2.78	1
35	Hiukkavaara	2344	5	370	892	204	3	1	0	0.46	108	-3.03	1
36	Korvensuora	2877	31	2350	6166	554	22	1	1	0.30	425	-3.28	1
37	Kiviniemi	1851	15	995	2820	315	11	0	0	0.27	310	-3.44	1
38	Varjakka	2854	6	400	1266	188	4	0	0	0.33	257	-3.48	1
39	Tannila	26817	2	136	263	53	1	0	0	0.39	241	-3.49	1
40	Madekoski	8316	14	884	2631	294	10	1	0	0.35	390	-3.51	1
41	Arkala	21637	1	109	254	33	1	0	0	0.33	159	-3.72	1
42	Pahkakoski-Räinä	17131	1	91	155	11	1	0	0	0.31	128	-3.82	1
43	Kontio	6984	8	471	1572	202	6	0	0	0.23	413	-4.02	1
44	Halosenniemi	3096	3	213	530	56	2	0	0	0.23	130	-4.05	1

*Mean value between years 1998–2016.

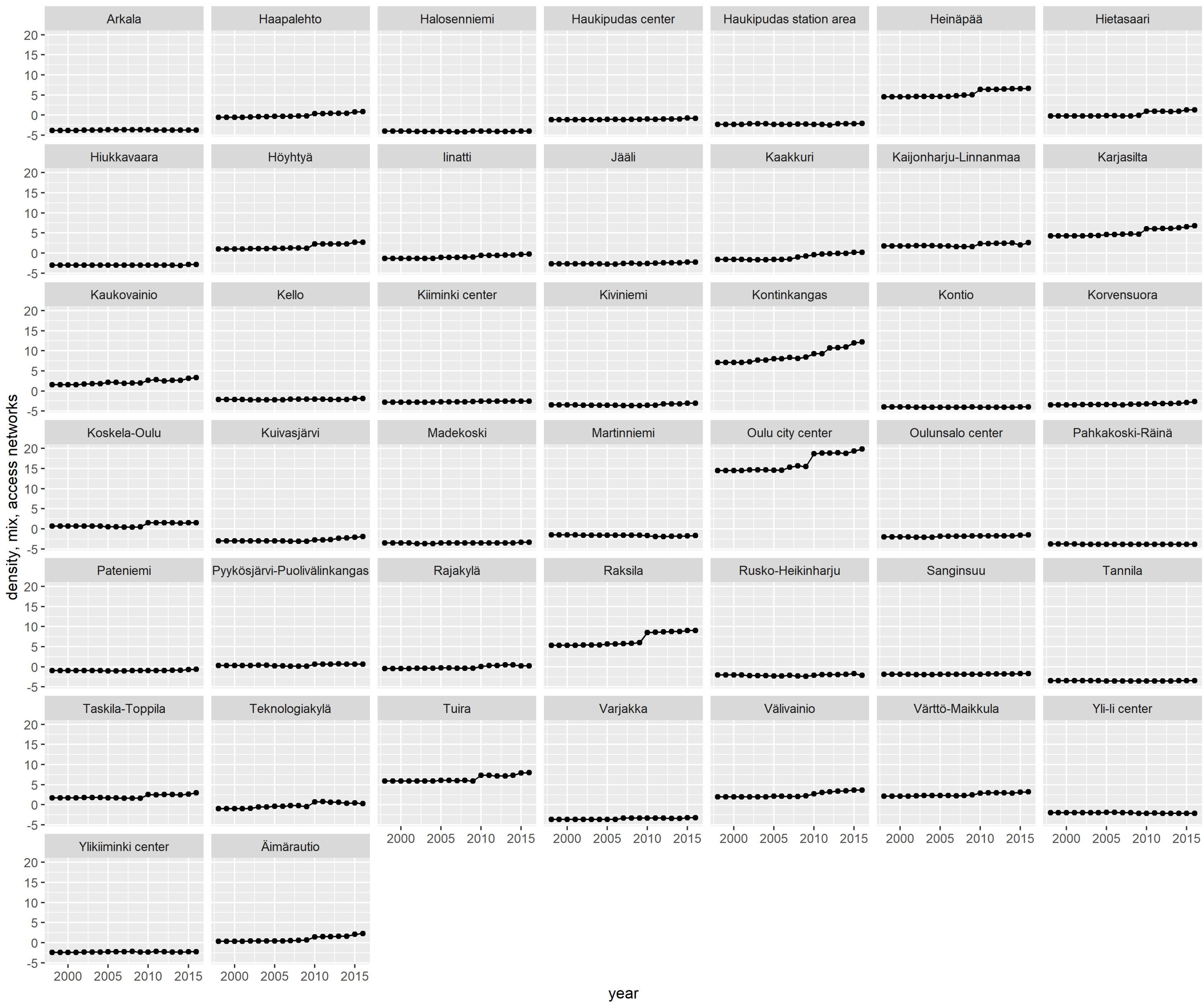

Figure S1. DMA-score: combined z-scores of floor area ratio, residents per hectare, jobs per hectare, entropy and intersections per hectare.

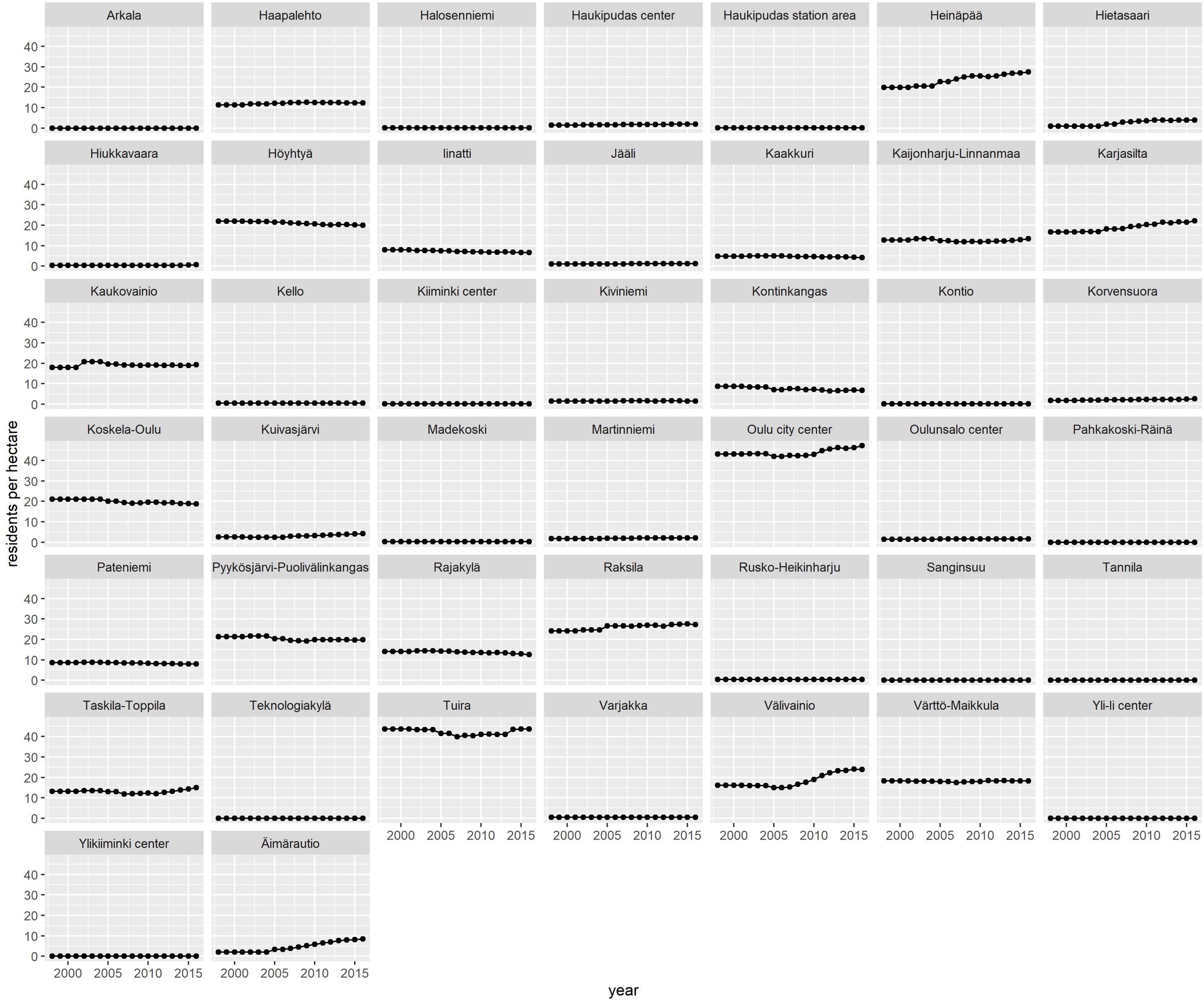

Figure S2. Density: residents per hectare.

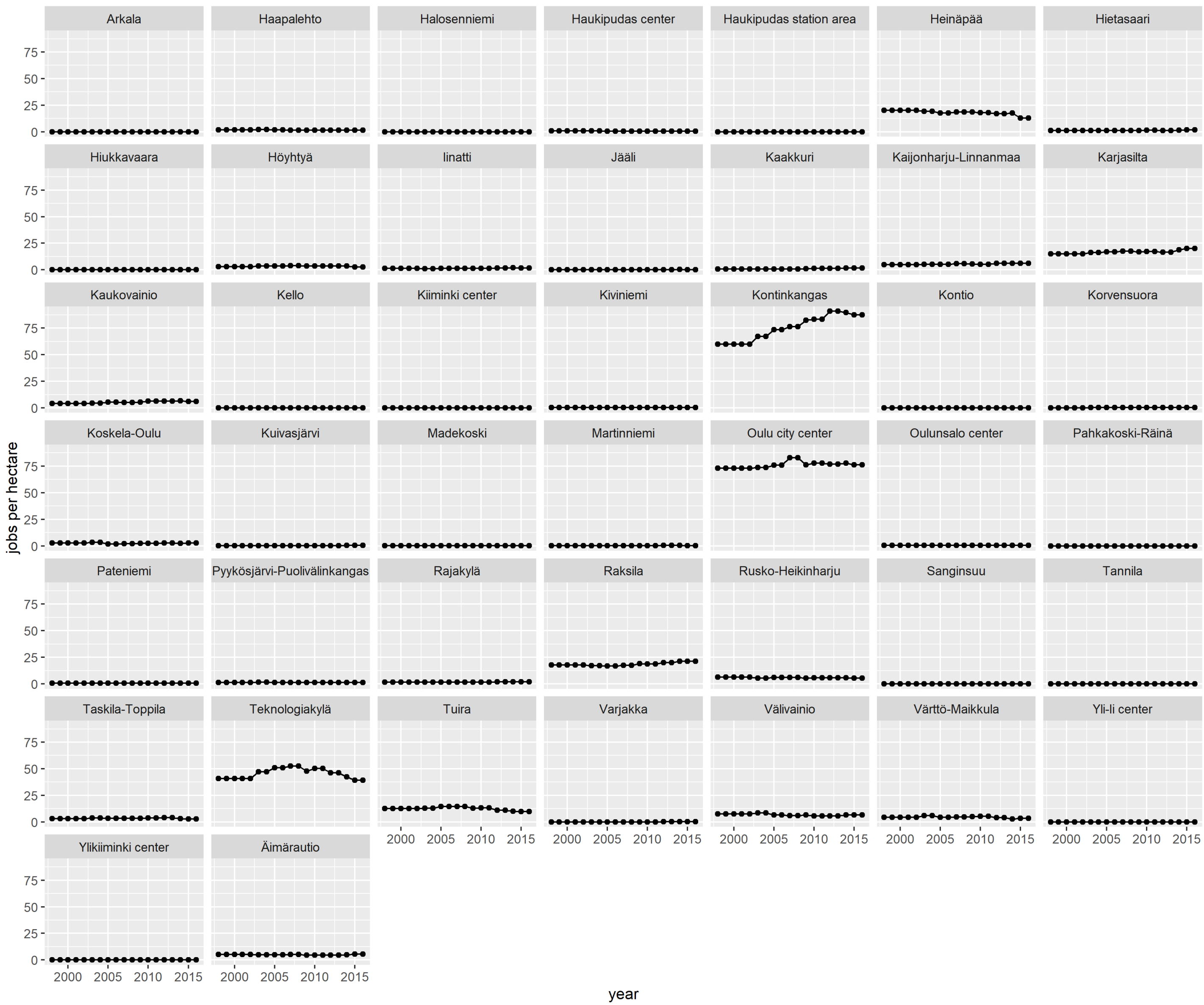

Figure S3. Density: jobs per hectare.

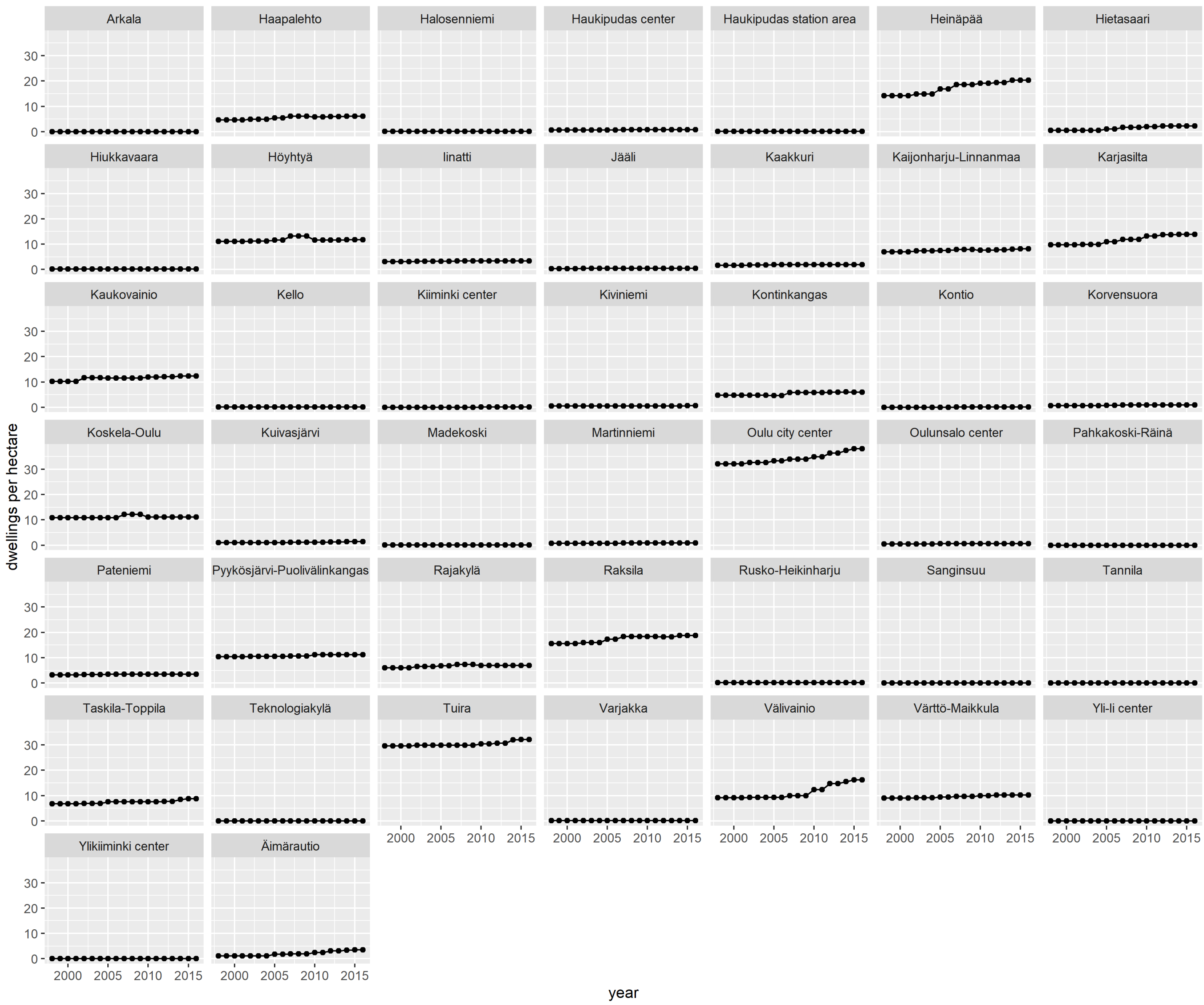

Figure S4. Density: dwellings per hectare.

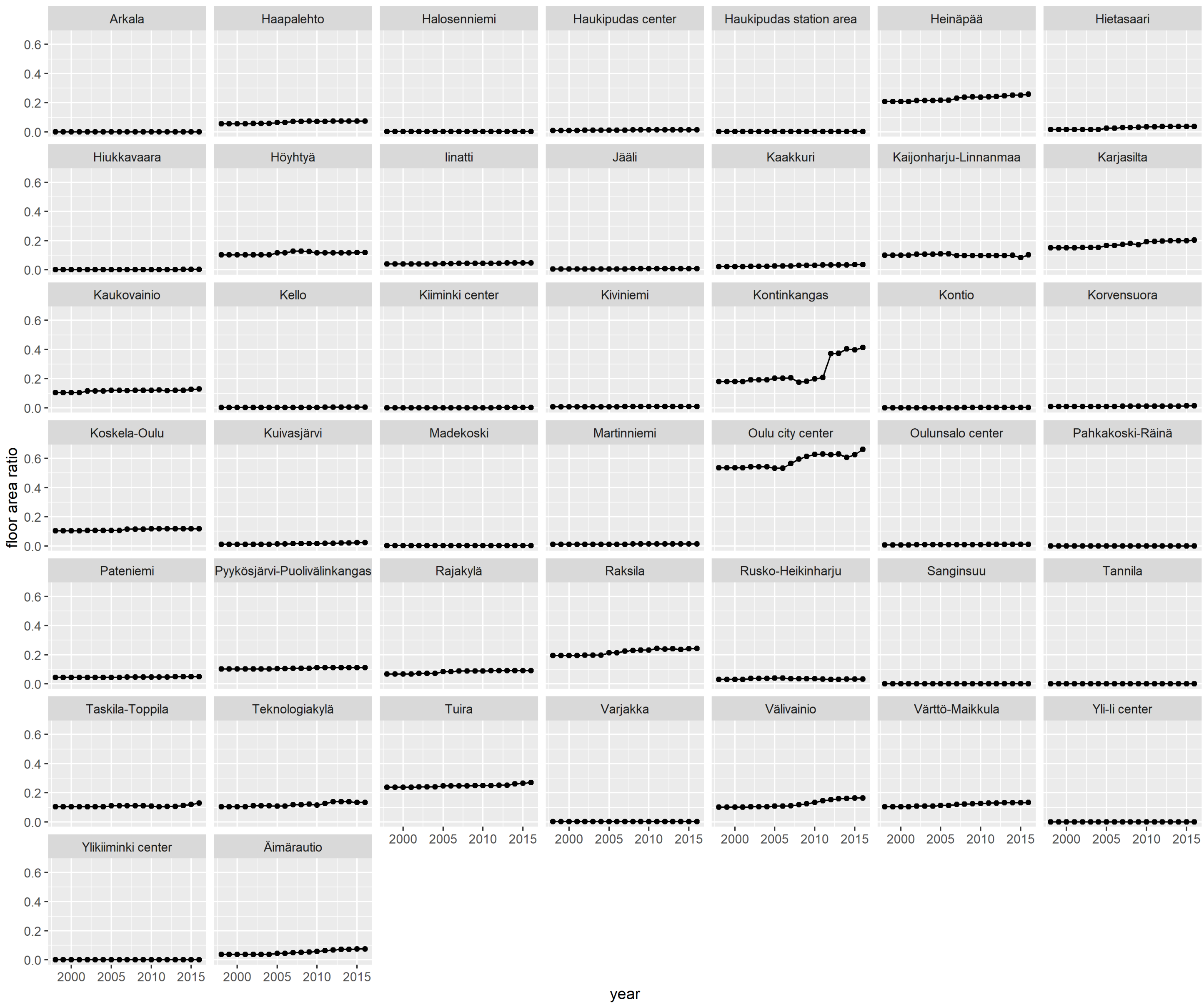

Figure S5. Density: floor area ratio.

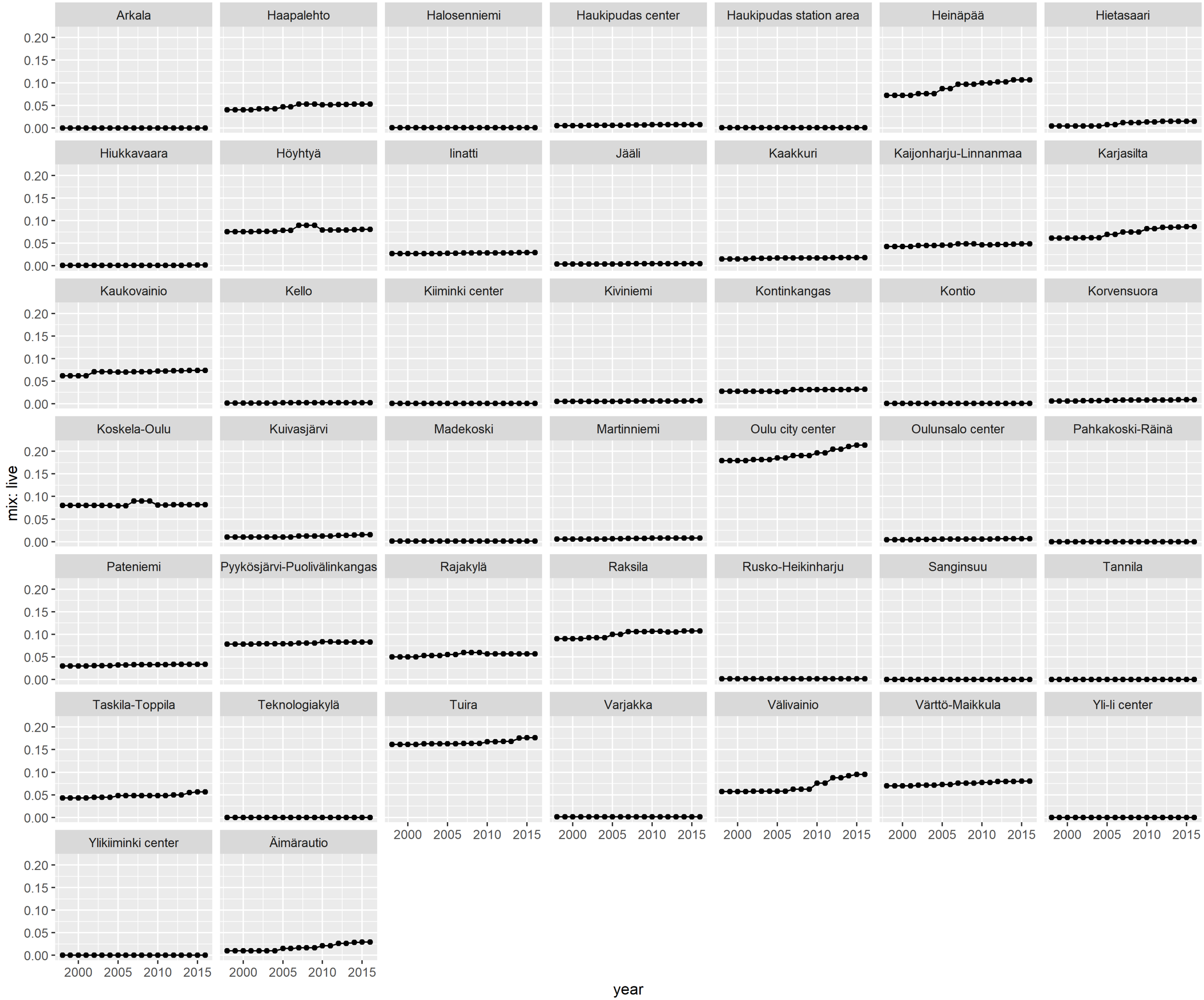

Figure S6. Mix: live (floor area of dwellings per site area).

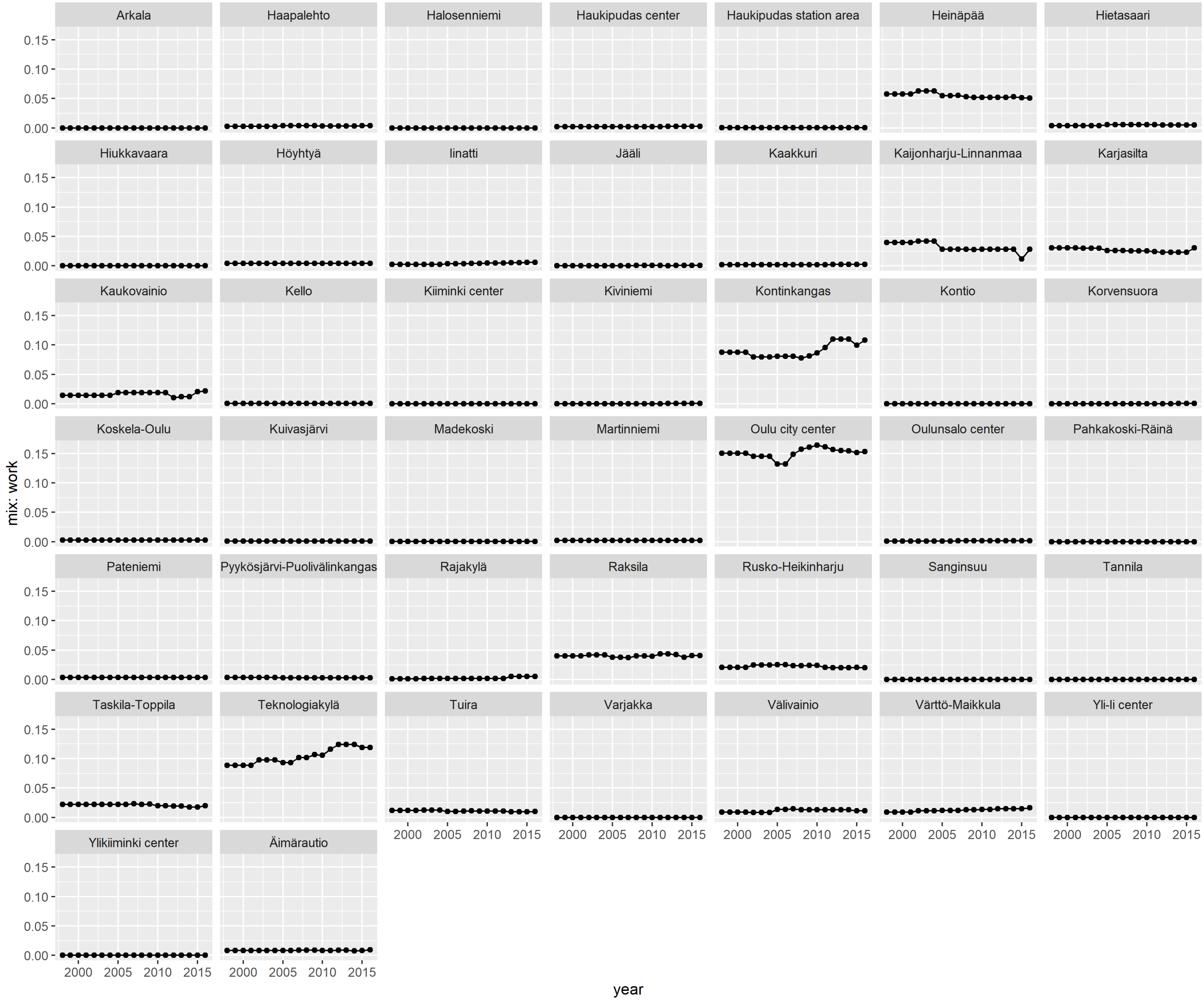

Figure S7. Mix: work (floor area of workplaces per site area).

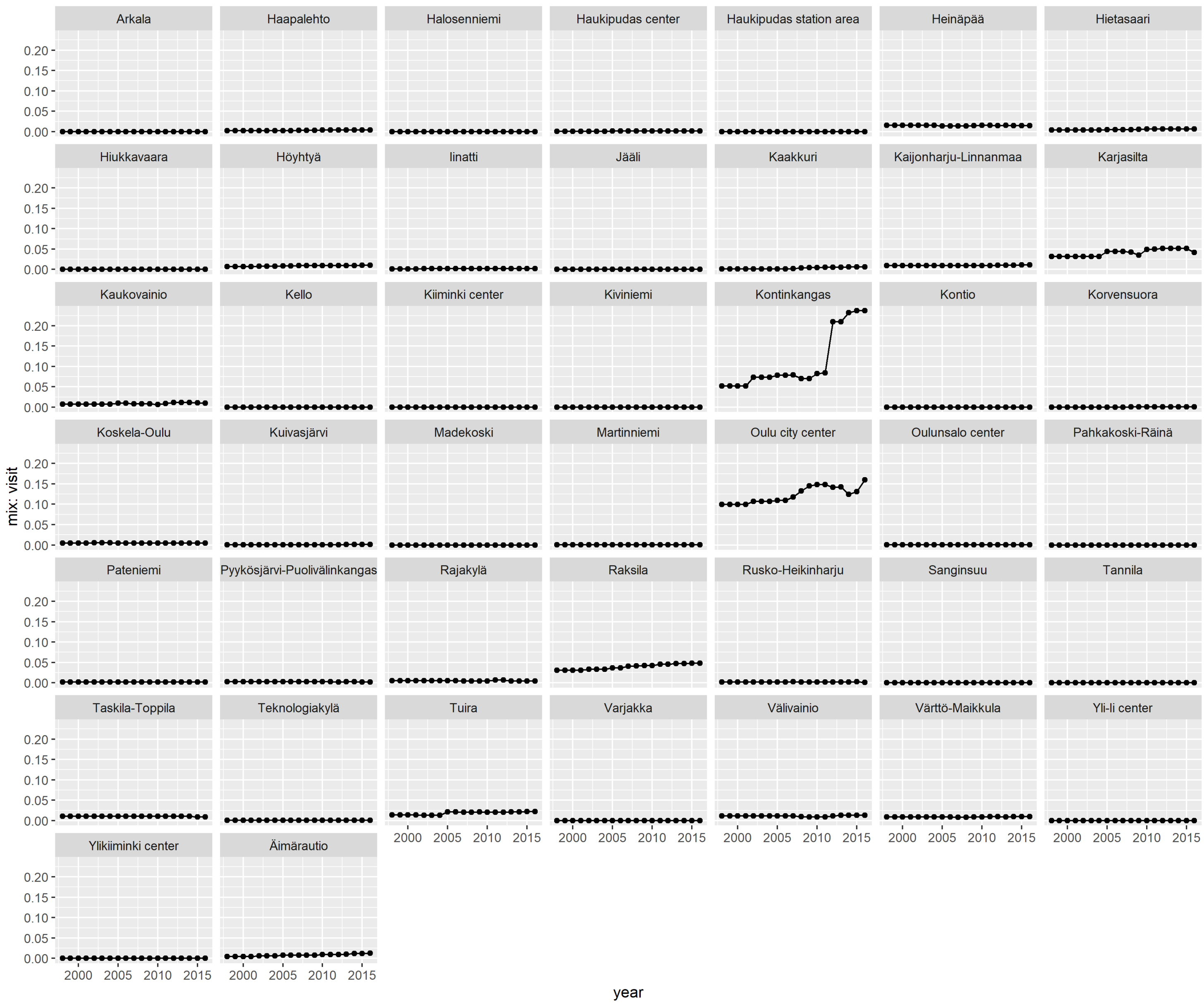

Figure S8. Mix: visit (floor area of amenities per site area).

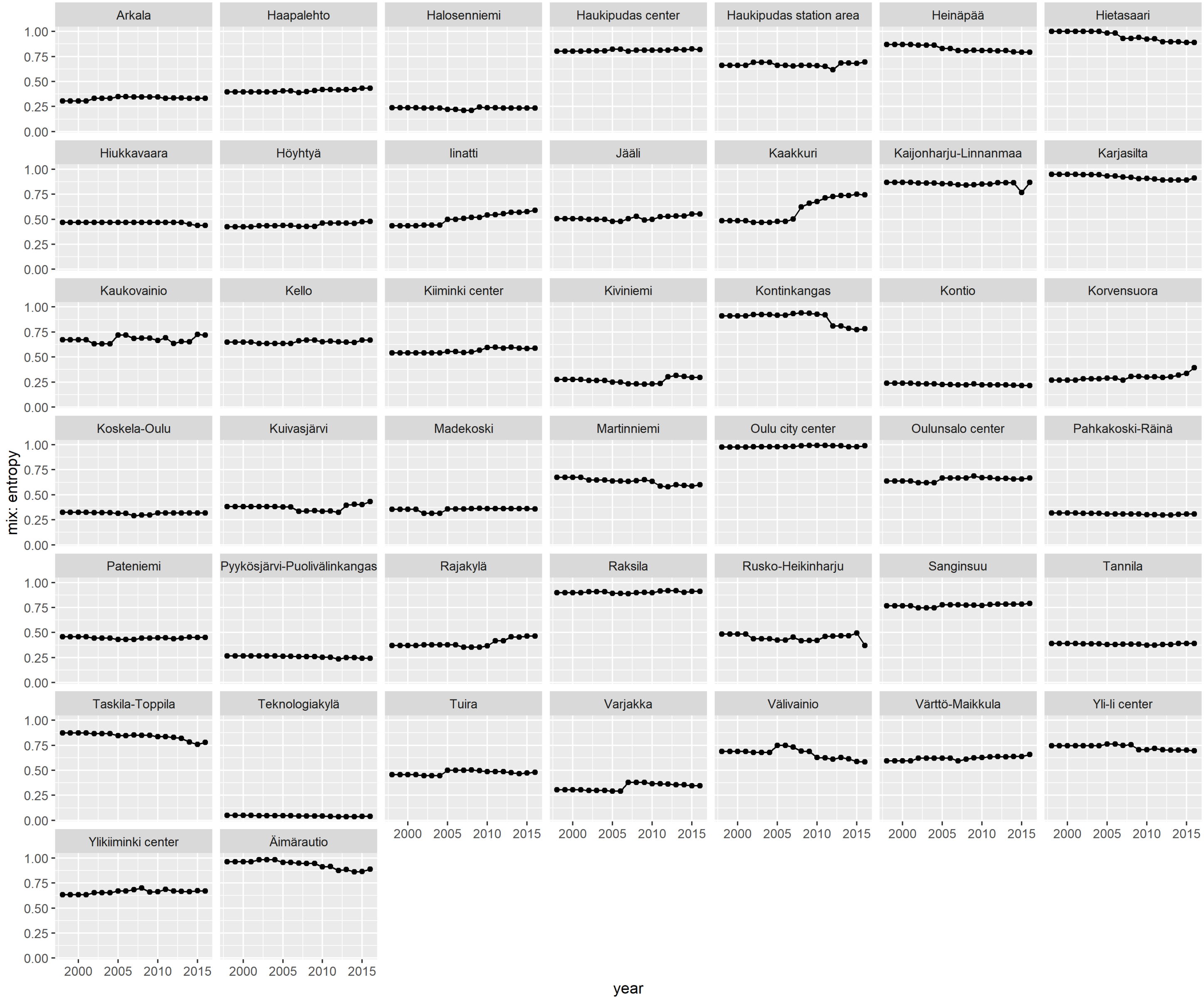

Figure S9. Mix: entropy score.

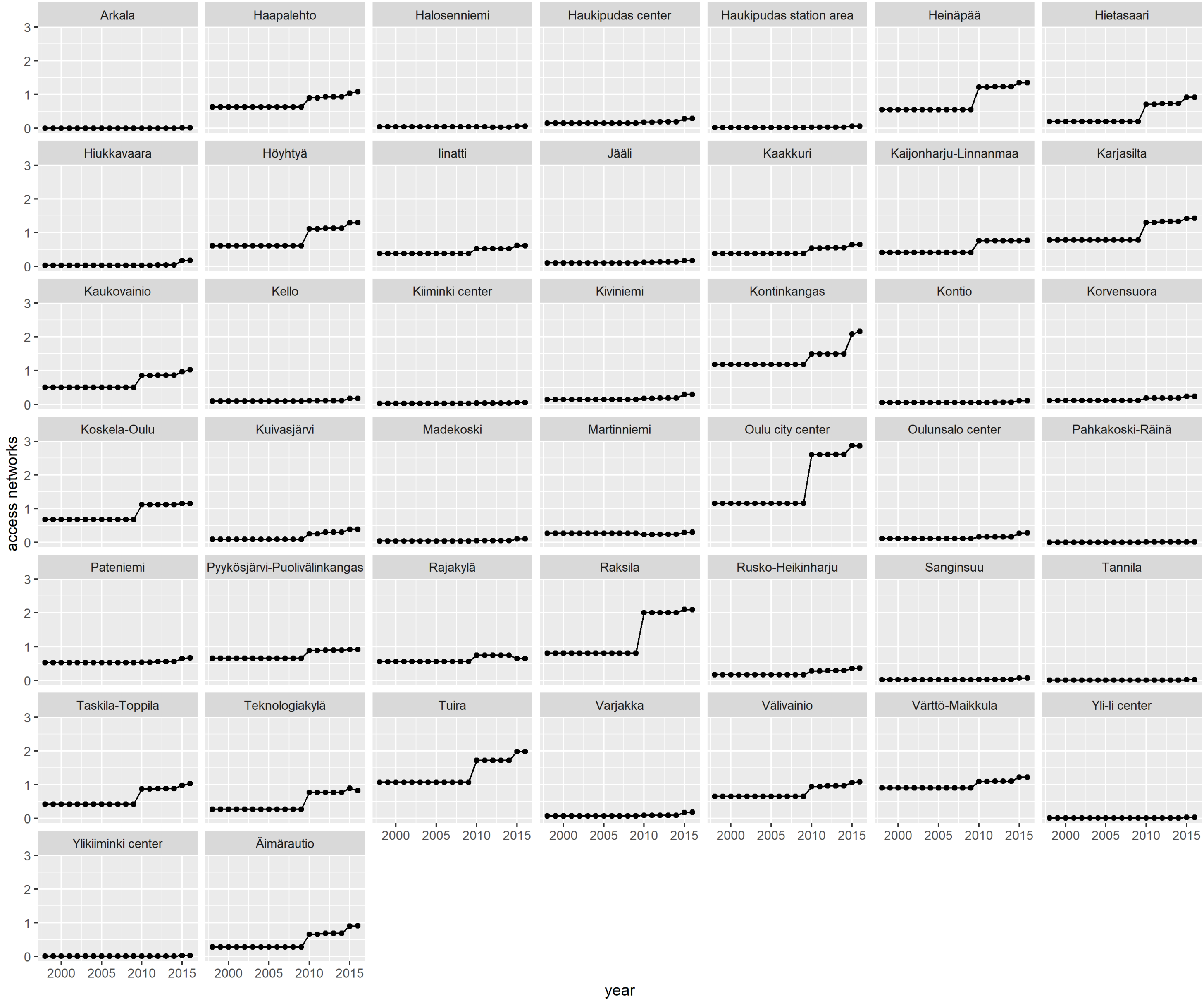

Figure S10. Access networks: intersections per hectare.

Results of the document analysis

Development of land use and transportation policies

Four main themes emerged from the land use and transportation planning policy analysis: 1) infill development and densification of the community structure, 2) mixing functions in local and regional centers to improve accessibility of services, 3) development of the city center and 4) increasing active transportation modal share. These themes are highly interconnected, and the overall goal of all policies has been the creation of a pleasant and sustainable city.

Infill and densification

All strategies related to community structure, housing and transportation development repeatedly emphasized the need for urban form densification between 1998 and 2016. Already, the 1993 land use master plan set the goal of increasing population density and creating more dwellings in the city center (City of Oulu, 1993). The most significant part of the 2004 land use master plan was the development corridor from north to south that was planned to offer possibilities for a high-quality urban structure in terms of mixing functions and supporting public transportation (City of Oulu, 2004). New dwellings were mainly directed to existing housing areas, but two new regional centers were also established in the eastern and southern parts of the urban fringe (City of Oulu, 2004). The 2013 land use program sought densification and housing construction, especially in the city center, and suggested that in the future, the same should be applied to existing suburban areas (City of Oulu, 2013b).

All city strategies also recognized the need for infill development, especially in relation to housing and services in local centers (City of Oulu, 1996, 1999, 2001a, 2005a, 2013a). Already, the 1999 city strategy stated that "housing construction and need for services are directed to suburban areas where existing resources and public transportation can be utilized, but also completely new housing areas need to be built because the population is growing" (City of Oulu, 1999). The goals presented in the city strategies were reflected in all environmental programs that aimed to reduce dependency of private motor vehicles (City of Oulu, 2001c, 2005b, 2014).

It was also recognized in the transportation strategies that urban form densification could increase the accessibility of services, and hence, decrease dependency on private motor vehicles (City of Oulu, 2013c). However, the 2003 transportation strategy also stated that due to intensified land use, traffic is expected to increase, and altogether prioritized car infrastructure projects such as highway expansion and parking conditions in the city center in the actual operational plans (City of Oulu, 2003).

Lately, the infill development plans have been especially directed close to existing walking, cycling and public transport networks (City of Oulu, 2016). Still, during the period 1998–2016, the growth of the city and housing production have been largely directed to new greenfield developments in the urban fringe. Single-family houses have dominated housing construction, but recently, more and more apartment houses have been planned closer to the city center (City of Oulu, 2016).

Mixing functions

The 1998 city strategy stated that "Commercial services will be located in the urban form systematically and in a balanced way so that they induce as little traffic as possible" (City of Oulu, 1996). The 2004 land use master plan stated that "the service network will be developed so that diverse amenities are easily accessible in local centers", but two new regional centers and new areas for work would also be established in the urban fringe (City of Oulu, 2004). The vitality of local centers and securing regional access to services were also set as goals in the land use, housing and transportation agreements with the state (Ministry of the Environment, 2013, 2016).

Mixing functions was also seen as important in transportation strategies. The 2003 transportation strategy recognized that the service structure is too dependent on the city center (City of Oulu, 2003). The 2013 transportation strategy stated that "accessibility of different functions from home define mobility choices" and highlighted that "good access to diverse functions reduces car dependency and should be the starting point in planning" (City of Oulu, 2013c).

The environmental program continued in the same line of thought, as the 2005 program recognized the need to "develop urban residential areas that accommodate sufficient population to support nearby services" (City of Oulu, 2005b). The 2014 environmental program stated that "services will be located in local centers that will be densified and reformed by mixing functions" (City of Oulu, 2014). However, the indicators that were set to be followed included only accessibility of the city center, daycare, schools and grocery stores (City of Oulu, 2014).

The land use program that guides the actual land use implementation process has only recently specifically focused on the matter (City of Oulu, 2016), and the previous programs have emphasized only housing production in infill development and not particularly assessed functional mix, except with a few casual remarks.

Development of the city center

All land use and transportations strategies have repeatedly emphasized the importance of developing the city center by the means that have been congruent to a great extent: increasing service level, increasing the number of dwellings and workplaces, mixing functions and emphasizing walking, cycling and public transportation.

In 2001, a development plan that dealt specifically with land use and transportation circumstances for the city center of Oulu was established (City of Oulu, 2001b). The primary goal of this development plan was to prioritize walking and cycling in the city center. According to the plan, urban form should be formed of a vivid business district surrounded by mixed-use neighborhoods that would reduce dependency on private motor vehicles. However, it was also stated that car traffic flow on main roads needs to be secured; the traffic load in junctions cannot exceed the road capacity, even in peak hours; and parking spaces corresponding to demand should be offered. Transportation strategies also repeated that accessibility of the city center by all modes of transportation should be guaranteed (City of Oulu, 2003, 2013c). In 2005, parking and public transportation circumstances also emerged in the city strategy (City of Oulu, 2005a) and were repeated in the 2007 and 2009 land use programs (City of Oulu, 2007, 2009).

Promoting walking, cycling and public transportation

Emphasis on walking, cycling and public transportation was a part of the city strategy already in 1998 (City of Oulu, 1996). It was also presented as part of the city's land use master plan in 2004 (City of Oulu, 2004) and in both fairly recent agreements on land use, housing and transportation with the state (Ministry of the Environment, 2013, 2016). The most recent land use masterplan from 2016 stated that "the aim is to limit the growth of car traffic and a moderate decrease in car traffic flow in trips to the city center is accepted" (City of Oulu, 2016). In all environmental programs, one of the primary ways to support sustainable growth was increasing the active transportation modal share and decreasing the need to travel (City of Oulu, 1997, 2001c, 2005b, 2014).

Also, both transportation strategies set the goal of increasing the modal shares of walking, cycling and public transportation and limiting the growth of car traffic, especially on short trips (City of Oulu, 2003, 2013c). However, the transportation strategies also stated that "smooth car traffic flow on major roads cannot be endangered" and "accessibility of the city center for cars need to be secured" based on the argument that the overall traffic levels are increasing due to growth of the city (City of Oulu, 2003, 2013c). Limiting the demand for driving to the city center was planned to be done via developing the circumstances for cycling and public transportation. Social conditioning, safety, marketing, communication and infrastructure were presented as means to promote walking and cycling.

Synthesis of document and quantitative analysis

Densifying community structure, mixing functions, developing the city center and increasing active transportation modal share were the main goals of community planning policies in the city of Oulu during the period 1998–2016.

The 2004 land use master plan sought infill and densification of the urban form especially within the development corridor from north to south (City of Oulu, 2004). The density of buildings, residents and workplaces increased according to the plan, especially in the inner urban area. However, it is questionable whether the goals were reached in the outer urban area and the urban fringe. The new regional centers established in the eastern and southern parts of the urban fringe have increased urban sprawl. Positive development in residential density occurred in some postal code areas in the outer urban area, and the density of jobs increased also in one postal code area in the urban fringe. However, generally infill development focused on dwellings as compared to the diversity of amenities.

The policy documents emphasized the need for a good service structure not only in the city center but also in local centers in suburban areas. It is apparent that different functions were mainly separated, and there were clearly defined zones for commerce, housing and workplaces according to modernist planning principles even though the most recent land use master plan from 2016 directed urban development more to areas with higher land use efficiency. Overall, functional mix decreased in most of the postal code areas in the city of Oulu during the period 1998–2016. The city center was the only area with balanced land use, according to the categories *live*, *work* and *visit*, and the others were predominantly characterized as housing or working areas. The growth in floor area, according to the functional mix categories, mostly focused on the inner urban area, which was especially evident in terms of the growth of amenities.

Developing the city center was one of the main community planning goals. There were improvements in the number of dwellings and workplaces, and functional mix and modal shares of walking and cycling increased. Hence, it seems that the plans to develop the urban DMA components were successfully implemented in the city center and the inner urban area. Still, the city wanted to guarantee undisturbed car traffic flow on major roads in the city center, which was also reflected in the development of parking capacity.

Despite the goal to emphasize walking cycling and public transport in all policies, active transportation modal share decreased by 2 percentage points from 1998 to 2016. Modal shares of walking and cycling increased in the inner city. In the outer urban area, some positive development was evident from 2010 onward, but in the urban fringe – where the majority of the population lived – car dependency increased. In addition, the modal share of public transportation remained low during the follow-up time and was not associated with the urban DMA.

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Table S2. Unadjusted multinomial logit model with DMA score as a continuous predictor. Car use was the reference level for the response.

	Model 1			
Predictors	*Odds Ratio*	*CI*	*p*	*Response*
DMA score	1.12	1.11 – 1.14	**<0.001**	Walking
DMA score	1.09	1.08 – 1.11	**<0.001**	Cycling
DMA score	1.06	1.04 – 1.09	**<0.001**	Public transport
Observations	9182			

Table S3. Adjusted multinomial logit model with DMA score as a continuous predictor. Car use was the reference level for the response.

	Model 2			
Predictors	*Odds Ratio*	*CI*	*p*	*Response*
DMA score	1.08	1.07 – 1.10	**<0.001**	Walking
Age	1.00	0.99 – 1.00	0.408	Walking
Sex [female]	1.61	1.42 – 1.82	**<0.001**	Walking
Employment [outside workforce]	1.41	1.12 – 1.77	**0.003**	Walking
Distance	0.92	0.85 – 1.00	0.059	Walking
Profession [other]	1.02	0.71 – 1.46	0.919	Walking
Profession [school]	4.17	2.79 – 6.24	**<0.001**	Walking
Profession [student]	1.03	0.77 – 1.39	0.825	Walking
Profession [worker]	0.73	0.56 – 0.96	**0.024**	Walking
Car ownership [no car]	11.01	8.85 – 13.70	**<0.001**	Walking
Year [2004]	0.88	0.69 – 1.13	0.324	Walking
Year [2010]	0.64	0.50 – 0.82	**<0.001**	Walking
Year [2016]	0.76	0.62 – 0.93	**0.007**	Walking
DMA score	1.04	1.02 – 1.06	**<0.001**	Cycling
Age	0.99	0.99 – 1.00	**0.023**	Cycling
Sex [female]	1.25	1.09 – 1.44	**0.002**	Cycling
Employment [outside workforce]	0.96	0.75 – 1.23	0.754	Cycling
Distance	0.66	0.58 – 0.74	**<0.001**	Cycling
Profession [other]	1.31	0.83 – 2.09	0.251	Cycling
Profession [school]	14.48	9.15 – 22.90	**<0.001**	Cycling
Profession [student]	2.49	1.75 – 3.54	**<0.001**	Cycling
Profession [worker]	1.33	0.96 – 1.84	0.083	Cycling
Car ownership [no car]	14.67	11.69 – 18.42	**<0.001**	Cycling
Year [2004]	1.27	0.96 – 1.69	0.092	Cycling
Year [2010]	1.17	0.88 – 1.55	0.280	Cycling
Year [2016]	1.18	0.92 – 1.50	0.186	Cycling

DMA score	1.00	0.97 – 1.03	0.974	Public transport
Age	0.98	0.97 – 0.99	**0.002**	Public transport
Sex [female]	2.10	1.62 – 2.72	**<0.001**	Public transport
Employment [outside workforce]	1.48	1.00 – 2.17	**0.049**	Public transport
Distance	0.85	0.71 – 1.02	0.083	Public transport
Profession [other]	1.25	0.61 – 2.57	0.539	Public transport
Profession [school]	3.28	1.47 – 7.31	**0.004**	Public transport
Profession [student]	2.57	1.47 – 4.48	**0.001**	Public transport
Profession [worker]	0.93	0.54 – 1.59	0.789	Public transport
Car ownership [no car]	17.65	12.81 – 24.30	**<0.001**	Public transport
Year [2004]	0.66	0.41 – 1.08	0.096	Public transport
Year [2010]	0.75	0.47 – 1.22	0.247	Public transport
Year [2016]	0.87	0.59 – 1.27	0.462	Public transport
Observations	7967			

Table S4. Unadjusted multinomial logit model with DMA class as a predictor (Urban fringe was used as the reference category). Car use was the reference level for the response.

	Model 3			
Predictors	*Odds Ratio*	*CI*	*p*	*Response*
Outer urban area [2]	1.88	1.66 – 2.13	**<0.001**	Walking
Inner urban area [3]	4.15	3.61 – 4.77	**<0.001**	Walking
Outer urban area [2]	2.36	2.09 – 2.67	**<0.001**	Cycling
Inner urban area [3]	3.00	2.57 – 3.50	**<0.001**	Cycling
Outer urban area [2]	1.32	1.03 – 1.69	**0.029**	Public transport
Inner urban area [3]	1.97	1.47 – 2.64	**<0.001**	Public transport
Observations	9182			

Table S5. Adjusted multinomial logit model with DMA class as a predictor (Urban fringe was used as the reference category). Car use was the reference level for the response.

	Model 4			
Predictors	*Odds Ratio*	*CI*	*p*	*Response*
Outer urban area [2]	1.47	1.23 – 1.76	**<0.001**	Walking
Inner urban area [3]	2.64	2.14 – 3.25	**<0.001**	Walking
Age	1.00	0.99 – 1.00	0.376	Walking
Sex [female]	1.54	1.36 – 1.74	**<0.001**	Walking
Employment [outside workforce]	1.39	1.11 – 1.75	**0.005**	Walking
Distance	0.91	0.83 – 0.99	**0.037**	Walking
Profession [other]	0.99	0.69 – 1.42	0.963	Walking

Profession [school]	4.24	2.83 – 6.34	**<0.001**	Walking
Profession [student]	1.01	0.75 – 1.36	0.936	Walking
Profession [worker]	0.71	0.54 – 0.93	**0.013**	Walking
Car ownership [no car]	11.09	8.91 – 13.81	**<0.001**	Walking
Year [2004]	0.87	0.68 – 1.11	0.254	Walking
Year [2010]	0.67	0.53 – 0.86	**0.001**	Walking
Year [2016]	0.80	0.65 – 0.98	**0.031**	Walking
Outer urban area [2]	1.49	1.21 – 1.83	**<0.001**	Cycling
Inner urban area [3]	1.84	1.44 – 2.36	**<0.001**	Cycling
Age	0.99	0.99 – 1.00	**0.022**	Cycling
Sex [female]	1.23	1.07 – 1.41	**0.004**	Cycling
Employment [outside workforce]	0.95	0.74 – 1.21	0.662	Cycling
Distance	0.71	0.62 – 0.81	**<0.001**	Cycling
Profession [other]	1.31	0.82 – 2.08	0.260	Cycling
Profession [school]	14.60	9.22 – 23.12	**<0.001**	Cycling
Profession [student]	2.36	1.65 – 3.35	**<0.001**	Cycling
Profession [worker]	1.29	0.93 – 1.79	0.123	Cycling
Car ownership [no car]	14.22	11.32 – 17.86	**<0.001**	Cycling
Year [2004]	1.24	0.93 – 1.64	0.140	Cycling
Year [2010]	1.18	0.89 – 1.56	0.259	Cycling
Year [2016]	1.17	0.92 – 1.49	0.211	Cycling
Outer urban area [2]	0.52	0.36 – 0.74	**<0.001**	Public transport
Inner urban area [3]	0.64	0.42 – 1.00	**0.048**	Public transport
Age	0.98	0.97 – 0.99	**0.001**	Public transport
Sex [female]	2.06	1.59 – 2.66	**<0.001**	Public transport
Employment [outside workforce]	1.47	0.99 – 2.17	0.054	Public transport
Distance	0.70	0.57 – 0.87	**0.001**	Public transport
Profession [other]	1.21	0.59 – 2.49	0.600	Public transport
Profession [school]	2.98	1.34 – 6.63	**0.007**	Public transport
Profession [student]	2.59	1.49 – 4.51	**0.001**	Public transport
Profession [worker]	0.91	0.53 – 1.56	0.722	Public transport
Car ownership [no car]	19.83	14.26 – 27.60	**<0.001**	Public transport
Year [2004]	0.69	0.42 – 1.12	0.134	Public transport
Year [2010]	0.80	0.50 – 1.29	0.362	Public transport
Year [2016]	0.95	0.65 – 1.40	0.795	Public transport
Observations	7967			