Urban form, vehicle emissions and energy use of commuters in the Netherlands

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Abstract
The influence of urban form on the travel behaviour of commuters has been of interest to geographers, transportation and urban researchers for some time. Many studies have examined the influence of urban form on commuting distance, travel time and mode choice. For example, previous studies have shown that the denser urban areas are associated with shorter commuting distances but longer commuting times and lower commuting speeds. Trip-chaining is often more prevalent amongst commuters from denser urban areas. On the other hand, commuters from less dense areas have longer journey distances but higher commuting speeds and shorter travel times. Less attention however has been paid to the influence of urban form on vehicle emissions and transport energy use. Using the Dutch National Travel survey data, this paper examines the influence of different types of urban form on transport emissions and energy consumption due to commuters' daily travel behaviour in the Netherlands over the last decade.

The results show that the commuters' daily CO_2 emissions and energy consumption have significantly increased in the last decade. Moreover, although more urbanised area has higher traffic density and lower travel speed, the commuters who reside in this area produced lower CO_2 emissions and consumed less energy compared to the commuters who reside in less urbanised area. However this does not mean that dense/compact city policy would automatically reduce the transportation emissions and energy consumption. As shown in the models, there are more important factors that influence the amount of CO_2 emissions and energy consumption of the commuters than urban form and built environment variables.

Introduction
Carbon dioxide (CO_2) emissions from transport in the Netherlands are increasing at a rate of around 2 % per year (Netherlands Environmental Assessment Agency, 2006). Not only is the transport sector in the Netherlands one of the largest energy consumers and sources of CO_2 emissions, it is also one of the fastest growing consumers of energy and producers of CO_2: other sectors are experiencing either stabilization or decline (Statistics Netherlands, 2006). In 2002, the transport sector in the Netherlands was responsible for more than one fifth of all CO_2 emissions and passenger transport accounted for more than half of all CO_2 emissions from the transport sector as a whole (Stead and Susilo, 2007).

A variety of measures exists that can be used to manage transport demand, energy use and CO_2 emissions. Banister et al (2000) for example identify four main types of measures:

1. market-based instruments – policies which rely on market incentives
2. regulation-based instruments – policies involving technical standards and regulations
3. lifestyle-based instruments – including policies which relate to quality of life, education and public information
4. public infrastructure/services – policies involving the provision of public infrastructure and/or public transport services

Within the second category of regulation-based instruments one can find land-use planning measures. Land-use planning has both direct and indirect impacts on transport and, conversely, transport has direct and indirect impacts on land use (Woolley and Young, 1994). Because of this, land-use planning has the potential to reduce transport demand, transport-related emissions and energy use. Clearly, land-use planning policies are just one of several types of policies that have the potential to reduce the environmental impacts of transport; other types of policies may have more immediate or far-reaching effects. Nevertheless, land use planning policies have some advantages, including the potential to reduce transport demand at source. As a result, there has been a growth in interest in managing transport demand by means of land-use planning (see for example Banister and Marshall, 2000). There are numerous studies that have recently examined the influence of various aspects of urban form on travel demand (for a review of these, see for example Anderson et al, 1996; Geurs & van Wee, 2004; Stead & Marshall, 2001).

Drawing on data from the Dutch National Travel Survey (NTS), this paper traces the trends of commuters' daily travel behaviour in the Netherlands and examines the influence of urban form on commuters' daily transport energy consumption and CO_2 emissions between 1990 and 2005.[1] The influence of socio-demographic variables as well as urban form and built environment factors on daily CO_2 emissions and energy consumption are examined using regression analyses. The paper also addresses differences between centralized and decentralized urban development and its implications for transport energy consumption and emissions.

Data and Methodology

This paper draws on data from the Dutch National Travel Survey (NTS) which provides detailed information about individuals, households and their journeys for the last three decades. NTS data have been collected continuously by Statistics Netherlands since 1978 using travel diaries. For each year up to 1993, the NTS recorded data for approximately 10,000 households, 20,000 individuals (and more than 80,000 journeys). During 1994 and 1995 the NTS was extended to include substantially more respondents and households each year and also to include children younger than 12, who were previously excluded from the survey (van Evert et al, 2006). Because of some differences in the way of recording certain variables before 1990, this paper only uses NTS data from 1990 onwards.[2]

Emissions of CO_2 per person were calculated using information from NTS data about each journey (mode, distance, fuel type, vehicle age, occupancy and speed) together with vehicle emission factors from COPERT, a computer programme to calculate emissions from road transport developed for the European Environment Agency (Ntziachristos & Samaras, 2000).[3] The built environment data were collected on a municipality basis for each respective year. Instead of using terms like monocentric and polycentric or central and suburban areas, this paper classifies the urban form according to the degree of urbanisation of the city (based on the number of addresses per km^2). Urban areas are categorised into five groups: very highly urbanised, highly urbanised, moderately urbanised, low urbanised and non-urbanised.[4] Other spatial variables including local job availability, public transport density, road network density and travel accessibility are examined. The analysis also includes various socio-demographic variables relating to gender, education, income, car-ownership and household size.

Trends in Commuting, Emissions and Energy Consumption

Between 1990 and 2005, the average daily travel distance for commuters increased by 10 % (from 53.5 km per day to 59 km per day) whilst the percentage of car trips and the average travel speed increased 6 % (*Figure 1a*) and the average daily travel time remained quite stable at around 84 minutes.

Whilst travel distance increased and the average daily travel time remained relatively stable, the average number of daily trips and visits fell. From 1990 to 2005, the number of commuters' daily trips and trip-chains fell by 25 % (from 4.3 to 3.5 trips/day) and 13 % (from 1.7 to 1.5 trip chains/day) respectively. The average number of daily activities (for both work and non-work activities) declined by one-third in 2005 compared to 1990 (*Figure 1b*). However, these substantial differences in trips and trip chains may be mainly due to survey refinements that took place during this period.

Despite the fact that commuters' daily travel time remained relatively stable between 1990 and 2005 and that commuters' daily travel distance increased only slightly, the energy consumption and the CO_2 emissions due to commuters' travel increased significantly (*Figure 2a*). Between 1990 and 2005, energy consumption and CO_2 emissions per day for commuters increased by 56 % and 51 %, respectively.

These increases in energy consumption CO_2 emissions are mainly due to increases in commuting distance. Between 1990 and 2005, the commute distance and time of commuters increased by 45% and 48% respectively (*Figure 2b*). The average travel distance by car increased by 12 % and the proportion of commuters who travelled as a car passenger decreased. In other words, more commuters became car drivers and the average occupancy of commuting journeys fell. The proportion of commuters who travelled by non-motorised modes (and therefore had zero emissions and energy consumption) decreased from 25 % in 1990 to 20 % in 2005.

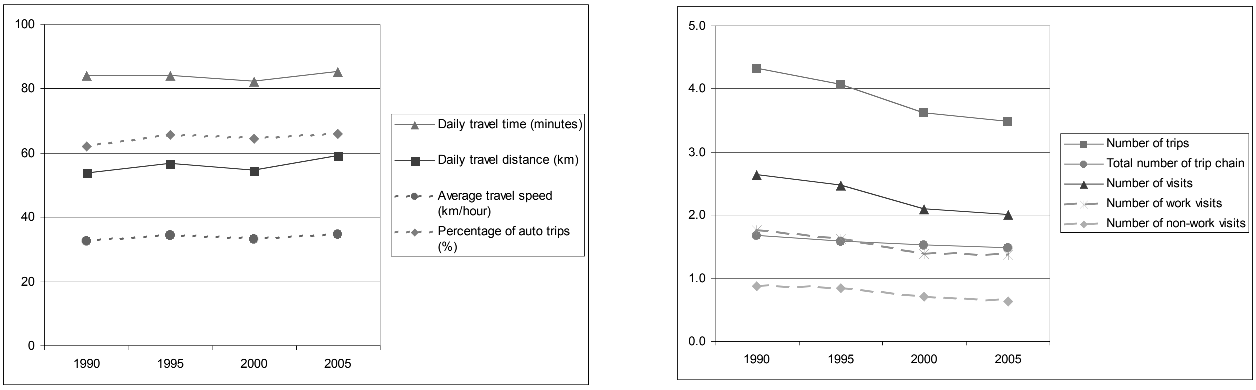
With the increase in commuting distance, the domination of energy consumption and CO_2 emissions due to commuting increased. In 1990, commuting accounted for 83% of daily trans-

1. The commuters included in this study are full-time workers (i.e. people who are employed at least 30 hours a week) who made at least one work-related trip on the day of the travel survey, whose travel origin and destination were in the Netherlands, and who started and ended their daily trip at their home location.

2. Land use variables are only available from 1993, so some analyses in this paper do not include 1990 data.

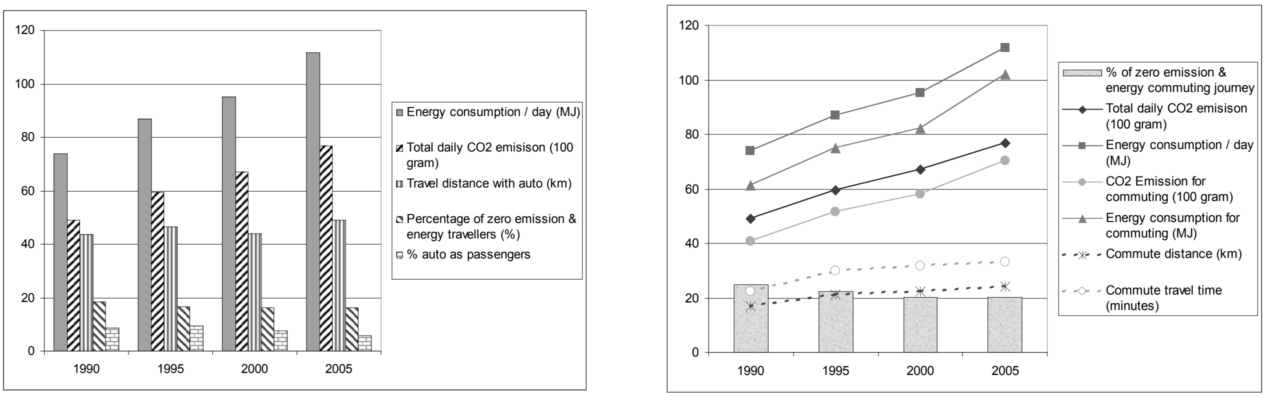
3. Information about distance, fuel type, vehicle age, occupancy and speed were used to calculate CO_2 emissions for car journeys. For journeys by other modes, information about mode and distance only were used to calculate CO_2 emissions using typical emission factors for the Netherlands according to analysis by van den Brink & van Wee (1997).

4. The home municipality is categorized as a very urbanised area if it has more than 2,500 addresses per km^2, as a highly urbanised area if it has 1,500–2,500 addresses per km^2, as a moderately urbanised area if it has 1,000–1,500 addresses per km^2, as a low urbanised areas if it has 500–1,000 addresses per km^2 and as a non-urbanised area if it has fewer than 500 addresses per km^2.



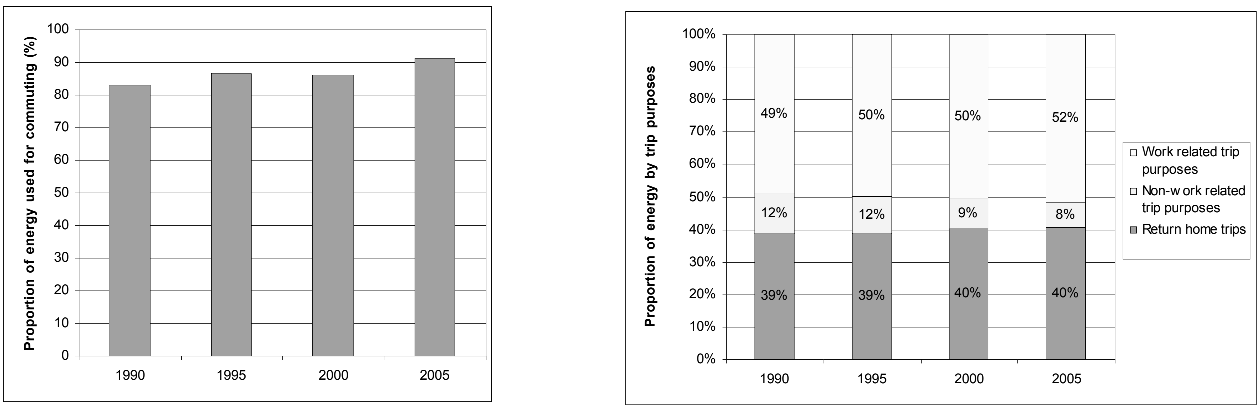
(a) (b)

Figure 1. Changes in commuting travel patterns, 1990-2005



(a) (b)

Figure 2. Changes in commuters' transport energy consumption and CO_2 emissions, 1990-2000



(a) (b)

Figure 3. Commuters' transport energy consumption, 1990-2005

port energy consumption whilst in 2005 commuting accounted for 91 % (*Figure 3a*). Non-work activities accounted for 12 % of commuters' daily energy consumption in 1990 whilst in 2005, non-work activities only accounted for 8 % of commuters' daily energy consumption (*Figure 3b*).

Trends by Urban Form

Classifying individuals based on the degree of urbanisation of the home municipality, based on the density of the addresses, produces observable distinct trends of travel behaviour, transport energy use and emissions according to different categories of urbanisation. *Figures 4a*, *4b* and *4c* show that although commuters from less urbanised areas travel further, they actually spend less time commuting, as they tend to travel at higher speeds than commuters from more urbanised areas. This is related to the traffic congestion in more urbanised area and the different of modal split in different types of areas: more car journeys in less urbanised areas and fewer journeys by foot, cycle and public transport. Commuters who live more urbanised areas make more stops in their commuting journeys (*Figure 4d).* As one would expect, more urbanised areas tend to have more public-transport and non-motorised commuters and fewer private-car commuters (*Figures 4e* and *4f*). Interestingly, the proportion of journeys by private cars by commuters only increased by 2 % between 1993 and 2005 in the Netherlands, whilst the proportion of journeys by public transport increased by 12 % and the proportion of journeys by non-motorised transport decreased by 13 %.

The trends of CO_2 emissions due to commuters' daily travel-activities are shown in *Figure 5*. Since the trends of energy consumption have very similar trends with CO_2 emissions, the figures for energy consumption are not shown here. Individuals who live in more urbanised areas produce fewer emissions per day, lower emissions per trip chain and lower emissions per visit than those who live in less urbanised areas. Residents of more urbanised areas also consume less energy per trip chain and per visit. Interestingly, CO_2 emissions per kilometre are relatively similar for residents of all types of urban area with the exception of residents of *very highly urbanised* areas. This is probably due to the higher use of public transport and non-motorised modes in *very highly urbanised* areas. Since the individuals who live in more urbanised areas tend to make more non-work visits, they also spend more energy and produce more emissions due to non-work visits than individuals who live in less urbanised areas.

The daily transport emissions and the energy consumption changes between 1995 and 2005 are shown in *Figure 6*. Daily transport emissions and energy consumption of commuters resident in less urbanised areas increased significantly more than commuters resident in more urbanised areas. Both the daily emissions and energy consumption of commuters resident in *very highly urbanised area* increased by 16 % between 1995 and 2005, whilst the daily emissions and energy consumption of commuters resident in *non-urbanised areas* increased by 38 % (*Figure 6a*). Between 1995 and 2005, emissions per kilometre travelled and per visit increased by a similar proportion for commuters resident in all types of area with the exception of residents of *very highly urbanised* areas. For commuters resident in these areas, emissions per kilometre travelled and per visit increased proportionally less (*Figure 6b*).

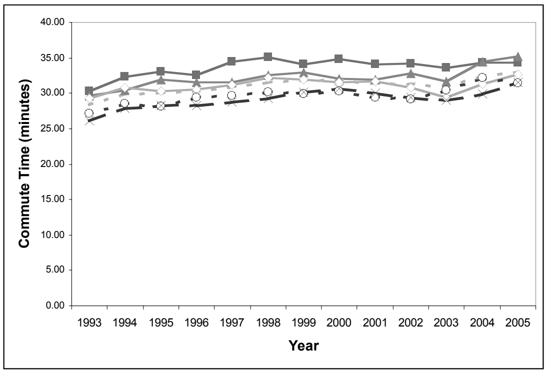
Synthesis Analysis

To validate the results of the above explanatory analyses and to examine the influence of socio-demographic variables and land-use factors on daily transport energy consumption and CO_2 emission, regression analyses were performed. These analyses were carried out for three points in time (1995, 2000 and 2005) in order to determine whether the influence of the variables were consistent. Regression analyses were carried out both with and without commuting distance as an explanatory variable. The results of the analyses are shown in the appendix and the salient results are summarised below. As might be expected, commuters' CO_2 emissions and energy consumption are highly influenced by car ownership, income, education and gender. The influence of these variables has increased over time. Naturally, CO_2 emissions and energy consumption are heavily influenced by travel to work distance, since commuting accounts for the majority of commuters' transport-related CO_2 emissions and energy consumption. A 1-kilometre increase in travel to work distance increased commuters' daily CO_2 emissions by 201, 224, and 231 grams in 1995, 2000, and 2005 respectively.

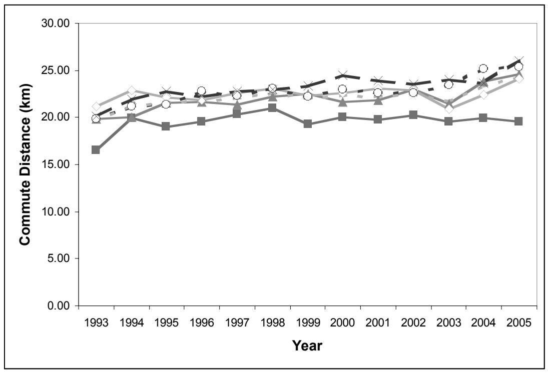
- Car-owning commuters produced 3.5, 3.9, and 5.0 kg more CO_2 per day (and consumed 50, 57, and 73 MJ more per day) than commuters without a car in 1995, 2000 and 2005 respectively.
- Commuters with high incomes (in the highest quintile) produced 2.3, 2.8 and 3.5 kg more CO_2 per day (and consumed 32, 39 and 48 MJ more energy per day) than commuters in other income groups in 1995, 2000 and 2005 respectively.
- Commuters who have received higher education produced 1.6, 1.7 and 1.4 kg more CO_2 per day (and consumed 23, 24 and 25 MJ more energy per day) in 1995, 2000 and 2005 respectively.
- Men produced 1.5, 1.6, and 1.9 kg more CO_2 per day (and consumed 22, 22, and 29 MJ more per day) than women in 1995, 2000, and 2005 respectively.

Even after commuting distance is taken into account, men, young and high-income commuters still produced more CO_2 and consumed more energy per day in each of the three years examined.

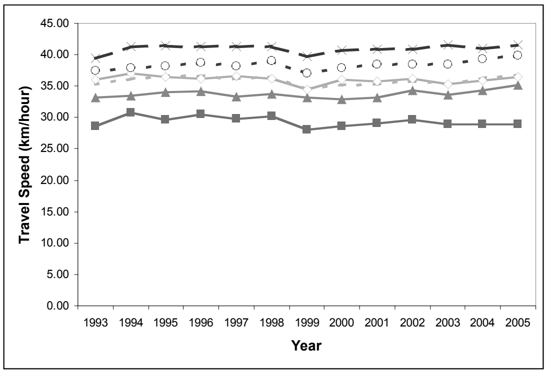
In terms of residential location, commuters who were resident in more urbanised areas tend to produce less CO_2 and consume less energy. Commuters who live in *very highly urbanised* area produced 1.3, 1.4, and 2.2 kg less CO_2 per day and used 19, 21 and 32 MJ less energy in 1995, 2000 and 2005 respectively. The results are less clear for commuters resident in *moderately* and *low urbanised* areas. The results of the analysis suggest that CO_2 emissions and energy consumption may not differ substantially between commuters who are resident in *moderately urbanised*, *low urbanised* or *non-urbanised* areas. The results are also inconclusive in terms of differences in CO_2 emissions and energy consumption for commuters who live



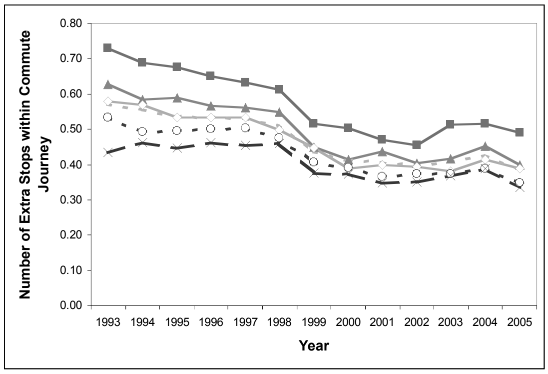
(a) Daily commuting-journey time (minutes)



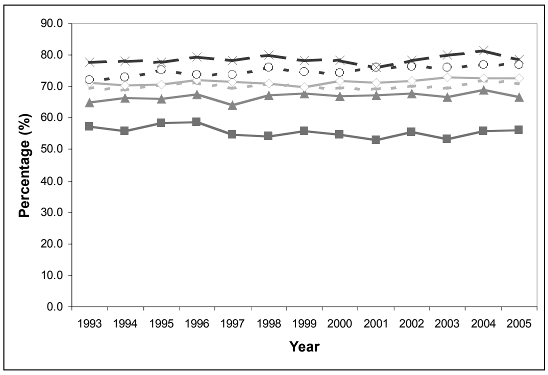
(b) Daily commuting-journey distance (km)



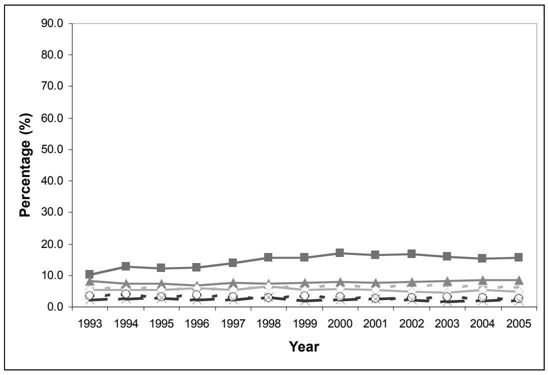
(c) Commuting speed (km/hour)



(d) Number of extra stops in commuting journey



(e) Percentage of journeys by car



(f) Percentage of journeys by train/bus/tram/metro

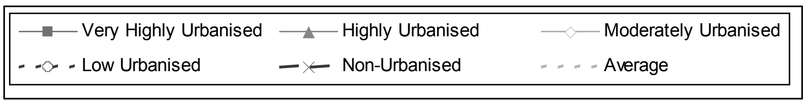
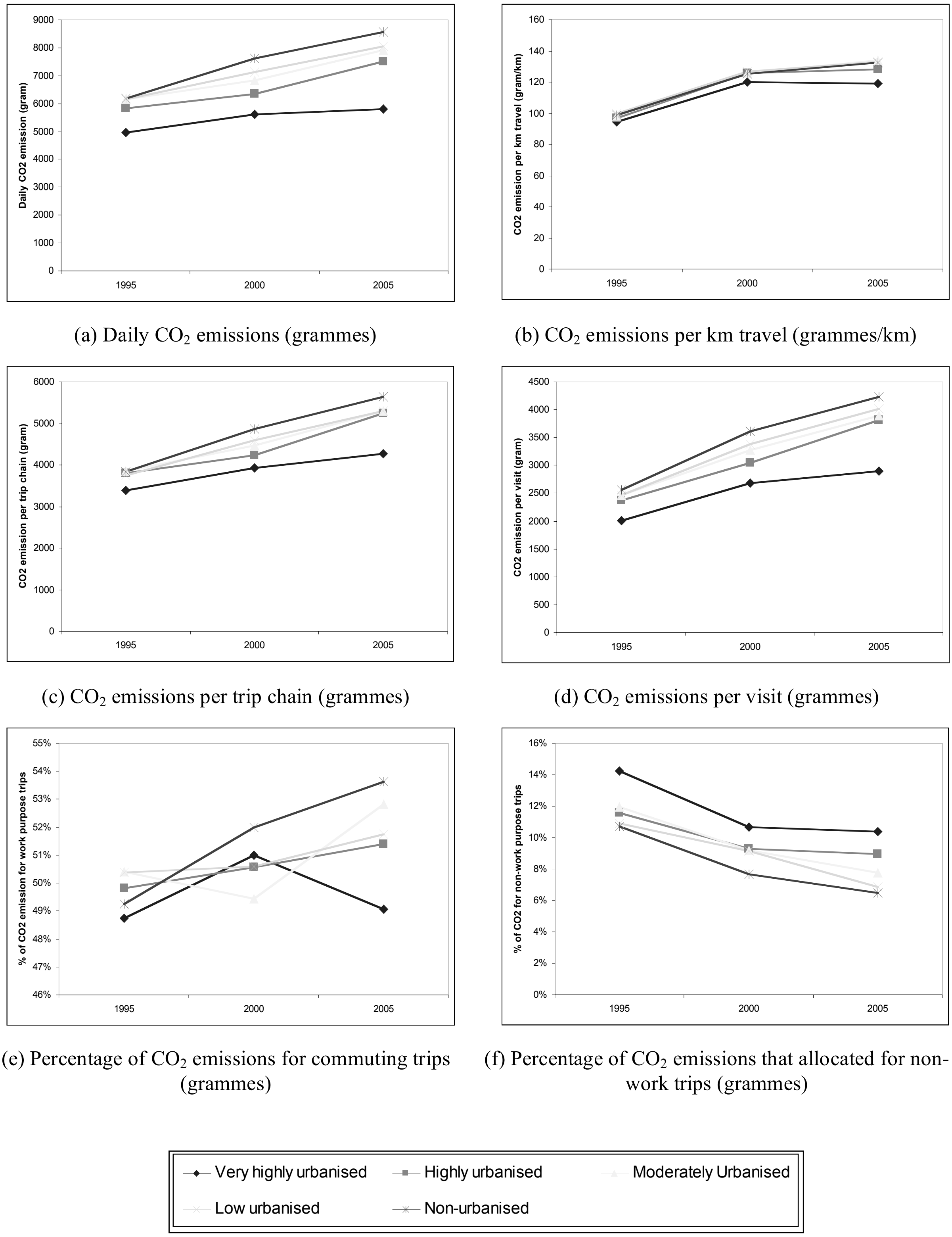


Figure 4. Trends in commuting according to home location

in Randstad metropolitan area.[5] The other land-use variables examined in this paper (job and population accessibilities, retail densities and transportation network densities in home municipalities) do not appear to have a consistent significant influence on CO_2 emissions and energy consumption in the three observed years.

Without the *commute distance* variable, the coefficients of determination (R^2) of the models are extremely low (less than 0.1), which shows that the CO_2 emissions and energy con-

5. Randstad Metropolitan Area (RMA) is an urban agglomeration in the Netherlands, consisting of the four main cities (Amsterdam, The Hague, Rotterdam and Utrecht) and the surrounding areas. With 7.5 million inhabitants (which is almost half the population of the Netherlands), it is one of the largest agglomerations in Europe.



(a) Daily CO_2 emissions (grammes)

(b) CO_2 emissions per km travel (grammes/km)

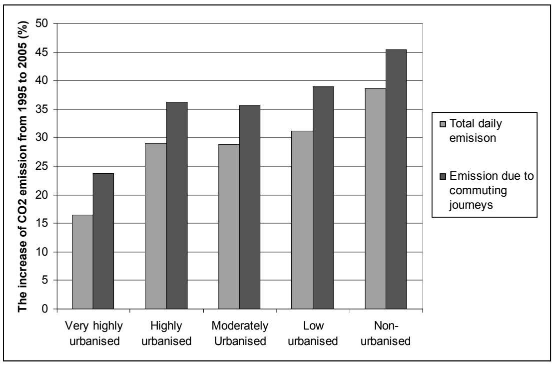
(c) CO_2 emissions per trip chain (grammes)

(d) CO_2 emissions per visit (grammes)

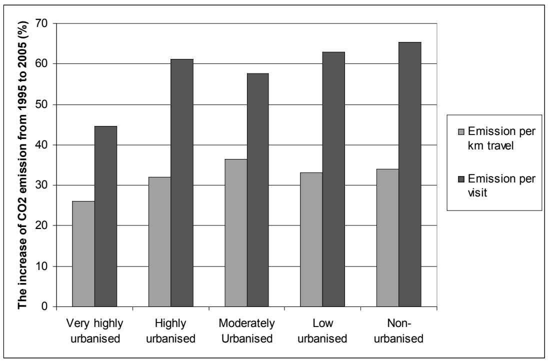
(e) Percentage of CO_2 emissions for commuting trips (grammes)

(f) Percentage of CO_2 emissions that allocated for non-work trips (grammes)

Figure 5. Trends in commuters' CO_2 emissions according to home location. The trends in energy consumption according to home location are very similar to trends in CO_2 emissions in Figure 5 and are therefore not shown in this paper.



(a)



(b)

Figure 6. Increases in commuters' transport emissions according to home location, 1995-2005. The trends in energy consumption according to home location are very similar to trends in CO_2 emissions in Figure 6 and are therefore not shown in this paper.

sumption of commuters is not strongly influenced by the socio-demographic, land use and accessibility variables examined here.

Conclusions

Using data from the Dutch National Travel Survey (NTS), this paper shows trends of commuters' daily travel behaviour in the Netherlands and examines the influence of urban form on commuters' daily transport energy consumption and CO_2 emissions across the last decade. Commuters' travel distance and travel time have increased since 1990 onwards; so too has the increase in daily CO_2 emissions and energy consumption. Commuters' transport-related CO_2 emissions and energy consumption both increased by more than 25 % between 1990 and 2005. Travelling to and from work accounts for the major component of the transport related CO_2 emissions and energy consumption of commuters.

Commuting time and distance differs somewhat according to the residential location of commuters. Residents of more urbanised areas have on average a slightly longer commuting time, a lower commuting distance, a lower commuting speed (due mainly to the fact that proportionally fewer use the car) and more stops in the commuting journey. Their commuting journeys are less car-based and more public transport based. The main change in the modal split of commuting journeys over recent years has been a fall in the use of non-motorised modes (foot and cycle). Average transport-related CO_2 emissions and energy use is lowest for commuters resident in very urbanised areas and highest for commuters resident in non-urbanised areas (similar results were reported by Banister in 1992 in the UK). The rate of increase in transport-related CO_2 emissions and energy use between 1995 and 2005 has been lowest for commuters resident in very highly urbanised areas and highest for commuters resident in non-urbanised areas.

Regression analysis indicates that socio-economic variables explain more of the variation in commuters' daily CO_2 emissions and energy use than the land-use variables examined in this paper. The most important socio-economic variables influencing CO_2 emissions and energy use are car ownership, income, education and gender. These results correspond with similar research in the Netherlands by Dieleman et al (2002) and also in the UK by Stead (2001), who looked at the relationships between land-use patterns, socio-economic variables and travel distance.[6] The results of this paper do not necessarily mean that land-use patterns do not have an influence on transport-related energy consumption and CO_2 emissions: they simply means that their effect is not as great as the socio-economic characteristics of travellers.

The focus of the analysis in this paper has been the possible effect of land-use variables at just one end of the journey (i.e. the origin – the home location) on transport-related energy consumption and CO_2 emissions. It is likely that land use variables for the destination, and possibly also the physical characteristics of the area between origin and destination, play just an important role in influencing transport-related energy consumption and CO_2 emissions. There are few examples of this type of research and this could be an interesting new direction for further research.

6. According to Stead (1999), travel distance is a fairly good indicator of emissions and energy use.

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Appendix

1. REGRESSION MODEL OF COMMUTERS' DAILY CO_2 EMISSIONS

	Without Commute Distance			With Commute Distance		
	1995	2000	2005	1995	2000	2005
Constant	**3396.3**	**3588.7**			**410.8**	
Male	**1495.0**	**1577.8**	**1905.6**	**454.4**	**220.9**	**333.7**
Aged 25 – 40	-2492.2*	**-2130.6**		**-2556.9**	**-898.3**	
Aged 40 – 65	-2381.2*	**-2084.0**		**-2590.3**	**-975.5**	
Aged more than 65	-2705.5*	**-2628.7**		**-2455.0**	**-910.2**	
High education	**1603.5**	**1713.1**	**1453.2**		**478.2**	-559.8*
Medium education	**553.3**	399.1*			**424.1**	
High income	**2325.0**	**2792.1**	**3458.3**	**763.1**	**603.8**	
Medium income		**781.3**				
Car availability	**3495.5**	**3931.5**	**4985.8**	**2438.5**	**2835.6**	**3549.9**
Number of household member	**-190.5**	**-206.5**		**-109.4**	**-152.9**	
Very highly urbanised resident	**-1340.9**	**-1430.6**	**-2223.3**	-266.6	**-428.5**	**-966.4**
Highly urbanised resident	**-486.2**	**-1099.9**	**-1000.4**		**-442.3**	**-679.3**
Moderately urbanised resident		**-976.8**			**-347.9**	
Low urbanised resident		**-633.5**		**234.7**	-179.1*	
Located in the Randstad Metropolitan Area (RMA)	**217.5**			**136.1**	**82.0**	**174.5**
Reside in one of the RMA main cities					-346.8*	
Home municipality Population [$x10^3$]		**-7.76**				
Number of job availability in home municipality						
Retail density in home municipality		**0.13**				
Population accessibility by car [$x10^{-6}$]			-1.57*			
Population accessibility by rail [$x10^{-6}$]		**10.55**				
Job accessibility by car [$x10^{-6}$]						
Job accessibility by rail [$x10^{-6}$]		**-23.59**				
Railway network density	**6.97**	**-2.55**	**-14.98**			
Highway network density		**1.90**	**1.66**			
Distance from closest train station (km)						
Distance from closest metro/bus station (km)			-0.06*		0.02*	
Distance from closest motorway entrance (km)		**-0.07**			**-0.02**	
Commute distance (km)	-	-	-	**200.71**	**224.44**	**231.15**
N	22026	25010	11037	22026	25010	11037
Mean of dependent variable: CO_2 emissions (grammes)	5932.1	6698.6	7680.0	5932.1	6698.6	7680.0
SD of dependent variable	7872.2	8124.1	10154.9	7872.2	8124.1	10154.9
R^2	0.060	0.071	0.055	0.516	0.668	0.547
Adjusted R^2	0.058	0.070	0.052	0.515	0.668	0.545

Note:
Only coefficients of the significant variables are shown in the tables.
Figures in bold are significant at α = 5%
Figures marked with * are significant at α = 10%

2. REGRESSION MODEL OF COMMUTERS' ENERGY CONSUMPTION

	Without Commute Distance			With Commute Distance		
	1995	2000	2005	1995	2000	2005
Constant	**45.70**	**50.02**			**6.29**	
Male	**21.63**	**21.98**	**28.76**	**6.66**	**3.31**	**6.74**
Aged 25 – 40		**-29.05**		-30.86*	**-12.09**	
Aged 40 – 65		**-29.24**		-30.88*	**-13.99**	
Aged more than 65		**-37.11**		-29.11*	**-13.46**	
High education	**22.52**	**23.67**	**25.42**		**6.68**	
Medium education	**7.99**	5.42*			**5.76**	
High income	**31.99**	**38.79**	**48.02**	**9.52**	**8.68**	
Medium income		**11.34**				
Car availability	**50.17**	**56.89**	**73.47**	**34.97**	**41.82**	**53.36**
Number of household member	**-2.99**	**-3.08**		**-1.82**	**-2.34**	
Very highly urbanised resident	**-18.83**	**-20.82**	**-31.92**	-3.37	**-7.03**	**-14.31**
Highly urbanised resident	**-6.47**	**-15.39**	**-14.35**		**-6.35**	**-9.85**
Moderately urbanised resident		**-13.53**	-7.37*		**-4.87**	
Low urbanised resident		**-8.83**		**4.50**	-2.58*	
Located in the Randstad Metropolitan Area (RMA)	**3.03**			**1.86**	**1.35**	**2.51**
Reside in one of the RMA main cities						
Home municipality Population [x10^3]		-0.11*				
Number of job availability in home municipality						-0.01*
Retail density in home municipality		0.002*				
Population accessibility by car [x10^{-6}]						
Population accessibility by rail [x10^{-6}]		0.15*				
Job accessibility by car [x10^{-6}]			0.04*			
Job accessibility by rail [x10^{-6}]		**-0.35**				
Railway network density	0.09*	**-0.04**	**-0.21**			
Highway network density		**0.03**	**0.02**			
Distance from closest train station (km)						
Distance from closest metro/bus station (km)			-0.0008*		**0.0003**	
Distance from closest motorway entrance (km)		**-0.0009**			**-0.0003**	
Commute distance (km)	-	-	-	**2.89**	**3.09**	3.24
N	22026	25010	11037	22026	25010	11037
Mean of dependent variable: energy consumption (MJ)	86.8	95.2	111.7	86.8	95.2	111.7
SD of dependent variable	119.0	112.7	138.5	119.0	112.7	138.5
R^2	0.053	0.077	0.064	0.466	0.665	0.583
Adjusted R^2	0.052	0.076	0.061	0.466	0.664	0.581

Note:
Only coefficients of the significant variables are shown in the tables.
Figures in bold are significant at α = 5%
Figures marked with * are significant at α = 10%