At which scale study links between polycentricity and transit patronage? Insights from Paris metropolitan area and Rhine-Ruhr mega-city region

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Abstract

Many articles tried to address the question of the "optimal" urban form regarding sustainable mobility (Newman & Kenworthy, 1999 ; a, 2008). Conclusions however remain controversial for very large metropolitan regions given complexity of multiscale organization of the metropolitan area (Schwanen et al., 2001 ; Banister, 2008 ; Le Néchet & Aguilera, 2012a) and the diversity of their associated mobility patterns, partly due to the inertia of both urban form and mobility habits (Klinger, 2016). In particular, the choice between individual (car, bike, walking) and collective (bus, train, carpool) forms of transport depend not only on the supply side (Kenworthy & Laube, 1996), but also on cultural and individual preference aspects (Donald et al., 2014). In the context of increasingly polycentric metropolis, we emphasize the importance of taking into account spatial organisation of flows to explain mode choice. This is important because commuting flows that start and end outside city centers are now an overwhelming majority are the most difficult to channel through transit. Moreover, with the emergence of Mega City Regions (Hall & Pain, 2006), exchange between activity cores might be an increasing important dimension to assess the sustainability of the global region. Hence, if the level of functional integration is weaker than classical "Daily Urban System", the commuting distance resulting from the proximity of several cities is high and typically not addressed by the planners (Conti, 2015).

We analyse harmonized commuting data in Paris and Rhine-Ruhr regions two metropolitan regions very similar in size (both 12,000 km^2) and population (both 12 M inh.) but with contrasted spatial and functional organisation. Paris is primarily monocentric, and the Rhine-Ruhr region polycentric. We showed a paradox that establishing a better self-containment of labour zones could lead to less transportation pooling and in the end a less sustainable mobility system, in so far as medium and long-range flows might not be effectively channelled via heavy transportation infrastructures. There is therefore a serious challenge in Paris, where polycentricity is an emerging phenomenon (Berroir & al., 2008), to maintain public transit's efficiency, hence/that is to ensure that journeys to employment centers are not undertaken, as is currently often the case, exclusively by car; in other words, as they grow, these flows could/should be channelled by effective public transport infrastructures.

Introduction

Many articles tried to address the question of the "optimal" urban form regarding sustainable mobility (Newman & Kenworthy, 1999 ; Banister, 2008). Conclusions however remain controversial for very large metropolitan regions given complexity of multiscale organization of the metropolitan area (Schwanen et al., 2001 ; Banister, 2008 ; Le Néchet & Aguilera, 2012a) and the diversity of their associated mobility patterns, partly due to the inertia of both urban form and mobility habits (Klinger, 2016). In particular, the choice between individual (car, bike, walking) and collective (bus, train, carpool) forms of transport depend not only on the supply side (Kenworthy & Laube, 1996), but also on cultural and individual preference aspects (Donald et al., 2014). In the context of increasingly polycentric metropolis, we emphasize the importance of taking into account spatial organisation of flows to explain mode choice. This is important because commuting flows that start and end outside city centers are now an overwhelming majority are the most difficult to channel through transit. Moreover, with the emergence of Mega City Regions (Hall & Pain, 2006), exchange between activity cores might be an increasing important dimension to assess the sustainability of the global region. Hence, if the level of functional integration is weaker than classical “Daily Urban System”, the commuting distance resulting from the proximity of several cities is high and typically not addressed by the planners (Conti, 2015).

The extensive literature on Transit Oriented Development (TOD, Cervero, 1994) has indeed contributed to the better understanding of the imbrication of scales of planning and especially the effects of a densification with high functional diversity around major public transportation nodes on transit ridership and active travel. This literature, firstly theoretical, has become more oriented towards operational field and now several monographies inspire from this concept (Loo, 2010 on New-York-City, USA, and Hong-Kong, China ; Knowles, 2012 on Copenhagen ; Ratner, 2013 on Denver, USA, among many). Indeed, Transit Oriented Development policies can now be implemented using recent contributions of the theoretical literature such as the importance of accessibility measurement at metropolitan scale (Wulfhorst, 2007 ; Papa & Bertolini, 2015). Yet for large metropolis, it is still unclear whether TOD principles can be applied at full scale because an efficient transit network would require a costly complete network. Hence questions remain about how monocentric and polycentric spatial configurations influence trip distance and transport mode shares.

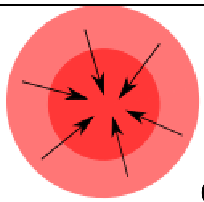
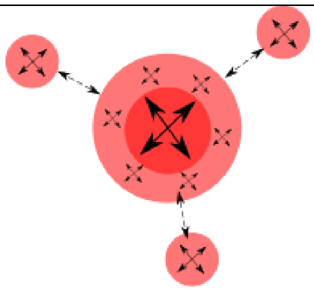
On the one hand, compact and monocentric spatial structures can lead to better efficiency of the public transportation network (Newman & Kenworthy, 1999). Some empirical evidence suggests the effect of monocentricity as fostering transit use for commuting trips. Figures for London (Urban Audit, 2004) and the Randstad (OECD, 2007) tend to show larger transit share for commuting in monocentric (London : 35% of commuting trips) than in polycentric cities (Randstad : 25% of commuting trips). Independently, study from Cirilli & Veneri (2009) on smaller cities in Italy shows similar results. Also, Le Néchet (2012b), studying 34 European cities from the UITP (International Union of Public Transport) millenium database (2001) showed that compact monocentric cities consumed less energy for transportation than sprawled polycentric ones, taking into account the socio-economic attributes of the cities.

On the other hand, polycentricity can be associated with shorter travel distances and less congestion, because of easier spatial co-adjustments of workers and companies regarding travel distances (co-location hypothesis of Gordon et al., 1989). Also, Brown et al. (2012) demonstrated on Metropolitan Statistical Areas (MSA) in U.S. with over than 500,000 inhabitants that the relative share of jobs in Central Business District (CBD) (hence monocentricity of the employment market) is not correlated with share of transit for commuting, when accounting for fuel prices, fare level, service frequency and coverage, and socio-demographic characteristics of local population.

Polycentricity can be characterized though the identification of clusters that approximately follows center-periphery model. However the quantification of polycentricity is very complex for there exist multiple forms of polycentricity corresponding to contrasted commuting patterns and to contrasted spatial structures. This difficulty makes it virtually impossible to make a definitive argument on whether polycentricity fosters transit patronage. Instead, we find it fruitful to disentangle the complexity of polycentric through three complementary dimensions of polycentricity : (i) morphological polycentricity : the way population and activities are clustered in space (see Champion, 2001) (ii) functional polycentricity : the amount of flows between morphological clusters compared to intra-clusters flows (iii) polarisation of flows : for intra-clusters flows, amount of flows that are oriented towards the economic core. The two last dimensions of polycentricity refer to Schwanen & al. (2001) typology of flow patterns within a daily urban system (DUS). We explore here the way those dimensions can in theory influence transit patronage through the idea that we some cells in the Origin-Destination matrix has a high value, indicating that several people are doing approximately the same commute, it is likely that an efficient transit system has be implemented. Hence, following Figure 1 gives some theoretical illustration of how this decomposition into three dimensions of polycentricity can lead to a better understanding of transit patronage. The following four examples detail the expected transit patronage in theoretical situations : it does not gives a full detail of the diversity of possible situations.

To study mobility patterns, we use quantitative data analysis which are proxies of energy consumption and GHG emissions : commuting travel distances and transport mode shares. We follow the approach by Casello (2007) on flows between employment cores, and wish to assess the extent to which polycentric urban form and dispersed distribution of flows are in favor of individual forms of transportation. In a context of great diversity of polycentric organisation of metropolitan regions at European scale (Le Néchet, 2015), we provide insight from two contrasted metropolitan organisation, comparing Paris in France and Rhine-Ruhr in Germany, respectively monocentric and polycentric metropolitan regions

(a) For a monocentric city with a high polarisation of flows, one can expect transit to be relevant for short trips within dense areas and long inter-city trips towards the city center, thanks to a spider network organization, but car is extensively used for all other types of trips.
(b) Emergence of suburban centers around nodes of transportation systems – Edge Cities, (Lee, 2006) leads to flows corresponding to the cross-commuting patterns from Schwanen & al. (2001). This type of polycentric urban structure is more frequent in the American context compared to European context (Bontje, 2005) and is in most cases built around the car. In this case travel distance is expected to be low (co-location hypothesis).
(c) In their studies of several Dutch conurbations, Schwanen & al. (2001) showed that polycentric configurations with cross-commuting flows (hence no prevailing center-periphery flows) could result in less frequent transit use, because “public transport system is not geared to this pattern of travel behaviour”. Indeed, an efficient transit system would be more expensive to build compared to the monocentric case because it requires point-to-point services to be competitive with the car (in terms of accessibility and travel time).
(d) Polycentric development defended by Banister (2008) and tenants of Transit Oriented Development can be described as medium clusters with as much self-containment as possible and easy transit use for local trips. However, unless a complete transit network is built (not only a spider map), transit share cannot be extremely high on average because of large amount of flows between periphery cores.

Theoretical configuration	**Spatial organisation**	**Expected transit performance**
 **(a)**	**Low morphological polycentricity** **Low functional polycentricity (central DUS)** **High polarisation of intracluster flows**	**Medium to High transit share for local trips (density)** **High transit share for long radial trips** **Low transit share for long non-radial trips** **Medium average trip distance**
 **(b)**	**Medium morphological polycentricity** **Medium functional polycentricity (cross commuting DUS)** **Small polarisation of intracluster flows**	**Medium transit share for local trips** **Low transit share for long trips** **Small to medium average trip distance**

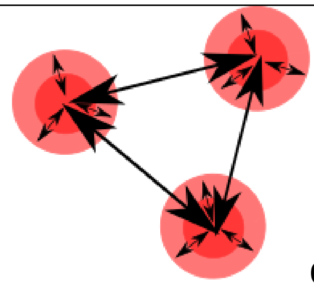
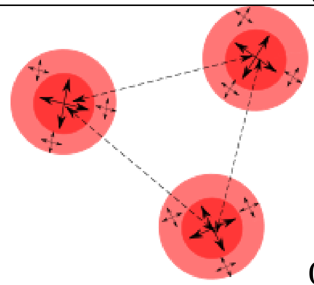
 (c)	**High morphological polycentricity High functional polycentricity (exchange commuting DUS) Medium polarisation of intracluster flows**	**Low transit share for local trips Medium transit share for long trips Large average trip distance**
 (d)	**High morphological polycentricity Medium functional polycentricity (cross commuting DUS) Low polarisation of intracluster flows**	**Medium transit share for local trips Low transit share for long trips Small average trip distance**

Figure 1 : Theoretical influence of some spatial structure and organization of flows on transit ridership and distances within polycentric urban regions.

Two case studies : Paris and Rhine-Ruhr metropolitan regions

We analyse harmonized commuting data in Paris and Rhine-Ruhr regions two metropolitan regions very similar in size (both 12,000 km^2) and population (both 12 M inh.) but with contrasted spatial and functional organisation. Paris is primarily monocentric, and the Rhine-Ruhr region polycentric. Among the large metropolitan regions studied by the planning litterature, Paris, London and the Randstad (Holland) are landmarks (Kloosterman & Lambregts, 2001). Rhine-Ruhr region has been less studied due to its hydrib nature between classical metropolitan area and mega-city region (Bloetevogel, 2001 ; Hall & Pain, 2006).

On might ask whether those two metropolitan areas in fact comparable? Increase in functional linkages between territories lead to the emergence of city regions (Scott, 2001), which are observed since the seminal research of Gottmann (1957). What Hall & Pain (2006) call "Mega City Regions" correspond to network of cities with important level of interaction. For instance in Europe, there is evidence for the emergence of an integrated metropolis within Randstad – the 7 Million inhabitants diamond linking Amsterdam, Rotterdam, the Hague and Utrecht (at least in Rotterdam – The Hague corridor, Meijers et al., 2014), among many other examples (Vienna / Bratislava, Brussels / Antwerp / other cities in Belgium, etc.).

Parr (2007), among others, showed the conceptual diversity of city definitions throughout Europe. Currently, there is currently no harmonized definition of metropolitan regions available at European scale (Bretagnolle et al., 2011). This is due to the very heterogeneous datasets available in each country, especially regarding commuting data : harmonization suffer from the challenge of . The boundaries of DUS, defined as catchment area around main job centers, depend upon the threshold values and type of available data (Hall & Pain, 2006). The catchment area defined by Urban Audit (2004) comes from Eurostat attempt to accommodate the diversity of statistical methods between countries. According to this definition, Paris DUS is the Ile-de-France region, very similar to INSEE[1] "Aires Urbaines" definition of 2011. However, North-Rhine Westphalia's main urban area (what we call "Rhine-Ruhr region ") is divided is divided into six different DUS: Ruhr basin, Düsseldorf, Köln, Mönchengladbach, Bonn and Wuppertal. It means that Rhine-Ruhr region, approximately taken as the sum of all six DUS, does not fully qualify as a DUS itself : there is not sufficient functional integration at this scale according to Eurostat.

[1] Institut National de la Statistiques et des Etudes Economiques, French statistical agency

There are however arguments in favor of comparing those two regions. The functional links between those six DUS are strong (according to PddV[2], 2004 database) and their contiguity constitutes an exception at European scale (Hall & Pain, 2006 ; Le Néchet, 2012c). Hence, among the 289 DUS identified by Eurostat, 181 identified DUS (62,6%) are isolated in space, and we found 28 pairs of contiguous DUS (Stockholm-Uppsala or Naples-Casteri for instance). We found only 12 occurrences of a cluster of contiguous LUZ with three or more DUS. Only one cluster is larger than Rhine-Ruhr region in terms of number of contiguous LUZ : one cluster in United Kingdom has 7 (Liverpool / Manchester / Kingston-upon-Hull / Sheffield / Wrexham / Stoke-on-Trent / Bradford-Leeds). This kind of polycentricity is still the exception not the norm for European metropolitan regions (Le Néchet, 2015).

Also, because we decided in the case of Rhine-Ruhr region to agglomerate different DUS into one geographical object, one would argue it would be fair to do the same with Paris urban region. According to Hall & Pain (2006), as a "mega-city region", Rhine-Ruhr can be compared to "Bassin Parisien", region of 18M inhabitants with Paris DUS (2/3 of population) at the heart. Figure 2 gives detailed repartition of population for Paris DUS within "Bassin Parisien" (left) and Rhine-Ruhr's six DUS within North-Rhine Westphalia (right). This representation shows how much Paris DUS' demography is dominant compared to the surrounding districts, and partly explains why we decided to stick with this delimitation for our case study. Similarly, the level of population density throughout the six following DUS : Ruhr Area, Cologne, Düsseldorf, Bonn, Wuppertal, Monchengladbach, is larger than what is found in virtually all nearby districts.

While acknowledging there is some similarity because of the existing weak links between Paris and other DUS (Rouen being the largest city outside Paris), we decided to stick with the Ile-de-France region for two main reasons: firstly, the ring of cities constituting the "Bassin Parisien" are much smaller that RR's DUS, and much further away from each other (200 km between Paris and Rouen). Also, there is no political agenda to integrate planning at this scale, when Knapp & Schmitt (2003), among others, discussed the governance of Rhine-Ruhr region at the scale we finally adopted. Finally, the delimitations adopted represent a compromise between the functional and the governance aspects of metropolitan regions.

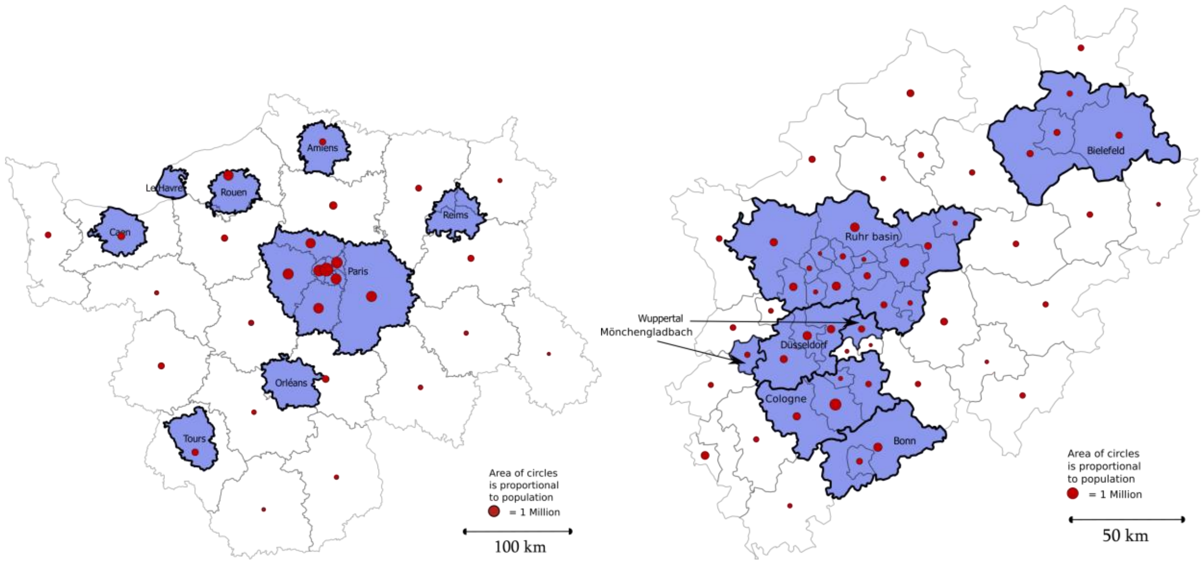


Figure 2 : Ile-de-France within Bassin Parisien (left) and Rhine-Ruhr's six DUS within North-Rhine Westphalia (right). Data at district level for France ("département", INSEE RGP, 2016) and Germany ("Kreis", Zensus 2011). Boundaries of Daily Urban Systems, in blue, from Eurostat (2004).

2 *Prognose der deutschlandweiten Verkehrsverflechtung 2025 : prevision of transport mode usage at German level (base year 2004, prevision year 2025).*

For Paris and the Rhine-Ruhr region, detailed case study boundaries have been determined using Knapp & Schmitt (2003) study as well as complementary data analysis of flows. Ile-de-France region has been chosen for Paris metropolitan area, and Rhine-Ruhr region is defined using Urban Audit "Larger Urban Zones" (LUZ) and PddV database (year 2004) as the 26 Kreis (districts) included are those within the six DUS or those with strong commuting links with these core areas. The level of functional integration of the Rhine-Ruhr region defined as such is fairly high, for commuting trips within Kreis represent only 65% of trips.

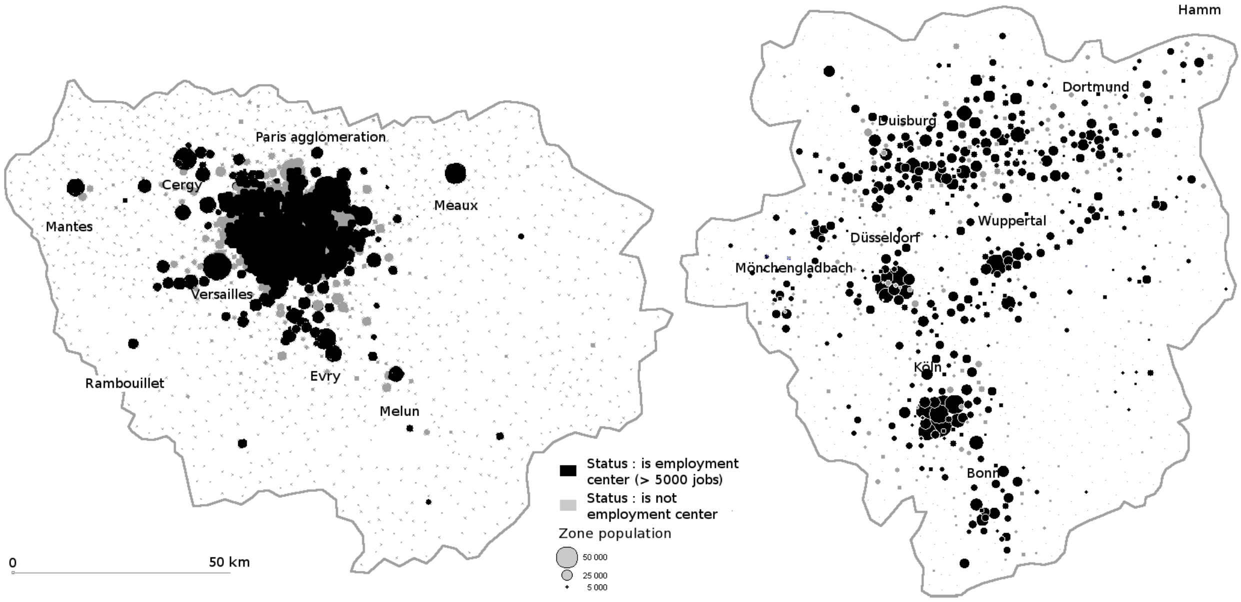


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Figure 3 : Map of Paris and Rhine-Ruhr metropolitan regions : boundaries, population densities and functional areas. Sources : INSEE (1999), IGVP[3] (2000).

What we expect from the comparison of mobility patterns between the two regions to give more detailed comprehension of what explains transit patronage. We wish to provide insights from two recent mobility databases : Mobilitat in Deutschland Database (MID, 2008) on 4 258 households within North-Rhine Westphalia (NRW), and Enquête Globale de Transport (2010) for Paris region on 14 885 households. Rhine-Ruhr area entirely lies within North-Rhine Westphalia (NRW), a German Länder of 18 million inhabitants in 2008, and is for the reference area because no detailed geographical information was available in MID database. The main cities outside Rhine-Ruhr area within NRW are Aachen, Münster and Bielefeld – around 300 000 inhabitants each, and altogether Rhine-Ruhr area accounts for 2/3 of total population of the Länder. The observed daily mobility within NRW compared to Rhine-Ruhr area are therefore expected to rely more on car and trips to be longer.

The results show the dominance of car based travel in the German region (39% versus 29% for daily mobility and 68% versus 37% for commuting purpose only). The distance of travel are much longer for NRW (17 km per trip versus 8 km for commuting trips). The results show for both regions the existence of longer trips for rail transport compared to individual motorized modes (+142% in NRW, +105% in Ile-de-France region). Also, illustrating the existence of cultural habits : walking appears higher for trips with main purpose '"workplace" in Paris region compared to NRW, and cycling is high in NRW compared to Paris region. This comparison based on recent but not harmonized database gives impetus for a deeper work aiming at comparing mobility for the actual metropolitan regions. The following section details the work achieved using four different databases, two per region.

3 Integrierte Gesamtverkehrsplanung Nord Rhein Westfalen : Transport and Planning integrated framework for North-Rhine Westphalia

Data harmonization

The main contribution of this article lies in the harmonisation of the mobility datasets to allow international comparison of commuting flows between the two metropolitan regions. The data used for Paris region comes from the 1999 French census (Recensement Général de Population – RGP) and the 2001 regional travel survey (Enquête Globale de Transport – EGT), and from two databases, IGVP, 2000 and PddV, 2004 for the Rhine-Ruhr region. The harmonization procedure had three steps:

1. to create comparable elementary statistical areas, to avoid distorting the comparison between the two regions
2. to create comparable mobility categories, in particular the breakdown into transport modes, which were not initially compatible between the two regions.
3. to adopt a harmonized definition of employment centres in the two metropolitan regions.

For Paris region, RGP data does not distinguish between transit modes, and has a specific category "two wheelers" that had to be allocated between car mode and active travel. To achieve the reallocation of transport modes into harmonized modes, we used EGT (2001) dataset with more detailed information about transport mode used for commuting, but only 10,000 households surveyed. For Rhine-Ruhr region, IGVP database has very high spatial resolution (2589 zones) but does only distinguish individual modes and collective modes ; on the other hand, PddV database is an OD matrix with six transport modes but available at Kreis level only (26 Kreis in Rhine-Ruhr region hence circa 500 km² per Kreis). Additional work has been done to make the two datasets compatible, which implied a modelisation of trips distinguished by Kreis at origin, Kreis at destination (urban / non-urban) and distance achieved.

The geographical division of the zones and the calculation of mobility indicators are harmonized at the OD (Origin-Destination)-matrices level. The level of French « communes » (administrative units) has been chosen as a reference statistical unit for both regions because it is the least disaggregated one: approximately one thousand zones is the maximum level of detail available for OD-matrices.
Reconstructed Rhine-Ruhr zones, similar to Paris « communes » have been created using a four steps procedure, based on 2589 North-Rhine Westphalia transport zones « Verkehr Zones » (VZ), the smallest geographical entity available from IGVP database, and 765 « Grund » zones, subdivisions of German municipalities. The objective was to create a partition of Rhine-Ruhr region with respect to the following constraints : (i) the average area should be as close as possible to the average area of "communes" in the Ile-de-France region, 10 km^2, (ii) constructed « Communes » cannot be part of two different « Grund » zones, to preserve the German administrative subdivisions, (iii) the Rhine-Ruhr « Communes » should be as homogeneous as possible regarding urban form, (iv) the shape of Rhine-Ruhr « Communes » should be as close to circles as possible.

The harmonization procedure adopted is as follows:

1) Case 1: if all VZ (Verkehr Zones) within a « Grund » are bigger than 10 km^2, then the created Rhine-Ruhr "Communes" = VZ
2) Case 2: if a Grund area is smaller than 10 km^2, then the created Rhine-Ruhr "Commune" = Grund
3) Case 3: if VZ = Grund, then the created Rhine-Ruhr "Commune" = VZ = Grund
4) Case 4: in all other cases (33% of Grunds), a manual method is achieved, detailed in the figure 3.

Figure 4 illustrates the manual procedure used for Waltrop area (north of Dortmund). Zones A1 and B1 cannot be aggregated because they are part of different « Grund » areas, according to rule (ii). To accommodate rule (i), A is divided into two zones, one urban and one suburban following the rule (iii) – density of zones shall be as homogeneous as possible. Zone B is divided into three zones for similar reasons. The subdivision between zones B2 and B3 is done according to rules (i) and (iv).

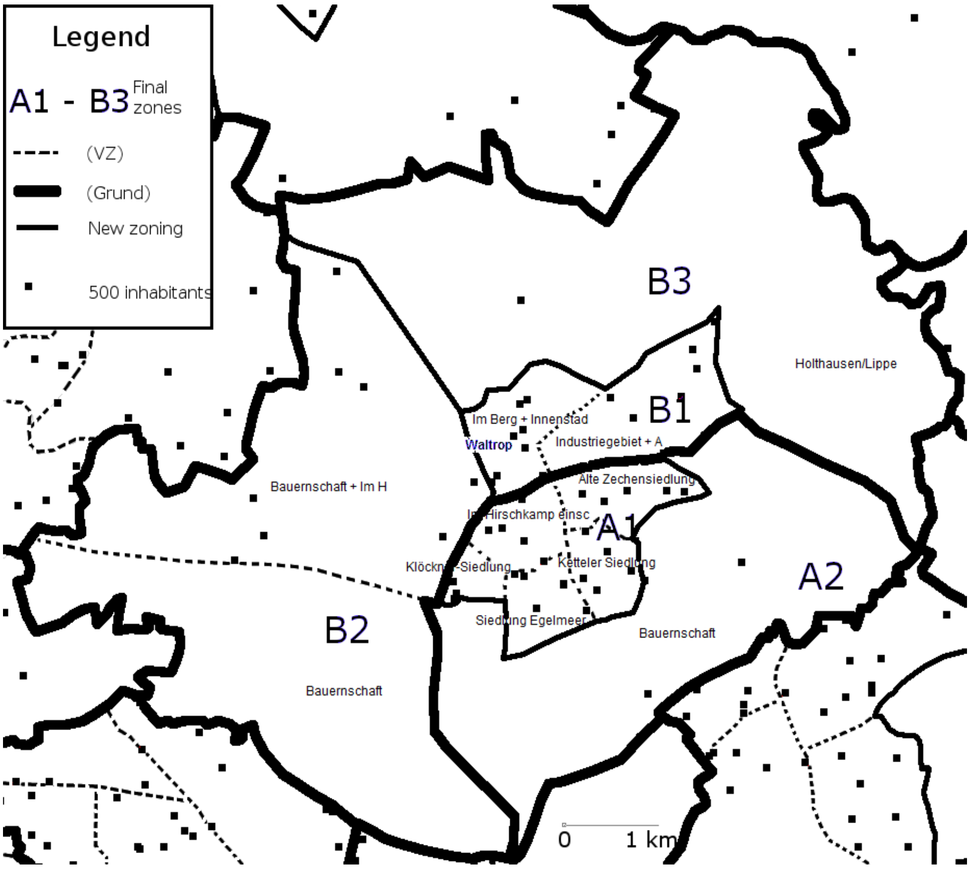

Figure 4 : Illustration of the manual procedure : aggregating transport zones in « communes » zones in north Dortmund, Rhine-Ruhr metropolitan region. Source : IGVP (2000).

In line with the sustainability issues raised at the beginning of this article, we chose to break transport modes into four categories for both regions (see below) that have very dissimilar sustainability outcomes :

- car (driver and passenger)
- train (suburban rail and Paris metro)
- other public transport (bus, tramways, U-Bahn[4])
- active travel (walking and cycling)

The geographical scale of available mobility data differs for the two regions: figure 5 summarizes the information type available for different geographical boundaries.

[4] *Untergrundbahn* : Rhine-Ruhr underground system

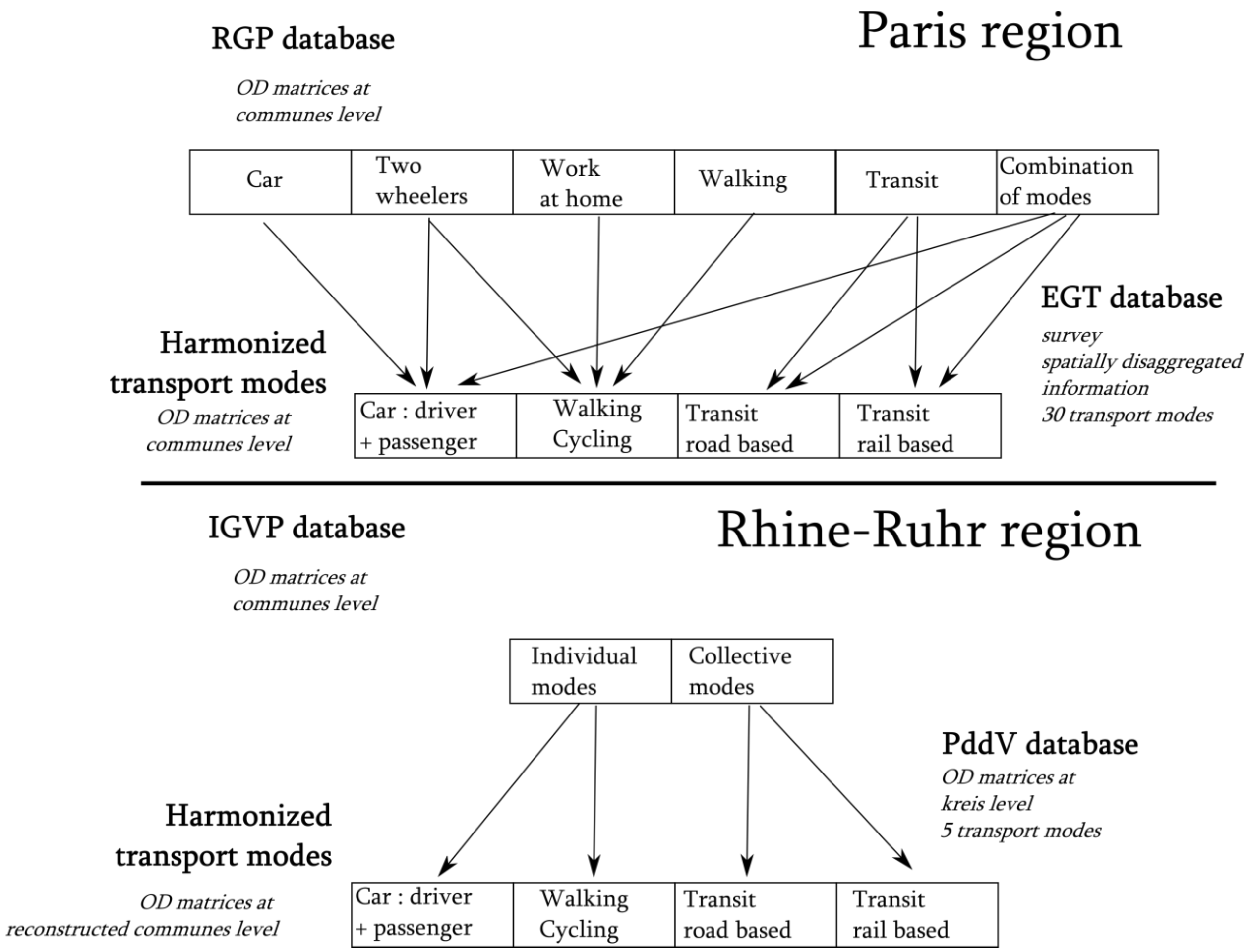

Figure 5 : Synthetic representation of the harmonization process of OD-matrices concerning geography and transport modes categorization.

To complete data harmonization, we used a simple procedure to detect employment areas within these two regions. This procedure is described below. This characterisation of zones with respect to their role as employment center is useful to give simple description of mobility. Thus, instead of classical central / pericentral / suburban / outer suburb classification of territories we qualify flows by their length (short, less than 5 km range, medium range and long, more than 20 km, range) and urban type at origin and destination. This non-monocentric framework is in line with recent literature on mobility within metropolitan regions (Courel & al., 2005): for Paris region, 70 % of all trips are achieved with their origin and destination in suburbs, so geographers need to adopt a more detailed typology of trips.

Employment areas have been defined in both regions using the same threshold: a “commune” is a job center provided it hosts more than 5,000 jobs. This definition is a simplification of the double threshold suggested by Giuliano & Small (1991) – employment threshold and density threshold, a simplification made possible by a very low dispersion of communes area in both regions leading to the density of jobs being redundant with the number of jobs in a zone. More sophisticated procedures (Redfearn, 2007) would go beyond the scope of this article. Figure 3 shows the two metropolitan regions at the same spatial scale, including the location of employment centers. The harmonization process allowed comparing the two metropolitan regions and exploring the organisation of commuting flows within them with respect to (i) travel distance and (ii) transport modes used.

Mobility patterns in Paris and Rhine-Ruhr regions

The harmonized data as well as some complementary data allows us to give a detailed picture of the mobility patterns in Paris and Rhine-Ruhr regions. Table 2 suggests greater importance of employment centers in Paris compared to the Rhine-Ruhr region not only quantitatively (in Paris they encompass 85 % of jobs against 70% in the Rhine-Ruhr region) but also regarding spatial concentration (15 % of communes are employment centers in Paris against 34 % in the Rhine-Ruhr region). Also, using density grid from European Environment Agency (2002) and detailed localisation of transit networks in both regions (IGVP, 2000 for Rhine-Ruhr region ; IGN[5] Route 500 database, 2006 for Paris region), we found that an larger share of inhabitants have an easy access to transit networks in Paris region compared to Rhine-Ruhr region, which is largely due to the exceptional density of Paris' metro system (Le Néchet, 2012c). Indeed, TOD principles can also apply to polycentric metropolis but the Rhine-Ruhr case suggests it can be hard to achieve without sufficient concentration of jobs in a small number of employment centers. This gives an idea of the challenge to overcome to change mobility behaviour in medium density dispersed and polycentric environment.

	Paris region	**Rhine-Ruhr region**
Number of zones	1300 communes	1265 constructed « communes »
Total population	11.0 M (1999)	11.9 M (2001)
Total area	12 012 km²	11 712 km²
Total employment	4.78 M	6.07 M
Number of employment centers	193 communes	430 constructed « communes »
Jobs in employment centers	4.11 M (86,0%)	4.31 M (71,0 %)
Jobs / workers ratio in employment centres	1,19	1,02
Proportion of residential population with easy access to urban transit (métro / Ubahn < 500m)	23.9%	13.4%
Proportion of residential population with easy access to suburban rail (R.E.R. [6]/ Sbahn < 1 km)	33.0%	18.5%

Table 1 : Geography of population and employment in Paris and Rhine-Ruhr metropolitan regions. Sources: RGP (1999), EGT (2001), IGVP (2000), PddV (2004), European Environment Agency (2002).

Table 2 gives an overview of commuting patterns within these two regions, showing greater use of public transport in Île-de-France (44%) than in the Rhine-Ruhr region (18%), and conversely greater use of active travel (walking and cycling) in the Rhine-Ruhr region (18% *versus* 12% in Paris). This is in line with the international literature: cycle share has been low in the Paris region since decades, and the case remains today even after the successful introduction of "Vélib" bike sharing system in 2007. At the same time, Paris's monocentric structure seems more compatible with high transit usage. 2001 figures in both regions show annual riderships higher in Paris region, 3 billions journeys in Paris region (RATP[7] + SNCF[8]) and 2 billions journeys in the Rhine-Ruhr region (VRR[9] – Rhine-Ruhr + VRS[10] – Köln / Bonn). Note that the average

5 Institut Géographique National, French agency about geographical information.

6 *Réseau Express Régional,* suburban railway network for Paris region

7 Régie Autonome des Transport Parisiens : Transport operator for Paris metro and suburban lines

8 Société Nationale des Chemins de Fer Français : National railway company in France

9 Verkehrverbund Rhein-Ruhr : Transport operator for Ruhr and Düsseldorf area

10 Verkehrverbund Rhein-Sieg : Transport operator for Cologne-Bonn area

commuting distance is similar in both regions: 13 kilometers in Paris, 14 kilometers in the Rhine-Ruhr region (commuting distance is taken as zero for intra-communes trips and as Euclidian distance adjusted by a factor of 1.3 for inter-communes trips, to take account of the presence of transport infrastructures as suggested in Aguilera, 2004). This reveals that despite a level of functional integration lower in Rhine-Ruhr region (five different DUS according to Eurostat), there is an even bigger challenge to reduce commuting distance, compared to Paris metropolitan region. This is a somehow surprising result, considering the fact that Eurostat's DUS constituting what we call "Rhine-Ruhr region" are separated, however this is in line with the figure that 35% of flows are between DUS instead of within a DUS.

	Paris		**Rhine-Ruhr**	
	(%)	**(km)**	**(%)**	**(km)**
Private vehicle	44.1	13.8	64.0	18.0
Walking/cycling	11.8	1.9	18.4	2.7
Train	35.1	15.9	6.0	22.9
Other public modes	9.0	9.0	11.6	8.2
Total	100.0	12.7	100	14.3

Proportion of	**Paris**	**Rhine-Ruhr**
Trips within employment centers	67,8 %	54,2%
Trips between employment centers and other communes	22,7 %	31,9 %
Trips outside employment centers	9,5 %	13,9 %
Trips within communes	24.7 %	19.9 %

Table 2 : Overview of commuting patterns in Paris and in the Rhine-Ruhr region : modes shares and average commuting distance, structure of flows. Sources: RGP (1999), EGT (2001), IGVP (2000), PddV (2004).

Beyond these average figures, spatial organisation of commuting behaviour differs in these two regions. We can see on the Figure 6 the transit share (at origin) in the two metropolitan regions: only the most populated "communes" of the Rhine-Ruhr region – Bonn, Cologne, Düsseldorf have high values of this indicator, when they are much more widespread in the Paris region. However, it is noticeable that certain urban zones, though very dense – Dortmund, Essen, Wuppertal – stand out very little on the map: while local mobility there is fairly well channelled into public transport, long distance trips are mostly achieved by private vehicle. This is explicable by the diffuse nature of urban form in the Ruhr area. For Paris region, the radial distribution is very marked/pronounced, whereas the situation is harder to interpret in the case of the Rhine-Ruhr region, where local centre-periphery models (Dortmund, Cologne, Bonn) are superimposed on a more polycentric structure, arising from the near-to-near links between big cities in the Rhine-Ruhr region (e.g. Essen-Bochum-Herne-Gelsenkirschen). By way of example, car use for commuting is not dominant in Paris city center and the inner ring (fewer than 40% of commuting trips).

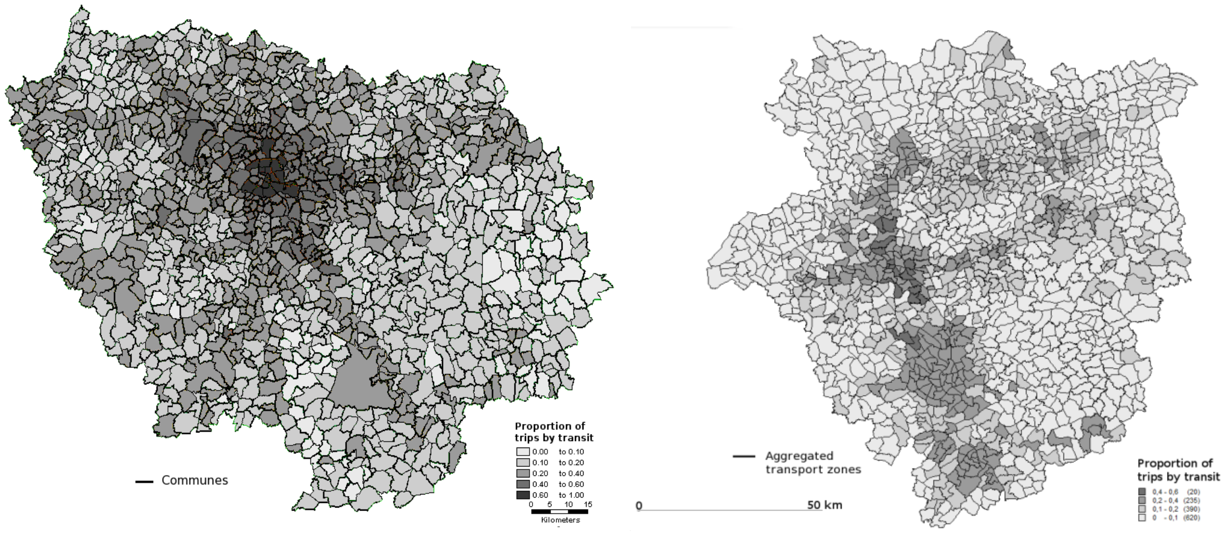

Figure 6: Proportion of commuting journeys by public transport, in Paris (left) and in the Rhine-Ruhr (right) region. **Sources: RGP (1999), EGT (2001), IGVP (2000), PddV (2004).**

A closer look at the breakdown of commuter journeys by transport modes and travel distance shows the difference in mobility patterns, with private vehicles being used primarily for medium distance trips in Paris, and for longer journeys in the Rhine-Ruhr region (figure 7). Therefore, it indicates different coevolutions of spatial structure and transportation infrastructure on the long term, with successive reinforcement of Paris radioconcentric structure (with the R.E.R. radial suburban network developed from 1965) and at the same time the building of a very extensive urban motorway network in the Rhine-Ruhr area (1400 km according to IGVP database, 2000, versus 1000 km in Paris region - source : IGN Route 500 database, 2006).

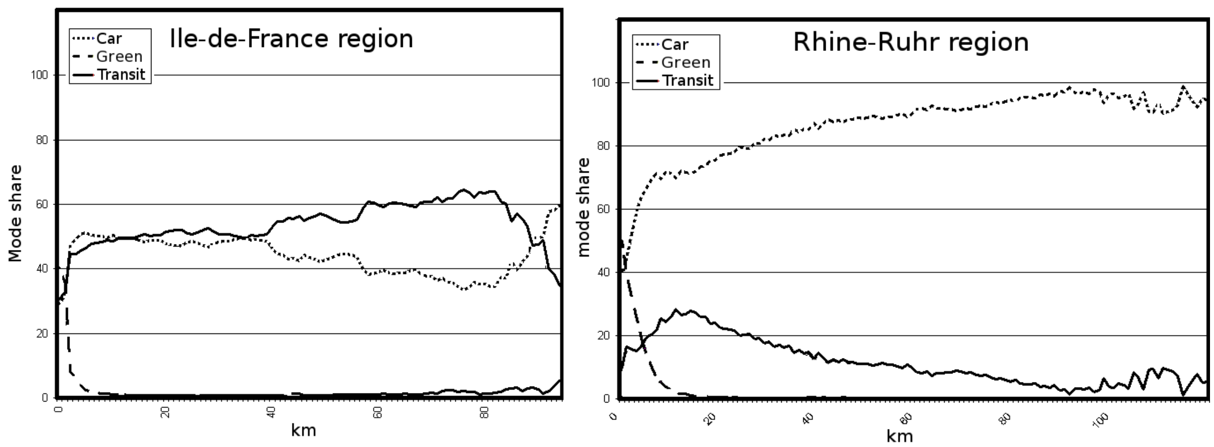

Figure 7: Modal shares by distance of commuting trip in Paris and Rhine-Ruhr regions. **Sources: RGP (1999), EGT (2001), IGVP (2000), PddV (2004).**

There is therefore a serious challenge in Paris, where polycentricity is an emerging phenomenon (Berroir & al., 2008), to maintain public transit's efficiency, hence/that is to ensure that journeys to employment centers are not undertaken, as is currently often the case, exclusively by car; in other words, as they grow, these flows could/should be channelled by effective public transport infrastructures.

As Table 3 shows, scarce flow is often associated with a lesser capacity for the transportation system to provide collective transit modes as opposed to car, independently from travel distance and local urban form.

Transit is chosen over car for 31% of trips (16% respectively) with scarce flows (less than 20 commuters) on OD-links in Paris region (Rhine-Ruhr region respectively), for 48% of trips (25% respectively) of trips with medium flows (between 20 and 400 commuters) on OD-links and for 60% of trips (25% respectively) of trips with large flows (more than 400 commuters) on OD-links. This effect is still present when analysing flows between employment centers only : the more people travel on a link, the more likely that transportation system has evolved towards allowing mass transit system on this link over the long term.

We acknowledge that this approach might present some bias, because of the co-linearities between residential and activity densities, trip distance and the flow amount on one link (according to the gravity model). There is a strong correlation between communes population density and the number of flows on one hand, and between communes population density and transit use on other hands ; not surprisingly, active travel use is higher for pairs of communes with large flows, and this is especially true in Paris region: Rhine-Ruhr region, despite the S-Bahn[11] regional railway system operated since the 1970's, proved unable to attract flows at the metropolitan level which represent 15% of all commuting trips. When Paris see a transit share among mechanised trips around constant around 50% of trips, regardless the trip distance, Rhine-Ruhr mobility figures show a dramatic decrease for long distance trips (from 25% of trips to 15% of trips).

		Paris			**Rhine-Ruhr**		
Flows	**Distance**	Transit among mecanised trips	Green modes share	% of total trips	Transit among mecanised trips	Green modes share	% of total trips
scarce flows (< 20 commuters)*(incl. trips between employment centers only)*	**short distance < 5km**	**11.50%**	**11.10%**	**0.60%**	**11.00%**	**21.50%**	**0.34%**
	(between employment centers)	*33.10%*	*1.70%*	*0.00%*	*19.50%*	*3.70%*	*0.00%*
	medium distance [5-20] km	**23.10%**	**1.20%**	**6.00%**	**18.70%**	**1.50%**	**10.40%**
	(between employment centers)	*40.00%*	*1.20%*	*1.20%*	*22.90%*	*0.30%*	*2.30%*
	long distance > 20 km	**39.80%**	**0.90%**	**6.90%**	**12.90%**	**0.10%**	**15.14%**
	(between employment centers)	*46.20%*	*0.80%*	*1.50%*	*16.80%*	*0.00%*	*5.97%*
	Total	**31.30%**	**1.40%**	**13.50%**	**15.80%**	**1.10%**	**25.88%**
	(between employment centers)	*43.40%*	*1.00%*	*2.70%*	*19.10%*	*0.10%*	*8.27%*
medium flows (between 20 and 400 commuters) *(incl. trips between employment centers only*	**short distance < 5km**	**32.50%**	**13.40%**	**9.70%**	**19.00%**	**25.60%**	**17.71%**
	(between employment centers)	*46.50%*	*5.90%*	*4.00%*	*25.50%*	*20.90%*	*6.14%*
	medium distance [5-20] km	**48.90%**	**1.10%**	**27.10%**	**28.10%**	**5.00%**	**23.43%**
	(between employment centers)	*55.80%*	*1.10%*	*18.00%*	*33.90%*	*4.30%*	*11.04%*
	long distance > 20 km	**66.00%**	**0.60%**	**6.10%**	**33.80%**	**0.10%**	**1.53%**
	(between employment centers)	*65.60%*	*0.60%*	*3.60%*	*38.10%*	*0.00%*	*1.03%*
	Total	**48.10%**	**3.80%**	**42.90%**	**25.10%**	**13.40%**	**42.66%**
	(between employment centers)	*55.80%*	*1.80%*	*25.50%*	*31.60%*	*9.70%*	*18.21%*
large flows (> 400 commuters) *(incl. trips between employment centers only)*	**short distance < 5km**	**56.10%**	**28.80%**	**34.10%**	**23.50%**	**40.90%**	**30.21%**
	(between employment centers)	*59.30%*	*27.80%*	*30.50%*	*25.20%*	*39.20%*	*23.88%*
	medium distance [5-20] km	**68.60%**	**1.70%**	**9.30%**	**44.80%**	**9.10%**	**1.25%**
	(between employment centers)	*70.00%*	*1.70%*	*8.90%*	*46.70%*	*8.60%*	*1.03%*
	long distance > 20 km	**74.70%**	**0.60%**	**0.20%**			
	(between employment centers)	*66.00%*	*0.50%*	*0.20%*			
	Total	**59.60%**	**22.90%**	**43.60%**	**24.80%**	**39.70%**	**31.45%**
	(between employment centers)	*62.40%*	*21.80%*	*39.60%*	*26.40%*	*37.90%*	*24.91%*
all flows *(incl. trips between employment centers only)*	**short distance < 5km**	**50.34%**	**25.20%**	**44.40%**	**21.76%**	**35.13%**	**48.25%**
	(between employment centers)	*57.82%*	*25.26%*	*34.50%*	*25.26%*	*35.41%*	*30.03%*
	medium distance [5-20] km	**49.57%**	**1.25%**	**42.40%**	**25.86%**	**4.09%**	**35.08%**
	(between employment centers)	*59.62%*	*1.29%*	*28.10%*	*32.99%*	*3.95%*	*14.37%*

[11] *Stadtschnellbahn* : suburban railway network for Rhine-Ruhr region

long distance > 20 km	**52.44%**	**0.76%**	**13.20%**	**15.58%**	**0.10%**	**16.67%**
(between employment centers)	*60.12%*	*0.65%*	*5.30%*	*21.06%*	*0.00%*	*7.00%*
Total	**50.85%**	**11.80%**	**100.00 %**	**23.71%**	**23.21%**	**100.00 %**
(between employment centers)	*59.16%*	*13.45%*	**67.80%**	*28.07%*	*25.79%*	**51.4%**

Table 3 : Cross table of average use of transport modes with respect to trip distance and importance of flows. Sources: RGP (1999), EGT (2001), IGVP (2000), PddV (2004).

Overall, using these figures we could establish that for commuting trips only, Paris region is more efficient per trip, in terms of energy consumption and CO2 emission (figures for energy and CO2 comes from ADEME, 2008 report). This is due partly to an average commuting distance higher in the German region, but in majority to the different transport modes breakdown. Using the average Paris mode shares for the categories showed in Table 3, we showed that both energy consumption and CO2 emissions differences between the two regions are largely due to a different ability to pool commuters together : using the same aggregated OD-matrix but changing the transport modes breakdown corresponding to each situation (scarce, medium, large flows and short, medium, long distance), we observed that the indicators reduce from +70% to +20% (CO2 emissions) and from +40% to + 15% (energy consumption).

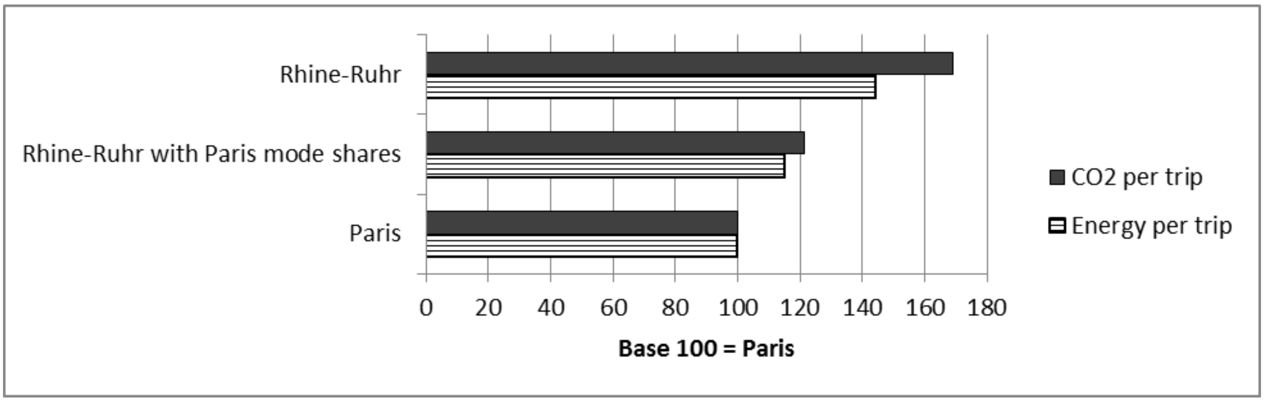

Figure 8 : relative performances of Paris and Rhine-Ruhr commuting system in terms of energy consumption and CO2 emissions.

Implications for planning

At a time when new major projects should pave the road for sustainability in those two metropolitan regions, there is a need to take into account the long-term coevolution of transportation networks and spatial structure, at the metropolitan level. Hence, apart from increasing population density around major transport nodes (Cameron & al., 2004), what can be done in order to increase the proportion of journeys undertaken by public transport is to increase on well selected links the flows that are likely to be undertaken by public transport above the threshold aforementioned, and to reduce the flows that are too far below it.

European and American cities remain generally fragmented, both functionally and administratively. However, the urban sprawl observed since the industrial revolution has resulted in administrative reorganisation in most European countries. The power balances between central government, metropolitan regions and local government entities are shifting, though slowly (Brenner, 1999 ; Lefèvre, 2009). The examples of Paris and of the Rhine-Ruhr regions illustrates the planning challenges facing urban regions with populations in the tens of millions, where multiple functional and decisional levels overlap: policies implemented at local or metropolitan level, influence the determinants of daily mobility on all spatial levels.

One might wonder which planning tools can be the most efficient to encourage wider share of transit for commuting within metropolitan regions. We emphasize, in this article, the necessity to look at existing flows between places in addition to indicators of local urban form and metropolitan structure to better understand the room for change in each metropolitan region.

The results found can have important repercussions in the planning process of large metropolitan regions: firstly it suggests the existence of a threshold above which a slight increase in flows can be associated, indirectly, with a large increase in transit use. In other terms, once planning for a new transportation infrastructure, one should consider the ability of the improved links to help the system to reach sufficiently high level of flows. If the association between total amount of flows and transit share is only indirect, it is important to take into account the existing metropolitan structure when studying a large metropolitan project. For some links, the target of number of commuter to reach might seem too far to justify large investments in transit systems unless density can increase significantly due to the project.

Demand for transportation is served differently in the links between communes that have the highest commute flows. Scarce demand cannot be served by heavy transport mode, which explains the amount of literature nowadays dedicated to new forms of car sharing (Neoh et al., 2015). Hence, we observe empirically an increase, in both regions, for equal travel distance, of the public transport share, with respect to the number of commuters on that OD link (the averages are calculated on regular logarithmic intervals). In order to prevent distortion resulting from potentially varying distances between zones, the averages have been calculated at 5-kilometre travel distance intervals, and all roughly follow an upward trend. While qualitatively expected, the way each metropolitan region can foster transit use when demand on a OD link change is crucial to assess the real potential of short to medium term change in mobility practices. Hence, the two metropolitan regions demonstrate different abilities to organize transportation system with mass transit infrastructures for the same amount of flows and the same distances: Paris region reaches around 80 % of trips by transit when flows are larger than 1,000 commuters, whereas the Rhine-Ruhr region only reaches 60 % for similar flows. This raises the question on what is the underlying reason for this 20 % difference. One interpretation can be that in the Paris region, the greatest flows concerns Paris' city center, with possible direct route connection compatible with high transit patronage, whereas in the Rhine-Ruhr region, such transportation organisation is not possible due to the more dispersed urbanization. Moreover, the radial network of Paris region gives more space for some links to have a high degree of intermediate centrality, meaning that the same rail link serve the journey of of lot of various OD-links.

This article has primarily sought to demonstrate the complexity of the overlaps between operational levels in two metropolitan regions with populations in excess of 10 million and it would be interesting to extend the scope of analysis to other regions of comparable size within or outside Europe. At what level(s) should urban coherence be encouraged to allow for a more sustainable development of metropolitan regions? We must consider the long term inertia in mobility, and more importantly of the social structures of governance (Paasi, 1986) to be able to influence the path of cities towards sustainability.

In this article, we have chosen to compare with harmonised data the Paris and Rhine-Ruhr metropolitan regions, in order to illustrate the complexity of mobility patterns construction over the long term. The use of harmonised data allowed international comparison of mobility within a polycentric common framework. We found similar average trip length for the two regions, which was surprising considering the very different spatial structures of the two metropolitan areas. Also, for commuting trips, we observed higher active travel use and car use in the Rhine-Ruhr metropolitan region, and higher transit use in the Paris area. These differences can be attributable to cultural differences or to differences in the interaction between the transportation system and the location of houses and activies. The latter was the focus of the study.

We showed a paradox that establishing a better self-containment of labour zones could lead to less transportation pooling and in the end a less sustainable mobility system, in so far as medium and long-range flows might not be effectively channelled via heavy transportation infrastructures. There is therefore a real challenge if we wish to reduce commuting distances, as advocated by the literature of Excess Commuting (Hamilton, 1982): it could result in less effective transportation system for the long distance and ultimately in an increase of car use within the metropolitan region.

Such counter-intuitive effects of planning policies decided merely at one spatial level have already been observed in the past (among many : Appert, 2004 about London). The Rhine-Ruhr region too seem in need to make long-term planning decisions, between on the one hand reinforcing the local level, and on the other hand improving the organisation of flows at the metropolitan level, which are at present primarily car based.
Whilst Paris metropolitan region seems better able to pool demand for transportation because of the existence of Paris city-center as a central hub, the region is at a turning point with the emergence of new centralities that are not necessarily compatible with maintaining an efficient radial public transport network. Figure 9 illustrate the challenge lying ahead for Paris agglomeration, having a new territorial organisation made up of 12 districts outside Paris city center. A future metro ring will deeply reconfigure accessibility within the metropolitan area, linking suburbs to one another. It will presumably transform the dominant radial nature of flows today. Two contradictory effects can be expected: on the one hand it might increase the number of workers living in less dense suburbs, where car is the main transport mode used, especially for non-commuting trips; on the other hand if densities increase sufficiently, one might expect transit use to be high in these areas that would ultimately look very much like Paris city center.

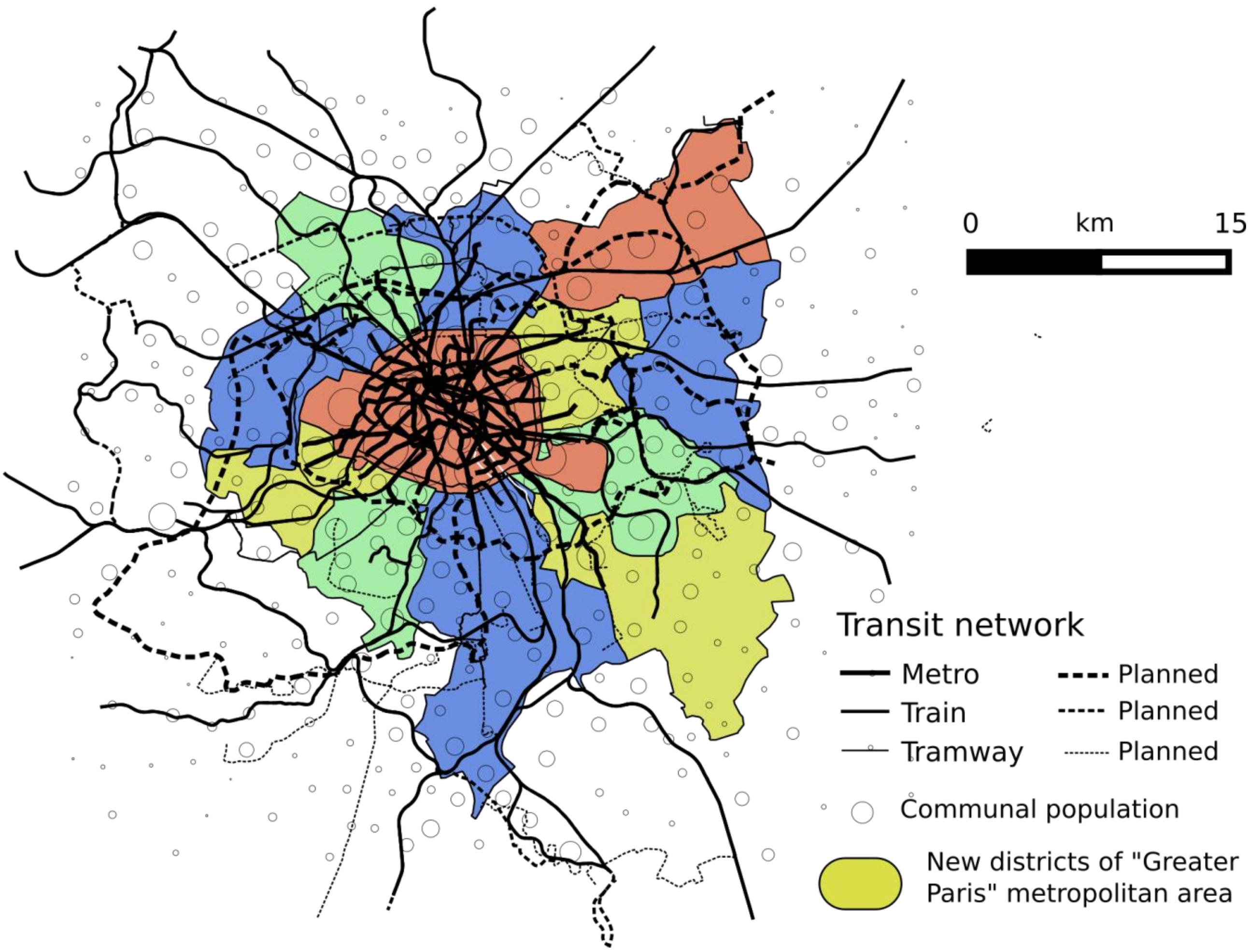

Figure 9 : Paris greater metropolitan area, and planned orbital metro (dotted line).

It should be noted that these figures should not be taken as proof that daily mobility is more sustainable in Paris than in the Rhine-Ruhr region. To take the research further, the spectrum of mobility needs to be widened, since commuting only accounts for a fraction of total mileage in metropolitan regions. Also, it increases the complexity of the spectrum of analysis, as it is more complicated to channel non-constraint trips by transit than commuting trips, especially in European context where jobs have high level of concentration.

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