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Analysis of public transportation in seven European cities: learnings for improving the transit network of Barcelona

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ANALYSIS OF PUBLIC TRANSPORTATION IN SEVEN EUROPEAN CITIES: LEARNINGS FOR IMPROVING THE TRANSIT NETWORK OF BARCELONA

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ABSTRACT

There are so many transport networks in the world, since some very complex to others that are simple. Public transport is not only a symbol of a city but also of its society. It is known that people chose the transport to use taking into account different variables of time, costs, comfort… but the question also can be, how do operators choose?

Different public transport authorizations have tried several times to put the variables of the operators together, sometimes trying to force them to show statistics and numbers of them. The reality we face is that this is not a reality. Some studies try to compare the classic variables of offer (car-km) or demand (passenger-km), but there is no indicator of correlation among velocity or energy consumption.

More important, there is no database where to consult cities' public transport with all its variables. And, added to this: each public system depends on each society where it is implanted. So it makes extremely difficult to make technical comparisons with no taking into account the random fact of the society.

The main objective of this study is to define a database to consult the indicators of public transport. With this database, analyze and compare the public transport of the cities in two steps: a first analysis of the city and a second comparing all the cities by transport and with the totality.

This comparison will lead to the fact that there is no comparison possible with some aspects, so analyzing each city and the comparisons; we can arrive to a formula that can help, in the future, to analyze other cities to incorporate to the existing database.

FINAL MASTER THESIS

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1. INTRODUCTION

This paper presents a study comparing Public Transport (PT) systems of seven European cities including main features of its supply and demand , alongside with its demographic and territorial characteristics.

The selected cities are: Barcelona (the city from which this report is made), Berlin (with a high share of public transport trips), Hamburg (which was the first European city to introduce bus lanes and with a similar PT use to Barcelona), London (where the suburban services are the oldest ones and with the highest rate of PT use), Madrid (capital of Spain and the city which has the more important metro development in Europe over the last 20 years), Munich (a city with similar features as Barcelona regarding its PT scheme) and Paris (the first metropolitan area un Europe, as far as the number of inhabitants is concerned, and the second one regarding the surface with a very outstanding PT system).

The aim of this study is to analyse the strengths and weaknesses of the public transport network of such seven cities, making a comparison among them, analysing main features mainly based on cost operation, revenues from tariffs, energy consumption, main features of its supply and demand for each one of the different modes of transportation: suburban trains, metro, tram, local and metropolitan buses.

To do that, the report presents first an introduction to the general data of each city, by identifying them in the context of the interest of this report.

So, the study is not a comparison of different PT system but a general comparison among the PT of the whole city one by one. To do that, the parameters of each mode of transport have been reduced to a common value: coach-km, passenger-km, EUR (cost and revenues), kWh, km/h and so on.

It has not been easy to catch all these needed data. The vast majority of them have been directly collected from internet and other sources. In some cases data have been estimated based on reasonable hypothesis. Not all cities provide data in a transparent way. It is necessary to say that the higher level of transparency has been got in the case of Barcelona, since both TMB and ATM website provide lot of detailed information. On the contrary, cities like Paris provide less comprehensible information.

In some cases the provided figures have been corrected in order to get a proper comparison. This is the case of Barcelona. In this city the accounts of the Bus and Metro service provided by TMB includes some items that have been excluded to make sure that a right comparison is done. This has been the case of the cost and revenues from the touristy bus (excluded) and the infrastructure costs and other external financial cost that were include in the ordinary accounts but excluded in this comparison.

1.1. Motivation

As was first introduced in the abstract, several parts of the public transport have not been recorded yet in a database. Even the European Union has asked for full transparency, it can be consulted in the paper (European Commission, 2017) and gives some advises for the correct shared information.

However, we live in an era where, although the information is highly easy to share, it also means an acquired power of each company. In the case of public transport, some data can be an exhibition of information that does not interest many companies, since they prefer to keep the distances with the competition.

We live in a time where small mobility and concern about climate change are affecting public transport (although this would give us a completely new work model) and the information is kept locked up to avoid competition from additional transport services.

Therefore, one of the reasons for doing this work is based on the search for information that many companies keep and do not want to share easily, in order to perform an analysis of each city and its public transport, analyzing pros and cons in each way Of transport.

This comparative need arises from a premise: Mobility is a multidimensional concept since it simultaneously expresses the potential for a movement as well as the movement itself. It is at start a choice to be exercised or not depending on economic and social goals (Rodrigue, 2017).

How can we compare two cities if they themselves are defined by different social roles, by different economies (even economies of scale can change between different cities)? Therefore, the idea of working on the one hand, cities separately, understand them, see what type of system they have and, from there, continue with an analysis that leads us to the key indicator to get a comparison between cities to replace the abstraction of considering society as a variable.

With the initial general data gathered (which will be exposed in the next pages), it can be determined the aim to proceed with further analysis of the different cities and transports presented, such as:

Ratio of trips per inhabitant

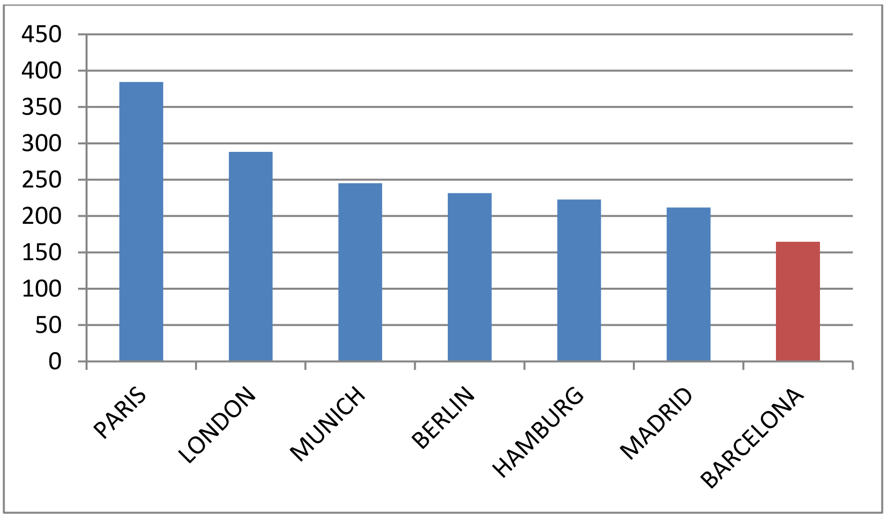


Figure 1. Trips per inhabitant of the cities studied. Source: own elaboration.

Barcelona present the lowest ratio of trips per inhabitant. This is reinforced with the usage of the public transport in front of the private vehicle:

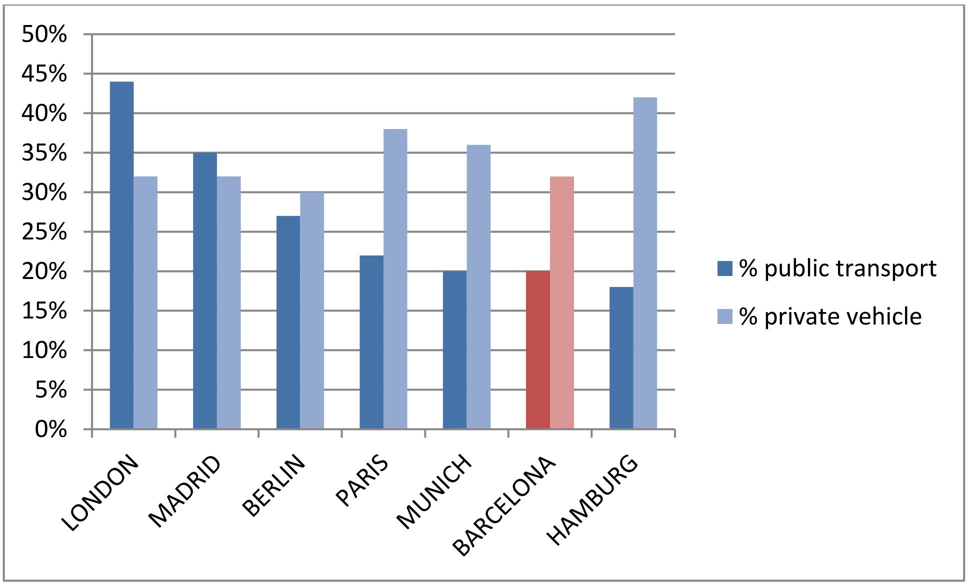


Figure 2. Modal split for public and private transport. Data ordered from highest use of public transport to lowest. Source: own elaboration.

So, it is remarkable that in the Catalan city, there is an important lack of usage of the public transport. There are only two cities where the usage of public transport overpasses the usage of the private vehicles.

It is surprising that Paris, that has a high ratio of trips per inhabitant, has not a very high usage of public transport. That means that most of the public transport trips are, possibly, realized in the inner city, not in an interurban term. On the contrary, London presents high value of modal split and also in number of trips per inhabitant.

On the other hand, can be analysed, as commented, the offer density of public transport lines, which leaves another curious factor: London has high density while Paris low.

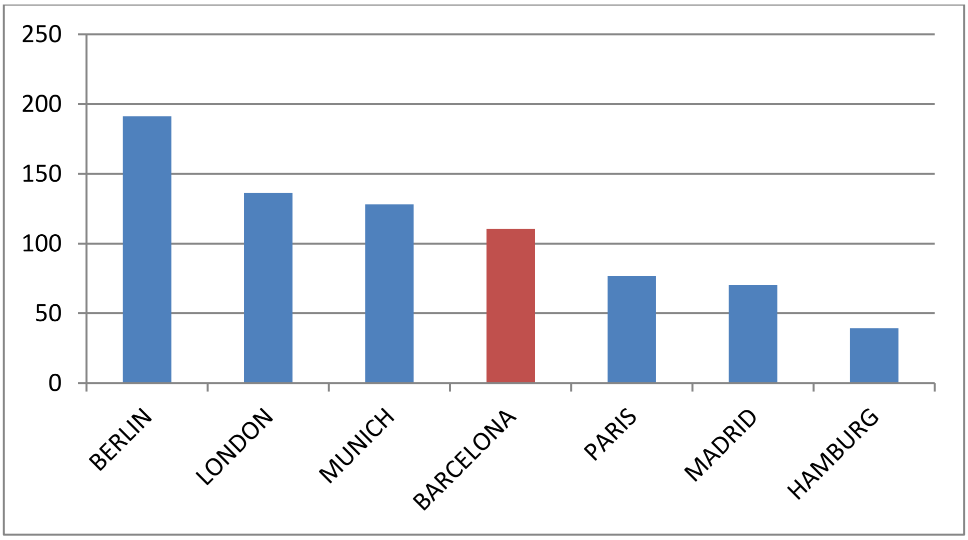


Figure 3. Transport density in thousand car-quilometer per unit of area. Source: own elaboration.

That indicates that the public transports analysed have very different aspects, so a more specific analysis among them, with more operational values must be run.

Other important aspects that modulate the public transport of a city are the possession tax of vehicles and the unemployment rate:

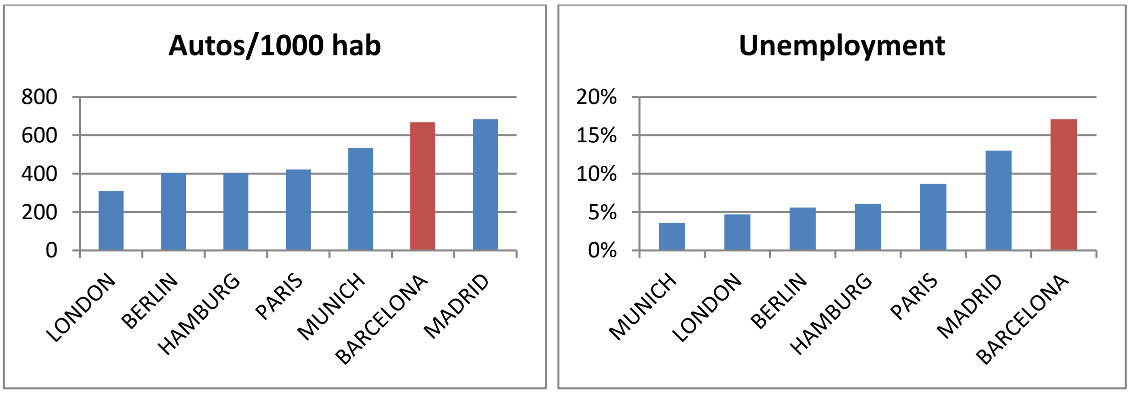


Figure 4. Demographic indicators. Source: own elaboration.

Again, London and Paris, two reference systems, have different ratios in this aspect. It is relevant to see that Madrid and Barcelona have quite similar numbers, despite the usage of public transport in Madrid is higher than in the Catalan capital.

Finally, other relevant aspects that we can find in this initial analysis are:

- **Commercial speed.** In general, a bad commercial speed makes the transport compromise with the users, who would rather prefer to use another way to travel. This is an important aspect to look to as, for example in Barcelona, there are many companies that influence on it. For instance, urban buses in Barcelona operated by *TMB* have a commercial speed of 13,3 km/h, way lower than other, but as *AMB* buses have higher speed, it has to be analysed carefully.
- **Prioritization of traffic lights in the developing world.** All cities analysed have, in general, priority traffic lights, although it was not always possible to find information on the same terms (intersections, traffic lights ...), it can be seen that in all cases, the priority is increasing annually.
- **Segregation of transport.** In most cities there are bus lanes and segregation for tram and other public transport services in the area. London is the city where more measures to improve road transport have been implemented, along with Berlin.

1.2. Objectives

As mentioned a few lines above, the objectives are clear and more given the previous premise that we have cited:

- Defining each city and its meanings of transportation, analyzing the main variables to use when comparing with other cities.
- Creating an indicator to use when comparing different cities and their transportation system.
- Analyzing the weakness and the strengths for the cities by itself and by comparison.
- Defining models to follow in each city, especially Barcelona, in order to create a better public transport solution.

2. Methodology

This work is a source of information search to create a database.

The tool used for the grouping and ease of data processing has been Excel, a tool for calculating and collecting data that has made it easier for us to play and determine which data were most relevant.

The research carried out through the reading of several annual reports of the different companies, as well as related pages that have been able to deal with similar issues, as will be cited at the relevant times.

Likewise, but, no data of such elaborate calculation have been found as the one proposed, there is an infinity of data to be treated that would be of interest or could redefine the indicators taken at the end.

For the final elaboration of the data, each city has been taken first, separately, adding the data that was collected. Subsequently, a table with all the data of all the cities has been created, so that a global vision of everything can be obtained.

Long time has been invested in thinking and talking about the concept of efficiency of a Public Transport Network. In this report the concept of efficiency is measured by two parameters.

A) Catchment of passengers (attraction of a PT system)

This is an easy parameter to be calculated. It is the quotient between the yearly passenger demand and the population living inside of the area of PT governance.

As told, data are calculated taking into account the area of governance of PT in each city. They are: London (TfL), Paris (STIF), Madrid (CRTM), Barcelona (ATM), Berlin, (land), Hamburg (land) and Munich (MVV).

B) A function that merges the 3 main parameters related to the efficiency when transporting passengers: speed, cost per unit and energy consumption.

To assess the cost and the energy efficiency of the metropolitan transport scheme, a new efficiency function has been defined. At the moment this new function will be called as PT Function, or Munich's function, in tribute to this Bavarian city which scores the highest value.

This function is defined as follows:

$$\textbf{PT Function} = S / (C*E) \qquad \textbf{(1)}$$

Where S = Speed (km/h): C = cost per unit (EUR/coach-km); E = Energy consumption per unit (kWh/coach-km).

3. State of the arth

As previously said and commented, there are not several comparison studies that take into account as much as this paper indicators, though there are several such as (Dhingra, 2011) that recall to some indicators. In general, the main indicators that we can find are:

- Operator and offer indicators: those that mean something in order to understand de service offered such as car – km, which indicates the performance of the service
- Demand indicators: those that, mainly, make the pint on the passengers, how the service is used by the passengers.

Those indicators, though, are typical and those are the ones that are easy to find, there is no problem for the administrations in offering this data. We can say that this is the "normal data".

The interest we find in this report is to analyze more than that. The collected data for each city and the transportation parameters are gathered in Annex. For each of seven cities a set of data are presented in raw format and grouped in 5 categories: suburban rail, metro services, tram services, urban buses and interurban buses.

For each city the gathered information for each kind of transport is the next:

Supply

- Coach-km (million)
- Rail Share supply
- Length (km)
- Energy (GWh)
- Energy Consumption per unit (kWh/coach-km)
- Energy Consumption per unit (kWh/passenger)
- Energy Consumption per unit (kWh/passenger-km)
- Speed (km/h)
- Annual Costs (M€)
- Cost/Coach-km (€)

Demand

- Passenger (million)
- Average passenger trip (km)
- Passenger-km (million)
- Rail share demand
- Annual incomes (M€)
- Cost/passenger-km (€)
- Cost/passenger (€)
- Energy / trip (kWh)
- Energy / pax-km (kWh)
- Incomes / passenger-km (€)
- Incomes / passenger (€)
- Occupancy (passenger-km/coach-km)
- Passenger / km network (million)

Some of these indicators have been esily obtained in the principal web of the transport operators. However, some of them, have been ridicously difficult to obtain, making us arribe to a conclusion: **the power of the data is more powerful than the power of the information and improvement**.

What concerns society today is fundamentally about climate change. There are numerous studies that deal with this issue, trying, above all, to gather information about the emissions that public transport may have. Likewise, what we often find, as in the case (PhD., 2016) is that the data they give us is generic or does not respond to a source beyond the brands that sell vehicles (and there is also no great transparency in it).

There is also this problem in other aspects, such as financial. There are parts of the accounts that the transport operators share without problems but always with some difficulty to find it or, even, on request.

In this regard, we must congratulate the city of Barcelona that has been one of the most transparent.

There are many initiatives to improve in this regard, but the question we must ask ourselves is whether operators have the same interest as we do in it.

We could also go into the detail of why choose some indicators or others. The truth is that when we talk about public transport, as we have said before, not only the numbers affect us to the final result of the application. Of course the fleet is important, but so are the people to whom the service is intended.

Mobility refers to the time and costs required for travel. Mobility is higher when average travel times, variations in travel times, and travel costs are low. Indicators of mobility are indicators of travel times and costs and variability in travel times and costs (National Academies of sciences engineering medicine, 2002). This point, it is important to take into account, people, the society in which they live, defines the mode of transport used. Therefore, the difficulty of making comparisons enters different cities, which respond to different mobility patterns due to their social differences. We are not talking only about the economic level (which is also a factor to take into account) but also in the way in which society understands mobility.

Therefore, we will proceed to the initial presentation of the cities, as such, and their transport system, to better understand what we have. All references in this section that follow are taken from the data collected, mostly, by operators or transport authorities.

4. The study cases

In order to make a correct comparison of the cities, the differences and similarities that cities present between them must be seen. So main territorial data of the seven cities appear below. This will help to understand which are the identifying details of the cities to see the impact of their public services and among each other.

With this information, a first glimpse can be done on which cities do present similarities in this assessment. Included are also data of users' preferences when choosing a mode of transport for their journeys (Modal share).

	BARCELONA	BERLIN
Territorial scope	Metropolitan region (7 fare zones)	Metropolitan area
Municipalities	346	67
Population (hab)	5.700.000	6.004.857
Annual PT Ridership	938.900.000	1.391.000.000
PT Trips/inhabitant	165	232
Area (km^2)	3,235	3.743
Density (inhabitants/ km^2)	1.762	1.604
Transport authority	ATM	VBB
Major PT operators	TMB, Renfe, FGC, AMB, TRAM	BVG, S-Bahn, Regio Bahn
	HAMBURG	**LONDON**
Territorial scope	Metropolitan	Metropolitan area
Municipalities	17	48
Population (hab)	3.458.000	13.879.757
Annual PT Ridership	770.500.000	4.000.000.000
PT Trips/inhabitant	223	288
Area (km^2)	8.616	8,382
Density (inhabitants/ km^2)	401	1.656
Transport authority	HVV	TfL
Major PT operators	Regio-Bahn, S-Bahn, Hochbahn, A-bahn, HHV	TfL, LUL, DfT, FirstGroup, LOROL, London Buses
	MADRID	**MUNICH**
Territorial scope	Metropolitan area	Metropolitan area
Municipalities	179	176
Population (hab)	6,545.809	2.899,000
Annual PT Ridership	1.385.700.000	710.919.090
PT Trips/inhabitant	212	245
Area (km^2)	8.496	5.530
Density (inhabitants/ km^2)	770	524
Transport authority	CRMT	MVV
Major PT operators	EMT, Renfe, Metro MADRID SA.	Regio Bahn, S-Bahn, MVV, MVG

Table 1. Cities identification data (1). Source: own, consulting main web of operators.

	PARIS
Territorial scope	Île-de-France (Metropolitan area)
Municipalities	8
Population (hab)	12.142.802
Annual PT Ridership	4.668.000.000
PT Trips/inhabitant	384
Area (km^2)	12.012
Density (inhabitants/ km^2)	1.011
Transport authority	STIF
Major PT operators	RATP, SNFC, OPTILE

Table 2. Cities identification data (2). Source: own, consulting main web of operators.

With this first vision, we can appreciate that the transport systems which attract more users (taking into account the ratio of passengers compared to the total number of inhabitants in the study area) are, as mentioned in the introduction, Paris and London, with about 400 and 300 passengers/inhabitant-year respectively. These two cities could become a model, with a transport system that offers features that could satisfy users demand. Later, a deeper look at the vehicle owned rate and congestion will be done, in order to analyse the city behaviour.

We do have to take into account that transit is not only a meaning of transportation but a mirror of the society. Each city has different people, so their behaviour will contribute to have different ways of public transport. In order to get through that, we will create the term "average city" meaning not only the average of values but of the behaviour of society, making easier to compare among cities.

In this ratio, the two Spanish cities analysed are placed in the lowest position, being the lowest the Catalan capital. This may reflect that improvements can still be done in order to make the system more attractive, and learn further ways of operating the transit.

Moreover, another fact that might help to analyse the structure of the services offered by the cities of this assessment would be the concept of *density of public transport service*. The comprehensive analysis of supply and demand in cities will be carried later, however there can be a first glance by seeing the volume of supply (total coach-km of PT) on the surface of each area.

Even though the features of every PT are quite different, it has been supposed that a rail (metro, suburban trains) coach is compared with a bus coach and a tram represents 2 coaches. So, Metro represents between 5 and 8 coaches, suburban train 5/6 coaches, tram 2 coaches, and buses (single or articulated) a single coach.

Considering what has been stated in the previous paragraph, we have (expressed in millions of coach-km/km^2):

	Density transport (coach-km/km$^{2)}$
BERLIN	191
LONDON	136
MUNICH	128
BARCELONA	111
PARIS	77
MADRID	71
HAMBURG	39

Table 3. Identification data for cities (3). Source: own, consulting main web of operators.

It can be observed that the two transportation systems mentioned above correspond to very different structures. While London has a much higher density of transport, Paris offers a less dense structure, but o the other hand it owns the highest ratio of trips per person. It will be necessary therefore to focus on seeing what are the reasons that lead to a better operational service (if we consider that users choose the best option for them). It is noteworthy that the two Spanish cities have similar value of this ratio to Paris, making clear what was said in the previous paragraph, the potential attractiveness could be better than it is nowadays , considering that Paris is a benchmark in terms of public transport.

From the above tables it can also be seen what cities have a shape and structure of public transport more similar to Barcelona. All analysed cities analysed have at some point or other similar values, but not one could be considered, strictly, "like" the Catalan capital. That is why a more complete analysis is necessary.

Regarding transport, there are no data beyond those of each mode, which are important and must be taken into consideration while performing the study to provide an idea of what kind of city are in each case . These are:

- *Possession rate of vehicles*: Number of vehicles for private use motorized listed as registered, divided per 1000 inhabitants.
- *Congestion Level*[1]*:*shows the percentage of overtime led to stoppages due to congestion over a year. A trip made in a 36% congestion indicates that the trip will be 36% longer.
- *Unemployment:* ratio between the number of jobless among the total number of active people.

	BARCELONA	**BERLIN**
Metro Service	TMB FGC 8 and 4 lines	10 U-bahn S-bahn lines 15
Tram Service	6 lines	24 lines
Types	*Segregated and shared*	*Segregated in most*
Commuter service	RENFE FGC 10 and 10 lines	20
Bus Service	TMB lines 99 + TO + + Municipal DGTM	197 lines
Prioritization of traffic lights	*200 crossings*	*1.000 intersections*
Type entry	*One entrance*	*Mostly one entrance*
Bus lane (km)	*172,22*	*101,5 km (230 lanes) /direction*
Possession rate of vehicles (cars/1000 inhabitants)	667,9	403,1
Congestion	31,0%	29,0%
Unemployment	17,1%	5,6%

Table 4. Identifying details of public transport (1). Source: own, consulting main web of operators.

[1] Information provided by (TomTom International BV, 2016)

	HAMBURG	LONDON
Metro Service	5 U-bahn stops 91 (2 operators) 6 S-bahn stops 68 (1 operator) and 2 A 32-bahn stops (AKN)	11 LU lines and 7 lines DLR
Tram Service	Fi service in 1922	4 lines
Types	-	*Separated and shared*
Commuter service	9 líniesi 26 stations Regiobahn	Rail and Overground lines 9
Bus Service	696 lines 9.640 stops (18 operators)	493 lines
Prioritization of traffic lights	*32% of traffic lights*	*5.120 traffic lights*
Type entry	*One entrance*	*One entrance, ticketing (some)*
Bus lane (km)	*Not segregated*	*300,00*
Possession rate of vehicles (cars/1000 inhabitants)	404,0	309,4
Congestion	33,0%	40,0%
Unemployment	6,1%	4,7%
	MADRID	**MUNICH**
Metro Service	12 + branch	8 8 U-bahn and S-bahn
Tram Service	4	13 lines (4 night)
Types	*Traffic light priority, separated and shared*	*55 km segregated wave green full length*
Commuter service	9	11 lines grouped into three networks
Bus Service	204 + 439	327 lines
Prioritization of traffic lights	*Two crossings*	*100% 18 lines; 45 lines (25-80%). A total of 55% of the traffic lights (33 lights adding per year)*
Type entry	*One entrance*	*All doors*
Bus lane (km)	*87.95 (39% segregated)*	*23,00*
Possession rate of vehicles (cars/1000 inhabitants)	684,3	535,4
Congestion	25,0%	30,0%
Unemployment	13,0%	3,6%
	PARIS	
Metro Service	16 lines (303 stops)	
Tram Service	10 lines (186 stops)	
Types	*Separated and shared*	
Commuter service	5 RER lines (257 stops) + 10 Transilien lines (383 stops)	
Bus Service	347 lines + 35 night	
Prioritization of traffic lights	*Especially in roundabouts*	
Type entry		
Bus lane (km)	*300 segregated*	
Possession rate of vehicles (cars/1000 inhabitants)	422,4	
Congestion	32,0%	
Unemployment	8,7%	

Table 5. Identifying details of public transport (2). Source: own, consulting main web of operators.

It can be seen that the higher index of vehicle ownership occurs in Madrid and Barcelona, the two cities with less unitary use of public transport. But Paris, a city with high demand for public transport per capita, has also a low level value and also a low congestion. In the case of London, it has a very low rate of vehicle ownership, placing the English capital in the crosshairs of reference (despite its congestion level is high). That is one of the main problems when dealing with surface public transit: it has to be placed at the same space than the private car.

4.1. Barcelona

Barcelona is the capital of Catalonia and the second largest city in Spain. It has a wide range of public transport and it continuous the improvements (extensions of the system, introducing orthogonal bus networks in the city, new fare system and zoning, among others).

The metropolitan region was divided from 2001 into six areas or crowns, and a seventh area including the municipalities of counties of Berguedà and Ripollès jave been added in 2014, offering special rates (apart from integrated tickets) to move from these areas to the city of Barcelona.

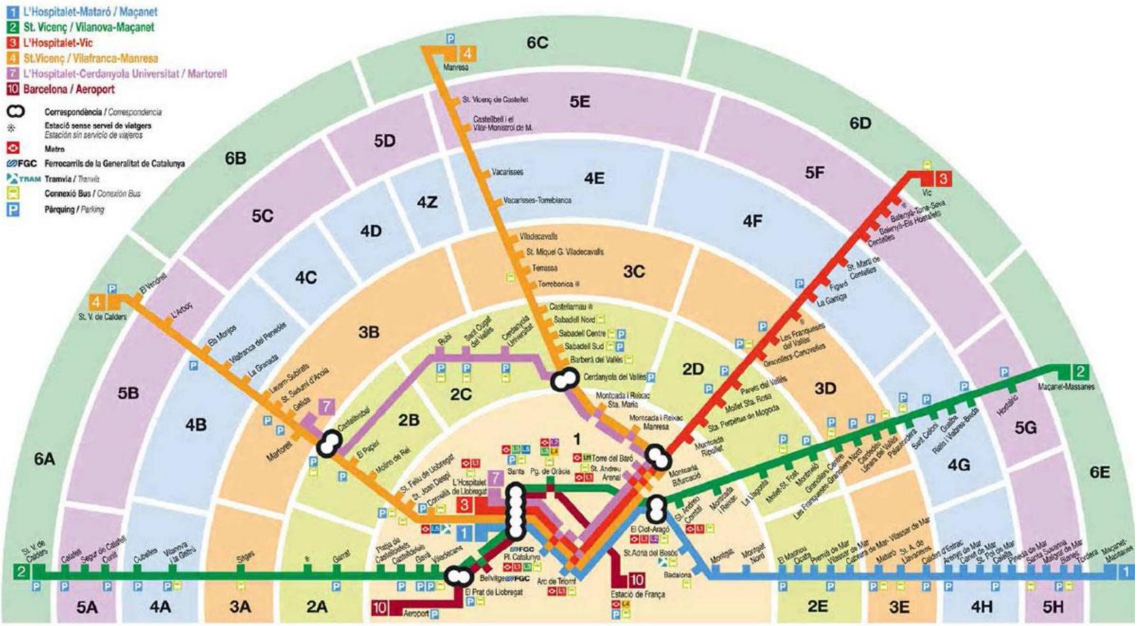


Figure 5. Map of fare zones in Barcelona. Source: TMB.

The authority of public transport in the metropolitan area of Barcelona is *AMB* (*Àrea Metropolitana de Barcelona)*, and the main operators are *TMB* (*Transports Metropolitans de Barcelona*) for buses and underground, *FGC* (*Ferrocarrils de la Generalitat de Catalunya)* operates the closer railway to the city, providing both metro and suburban trains), TRAM is in charge of the tramway system and, finally, RENFE, as in the case of Madrid, operates the suburban railways (and as well regional trains at more long distance and higher speed which are have not been analised in this report). There are also buses from *AMB* and other companies, mainly in the suburban and interurban transport. As has been mentioned, all PT services run in an integrated fair scheme from 2001. The financial knot is the Autoritat del Transport Metropolità, (Metropolitan Transport Authority) a mixed local-regional body which I in charge of collecting money from the public administrations and distribute it to the operators.

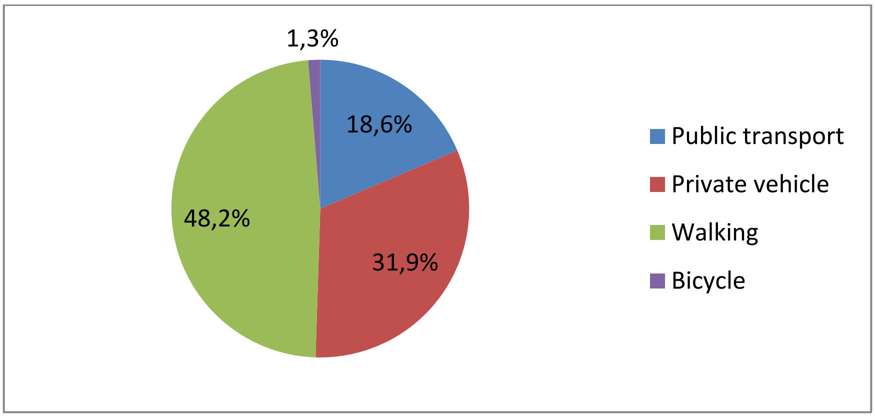


Figure 6. Modal share of different modes of transport in Barcelona. Source: own elaboration.

In the metropolitan area, the modal share of public transport is quite low, just a 18,6% . As mentioned previously, this share does not reflect the high rate public transport inside the city of Barcelona, where it would raise up to 29,5% of use of public transport, in front of 19,8% of private vehicles (in Barcelona the modal share is split in reverse than in the metropolitan area).

4.2. Berlin

Berlin is Germany's capital, being the largest city in Central Europe, with a very wide range of PT services, including services on the river, as in the case of London.

The metropolitan region of Berlin is divided into three zones, leaving the central area of the city in the first one.

Public transport in Berlin is managed by the authority *VBB*, while metro, bus and tram are operated by *BVG* and the suburban trains, both Regio Bahn and S-Bahn, are in charge of Deutsche Bahn *DB*. Since 1999 *VBB* established an integrated fare system, including the whole Brandenburg region.

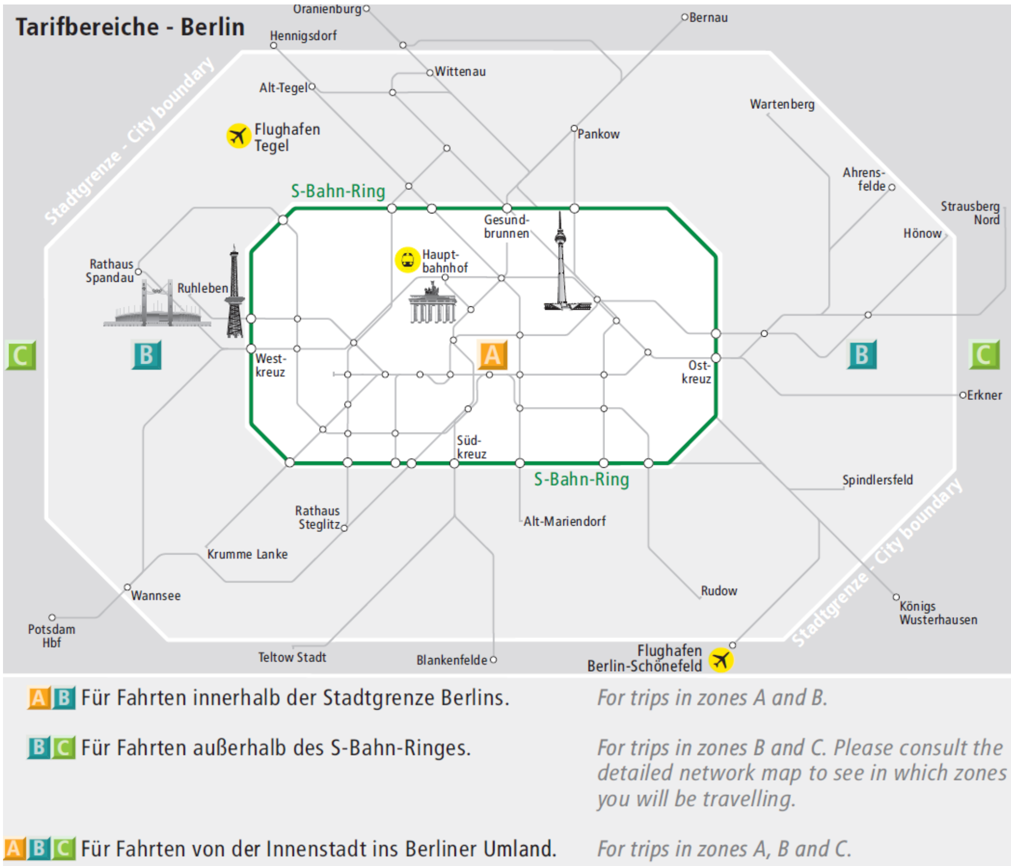


Figure 7. Map of fare zones in Berlin. Source: VBB.

The metropolitan area of Berlin is highly comparable to Barcelona in terms of population, despite the extension of its territory is larger. Regarding the rate of ownership of vehicles, both cities have similar figures but, in Berlin, the use of public transport exceeds the one from Barcelona by almost 10%, competing with private vehicles.

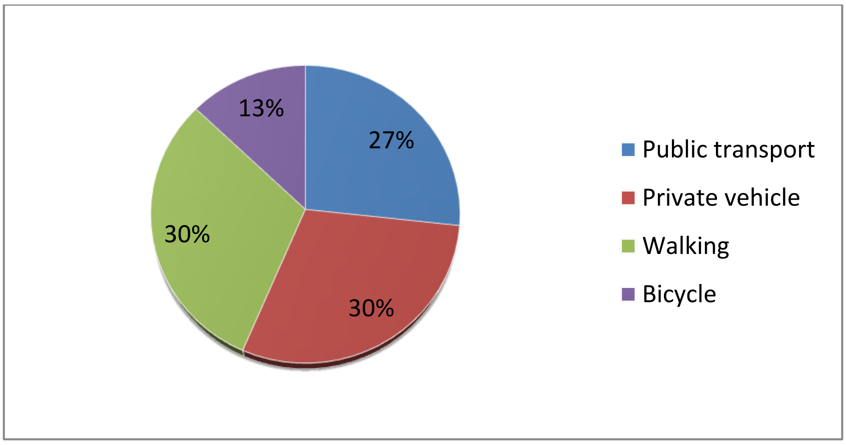


Figure 8. Modal share of different modes of transportation in Berlin. Source: own elaboration.

As in previous cases, the metropolitan area contains fewer municipalities, so major travel routes are done in the German capital.

4.3. Hamburg

Hamburg is the second largest city in Germany, presenting an extensive public transport network, although it does not provide tramway services since 1922. There are buses, metro and suburban train services, as well as the ferry service in the river.

The metropolitan area is divided into five zones, leaving, as in previous cases, the centre of the city in the central crown. The first and second zones embrace all the city, leaving the others to the suburbs that surround it.

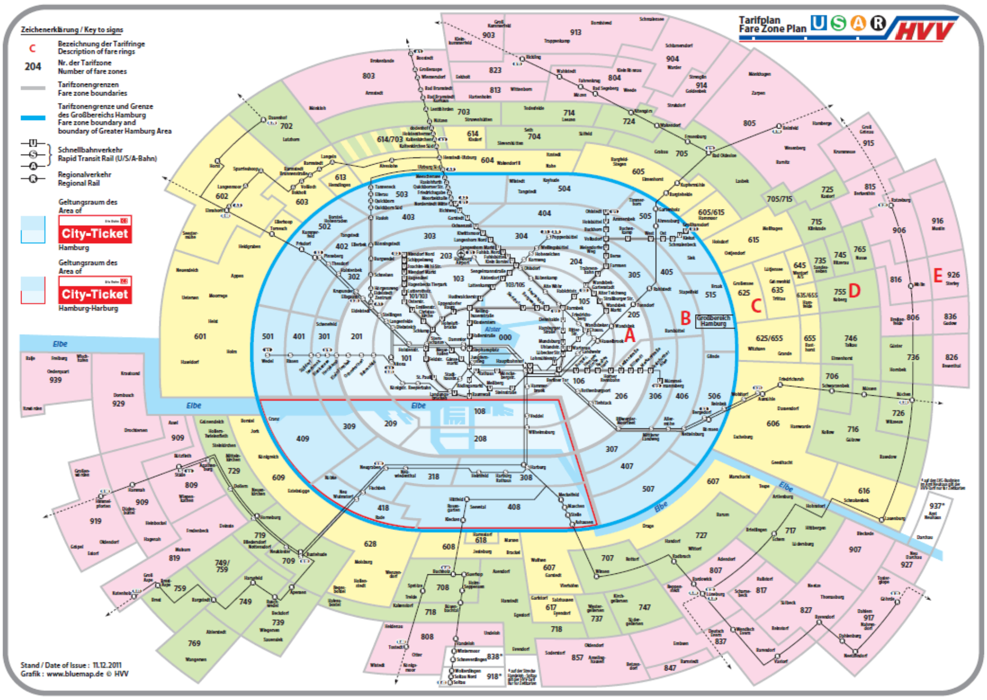


Figure 9. Map of fare zones Hamburg.

Public transport has three main areas: the city of Hamburg, Lower Saxony and Schleswig-Holstein, in which run PT services covered by 28 operators. The main operators are *HHA,* regarding metro and bus, and *VHH* for other buses and, as in all Germany, *DB* for the suburban rail service, both Regio and S Bahn. The integrated fare system Hamburg started its service in 1965.

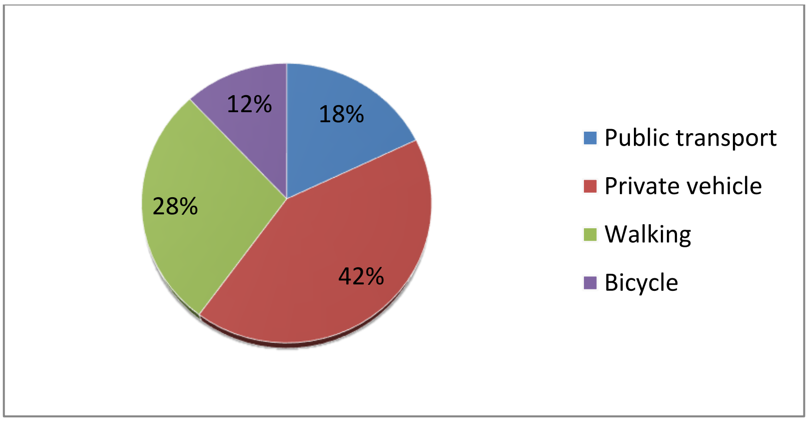


Figure 10. Modal share of different modes of transportation in Berlin. Source: own elaboration.

Public transportation in Hamburg is the area that presents less attraction (in terms of modal split), 0,4% lower than in Barcelona, even the number of trips per inhabitant is not the lowest seen in this comparison. So, with a population density similar to Barcelona, this city can be interesting to analyse as the modal share of public transport is practically the same and also the number of trips generated per inhabitant.

4.4. London

London, capital of Britain, is a city with a full range of comprehensive public service from suburban services varied (Rail, TfL rail) to metro (London Underground, London Overground and DLR), bus and tram services including some river ships (which cannot be analysed because they have no viable comparison to other cities).

As far as public transport is concerned, London's metropolitan area is divided into nine zones, which cover the whole city. The central part of the zones is the one that includes the city itself and the centre, just like in Barcelona's case.

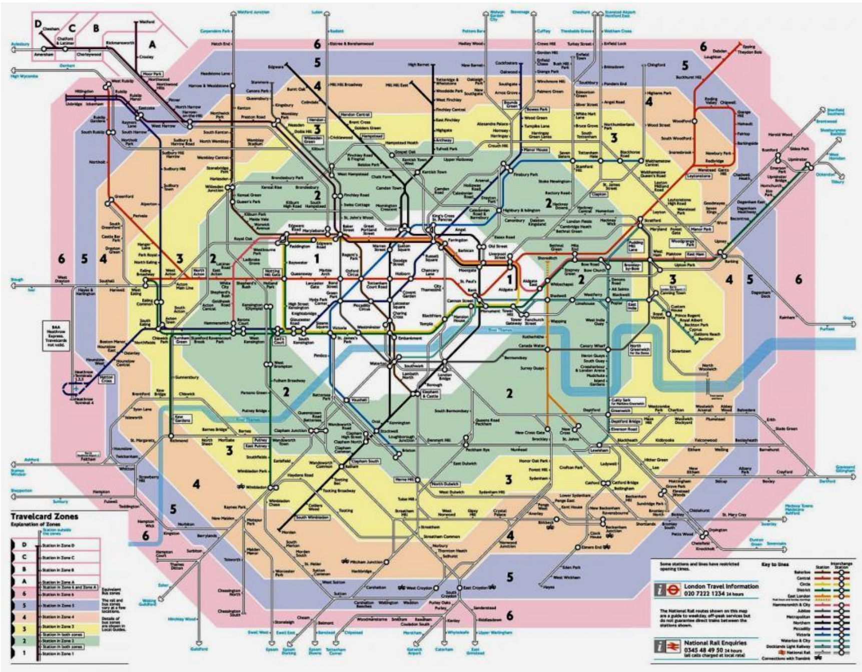


Figure 11. Map of fare zones in London. Source: TFL.

Transport is one of the four main areas of London's administration. All public transport is operated by Transport for London (TfL). Since 1933, the services of metro, bus and tramway began to take part of an integrated system. From 2007 the company also took control on some local railway lines from the so-called London Overground.

One of the differences between the mode of operation of both cities is that the thickness of operation covers the entire area of London Greater London (corresponding to the metropolitan area of Barcelona, with a total of 1,572 km^2 and 8,5 million, larger than the widely Barcelona).

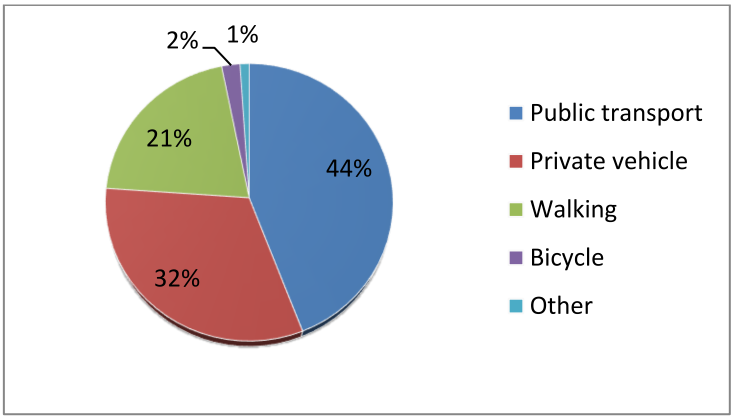


Figure 12. Modal share of different modes of transport in London. Source: own elaboration.

The percentage of use of public transport in the region of London is the highest in Europe, surpassing all other modes. London is the only city, as discussed below, among the selected in the study, where the entire range of public transport modal share has a superior value than the car. This is reflected also in city driving. Until 2011, the number of trips made by private transport has been reduced, stopping at 5,9 million trips per day (of which more than 3,6 million were made with more than one passenger).

One remark to be done is the number of municipalities that make up the metropolitan area of London, which is lower than in the case of Barcelona. This is an indicator that municipalities have a greater area than the ones in Barcelona, so it is expected that the average travel distance will be longer than the one in Barcelona, and so more potent interurban network.

4.5. *Madrid*

Madrid is the capital of Spain, the third most populated areas in Europe. The public transport network that supply the city of Madrid is, in most of the cases studied, complete from suburban rails to local buses.

Madrid metropolitan area is divided into four crowns (A, B, C, E). The area A comprises the entire territory of the city of Madrid, and the last one comprises the most remote areas of the capital, including the municipalities of near provinces as Toledo, Guadalajara, Avila and Segovia.

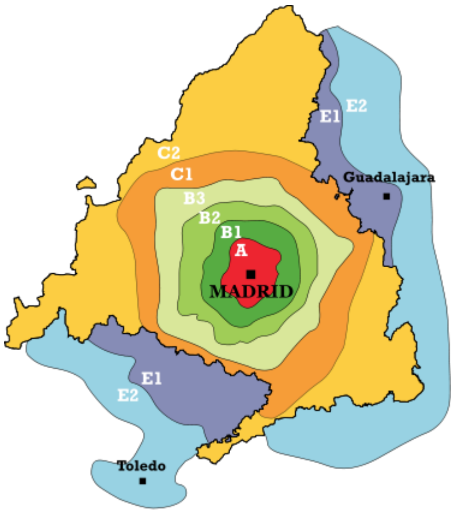


Figure 13. Map of fare zones in Madrid. Source. CRTM.

Public transport is run by *Consorcio Regional de Transportes regular Madrid* (CRTM), a public company dependent on Madrid. The Madrid's bus is operated by the EMT *(Empresa Municipal de Transportes)* , Metro and trams service are maneged by *Metro Madrid* , *RENFE* in the case of the suburban trains, and a range of private companies that manage bus services under concessions and one peripheral rail line outside of the capital.

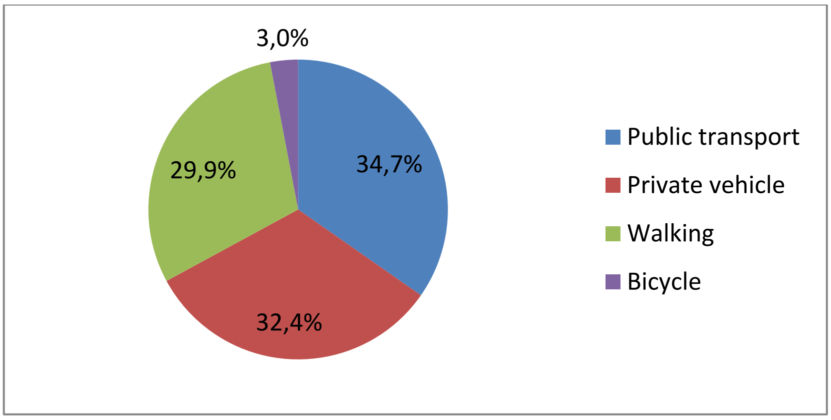


Figure 14. Modal share of different modes of transportation in Madrid. Source: own elaboration.

The modal share of public transport in Madrid is one of the highest of this study, although its number of trips per inhabitant ist no very high . In general, most trips are made on the metro (more than 40% of them), followed by bus (30%) and other transport. It is surprinsing the low shareof the tramway: it is barely use by citizens, being a fairly recent acquisition in the territory, it is maybe not having too good reception.

4.6. Munich

Munich is the third largest city in Germany, with a range of powerful public transport including suburban services (Regio Bahn), metro (S-Bahn, U-Bahn), buses and trams.

The metropolitan area is divided into four fare zones, with the city located in the first zone.

Train connections provide lots of links with the entire German region and as well with the whole country and with an extensive international network. All these train services are operated by Deutsche Bahn. Urban services are operated by MVG, grouping, finally, all means of transport in the MVV managing body.

The operations of public transport in Munich began to form an integrated system with services run by the MVV from 1978, with a restructuration of the tariff system and zoning in 1999, similar to the case of Barcelona (2001).

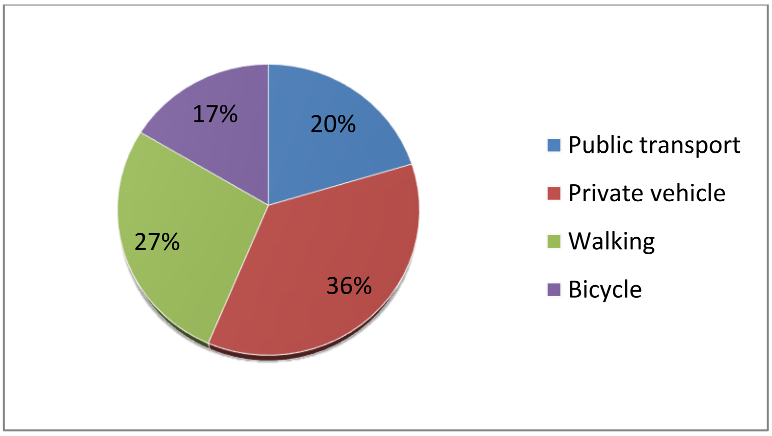


Figure 15. Modal share of different modes of transportation in Munich. Source: own elaboration.

With less population density than Barcelona, Munich has a higher rate of vehicles ownership per capita than the Catalan capital. Munich has, however, more use of public transport in the metropolitan area than Barcelona (2,4% more), although not comparable with the use of private vehicles, which is exceed by more than 10%.

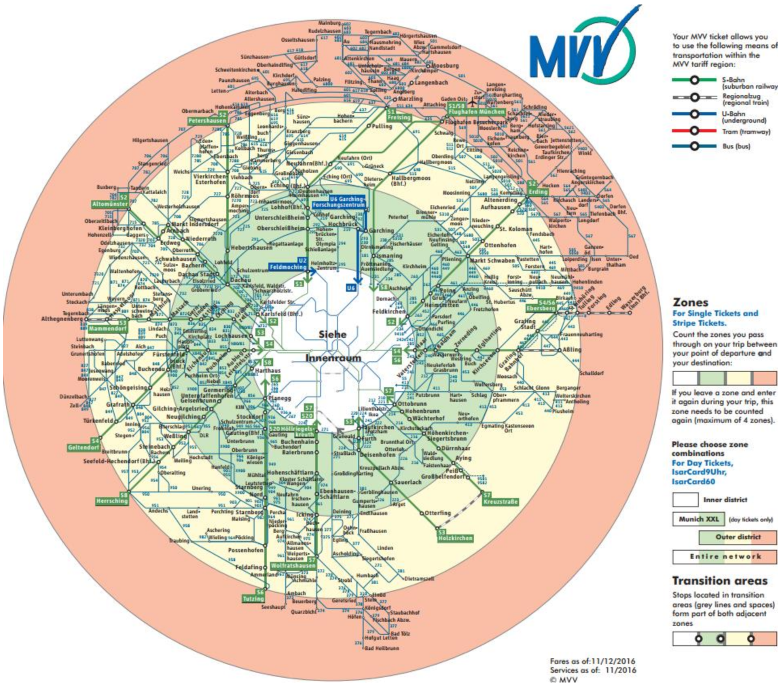


Figure 16. Map of fare zones Munich. Source: MVV.

As in the case of London, and as it will be seen in the other cities, the metropolitan area of Munich includes a smaller number of municipalities, which indicates that the trips that have to take users to move between towns, tend to be higher than those cities with greater number of municipalities.

It should be noted, however, that comparisons are being made globally to the entire metropolitan area of Barcelona. The data from the use of public transport is lower if we focus on the use of the Barcelona city area only (where the modal share of public transport rises to 29,5%).

4.7. Paris

Paris is the capital and with the region Ile-de-France is the largest metropolitan area in Europe. The transport system of Paris, as seen, is one of the most efficient throughout Europe. The offer ranges from rail to bus, metro and tram, in a fully connected and integrated system. With a wide range of public transport systems, Paris bet for dedicated lanes to buses and taxis, and the largest public bicycle system around all Europe. All this measures had led, in a certain manner, to an increase in congestion for the private vehicles.

The region is divided into six crowns, leaving the centre as the main area that includes the city of Paris itself. The distribution of tariffs does not respond only to the number of zones crossed, it also counts with the distance from the zone to the centre of the capital, having different offer of tariffs if the user doesn't arrive to the city centre.

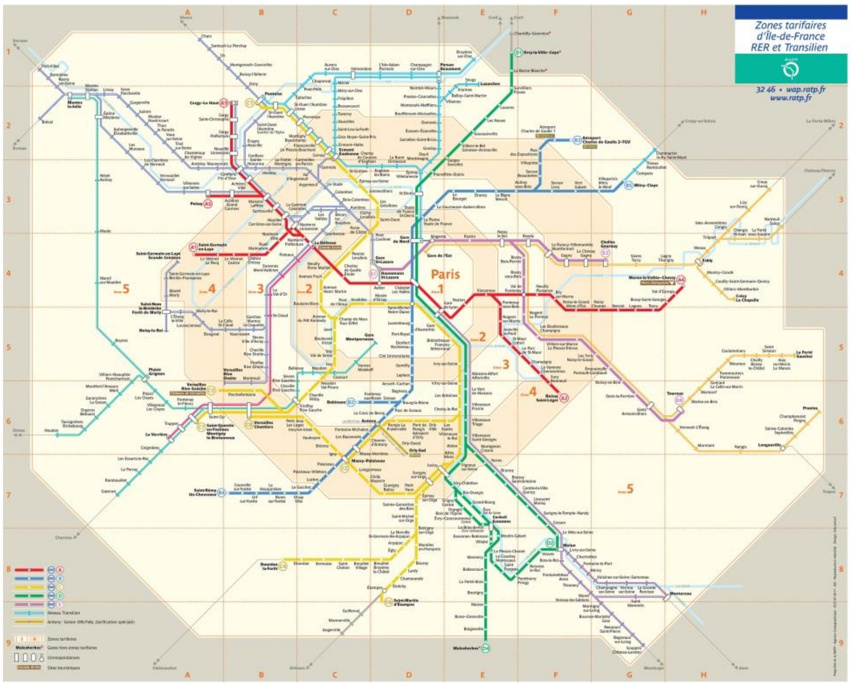


Figure 17. Map of fare zones Paris. Source: STIF.

The Paris transport authority is given by *STIF* (*Syndicat des Transports of Île-de-France*), despite the *RATP* (*Régie Autonome des Transports Parisiens*) operates all transport in and out of the capital Paris and *SNCF (Société Nationale des Chemins de Fer Français*, a state railway company network that covers the whole France) operates all transport outside the capital and only penetrates (with exceptions). Metro, Tram, most bus services and some sections of the RER are operated by RATP. The rest of the RER and *Transilien*, are managed by SNCF.

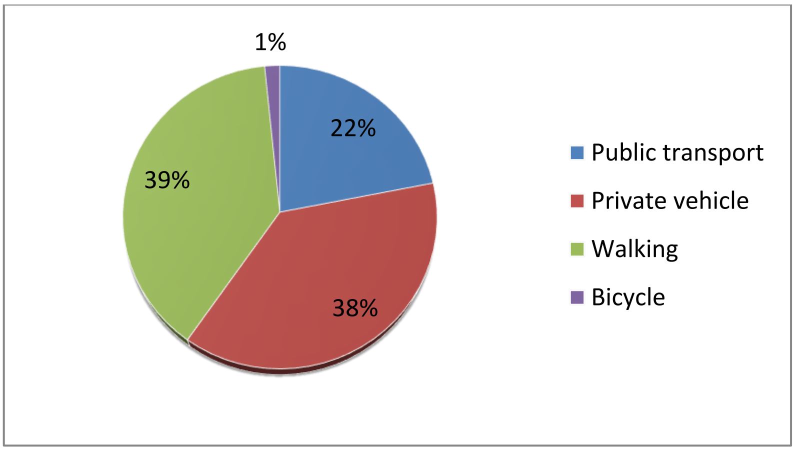


Figure 18. Modal share of different modes of transportation in Paris. Source: own elaboration.

Despite attracting users, as mentioned, the rate of car ownership is quite high, reflecting the use of private vehicles, which exceeds 16% public transport. However the share is in the city of Paris is higher than we have in the Catalan capital, which makes it interesting for analysis.

5. City analysis

5.1. Barcelona's public transport system

In the transport system of Barcelona there are, as in previous cases, coexistence of public and private services, making 48,3% travel in private vehicles, while public transport takes 34,7% of the share. Barcelona, capital of Catalonia and the second largest city in Spain, has one of the most important ports of the Mediterranean (so that freight, that is not analysed in this report, has a significant weight in the system). It has a wide offer of public transport and, also, airport transit.

The demand for transport in the city in recent years has increased, as well as private vehicles has been decreasing, encouraging improvement of the first one. Two of the main changes that the authorities have been working with are: the introduction of an orthogonal bus network (speeds and frequencies higher than the conventional network) and the introduction of two subway lines with autonomous driving L9 and L10, crossing the entire city, connecting one to the airport and to the port area the other.

The public transport, if the focus is put on the metropolitan area, is operated mainly by Transports Metropolitans de Barcelona (TMB), with metro, bus, and other types of tourist services not covered by the study. The city also offers tram services (operated by the Metropolitan Transportation Authority (ATM), short distance rail (of which four are considered part of the subway), operated by the *Ferrocarrils de la Generalitat de Catalunya* (*FGC*) and regional train services, midway and short distance, operated by *RENFE*.

Otherwise, the city also offers taxi service and bikes (only for residents, so rents for tourists are not affected), which will not be analysed in this report.

<u>Metro and tram services</u>

	Overview	**Number of coach-km (M)**	**Annual ridership (M)**	**Average transfer trips per day (M)**
Metro Barcelona	*Rapid transit of the city*, made a total of 10 lines (two of them in the future will be just one) and railways (FGC) of the first ring of the integrated fare system. There are a total of 143 km, 209 stations and commercial speed of 29,4 km/h.	97,7	425,8	1,3
TRAM	*Light rapid transit of the city*, made a total of six lines operating in nine municipalities. There are a total of 56 stops and 29,1, with commercial speed of 17,9 km/h.	2,5	26,8	0,9

Table 6. Basic data of the metro and tram services in the metropolitan area of Barcelona. Source: own elaboration.

Suburban rail services

	Overview	Number of coach-km (M)	Annual ridership (M)
RENFE	10 metropolitan lines, with 526,5 km of route network. The speed commercial operation around 50,1 km/h. It has also the FGC lines corresponding to the other crowns Integrated Fare System (which are not first ring).	121,3	120,7

Table 7. Basic data services outskirts of the metropolitan area of London. Source: own elaboration.

Bus services

Barcelona Bus services are operated by different companies. TMB operates the urban services and ATM, while intercity DGTM and are operated by local groups.

	Overview	Number of coach-km (M)	Annual ridership (M)
Urban	With a total of 204 lines and 2,229,4 km of network. Opera commercial speed of 16,6 km/h.	75,8	282,4
Intercity	With a total of 390 km of lines and 12684,8 network. Opera commercial speed of 33,7 km/h.	58,7	73,7

Table 8. Basic details of bus services in the metropolitan area of London. Source: own elaboration.

5.2. Berlin's public transport system

Berlin presents a broad and complete public transport network by combining several modes of transport. It is a city where car ownership rate is medium, below the average of the country (403,1 cars per 1000 inhabitants, in front of 500 in Germany).

The city of Berlin is one of the pioneers and most dedicated to public transport. To encourage modal shift from private vehicles to the public use, the city provides numerous zones of Park & Ride (parking areas near stations utilities in order to leave the car there and take the public transport, decongesting the city centres), limited circulation areas with high occupancy vehicles and a system of car sharing (car rental for a short period of time).

Public transport in Berlin is gestioned by *Verkehrsverbund Berlin-Brandenburg* (*VBB*) authority, but the operation is divided into different public and private companies. The S-bahn and services of railway, are operated by DB, the subway, tram and bus are operated by the *Berliner Verkehrsbetriebe (BVG).*

A curiosity that can be checked in the city is the service of taxis, there is special low cost tarifs for distances below 2 km, 4€.

In Berlin, the bikes take considerable importance. With 13% of modal split for cycling, it is one of the cities with the highest modal share in Europe. The city of Berlin has 620 kilometers of bike lanes, some areas shared with motorized vehicles, pedestrians and others completely segregated. The public bicycle system is the same as in Munich, run by DB.

Metro and tram services

	Overview	**Number of coach-km (M)**	**Annual ridership (M)**
U-bahn	*Rapid transit* of the city, comprising 10 lines. It has 152 km of network and operates at a commercial speed of 30,9 km/h.	172,3	553,1
S-bahn	*Rapid transit* that complements the subway, comparable to the FGC. It consists of 15 lines and covers the area of the metropolitan area. It has 328 km of network and operates at a commercial speed of 40 km/h.	263,0	413,9
Tramway	*Light Rapid Transit*. It comprises a total of 22 lines. It has 192 km of network and operates at a commercial speed of 19 km/h.	19,7	193,6

Table 9. Basic data of the metro and tram services in the metropolitan area of Berlin. Source: own elaboration.

Suburban rail services

	Overview	**Number of coach-km (M)**	**Annual ridership (M)**
R-bahn	Commuter service offered by DB. Tthe network that passes through Berlin and Brandenburg has a length of 2357 km and consists of 47 lines (20 enter the city of Berlin itself), operated by five different companies at a commercial speed of 60 km/h.	151,8	33,6

Table 10. Basic data services outskirts of the metropolitan area of Berlin. Source: own elaboration.

Bus services

The bus service offered by the company BVG public, can be broken down into the following:

- 122 lines of conventional types, some double floor.
- 13 express lines that offer direct reinforcement.
- Bus lines 17 Rapid Transit (BRT) operating 24 hours, complementing the night network.
- 45 night lines, nine of the which realize a route following the metro lines when those are not opened.

Due to the lack of information from the entire metropolitan area network (privately) will show data on the public entity described above.

	Overview	Number of coach-km (M)	Annual ridership (M)
Urban	With a total of 197 lines and 1694 km, operating in commercial speed of 19,5 km/h.	89,3	433,0

Table 11. Basic details of bus services in the metropolitan area of Berlin. Source: own elaboration.

5.3. Hamburg's public transport system

Hamburg is the only area from the ones in the analysis that does not have tram service (from 1922, when most cities decided to end tram services). However, the public transport carries over 700 million users a year, offering train, metro and bus.

Hamburg was the first European city to introduce the idea of bus lane and today presents a very complete and varied bus network, with different types of service during the day and night. These services will be detailed later.

As in the case of Berlin, and most capital, promotion of reducing private vehicle is a major action points of the transport networks. So has an extensive system of car sharing.

The transport authority is *Hamburger Verkehrsverbund* (*HVV*), founded in 1965 with four operators: *Hamburger Hochbahn AG* (*HHA*, main operator of buses and metro), *Deutsche Bindesbahn* (service charge and suburban trains) and *Verkehrsbetriebe Hamburg-Holstein* (*VHH* operator of some subway lines). Two years after its creation, has a tariff system integrated in all modes of transport.

The public bicycle system is the same as in Munich and Berlin (in fact, common throughout Germany with a performance very similar to *Bicing* in Barcelona), operated by DB. In addition, many companies offer bicycle rental services for tourists.

<u>Subway services</u>

	Overview	Number of coach-km (M)	Annual ridership (M)
U-bahn	*Rapid transit of the city*, comprising five lines and 91 stops. It has 104,4 km of network (with distance between stops quite large) and operates at a commercial speed of 33,3 km/h.	85,6	232,4
S-bahn	*Rapid transit that complements* the subway, comparable to the FGC. It consists of 6 lines (68 stops) and covers the area of the metropolitan area. It has 146,8 km of network and operates at a commercial speed of 40 km/h.	69,3	271,1

Table 12. Basic data of the metro and tram services in the metropolitan region of Hamburg. Source: own elaboration.

Suburban rail services

	Overview	Number of coach-km (M)	Annual ridership (M)
R-bahn	Commuter service offered by DB 9 lines that cover 188,1 km with 26 stations, a commercial speed of approximately 60 km/h.	85,6	232,4
A-bahn	*Rapid transit complementary* to the previous two. consists of three lines and 41 stations. The network has 89 km in length and operates at a commercial speed of 60 km/h.	69,3	271,1

Table 13. Basic data services outskirts of the metropolitan region of Hamburg. Source: own elaboration.

Bus services

There are different offers of bus, as mentioned above: *Metrobus* (buses high frequency in the two downtown areas) 22 lines; *Schnellbus* (rapid lines), 10 lines; *Eilbus (*reinforcing lines for the morning and evening commute*),* 4 lines; *Natchbus* (lines night from Sunday to Thursday from 0:00 to 5:00) 19 lines; *Stadtbus* (conventional lines) the other lines.

Although the type information lines can be found in Hamburg available, the data about annual production of buses is not segregate by the different types, but presented jointly.

	Overview	Number of coach-km (M)	Annual ridership (M)
Urban	Service 111 lines and 1.330 bus stops, with a total of 927,1 km. The fleet operates at a commercial speed of 18,6 km/h.	50,3	211,7
Intercity	Service 585 lines and 8.310 bus stops, with a total of 13.096 km. The fleet operates at a commercial speed of 20,0 km/h.	65,2	220,2

Table 14. Basic details of bus services in the metropolitan region of Hamburg. Source: own elaboration.

5.4. London's public transport system

In the transport system in London are living both public and private services, 44% journeys undertaken in the city are held by public transport, leaving 32% to private service. London acts as a hub for rail networks, road and airport.

The demand for public transport in the city has increased in recent decades, as in Barcelona, promoting the exchange of private vehicles to public transport, while the second offer has to be improved.

The public transport service is operated, mostly by the agency Transport for London (*TfL* from now on), which controls the metro, bus, tram, Docklands Light Railway (streetcar service type) services by the River, London Overground (commuter type service as an extension of the metro) and services to major roads. Other railway companies are franchise operated by the Department for Transport (*DFT* from now on).

London has a bicycle rental service (Bike Sharing), daily, monthly or annual basis, similar to that offered by the city of Barcelona, as well as taxis.

Metro and tram services

	Overview	Number of coach-km (M)	Annual ridership (M)	Average transfer trips per day[2] (M)
London Underground	*Rapid transit*, seven deep lines deep and four sub-superficial. It was the first of its kind, inaugurating the first line in 1863. It has a total of 270 stations, 469 km of network and operates at a commercial speed of 33 km/h.	578,0	1,349,0	3,7
DLR	*Light Rapid Transit that* complements the metro opened in 1987. It consists of seven lines and covers the area of the metropolitan area. It has a total of 45 stations, 39 km network and operates at a commercial speed of 35 km/h (although they can reach 64 km/h)	17,7	117,0	0,3
Tramway	*Light Rapid Transit* opened in 2000. It has a total of 4 lines and 39 stations, 28 km of network and operates at a commercial speed of 25 km/h.	3,0	27,0	6,5[3]

Table 15. Basic data of the metro and tram services in the metropolitan area of London. Source: own elaboration.

[2]Trips to transfer the subway do not have exchanges between different lines of the same, as is the case of Barcelona, only exchange with other modes. Each time the mode of transport is part of a trip transfer is counted, so the total transfer trips ends up being greater than the number of total trips, since these features are the dominant mode of travel.

[3] Incloent bus, no s'han pogut trobar les dades separades.

Suburban rail services

In addition to the London Overground, we find National Rail services. This is part of the Association of Train Operating Companies, and service could be assimilated to offer regional services that RENFE has the Catalan territory.

	Overview	Number of coach-km (M)	Annual ridership (M)	Average transfer trips per day (M)
London Overground	It operates as a part of National Rail by Arriva Rail London (TfL privately owned franchise) with a total of 9 lines (112 stations) and 167 km of network length. The commercial speed is around 50 km/h.	42,0	184,4	3,3
TfL Rail	Line that crosses the city, 167 km in length with commercial speed of around 50 km/h.	5,6	47,0	nd

Table 16. Basic data services outskirts of the metropolitan area of London. Source: own elaboration.

Bus Service

	Overview	Number of coach-km (M)	Annual ridership (M)	Average transfer trips per day (M)
London Buses	There are a wide variety of supply: from the classic double-decker buses, to bus type BRT (Bus Rapid Transit). It consists of 493 lines and 6,500 km of total length of the network. The general commercial speed is 15,2 km/h.	493,0	2,314,0	6,5[2]

Table 17. Basic details of bus services in the metropolitan area of London. Source: own elaboration.

5.5. Madrid's public transport system

Madrid is the capital of Spain, being the biggest city, in terms of habitants, of the country. It is also one of the largest metropolitan areas in Europe, behind Paris and London. The transportation in Madrid is well-known for its highly developed road infrastructure on road and rail transport. The public transport has a very good impact on the society being totally competitive with the private car (32,4% of share for public transport and 34,7% for private).

The area presents service of metro, tramway, bus and rail, being in constant improvement and policies of extension. As in most of the studied areas, the inner city users take mainly the metro and the buses offered by the *ETM,* but as a main reason for this is the lack of this services in the periphery, so this is why plans of extension are being studied. All the periphery and suburbs area are, thought, well connected with the short distance rail and intercity buses.

The main authority in Madrid is the *Consorcio Regional de Transportes de Madrid (CRTM)*, but the main operators for the different services are: *EMT* for the urban buses, *RENFE* for the short distance trains (and also operates middle and long distance trains), *Metro de Madrid* for the metro and some tram services, and other private operators which have part of the lines of rail or road in concession. The private sector on the operation of public transport is highly strong in Madrid, but all controlled and directed by the *CRTM*.

As in all the cities studied, there is also an offer of public bicycle service, in an attempt of reducing pollution and emissions from the use of vehicles. This service is called *BiciMAD* and offers a wide range of electric bicycles. Measures for incrementing the bicycle usage have been implemented since 2012, reflected on the increase of usage of that mode of transport. This measures are: more bicycle lanes, more parking and special lanes to put bicycles at the first line in traffic lights.

<u>Subway and tram services</u>

while the metro is the most used mode of transport in the city, the tramway is leaved in a very low position, reflexed on the very low ridership that presents. It seems that it has not a very good impact on the society.

	Overview	**Number of coach-km (M)**	**Annual ridership (M)**
Metro Madrid	*Rapid transit of the city*, comprising 13 lines and 236 stops. It has 269,5 km of network (with distance between stops of about 500 m) and operates at a commercial speed of 28,3 km/h.	165,3	569,0
Concesiones Ferroviarias	*Rapid transit* line in concession. It has 19 km in 5 stations and operates at a commercial speed of 54,4 km/h.	3,5	5,9
Tram	*Light Rapid transit* of 35,8 km in 57 stations. It operates at a commercial speed of 21,5 km/h.	12,6	14,7

Table 18. Basic data of the metro and tram services in the metropolitan area of Paris. Source: own elaboration.

<u>Train services</u>

	Overview	**Number of coach-km (M)**	**Annual ridership (M)**
Cercanías	Service around 9 lines that run 778,3 km with 94 stations, a commercial speed of 44,5 km/h.	145,3	227,8

Table 19. Basic data services outskirts of the metropolitan area of Paris. Source: own elaboration.

Bus services

	Overview	Number of coach-km (M)	Annual ridership (M)
Urban	Service with 204 lines and a total of 1.533,7 km. The fleet operates at a commercial speed of 13,4 km/h.	87,8	405,9
Intercity	Service with 439 lines and a total of 8.447,0 km. The fleet operates at a commercial speed of 23,7 km/h.	172,0	207,3

Table 20. Basic details of bus services in the metropolitan area of Paris. Source: own elaboration.

5.6. Munich's public transport system

Munich has one of the most punctual public transport systems in the world and living with a wide range of services. The tram service is remarkable, which since 1876 has been in operation, even when in most cities, trams disappeared because of little use.

The demand for public transport in the city has, like most cities, been increasing in recent decades. This increase is partially due to the changes that has adopted the system: fleet renewal, introduction of electronic card fare system, among others less important.

The public transport is operated by *Münchner Verkehrs- und Tarifverbund GmbH* (*MVV*In general, bus, metro and tram are operated by Münchner Verkehrsgesellschaft (MVG), along with some private operators, while the services of S-bahn (service similar to the *FGC*) and R-bahn, are managed by *Deutsche Bahn* (DB).

The transport system in Munich ensures, in general terms, that any user is within 500 meters of a public transport stop or station. In general, rapid transit lines have very large distance between stops, about a kilometer. General bus or light transit (such as tramways) have distances about 500 m.

As Barcelona, in Munich there is also a system of supply of bicycles, along with a steady increase in the number of lanes. As seen above, the cycling modal share has virtually the same impact than represents the public transport in Barcelona. This system of shared bicycles, Call a Bike, is operated by DB, entering service in 2000.

Metro and tram services

	Overview	Number of coach-km (M)	Annual ridership (M)
U-bahn	*Rapid transit of the* city, comprising eight lines. There are a total of 96 stations, 95 km network (leaving an average spacing between stops of almost 1 km) and operates at a commercial speed of 35,1 km/h.	69,2	398,0
S-bahn	*Rapid transit that* complements the subway, comparable to the FGC. It consists of eight lines and covers the metropolitan area. It has a total of 150 stations, 434 km of network and operates at a commercial speed of 40 km/h.	163,0	268,8
Tramway	*Light Rapid Transit*. It comprises a total of 13 lines. It has a total of 166 stations, 79 km network and operates at a commercial speed of 18 km/h.	8,3	119,0

Table 21. Basic data of the metro and tram services in the metropolitan area of Munich. Source: own elaboration.

Suburban rail services

	Overview	Number of coach-km (M)	Annual ridership (M)
R-bahn	Commuter service consisting of 11 lines grouped into three networks: Werdenfels, Ring West and Ring Ost. The company does not provide information about the length of the network and determines medium speed operation of 60 km/h.	390,0	360,0

Table 22. Basic data services outskirts of the metropolitan area of Munich. Source: own elaboration.

Bus services

	Overview	Number of coach-km (M)	Annual ridership (M)
Urban	Service 71 day and 14 night lines, with a total of 482 km and 974 stops. The fleet operates at a commercial speed of 18,1 km/h.	32,5	193,0
Intercity	Service of 174 lines covering 4840,9 km commercial speed of 25 km/h.	37,0	45,0

Table 23. Basic details of bus services in the metropolitan area of Munich. Source: own elaboration.

5.7. Paris' public transport system

The public transport system in Paris is a very complete and with high service usage and structure, making it one of the most efficient that we can find in Europe, along with London. One peculiar thing about Paris is that, even the number of trips per inhabitant is quite elevated, the usage of the public transport does not exceed the usage of private (22% in front of the 38% of the private transport). This may occur because of the extension of the metropolitan area. As in the case of Barcelona, if the study is oriented only in the city centre, numbers are slightly different and the usage of public transport increases in front of the car.

The metro is the most used transport in the city, connecting all districts and municipalities, complemented with a strong network *RER* (*Réseau Express Régional*) for municipalities and *Transilien* away from the capitals.

As in most European cities today, Paris is committed to a cleaner transport system and efficient energy, hence re-introduce trams in the 90s.

As mentioned above, the authority that manages the transport operators is *STIF*, and *RATP* and *SNFC* the main operators. These two share operation of *RER* and tram lines, leaving only to *RATP* the control on the metro and bus (with *OPTILE,* that operates a small part of it and school transport, mainly). The *Transilien* is fully operated by *SNFC*. *STIF* is responsible for managing frequency, schedules, contracts ...

Since July 2007, following the pattern of most cities, Paris offers a public bike hire (operation similar to *Bicing* in Barcelona). The system offers 30 free minutes and 45 if you are subscribed.

Subway and tram services

The metro service is offered in the city has two circular lines, leaving the other diametrically across the city.

	Overview	Number of coach-km (M)	Annual ridership (M)
Subway	*Rapid transit of the city*, comprising 16 lines and 303 stops. It has 214 km of network (with distance between stops of about 500 m) and operates at a commercial speed of 27 km/h.	253,5	1519,0
Tramway	*Light rapid transit* with 104,7 km of network and a commercial speed of 19 km/h.	12,0	287,0

Table 24. Basic data of the metro and tram services in the metropolitan area of Paris. Source: own elaboration.

Train services

The service consists of suburban *Transilien*, which also form part of RER lines. Both make up a large network penetrates the municipalities furthest from the city centre.

	Overview	Number of coach-km (M)	Annual ridership (M)
RER	Service around 5 lines that run 587,0 km with 257 stations, a commercial speed of 47 km/h.	288,4	478,0
Transilien	Fully network of short distance trains. It consists of 10 lines. It has 1,299 km long and operates at a commercial speed of 47 km/h.	196,7	962,0

Table 25. Basic data services outskirts of the metropolitan area of Paris. Source: own elaboration.

Bus services

STIF provides data service of "*Bus à Paris*" (considered as an urban service) and "*grande et petite courones bus*" (considered intercity service). The total offer service has 347 lines, including night lines.

	Overview	**Number of coach-km (M)**	**Annual ridership (M)**
Urban	Service with a total of 597 km. The fleet operates at a commercial speed of 14 km/h.	42,1	329,0
Intercity	Service with a total of 3264 km. The fleet operates at a commercial speed of 20,0 km/h.	119,5	1081,0

Table 26. Basic details of bus services in the metropolitan area of Paris. Source: own elaboration.

6. Data analysis and comparison

Absolute data values do not make much sense by their own. Much more interesting is the comparison among them. Therefore, in this chapter an intense comparison among the data and the obtained parameters for each city is made.

6.1. Supply data

Data supply are presented sorted by different type of the supply parameters. All the data can be checked in the annexes of this work. The data, as commented before, has been organized in tables using excel, in order to correlate all the indicators.

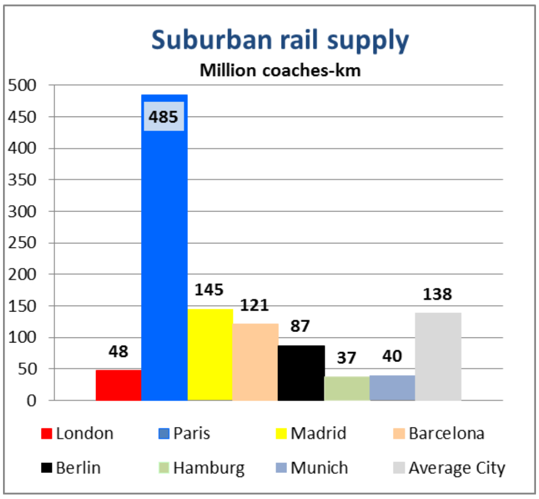
6.1.1. Transportation supply

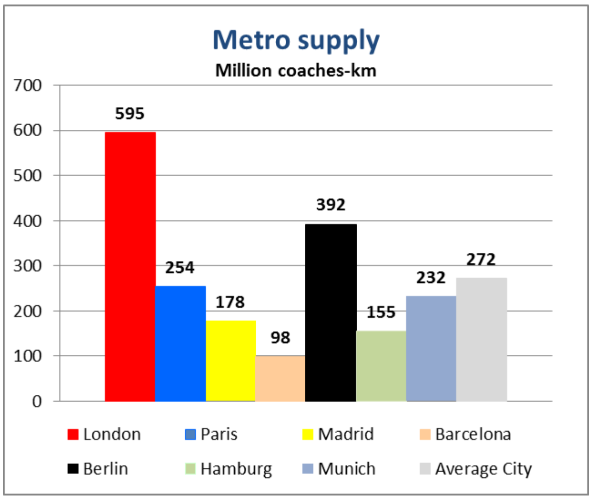
Next table show the figures of the amount of transport supply expressed in terms of coach-km.

	Suburban Rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
	Coach-km (milion)					
London	48	595	3	493	0	1.139
Paris	485	254	12	42	308	1.100
Madrid	145	178	13	89	173	597
Barcelona	121	98	3	76	59	356
Berlin	87	392	20	89	0	588
Hamburg	37	155	0	50	13	255
Munich	40	232	8	32	37	350
Average City	138	272	8	124	84	627

Table 27. Data supply for mode of transport and city. Coach-km. Source: own elaboration with excel.

These figures are represented in next graphs.

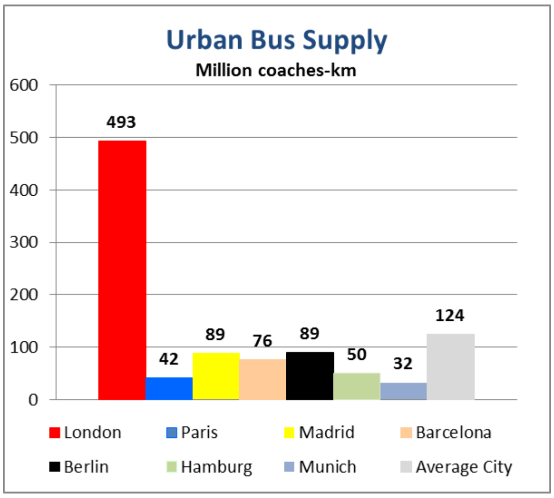


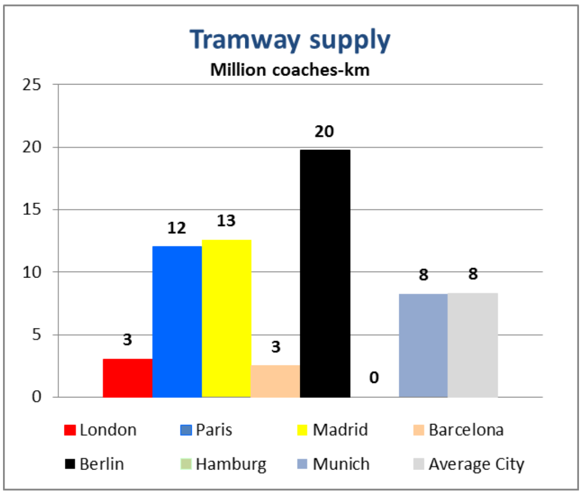


Graph 1. Suburban rail supply. Coach-km (left). Metro supply. Coach-km (right). Source: own elaboration with excel.

Regarding suburban rail supply, Paris provides to its metropolitan area the same amount of transport, in terms of coaches-km, than the rest of cities together. German cities and London are at the end of the ranking, which is quite normal taking into account that in London the majority of suburban rail service is produced by trains of the National rail, which have been excluded of in this report, and the three German cities do not have the metropolitan territory as the other cities do.

In Metro supply stands out London, clearly leading the ranking, and Madrid in the second place. Barcelona has de poorest figures despite its great length, which confirms the need of intensifying the service in the existing metro services in the Catalan capital.

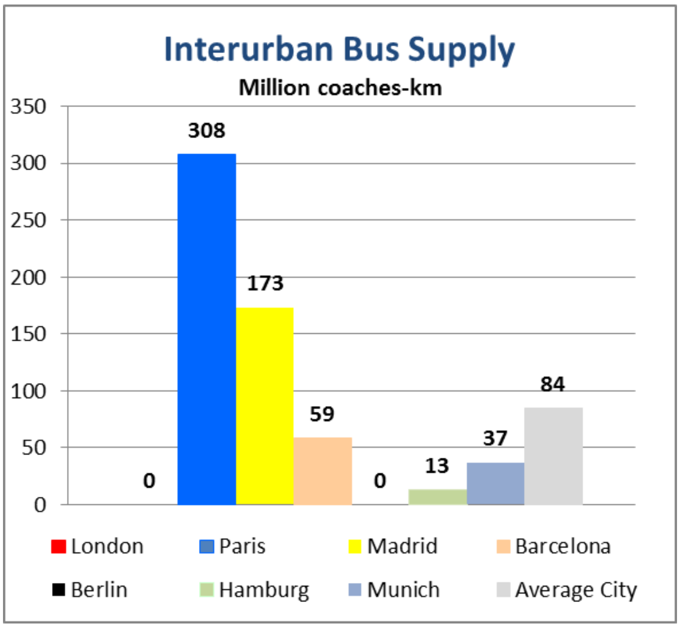




Graph 2. Urban bus supply. Coach-km (left). Tramway supply. Coach-km (right). Source: own elaboration with excel.

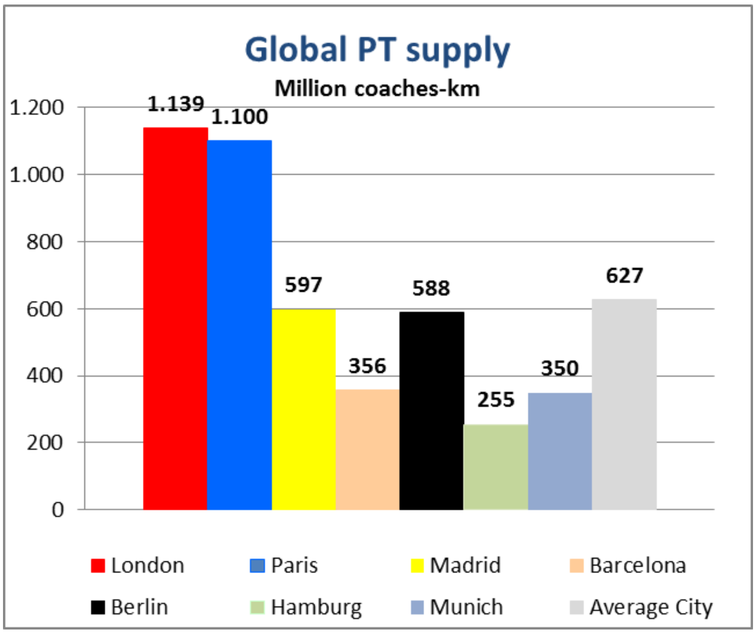
As far as urban bus supply, London provides more supply than the rest of six cities together. At a very far distance appear Berlin and Madrid, and Munich in the end of the list.

In the field of trams, Berlin is distinguished by its excellent position, leading the ranking, followed by Madrid and Paris. Madrid is actually a very curious case, since has a lot of tram supply but a very lower demand, as it will be described in the next chapter. Barcelona and London are scoring poor, but Barcelona is planning the link between both trams networks which will cause a significant increase in terms of tramway supply. As told, Hamburg has no tram network, which is an odd feature of the Hanseatic city, taking into account that more than 230 European cities has a tram network.



Graph 3. Interurban bus supply. Coach-km. Source: own elaboration with excel.

As told, Paris has a great interurban bus supply, with more supply than the rest of cities together. Madrid stands out in second position and Barcelona in the third one. Nor Berlin neither London has an own interurban network, although they exist, but not any statistic has been found. On the other hand, the wide rail scheme in the German and British capitals ensures than the dominant mode of transportation is rail in both cities in this kind of relations.



Graph 4. Global PT supply. Coach-km. Source: own elaboration with excel.

As a whole, naturally London and Paris are the cities which are leading the ranking regarding PT supply, followed by Madrid and Berlin, then Barcelona, Munich and finally Hamburg. In next chapters the amount of supply will be crossed with the number on inhabitants.

The share of each mode of transportation and the global rail share of each city is maybe one of the most interesting data. They appear below.

Rail Share Supply (coach-km)								
	Suburban Rail	**Metro**	**Tramway**	**Urban Bus**	**Interurban Bus**	**Total**	**Rail**	**Bus**
London	4%	52%	0%	43%	0%	100%	57%	43%
Paris	44%	23%	1%	4%	28%	100%	68%	32%
Madrid	24%	30%	2%	15%	29%	100%	56%	44%
Barcelona	34%	27%	1%	21%	16%	100%	62%	38%
Berlin	15%	67%	3%	15%	0%	100%	85%	15%
Hamburg	14%	61%	0%	20%	5%	100%	75%	25%
Munich	11%	66%	2%	9%	11%	100%	80%	20%
Average City	22%	43%	1%	20%	13%	100%	67%	33%

Table 28. Share of each mode of transportation, and rail and bus supply. Source: own elaboration with excel.

We can appreciate that the role of the rail is very important in German cities and decrease for the rest of cities until reaching the last place for London with a poor figure of 57%. But it must be noted that the figures of British National Rail when providing services in London have not been included even though the majority of such services are not metropolitan ones, but interurban ones.

6.1.2. Energy consumption

	Suburban Rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
	Energy consumption (GWh)					
London	112	1.136	12	2.982	0	4.241
Paris	757	800	50	292	1.882	3.782
Madrid	203	602	54	609	892	2.360
Barcelona	200	305	11	525	363	1.403
Berlin	226	876	87	549	0	1.738
Hamburg	96	372	0	310	80	858
Munich	104	557	38	200	207	1.107
Average City	243	664	36	781	489	2.213

Table 29. Energy spent in providing PT supply for mode of transport and city. GWh. Source: own elaboration with excel.

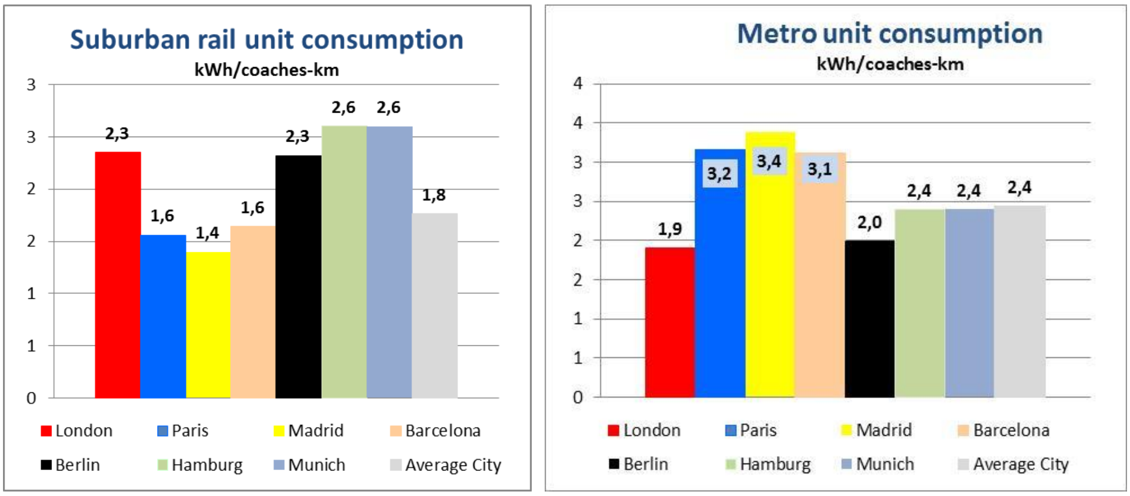
The global energy consumption has a relative interest since what it is important is the efficiency in this consumption, not the absolute amount of spent energy.

6.1.3. Energy consumption per unit

	Suburban Rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
	Unit Consumption (kWh/Coach-km)					
London	2,3	1,9	3,8	6,0	0,0	3,7
Paris	1,6	3,2	4,2	6,9	6,1	3,4
Madrid	1,4	3,4	4,3	6,9	5,2	3,9
Barcelona	1,6	3,1	4,3	6,9	6,2	3,9
Berlin	2,3	2,0	3,9	5,5	0,0	2,6
Hamburg	2,6	2,4	0,0	5,5	5,5	3,4
Munich	2,6	2,4	4,7	6,2	5,6	3,1
Average City	1,8	2,4	4,3	6,3	5,8	3,5

Table 30. Energy per unit spent in providing PT supply for mode of transport and city. KWh/coach-km. Source: own elaboration with excel.

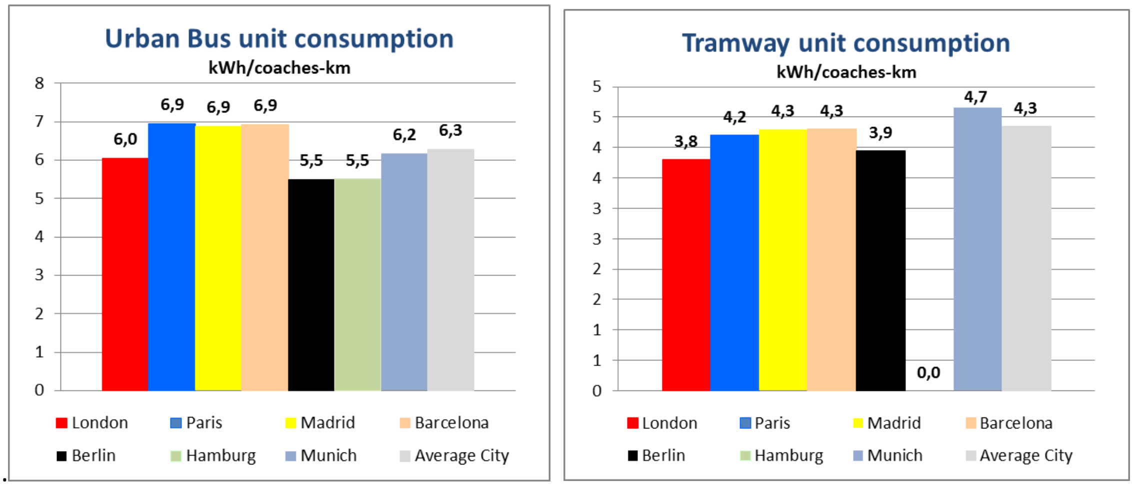
As told, the consumption per unit of transportation is the outstanding magnitude in the field of the efficiency.



Graph 5. Suburban rail unit consumption kWh/Coach-km (left).Metro rail unit consumption kWh/Coach-km (right). Source: own elaboration with excel.

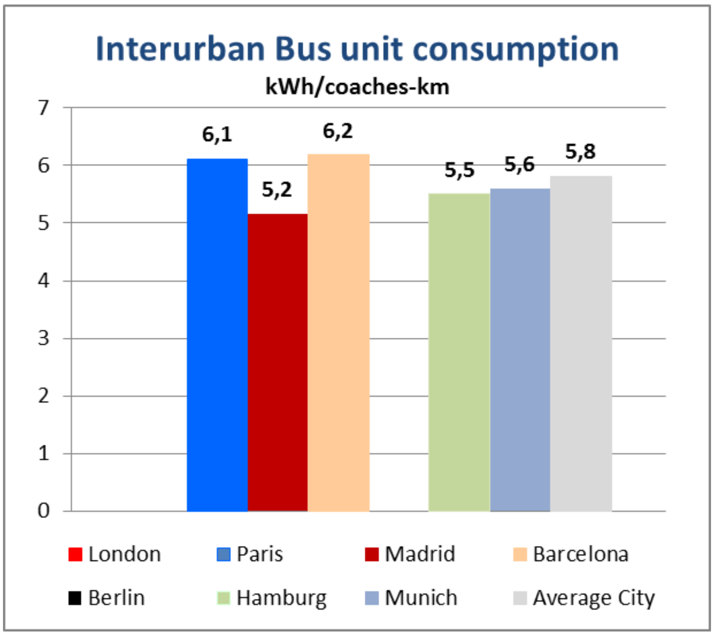
According with this classification the most efficient suburban rail system is Madrid, followed by Paris and Barcelona. Since in some cases, due to the lack of transparence, the figures of the energy consumption have been to be estimated, the classification of the energy efficiency of each mode of transportation must be taken with certain prudence.

While the Spanish Suburban rails are the best placed in the list, the Spanish Metro systems are the less efficient. This is probably due to the fact that the distance between metro stations in Spain are shorter than in other countries. The distance inter-station is one of the factors that influences more in this topic. On the other hand, since the traction technologies are similar in all metro set trains, other factors that influence are the depth of the stations, which needs more ventilation and air renovation, lifts and escalators, and air conditioning needs, very important in summer in Spain, might justify the differences

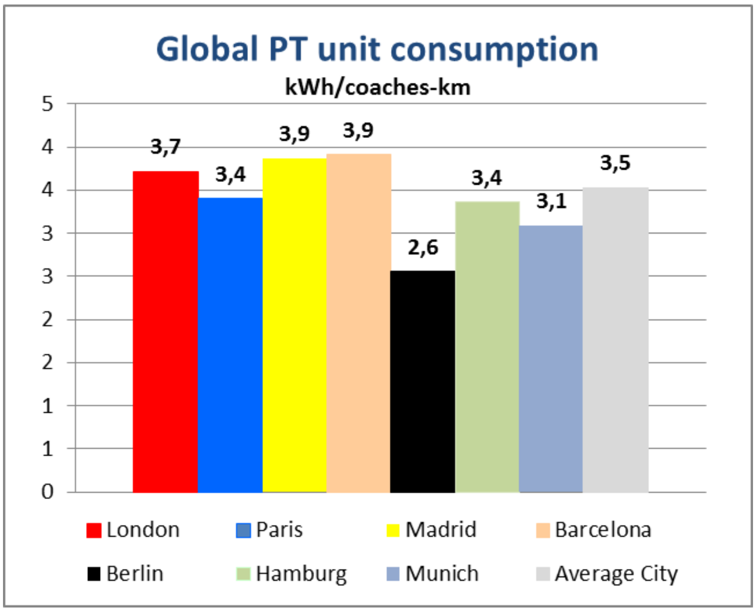


Graph 6. Urban bus unit consumption kWh/Coach-km (left Tramway unit consumption kWh/Coach-km (right). Source: own elaboration with excel.

Regarding the bus consumption, all cities are placed in a similar position, standing out, in the sense of a lower consumption, those which have a higher speed of their fleets. Tramway consumption is similar in all cities. And the same happens in interurban buses, which is showed in next graph.



Graph 7. Interurban bus unit consumption. kWh/Coach-km. Source: own elaboration with excel.



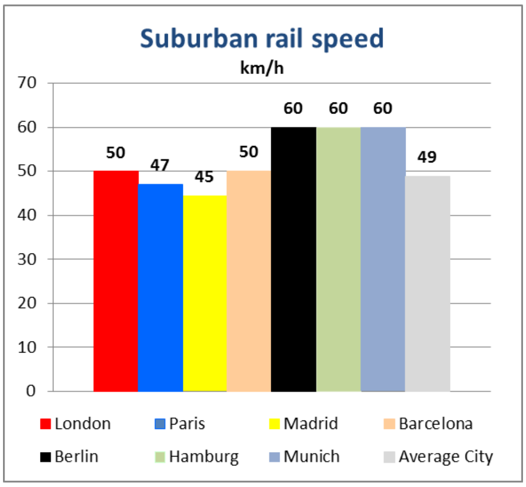
Graph 8. Global PT unit consumption. kWh/Coach-km. Source: own elaboration with excel.

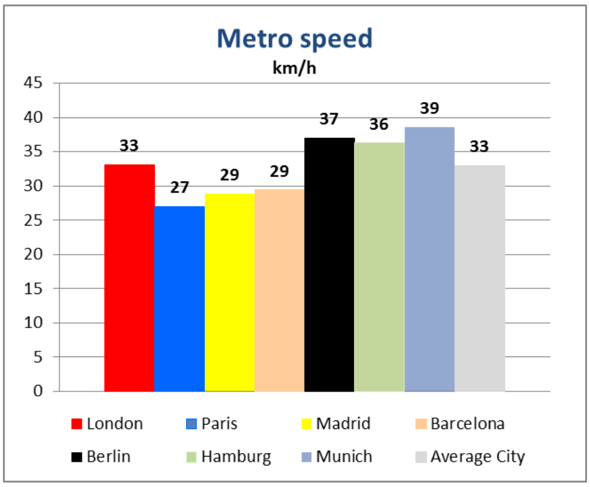
When we analyze the efficiency figures, a possible lack of information is less important in the global overview. Globally, the energy needed in providing transport services in these cities come from reliable sources. The graphic shows a leadership of the German cities, which can be explained by its higher use of the most efficient mode of transportation, which is the rail, and a higher speed. This data will be confirmed in next item.

6.1.4. Speed

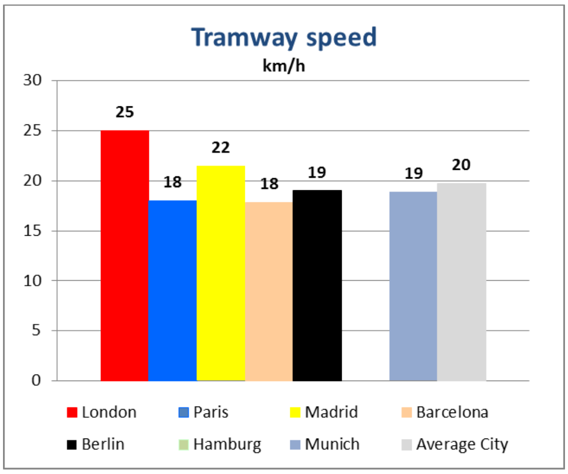
	Suburban Rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
	Speed (km/h)					
London	50	33	25	15	0	26
Paris	47	27	18	14	20	33
Madrid	45	29	22	13	24	29
Barcelona	50	29	18	17	34	34
Berlin	60	37	19	20	0	37
Hamburg	60	36	0	19	20	35
Munich	60	39	19	18	25	37
Average City	49	33	20	16	23	32

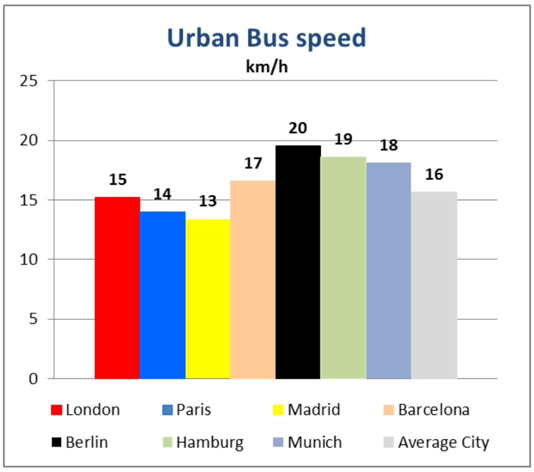
Table 31. Speed in providing PT supply for mode of transport and city km/h. Source: own elaboration with excel.



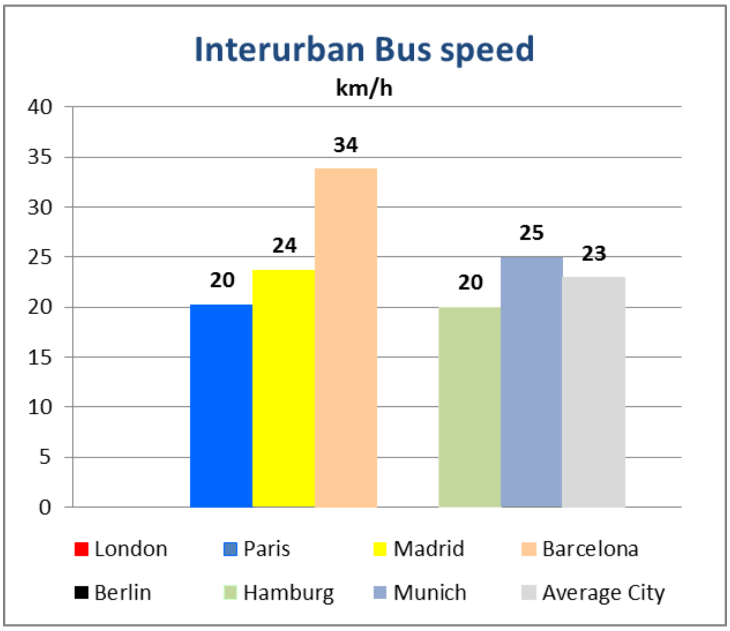


Graph 9. Suburban rail speed (left). Metro speed (right). Source: own elaboration with excel.

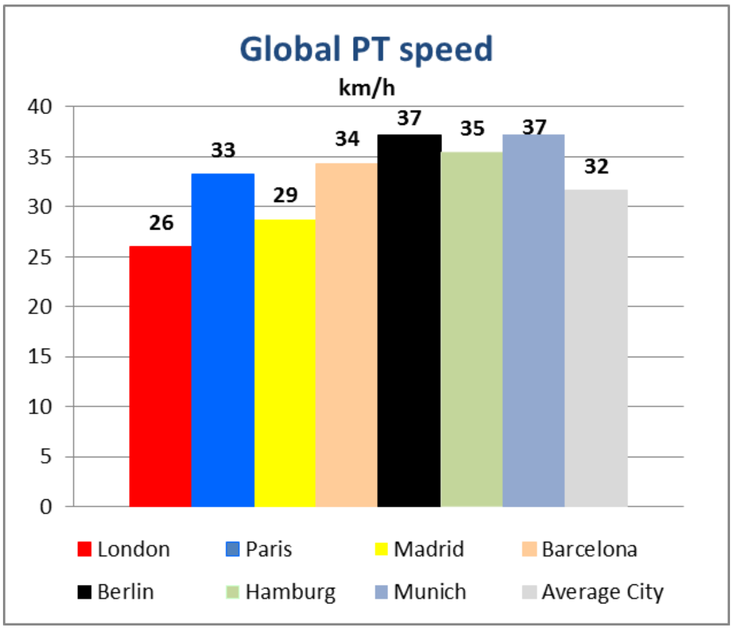




Graph 10. Tramway speed (left). Urban bus speed (right). Source: own elaboration with excel.



Graph 11. *Interurban bus speed.* Source: own elaboration with excel.



Graph 12. Global PT speed. Km/h. Source: own elaboration with excel.

These graphs are discussed together.

In the chapter of suburban rail, the speed is on average 49 km/h. Over these values we find German cities, 60 km/h, which are the single ones placed above the average. We should take these data with prudence since some of them have had to be estimated due to the lack of transparence or certain transportation authorities or companies.

The values of metro speed are more reliable since all come from annual reports. The lowest values are found in Paris and Spain, and this data matches with the fact that the distance inter-stations in those cities are shorter than in the northern countries, because it is clear that a short inter-station distance means less speed.

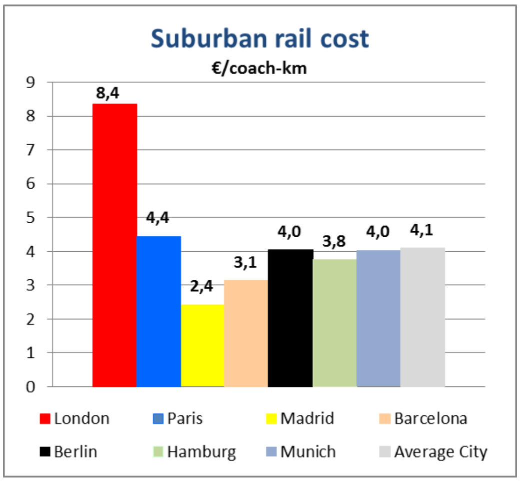
Regarding the tram speed all cities are placed at the same level, and share the value of the average city, except London. This is probably due to that the London's tram scheme was created over a disused railway network. So interstation distances are longer that in an standard tram exploitation.

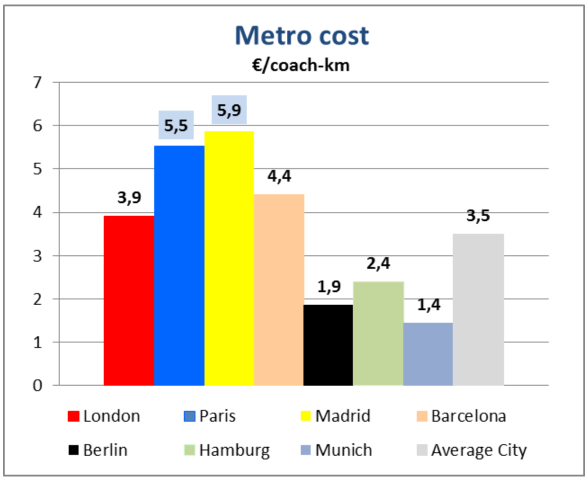
More differences are found among the speeds of urban bus services. The lowest is Madrid and the highest is Berlin. In this topic there are amazing paradoxes. A city like Barcelona may have a very low urban bus peed, 13 km/h, but the bus results have been accounted including the data of the suburban bus network which is quite faster than the urban one. London, Paris and Madrid have pure urban services that have more difficulties to run in a quick way than those which also have services in suburban areas.

6.1.5. Transport Supply Cost

	Suburban Rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
	Cost/Coach-km (€)					
London	8,4	3,9	12,8	6,1	0,0	5,1
Paris	4,4	5,5	12,5	7,2	2,5	4,4
Madrid	2,4	5,9	9,2	6,0	4,1	4,7
Barcelona	3,1	4,4	9,2	6,2	3,5	4,3
Berlin	4,0	1,9	8,6	6,1	0,0	3,2
Hamburg	3,8	2,4	0,0	6,1	3,5	3,4
Munich	4,0	1,4	8,6	5,3	3,5	2,6
Average City	4,1	3,5	9,8	6,1	3,2	4,2

Table 32. Cost per unit in providing PT supply for mode of transport and city. EUR/coach-km. Source: own elaboration with excel.

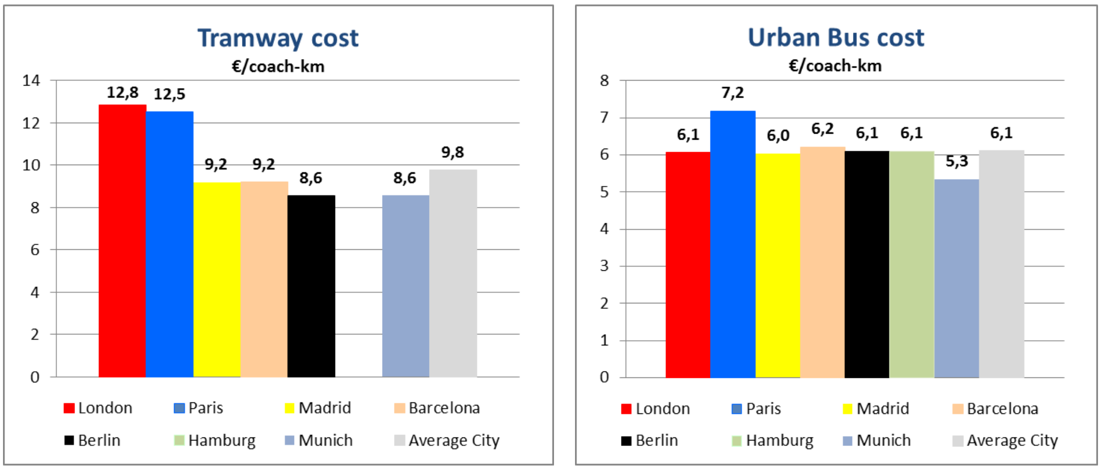




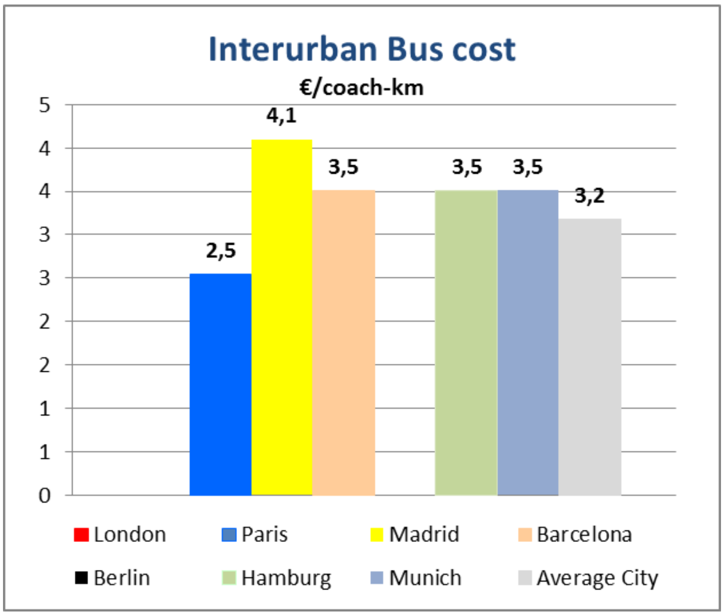
Graph 13. Suburban (left) and metro (right) cost per unit. Source: own elaboration with excel.

Costs per coach of suburban trains are ranging from London, with a cost which is the double of the average city and Madrid which has the lowest value, in a scale 3:1. Most operation costs are placed around the average. The exception is London. Probably this is due to the scarce service of suburban TfL rail, which distorts the values. Remarkable is the fact that the Spanish suburban rail is cheaper than the average. It is quite known than Renfe's exploitation costs are quite low.

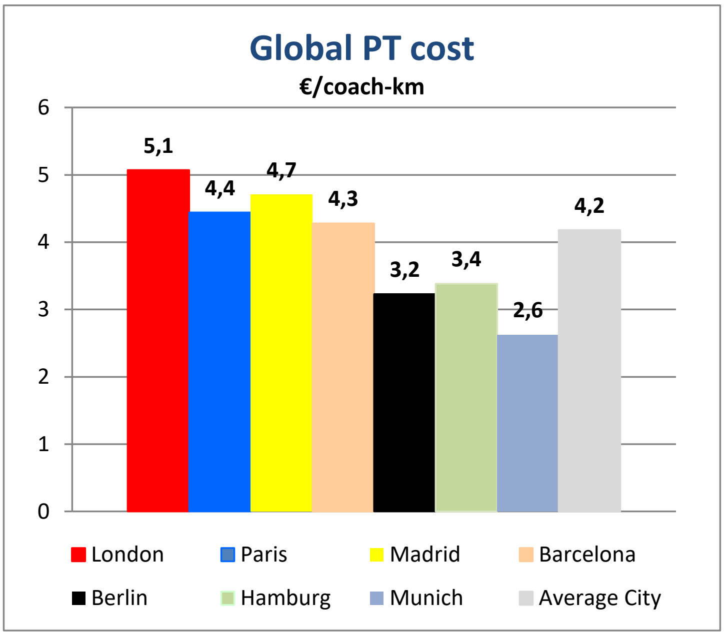
Regarding the metro cost, the higher one is surprisingly Madrid.



Graph 14. Tramway (left) and Urban bus (right) cost per unit. Source: own elaboration with excel.



Graph 15. Interurban bus cost per unit (EUR/coach-km). Source: own elaboration with excel.



Graph 16. *Global PT cost per unit (EUR/coach-km).* Source: own elaboration with excel.

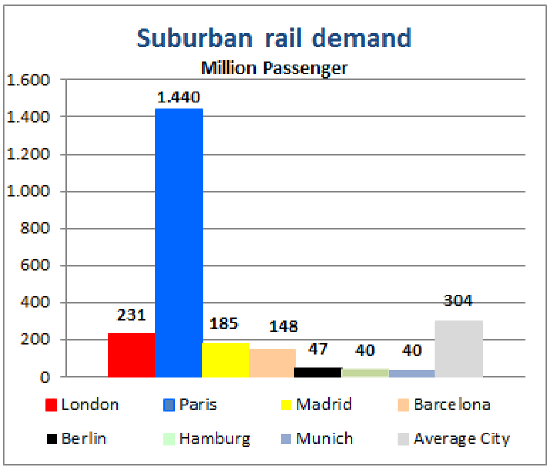
6.2. Demand data

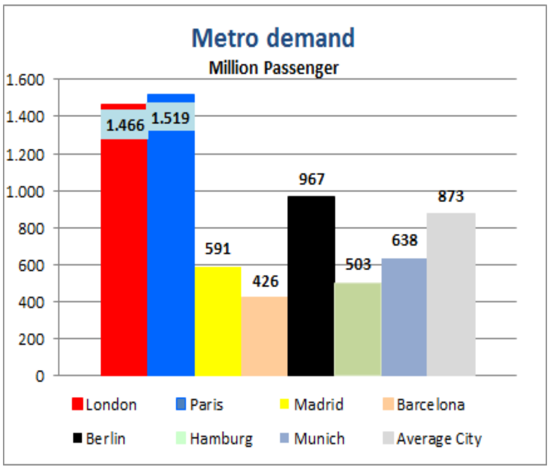
Data are sorted by different type of parameters of the demand. The data demand are more important than the supply ones, since the core of PT schemes is moving people, passengers, but not rolling stocks, trains or buses.

6.2.1. Passengers demand

	Suburban Rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
	Passengers (milion)					
London	231	1.466	27	2.314	0	**4.038**
Paris	1.440	1.519	287	330	1.092	**4.668**
Madrid	185	591	16	430	224	**1.446**
Barcelona	148	426	27	282	74	**956**
Berlin	47	967	194	432	0	**1.640**
Hamburg	40	503	0	212	44	**799**
Munich	40	638	119	193	45	**1.035**
Average City	304	873	96	599	211	**2.083**

Table 33. Demand in PT for mode of transport and city. Source: own elaboration with excel.

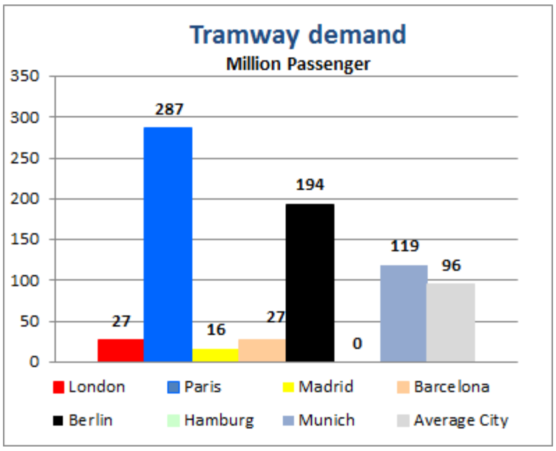


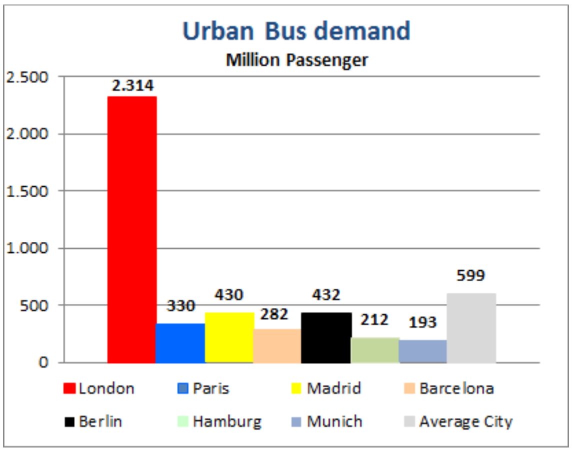


Graph 17. *Demand in suburban rai (passengers) (left). Demand in metro (passengers) (right).* Source: own elaboration with excel.

As far a suburban train demand is concerned, Paris stands clearly out. The French capital alone catches more passengers in this category than the rest of the cities together. This is due to the fact that the territory of the metropolitan area of Paris is many times much greater than other cities and also due to its great and high density suburban rail. Paris has three times more passengers in this item than the average European city.

As for the metro service, the ranking is led by Paris and London, with not very much difference between these two big agglomerations, followed by Berlin, Madrid, Munich, Hamburg and Barcelona, city which is placed in the last place of the ranking. Three cities are placed above the results of the average city.

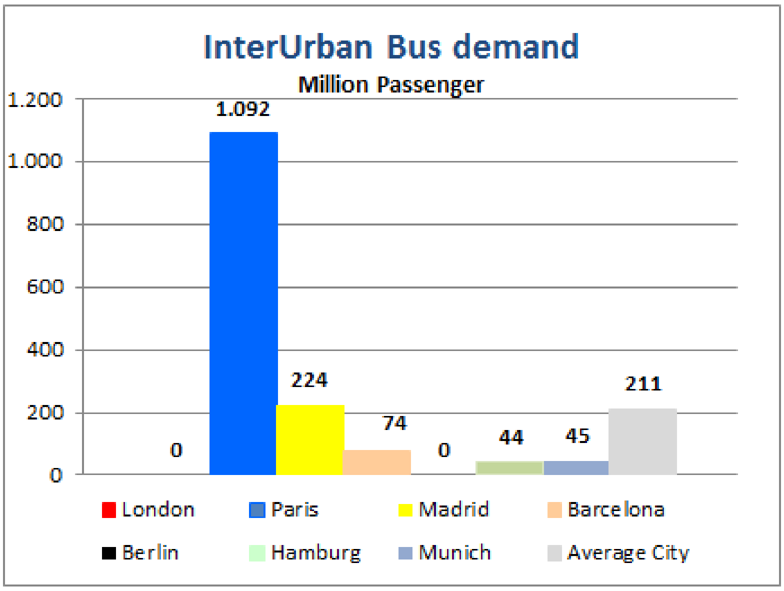




Graph 18. Demant in tramway (left) and urban bus (right). Source: own elaboration with excel.

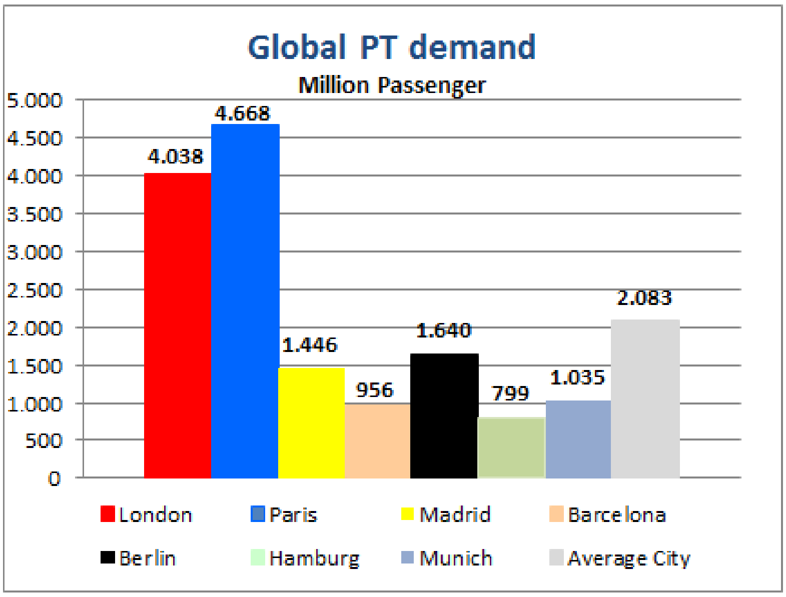
Regarding the tramway figures, Paris is also clearly leading the classification with three times more passenger than the average city. It is followed by Berlin and Munich. London, Barcelona and Madrid appear a long way away, which shows the lack of tradition in trams on these cities; although in the case of Barcelona the simply linking of both network trams could contribute with 100 million additional yearly passenger, according to the studies of the city council which has recently approved the link of trams crossing the center city. Remarkable is the fact that Hamburg does not have a tram, a singularity in the transportation European landscape.

As far as urban buses is concerned, London id clearly leading the classification with more passengers than the other six cities together. It is quite known than despite of the great extension of Londoner metro network, what in the British capital is remarkable is the huge usage of buses.



Graph 19. Demand in interurban bus. Passengers Source: own elaboration with excel.

In the field of interurban buses, Paris is leading as well the ranking with more passengers than the rest of the cities together, although it could be argued that most of these passengers are suburban ones. In the field of buses there is not a clear difference between local, suburban and regional passengers. Berlin and London do not have interurban bus service in the terms of a regional service. In the ranking after Paris appears Madrid and at a very long distance Barcelona, Munich and Hamburg.



Graph 20. *Demand in the global transport system. Passengers.* Source: own elaboration with excel.

The global demand of passengers in the five types of categories is led by Paris and London, at a similar level, followed at a long distance by Berlin, Madrid, Munich, Barcelona and Hamburg. The average city has 2.083 million passengers per year, and only two cities, the big agglomerations, are above of this value.

Next, the demand data are presented in terms of passenger-km which emerge based on the average length of trips in different cities.

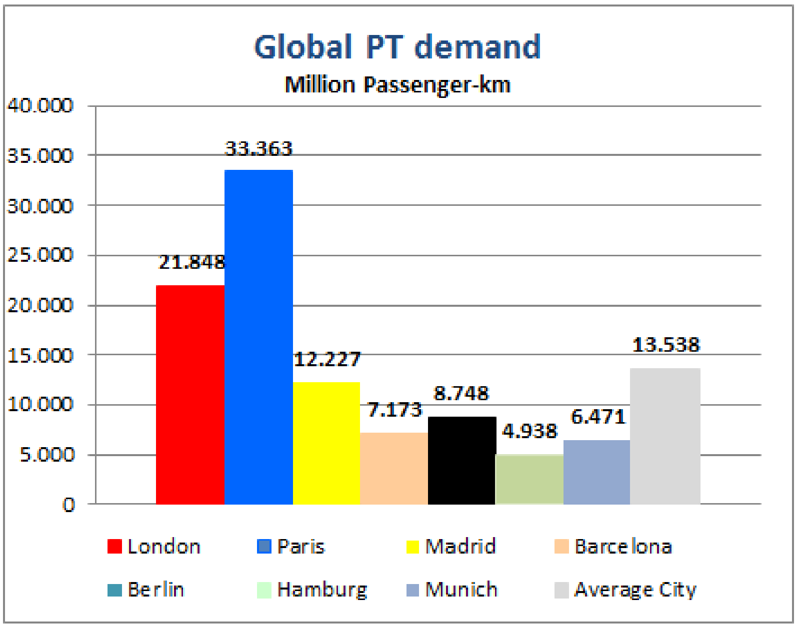
	Suburban Rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
	Pax-km (milion)					
London	1.440	12.081	140	8.188	0	**21.848**
Paris	19.615	7.714	913	864	4.257	**33.363**
Madrid	3.323	3.583	49	1.462	3.810	**12.227**
Barcelona	3.409	2.135	83	918	628	**7.173**
Berlin	907	5.800	596	1.445	0	**8.748**
Hamburg	825	3.014	0	659	440	**4.938**
Munich	936	4.211	333	540	450	**6.471**
Average City	4.351	5.506	302	2.011	1.369	**13.538**

Table 34. Demand for mode of transport and city. Passengers-km. Source: own elaboration with excel.

	Suburban Rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
	Average trip per passenger (km)					
London	6,2	8,2	5,2	3,5	0,0	5,4
Paris	13,6	5,1	3,2	2,6	3,9	7,1
Madrid	18,0	6,1	3,1	3,4	17,0	8,5
Barcelona	23,1	5,0	3,1	3,2	8,5	7,5
Berlin	19,2	6,0	3,1	3,3	0,0	5,3
Hamburg	20,7	6,0	0,0	3,1	10,0	6,2
Munich	23,4	6,6	2,8	2,8	10,0	6,3
Average City	14,3	6,3	3,2	3,4	6,5	6,5

Table 35. Average trip per passenger for mode of transport and city, km. Source: own elaboration with excel.

The longest average trip takes place in Madrid and the shortest in Berlin, which matches quite well with the concept of a city-region, a little bit isolated, regarding other German agglomerations.



Graph 21. Demand in the global transport system. Passengers-km. Source: own elaboration with excel.

The graph above shows the good position of Paris. Compared with the demand in terms of just passengers, when it is measured in terms of passenger-km it is still better, with a remarkable increase of the gap with the second one in the list, London. This is due to the fact that the average trip of passengers in Paris is higher than in other cities. Naturally, there is a certain proportion between the size of the agglomeration/city and the average trip of its residents.

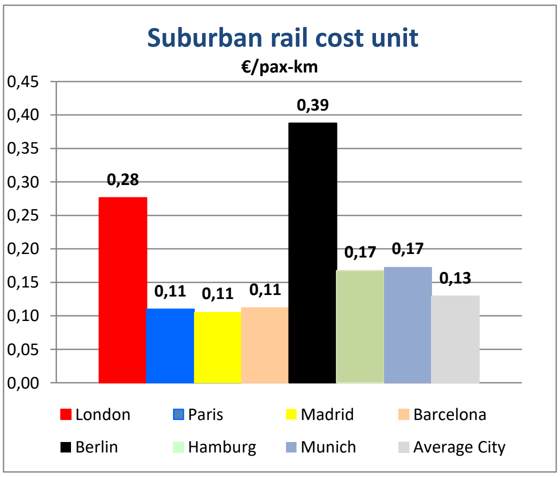
6.2.2. Cost per passenger

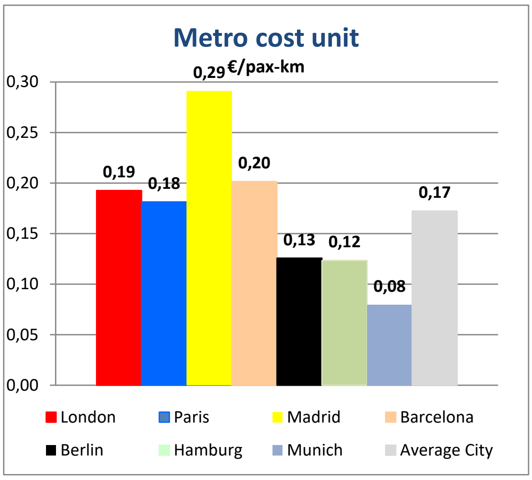
Next table indicates the cost per passenger of each mean of transportation. The most relevant cost is not the absolute cost of each trip but the cost per unit expressed in terms of EUR / passenger-km.

	Suburban Rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
	Cost / pax-km (€)					
London	0,28	0,19	0,28	0,36	0,00	**0,26**
Paris	0,11	0,18	0,16	0,35	0,18	**0,14**
Madrid	0,11	0,29	2,37	0,36	0,19	**0,22**
Barcelona	0,11	0,20	0,28	0,51	0,33	**0,21**
Berlin	0,39	0,13	0,28	0,38	0,00	**0,19**
Hamburg	0,17	0,12	0,00	0,47	0,10	**0,17**
Munich	0,17	0,08	0,21	0,32	0,29	**0,13**
Average City	0,13	0,17	0,27	0,38	0,20	**0,19**

Table 36. Cost per passenger-km for mode of transport and city. EUR/passenger-km. Source: own elaboration with excel.

Next graphs show the differences among cities depending on the means of transportation.



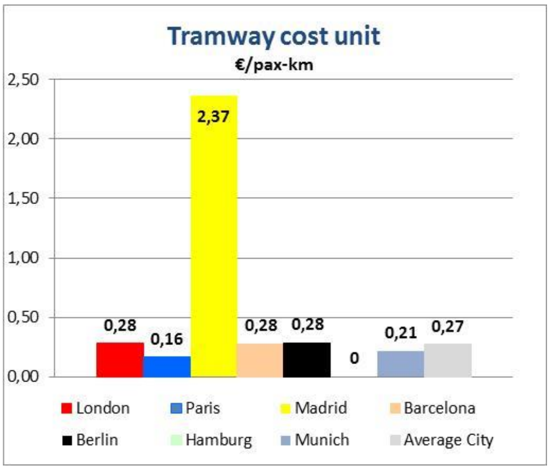


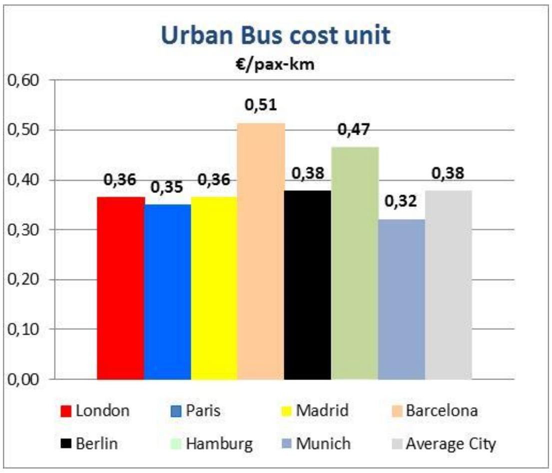
Graph 22. Suburban rail (left) and metro (right) cost per pasenger-km. Source: own elaboration with excel.

In the case of suburban train costs, Berlin stands out for its high value. Maybe it is due to the fact that it is not a very frequented service. Apart of this case, and that of London, which is not very representative due to the low level of service done in the British capital under the umbrella of TfL, the rest of cities are aligned with similar values.

The case of the metro is different. In this scheme Madrid stands out for its high cost per unit. This fact is related to the relative low level of occupation of the new lines built out of the administrative borders of the city of Madrid. The rest of cities can be divided into two groups. First group: those that have an intermediate cost per unit. Here it is Barcelona, Paris and London. And second, those cities with a low level of cost, the German ones: Berlin, Hamburg and Munich.

This is due to the high level of use of the metro network. Very remarkable is the case of Munich whose case will be discussed in depth later.

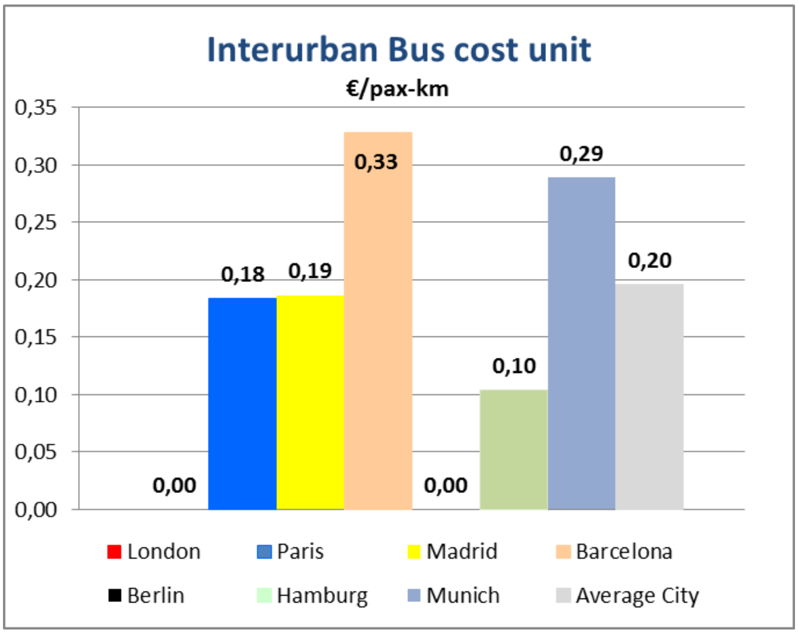




Graph 23. Tramway (left) and urban bus (right) cost per passenger-km. Source: own elaboration with excel.

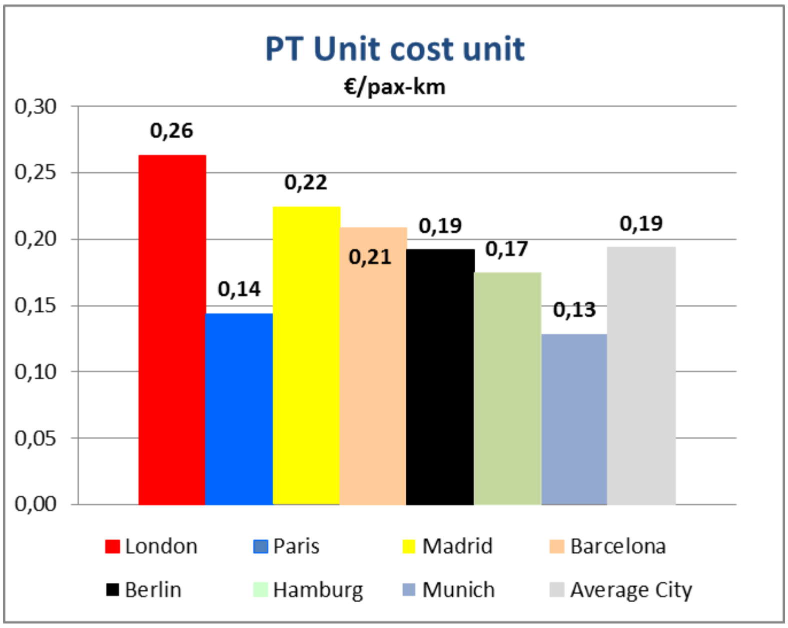
When it comes to the tram cost per unit, cities may be classified in two categories of cities: Madrid and the rest of cities. Madrid appears with a very high cost per unit, ten times higher than the average city. This is due to the low level of use of its trams. The lower cost is that of Paris and, again, it must be explained by the very high use of the tramway network in the French capital.

As it regards the cost per unit of the urban bus, the best case is Munich and the worst Barcelona, which has a cost 30% higher than the average. High wages, a lower use of the network, short mileages and low speeds of circulation are normally the facts that tend to produce these poor results.



Graph 24. Cost per passenger-km in interurban bus. Source: own elaboration with excel.

When we talk about the interurban bus cost per unit, the worst case is again Barcelona and the better is Hamburg. The facts that may explain these results usually are the low level of use of those services.



Graph 25. Cost per passenger-km in the global PT network. Source: own elaboration with excel.

On average, over the whole PT network, the higher level of cost per unit is done in London, and the lower in Munich, followed at a very short distance by Paris. The rest of cities are placed at the same level than the average city. The higher is the rail usage use in city, lower is its costs as a whole. So it seems to be clear that the share of rail usage, higher or lower, is the main factor to explain the differences among cities.

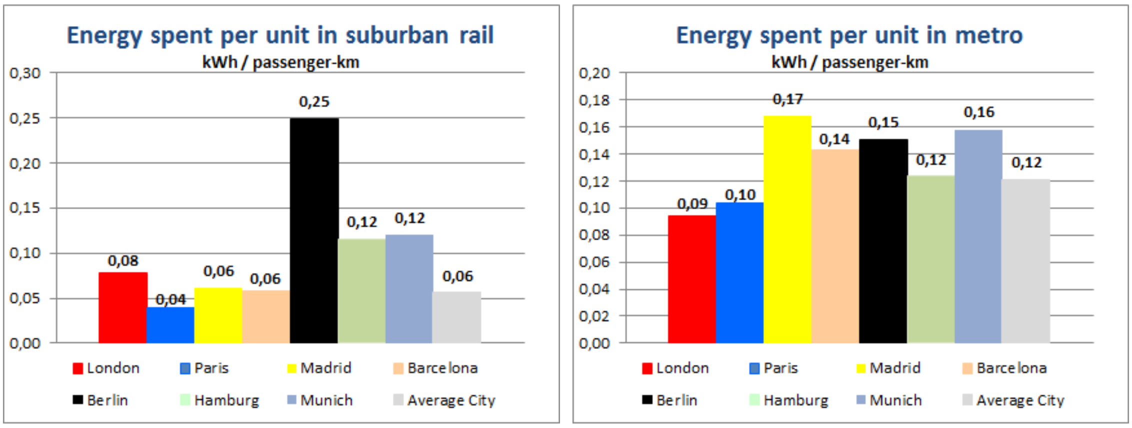
6.2.3. Energy per trip

The energy spent per passenger-km has also been calculated. This is a very relevant parameter since it affects the core of the sustainability. Data on such topic are the next:

	Suburban Rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
	Energy spent per unit (kWh / passenger-km)					
London	0,08	0,09	0,08	0,36	0,00	0,19
Paris	0,04	0,10	0,06	0,34	0,44	0,11
Madrid	0,06	0,17	1,11	0,42	0,23	0,19
Barcelona	0,06	0,14	0,13	0,57	0,58	0,19
Berlin	0,25	0,15	0,15	0,38	0,00	0,19
Hamburg	0,12	0,12	0,00	0,47	0,18	0,17
Munich	0,12	0,16	0,39	0,48	0,10	0,18
Average City	0,06	0,12	0,12	0,39	0,36	0,16

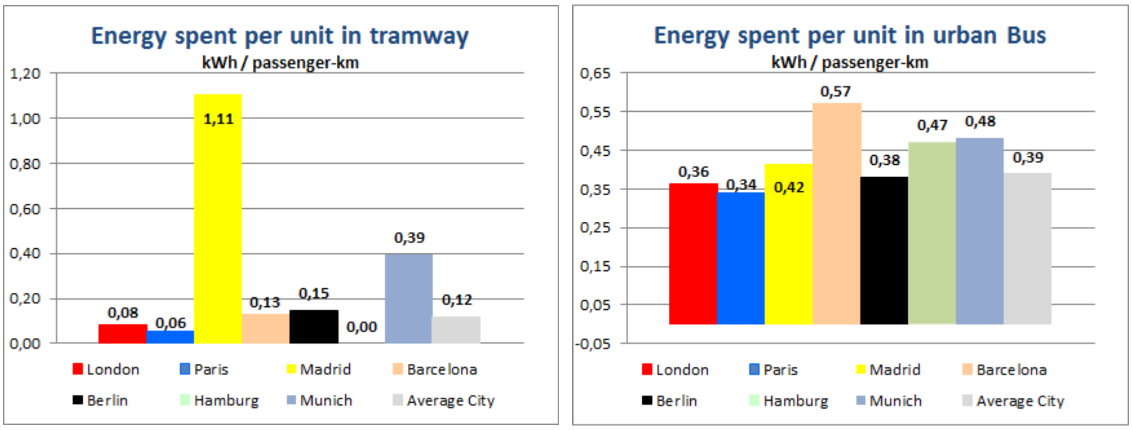
Table 37. Energy spent (kWh/passenger-km). Source: own elaboration with excel.

Next graphs show the differences among cities and system of transportation.



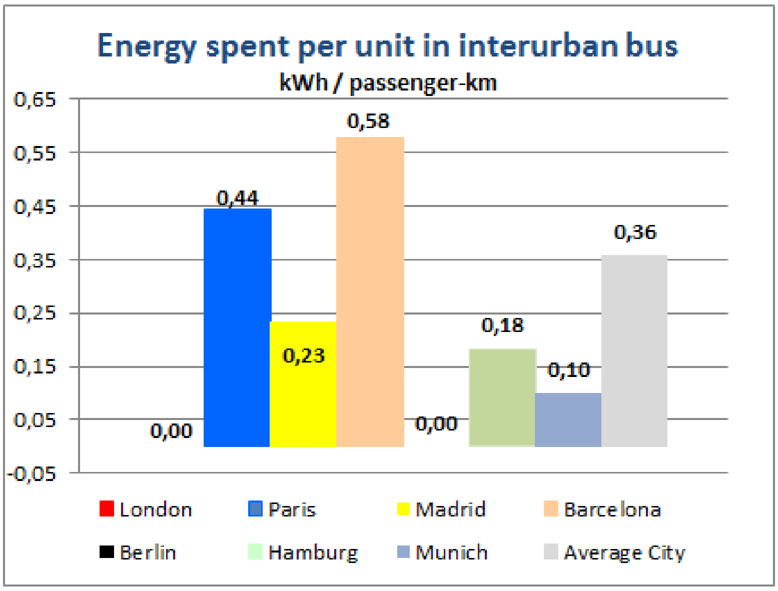
Graph 26. Energy spent suburban rail (left) Energy spent metro (right). Source: own elaboration with excel.

In the field of suburban rail service most cities are placed around the average city, but the German cities have a higher value. The maximum is Berlin due the scarce use of such kind of trains. As a whole, the energy consumption per unit is very low, 0,06 kWh / passenger-km, which is the half of the energy consumption in metro services. This is normal since the level of consumption is very influenced by the distance between two stations which is higher in the case of suburban rail services. The consumption per unit is also very influenced by the rate of occupation. So, lower occupations, like in the case of Madrid, mean as well higher level of consumption.



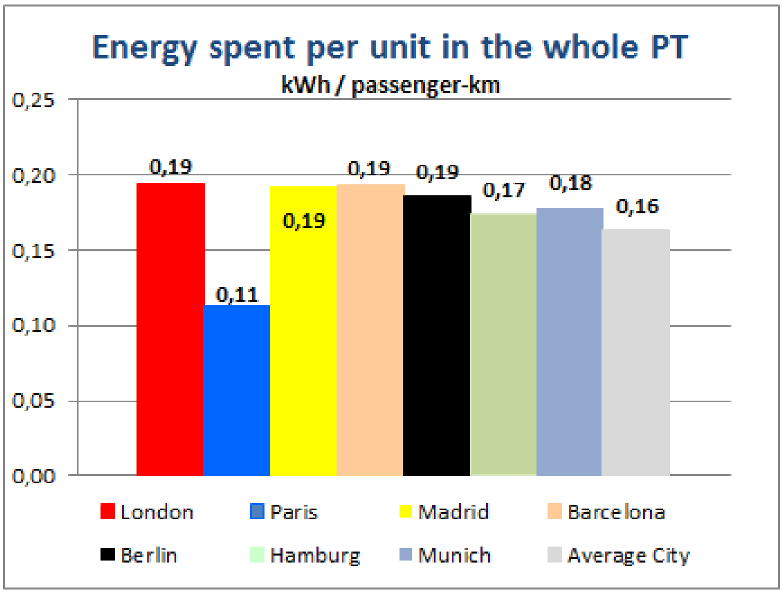
Graph 27. Energy spent tram (left). Energy spent urban bus (right). Source: own elaboration with excel.

Regarding the energy consumption in trams Madrid is standing out due, as told, to its lower level of usage of such mean of transportation. As a whole, the average energy consumption in tram has the same value than in metro services. This feature could be a surprise but it is not. In trams services the single consumptions are those of traction and on the contrary, in metro services there are much other consumption linked to the energy facility needs.



Graph 28. Energy spent interurban bus (kWh/pax-km). Source: own elaboration with excel.

As far as the energy consumption in interurban bus services is concerned, there are great deviations from the average value. This is du, not to a different efficiency of vehicles traction , but to its different level of vehicles occupation.



Graph 29. Energy spent whole PT network (kWh/pax-km). Source: own elaboration with excel.

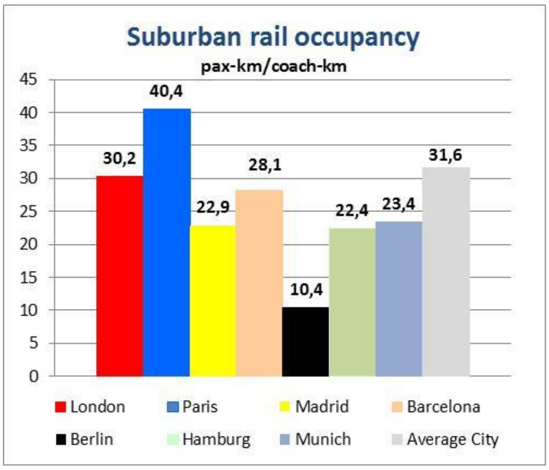
As a whole, the most efficient PT system is that of Paris, in unitary terms: long distance trips, high rate of rail usage…, induces to this. In the comparison among means of transportation, the energy consumption per unit in metro is the half than in tram and juts means the 15% of the energy needed to move a passenger in the same distance.

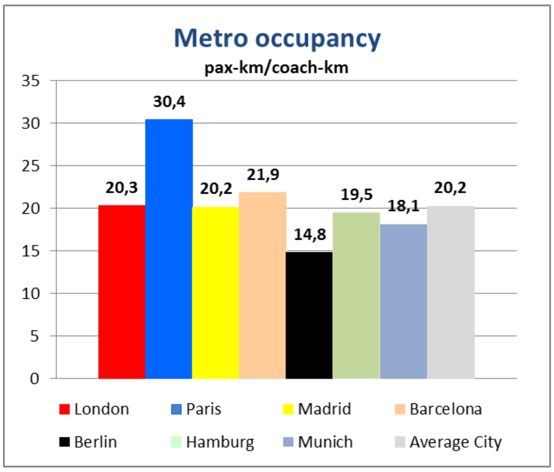
6.2.4. Occupancy

The occupation is defined as the quotient between the demand, defined by the number of passenger-km, and the supply, defined by the number of coach-km. This parameter defines very well the social profit got by PT exploitations and represents the average occupation of the network during the whole day.

	Suburban Rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
	Occupancy (pax-km/Coach-km)					
London	30,2	20,3	46,1	16,6	0,0	19,1
Paris	40,4	30,4	76,1	20,5	13,8	30,0
Madrid	22,9	20,2	3,9	16,5	22,0	20,1
Barcelona	28,1	21,9	33,2	12,1	10,7	20,2
Berlin	10,4	14,8	30,2	16,2	0,0	15,4
Hamburg	22,4	19,5	0,0	13,1	33,8	19,4
Munich	23,4	18,1	40,4	16,6	12,2	20,7
Average City	31,6	20,2	36,4	16,2	16,3	21,6

Table 38. Occupancy for mode of transport and city. (passenger-km/Coach-km). Source: own elaboration with excel.

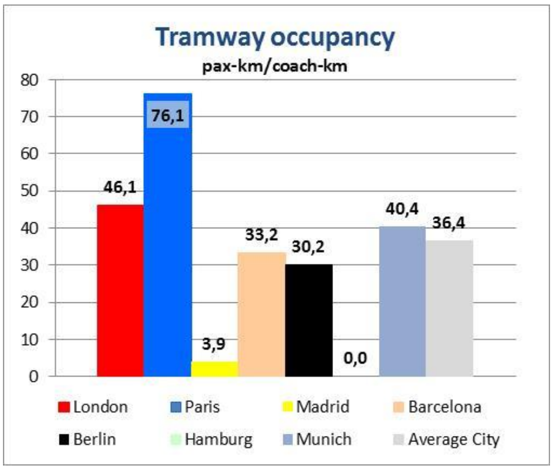


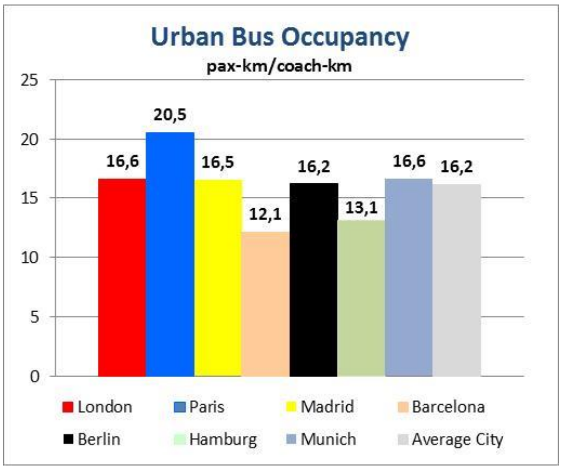


Graph 30. Occupancy for suburban rail (left). Occupancy for metro (right). Source: own elaboration with excel.

As it has been previously stated, Paris has the highest level of suburban rail use and Berlin the lowest. There is a scale of 4 to 1 between these two cases. The rest of cities are placed in an intermediate position. Remarkable is the data that six cities –all out of Paris- are below of the average city. This fact shows the potential of increasing the use of suburban trains in those six cities.

The same patron of suburban rail behavior appears in the occupancy rate of metro, but the differences among cities are not so intense like in the previous case. Five cities are placed at the same level than the average city. Distance between the worst and the better case has been reduced to 2 to 1 instead of the previous 4 to 1.

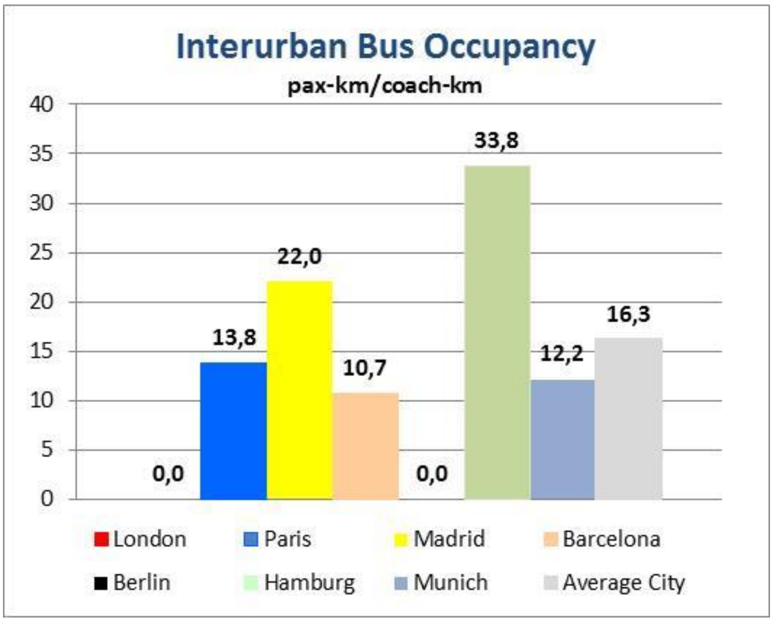




Graph 31. Occupancy for tramway (left). Occupancy for urban bus (right). Source: own elaboration with excel.

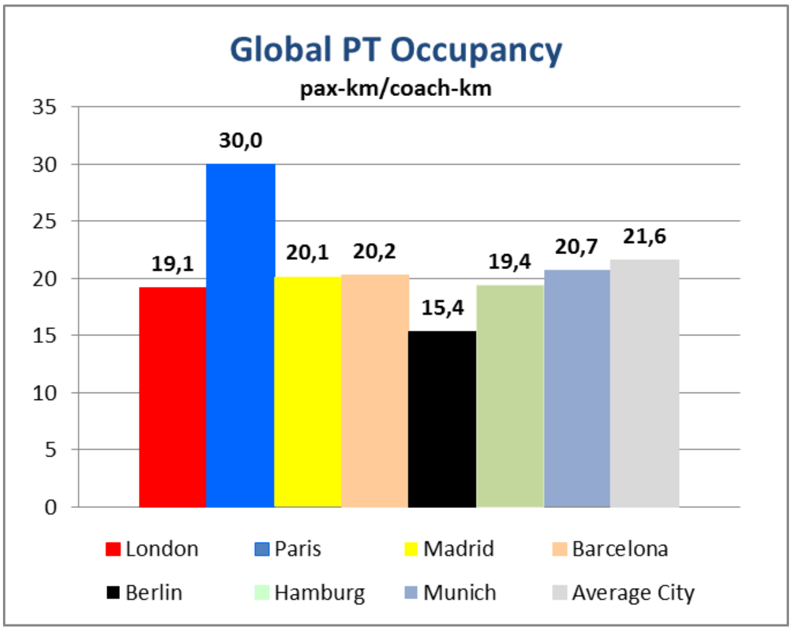
In the case of tramways the differences grow back again. Paris has a level of tram occupancy which is 20 times higher than Madrid, but the rest of five cities --since Hamburg has no tram-- remain at a similar level, aligned with the average city.

Less differences are found when we talk about the urban bus occupancy. Except Barcelona and Hamburg, the other cities are placed at the level of the average city. Paris shows that there may be a path to grow for cities with lower usage rates of urban buses.



Graph 32. Occupancy for interurban bus. Source: own elaboration with excel.

In the case of interurban buses, Hamburg is the better case and Barcelona the worst. There are quite differences among cities



Graph 33. Occupancy for the global PT network. Source: own elaboration with excel.

As a whole, the better city regarding its level of occupancy rate is Paris and the worst Berlin, even though there are not many differences among cities, since the majority of them are placed at the same level of the average city.

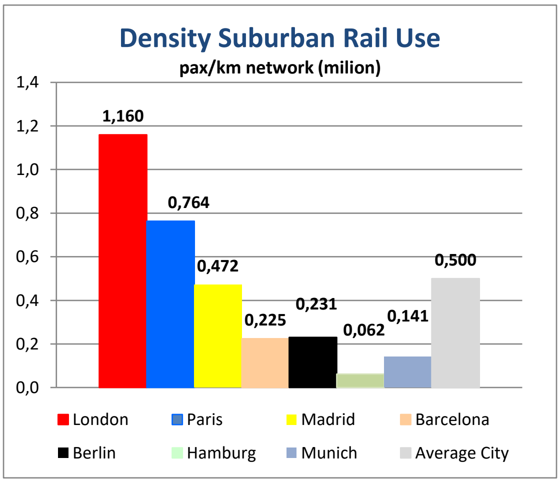
6.2.5. Density of usage of the network

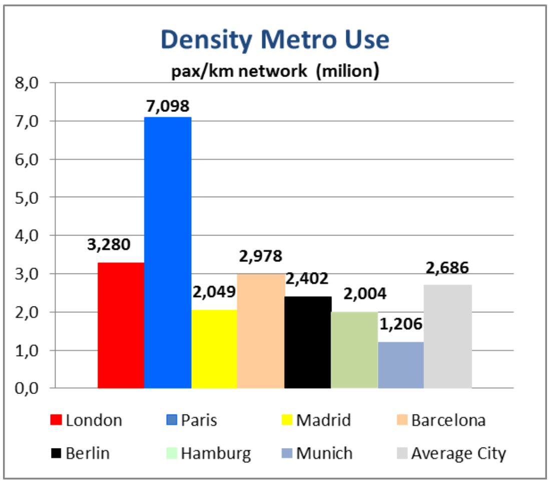
The density of use of network is defined as the quotient between the demand, measured in terms of passenger-km, and the length of the PT network in km.

The provided data based on this statistic are less relevant than the others parameters, since having a long network in the PT in a city does not necessarily mean having a very powerful network. Due to that the figures are just commented in the results of the global network.

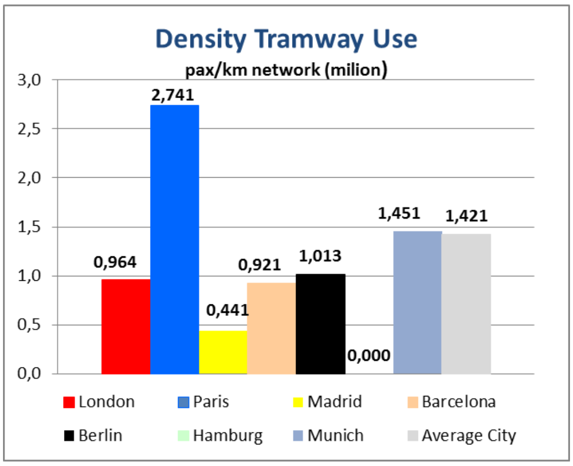
	Suburban Rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
	Pax / km network (milion)					
London	1,160	3,280	0,964	0,356	0,000	0,563
Paris	0,764	7,098	2,741	0,553	0,229	0,617
Madrid	0,472	2,049	0,441	0,280	0,027	0,135
Barcelona	0,225	2,978	0,921	0,127	0,006	0,061
Berlin	0,231	2,402	1,013	0,255	0,000	0,658
Hamburg	0,062	2,004	0,000	0,228	0,003	0,054
Munich	0,141	1,206	1,451	0,390	0,009	0,165
Average City	0,500	2,686	1,421	0,300	0,034	0,225

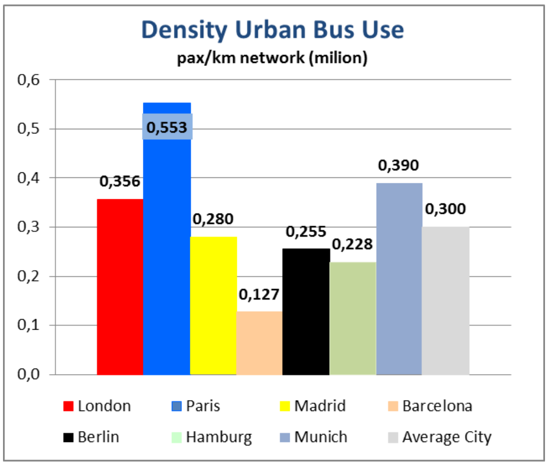
Table 39. Density of usage for mode of transport and city. (passenger/km network). Source: own elaboration with excel.



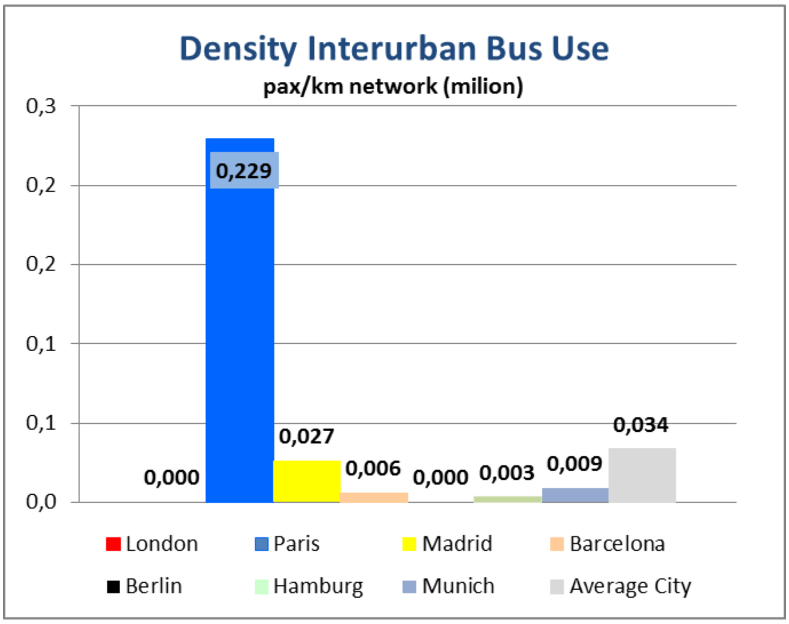


Graph 34. Density of usage for suburban rail (left). Density of usage for metro (right). Source: own elaboration with excel.

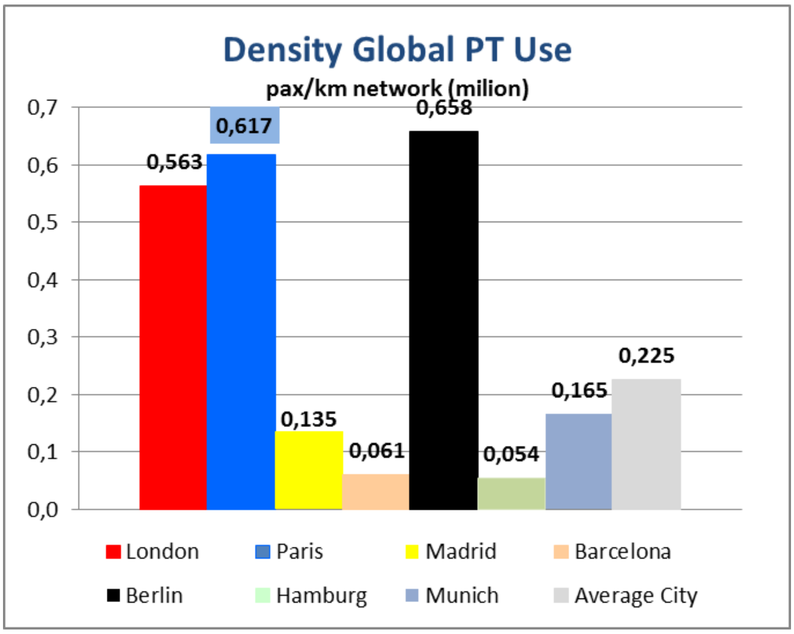




Graph 35. Density of usage for tramway (left). Density of usage for urban bus (right). Source: own elaboration with excel.



Graph 36. Density of usage for interurban bus. Source: own elaboration with excel.



Graph 37. Density of usage for the global PT network (passenger/km network). Source: own elaboration with excel.

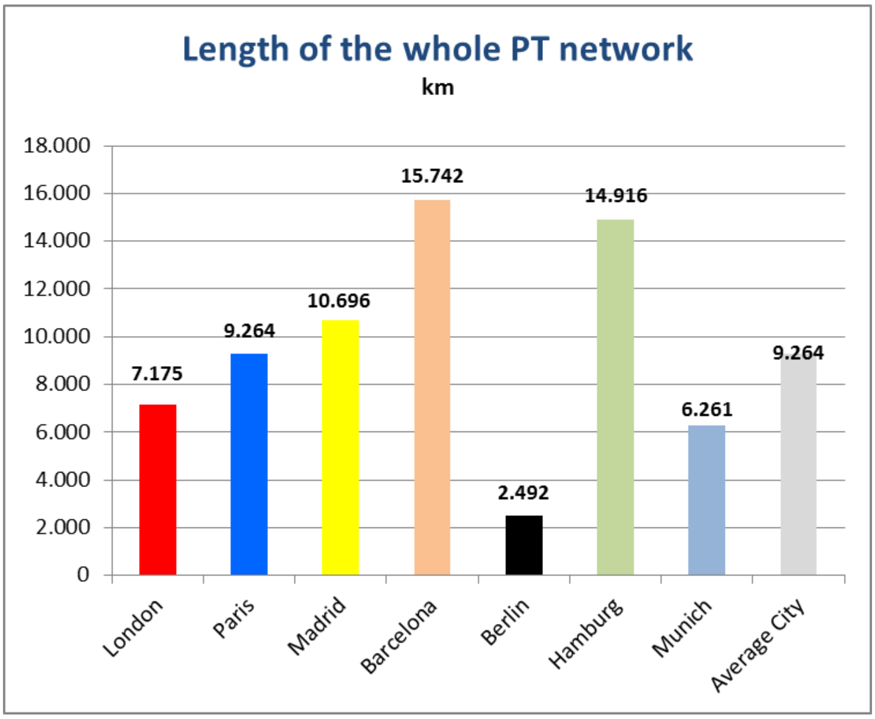
As far the length of the network is concerned, great differences are appreciated among cities; the highest values are those of Madrid and the poorest appear in Hamburg and Barcelona, with a range of 10 to 1 between these values. It is clear that this does not mean than the cities with the highest score has a more frequented network, but what it means is that in these cities there is a shorter network.

Data on the length of each PT network are the next:

	Suburban Rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
	Length (km)					
London	200	447	28	6.500		7.175
Paris	609	325	67	1.997	6.266	9.264
Madrid	391	289	36	1.534	8.447	10.696
Barcelona	656	143	29	2.229	12.685	15.742
Berlin	205	403	191	1.694		2.492
Hamburg	642	251		927	13.096	14.916
Munich	283	529	82	495	4.872	6.261
Average City	609	325	67	1.997	6.266	9.264

Table 40. Length (km) of PT network, by mode of transport and city. Source: own elaboration with excel.

In the next graph the length of the PT network of each city is presented. The longest network is Barcelona and the shortest Berlin. This is because Barcelona's suburban rail network reaches the Pyrenees in the French border, even though not many users of the so-called *Cercanias* trains use this rail system out of the metropolitan region, and, as in the same case of Hamburg, interurban bus network has an enormous capillarity and therefore many routes, some of them with poor figures of passengers.



Graph 38. Length of PT network, by mode of transport and city. Km. Source: own elaboration with excel.

Next table represents the rate of coverage of operational costs by current incomes.

Coverage of expenses	Suburban Rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
London	81%	90%	69%	65%		76%
Paris	35%	61%	105%	66%	100%	57%
Madrid	47%	46%	10%	46%	23%	39%
Barcelona	50%	64%	61%	43%	32%	50%
Berlin	31%	106%	103%	103%		90%
Hamburg	100%	100%		100%	100%	100%
Munich	69%	198%	185%	150%	35%	139%
Average City	45%	83%	91%	70%	59%	69%

Table 41. Coverage of costs operation by regular incomes. Source: own elaboration with excel.

German cities trend to have balanced accounts, outstanding in that purpose the city of Munich in which thanks to its high productivity the local operator even can return money to the city. In this topic the worst case is Madrid, (coverage of 39%) due to the low level of occupancy (and therefore incomes) in some metro lines out of the center city and in all tramways lines. Barcelona is placed in a mid-term, 50% of coverage, while Paris is placed at a level of 57% and London in higher position, 85%.

6.3. Efficiency of Public Transport Network

6.3.1. Catchment of passengers

This is an easy parameter to be calculated. It is the quotient between the yearly passenger demand and the population living inside of the area of PT governance.

	AREA OF GOVERNMENT OF PT		
Demographic	Inhab	Surface (km2)	Density (inhab/km2)
London	8.817.300	5.618	1.569
Paris	12.246.234	12.012	1.020
Madrid	6.587.711	8.022	821
Barcelona	4.747.035	2.464	1.926
Berlin	3.613.495	892	4.052
Hamburg	1.830.584	755	2.424
Munich	2.899.000	5.530	524
Average City	5.820.194	5.042	1.154

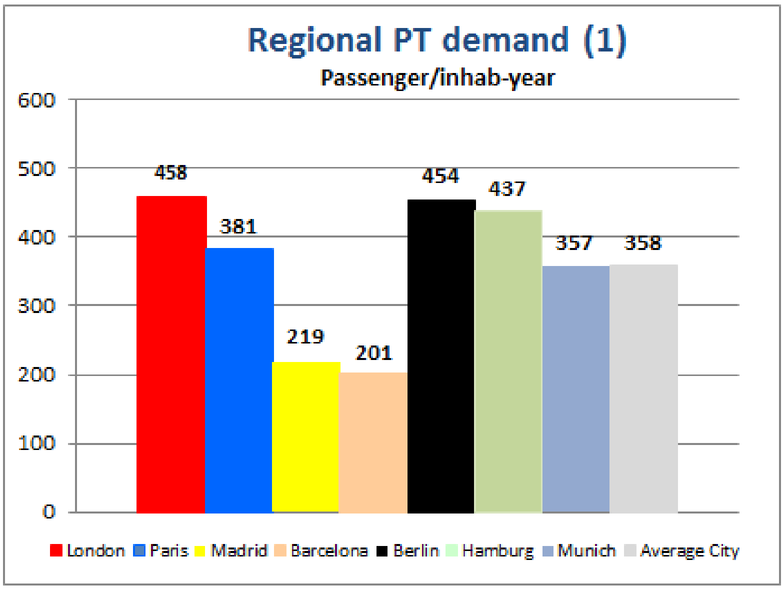
Table 42. Main features of the metropolitan areas. Source: own elaboration with excel.

As told, data are calculated taking into account the area of governance of PT in each city. They are: London (TfL), Paris (STIF), Madrid (CRTM), Barcelona (ATM), Berlin, (land), Hamburg (land) and Munich (MVV).

	AREA OF GOVERNMENT OF PT		
	Passengers / inhab	**Passengers-km / inhab**	**Coach-km / inhab**
London	458	2.478	129
Paris	381	2.724	90
Madrid	219	1.856	91
Barcelona	201	1.511	75
Berlin	454	2.421	163
Hamburg	437	2.698	139
Munich	357	2.232	121
Average City	358	2.326	108

Table 43. Main territorial parameters regarding PT demand and supply in metropolitan areas. Source: own elaboration with excel.

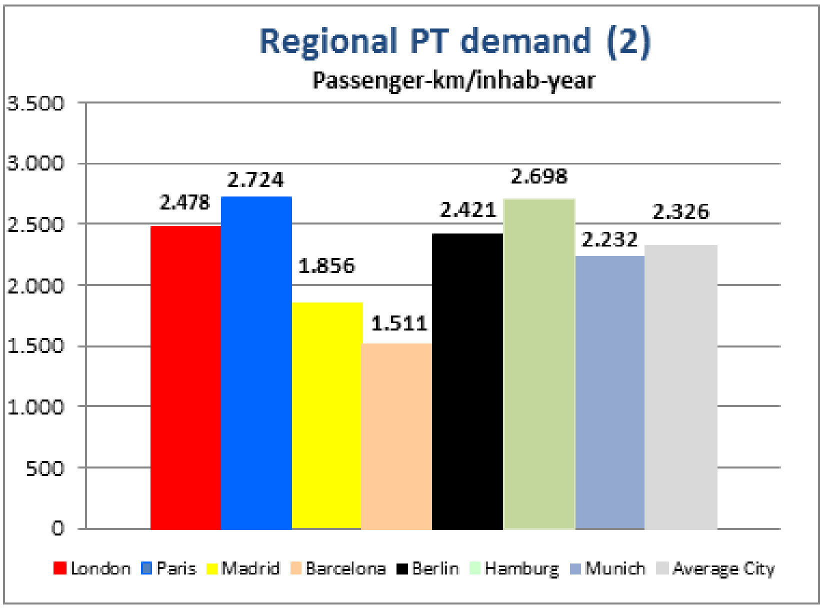
These figures are represented in the next graphs.



Graph 39. *Yearly demand of PT per inhabitant. Passenger/inhab-year* Source: own elaboration with excel.

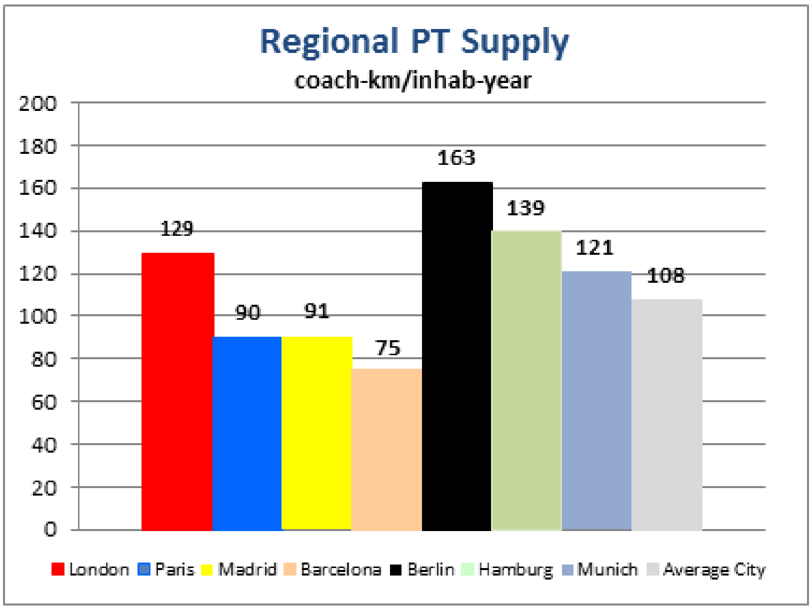
This is one of the most important graphs and shows that the most efficient cities in catching passengers for PT are London, Berlin and Hamburg. The less efficient are the Spanish ones, Madrid and Barcelona. Paris and Munich are placed in an intermediate level, at the same range of the average city.

Although the cities of Barcelona and Madrid have a very powerful local PT network, their supply is too concentrated in the inner city. Since the regional area in which the assessment has been done is quite wide, 8.000 km2 in the case of Madrid and 2.500 km2 in Barcelona, the lack of a consistence rail service out of the conurbated area impairs their figures. During so long time political messages in Spain have been focused in building metro network that there is a clear lack of PT supply beyond the central city, which matches with the conurbated and metro/tram area.



Graph 40. Yearly demand of PT per inhabitant. Passenger-km/inhab-year. Source: own elaboration with excel.

When the analysis is made based on passenger-km instead of passengers, the shape of the graph changes softly. The gap between the best and worst case decreases. The best now is Paris, followed by Hamburg and London, which falls to third place. In passenger terms the quotient between the first and the last one was 2.3 and now is 1.8 in terms of passenger-km. The Spanish cities are placed again at the bottom of the classification.



Graph 41. Yearly supply of PT per inhabitant. Coach-km/inhab-year. Source: own elaboration with excel.

As it comes to supply, Berlin is leading the ranking of provided PT in terms of coach-km / inhabitant-year, followed by Hamburg, London and Munich. Barcelona is again the last one.

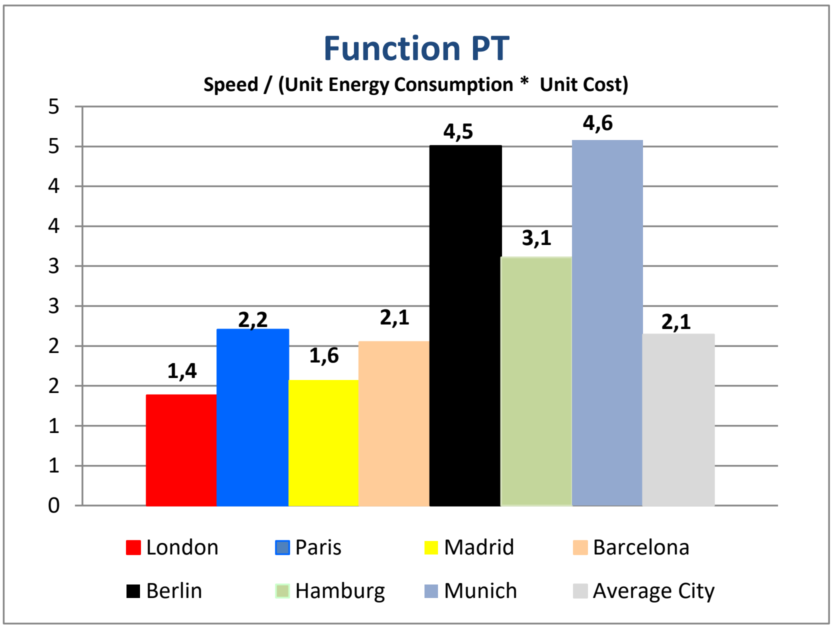
6.3.2. Cost and the energy efficiency function

This function is defined as follows:

$$\textbf{PT Function} = S / (C*E) \qquad (2)$$

Where S = Speed (km/h): C = cost per unit (EUR/coach-km); E = Energy consumption per unit (kWh/coach-km).

The values of this efficiency for each city are the next:



Graph 42. *PT Function* ***(S / (E * C))*** *for each city.* Source: own elaboration with excel.

There are big differences among values. As told the highest score is for Munich, followed at a very short distance by Berlin. Hamburg is the third one, while London closes the ranking.

This absolute data may also be classified in a relative scale.

	Relative scale PT Function
London	1,00
Paris	1,60
Madrid	1,14
Barcelona	1,49
Berlin	3,26
Hamburg	2,25
Munich	3,31
Average City	1,55

Table 44. Function relative scale. Source: own elaboration with excel.

It has been observed that this efficiency function is very well correlated with some other parameters related to the efficiency. Those are rails share, speed and energy consumption per unit.

Correlation of Function PT				
with Rail Share	with Unit cost	with Speed	with Unit Energy consumption	with PT Supply (coach-km)
0,96	-0,96	0,86	-0,89	-0,50

Table 45. Correlation of the PT Function with other parameters . Source: own elaboration with excel.

PT Function shows a very high correlation with the average rail share and speed. In other words, the PT Function shows that the higher is the use of rail, higher is also the efficiency of its PT scheme.

While London has a bad score due to its high share of bus usage (43%), Munich gets the best score thanks to its high rail share (80%).

We can conclude by saying that these two parameters, catchment of passengers and the Function PT (or Munich's Function) describes very well the efficiency of PT scheme and may guide us on which should be the roadmap of PT authorities in cities in the coming years for getting a more attractive and sustainable PT scheme.

A final and summarized function to assess the global efficiency of PT networks is defined by adding both parameters, catchment and PT Function, through a simply algebraic function.

It is not really easy to assign a weight to each one of these two parameters. This report bets on a weighting of 2 to 1. The catchment weighs the double than the PT Function. This choice is based on the principle that the success of public policy in favour of sustainable goals is catching passengers and the second goal consists in that these passengers travel in the most sustainable way. Having set this summary function, next results are got.

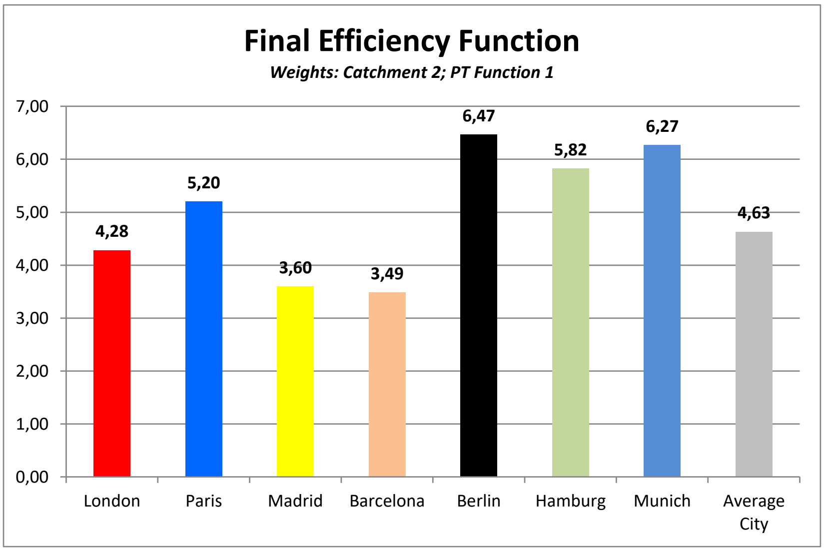
			Final Efficiency
			Weights
	Catchment	PT Function Relative scale	*2 and 1*
London	*1,64*	*1,00*	*4,28*
Paris	*1,80*	*1,60*	*5,20*
Madrid	*1,23*	*1,14*	*3,60*
Barcelona	*1,00*	*1,49*	*3,49*
Berlin	*1,60*	*3,26*	*6,47*
Hamburg	*1,79*	*2,25*	*5,82*
Munich	*1,48*	*3,31*	*6,27*
Average City	*1,54*	*1,55*	*4,63*

Table 46. Catchment and PT Function coefficients. Source: own elaboration with excel.

Values of this table have been obtained as follows:

The catchment and PT Function columns indicate the quotient between the respective value of a given city and the city with the lowest value which is Barcelona in the case of catchment and London in the PT Function.

The results are showed in the next graph.



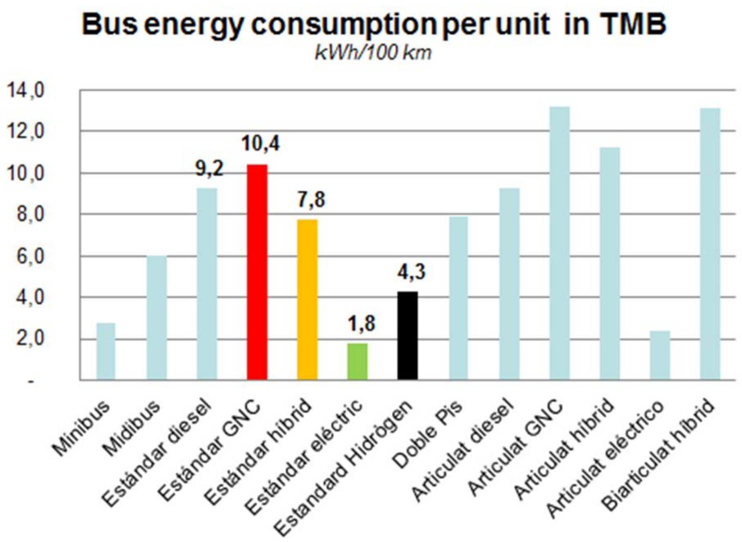
Graph 43. Final Efficiency PT. Source: own elaboration with excel.

According with this classification Berlin is the best city in the purpose of catching passengers and doing it in the most sustainable way, followed at a short distance by Munich and Hamburg, and followed at a certain distance by Paris and London and the Spanish cities, Madrid and Barcelona, which are closing the ranking and are the worst.

7. Conclusions

With all the information previously analyzed in mind, the main conclusions that can be extracted from this thesis analysis are:

1. The survey shows that cost per passenger-km in metro services is the half than in buses and 2 / 3 of a tram trip. A trip made in tram cost 70% of what costs in a bus.
2. Energy consumption per unit in metro is the half than in tram and juts means the 15% of the energy needed to move a passenger in the same distance.
3. Leaving aside the needed social analysis when providing new rail lines or increasing the capacity of the exiting ones, it is clear than the higher is number of share rail in terms of demand and supply; higher also is its efficiency. Traditional parameters linked to rail, like speed, low energy consumption per passenger and lower costs per passenger are confirmed by the success when dominant rail schemes are provided in the assessed cities.
4. Investments in providing new PT infrastructures and in improving the current services should be spread all over the whole metropolitan territory instead of being concentrated in the center of cities. The case of the Spanish cities shows that despite huge investments in the metro network in the inner city, the result on the whole metropolitan area is quite poor.
5. The electrification of buses will also contribute to make the PT schemes more sustainable and these buses for sure will be more used due to the increase of comfort (attractiveness) in a trip which is made under electric traction basis. The energy consumption of a bus when it is 100% electric decreases dramatically regarding a bus with thermic engine. Next graph shows the different consumptions depending on the traction over the fleet of TMB (Transports Metropolitans de Barcelona). It is clear that an electric bus spends 80% less energy than a diesel bus, 83% less than a Natural Gas bus, 77% less than a hybrid bus, and the half of a H2 bus based on fuel cells engine.



Graph 44. Energy consumption per unit and type of traction in buses. kWh/100 km. Source: own elaboration with excel.

6. When PT fleets are fueled with renewable electricity, which is the case of Spanish rail and metro systems, the contribution of their passengers to climate change is zero.

7. Trams have higher energy efficiency than buses. The good results obtained by Munich and Berlin show that in urban corridors with many buses, shifting from a bus scheme to a tram one may be a good alternative to be evaluated.

7.1. Recommendations for each city

A first general recommendation for all cities may be given. Nowadays, the topic of the climate crisis in Europe is arising in a strong way. This new scenario must be t must be used to impose more ambitious objectives on the growth of the passage in local public transport networks.

A second general recommendation could be provided for all cities, which is the potential of increasing suburban rail trips as it has been showed in the case of Paris.

A third recommendation for all cities is analyzing in a deep way their Efficiency Function as it has been defined in this report and compare their supply with those which get better scores.

LONDON

Londoner authorities should consider the possibility of setting up a tram network in corridors with frequent buses. The efficiency of trams, its higher speed, its mayor capacity and its attractiveness could decrease operation cost and energy consumption in such corridors.

PARIS

Not any specific recommendation is made for Paris. Some years ago the city decided to enlarge the urban/suburban rail system, based on a Rapid metro, extensions of the current metro network and new tram lines which will increase the capacity of transportation of the city, will increase the speed and decrease the energy consumption per unit.

MADRID

Apart of Barcelona, Madrid is the city which scores worst, so that some recommendation could be done for Madrid. The main goal of its transport policy should be trying to increase the occupation of tram lines, and metro lines beyond of the inner city. In parallel, city should plan substitution of some main suburban bus corridors by rails or cutting some direct bus lines to the center city and replacing such accesses by a combination of bus-rail scheme. The main goal of Madrid should be increasing the public transport use out the administrative borders of Madrid.

BARCELONA

Barcelona is the city which is scoring poor in the global PT function. This is a consequence, not of its metro and tram scheme, which is really brilliant, but a lack of efficient transport scheme out of the connurbated area of Barcelona. So, the suggestion is to set up a real integrated rail scheme in the second and third crown of the metropolitan region taking advantage of the existing but not yet integrated rail scheme. In this surrounding area, a lot of people are living there and they do not have a consistent rail schemes. In the inner city the opening of the central section of metro line 9 and the link of both trams along the Avinguda Diagonal will also contribute to improve its current poor position in this comparison.

BERLIN

Not any specific recommendation is made for Berlin. Year by year the growth of the tram network to the western side is constant and it is a good signal that city has a good roadmap.

HAMBURG

The main recommendation that could be given to Hamburg could be considering the introduction of a tram system in the city. As said in the case of London, in main corridors trams is a better option than buses.

MUNICH

Not any specific recommendation is made for Munich. The Bavarian capital has a very well PT scheme; it is very efficient and even provides money, in return, to the city.

The last but not the less, a first type of database have been created, a first indicator to keep on trying to generate a public system that covers all the cities, integrated with all the society and beyond barriers.

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APPENDIX 1. Detailed Excel Data

Legend of the data source:

Legend:

Dades de Barcelona
Dades estimades
Dades a contrastar
Dades Munich
Dades COMET-NOVA
Dades de DB Rergio
Dades de DB Rergio * 0,75
Pendent cost RB
AusRail 2008 (Berlin)
Berlin 2013 in Zahlen

Some data was not possible to calculate because of lack of the information. Some data was approximated taking into account the similarities observed.

BERLIN

OPERATIVE DATA 2016	Berlin & Brandenburg				
		2.015			
	R-Bahn	U-Bahn	S-Bahn	Tramvia (x2)	Bus Urbà
OFERTA					
Wait (min)	20	10	10	10	10
Car-hour		1.244		329	1.379
Cars in train	4	8	8	2	
Coach-km (millions)	87,0	172,3	263,0	19,7	89,3
Places-km					
Network length (km)	204,6	146,3	256,2	191,2	1.694,0
Energy consumption (GWh)	226,2	244,9	631,3	87,2	548,9
Unit consumption (kWh/coach-km)	2,6	1,4	2,4	3,8	6,1
Unit consumption (kWh/pax)	4,79	0,44	1,53	0,45	1,27
Unit consumption (kWh/pax-km)	0,07	0,10	0,19	0,15	0,38
Speed (km/h)	60,0	30,9	40,0	19,0	19,5
Annual Costs (M€)	351,62	390,00	339,20	169,09	544,43
Unit cost (€/coach-km)	4,04	2,26	1,29	8,57	6,10
DEMANDA					
Passenger (millions)	47,3	553,1	413,9	193,6	432,0
Mean passenger trip (km)	19,2	4,5	8,0	3,1	3,3
Passenger-km (millions)	907,2	2.489,0	3.311,2	595,6	1.445,1
Fare revenues (M€)	107,8	380,0	393,4	174,2	561,6
Unit passenger cost (€/pax-km)	0,39	0,16	0,10	0,28	0,38
Unit passenger cost (€/pax)	7,44	0,71	0,82	0,87	1,26
Unit passenger revenue (€/pax-km)	0,12	0,15	0,12	0,29	0,39
Unit passenger revenue (€/pax)	2,28	0,69	0,95	1,00	1,00
Occupancy rate (pax-km/coach-km)	10,43	14,44	12,59	30,19	16,19
Passengers/km of network	230.938,4	3.780.587,8	1.615.534,7	1.012.552,3	338.823,8
Dispersion (pax/coach-km)	0,5	3,2	1,6	9,8	4,8
Level of congestion (pax/car-hour)	#¡DIV/0!	0,4	#¡DIV/0!	0,6	0,3

Grouped data

	Suburban rail	Metro	Tramway (x2)	Bus Urbà	Total
SUPPLY					
Coach-km (milion)	87,0	392,3	19,7	89,3	588,3
Length (km)	204,6	402,5	191,2	1.694,0	2.492,3
Energy (GWh)	226	876	87	549	1.738
Unit Consumption (kWh/coach-km)	2,32	1,99	3,95	5,49	2,55
Unit Consumption (kWh/pax)	4,79	0,91	0,45	1,27	1,06
Unit Consumption (kWh/pax-km)	0,25	0,15	0,15	0,38	0,19
Speed (km/h)	60	37	19	20	37
Annual Costs (M€)	352	729	169	544	1.794
Cost/Coach-km (€)	4,04	1,86	8,57	6,10	3,23
DEMAND					
Passenger (milion)	47,3	967,0	193,6	432,0	1.639,9
Average passenger route (km)	19,2	6,0	3,1	3,3	5,3
Pax-km (milion)	907,2	5.800,2	595,6	1.445,1	9.343,7
Incomes (M€)	107,8	773,40	174,2	561,6	1.617,0
Cost/pax-km (€)	0,39	0,13	0,28	0,38	0,19
Cost/pax (€)	7,44	0,75	0,87	1,26	1,09
Income / pax-km (€)	0,12	0,13	0,29	0,39	0,17
Income / pax (€)	2,28	0,80	0,90	1,30	0,99
Occupancy (pax-km/Coach-km)	10,43	14,79	30,19	16,19	15,37
Passengers/km Network (milion)	0,231	2,402	1,013	0,255	0,658

Table 47. Data source, excel. Source: own elaboration with excel.

LONDON

OPERATIVE DATA 2016	Londres					
	LO (Overground)	TfL Rail	LU (Tube)	DLR	Tramvia (x2)	TfL Bus
OFERTA						
Wait (min)	20	10	2	10	5	5
Car-hour	96	30	543	149	35	6.780
Cars in train	4	5	7	3	2	
Coach-km (millions)	42,0	5,6	578	17,7	3,0	493,0
Places-km	2.000		71.804	3.366	634	30.386
Network length (km)	167,0	32,5	408,0	39,0	28,0	6.500,0
Energy consumption (GWh)	100,1	11,8	1.083,0	53,1	11,6	2.981,7
Unit consumption (kWh/coach-km)	2,4	2,1	1,9	3,0	3,8	5,4
Unit consumption (kWh/pax)	0,543	0,251	0,803	0,454	0,428	1,289
Unit consumption (kWh/pax-km)	0,105	0,024	0,095	0,085	0,083	0,364
Speed (km/h)	50,0	50,0	33,0	35,0	25,0	15,2
Annual Costs (M€)	288,00	110,00	2.201,00	126,00	39,00	2.987,00
Unit cost (€/coach-km)	6,86	6,86	3,81	6,86	12,83	6,06
DEMANDA						
Passenger (millions)	184,4	47,0	1.349,0	117,0	27,0	2.314,0
Mean passenger trip (km)	5,2	10,3	8,5	5,3	5,2	3,5
Passenger-km (millions)	953,5	486,1	11.458,0	622,6	140,0	8.188,0
Fare revenues (M€)	234,0	89,0	1.914,0	171,0	27,0	1.952,0
Unit passenger cost (€/pax-km)	0,30	0,23	0,19	0,20	0,28	0,36
Unit passenger cost (€/pax)	1,56	2,34	1,63	1,08	1,44	1,29
Unit passenger revenue (€/pax-km)	0,25	0,18	0,17	0,27	0,19	0,24
Unit passenger revenue (€/pax)	1,27	1,89	1,42	1,46	1,00	0,84
Occupancy rate (pax-km/coach-km)	22,7	86,55	19,84	35,18	46,05	16,61
Passengers/km of network	1.104.192	1.446.153,8	3.306.372,5	3.000.000,0	964.285,7	338.823,8
Dispersion (pax/coach-km)	4,4	8,4	2,3	6,6	8,9	4,7
Level of congestion (pax/car-hour)	1,9	1,6	2,5	0,8	0,8	0,3

Grouped data

	Suburban rail	Metro	Tramway	Urban Bus	Total
SUPPLY					
Coach-km (milion)	47,6	595,2	3,0	493,0	1.141,9
Length (km)	199,5	447,0	28,0	6.500,0	7.174,5
Energy (GWh)	111,9	1.136,1	11,6	2.981,7	4.241,2
Unit Consumption (kWh/coach-km)	2,35	1,91	3,80	6,05	3,71
Unit Consumption (kWh/pax)	0,48	0,77	0,43	1,29	1,05
Unit Consumption (kWh/pax-km)	0,08	0,09	0,08	0,36	0,19
Speed (km/h)	50,0	33,1	25,0	15,2	26,0
Annual Costs (M€)	398,00	2.327,00	39,00	2.987,00	5.751,00
Cost/Coach-km (€)	8,36	3,91	12,83	6,06	5,07
DEMAND					
Passenger (milion)	231,4	1.466,0	27,0	2.314,0	4.038,4
Average passenger route (km)	6,2	8,2	5,2	3,5	5,4
Pax-km (milion)	1.439,6	12.080,6	140,0	8.188,0	21.848,2
Incomes (M€)	323,0	2.085,00	27,0	1.952,0	4.387,0
Cost/pax-km (€)	0,28	0,19	0,28	0,36	0,26
Cost/pax (€)	1,72	1,59	1,44	1,29	1,42
Income / pax-km (€)	0,22	0,17	0,19	0,24	0,20
Income / pax (€)	1,40	1,42	1,00	0,84	1,09
Occupancy (pax-km/Coach-km)	30,23	20,30	46,05	16,61	19,13
Passengers/km Network (milion)	1,160	3,280	0,964	0,356	0,563

Table 48. Data source, excel. Source: own elaboration with excel.

MADRID

OPERATIVE DATA 2016	Madrid					
		2016				
	Renfe	Metro	Conc. Ferro	Tramvia (x2)	Urbà	Interubà
OFERTA						
Wait (min)		4	6	7	9	32
Car-hour	1.127	2.320	56	185	1.908	1.810
Cars in train						
Coach-km (millions)	145,3	180,0	3,5	12,6	87,8	172,0
Places-km						
Network length (km)	391,0	269,5	19,0	35,8	1.533,7	8.447,0
Energy consumption (GWh)	203,4	589,7	11,5	54,2	609,1	886,1
Unit consumption (kWh/coach-km)	1,4	3,3	3,3	4,3	6,2	4,6
Unit consumption (kWh/pax)	0,893	1,010	1,943	3,686	1,501	4,275
Unit consumption (kWh/pax-km)	0,050	0,168	0,162	1,189	0,441	0,251
Speed (km/h)	44,5	28,3	54,4	21,5	13,4	23,7
Annual Costs (M€)	351,63	1.033,00	9,09	115,92	533,65	705,20
Unit cost (€/coach-km)	2,42	5,74	2,60	9,20	6,08	4,10
DEMANDA						
Passenger (millions)	227,8	584,0	5,9	14,7	405,9	207,3
Mean passenger trip (km)	18,0	6,0	12,0	3,1	3,4	17,0
Passenger-km (millions)	4.100,4	3.504,0	70,8	45,6	1.380,1	3.524,1
Fare revenues (M€)	205,8	480,0	4,4	10,9	246,8	153,4
Unit passenger cost (€/pax-km)	0,09	0,29	0,13	2,54	0,39	0,20
Unit passenger cost (€/pax)	1,54	1,77	1,54	7,89	1,31	3,40
Unit passenger revenue (€/pax-km)	0,05	0,14	0,06	0,24	0,18	0,04
Unit passenger revenue (€/pax)	0,90	0,82	0,74	0,74	0,61	0,74
Occupancy rate (pax-km/coach-km)	28,22	19,47	20,23	3,62	15,72	20,49
Passengers/km of network	582.608,7	2.166.975,9	310.526,3	410.614,5	338.823,8	24.541,3
Dispersion (pax/coach-km)	1,6	3,2	1,7	1,2	4,6	1,2
Level of congestion (pax/car-hour)	0,2	0,3	0,1	0,1	0,2	0,1

Grouped data

	Suburban rail	Metro	Tramway (x2)	Urban Bus	Interurban Bus	Total
SUPPLY						
Coach-km (milion)	145,3	177,5	12,6	88,5	173,1	609,6
Length (km)	391,0	288,5	35,8	1.533,7	8.447,0	10.696,0
Energy (GWh)	203,4	601,5	54,2	609,1	891,8	2.360,1
Unit Consumption (kWh/coach-km)	1,40	3,39	4,30	6,88	5,15	3,87
Unit Consumption (kWh/pax)	1,10	1,02	3,43	1,42	3,98	1,63
Unit Consumption (kWh/pax-km)	0,06	0,17	1,11	0,42	0,23	0,19
Speed (km/h)	44,5	28,8	21,5	13,4	23,7	28,7
Annual Costs (M€)	351,63	1.042,55	115,92	533,65	709,71	2.753,46
Cost/Coach-km (€)	2,42	5,87	9,20	6,03	4,10	4,71
DEMAND						
Passenger (milion)	184,6	591,0	15,8	430,1	224,1	1.445,6
Average passenger route (km)	18,0	6,1	3,1	3,4	17,0	8,5
Pax-km (milion)	3.322,8	3.583,2	49,0	1.462,3	3.809,7	12.276,0
Incomes (M€)	166,8	484,59	11,7	246,8	165,8	1.075,7
Cost/pax-km (€)	0,11	0,29	2,37	0,36	0,19	0,22
Cost/pax (€)	1,90	1,76	7,34	1,24	3,17	1,90
Income / pax-km (€)	0,05	0,14	0,24	0,17	0,04	0,09
Income / pax (€)	0,90	0,82	0,74	0,57	0,74	0,74
Occupancy (pax-km/Coach-km)	22,87	20,19	3,89	16,52	22,01	20,14
Passengers/km Network (milion)	0,472	2,049	0,441	0,280	0,027	0,135

Table 49. Data source, excel. Source: own elaboration with excel.

BARCELONA

OPERATIVE DATA 2016	Barcelona									
			2.016							
	Rodalies BCN	FGC Resta STI	Metro	FGC 1 corona	Tramvia (x2)	Bus TMB	Bus AMB	DGTM	Municipal	Tot FGC
OFERTA										
Wait (min)										
Car-hour	72	64	256	94	46	834	614	639	243	
Cars in train										
Coach-km (millions)	101,6	19,7	85,8	11,9	2,5	38,5	37,3	45,1	13,6	31,6
Places-km										
Network length (km)	533,1	122,9	119,0	24,0	29,1	857,1	1.372,3	11.538,8	1.146,0	146,9
Energy consumption (GWh)	142,2	57,3	270,0	34,6	10,8	286,6	238,1	276,3	86,8	92,0
Unit consumption (kWh/coach-km)	1,4	2,9	3,1	2,9	4,3	6,6	5,7	5,5	5,7	2,6
Unit consumption (kWh/pax)	1,287	1,550	0,708	0,782	0,401	1,464	2,749	8,150	2,181	1,131
Unit consumption (kWh/pax-km)	0,051	0,089	0,142	0,152	0,129	0,505	0,681	0,543	0,727	0,105
Speed (km/h)	53,0	35,0	28,6	35,0	17,9	13,3	20,0	40,0	13,0	35,0
Annual Costs (M€)	245,87	135,25	350,00	80,17	23,00	277,20	193,96	135,30	70,72	215,42
Unit cost (€/coach-km)	2,42	6,87	4,08	6,74	9,20	7,20	5,20	3,00	5,20	6,82
DEMANDA										
Passenger (millions)	110,5	37,0	381,5	44,3	26,8	195,8	86,6	33,9	39,8	81,30
Mean passenger trip (km)	25,0	17,5	5,0	5,1	3,1	2,9	4,0	15,0	3,0	10,8
Passenger-km (millions)	2.762,5	646,2	1.907,5	227,9	83,1	567,8	349,9	508,5	119,4	874,10
Fare revenues (M€)	138,7	52,4	254,5	22,5	14,0	110,1	93,4	43,0	22,3	74,87
Unit passenger cost (€/pax-km)	0,09	0,21	0,18	0,35	0,28	0,49	0,55	0,27	0,59	0,25
Unit passenger cost (€/pax)	2,23	3,66	0,92	1,81	0,86	1,42	2,24	3,99	1,78	2,65
Unit passenger revenue (€/pax-km)	0,05	0,08	0,13	0,10	0,17	0,19	0,27	0,08	0,19	0,09
Unit passenger revenue (€/pax)	1,26	1,42	0,67	0,51	0,52	0,56	1,08	1,27	0,56	0,92
Occupancy rate (pax-km/coach-km)	27,2	32,8	22,2	19,2	33,2	14,7	9,4	11,3	8,8	27,7
Passengers/km of network	207.278,2	301.057,8	3.205.882,4	1.845.833,3	920.962,2	338.823,8	63.105,7	2.937,9	34.729,5	553.437,7
Dispersion (pax/coach-km)	1,1	1,9	4,4	3,7	10,7	5,1	2,3	0,8	2,9	2,6
Level of congestion (pax/car-hour)	1,5	0,6	1,5	0,5	0,6	0,2	0,1	0,1	0,2	#¡DIV/0!

Grouped data

	Suburban rail	Metro	Tramway (x2)	Urban Bus	Interurban Bus	Total
SUPPLY						
Coach-km (milion)	121,3	97,7	2,5	75,8	58,7	358,5
Length (km)	656,0	143,0	29,1	2.229,4	12.684,8	15.742,3
Energy (GWh)	199,6	304,6	10,8	524,7	363,1	1.402,8
Unit Consumption (kWh/coach-km)	1,65	3,12	4,30	6,92	6,19	3,91
Unit Consumption (kWh/pax)	1,35	0,72	0,40	1,86	4,93	1,47
Unit Consumption (kWh/pax-km)	0,06	0,14	0,13	0,57	0,58	0,19
Speed (km/h)	50,1	29,4	17,9	16,6	33,7	34,4
Annual Costs (M€)	381,12	430,17	23,00	471,16	206,02	1.511,47
Cost/Coach-km (€)	3,14	4,40	9,20	6,22	3,51	4,28
DEMAND						
Passenger (milion)	147,5	425,8	26,8	282,4	73,7	956,2
Average passenger route (km)	23,1	5,0	3,1	3,2	8,5	7,5
Pax-km (milion)	3.409	2.135	83	918	628	7.256
Incomes (M€)	191,1	276,97	14,0	203,5	65,3	750,9
Cost/pax-km (€)	0,11	0,20	0,28	0,51	0,33	0,21
Cost/pax (€)	2,58	1,01	0,86	1,67	2,80	1,58
Income / pax-km (€)	0,06	0,13	0,17	0,22	0,10	0,10
Income / pax (€)	1,30	0,65	0,52	0,72	0,89	0,79
Occupancy (pax-km/Coach-km)	28,10	21,86	33,23	12,11	10,70	20,24
Passengers/km Network (milion)	0,225	2,978	0,921	0,127	0,006	0,061

Table 50. Data source, excel. Source: own elaboration with excel.

MUNICH

OPERATIVE DATA 2016	Munich					
	R-Bahn	U-Bahn	S-Bahn	Tramvia (x2)	Bus Urbà	Bus Interurbà
OFERTA						
Wait (min)	25	5	25	2	6	
Car-hour	443	520	420	98	480	
Cars in train	4	6	8	2	1	1
Coach-km (millions)	10,0	69,2	163,0	8,3	32,5	37,0
Places-km		9.909,0		1.521,0	3.024,0	
Network length (km)	283,0	95,0	434,0	82,0	495,0	4.872,0
Energy consumption (GWh)	26,0	166,0	391,3	38,4	200,0	207,3
Unit consumption (kWh/coach-km)	2,6	2,4	2,4	4,7	5,5	5,0
Unit consumption (kWh/pax)	0,650	0,417	1,630	0,323	1,036	4,606
Unit consumption (kWh/pax-km)	0,071	0,097	0,157	0,115	0,370	0,461
Speed (km/h)	60,0	35,1	40,0	18,9	18,1	25,0
Annual Costs (M€)	40,42	125,59	210,32	70,73	173,22	129,96
Unit cost (€/coach-km)	4,04	~~1,82~~	1,29	8,57	5,34	3,51
DEMANDA						
Passenger (millions)	40,0	398,0	240,0	119,0	193,0	45,0
Mean passenger trip (km)	23,4	4,3	10,4	2,8	2,8	10,0
Passenger-km (millions)	936,0	1.711,4	2.500,0	333,2	540,4	450,2
Fare revenues (M€)	112,3	437,8	228,0	130,9	260,6	45,0
Unit passenger cost (€/pax-km)	0,04	0,07	0,08	0,21	0,32	0,29
Unit passenger cost (€/pax)	1,01	0,32	0,88	0,59	0,90	2,89
Unit passenger revenue (€/pax-km)	0,12	0,26	0,09	0,39	0,48	0,10
Unit passenger revenue (€/pax)	2,81	1,10	0,95	1,10	1,35	1,00
Occupancy rate (pax-km/coach-km)	93,60	24,74	15,33	40,37	16,65	12,16
Passengers/km of network	141.342,8	4.189.473,7	552.995,4	1.451.219,5	338.823,8	9.240,6
Dispersion (pax/coach-km)	4,0	5,8	1,5	14,4	5,9	1,2
Level of congestion (pax/car-hour)	0,1	0,8	0,6	1,2	0,4	#¡DIV/0!

Grouped data

	Suburban rail	Metro	Tramway (x2)	Urban Bus	Interurban Bus	Total
SUPPLY						
Coach-km (milion)	443	950	98	480	ND	1.971
Length (km)	283,0	529,0	82,0	495,0	4.872,0	6.261,0
Energy (GWh)	104,0	557,3	38,4	200,0	207,3	1.107,1
Unit Consumption (kWh/coach-km)	2,6	2,4	4,7	6,2	5,6	3,1
Unit Consumption (kWh/pax)	2,600	0,874	0,323	1,036	4,606	1,070
Unit Consumption (kWh/pax-km)	0,111	0,132	0,115	0,370	0,461	0,163
Speed (km/h)	60,0	38,5	18,9	18,1	25,0	37,2
Annual Costs (M€)	161,67	335,91	70,73	173,22	129,96	871,49
Cost/Coach-km (€)	4,04	1,45	8,57	5,34	3,51	2,63
DEMAND						
Passenger (milion)	40,0	638,0	119,0	193,0	45,0	1.035,0
Average passenger route (km)	23,4	6,6	2,8	2,8	10,0	6,3
Pax-km (milion)	936,0	4.211,4	333,2	540,4	450,2	6.804,4
Incomes (M€)	112,3	665,80	130,9	260,6	45,0	1.214,6
Cost/pax-km (€)	0,17	0,08	0,21	0,32	0,29	0,13
Cost/pax (€)	4,04	0,53	0,59	0,90	2,89	0,84
Income / pax-km (€)	0,12	0,16	0,39	0,48	0,10	0,18
Income / pax (€)	2,81	1,04	1,10	1,35	1,00	1,17
Occupancy (pax-km/Coach-km)	23,40	18,13	40,37	16,65	12,16	19,00
Passengers/km Network (milion)	0,141	1,206	1,451	0,390	0,009	0,165

Table 51. Data source, excel. Source: own elaboration with excel.

PARIS

OPERATIVE DATA 2016	París						
	RER	Transilien	Métro	Tramvia (x2)	Bus à Paris	Bus petite et grande courones	Noctilien
OFERTA							
Wait (min)	20	20	2	10			
Car-hour							
Cars in train	7	7	5	2	1	1	
Coach-km (millions)	288,4	196,7	253,5	12,0	42,1	119,5	7,2
Places-km							
Network length (km)	587,0	1.299,0	214,0	104,7	597,0	3.264,0	1.500,0
Energy consumption (GWh)	450,0	306,9	800,0	50,4	292,3	736,1	31,0
Unit consumption (kWh/coach-km)	1,6	1,6	3,2	4,2	6,2	5,5	3,9
Unit consumption (kWh/pax)	0,941	0,319	0,527	0,176	0,889	0,681	2,822
Unit consumption (kWh/pax-km)	0,086	0,021	0,104	0,055	0,338	0,176	0,370
Speed (km/h)	47,0	47,0	27,0	18,0	14,0	20,0	30,0
Annual Costs (M€)	700,00	1.456,00	1.400,00	150,00	302,00	770,00	32,48
Unit cost (€/coach-km)	2,43	7,65	5,52	12,50	7,17	6,44	4,51
DEMANDA							
Passenger (millions)	478,0	962,0	1.519,0	287,0	329,0	1.081,0	11,0
Mean passenger trip (km)	10,9	15,0	5,1	3,2	2,6	3,9	7,6
Passenger-km (millions)	5.214,0	14.401,0	7.714,0	913,0	864,0	4.173,0	84,0
Fare revenues (M€)	450,0	297,0	850,0	158,0	198,0	757,0	22,0
Unit passenger cost (€/pax-km)	0,13	0,10	0,18	0,16	0,35	0,18	0,39
Unit passenger cost (€/pax)	1,46	1,51	0,92	0,52	0,92	0,71	2,95
Unit passenger revenue (€/pax-km)	0,09	0,02	0,11	0,17	0,23	0,18	0,26
Unit passenger revenue (€/pax)	2,00	1,50	2,00	2,00	1,00	1,00	2,00
Occupancy rate (pax-km/coach-km)	18,08	73,21	30,43	76,08	20,52	34,92	11,67
Passengers/km of network	814.310,1	740.569,7	7.098.130,8	2.741.165,2	338.823,8	331.188,7	7.333,3
Dispersion (pax/coach-km)	1,7	4,9	6,0	23,9	7,8	9,0	
Level of congestion (pax/car-hour)	#¡DIV/0!	#¡DIV/0!	#¡DIV/0!	#¡DIV/0!	#¡DIV/0!	#¡DIV/0!	

Grouped data

	Suburban rail	Metro	Tramway	Urban Bus	Interurban Bus	Total
SUPPLY						
Coach-km (milion)	485,1	253,5	12,0	42,1	307,7	1.112,4
Length (km)	1.886,0	214,0	104,7	597,0	4.764,0	-
Energy (GWh)	756,9	800,0	50,4	292,3	1.882,1	3.781,8
Unit Consumption (kWh/coach-km)	1,56	3,16	4,20	6,94	6,12	3,40
Unit Consumption (kWh/pax)	0,53	0,53	0,18	0,89	1,72	0,81
Unit Consumption (kWh/pax-km)	0,04	0,10	0,06	0,34	0,44	0,11
Speed (km/h)	47,0	27,0	18,0	14,0	20,2	33,3
Annual Costs (M€)	2.156,00	1.400,00	150,00	302,00	782,91	4.790,91
Cost/Coach-km (€)	4,44	5,52	12,50	7,17	2,54	4,44
DEMAND						
Passenger (milion)	1.440,0	1.519,0	287,0	330,0	1.092,0	4.668,0
Average passenger route (km)	13,6	5,1	3,2	2,6	3,9	7,1
Pax-km (milion)	19.615,0	7.714,0	913,0	864,0	4.257,0	34.276,0
Incomes (M€)	747,0	850,00	158,0	198,0	779,0	2.732,0
Cost/pax-km (€)	0,11	0,18	0,16	0,35	0,18	0,14
Cost/pax (€)	1,50	0,92	0,52	0,92	0,72	1,03
Income / pax-km (€)	0,04	0,11	0,17	0,23	0,18	0,08
Income / pax (€)	0,52	0,56	0,55	0,60	0,71	0,59
Occupancy (pax-km/Coach-km)	40,43	30,43	76,08	20,52	13,83	30,81
Passengers/km Network (milion)	0,764	7,098	2,741	0,553	0,229	2,087

Table 52. Data source, excel. Source: own elaboration with excel.

HAMBOURG

OPERATIVE DATA 2016	Hamburg				
	R-Bahn	A-Bahn	U-Bahn	S-Bahn	Bus Urbà	Bus Interurbà
OFERTA						
Wait (min)	15	15	10	15	10	
Car-hour	555	56	839	492	820	1.447
Cars in train	3	2	7	5		
Coach-km (millions)	30,5	6,3	85,6	69,3	50,3	13,0
Places-km	7.636,2	894,2	8.244,5	11.887,1	3.920,4	5.170,2
Network length (km)	559,9	81,6	104,4	146,8	927,1	13.096,0
Energy consumption (GWh)	79,3	16,4	205,4	166,3	309,8	80,3
Unit consumption (kWh/coach-km)	2,6	2,6	2,4	2,4	5,5	5,5
Unit consumption (kWh/pax)	2,95	1,25	0,88	0,61	1,46	1,82
Unit consumption (kWh/pax-km)	0,071	0,083	0,148	0,102	0,470	0,122
Speed (km/h)	60,0	60,0	33,3	40,0	18,6	20,0
Annual Costs (M€)	~~123,27~~	14,99	282,48	89,40	306,83	45,77
Unit cost (€/coach-km)	4,04	2,38	3,30	1,29	6,10	3,51
DEMANDA						
Passenger (millions)	26,9	13,1	232,4	271,1	211,7	44,0
Mean passenger trip (km)	19,2	15,0	6,0	10,4	3,1	15,0
Passenger-km (millions)	628,8	196,5	1.387,3	1.626,6	658,7	660,5
Fare revenues (M€)	95,0	18,6	255,6	257,5	254,1	39,2
Unit passenger cost (€/pax-km)	0,20	0,08	0,20	0,05	0,47	0,07
Unit passenger cost (€/pax)	4,59	1,14	1,22	0,33	1,45	1,04
Unit passenger revenue (€/pax-km)	0,18	0,09	0,18	0,16	0,39	0,06
Unit passenger revenue (€/pax)	3,54	1,42	1,10	0,95	1,20	0,89
Occupancy rate (pax-km/coach-km)	20,62	31,19	16,21	23,47	13,09	50,66
Passengers/km of network	47.955,0	160.539,2	2.225.842,9	1.846.730,2	338.823,8	3.362,6
Dispersion (pax/coach-km)	0,9	2,1	2,7	3,9	4,2	3,4
Level of congestion (pax/car-hour)	0,0	0,2	0,3	0,6	0,3	0,0

Grouped data

	Suburban rail	Metro	Urban Bus	Interurban Bus	Total
SUPPLY					
Coach-km (milion)	611	1.331	820	1.447	4.209
Places-km	36,8	154,9	50,3	13,0	255,0
Length (km)	641,5	251,2	927,1	13.096,0	14.915,8
Energy (GWh)	95,7	371,8	309,8	80,3	857,6
Unit Consumption (kWh/coach-km)	2,6	2,4	5,5	5,5	3,4
Unit Consumption (kWh/pax)	2,395	0,738	1,464	1,824	1,073
Unit Consumption (kWh/pax-km)	0,116	0,123	0,470	0,182	0,174
Speed (km/h)	60,0	36,3	18,6	20,0	35,4
Annual Costs (M€)	138,26	371,88	306,83	45,77	862,74
Cost/Coach-km (€)	3,76	2,40	6,10	3,51	3,38
DEMAND					
Passenger (milion)	40,0	503,5	211,7	44,0	799,2
Average passenger route (km)	20,7	6,0	3,1	10,0	6,2
Pax-km (milion)	825,3	3.013,9	658,7	440,4	4.938,3
Incomes (M€)	113,6	513,16	254,1	39,2	920,0
Cost/pax-km (€)	0,17	0,12	0,47	0,10	0,17
Cost/pax (€)	3,46	0,74	1,45	1,04	1,08
Income / pax-km (€)	0,14	0,17	0,39	0,09	0,19
Income / pax (€)	2,84	1,02	1,20	0,89	1,15
Occupancy (pax-km/Coach-km)	22,43	19,46	13,09	33,77	19,36
Passengers/km Network (milion)	0,062	2,004	0,228	0,003	0,054

Table 53. Data source, excel. Source: own elaboration with excel

APPENDIX 2. Metro line maps

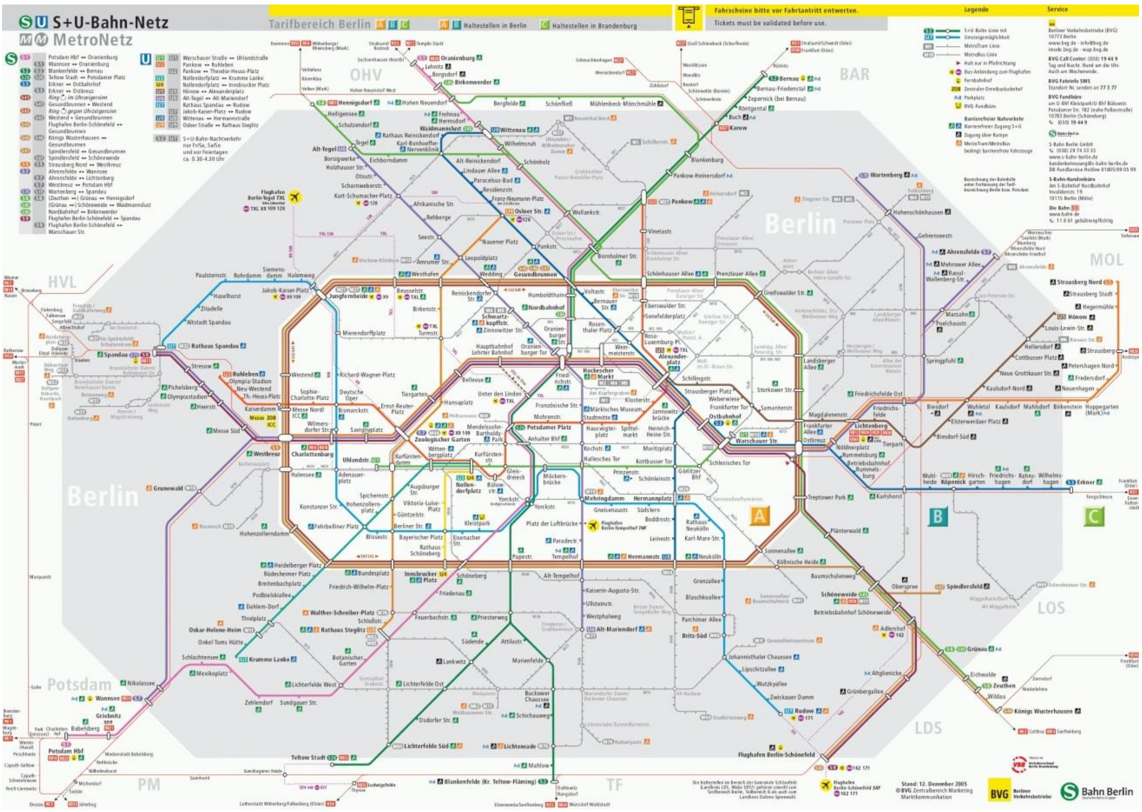
BARCELONA

Graph 45. Metro scheme BCN. Source: Mapa metro Barcelona (web)

The metro of Barcelona has a “zero transfer” or “door to door” structure. The majority of the stations have a distance separation lower than 500m, which makes it kind on inefficient. The new metro lines that are being built, count with higher distances, making possible to increase the commercial speed. The metro has been created while the demand was growing; it was not planned such the new bus network (orthogonal). Most of the lines cross the city in weird shapes (such as the green line, which makes kind of a unfinished round trip in the city centre. There is no clear structure.

Even though, the speed of the metro of Barcelona reaches, in average, 29 km/h. This mainly happen because the speed for the two automatic lines is taken into account; if they are not taken into account it would become lower, in the order of 27 km/h, which is quite slow taking into consideration the other cities.

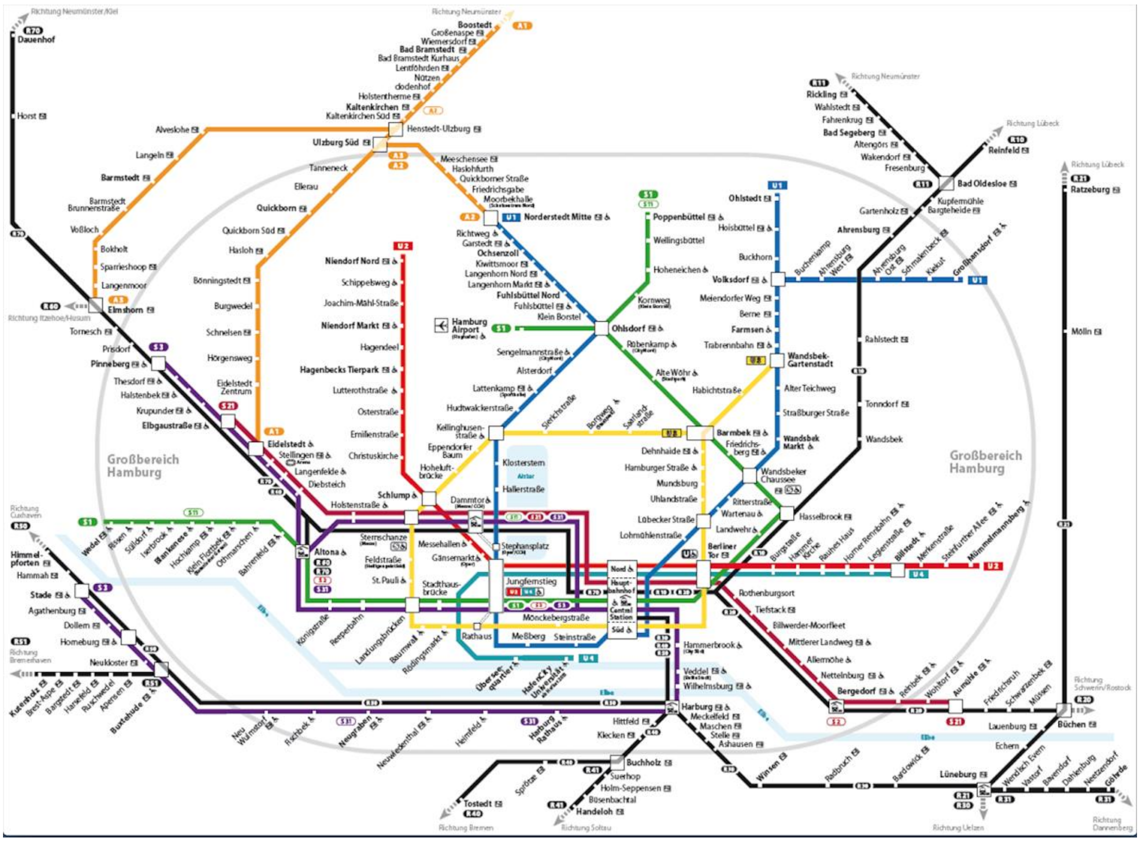
BERLIN



Graph 46. Map scheme Metro Berlin. Source: BVG.

It has a really similar pattern than in Hamburg. The city centre is denser while the periphery has more limited offer. Even though, berlin is the densest city, in terms of offer per unit of surface, among the studied cities. This pattern of making the city centre a hub for the lines is repeated in the three German cities in the study, as can be seen too in the following map for the city of Munich.

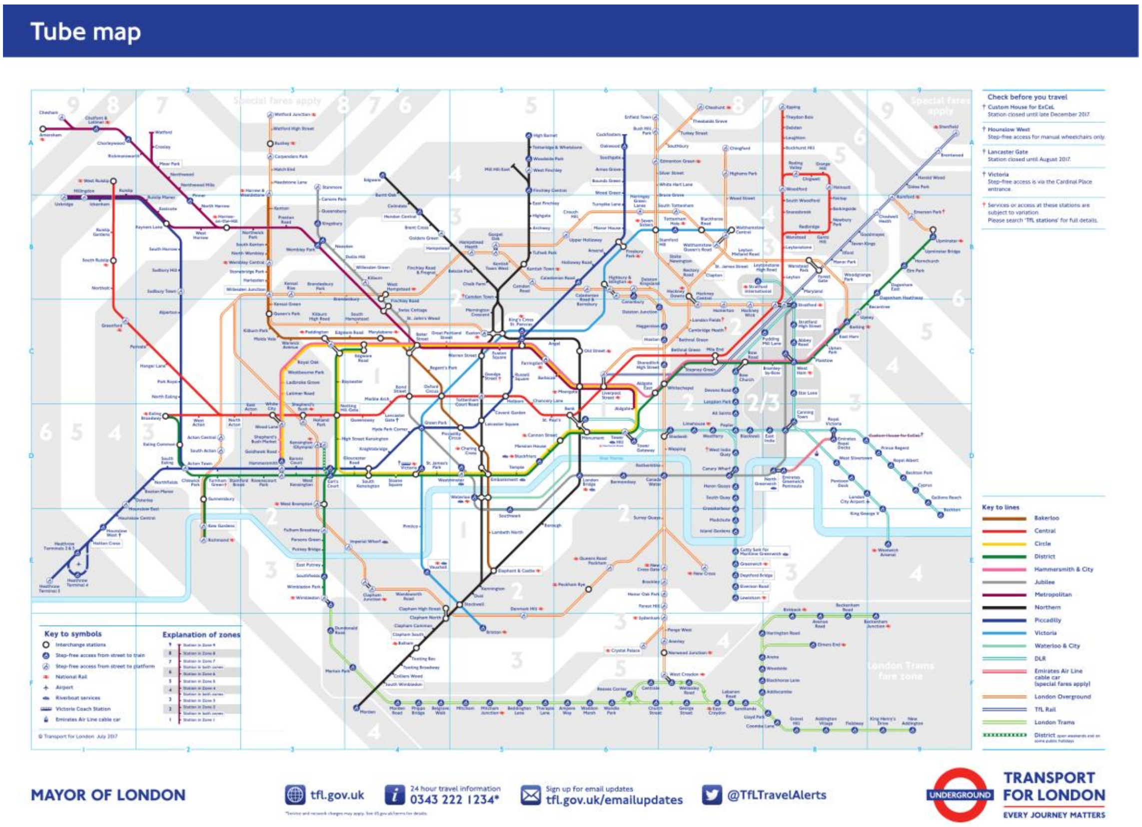
<u>HAMBURG</u>



Graph 47. Mal scheme Metro Hambourg. Source: HVV. (black lines not in this part)

With one circular line, and a majority of hub & spoke lines crossing the city centre, Hamburg presents a very structured network. At the city centre high frequencies can be found as there is more than one line covering the area, while the periphery gets lower ones. This structure can be the main reason why it has almost 50% of the share of public transportation in the whole metropolitan area. It has an structured network, but it is only dense at the strategic points (centre of the city, where most of the business are held).

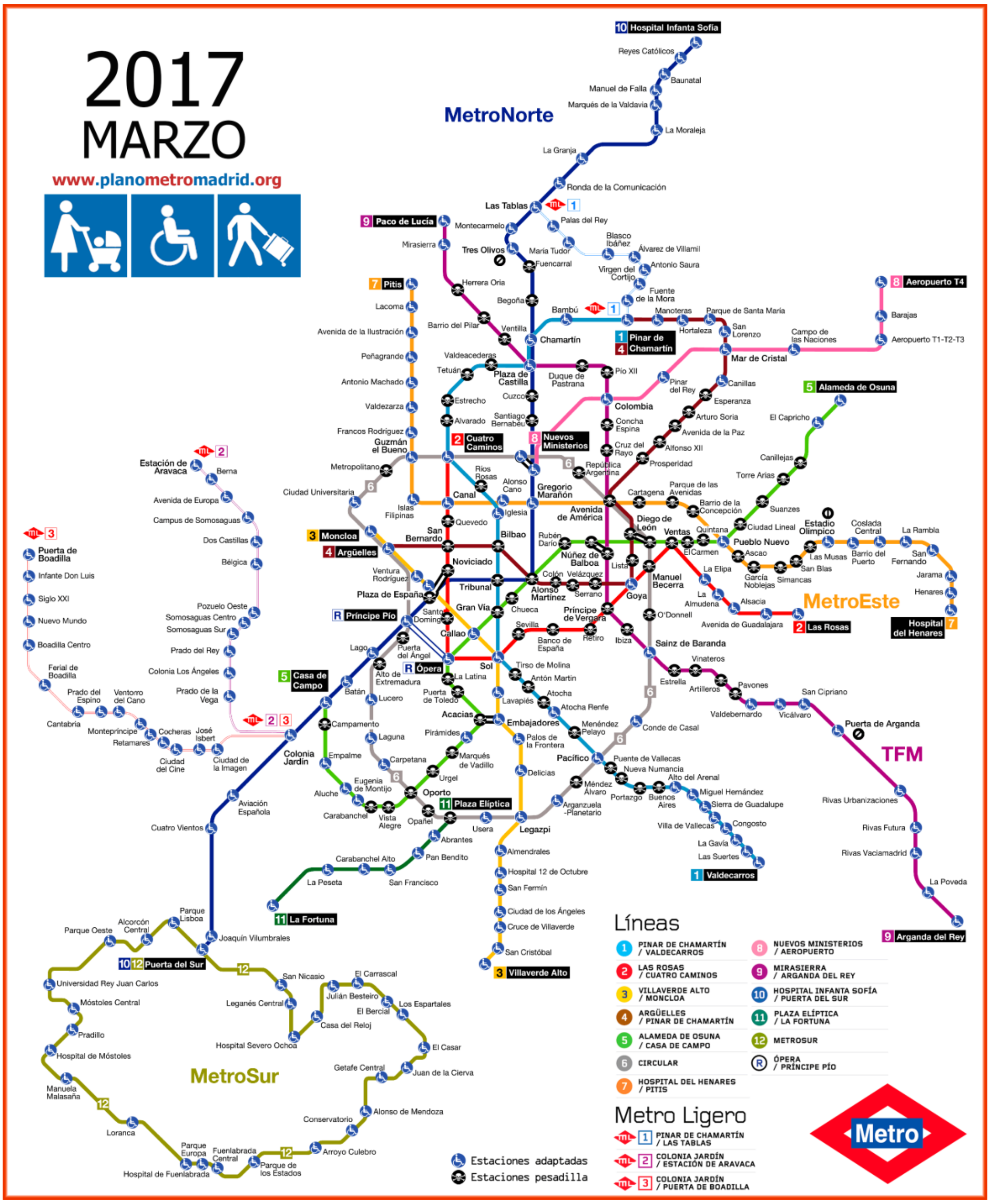
LONDON



Graph 48. Map scheme metro London. Source: TfL.

London's metro structure seems to recall to a kind of a hybrid network: it is denser in the city centre, making it kind of a hub for the lines, following more or less a grid structure, while in the periphery spreads as a radial network. Most of the *DLR* lines, serve as an extension to the suburbs, making the metro be more attractive to them, even the usage of the metro is one of the lowest from the study.

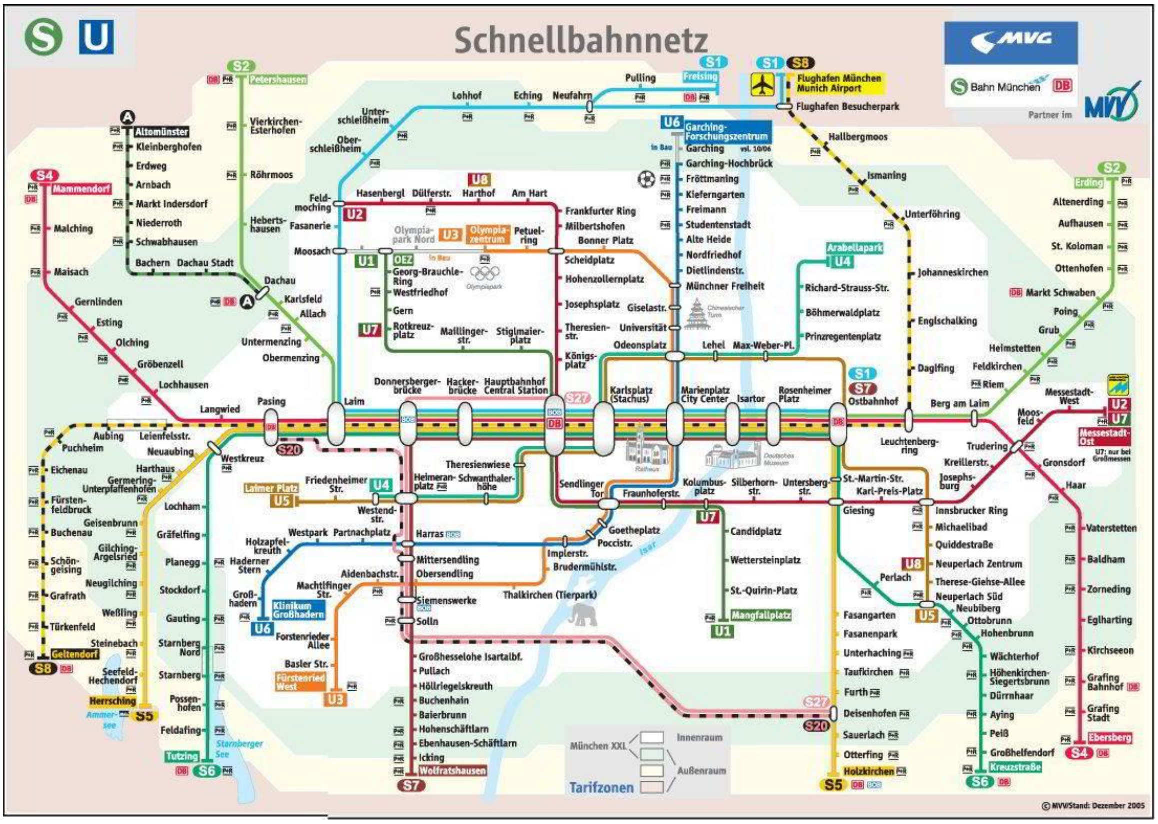
MADRID



Graph 49. Map shceme metro Madrid. Source CRMT

Again, as in the case of Barcelona, the metro does not have a clear structure. It is obvious that the lines are mostly grouped in the centre (called “*La Almendra*”) and do not enter much in the periphery area.

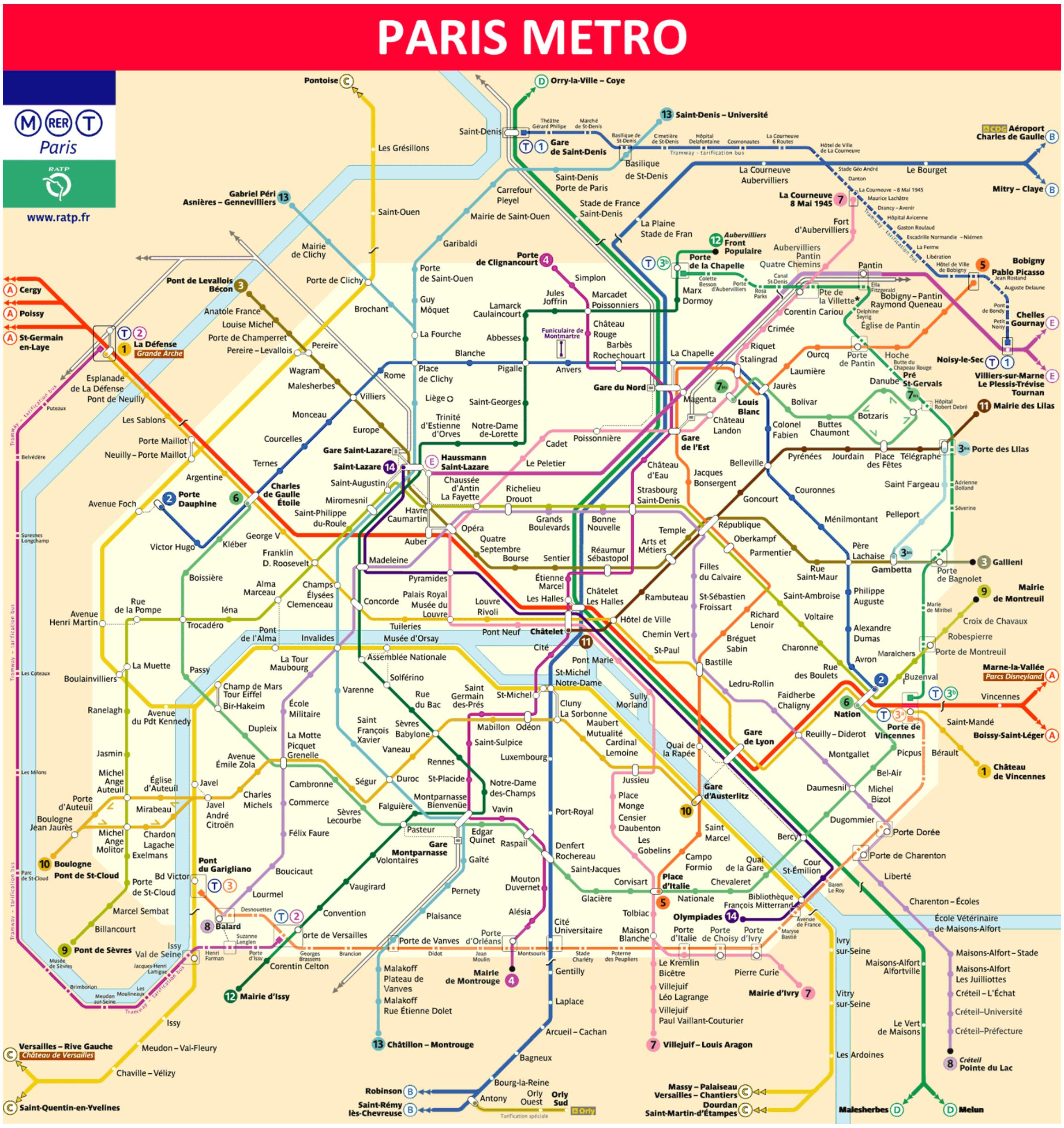
MUNICH



Graph 50. Map shceme metro Munich. Source MVV

As commented previously, the same structure than in the other German cities, is repeated. This may be the reason for which the three cities have a modal share of the metro of 50%, making it the most used public transport. The simplicity in the pattern makes it an easy choice, and the high frequencies in the centre, the best option.

PARIS

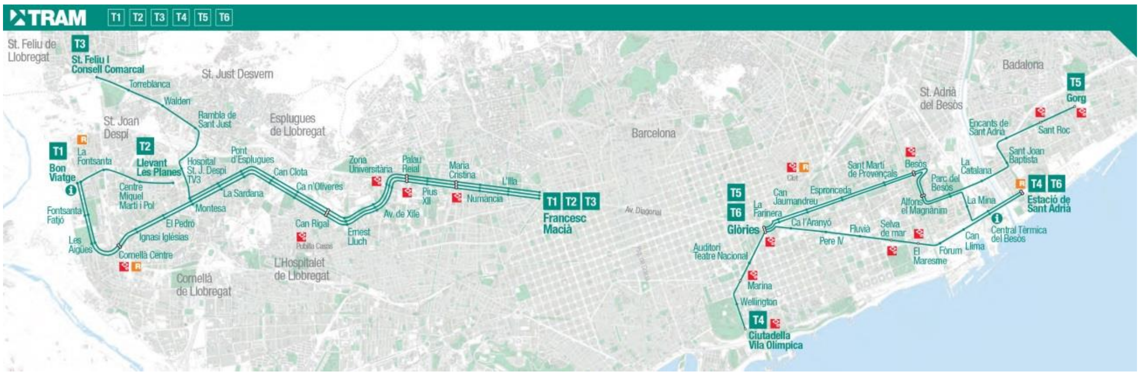


Graph 51. Map shceme metro Paris. Source SNFC.

As in the case of Barcelona, the metro of Paris does not seem to have a very structured system. It can be noticed that there is some kind of pattern with lines crossing the city, but not entering so in the suburbs and the periphery, main reason why the density of coach-km per unit of area is low. Apparently, there is no objective reason of why it is the less used metro among the studied.

APPENDIX 3. Tramway line maps

<u>BARCELONA</u>



Graph 52. Map shceme tramway Barcelona. Source TRAM.

The case of Barcelona is an exception among the others. The tramway lines of the city penetrate into the periphery and avoid the city centre. This network is part of a plan extension that pretends to grow up in the centre of the city, making the tram a true connection with the periphery.

It is easy to see why the low usage of the network: it compulsory implies to change the mode of transport as, when it enters to the city, doesn't arrive to many different places. It is similar to a hub and spoke network, it aims the user to take another transportation system to finish the trip.

But, yet, the network has a lack of coverage in the centre that makes it less attractive to users.

BERLIN

Graph 53. Map shceme tramway Berlin. Source BVV.

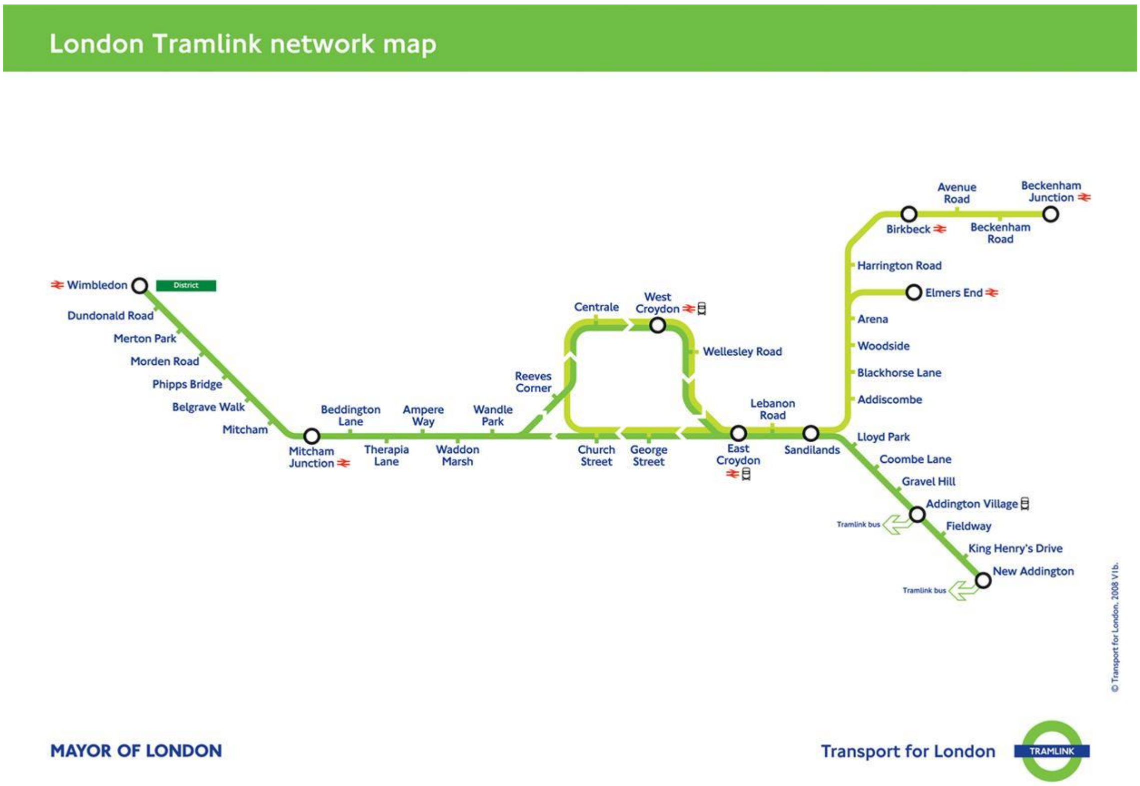
Berlin presents a highly developed network, with connections with the suburbs. The network is more dense in the city itself, being more spread as it goes away from it. It has a highly radial structure from the centre to the suburbs, even two different points of radially can be detected in different areas, allowing the perception of the user to see the network as a whole.

This is because there can be fund different kinds of tramways:

- Metro Tram lines: lines of high frequency of light rapid transit
- Tram lines: classical tramway lines, with lower frequencies

Berlin presents, so, the most developed tramway network.

<u>LONDON</u>

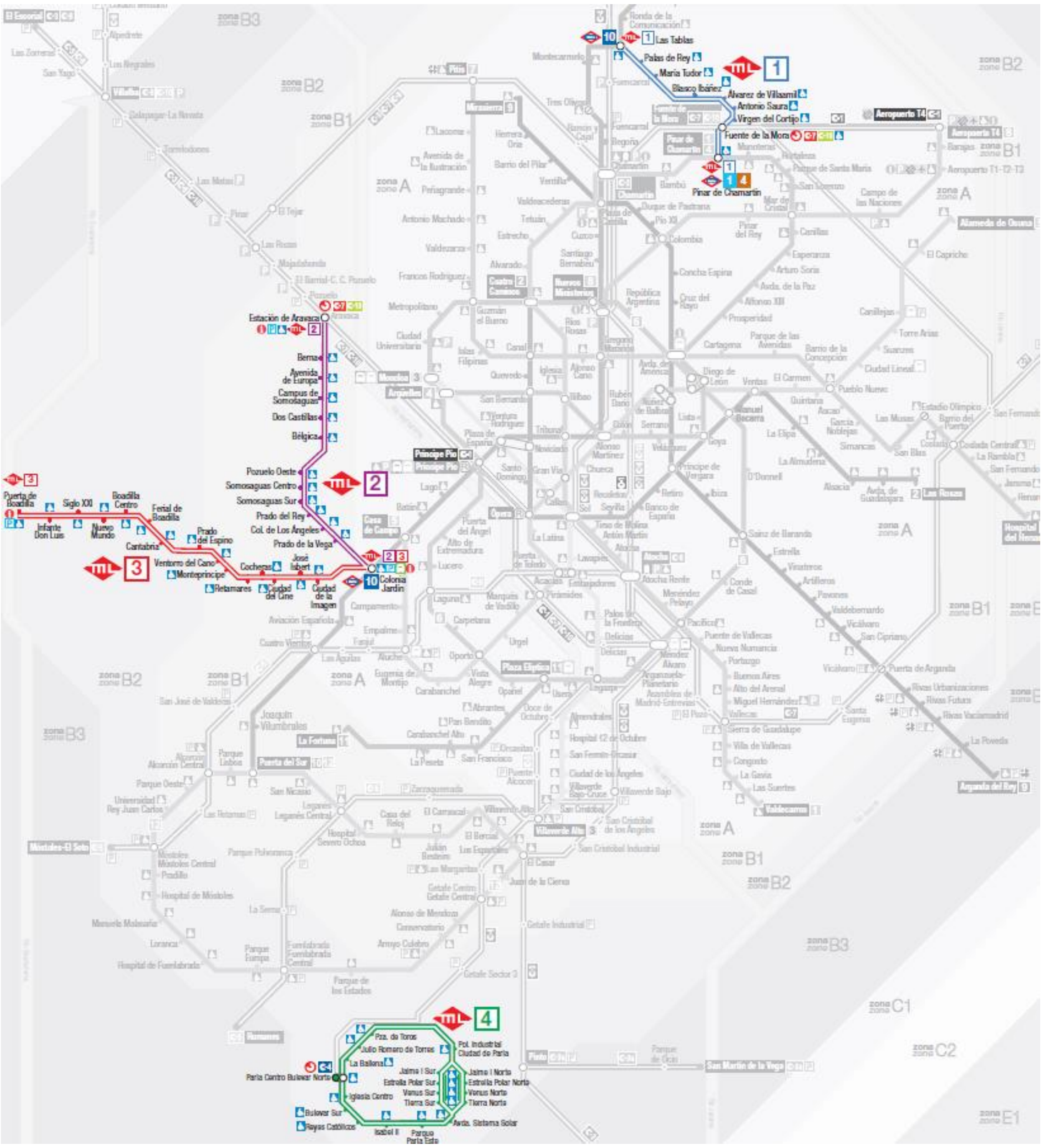


Graph 54. Map shceme tramway London. Source TfL.

Similar to Barcelona, the tramway of London penetrates into the city in a small area, sharing part of the route with more than one line. It only covers a part of the territory, situated at the south.

The tram acts like a truly extension of the metro, as it serves some regions with no underground available. It is a high frequency service, but it is not still developed until the final solution needed (reason why changes are being made and considering the change of routes).

MADRID



Graph 55. . Map shceme tramway Madrid. Source CRMT.

It was seen in the report that Madrid had one of the lowest modal shares of the tramway. With the map, the reason is almost immediately known. In Madrid the tramway acts like a feeder from some suburbs to the centre, where other modes of transport must be taken. It tries to increase *intermodality* but with a very low offer of transport for the tramway.

So, as in the case of Barcelona, this tramway system has no clear structure of network, being only a feeder or extension of other modes that do not arrive so far.

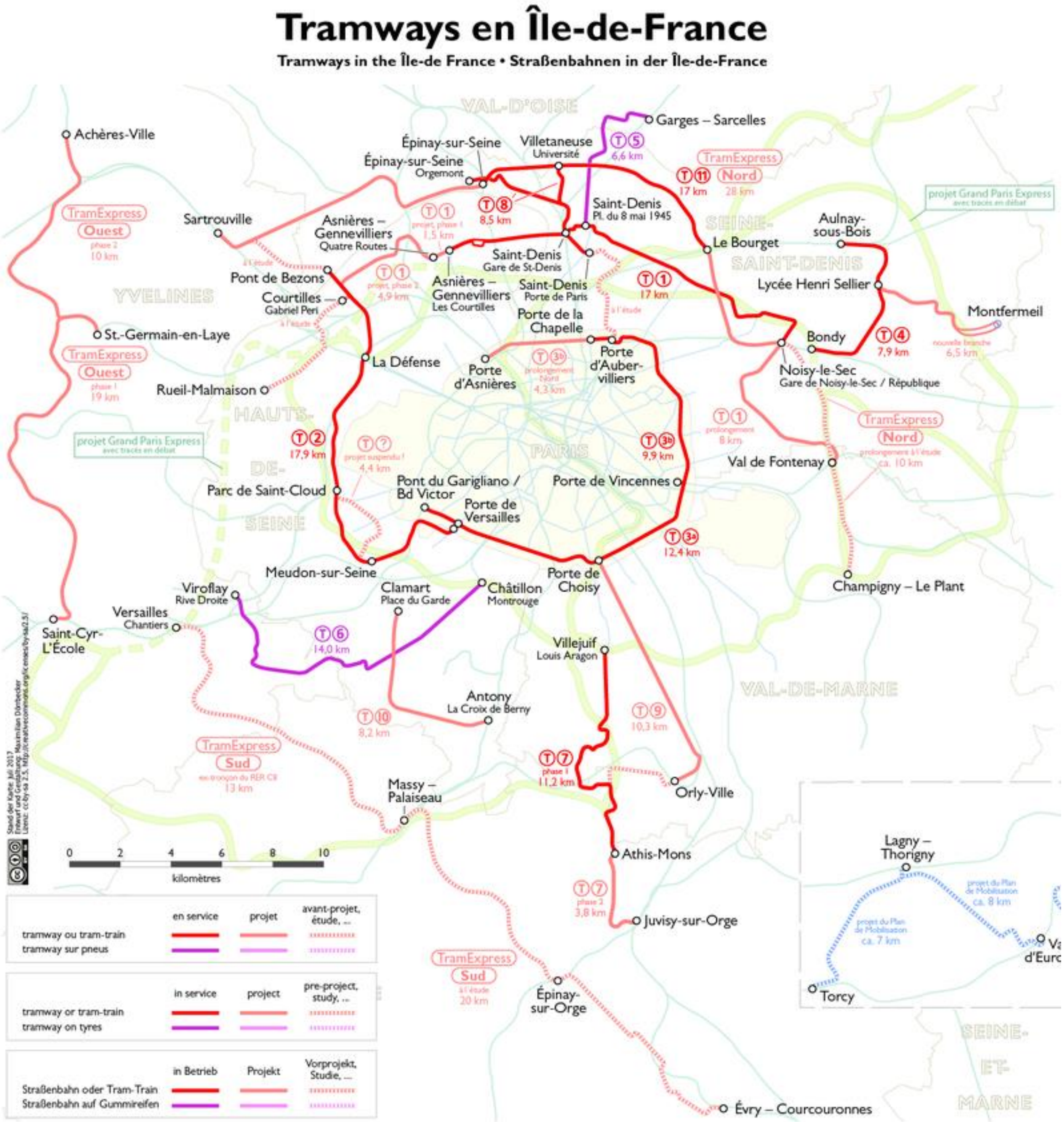
MUNICH

Graph 56. Map shceme tramway Munich. Source MVG.

As happened with the metro, the more structured networks of tramway are found in Germany. In Berlin, a radial network with two initial focus was seen, in Munich, a hybrid one is developed. The city centre agglomerates the majority of the lines, sharing part of the routes, while on the periphery lines tend to split. Except for one line, all of them go to the city centre or pass through.

Even the density on extension is not quite elevated, the modal share is indeed as the structure of the network makes it a network itself, not the complement for another mode of transport.

PARIS



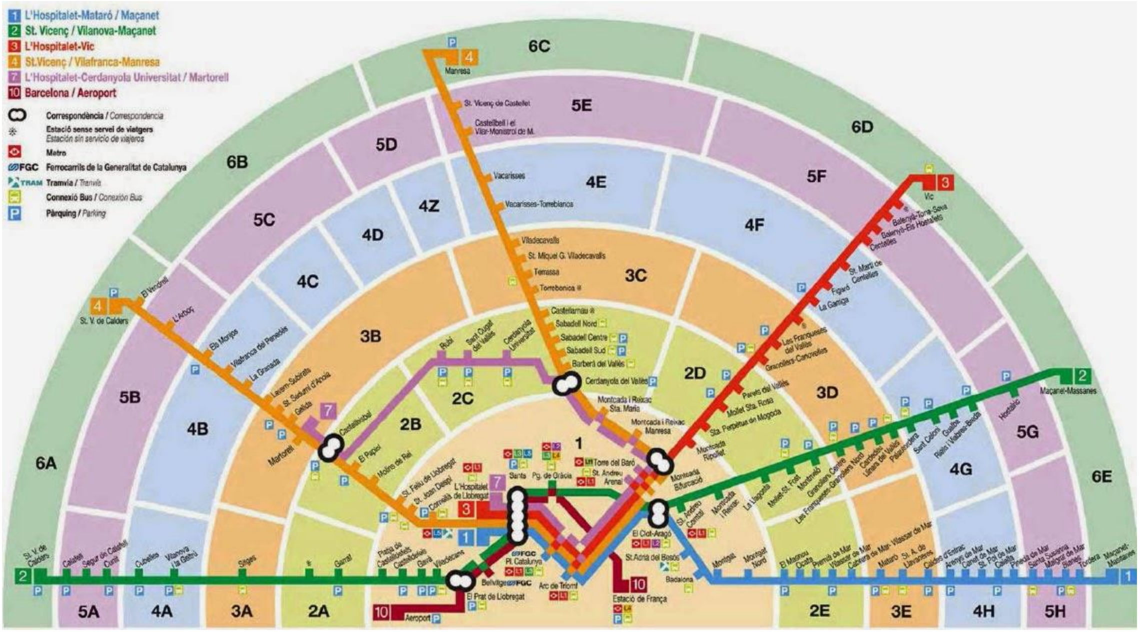
Graph 57. Map shceme tramway Paris. Source SNFC.

Tramways in Paris are difficult to classify. While they do not seem to answer to any pattern, the modal split is quite high in comparison to other cities.

Tramways are an extension for the metro and *RER* lines that do not have the possibility to run into some regions of the metropolitan area, so they give coverage to more territory.

APPENDIX 4. Suburban railway line maps

BARCELONA

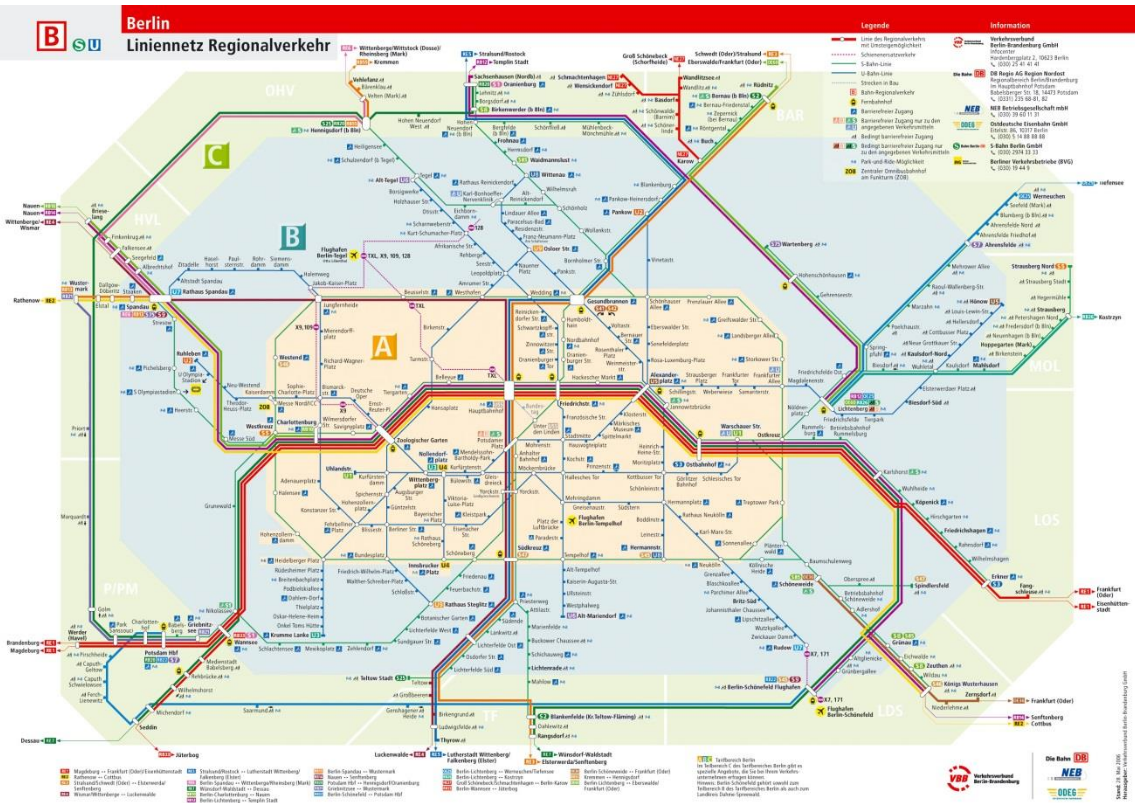


Graph 58. Map shceme railway Barcelona. Source RENFE.

As can be seen in the image, Barcelona's suburban rail network has a radial disposition in order to get to all the municipalities in the fare zones. Suburban rails (*Renfe)* are complemented with the short distance trains of the *FGC*.

The structure focuses its service in the Catalan capital, where all the lines have "born and die". It is, so, a clear structure of a hub where you arrive to Barcelona and get to take another PT in order to move within the city, even there are many stops inside the city itself.

BERLIN

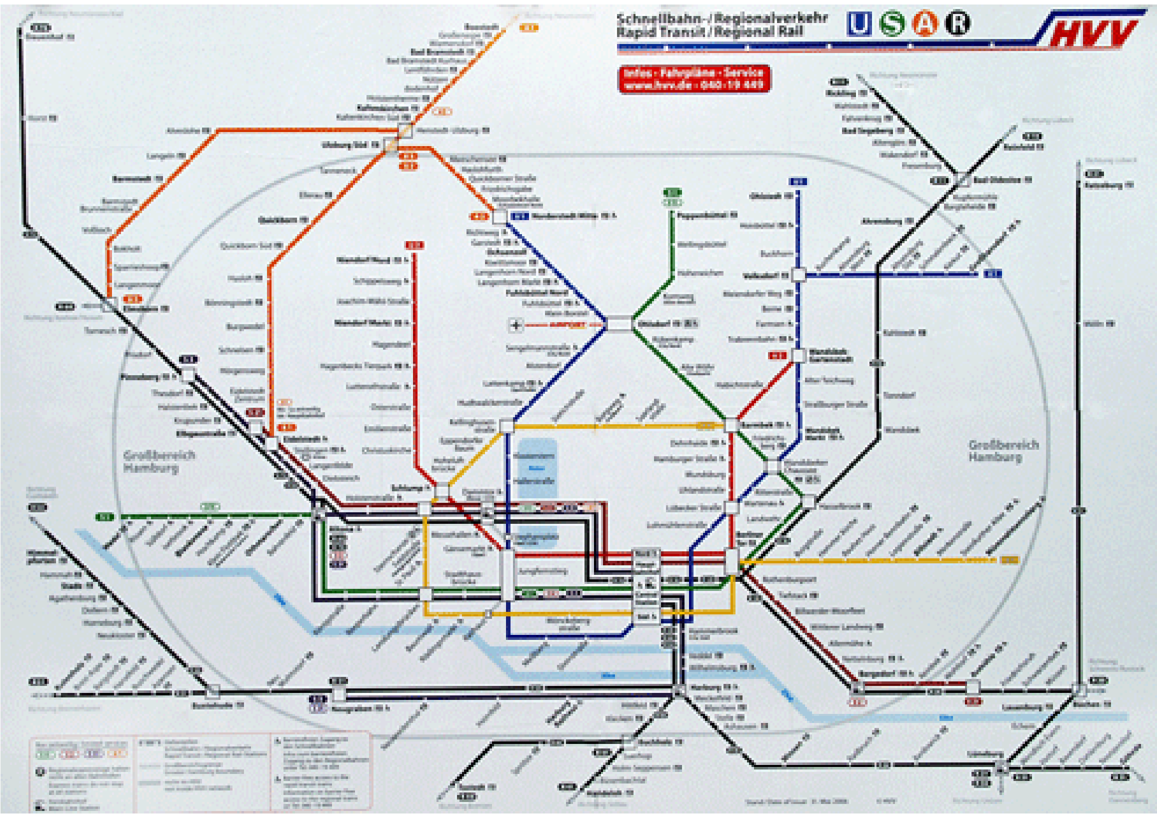


Graph 59. Map shceme railway Berlin. Source DB Regio.

Berlin presents a structured network. Many lines cross the city vertically and horizontally, with several stops in it and then extend to the periphery. There are also many lines that operate only the periphery, making it dispose of a “metro” network to connect.

The railway of Berlin acts not only as a passenger feeder to the capital but also as a kind of metro for the communication between municipalities, allowing to get to near places without having to cross the city.

<u>HAMBURG</u>

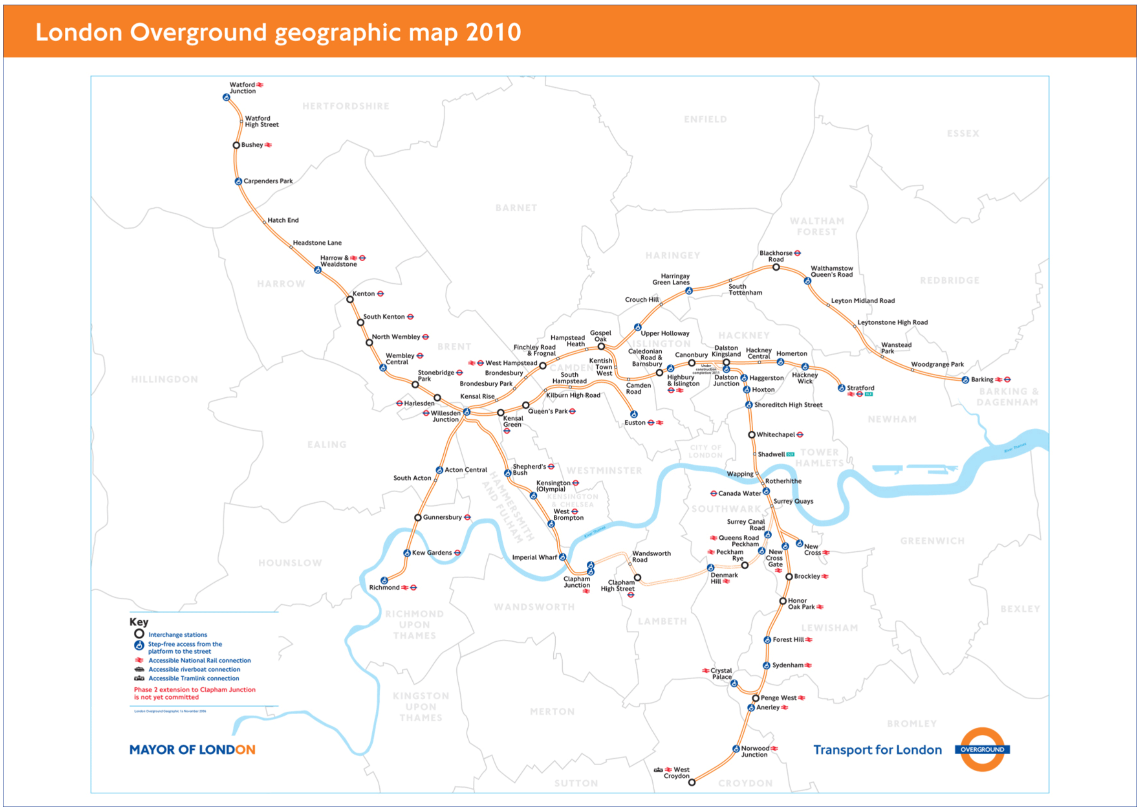


Graph 60. Map shceme railway Hamburg. Source hvv.

The lines that represent the *Regio Bahn* are the black ones. As it can be seen they cover entirely half of the periphery (the other half is mainly covered by S-Bahn).

Some lines of the service cross the city with several stops in there and others serve as a kind of metro system for the periphery.

LONDON

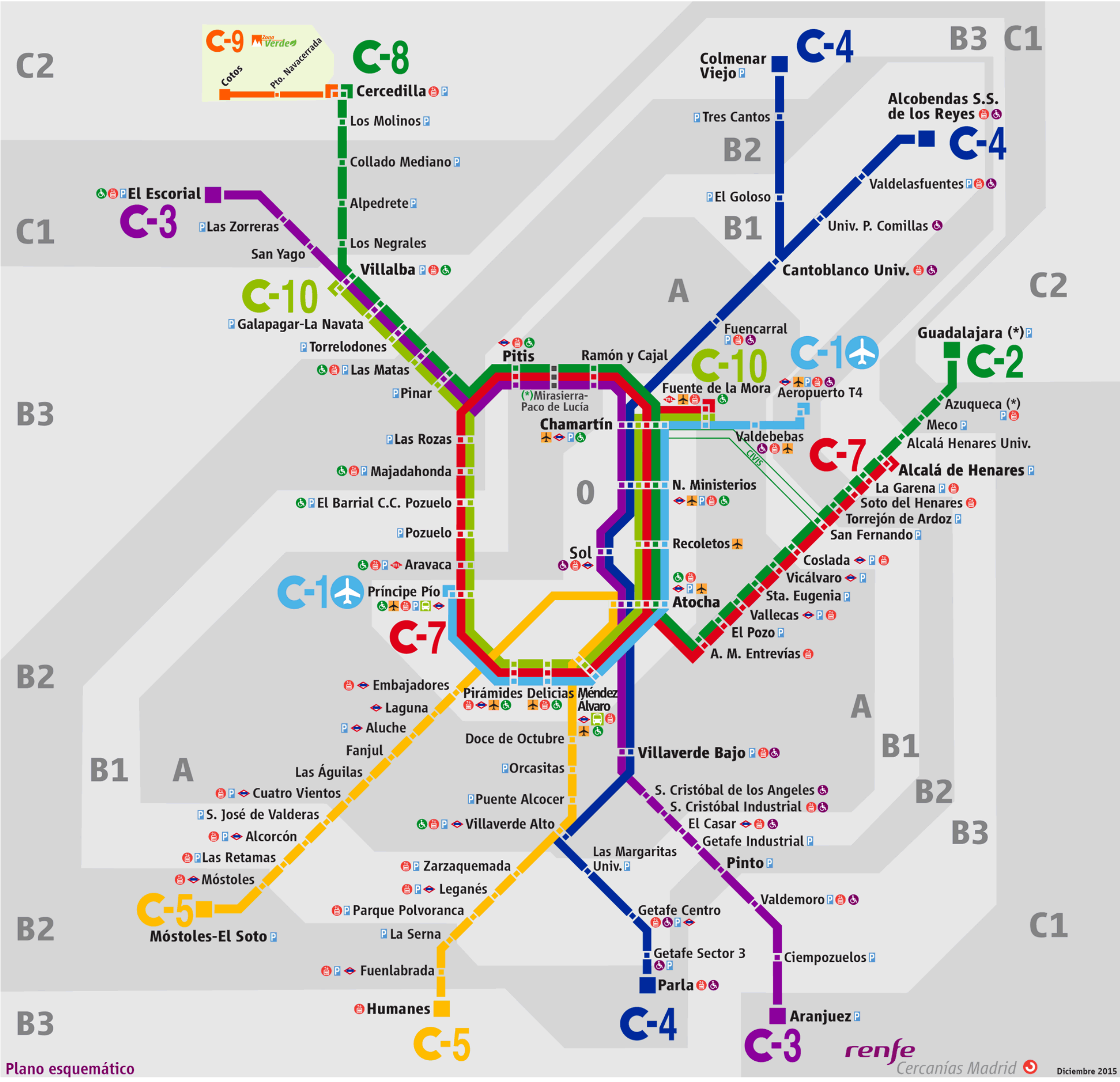


Graph 61. Map shceme railway London. Source TfL.

The London Overground, as seen in the report, has little offer on the area of London. It do covers some part of the periphery but it is focused mainly in the inner city.

It presents kind of a radial form, crossing the river and giving a minimum coverage that, mainly, complements the metro services of the city. There are several stops so it acts as a feeder to the city, mainly.

MADRID

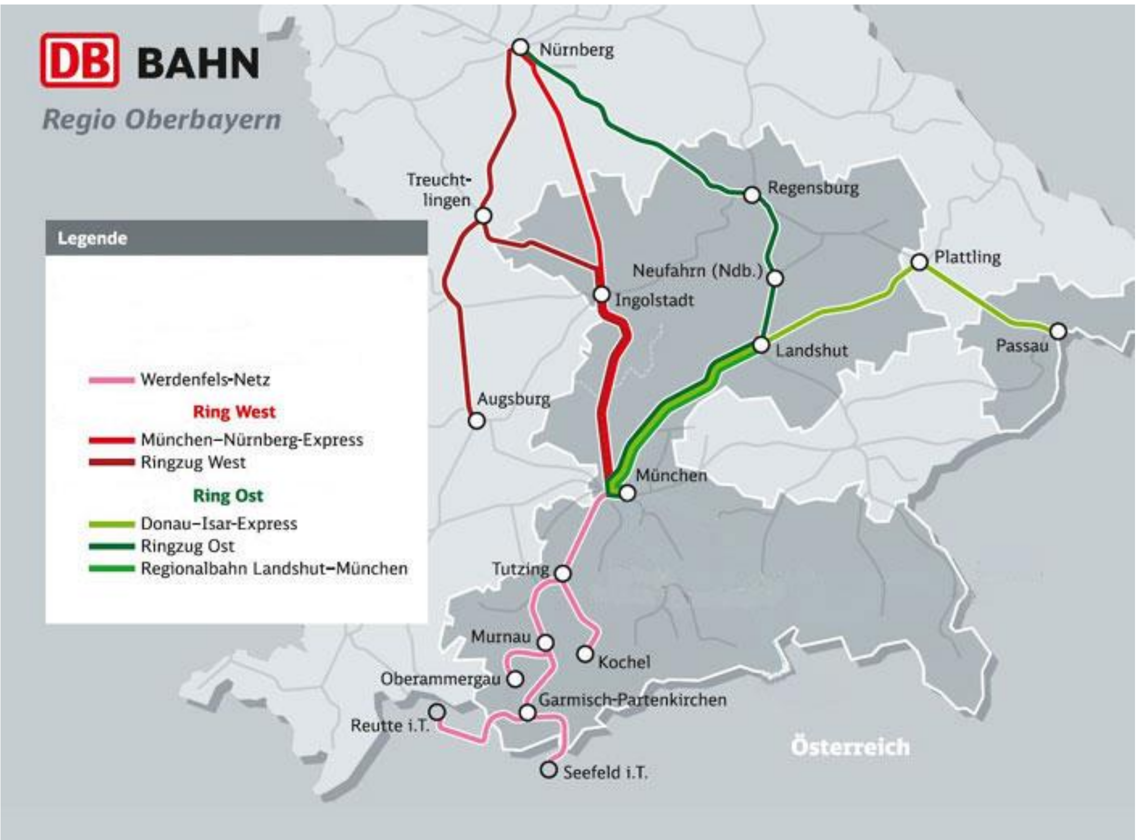


Graph 62. Map shceme railway Madrid. Source RENFE.

The structure is similar to the Barcelona's train. The networks presents several stops in the capital, surrounding it and then extends radially to the periphery.

It acts as a feeder from the periphery to the capital.

MUNICH

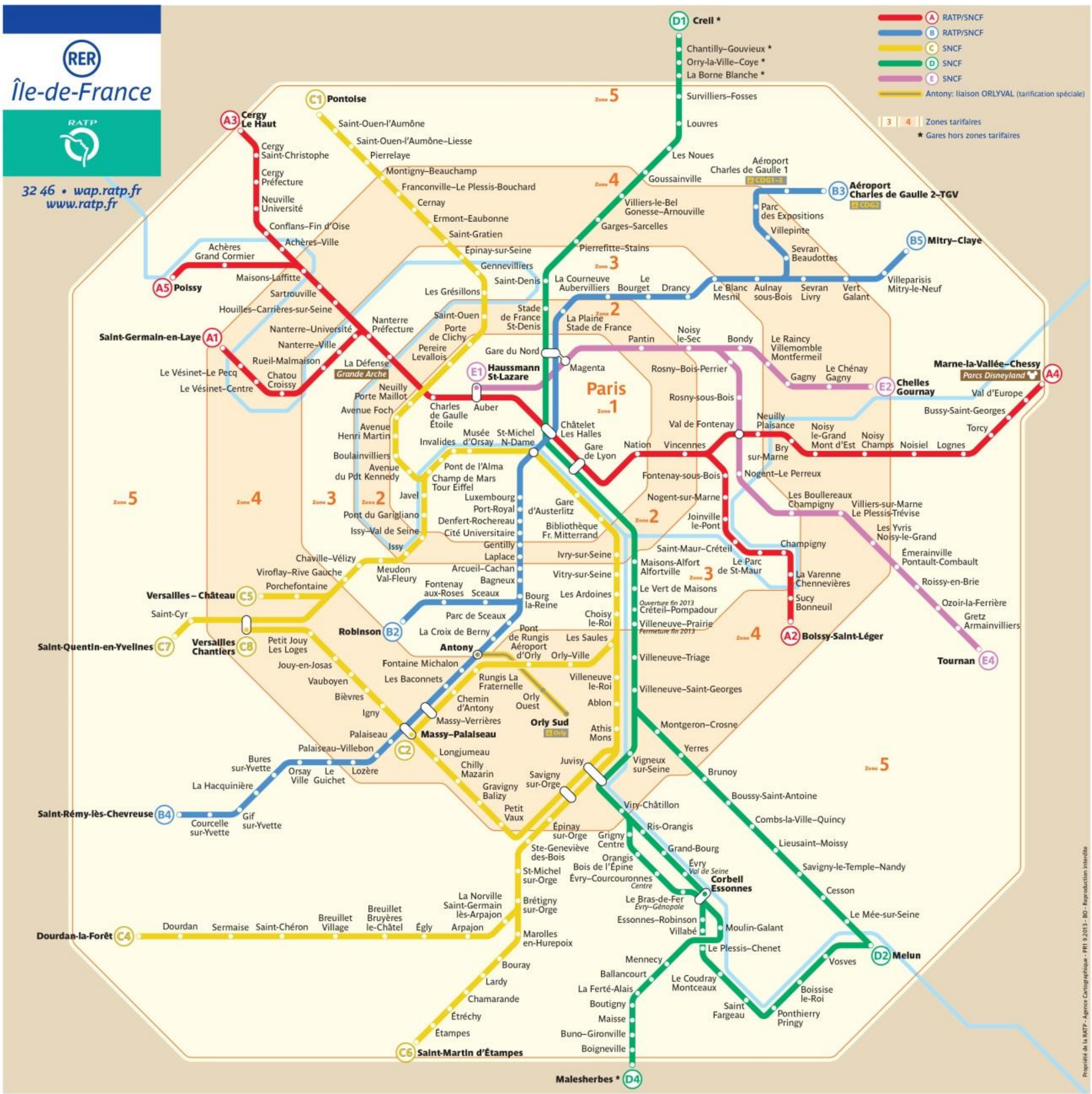


Graph 63. Map shceme railway Munich. Source DB Regio.

Munich *Regio Bahn* covers great part of the territory giving service to the periphery and penetrating into the capital with the lines of the two rings in the image.

It serves, mainly as a feeder to the capital, but also gives coverage to the periphery acting, like the other German cases, as a metro for the suburbs.

PARIS



Graph 64. Map shceme railway Paris. Source SNFC.

Paris offers the most complete network of suburban rail. It has several stops in the capital but also offers service to the periphery, connecting between municipalities. In general presents a radial structure, with some lines crossing the city vertically and horizontally, even a circular line.

Most of the lines have ramifications at the edges, covering more territory.