Travel Energy Consumption and the Built Environment: Evidence from Flanders

Consommation d'énergie lors des trajets et environnement du bâti : chiffres probants de la Flandre

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This paper examines the relationship between energy consumption, daily travel distance and spatial characteristics in Flanders (and partly also in Brussels), in the north of Belgium. Important regional variations in commute-energy consumption are noticed, which are related to the spatial-economic structure including aspects of population density and spatial proximity. It is found that mode choice appears to be of little impact for the energy performance of home-to-work travel at the scale of the Flanders region, while proximity between home and work locations is paramount. At the other hand, when assessing overall daily travel patterns including non-work travel, variables based on the spatial distribution of jobs do not show significant effects on the travel distance. This finding qualifies the limited importance of the commute : today, it are mainly non-professional travel is growing. It can be concluded that residential density and land use mix in urban areas is the best guarantee for curbing excessive mobility.

Cet article examine le rapport qui existe entre la consommation d'énergie, les distances à parcourir chaque jour et les caractéristiques spatiales en Flandre (et en partie également à Bruxelles), dans le nord de la Belgique. On y relève d'importantes variations au niveau des trajets journaliers-consommation d'énergie, liées à la structure économico-spatiale, en ce inclus certains aspects liés à la densité de population et à la proximité spatiale. Il apparaît que le choix du mode semble avoir peu d'impact sur la performance énergétique du trajet domicile-bureau à l'échelle de la région flamande, tandis que la proximité entre le domicile et le lieu de travail se révèle être d'une importance capitale. D'autre part, lorsqu'on évalue les modèles de déplacement professionnel, quotidien et global, en ce inclus le déplacement non professionnel, les variables basées sur la répartition spatiale des emplois n'indiquent pas d'effets significatifs sur les distances à parcourir. Ces résultats nuancent l'importance restreinte du trajet journalier : de nos jours, c'est principalement le trajet non professionnel qui est en hausse. On peut conclure que le mélange de densité résidentielle et d'utilisation de la terre dans les zones urbaines constitue la meilleure garantie pour restreindre la mobilité excessive.

Mots-clé : Développement spatial durable, comportement de voyage, performance énergétique, Flandre

Keywords : Sustainable spatial development, travel behaviour, energy performance, Flanders

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Following Newman and Kenworthy (1989), many researchers have put forward the energy efficiency of urban transport as a sustainability indicator. Although Newman and Kenworthy (1989) were repeatedly criticized because of methodological reasons, the rationale for the use of energy performance as an indicator for measuring the sustainability of transport in relation to spatial structure kept upright.

First, this paper investigates the link between spatial structure and energy consumption for home-to-work travel in Flanders (Belgium), from the point of view of the residence (as the origin of commuter trips). To this end the concept of a commute-energy performance (CEP) index will be developed and tested. The interest of this indicator is that it clarifies the ratio between the share of energy consumption that can be attributed to the mode choice, and the share that is on the account of the distance travelled. This indicator is not only considered as a proxy for the sustainability of the commute system in itself, but by extension for the sustainability of the spatial-economic structure as a whole with regards to the spatial distribution of the housing market and the labour market.

Second, we extend the assessment to all quasi-daily trips, based on the conclusions we draw from the composition of the CEP index. This will be done by means of regression analysis, establishing links between some spatial proximity characteristics and the daily distances travelled (which we use in this case as a proxy for CEP).

Kobe Boussauw — Photo F. Dor

The results are a basis for further research, which aims to determine the resilience of spatial structures in a climate of incipient fuel scarcity. A better understanding of this matter will uncover social and spatial evolutions, and lead to a policy that facilitates a more sustainable development.

Energy use and urban spatial structure

The main thesis of Newman and Kenworthy (1989, 1999) is the existence of an inverse relationship between urban density and energy consumption for transport. Their research was based on data from 32 world cities. In a critical reaction to Newman and Kenworthy's (1999) conclusions, based on a new analysis of the same data, Mindali et al. (2004) argue that the assumed general correlation between density and energy consumption for transport is in fact only valid for certain aspects of the urban structure, i.e. in the central business district. Banister (1992) and Banister and Banister (1995) applied a similar methodology as Newman and Kenworthy (1989) on British cities, using data from the National Travel Survey (1985-1986) and the 1981 census. For London, the city with the highest overall density, the analysis does not support Newman and Kenworthy's thesis: energy consumption per capita is slightly higher in the capital than the average in

the other surveyed cities (> 25,000 inhabitants). Dodson and Sipe (2008), on the other hand, introduced the concept of an "oil vulnerability index" as a quantification of the vulnerability of a spatial entity to rising oil prices, and also take social factors (such as income) into account. They found that those parts of the outer urban fringe where no public rail transport is available, are the most vulnerable.

Commute-energy performance (CEP) index for Flanders and Brussels

In order to exemplify the relationship between the spatial configuration of an urban region and energy use we develop a commute-energy performance (CEP) index. This index is obtained by dividing the total amount of energy consumption for home-to-work travel per census ward (i.e. the smallest geographical research unit) by the working population (active workforce) that lives in the census ward.

In order to take into account the differences in energy efficiency between the different transport modes used, the home-to-work trips are split up into motorized (fuel consuming) trips (car, public transport) and non-motorized trips (on foot, bicycle). For public transport there are significant differences in energy efficiency between bus, tram, metro, and train. Hence, we calculate the mean energy consumption per passenger in relation to the type of public transport used. To keep the relationship between the mode and the distance travelled, for each mode a correction factor is derived from the average trip length that is travelled by each transport mode. For example, train commuters usually cover larger distances than car commuters, or cyclists. Finally the resulting number of person kilometres per mode is multiplied with a standardized value for the energy consumption per mode.

The data used to calculate the CEP index for Flanders and Brussels are drawn from various sources. The so-called General Socio-Economic Survey 2001 (SEE 2001, see: Verhetsel et al., 2007) is a comprehensive survey of the Belgian population (excluding children younger than six years old), which has its origin in the ten-yearly census. The questionnaire of SEE 2001 assesses the distance between home and work and the transport mode used. Data on the average trip length per mode is based on the Travel Behaviour Research survey in Flanders (OVG1, 2001) (Zwerts and Nuyts, 2004). The standardized values for the energy consumption per mode are taken from De Vlieger et al. (2006), and are based on the French research by Enerdata (2004). All energy values are converted to kilowatt hour per person kilometre (kWh/pkm). In each case the final energy consumption by the vehicle is considered. For the category "car as passenger» the same value is applied as for the category "car driver", since the default value is set per person and already takes into account the average occupancy rate of the vehicle. More specific variations in energy consumption, such as the distinction between diesel and gasoline cars, or regional differences in the composition of the fleet of personal cars or the ridership of buses and trains, are not taken into account. Further details on the calculation are provided in Boussauw and Witlox (2009).

Results

Spatial distribution of the CEP index

We calculate the CEP index for home-to-work travel, based on the departure zones. Because of the limitations of the available data, the resulting map (Fig. 1) should only be interpreted as an approximation, which aims to uncover the gradients with regard to energy consumption for home-to-work travel in Flanders and Brussels.

According to the mapped CEP index, energy consumption for home-to-work travel seems to be particularly high in those regions which in spatial planning terminology are defined as the countryside (A1-8) (codes are tagged on the map). These regions have in common that they possess a relatively rural character, compared to the labour markets where they are focused on. The regions A1 and A3, for example, are influenced by the labour markets in the metropolitan and urban areas of Brussels, Ghent and Leuven, even if those are relatively distant (Van Nuffel, 2007). In addition, commuters in these rural regions have on average higher incomes which allow them to live outside the city centres in relatively quiet and green environments, being less sensitive to the financial impact of the large daily commuting distances.

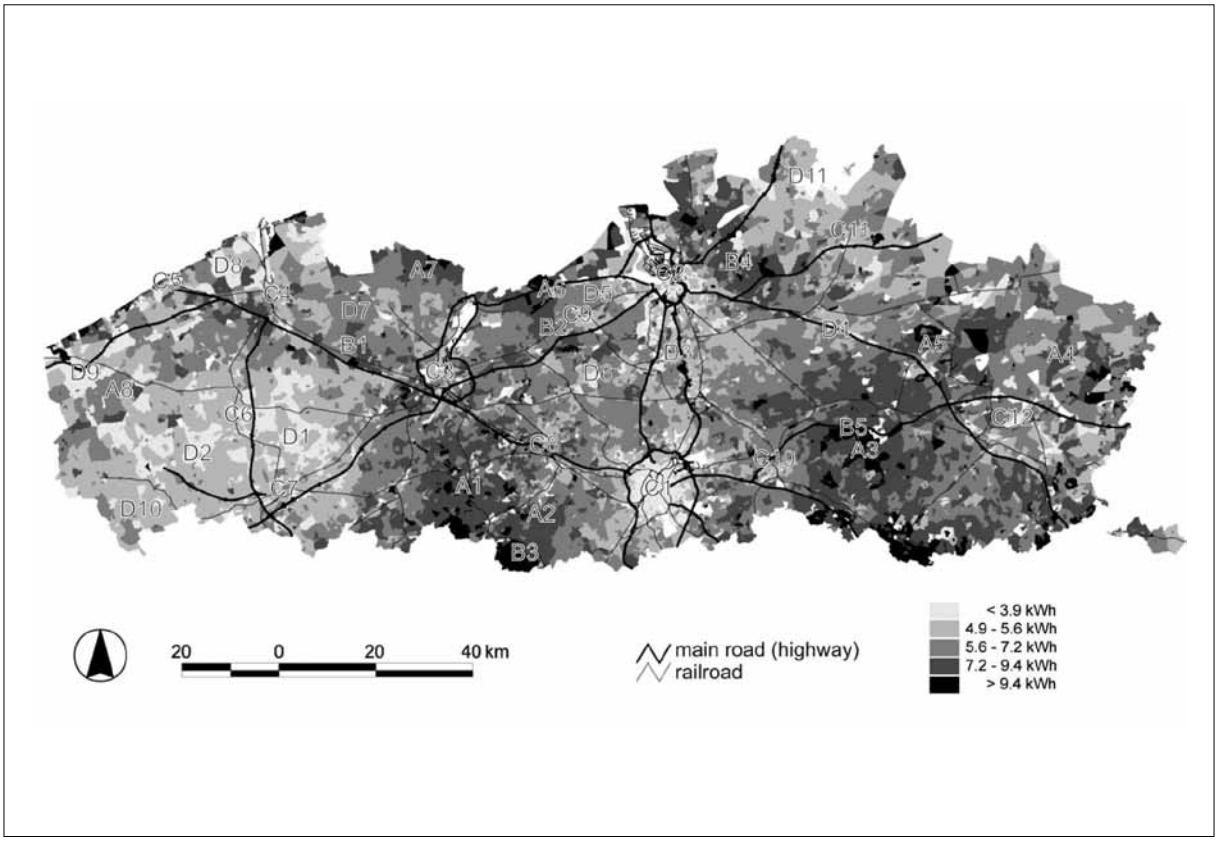

Fig 1. *Daily energy consumption per capita for home-work travel (kWh).*

Apart from that, some corridors along the motorways are strongly reflected in the map. The locations B1-4 catch the eye. It is clear that in these cases the increased accessibility by the presence of a motorway has contributed to enlarge commuting distances and the increased importance of the car as a transport mode. The area, in which the energy consumption is pre-eminently low, is the Brussels capital region (C1). The Flemish urban area around Brussels has a more or less comparable pattern, but still scores worse than the Brussels' municipalities. This result concurs with what might be expected, as the Brussels region represents the largest job market of the country, and also has the highest population densities. It is therefore consistent with the idea that the match in the labour market supply and demand is achieved within short distances. Moreover, the metropolitan spatial structure is responsible for the relatively large influence of other parameters on the energy consumption, such as modal split and vehicle ownership. This will be discussed below.

Similar patterns occur in the two other metropolitan areas of Antwerp (C2) and Ghent (C3), in which the effect of the metropolitan structure of Antwerp clearly outreaches the case of Ghent. In all regional urban areas, we also find lower energy consumption than the average. But also outside the metropolitan and regional urban areas, there are a number of regions that come out on the right side by their significantly lower energy consumption. The most contiguous region we find at D1-2. This region is characterized by a strong sprawl of less specialized labour, and a strong spatial interweaving of the labour market with the residential structure. The importance of location-bound industries, in particular in the agricultural sector, probably plays a part in this. So, the distance between home and workplace remains relatively confined.

Furthermore, also the corridor Brussels-Mechelen-Antwerp (D3), an important transport artery, scores remarkably well on the map, as well as a part of the economic network of the Albert canal (D4). These economically strong areas have high concentrations of employment in a - at the scale of Flanders - relatively good mix with the residential structure. We see the same phenomenon, albeit on a smaller scale, arising in D5-D7.

The rural areas D8-D11 show rather low figures. Apparently, the relatively poor accessibility of these regions has caused only a few long distance commuters to settle here. In addition, the low population and building density in these regions makes that a rather large share of the population is still working in the local agribusiness.

Spatial patterns and relation to home-to-work distance
To discern the relationship between CEP and average commuting distance, the Pearson's correlation coefficient was calculated (with census ward as a spatial unit). The obtained value is 0.95, meaning that the energy consumption for home-to-work travel is first and foremost determined by the distance between home and workplace. Contrary to what is generally assumed, it appears that the used transport mode plays only a very limited role. This can partly be explained by the fact that the average distance covered by train commuters (on average 48 km in 2000) is much larger than the average journey that is made by car (on average 20 km). Secondly, the bicycle is only an alternative for short trips, which makes this mode only marginally represented in the total number of kilometres. Based on the last finding, in the next section we will limit the assessment to the distance travelled, not going into details on the mode used.

Beyond commuting: general relationships between travel distance and spatial-morphological characteristics

In the next sections, we will extend the assessment to all forms of quasi-daily travel behaviour, linking travelled distance to some spatial proximity characteristics. However, note that also here we only consider the spatial characteristics of the home end of the trip, i.e. the residential area of the respondent. Spatial characteristics of other trip ends, e.g. work place, shopping location, school environment etc. are not taken into account, mainly because of lack of reliable data.

We use regression analysis, with daily kilometrage per person as the dependent variable. Explanatory variables consist of a number of measures of spatial proximity that are observed at various aggregation levels around the individual residential locations. In addition, a number of socio-economic variables are used as control variables. The applied data sets are described below.

After building the model, the obtained equation is used to estimate the mobility generating character of each neighbourhood (i.e. census ward) in Flanders. For each ward the relevant spatial variables are recalculated, from which the expected daily number of generated kilometres per person is regressed. These values are then displayed in the form of a map. When interpreting the map, it is important to realize that the extent to which spatial structure explains the mobility of a resident of any area is indicated by the coefficient of determination (R^2) of the regression equation.

Dependent variable (PKM)

The daily kilometrage per person is used as the dependent variable. The data source is the Travel Behaviour Survey for Flanders (OVG3) (Janssens et al., 2009). OVG3 is a mobility survey conducted during 2007-2008 of 8,800 respondents over the age of 6 years and living in the Flanders region (excluding the Brussels Capital Region). The selection is based on a sample from the national register. The home address of the respondents is recorded. Respondents are asked to keep track of all their trips during a predetermined random day by means of a travel diary. Of the 8,800 respondents, 7,273 have actually moved on that day, and have reported the perceived distance covered by their trips. In our analysis we use the sum of the lengths of all trips reported by the respondent. Because of the nature of the data possible biases inherent in the use of travel diaries should be taken into account (Witlox, 2007).

Explanatory variables

A total of six explanatory variables have been selected (in addition to the control variables, that are discussed subsequently), each of which can be considered as a measure for the mutual spatial proximity with regard to potential destinations. The variables are: (i) accessibility, (ii) residential density, (iii) land use diversity, (iv) job density, (v) minimum commuting distance, and (vi) proximity of facilities. The construction of these variables is explained in the following paragraphs.

Per respondent a circular zones has been drawn of which the midpoint is the reported residential location, with a radius equalling 1 km. Within these circles, data is then averaged on the basis of the proportional overlap with the original zones associated with the used data sets (these are census wards, traffic analysis zones (TAZ's) and a one kilometre square grid respectively).

Accessibility (ACC)

For each census ward, the total distance that should be covered to visit each resident of any other census ward in the study area once and return back home, is summed. This accessibility index thus gives a measure of the interaction opportunities with all other inhabitants of Flanders and Brussels, based on physical distance.

Residential Density (POPD)

The residential density is based on government population data for 2007, aggregated by census ward in Flanders.

Land use diversity (DIV)

To approximate the degree of land use mix, the Strucnet file of the National Geographic Institute (NGI, 2009) was used, containing all buildings that are represented by the official topographic maps with scale 1:10 000. The buildings are divided into categories.

To calculate spatial-functional diversity, we employ the Shannon index. This index is used in landscape ecology as a measure of morphological diversity (Nagendra, 2002). The calculation was done for a square grid based on an area of 1 km², after which results were proportionally aggregated within the three described circular zones.

Job density (JOBD)

Job density is based on commuting data as provided by the Multimodal Model for Flanders (MMM, version 2007). MMM is a simulation of all personal trips in the Flanders region formatted as an origin-destination (OD) matrix and is based on a combination of various sources of socio-economic data. MMM aggregates arrivals of all commuting trips between 4 am and 11 am in the morning traffic within TAZ's, which are comparable to, but typically slightly larger than, census wards.

Minimum commuting distance (MCD)

This variable was constructed based on the OD-matrices for commuting between 4 am and 11 am, as they were simulated in the MMM. The principle of the method implies that any departure (in this case in the morning traffic) is linked to the nearest possible arrival (also in morning traffic). Per TAZ, the number of departures as well as the number of arrivals are retained, but the in reality existing tie between origins and destinations is cut in order to minimize the total distance travelled within the system. This theoretical exercise provides a good measure of the spatial proximity between the housing market and the labour market. The data are results provided by Boussauw et al. (2010), where details on the calculation can be found.
Proximity to facilities (SPROX)

This variable was constructed based on the spatial distribution of non-work related destinations that are often visited by an average Flemish household, such as schools, shops, cafes, sports clubs, banks, medical services, ... Per census ward the minimum distance was calculated that needs to be covered by an average Flemish family to get its weekly programme done when always opting for the closest facility within each destination class. This weekly programme for an average family was determined based on data from the second phase of the Travel Behaviour Survey for Flanders (OVG2) (Zwerts and Nuyts, 2004). The data are results provided by Boussauw and Witlox (2010), to which we refer for further calculation details.

Control variables

The OVG3 (Janssens et al., 2009) contains a number of socio-economic data that may explain part of the variance in the reported distance. These variables are : education level (EDU), income level (INC), age (AGE) and gender (GND). We include these in the model as control variables. This means that our research does not focus on the explanatory power of these socio-economic variables, although it is supposed that they make the regression equation more fitting. The selected control variables all exhibit a statistically significant relationship with the reported travel distance and make an important contribution to the model fit.

Education and income levels are included as continuous variables. Because of the assumed non-linear influence of the respondent's age, the age variable is recoded into four dummy variables. Following categories are considered: 0-19 years, 20-39 years, 40-59 years and 60-79 years, while 80 years or older is used as the reference category. Gender is obviously a dummy variable; male is considered as the reference group.

Analysis

For the variables accessibility (ACC), job density (JOBD) and minimum commuting distance (MCD), no significant effects were yielded. In contrast to our expectations from the first sections of this paper, two of these variables are related to the spatial distribution of jobs (JOBD and MCD). Although this outcome is unexpected, it can be explained by the small proportion of today's commuter traffic in the total number of trips (20.6%) and total distance travelled (34.5%) (Janssens et al., 2009). Finally, these variables were excluded from the equation. The purified regression equation is as follows :

$$\log_e(PKM) = \alpha + \beta_1 \cdot POPD + \beta_2 \cdot DIV + \beta_3 \cdot SPROX + \gamma_1 \cdot AGE_{0\text{-}19} + \gamma_2 \cdot AGE_{20\text{-}39} + \gamma_3 \cdot AGE_{49\text{-}59} + \gamma_4 \cdot AGE_{60\text{-}79} + \gamma_5 \cdot GND + \gamma_6 \cdot EDU + \gamma_7 \cdot INC + \varepsilon \quad (1)$$

The results of the regression analysis are given in Table 1.

$R^2 = 0.143$	coefficient	p-value
(constant)	1.502	0.000
POPD	-3.99 . 10-5	0.000
DIV	-0.278	0.001
SPROX	0.004	0.000
AGE0-19	0.847	0.000
AGE20-39	1.066	0.000
AGE40-59	0.969	0.000
AGE60-79	0.624	0.000
GND	-0.245	0.000
EDU	0.173	0.000
INC	0.111	0.000

Table 1. *Coefficients of the regression analysis*

The results are consistent with the literature: significances are satisfactory (all results are within the 0.01 confidence level) at a low coefficient of determination (R^2 = 14.3%). The relationships found meet the expectations. A higher population density and a higher degree of spatial diversity are associated with shorter travel distances. Also, a larger minimum distance to reach daily facilities is associated with shorter real travel distances. The age group between 20 and 59 years exhibits the most intensive travel pattern, while women are less mobile than men. Both a higher level of education and a higher income are associated with increased mobility.

The relatively small share of the observed variance that is explained by the model, is common for mobility research. Although this phenomenon is in part due to data deficiencies (including underreporting and randomization of reporting days), the truth lies perhaps in the importance of the many random factors that form the underlying reason for a significant share of individual trips, but are difficult or even impossible to model. An example of this is the so-called random taste variation that is accounted for in many discrete choice modelling techniques (Train, 2003, p. 46). In Flanders, we find similar difficulties in travel behaviour modelling attempts in Witlox and Tindemans (2004).

Forecasting model for Flanders

In order to develop a forecasting, area covering, model based on the results of the regression analysis, we isolate the spatial variables. To this end, the control variables are made constant by equalling these to the mean value of the considered variable in the dataset. Formally :

$$a_{ctrl} = 1.502 + 0.847 \cdot \overline{AGE_{0\text{-}19}} + 1.066 \cdot \overline{AGE_{20\text{-}39}} + 0.969 \cdot \overline{AGE_{40\text{-}59}} + 0.624 \cdot \overline{AGE_{60\text{-}79}} - 0.245 \cdot \overline{GND} + 0.173 \cdot \overline{EDU} + 0.111 \cdot \overline{INC} = 3.133 \quad (2)$$

Based on the regression coefficients for the spatial variables the expected amount of generated kilometres per inhabitant PKMw for each census ward in Flanders w is determined as follows :

$$-0.245 \cdot \overline{GND} + 0.173 \cdot \overline{EDU} + 0.111 \cdot \overline{INC} = 3.133 \quad (3)$$

The mapped result is shown in Fig. 2. The expected amount of generated kilometres per inhabitant based on characteristics of spatial proximity and averaged by census ward is approximately normally distributed and is characterized by the values that are shown in Table 2.

N = 9205			km
	km	5% percentile	15.3
Mean	23.0	25% percentile	20.2
Median	23.0	75% percentile	25.8
standard deviation	5.1	95% percentile	30.1

Table 2. *Features of the distribution of daily generated mobility per capita as expected by the model, based on census wards in Flanders*

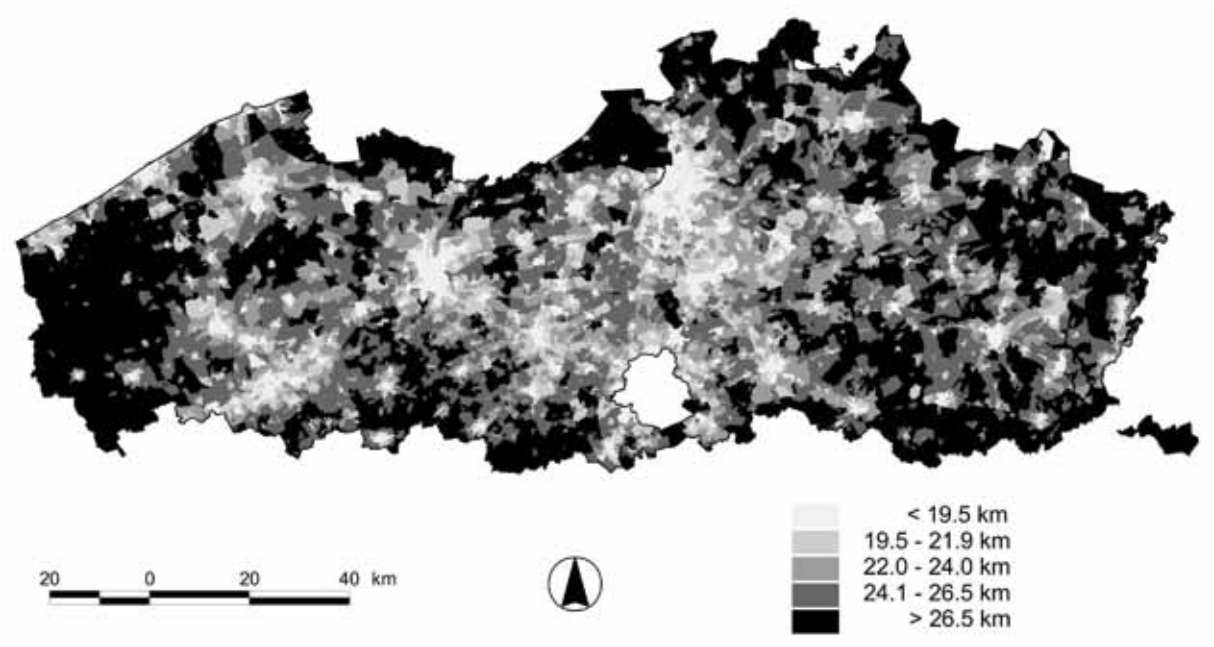

Fig 2. *Spatial distribution of the estimated generated mobility per capita based on characteristics of spatial proximity*

The 95-percentile value is almost twice as large as the 5-percentile value. This means that, based on characteristics of spatial proximity, the 5% best-located census wards are estimated to generate only half of the mobility of the 5% worst-located wards.

As expected and as shown in Fig. 2, urban areas yield the lowest values, particularly in the historical city centres and a number of nineteenth-century neighbourhoods in Ghent and Antwerp. In regional urban areas mainly Leuven, Mechelen, Aalst, Brugge and Oostende score well. Also the edge of the Brussels conurbation scores quite well, although the agglomeration effect decays rapidly while moving away from the centre of the capital. When we examine regions instead of cities, we see that typically rural areas as well as green and wooded areas with scattered development score badly. Conversely, the immediate vicinity of large agglomerations score well, just as the highly suburbanized areas Kortrijk-Leie (in the south-west) and the so-called Flemish Diamond (the area cornered by Ghent, Antwerp, Leuven and Brussels).

Since the OVG3 dataset includes no data on Brussels residents, we cannot a priori state that the modelling results are also valid for Brussels. However, it is possible to extrapolate results, since we do have spatial data for census wards that are located in the Brussels region. Elaborating on this is beyond the scope of this paper, but it should be stressed that the level of spatial proximity is much higher in Brussels compared to Flanders, while travel distances are indeed much lower (Montulet et al., 2007).

Conclusions

We have argued that the energy performance of the transport system is an important approximate indicator for the sustainability of a spatial structure. This is certainly true when advocating a so-called low carbon economy is put increasingly higher on the political agenda. Obviously the link with the spatial or urban (re)development of cities should be made as well. Having a better understanding of the mechanisms that cause the major observed regional variations in energy consumption will lead to better land-use planning in practice.

The issue of proximity in planning remains very important. In home-to-work travel, the distance between home and workplace is to a very large extent determinant for the energy performance of the commuting system. Contrary to the conventional belief, the mode used is of less importance. In this respect we notice a discrepancy with the current mobility policy of the Flemish government, which is very much focused on the reduction of the share of car drivers, but much less on a reduction of the number of kilometres, despite an increase by 10% of the average commuting distance between 1991 and 2001 (Verhetsel et al., 2007).

However, when we extend the analysis to all quasi-daily travel, which consists mainly of non-work travel, the spatial distribution of jobs in relation to housing looses iterest. In contrast, residential (population) density, proximity of facilities and spatial diversity (functional mix) seem to be determinant when it comes to the relationship between sustainability of daily travel patterns and spatial (land use) characteristics (Boussauw et al., 2011).

Not unexpectedly, the most urbanized areas turn out to be the most resilient and sustainable locations. This means that a further increase of residential density and land use mix in urban areas is the best guarantee for curbing excessive mobility and preparing for the end of cheap oil. However, this conclusion requires some qualification: there are limits to increasing density and land use mix targeted to sustainable mobility patterns, primarily by environmental standards and social desirability (Gordon and Richardson, 1997).

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Références

Banister D. (1992) *Energy use, transport and settlement patterns*. Sustainable Development and Urban Form ed M.J. Breheny, pp. 160-181. Pion Ltd., London.
Banister D. and Banister C. (1995) *Energy consumption in transport in Great Britain : Macro level estimates*. Transportation Research Part A, 29, 21-32.
Boussauw K., Neutens T. and Witlox F. (2010) *Minimum commuting distance as a spatial characteristic in a non-monocentric urban system : the case of Flanders*. Papers in Regional Science, 89.
Boussauw K., Neutens T. and Witlox F. (2011) *The relationship between spatial proximity and travel-to-work distance : The effect of the compact city*. Regional Studies (forthcoming).
Boussauw K. and Witlox F. (2009) *Introducing a commute-energy performance index for Flanders*. Transportation Research Part A, 43, 580-591.
Boussauw K. and Witlox F. (2010) *Excess travel in non-commuting trips : a regional case study*. Lisbon : Proceedings of the World Conference on Transport Research.
De Vlieger I., Cornelis E., Panis L., Schrooten L., Govaerts L., Pelkmans L., Logghe S., Vanhove F., De Ceuster G., Macharis C., Pekin E., Van Mierlo J., Timmermans J.-M., Matheys J., Van Bladel K., De Jong M., De Geest C., and Van Walsum E. (2006) MIRA (2006) *Milieurapport Vlaanderen, Achtergronddocument 2006, Transport*. Vlaamse Milieumaatschappij, Aalst.
Dodson J. and Sipe N. (2008) *Shocking the suburbs : urban location, homeownership and oil vulnerability in the Australian city*. Housing Studies, 23, 377-401.
Enerdata S.A. (2004) *Efficacité Energétique des Modes de Transport : Rapport Final*. Grenoble-Gières.
Gordon P. and Richardson H. W. (1997) *Are compact cities a desirable planning goal ? Journal of the American Planning Association*, 63, 95-106.
Janssens D., Moons E., Nuyts E. and Wets G. (2009) *Onderzoek Verplaatsingsgedrag Vlaanderen 3 (2007-2008).* Brussel-Diepenbeek : Universiteit Hasselt.
Mindali O., Raveh A. and Salomon I. (2004) *Urban density and energy consumption : a new look at old statistics.* Transportation Research Part A, 38, 143–162.
Montulet B., Hubert M. and Huynen Ph. (2007) *Être Mobile. Vécus du Temps et Usages des Modes de Transport à Bruxelles.* Brussels : Facultés universitaires Saint-Louis.
Nagendra H. (2002) *Opposite trends in response for the Shannon and Simpson indices of landscape diversity*. Applied Geography, 22, 175–186.
Newman P. and Kenworthy J. (1989) *Cities and Automobile Dependence*. A Sourcebook. Gower, Aldershot.
Newman P. and Kenworthy J. (1999) *Sustainability and cities : overcoming automobile dependence*. Island Press, Washington DC.
NGI (2009) *Structuur en codering van de gegevens top10v-gis en top50V-gis*. National Geographical Institute of Belgium from http://www.ngi.be/Common/articles/CA_Top10V-GIS_TOP50V-GIS/restruct_doc_nl.htm.
Train K. (2003) *Discrete Choice Methods with Simulation*. Cambridge, UK: University Press.
Van Nuffel N. (2007) *Determination of the number of significant flows in origin–destination specific analysis : The*

case of commuting in Flanders. Regional Studies, 41, 509-524.
Verhetsel A., Thomas I., Van Hecke E. and Beelen M. (2007) *Pendel in België. Deel I : de Woon-Werkverplaatsingen*. Federale Overheidsdienst Economie, KMO, Middenstand en Energie, Brussels.
Witlox F. and Tindemans H. (2004) *Evaluating bicycle-car transport mode competitiveness in an urban environment*. An activity-based approach. Journal of World Transport Policy & Practice, 10, 32-42.
Witlox F. (2007) *Evaluating the reliability of reported distance data in urban travel behaviour analysis*. Journal of Transport Geography, 15, 172-183.
Zwerts E. and Nuyts E. (2004) *Onderzoek Verplaatsingsgedrag Vlaanderen 2000-2001*. Ministerie van de Vlaamse Gemeenschap, Brussels-Diepenbeek.