# *Home-to-work commuting, spatial structure and energy consumption: A comparative analysis of Wallonia and Flanders, Belgium*

**Sébastien Dujardin**[1]
*Kobe Boussauw*[2]
*Florence Brévers*[1]
*Jean-Marc Lambotte*[1]
*Jacques Teller*[1]
*Frank Witlox*[2]

***Abstract***: *Considering the need to address the sustainability of transport in Belgium, this paper discusses the effects of the urban spatial structure on home-to-work travel energy consumption through a comparative analysis of Wallonia and Flanders (Belgium).*
*A commute-energy performance (CEP) index was calculated at the former municipality scale, evaluating variations of energy use between the two regions for the reference year 2001. Moreover, the evolution of the CEP index between 1991 and 2001 is also assessed.*
*Results highlight an important dichotomy between the two regions: overall, the 2001 CEP index appears to be much better in Flanders than in Wallonia. A comparison of land use, spatial structure and socioeconomic factors allows explaining cross-regional and temporal variations. Finally, population change between 2001 and 2010 stresses current challenges underlying the evolution of the commute-energy performance between 1991 and 2001.*

***Keywords***: spatial planning, home-to-work commuting, energy consumption, comparative analysis, Wallonia, Flanders

## 1. Introduction

Since the 1970's energy crisis, governments all around the world, Belgium included, set reduction of oil dependence through improved energy efficiency as a high priority. Energy issues drew public attention once more in the 1990's as oil prices rose again, but also because of an emerging public and consumer's demand for increased liveability, sustainability and climate protection at all levels (Blanco et al., 2009). Today, reducing energy consumption remains on the top of a number of political agendas for two main reasons: (1) greenhouse gas (GHG) emissions from human activities are proved to cause global warming (IPCC, 2007; Davoudi et al., 2009), and (2) a major mismatch between oil production and demand is expected within the next decades, an evolution that is commonly known as "peak oil" (Wautelet, 2008; Aleklett et al., 2010). Climate change and peak oil issues are bound to have far-reaching consequences for the economy in general, but also for the transport sector and mobility in particular.
The observed tendency is however not in line with current energy saving targets: levels of mobility have increased substantially over the recent past in most developed countries due to a rapid decline in transport costs combined with an increase in travel speed (Ewing, 1994), while fuel efficiency per car improved only to a limited extent (De Vlieger et al., 2006). This led to decentralisation and an overall growth of fuel consumption and carbon emissions by motorised transport. Travel patterns mostly rely on fossil fuels and are increasingly dependent on the car (Banister, 2005), while the worldwide oil dependence rate of the global transport sector is about 95% (IEA, 2008).

[1] Lepur, Research Centre on Territorial, Urban and Rural Sciences, University of Liège, 1 Chemin des Chevreuils, 4000 Liège, Belgium
[2] Geography Department, Ghent University, Krijgslaan 281 (S8), 9000 Ghent, Belgium

In terms of emissions, transport accounts for about 14% of greenhouse gas emissions worldwide (World Resource Institute, 2009), and even more within industrialised countries. In Belgium for instance, the share of transport represents 20% of total greenhouse gas emissions (CNC, 2010). In this context, analysing and monitoring the evolution of travel behaviour is becoming crucial in order to anticipate and adapt towards possibly rapid changes and an uncertain future.

One of the main factors influencing general travel behaviour, and home-to-work commuting in particular, is the spatial structure of a territory. The spatial distribution of housing and jobs may thus play an important role in determining modal shares and travelled distances, and consequent geographical differences in overall commute energy consumption.

Drawing upon Boussauw and Witlox's (2009) commute-energy performance (CEP) index, this paper evaluates variations of energy use for the purpose of commuting in Belgium in relation to differences in spatial structure. After presenting some methodological considerations, including the nature of travel data and the calculation of regional energy consumption rates by travel mode, similarities and differences in travel patterns between Flanders and Wallonia are described for 2001. The evolution of the CEP index between 1991 and 2001 is also assessed. Land use, spatial structure and socioeconomic factors are taken into account in order to explain the observed cross-regional and temporal variations. Finally, population changes from 2001 to 2010 are provided to support the discussion on spatial variations in the future evolution of home-to-work commuting in Belgium and their potential impacts on energy consumption and GHG emissions.

## 2. <u>Home-to-work commuting, spatial structure and the associated energy consumption</u>

Although the share of commuting in overall travel is declining, home-to-work travel is still representing a considerable amount of travel that is growing steadily. Commuter trip lengths have increased systematically over the past decades. This trend was observed in Belgium (Boussauw, 2011, p. 33), the US and the UK, and we may assume that this evolution is manifest throughout the Western world (Aguilera, 2005).

For Belgium, Hubert and Toint (2002) report that 18% of all trips ended at the workplace or at school. In Flanders, the Travel Behaviour Survey - OVG 2001 (Zwerts and Nuyts, 2004) shows more detail by pointing out that the (home-to-work) commute represents 21% of all trips, that is 35% of all kilometres travelled in daily travel patterns. In Wallonia, the (home-to-work) commute represents 38% of the amount of kilometres travelled on a working day, which accounts for 22,6% of the number of the trips (IWEPS, 2008). Consequently, we may conclude that roughly one third of the adverse effects of daily person mobility in Belgium are caused by commuter traffic.

Newman and Kenworthy's (1989) seminal work on the relationship between urban form and sustainability of travel patterns showed a strong inverse relationship between population density and travel energy consumption per capita. However, Newman and Kenworthy (1989) have been heavily criticized, mainly because of methodological reasons related to the demarcation of the assessed cities. Although the concept of measuring the sustainability of travel through oil consumption rates is still valid, it is probably more interesting to study spatial variations of this variable throughout an urban region with varying spatial and economic characteristics, instead of limiting the observations within an arbitrarily demarcated city border.

An interesting theme in the literature is the relationship between processes of urban sprawl and the increase in commuting trip length (Ewing and Cervero, 2010). Although the concept of urban sprawl may be defined in many ways, changes in the distribution of the population seem to be an important part of it. However, this reasoning does not necessarily imply a one-way causality. Gilbert and Perl (2008, p. 235) formulate this phenomenon as follows: "Sprawl is believed to be facilitated by car ownership and use and also to contribute to it, in a positive feedback loop that reinforces both low-density development and motorization."

Although commuter trip lengths have been studied before (e.g. Cervero, 1996; Peng, 1997), traditionally much more attention is paid to commuter travel time (Vandenbulcke et al., 2009). From a merely economical point of view, travel time seems to be more important than trip length. However, since the link between fuel consumption and trip length is much more straightforward than the link with travel time, we state that the study of physical distance may gain interest again through climate targets and possibly rising energy prices.

In Belgium, population censuses from 1991 and 2001 provide trip length and transport mode data for most of the commuters, along with their residential address. This allows us mapping the home based commute energy performance in a geographically disaggregated way, and to assess links with variations in spatial characteristics, with regional economic performance, and with demographic shifts.

## 3. Methodology

### 3.1. Dataset

#### 3.1.1. National Socio-Economic Surveys – 1991 and 2001

Travel data used for the calculation of the CEP index in 2001 and its evolution between 1991 and 2001 were extracted from the 1991 and the 2001 National Socio-Economic Surveys (SES). The 2001 SES (see Verhetsel et al., 2007) is the last ever decennial comprehensive census survey of the Belgian population over six years old. The general response rate was about 95% with some variations depending on the sections of the questionnaire. The main advantage of such surveys is the provision of a large and almost comprehensive sample.

The main drawback is that the dataset only provides information about home-to-work and home-to-school journeys, but does not provide information on other travel purposes. Thus, not all travel purposes were included in the calculations. Since home-to-work commuting is becoming increasingly less meaningful in daily travel patterns in the Western world (Pisarski, 2006, p.2), one could argue that calculating transport energy performances based only on those trips is misleading. Nevertheless, these trips remain an interesting study object as the commute, being systematic and repetitive, has much more structural power than other forms of travel have. In addition, the commute presented by far the highest average trip length on a working day at the time of the SES 2001 (Hubert and Toint, 2002; IWEPS, 2008), making an average daily home-to-work trip much more energy consuming and polluting than e.g. an average shopping or school trip. Moreover, only people travelling daily to a 'fixed' working place, namely 'home-to-work commuters' were taken into account. Workers with a variable working place or working from home were not asked to complete the questions regarding mobility in the SES. Finally, only the main travel mode was kept for the purpose of the analysis, although many commuters use a combination of several modes of transportation.

#### 3.1.2. Population changes in Belgium between 2001 and 2010

Population data for 2001 and 2010 come from the FPS Economy, Directorate-general Statistics and Economic Information (DGSEI) population surveys.

### 3.2. The commute-energy performance (CEP) index

The evaluation of transport energy consumption is based on Boussauw and Witlox's (2009) commute-energy performance (CEP) index, which takes into account, for each spatial entity considered, average home-to-work distances (all modes and for each mode individually), modal shares and average energy consumption rates by travel mode.

For the three Belgian regions, Table 1 presents the regional average commuting trip length by mode used in the CEP calculations for 1991 and 2001, and Table 2 summarizes the average energy consumption figures by mode.

| Mode | 1991 | | | 2001 | | |
|---|---|---|---|---|---|---|
| | **Flanders[1]** | **Wallonia[2]** | **Brussels[3]** | **Flanders[1]** | **Wallonia[2]** | **Brussels[3]** |
| Car driver | 20,3 | 20,1 | 14,1 | 20,3 | 24,1 | 14,1 |
| Car passenger | 17,4 | 20,1 | 10,0 | 17,4 | 24,1 | 10,0 |
| Motorcycle | 10,8 | 13,2 | 4,4 | 10,8 | 12,1 | 4,4 |
| Metro[4] | 18,9 | 12,9 | 5,5 | 18,9 | 14.4 | 5,5 |
| Tram[4] | 18,9 | - | 3,9 | 18,9 | - | 3,9 |
| Bus[4] | 18,9 | 12,9 | 4,4 | 18,9 | 14,4 | 4,4 |
| Train | 48,5 | 47,7 | 51,4 | 48,5 | 50,7 | 51,4 |
| Bicycle | 4,1 | 5,6 | 3,8 | 4,1 | 4,7 | 3,8 |
| On foot | 2,1 | 1,8 | 0,8 | 2,1 | 1,8 | 0,8 |

[1] Based on OVG (2001) (Zwerts and Nuyts, 2004)
[2] FPS Economy, DGSEI, SES 2001
[3] Based on MOBEL 1998-1999 (Toint et al., 2001)
[4] Because of data limitations, metro, tram and bus have been assigned the same value in Flanders and Wallonia

**Table 1 : Average trip length by mode used for the CEP calculations (km)**

| Mode | Flanders[1] | Wallonia[2] | Brussels[3] |
|---|---|---|---|
| Car | 0,45 | 0,45 | 0,45 |
| Motorcycle | 0,41 | 0,41 | 0,41 |
| Metro, Tram, Bus | 0,26 | 0,35 | 0,12 |
| Train | 0,15 | 0,15 | 0,15 |
| Bicycle | 0,00 | 0,00 | 0,00 |
| On foot | 0,00 | 0,00 | 0,00 |

[1] Based on (Teller et al., 2010)
[2] Teller et al. (2010)
[3] Based on Teller et al. (Teller et al., 2010) and MOBEL 1998-1999 (Toint et al., 2001)

**Table 2 : Average energy consumption by mode in Belgium (kWh/pkm)**

Due to a lack of data on energy consumption rates per travel mode in Belgium, figures from table 2 were calculated in collaboration with the Walloon Air and Climate Agency (AWAC), for the Walloon region. They were obtained by dividing the total amount of energy consumed for a given travel mode, calculated on the basis of the annual mileage and the fuel type, by the occupation rate of such a mode (see Teller et al., 2010). The results are expressed in kWh by passenger kilometre. In order to harmonise the calculations for the three regions, the Walloon figures for the car, motorcycle and train were applied to the Flemish and Brussels region whereas the figures for the metro, bus and tram were adapted to the regional context of those two regions. A limit attached to those energy consumption rates is that they are regional average figures. Yet, occupation rates of public transports may vary significantly depending on the nature (urban or rural) of the area and on the time of the day or the week. Moreover, in the case of motorised travel modes, congestion is not taken into account, although more energy is consumed when driving in congested traffic.

### 3.3. Methodological differences in the CEP index calculation for Flanders and Wallonia

The major problem when calculating the CEP index for Flanders and Wallonia comes from differences between the two initial datasets. Although these are drawn upon the same survey, data were delivered at different levels of aggregation (one at the individual level, the other at the census block level) and details (distances by travel mode were not given for Flanders), which complicates the harmonisation of both methodologies. In order to address this issue, we adopted the less detailed level of data. For instance, regional average trip lengths by mode were used in order to approximate the individual commuter data (see Table 1).
The average commuting trip length by mode was derived from the Travel Behaviour Research project (OVG 2001) (Zwerts and Nuyts, 2004) for Flanders, and from the Belgian Mobility Survey (MOBEL 1998-1999) (Toint et al., 2001) for Brussels. These values were also used for the 1991 recalculation, but comparing with the more accurate data for Wallonia, the bias that may have occurred from this simplification can be considered as very minor. In Wallonia, average commuting trip length by mode was calculated from the initial dataset.
Contrarily to the trip length by modes, modal shares used for CEP index calculations were provided at a disaggregated level: values used were specific to each former municipality within every region.

## 4. <u>The CEP index in Belgium: comparative analysis of Wallonia and Flanders</u>

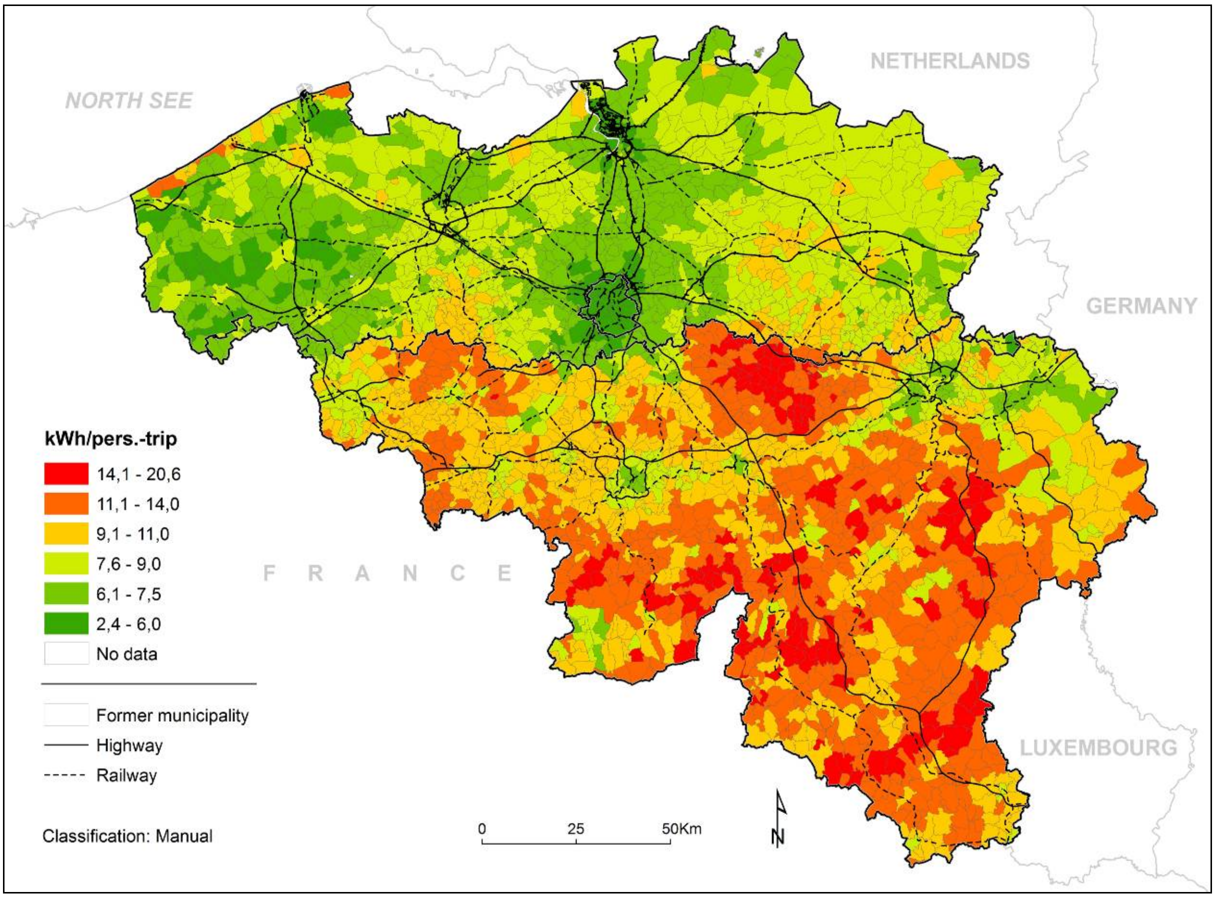
### 4.1. The 2001 CEP index

The CEP index is calculated for all of Belgium for the reference year 2001, as illustrated in Map 1. In an average former municipality, less energy is consumed for home-to-work commuting in Flanders (7,5 kWh/pers.-trip) compared to Wallonia (11,0 kWh/pers.-trip). Commuters living in Brussels are much more energy efficient (4,6 kWh/pers.-trip). A greater variability in travel behaviour is observed in the southern region of the country, as highlighted by the higher standard deviation value of Wallonia compared to Flanders (2,3 and 2,0 kWh/pers.-trip respectively). A comparison of the 5$^{th}$ percentile for Wallonia (7,6 kWh/pers.-trip) with the average CEP index for Flanders (7,7 kWh/pers.-trip) underlines that only 5% of Walloon former municipalities are below the Flemish average consumption rate. Note that the figures below are based on the aggregated values by former municipality, they are not statistics based on individual commuters.

| | 1991 | | | 2001 | | | 1991-2001 evolution | |
|---|---|---|---|---|---|---|---|---|
| **Mode** | **Flanders** | **Wallonia** | **Brussels** | **Flanders** | **Wallonia** | **Brussels** | **Flanders** | **Wallonia** |
| N | 1116 | 1471 | 27 | 1117 | 1471 | 27 | | |
| Missing data | 1 | 5 | 0 | 1 | 0 | 0 | | |
| Mean | 7,4 | 9,4 | 4,2 | 7,7 | 11,0 | 4,6 | 4% | 17 % |
| Median | 7,5 | 9,2 | 4,2 | 7,6 | 10,8 | 4,7 | | |
| Standard deviation | 1,6 | 2,1 | 0,6 | 1,2 | 2,3 | 0,5 | | |
| 5 % percentile | 4,8 | 6,1 | 3,1 | 5,7 | 7,6 | 3,7 | 18,8% | 24,6% |
| 25 % percentile | 6,3 | 7,8 | 3,8 | 6,8 | 9,4 | 4,3 | 13,9% | 20,5% |
| 75 % percentile | 8,5 | 10,7 | 4,6 | 8,4 | 12,2 | 4,9 | -1,2% | 14,0% |
| 95 % percentile | 10,1 | 13,5 | 5,3 | 9,9 | 15,3 | 5,4 | -1,9% | 13,3% |

**Table 3 : Statistical features of the CEP index distribution by region, based on former municipalities (kWh/pers.-trip).**

**Map 1 Energy efficiency of home-to-work commuting in Belgium in 2001 (former municipality)**



In Wallonia, former municipalities with good commute-energy performances (i.e. low CEP values) are found within densely populated areas. The two main urban agglomerations, Liège and Charleroi, and the main cities of Mouscron, Tournai, Mons, Namur, Verviers, and Eupen are amongst the most energy efficient areas of Wallonia. Many other entities located outside the old industrial basin also present low consumption rates. Most of these are small towns of the south-south-east periphery of Brussels (Ottignies, Braine-l'Alleud, Wavre), but some others are located in the southern, less densely populated part of Wallonia (Chimay, Marche-en-Famenne, Spa, Arlon). All of these areas concentrate employment and population, offering a good land use mix at the local scale as well as good public transportation systems. Those two characteristics induce shorter commuting distances and thus more energy efficient travel behaviour.

Former municipalities with high energy consumption rates are usually located far from employment centres, where the poor accessibility to public transports makes the car the most prominent travel mode, which induces long commuting distances by car and thus more GHG emissions. This can be observed on a regional scale within areas located at 30 km (and more) from the main cities of Wallonia and from the metropolitan areas of Brussels and Luxembourg. This is especially true between Liège, Namur and Brussels, as well as close to the Luxembourg border. Nonetheless, on a local scale, some former municipalities within these remote areas show better CEP values than the regional average (less than 11 kWh/pers.-trip): energy performances are locally better within a 10 to 15 km radius around small towns. This becomes particularly clear in former municipalities from the southern part of Wallonia, where the influence of main cities and metropolitan areas is weak, but where there is an influence of smaller employment centres (e.g. Marche-en-Famenne, Chimay). At both scales, the further commuters are located from centres where population and employment is concentrated, the higher the energy consumption rate becomes.

In Flanders, good scores are observed in Antwerp and the wide surroundings of the metropolitan areas of Brussels and Antwerp, including the corridor in between which contains the city of Mechelen, and extends towards the city of Leuven. Other areas that are scoring well are the region of Kortrijk-Roeselare-Leie, the surroundings of Ghent (especially the northern part which is close to the port industry), and some regional cities (Hasselt-Genk, Brugge). In the very western part of Flanders, the low CEP values are of minor importance because of the small amount of residents in this rural area.

Areas showing rather bad scores are the south of the province of Oost-Vlaanderen (where employment is scarce), the south (around the E40 motorway) and the west of the province of Limburg and the adjacent (eastern) part of the province of Vlaams-Brabant. The western part of the E40 also appears to have induced some long distance commuting due to urban sprawl. On the coast, some areas present high scores, although there may be some biases due to secondary residences that are declared by respondents as the official residence, since municipal taxes are low or non-existent in some coastal municipalities.

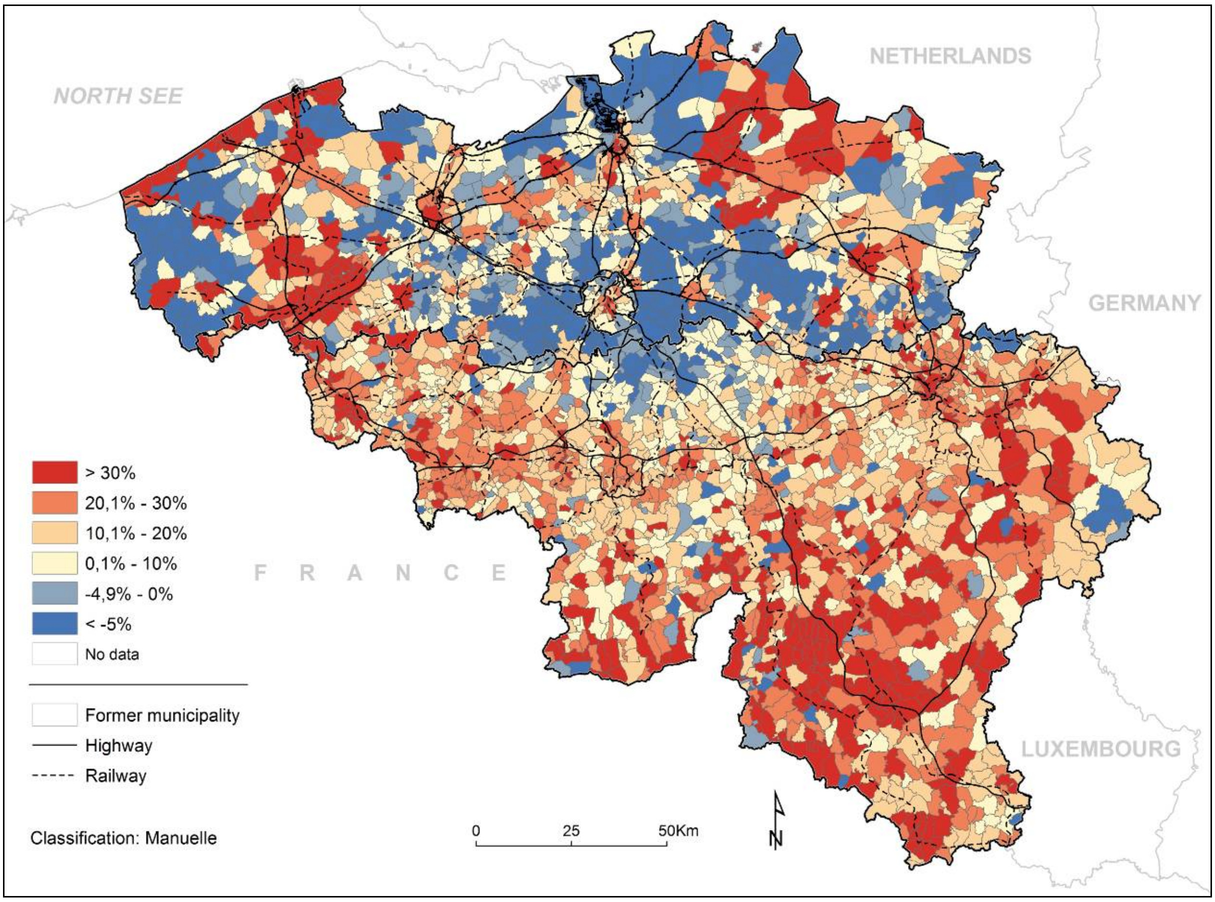
The Brussels capital region shows the best scores and is performing rather impressively in comparison with the two other regions. However, the Brussels capital region consists of a very compact urban area, which makes the comparison with the two other administrative regions not straightforward. Commuters who live in Brussels do not only travel to work over much shorter distances than inhabitants in the rest of Belgium, they also use much more often local public transport. Moreover, the decent ridership rates and the high degree of electric and rail bound urban transit lead to a lower amount of energy consumption per passenger-kilometre in public transport, compared to the rest of Belgium. However, it may well be that the efficiency of car trips in the Brussels area is lower than outside because of the less smooth traffic conditions, which may bias results somewhat.

Another aspect that should be taken into account is the fact that the map only shows the energy performance of commuters who live in Brussels. Commuters who work in Brussels will rather show high CEP values, because of the high concentration of jobs (Boussauw et al., 2011) which entails long distance travel. the compact urban structure of Brussels may have contradictory effects on the overall commute energy performance.

### 4.2. Evolution of the CEP index in Belgium between 1991 and 2001

The evolution of the CEP index between 1991 and 2001 has been calculated on the basis of former municipalities' CEP values for 1991 and 2001, and not on disaggregated values. Overall, energy consumption between 1991 and 2001 increased the most in Wallonia, especially within the southern part of the region. In Flanders, although consumption rose in some parts of the region, most of the territory witnessed a decrease of the CEP index (see Map 2). This can be partly explained by the better job market situation in Flanders compared to Wallonia (Marissal et al., 2006): when more job opportunities are available, workers are not forced to travel long distances to find a job. However, it should be stressed that areas where the CEP values decreased are often sparsely populated. In Flanders, the map seems to suggest that the commute energy performance of an average commuter improved, which is actually not the case. When calculated at census block level, the average commute energy performance rose in Flanders by about 15% over the considered time span, while in Brussels it rose by about 11%.

**Map 2 Evolution of the CEP index for Belgium between 1991 and 2001 (former municipality)**




A comparison of land use, spatial structure and socioeconomic factors underlines cross-regional variations, but also sheds light on common features between the two regions.

In Wallonia, the strong increase of the CEP index observed in the southern part of the region (over 30%) can be explained by the decrease of local job opportunities between 1991 and

2001 (partly due to the decline of the agriculture sector) and the greater dependence of rural and small-town dwellers on the car. In addition, this area witnessed over that period the arrival of new residents working in the main employment centres of Wallonia but also in Luxembourg. The latter's strong attractiveness, but also the scarcity of available land in this country, pushes Belgian households working in the Luxembourg to settle down further and further from the border where more land is available and prices are accessible (Vanneste et al., 2007).

In Flanders, a modal shift towards the car and an increase in the travelled distance to work led to a strong increase of the CEP index in the area of Kortrijk-Roeselare-Leie and in the east of Antwerp. Although the use of bicycle in 2001 remains above 12% within these areas, it critically felt between 1991 and 2001 at the advantage of the car (Verhetsel et al., 2007), explaining part of the evolution of energy efficiency of these areas. On the coast, although employment losses may be the reason behind some of the increase in CEP, there may also be some link with the issue of secondary residences (as mentioned earlier). However, the reasons behind this evolution merit some more thorough research.

Within both regions, a common feature exists amongst major and small cities and their periphery. As shown on the map, most urban centres present an increase of the CEP index between 1991 and 2001, while outside Brussels (including the north of Wallonia) and outside most Flemish cities, commute-energy efficiency improved. This tendency is also confirmed by figures from Table 3: the 1991-2001 evolution of the four percentile values of CEP index in Wallonia and Flanders reveals that the energy consumption for home-to-work commuting increased the most within low values of the distribution, that is within the most energy efficient areas of the country (the main urban centres). On the opposite, peripheral areas tend to present a lower increase in the CEP values in Wallonia and even a slight decrease in Flanders.

On the one hand, the decrease of commute-energy efficiency within cities can be explained by the "metropolisation" effect of the economic shift towards service industries. From a geographical point of view, this transformation relies mainly on agglomeration effects which are present mainly in the capital, but to a certain extent also in Antwerp. This becomes particularly clear within cities of the old Walloon industrial basin where the number of workers commuting to Brussels, Lille or Luxembourg increased significantly between 1991 and 2001. On the other hand, high consumption rates within cities are also due to the decentralization of businesses outside main urban agglomerations. The migration of many activities (including industrial zones, retail centres, hospitals, and business parks) from traditional urban locations to cheaper peripheral locations, coupled with poor mixed-use development and restrained accessibility to public transport, led to an increase of the average mileage of urban residents, and thus more energy consumption. Besides, the growing importance of agglomerations in terms of number of jobs also widened the opportunity range of those living in urban centres, which may have lead to longer distances travelled, and thus more energy consumption for commuting.

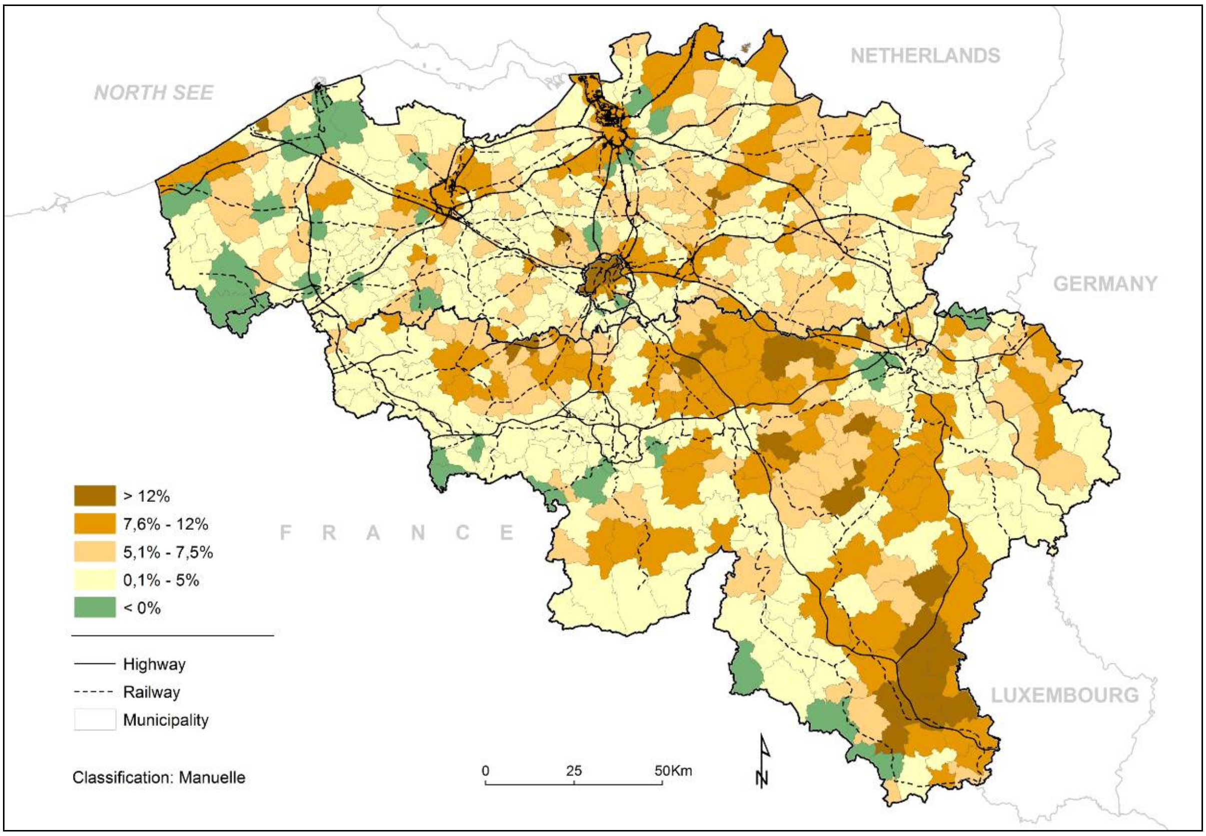
In peripheral areas, decentralization allowed, to some extent, bringing jobs closer to workers, which led to lower average journey lengths and thus less energy consumption. This mainly affected areas located around Brussels, including across the linguistic border. A CEP index decrease is also observed around the main urban centres of Flanders, but is not perceptible in the surroundings of the Walloon main cities. The relatively high population density and the important job creation rates within these areas allowed bridging the mismatch between employment and residential use observed in other peripheral locations of the country. Nonetheless, as most of the population lives in urban areas and commute-energy consumption decrease only affects a small part of the working population, an overall increase of travelled distances and energy consumption at the national scale is still observed.

### 4.3. The 2001 CEP index variation from national average and population changes between 2001 and 2010

Taking into account population changes in Belgium between 2001 and 2010 allows highlighting the current challenge underlying the evolution of commute-energy performances if the 1991-2001 observed tendency was pursued. Indeed, considering the spatial patterns of demographic trends helps supporting the understanding of the way commuting behaviour may evolve over time: to what extent population losses take place within most energy efficient areas? Are energy inefficient areas characterized by strong population gains?

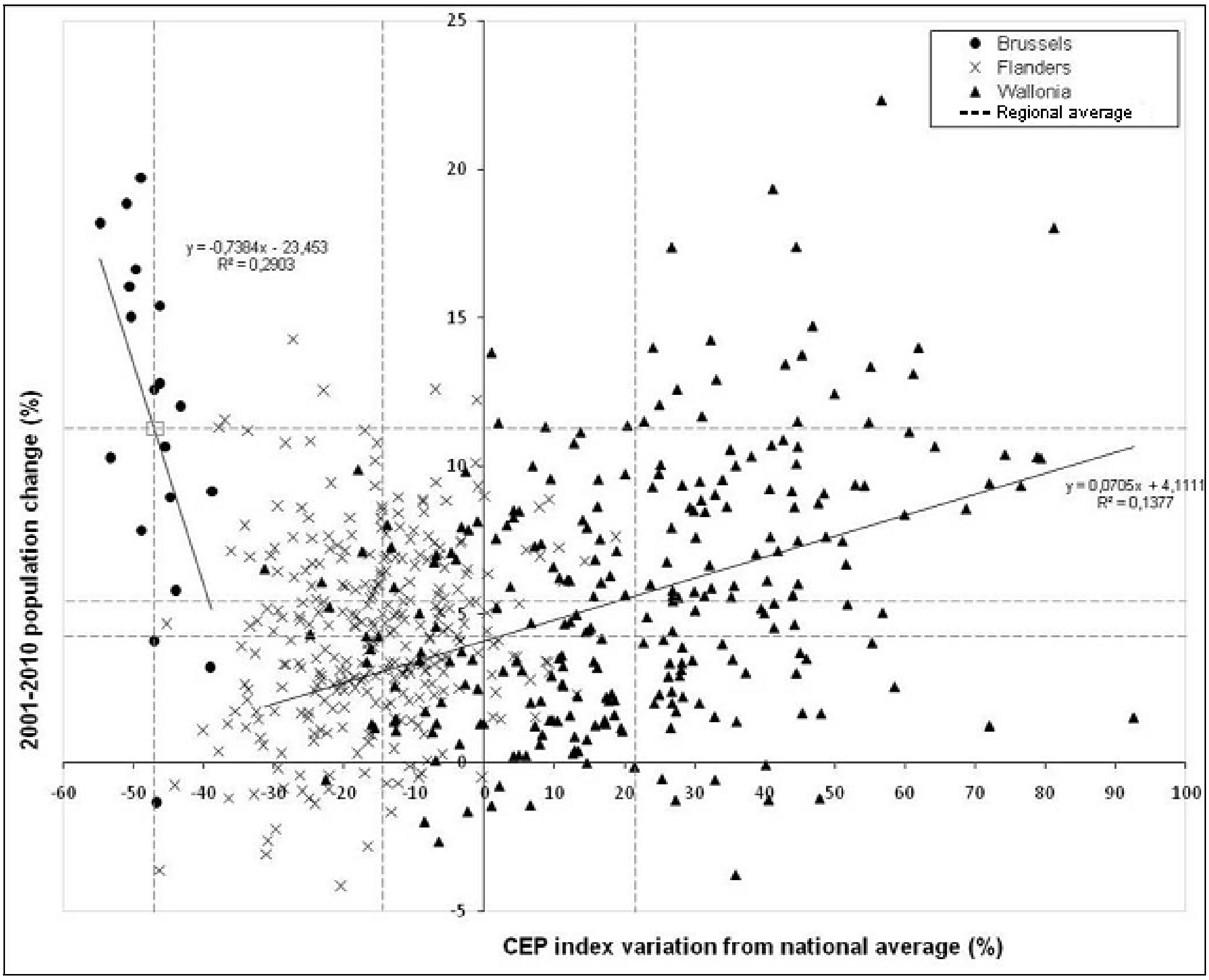
As presented in Map 3, most areas of Belgium were characterized by a population increase between 2001 and 2010. In Wallonia, the strongest evolutions were observed outside the main cities, especially in the south-east periphery of Brussels and near the Luxembourg border. In Flanders, the most important population gains were found within the main cities (Ghent, Antwerp, Leuven and part of the agglomeration around Brussels), but also on the coast and near the Netherlands border. Brussels showed strong population increases in the western part of the agglomeration.

**Map 3 Population changes in Belgium between 2001 and 2010 (municipality)**




Such differentiated spatial patterns of population changes, between Wallonia and Flanders but also within each region, are bound to have contrasting impacts on the commute-energy consumption. To illustrate this fact, Figure 1 opposes the 2001-2010 population changes and the variation of the 2001 CEP index from the national average, based on municipalities.

**Figure 1 Comparison between the 2001 CEP index variation from national average and 2001-2010 population changes by region, based on municipalities[1]**




1 Note that regression equations are only presented to illustrate the major differences in trends between regions. No equation is presented for Flanders as no clear tendency could be observed and the $R^2$-value was extremely low. Since the regression is applied on zones that share borders (and not on individual respondents) spatial autocorrelation may occur, causing some bias of the coefficients and $R^2$-values.

A comparison between Brussels, Flanders and Wallonia sheds light on substantial regional differences. In Wallonia, municipalities are, on average, characterised by a CEP index above the national average, and only a few are under the Flanders average. Within Flanders, commute-energy performances of most municipalities are under the national average, but most importantly none of them are above the Walloon average.

In Wallonia, CEP index variations from the national average tend to be stronger where population growth is important: areas where home-to-work commuting was more energy consuming in 2001 are those which generally presented the highest population increase between 2001 and 2010.

Such a positive correlation is less clear in Flanders: although there is also a slightly positive trend, the scattered distribution pattern confirms that energy efficient areas witnessed either population gains or population losses between 2001 and 2010.

On the opposite, the case of Brussels is particularly evident: a strong negative correlation amongst the 19 municipalities is observed, which means that the highest population increases between 2001 and 2010 occurred in the most energy efficient areas.

## 5. Conclusions and perspectives

This paper addressed the sustainability of home-to-work commuting in Belgium through a comparative analysis of Flanders and Wallonia.

On average, less energy is consumed for home-to-work commuting in Flanders compared to Wallonia. Land use, spatial structure and socioeconomic factors allow explaining spatial and temporal variations, within and between regions. In both regions, former municipalities with a good commute-energy performance (CEP) index are found within densely populated areas. Former municipalities with a high energy consumption rates are usually located far from employment centres, where the poor accessibility to public transport makes the car the most prominent travel mode, which induces more greenhouse gas emissions. This can be observed on a regional scale within areas located at 30 km (and more) from main urban agglomerations. Nonetheless, on a local scale, some former municipalities within these remote areas show better CEP values than the regional average: energy performances are locally better within a 10 to 15 km radius around small towns.

Between 1991 and 2001, most urban centres of Belgium present an increase of the CEP index, while commute-energy efficiency improved outside Brussels (including the north of Wallonia) and outside most Flemish cities. The decrease of commute-energy efficiency within cities can be explained by the "metropolisation" effect and the decentralization of businesses outside the main urban agglomerations. In peripheral areas, decentralization led to lower average journey lengths and thus less energy consumption. However, an overall increase of travelled distances and energy consumption at the national scale is observed, as areas where the CEP values decreased are often sparsely populated.

Since population densities seem to play an important role in transport energy efficiency, population changes in Belgium between 2001 and 2010 were surveyed. This allowed highlighting the current challenge underlying the evolution of commute-energy performances, by supporting the understanding of the way commuting behaviours may evolve over time and across regions. In Wallonia, areas where home-to-work commuting was more energy consuming in 2001 are those which generally presented the highest population increase between 2001 and 2010. On the opposite, in Flanders population growth distribution is rather neutral in terms of commute energy performance. Therefore, important population growths within municipalities already presenting bad commute energy performances is bound to have a negative impact on the household's average energy consumption for home-to-work commuting.

Nonetheless, it must be bear in mind that the link between spatial structure and sustainability of transport does not solely rely on demographic characteristics. The evolution in fuel prices may have major impacts on residential and businesses location choices, leading to new differentiated travel patterns. Technological factors, such as the evolution of fuel efficiency, are not to be neglected either.

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