

# Comparative analysis of passenger transport sustainability in European cities



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## ABSTRACT

Sustainable development in its three dimensions – economic, social and environmental – has become a major concern on an international scale. The problem is global, but must be solved locally. Most of the world's population lives in cities that act as centres of economic growth and productivity, but which – if they develop in the wrong direction – can cause social inequalities, or irreversibly harm the environment. Urban transport causes a number of negative impacts that can affect sustainability targets. The objective of this study is to propose an analysis of sustainability of urban passenger transport systems based on available indicators in most cities. This will serve to benchmark the practices of different cities and manage their transport systems. This work involves the creation of composite indicators (CI) to measure the sustainability of urban passenger transport systems. The methodology is applied to 23 European cities. The indicators are based on a benchmarking approach, and the evaluation of each aspect in each case therefore depends on the performance of the whole sample. The CI enabled us to identify which characteristics have the greatest influence on the sustainability of a city's transport system, and to establish transport policies that could potentially improve its shortcomings. Finally, the cities are clustered according to the values obtained from the CIs, and thus according to the weaknesses and strengths of their transport systems.

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## 1. Introduction

Concern about the evolution of human settlements and the unavoidable effects of social development on the environment were first viewed by the global community as comprising three main dimensions – economic, social and environmental – at the Conference on the Human Environment in Stockholm (United Nations, 1972), which marked the earliest definition of the basis of sustainability. The conclusions included the need to safeguard and improve the human environment for present and future generations as a goal to be pursued together with worldwide economic and social development. Since the declaration of these principles, sustainability has become a major concern for decision makers and management stakeholders (Newman and Kenworthy, 1999; Jeon and Amekudzi, 2005; Haghsheenas and Vaziri, 2012).

This sustainable development must be applied to cities on a global basis, as they play a key role in our society. Cities are important generators of wealth, employment and productivity, and often serve as the engines of their national economies (OECD, 2013). According to the Green Paper, just under 85% of the EU's gross domestic product is created in urban areas, which are home to over 60% of the population (European Commission, 2007). Analyses of the challenges facing cities in their efforts to achieve a more sustainable development invariably give a high priority to the problems of mobility and access (Newman and Kenworthy, 1999; UNECE, 2011). At the urban level, where transport problems are more acute and concentrated, achieving a sustainable form of mobility is a prerequisite for improving the environment – including social aspects –, and enhancing economic viability (European Commission, 1996). Some problems in meeting this challenge were raised in the EU 2011 White Paper on transport, namely congestion and its consequences on delays – and thus on the economy –, noise, air pollution, GHG emissions, impacts on land or accidents (European Commission, 2011).

Urban transport therefore has several negative impacts that can hinder the achievement of sustainability targets. According to TERM (2000), these can be prevented by identifying key indicators that can be tracked and compared with concrete policy objectives,

*Abbreviations:* CI, composite indicators; EMTA, European Metropolitan Transport Authorities; MMO, Metropolitan Mobility Observatory (Spain); PT, public transport; PTA, Public Transport Authorities.

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based on the premise: “You can’t manage what you can’t measure”. Within this framework, the aim of this research is to identify practical indicators to analyse the economic, social and environmental sustainability of urban passenger transport systems. This would help to manage the different aspects of sustainability from a comprehensive point of view and would also make it easier to benchmark one city’s performance against another’s. The first section of the paper explains the process for selecting the indicators and the cities in the analysis. The next section contains the methodologies used to compile, compare and classify the chosen indicators, in order to analyse different sustainability aspects of urban passenger transport systems in the 23 European cities selected. The final sections include the results of the analysis and some conclusions.

## 2. Measuring sustainability using indicators

There is a common consensus as to the usefulness of indicators to highlight the many overlapping areas of sustainability, and the need to achieve sustainable urban transport systems has been largely discussed (TERM, 2000; Newman and Kenworthy, 1999). But before selecting the appropriate indicators for measuring sustainable transport, we should rely on an established definition. We have therefore, selected a definition supported by international institutions (Council of the European Union, 2001; OECD, 2001). According to this definition, a sustainable transport system should be analysed from three different dimensions:

- Economic: affordable, operates fairly and efficiently, offers choice of transport mode, and supports a competitive economy, as well as balanced regional development,
- Social: allows the basic access and development needs of individuals, companies and societies to be met safely and in a manner consistent with human and ecosystem health, and promises equity within and between successive generations
- Environmental: limits emissions and waste within the planet’s ability to absorb them, uses non-renewable resources at or below the rates of development of renewable substitutes while minimizing the impact on land and the generation of noise.

There are some authors that propose other dimensions of sustainability (Holden et al., 2013) according to different approaches of the Brundtland Report (WCED, 1987). In this paper we have chosen the above mentioned definition that has been used in many studies in the field of urban passenger transport (Miranda and Rodrigues da Silva, 2012; Haghsheenas and Vaziri, 2012). However most of the aspects included in any of the approaches are common although they are structured in different way.

### 2.1. Literature review

In order to select which indicators were more appropriate to assess sustainability of urban passenger transport systems, a literature review of several initiatives with similar scope was carried out. This section summarises this literature review in regard to the indicators used. The indicators selected should as far as possible incorporate all the aspects mentioned in the chosen definition of sustainable transport systems.

Some authors consider sustainable transportation indicators as decision-making tools which should reflect economic, social and environmental impacts (Litman, 2009), while others (Nicolas et al., 2003) focus their indicators on the issues raised by urban resident mobility and consider surveys of household trips as a highly valuable data source. Here it is worth noting the study carried out by Jeon and Amekudzi (2005), who characterised the emergent thinking on what constitutes urban transportation sustainability

and how to measure it in their collection and classification of indicators used by 16 international institutions – mainly relating to planning and infrastructure provision. Finally, other approaches have focused their analysis on the assessment of policies, in terms of efficiency and equitable functioning (Savelson et al., 2006; Zito and Salvo, 2011).

As a result of this literature review, Table 1 shows the most commonly used indicators directly related to urban transport sustainability, we have classified them into three dimensions – economic, social and environmental. There is a greater range of indicators in the social and environmental than in the economic category. The most frequently applied indicator for measuring social sustainability is the number of transport fatalities; for environmental sustainability it is land consumption of transport infrastructures; and for the economic aspect user transport costs and public expenditure.

The aim of this review was to identify significant indicators for measuring sustainability in order to choose appropriate and available indicators from our sources which are described below.

### 2.2. Data collection

The research to develop a group of indicators in and to analyse the different dimensions of sustainability regarding urban passenger transport, was initially focused in Spanish cities, due to the existence of a homogeneous database with a sufficient number of cities. In order to achieve a wider scope for comparison, and to avoid an overly biased analysis – referring only to cities in southern Europe – we decided to include other cities from central and northern Europe.

#### 2.2.1. Main data sources

At the European level there are two associations that collect and publish urban transport information from a representative group of cities<sup>1</sup> and promote the exchange of information and good practices in the field of public transport organisation, planning and funding. The Metropolitan Mobility Observatory (MMO, 2014) is a platform comprising 24 public transport authorities (PTA) in the main Spanish cities. The European Metropolitan Transport Authorities (EMTA, 2014) is an association whose members are the bodies responsible for public transport in 28 European cities. Both publish reports analysing the mobility patterns of the participating cities, using indicators. These reports were the main sources for our research; the year of reference for the analysis was 2010 (Monzón et al., 2012; EMTA, 2012a,b).

For the analysis, we selected 18 of the 24 cities in the MMO – those that had sufficient information available for the scope of the study. As the MMO is a national observatory, all of them were Spanish. For a wider scope, the cities to include from central and northern Europe needed to be from different countries and to have enough information on them available. Four cities with these criteria were selected from the EMTA report: Paris, London, Stockholm and Amsterdam. The rest were discarded, mainly due to lack of key data.

While Paris and London were notable for being the most populated cities (>7 mill. inhab.) in the EMTA association, Amsterdam (1.4 mill. inhab.) was characterized by having the highest modal share of non-motorised modes (56%), and Stockholm (2 mill. inhab.) for having the highest ticket prices. All these differences could through up interesting conclusions in the

<sup>1</sup> In this context, the term “city” refers to the urban geographical area in which there is a high degree of interaction between its urban centres in terms of trips, relationships and economic activity. This concept is often called the Metropolitan Area (MMO, 2014; EMTA, 2014).

**Table 1**

Review of indicators for measuring transport sustainability.

Sustainability dimension	Indicators	Authors											Sustainability aspects according to the definition
		Newman and Kenworthy (1999)	Nicolas et al. (2003)	Jeon and Amekudzi (2005)	Zegras (2006)	Savelson et al. (2006)	Zhang and Guindon (2006)	Litman (2009)	Tanguay et al. (2010)	Zito and Salvo (2011)	Haghshenas and Vaziri (2012)	Santos and Ribeiro (2013)	
Economic	Coverage ratio of public transport	X		X									Efficiency in operation
	Public expenditure on transit		X	X		X	X			X	X	X	Balances in regional development/ affordability
	Time spent		X	X	X						X		Competitive economy
	Congestion		X					X				X	
Social	Costs of transport for users		X	X		X	X			X	X	X	Affordability
	Transport fatalities per inhabitant	X		X	X	X	X		X	X	X	X	Safety consistency with human health
	Accidents			X	X	X	X		X			X	
	Distance travelled		X			X			X				Accessibility
	Motorisation rate/% of car-owning households		X			X		X					
	Density of public transport network			X						X	X	X	Accessibility and equity
	Quality of public transport			X	X			X				X	Quality of accessibility
	Affordability of public transport by lower income residents			X				X					Equity
	% of residents with public transit service within 500 metres			X		X				X			Accessibility and equity
	Quality of accessibility for people with disabilities			X				X				X	
Environmental	Vehicle-km per capita	X				X							Emissions/ use of resources/ waste
	Non-motorised modal share	X				X		X				X	Impacts on land
	Parking spaces in city centre	X	X										
	Land consumption of transport infrastructures		X	X	X	X	X	X		X	X	X	
	Length of cycleway	X				X		X		X			Land use (affects emissions and use of resources)
	Length of pedestrian streets	X				X		X					Use of resources
	Energy consumption		X	X		X					X	X	Emissions
	Emissions			X		X		X		X	X	X	
	Levels of CO, NOx, hydrocarbons and particles		X	X	X					X		X	
	Noise intensity levels		X	X	X		X					X	Noise generation

**Table 2**

Cities included in the analysis.

Population	City	Country
>5 mill. inhab.	1	Paris
	2	London
	3	Madrid
	4	Barcelona
5–1.5 mill. inhab.	5	Stockholm
	6	Valencia
	7	Murcia
	8	Seville
	9	Amsterdam
1.5–1 mill. inhab.	10	Bilbao
	11	Asturias
	12	Malaga
	13	Majorca
1–0.5 mill. inhab.	14	Gran Canaria
	15	Cadiz
	16	Saragossa
	17	Gipuzkoa
	18	Tarragona
	19	Granada
	20	Pamplona
	21	Girona
	22	Corunna
	23	Leon

**Map 1.** Geographical location of the Spanish cities included in the analysis

comparative analysis. Table 2 shows all the cities analysed in this research. The final sample was therefore composed of 23 cities. Although this sample is rather small from a statistical point of view, it is fairly homogeneous and comparable, and produced conclusions that were very logical and adapted to the context. It also allowed us to check the consistency of the data sets and calculate several specific indicators that were unavailable from common sources for all the cases, for example by consulting the websites of certain Public Transport Authorities.

### 2.2.2. Other required data and their sources

Not all the necessary information was collected from the OMM and EMTA reports. Data on accidents in cities was supplied by official reports, in most cases by government institutions in charge of road safety.<sup>2</sup> Information on fare discounts for students on public transport had to be checked and supplemented with

information on PTA webpages.<sup>3</sup> The most recent data on length of urban roads per area for Spanish and European cities, dating from 1998 to 1999, was collected from other sources.<sup>4</sup> It was assumed that the length of urban streets and roads has not changed significantly since then. This approach is considered admissible, given the fact that the length of the road network in established urban areas appears to be relatively constant (Farahani et al., 2013).

The data from all the above sources were compared with the information used to build the indicators collected originally. The last column in Tables 3–5 shows the availability of data for each indicator, and therefore the indicators that could be used in the study.

### 2.3. Indicators selection

The first step of the research was to summarise each sustainability dimension in one single indicator. But sustainability

<sup>2</sup> Ministerio del Interior-Dirección General de Tráfico (2010); TfL (2010a); Ministère de l'Écologie, de l'Énergie, du Développement durable et de la Mer (2010); Stockholm Stad-trafikkontoret (2009); Reurings et al. (2012); Bizcaiko Foru Aldundia (2010).

<sup>3</sup> TUZSA (2010); TFG (2010); Empresa Municipal de Transportes Públicos de Tarragona S.A (2010); Ayuntamiento de A Coruña (2010); TfL (2010b); RATP (2010).

<sup>4</sup> For Spanish case studies: Ministerio de Fomento (1998); for the rest: Newman and Kenworthy (1999).

is a multidisciplinary concept: economic sustainability may refer to productivity, public expenditures or affordability for users; social sustainability may involve safety, accessibility or equity; and environmental sustainability may refer to energy, pollution or land occupation. The indicator for each sustainability dimension must therefore be composed of several indicators in order to reflect all possible aspects of the sustainability dimensions.

However, if the indicators are also intended to be used for management, they must be able to support decision making geared to sustainability objectives, and be capable of measuring policy impacts (Newman and Kenworthy, 1999; Gudmundsson, 2003). Several studies have analysed the requirements that indicators must fulfil to meet this challenge. May et al. (2008) defined these requirements based on surveys of decision makers and other stakeholders in the transport planning sector; according to the results, indicators must be easy to understand and sensitive enough to reveal changes affecting sustainability targets. Jourmard and Gudmundsson (2010) added more criteria for assessing indicator selection:

- Target relevance: each indicator must be related to one aspect of sustainable transportation.
- Validity: indicators must measure the aspect they are supposed to measure.
- Values for calculations should be unambiguous and should not depend on interpretations.
- Data should be available and measurable, and the source must be reliable.

Subsequently, Haghshenas and Vaziri (2012) added that indicators should be able to be standardised by city size.

The most suitable indicators were selected following these guidelines, which can be summarised in seven basic requirements. Tables 3–5 show how far the indicators collected in the literature review meet these requirements. The indicators finally selected (Tables 3–5, first column) fulfil the seven requirements.

For the economic dimension (Table 3), the selected indicators were coverage ratio of public transport, average time spent travelling per user and cost of transport to users, reflecting costs to public authorities per user, productivity losses and user costs. Although the overall public expenditures on transit was also available, it is strongly dependent on city size, and may vary depending on interpretations.

The most appropriate social related indicators (Table 4) were number of transport fatalities per inhabitant, density of the public transport network and discounts on public transport fares for seniors and students, for the purpose of measuring safety, accessibility and equity. In the safety indicators, the number of accidents was also available, but is more ambiguous than the number of fatalities, as it depends on the reporting rate and the definition of an accident, which may vary from country to country. The indicator measuring accessibility to public services for the disabled was discarded as it depended on interpretation, in some cases it referred to stations or stops, and in others to vehicles.

The only suitable indicators for the environmental dimension (Table 5) were land consumption of transport infrastructures, energy consumption, and emissions produced by public transport modes per user. The share of non-motorised transport modes was not considered a suitable indicator as it is not a direct measure of the quantity of emissions, energy or noise, although the increase in the use of soft modes point to a reduction in them. Finally, air and noise pollution levels are not solely the result of urban mobility (Nicolas et al., 2003; Smith et al., 2013), and are therefore

unsuitable for measuring environmental urban transport sustainability (Nicolas et al., 2003).

The indicators finally selected are listed and formulated in Table 6.

In summary, the selection process was methodical and involved several steps. First, we carried out a review of the literature on urban transport indicators for measuring sustainability; this produced a list of indicators that are generally accepted by the scientific community and could be used for our objective. Secondly, the suitability of the indicators for management purposes was evaluated. Three indicators were available in the sources for each sustainability dimension and considered to be appropriate. These indicators were therefore selected to be compiled into a single indicator for each dimension.

### 3. Methodological procedure for the analysis

After describing the indicators to measure urban transport sustainability, in this section we present the methodology followed to analyse and compare urban transport sustainability in the selected cities. First, we compiled the selected indicators in one single index for each sustainability dimension and each city. These indexes are called composite indicators (CI), and are based on a benchmark approach, namely on the comparison between cases; values for each city therefore depend on the average performance of the rest. Second, we identified which characteristics contribute most to achieving a sustainable urban transport system. In this step, existing correlations between sustainability scores (CI-values) for all cities and other variables such as size, wealth or modal share, were explored by analysing Pearson correlation coefficients. Finally, we cluster the cities according to how close their transport systems are to being economically, socially and environmentally sustainable, using the CIs as classification variables.

#### 3.1. Sustainable composite indicators

Composite indicators (CIs) can be used to summarise complex or multi-dimensional issues in order to support decision makers as they provide a big picture, and can be easier to interpret than trying to find a trend in many separate indicators (Saisana and Tarantola, 2002). CIs are increasingly being recognised as a useful tool in policy analysis, as they can provide simple comparisons of cities that can be used to illustrate complex and sometimes elusive issues in wide-ranging fields, e.g. environment, economy, society or technological development. CIs are easier to interpret and have proven useful in benchmarking different performances (Nardo et al., 2005).

A report by the EC-Joint Research Centre (Saisana and Tarantola, 2002) recommends appropriate treatments and normalisations for obtaining composite indicators. Before computing a composite indicator, the sub-indicators must be normalised (all transformed into the same unit). Five methods are proposed in the report. Three of them are based on rankings, this has the advantage of simplicity, but we discarded them because they imply a loss of absolute level information. The other two are explained below.

The standardised values method has been very widely used (Saisana and Tarantola, 2002; World Economic Forum, 2001; Haghshenas and Vaziri, 2012). The CI is based on the standardised scores for each indicator which equals the difference in the indicator for each city and the mean for the whole sample, divided by the standard error. This method is sensitive to outliers, as the range between the minimum and maximum observed standardised scores will vary for each indicator. In this context, this sensitiveness is desirable: the method gives greater weight to an



**Table 3**

Indicator requirements for measuring the efficiency of transport management. Economy.

Economic dimension- Indicators								
Selected indicators	Requirements  Indicators (most common unit of measure)	Target relevance Each indicator must show one aspect of sustainability (Journard and Gudmundsson ,2010) (Haghshenas and Vaziri , 2012)	Standardized Indicators should be standardized by city size for comparison (Haghshenas and Vaziri , 2012)	Validity Indicators must actually measure the issue it is supposed to measure (Journard and Gudmundsson ,2010) (Haghshenas and Vaziri , 2012)	Transparency Easy to understand (Journard and Gudmundsson ,2010) (Haghshenas and Vaziri , 2012) (May et al., 2008).	Sensitivity Able to reveal cities sustainable transport changes (Journard and Gudmundsson ,2010) (May et al., 2008)	Unambiguous Do not depend on interpretations (Journard and Gudmundsson ,2010)	Data available, measurable and reliable in the data base (May et al., 2008). (Journard and Gudmundsson ,2010)
X	Coverage ratio of public transport (%)	Public costs per user	YES	YES	YES	YES	YES	YES
	Public expenditure on transit (currency units)	Overall public spending	NO	YES	YES	YES	NO	YES
X	Time spent (min per person per day)	Productivity losses	YES	YES	YES	YES	YES	YES
	Congestion (overall hours lost)		NO	YES	YES	YES	NO	NO
X	Costs of transport for users (currency units per person per day)	User costs	YES	YES	YES	YES	YES	YES

**Table 4**

Indicator requirements for measuring the efficiency of transport management. Society.

Social dimension- Indicators								
Selected Ind.	Requirements  Indicators (most common unit of measure)	Target relevance	Standardized	Validity	Transparency	Sensitivity	Unambiguous	Data available, measurable and reliable
X	Transport fatalities per inhabitant (fatalities per inhabitant)	Safety	YES	YES	YES	YES	YES	YES
	Accidents (accidents per inhabitant)		YES	YES	YES	YES	YES (but it is more ambiguous than no of fatalities)	YES
	Distance travelled (km per person per day)	Facility for users to reach their needs	YES	YES	YES	NO (it is more likely to reveal sustainable land use changes)	NO (usually estimated by users)	NO
	Motorisation rate (no of cars per 1.000 inhabitants)	Car availability	YES	YES	YES	NO (sustainability is more related to car use than car availability)	YES	YES
X	Density of public transport network (km of PT network per area)	Accessibility of PT and supply range	YES	YES	YES	YES	YES	YES
	Quality of public transport (users scores)	Quality of PT	YES	YES	NO	YES	NO	NO
X	Affordability of public transport by lower income residents (costs of transport for users divided by lower incomes or % of discounts for lower income users)	Equity	YES	YES	YES	YES	YES	YES
	Residents with public transit service within 500 metres (%)	Physical accessibility to PT	YES	YES	YES	YES	YES	NO
	Quality of accessibility for people with disabilities (% of services accessible to the disabled)	Physical accessibility to PT for disabled	YES	YES	YES	YES	NO (services include vehicles, stations, stops...)	YES

**Table 5**

Indicator requirements for measuring the efficiency of transport management. Environment.

Environmental dimension- Indicators								
Selected Ind.	Requirements Indicators (most common unit of measure)	Target relevance	Standardized	Validity	Transparency	Sensitivity	Unambiguous	Data available, measurable and reliable
	Vehicle-km per capita (vehicle-km per inhabitant)	Emissions, energy and noise due to motorised transport	YES	YES	YES	YES	YES	NO
	Non-motorised modal share (% of total trips)		YES	NO (although increasing the use of soft modes is assumed to cause a reduction in these impacts, it is not a direct measure)	YES	YES	YES	YES
	Parking spaces in city centre (number)	Land distribution	NO	YES	YES	YES	YES	YES
X	Land consumption of transport infrastructures (km <sup>2</sup> of road network per area)		YES	YES	YES	YES	YES	YES
	Length of cycleway (km)		NO	YES	YES	YES	YES	YES
	Length of pedestrian streets (km)		NO	YES	YES	YES	YES	NO
X	Energy consumption (energy units per traveller)	Energy efficiency	YES	YES	YES	YES	YES	Only for PT
X	Emissions (mass units per traveller)	Air pollution due to motorised transport	YES	YES	YES	YES	YES	Only for PT
	Levels of CO, NOx, hydrocarbons and particles (air concentration)		YES	NO (air and acoustic pollution are not only due to transportation)	YES	YES	YES	YES
	Noise intensity levels (sound units)	Acoustic pollution due to motorised transport	YES		YES	YES	YES	NO

indicator in cities with extreme values.

$$CI_{D,c} = \frac{\sum_{i=1}^n w_i \times y_{ic}}{\sum_{i=1}^n |w_i|}, \text{ where } y_{ic} = \frac{x_{ic} - \bar{x}_i}{\sigma_i} \quad (1)$$

$CI_{D,c}$  is the composite indicator related to the dimension of sustainability D (economic, social or environmental), for the city c.  $n$  is the total number of indicators included in the composite indicator ( $n=3$ ).

$w_i$  is the weight given to indicator in the composite index.  $x_{ic}$  is the value of the indicator  $i$  for the city  $c$ .  $\bar{x}_i$  and  $\sigma_i$  are the mean and the standard error of indicator  $i$ .

Finally, re-scaled values method, which is also very widespread (Saisana and Tarantola, 2002; World Economic Forum, 2001), is similar to the method above, except that it uses re-scaled values of the constituent indicators ( $y_{ic} = (x_{ic} - \min(x_i)) / \text{range}(x_i)$ ). The result is that the standardised scores for all indicators have an identical range. This makes the method more robust when there are outliers. However, this characteristic introduces the opposite problem, namely that the range is increased for indicators with very little variation. These indicators will therefore contribute more to the composite indicator than they would using the standardised values method. The result is that the method of re-scaled values is more dependent on the value of the weights.

The standardised values method was in the end selected. On the one hand, we did not want indicators with a smaller range of variation (such as coverage ratio) to make a great difference

between the cities; we preferred these differences to be caused by indicators with a larger range of variation (such as number of fatalities per inhabitant or land occupation). On the other hand, we wanted to penalise or reward extreme values; for example, a city with too many accidents would rarely have a good social CI. Moreover, this method has the advantage of being less dependent on the weights of each indicator. In our calculations we assigned weights equal to one ( $|w_i| = 1$ ) to each sub-indicator, measuring different aspects of each sustainability dimension, and none of them should be underestimated. The sign of  $w_i$  depends on the meaning of the indicator. If an increase in the value of the indicator makes the transport system less sustainable,  $w_i < 0$  (for example the number of fatalities); conversely if an increase in the value of the indicator makes the transport system more sustainable,  $w_i > 0$  (Haghshenas and Vaziri, 2012). A considerable number of authors have applied the same formula (standardized values) and the same weights simplification ( $|w_i| = 1$ ) to estimate sustainability indicators (World Economic Forum, 2001; Rassafi and Vaziri, 2007; Haghshenas and Vaziri, 2012).

The composite indicators for each sustainability dimension have the following formulations:

$$CI_{econ} = \frac{x_{Cv.Ra} - x_{Cost.us} - x_{Time}}{3} \quad (2)$$

$$CI_{soc} = \frac{-x_{Fatal} + x_{Ntw.den} + x_{Soc.tar}}{3} \quad (3)$$

**Table 6**  
Description of selected indicators.

	Abbreviation	Indicator	Description	Unit
Economic	$x_{Cv,Ra}$	Coverage ratio for public transport	$\left( \frac{\text{Tariff revenues}}{\text{maintenance and operation costs}} \right) \times 100$	%
	$x_{Cost,us}$	Ratio between cost of transport for user and GDP per capita	$\frac{\text{Single public transport ticket price}}{\text{GDP per capita}} + \frac{\text{Price per litre of petrol}}{\text{GDP per capita}}$	–
	$x_{Time}$	Time spent travelling per capita	Time spent travelling per day and person	min
Social	$x_{Fatal}$	Traffic fatalities per capita	$\frac{\text{No. of traffic fatalities in urban area per year}}{\text{million inhabitants}}$	No./mill. inhab.
	$x_{Ntw,den}$	Public transport network density	$\left[ \frac{\text{(length of railmodes/service area)}}{\text{Max. density of rail network in all cases}} \right] + \left[ \frac{\text{(length of bus modes/service area)}}{\text{Max. density of busnetwork in all cases}} \right]$	–
	$x_{Soc,tar}$	Reduction of public transport fares for students and old people	(% PT tariff reduction for students $\times$ % students in MA) + (% PT tariff reduction for old people $\times$ % old people MA)	–
Environmental	$x_{Lnd,con}$	Land consumption for transport infrastructure	Length of urban roads/metropolitan area surface	km/km <sup>2</sup>
	$x_{Ener,PT}$	Public transport energy consumption per user	Annual energy consumption (rail modes + buses)/millions of public transport users per year	TEP/ million users
	$x_{Emis,PT}$	Public transport emissions per user	Petrol annual consumption by buses/millions of bus users per year	TEP/ million users

$$CI_{env} = \frac{-x_{Lnd,con} - x_{Ener,PT} - x_{Emis,PT}}{3} \quad (4)$$

Due to the normalization method, each  $x_{ic}$ , and therefore each CI, had different ranges. Another consequence is that CIs were slightly more influenced by indicators with greater variability between cities, i.e.  $CI_{econ}$  was more influenced by the time spent travelling than by coverage ratio.

Weights assigned to the CIs to obtain global sustainability scores ( $CI_{sust}$ ) were procured from a study carried out by [Guzman et al. \(2014\)](#). These authors analysed the opinions of public decision makers, company representatives and researchers involved in transport and urban planning in order to obtain appropriate weights for each sustainability dimension. The weights were obtained to calculate a global sustainability indicator which considered the three dimensions, in order to evaluate the implementation of passenger urban transport related policies in the European context. The output weights were 0.289 for the economic dimension, 0.357 for the social dimension and 0.354 for the environmental dimension. In any case their values are quite similar and will not therefore have a big impact on the results.

$$CI_{sust} = 0.289 \times CI_{economic} + 0.357 \times CI_{social} + 0.354 \times CI_{environmental} \quad (5)$$

Following this process we have calculated the values of the CI for each dimension in each city. Then they are aggregated to provide the CI of global sustainability for each city. Those results are presented in [Table 10](#), within the results analysis. They are also used for the correlation and cluster analysis that follow.

### 3.2. Correlation analysis

The CIs are assumed to be a comparative measure of urban passenger transport sustainability in each city. In order to detect the relationships between certain of a city's characteristics such as population or GDP and the sustainability of their transport systems, we explored the existing correlations between the CIs ([Table 10](#)) and those city's characteristics available in the data sources (see [Section 2.2](#)). The Pearson correlation analysis was chosen for this purpose (similar approaches can be found in

[Haghshenas and Vaziri \(2012\)](#)). For the analysis to be valid, at least one of the variables (in this case the CIs) has to be normally distributed ([Huck, 2000](#); [Breakwell et al., 2005](#)).

A very widespread method to test normality is the Kolmogorov–Smirnov (K–S) and Shapiro–Wilk (S–W) test. If the test is not significant (usually  $Sig > 0.05$  for a level of confidence of 95%), this tells us that the distribution of the sample is not significantly different from a normal distribution (i.e. it is probably normal) ([Breakwell et al., 2005](#)). We chose this method despite its severity, as it has been considered by many authors to be appropriate for testing small samples, and some have applied it to samples  $n < 23$  ([Lilliefors, 1967](#); [Conover, 1972](#)).

The CIs were verified by the K–S and S–W test. Social, environmental and global sustainability CIs passed the test showing high significances ( $Sig > 0.05$ ), and therefore can be considered normally distributed variables. The significance of the economic CI ( $Sig = 0.032$ ) was slightly below 0.05; however, this value is acceptable using some authors' criteria ([Eckel and Grossman, 1998](#); [Öztuna et al., 2006](#); [Lorenz, 2009](#); [Yap and Sim, 2011](#)), who argue that the K–S and S–W test is the most powerful and the strictest. We also contrasted these results with alternative graphical and numerical tests, following the recommendations of [Hair et al. \(2010\)](#). Regarding numerical test, [Table 7](#) shows the skewness values, and the z-values of skewness and kurtosis. None of these contrast tests revealed significant differences from normal distribution,<sup>5</sup> and we therefore considered economic CI as normally distributed.

Finally, once the Pearson correlation coefficients were calculated, they were tested with a two-tailed test, since there was no specific direction to the hypothesis being tested ([Breakwell et al., 2005](#)). The significance analysis depends on the sample size; the smaller the sample, the higher the Pearson coefficient will have to be in order to prove the correlation between variables. This study therefore only shows characteristics with a high impact on transport sustainability.

<sup>5</sup> Values inside the range  $\pm 1$  for skewness and  $\pm 1.96$  for both z-values tells us that the distribution of the sample is not significantly different from a normal distribution Z-values of skewness and kurtosis outside the range  $\pm 1.96$  indicate a not normal distribution for a 0.05 significance level.



**Table 7**

Normality test results for composite indicators.

	Kolmogorov–Smirnov <sup>a</sup>			Shapiro–Wilk			Skewness and Kurtosis		
	Statistic	df	Sig. (>0.05)	Statistic	df	Sig. (>0.05)	Skewness (>–1)(<1)	Z-Skewness (>–1.96)(<1.96)	Z-Kurtosis (>–1.96)(<1.96)
CI <sub>econ</sub>	0.189	23	0.032	0.931	23	0.115	0.897	1.865	1.073
CI <sub>soc</sub>	0.105	23	0.200 <sup>b</sup>	0.976	23	0.837	–0.192	–0.399	–0.745
CI <sub>env</sub>	0.120	23	0.200 <sup>b</sup>	0.954	23	0.354	–0.463	–0.963	–0.491
CI <sub>sust</sub>	0.157	23	0.145	0.922	23	0.073	–0.943	–1.960	0.941

<sup>a</sup> Lilliefors significance correction.<sup>b</sup> This is a lower bound of the true significance.

### 3.3. Cluster analysis

The last step of the process was to classify the 23 cities according to the sustainability of their passenger transport systems in the three dimensions, measured by the CIs (Table 10). The method used for the classification was the cluster analysis, which aims to reduce the dimensionality of a data set by exploiting the similarities/dissimilarities between the cases (the cities). The techniques can be hierarchical if the classification has an increasing number of nested classes, and non-hierarchical when the number of clusters is decided ex ante (Nardo et al., 2005).

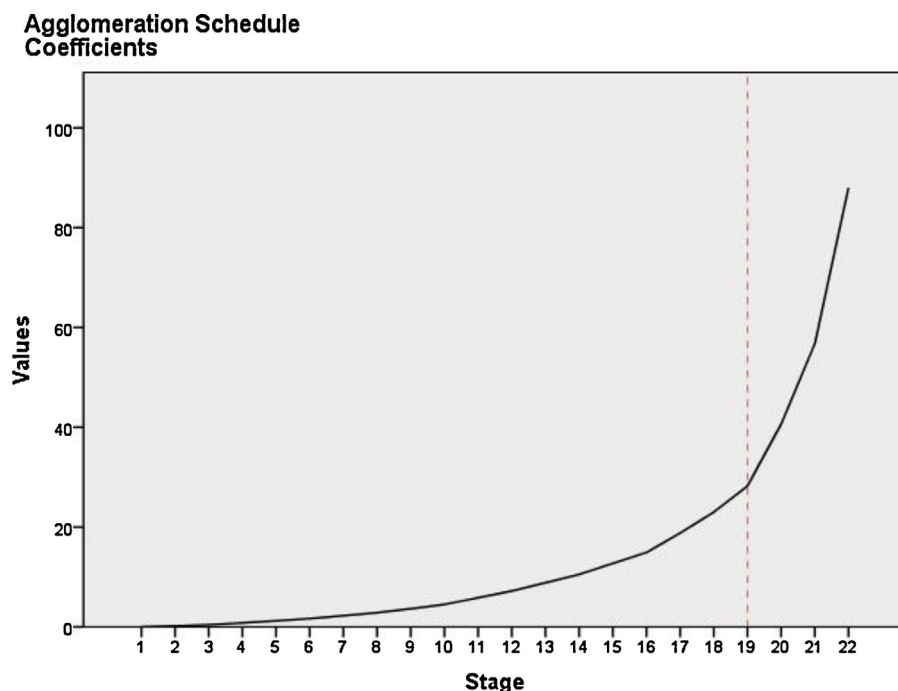
In order to cluster the cities and taking the CI<sub>econ</sub>, CI<sub>soc</sub>, CI<sub>env</sub> and CI<sub>sust</sub> of each city as the classification variables, we first set the appropriate number of clusters, using a hierarchical method: the Ward method with squared Euclidean distance measurement. This means that membership of the cluster is determined by calculating the sum of the squared deviations of elements from the mean of the cluster (Nardo et al., 2005). The squared distances were selected for being suitable when there are negative values – which is the case of the CIs. The method is an agglomerative procedure where a pair of clusters merge at each step. As the process continues fusing clusters, the similarity between cities belonging to the same cluster decreases and the linkage distances increase.

Economic, social, and environmental CIs have different ranges within the sample of cities, and as the cluster classification measures distances, some sustainability dimension could be

omitted. To avoid this, the CIs were again normalized using Z-scores formulation, the most commonly used for this purpose in cluster analysis (Hair et al., 2010).

The decision to take the optimum number of clusters is largely subjective, although looking at the plots of agglomeration coefficients, and linkage distance across fusion steps may help (Milligan and Cooper, 1985). By looking at the agglomeration schedule and the dendrogram, we decided to classify the cities into four clusters. In the agglomeration schedule (Fig. 1) the optimal step could be said to be number 19, from this point forward, agglomeration coefficient values start to grow rapidly. In step 19, the cities aggregated with Paris (city no. 1) were fused with the cities aggregated with Amsterdam (city no. 9) (Table 8). The dendrogram plot (Fig. 2) illustrates the arrangement of the clusters; the linkage distances for the four clusters appear to be acceptable, and they grow significantly in the next step of the aggregation, where the method forms three clusters.

Unlike the previous method, the *k*-means method of clustering is not hierarchical, and therefore starts from a previously stated number of clusters (=k) and centroids. It is used when the aim is to divide the sample in *k* clusters with the greatest possible differentiation. The algorithm departs from the initial situation moving the objects in and out of the clusters in order to minimise the variance of the elements within the clusters, and maximise the variance of the elements outside the clusters (Nardo et al., 2005).

**Fig. 1.** Coefficient values in each step of agglomeration.

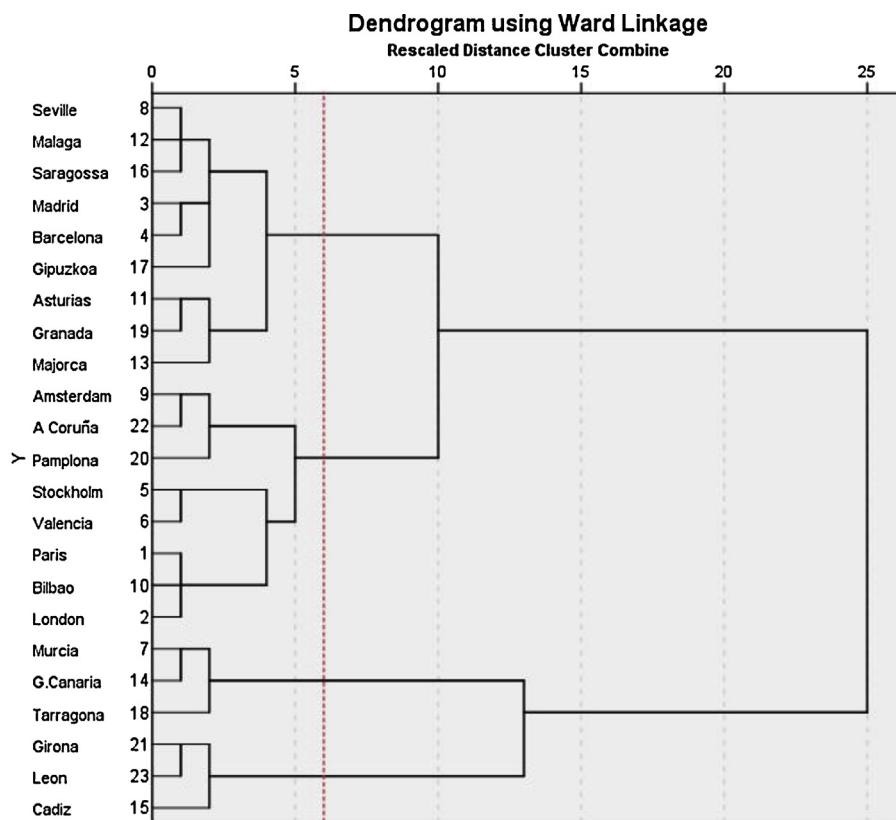


Fig. 2. Cluster arrangement.

The *k*-means method is used here to test the stability of the resulting clusters. We set  $k=4$ , and iterations were started from centroids obtained with the Ward method, again using squared Euclidean distance measurement. SPSS made only two iterations and the final results differed only in the assignment of one city (Valencia). Although this could not be interpreted as a confirmatory analysis (we entered the starting centroids), the low number of iterations and the similarities between final clusters show some stability in the results (Hair et al., 2010). The *k*-means method changes the cities from one cluster to another in order to obtain the best solution; while in the Ward method, once the elements have been fused, they remain in the same cluster. Therefore *k*-means could correct some aggregation done in Ward method stages.

The ANOVA analysis (Table 9) shows high *F* values, which means that all the variables contribute to the cluster classification (Breakwell et al., 2005; Hair et al., 2010), especially the social and global sustainability indicators. This could prove that the classification makes sense, because the cities contained in each cluster show high similarities among them considering their CIs values (sustainability scores), and high differences with the rest.

As a result, all cities were classified according to the CI scores obtained in the different sustainability dimensions. Firstly, we identified the optimal number of clusters, which was set at four by a hierarchical method. Secondly, the stability of the result was tested by *k*-means, entering the number of clusters and centroids obtained in the first step. We selected this second agglomeration (*k*-means can rectify results obtained by hierarchical method), presented in Section 4.3. Finally, an ANOVA analysis confirms the consistency of the clusters (all variables contributed to the classification).

## 4. Results and discussion

This section contains an analysis of the composite indicators obtained for the 23 cities, and a study of the correlations between the variables related to urban transport systems' sustainability and the general characteristics of the cities. Finally, the cities are classified into four groups based on their sustainability scores; each group is characterised by an average profile: the cluster centroid.

### 4.1. Composite indicator results

The evaluation was based on the average performance of the sample. On this occasion, the sample included European cities which some authors consider to be among the most sustainable in the world (Haghshenas and Vaziri, 2012; Newman and Kenworthy, 1999).

Due to the normalization method, each CI was slightly more influenced by factors with wider ranges, and more variability between cities. For example,  $CI_{econ}$  was more influenced by total travel time than by coverage ratio as there is greater variability in travel time between the cities.

The economic CI was substantially influenced by total time spent travelling, which was higher for big cities. Big cities were also characterized by a lower coverage ratio (they normally had a more comprehensive offer of public transport, including metro and rail modes with high operational costs). The most populated cities were therefore more penalised by economic indicators. In fact, almost all cities analysed with more than 1.5 mill. inhab., namely Paris, London, Stockholm, Madrid, Barcelona, Valencia and Seville achieved negative scores for  $CI_{econ}$ .

**Table 8**

Fusion of clusters and coefficient values in each step of the agglomeration process.

Agglomeration schedule-coefficients				
Stage Fig. 1 – horizontal axis	Combination of clusters in each stage Fig. 2		Values Fig. 1 – vertical axis	
	Group	Group		
1		8	12	0.020
2		1	10	0.182
3		3	4	0.427
4		8, 12	16	0.815
5		11	19	1.215
6		9	22	1.678
7		5	6	2.242
8		21	23	2.870
9		1, 10	2	3.633
10		7	14	4.497
11		11, 19	13	5.849
12		3, 4	17	7.205
13		7, 14	18	8.860
14		3, 4, 17	8, 12, 16	10.540
15		15	21, 23	12.730
16		9, 22	20	14.929
17		1, 10, 2	5, 6	18.806
18		3, 4, 17, 8, 12, 16	11, 19, 13	23.020
19		1, 10, 2, 5, 6	9, 22, 20	28.249
20		1, 10, 2, 5, 6, 9, 22, 20	3, 4, 17, 8, 12, 16, 11, 19, 13	40.626
21		7, 14, 18	15, 21, 23	56.749
22		1, 10, 2, 5, 6, 9, 22, 20, 3, 4, 17, 8, 12, 16, 11, 19, 13	7, 14, 18, 15, 21, 23	88.000

Table 10 shows the CI scores obtained; cities are ordered by population size. Negative scores indicate they are less sustainable than the average of the sample, while positive results indicate they are more sustainable than the average. Spanish cities had a poorer assessment within the social dimension than the four European non-Spanish ones. Although the number of urban fatalities was the factor with the greatest impact in this particular CI, the higher scores of foreign cities could be attributed more to the joint effect of a denser public transport network, and higher discounts in social fares.

Environmental scores were more affected by land consumption and public transport emissions per user. Cadiz, Tarragona and Gran Canaria had the worst evaluation; all three cities are fairly disperse, with few public transport users, and their public transport systems consumed a high quantity of resources per passenger compared to the rest. In contrast, cities with greater use of public transport were very efficient with regard to consumption and emissions per passenger; these included cities like Paris, London, Madrid, Barcelona, Bilbao and Saragossa, although London did not receive a very good  $CI_{env}$  due to land occupation. The best scores for global sustainability were obtained by Bilbao, Pamplona, Paris, London and Bilbao.

#### 4.2. City and mobility characteristics

Sustainability indicators must be able to determine the characteristics that enhance sustainability in urban transport (Haghshenas and Vaziri, 2012). In this stage of the process, we determined which global variables facilitate or hinder the implementation of a sustainable transport system in cities.

We therefore analysed the correlations between some characteristics (modal share, urban density, GDP per capita, population ...) and the CIs. Haghshenas and Vaziri (2012) also applied this method with cities all over the world using different indicators. Their coefficients were lower, probably because the sample was more heterogeneous, while cities in this study had more similarities.

Table 11 shows the results of the Pearson correlations. We tested correlations with variables contained in MMO and EMTA reports, but only the variables listed in the table were significant. According to the results, and the indicators selected, economic sustainability CI is negatively correlated with public transport share. Generally, cities with high-quality public transport networks and a wide range of services have lower coverage ratios, such as Stockholm, Gipuzcoa or Madrid. These networks tend to capture a large part of the travel demand in spite of having higher ticket prices, a fact that also penalised these public transport systems in terms of economic sustainability. Finally, in the most populated cities, people spent more time travelling per day. These larger cities were typically characterised by better public transport networks, higher ticket prices and a more generalised use of public transport, and therefore worse  $CI_{econ}$  scores. It is worth noting that the selected and available indicators are partial, and the analysis omits some important factors such as road investment, which affects both private and public transport. What can be inferred from the results, is that to achieve high quality in PT networks implies a cost for public authorities and users, and this cost affects certain aspects of economic sustainability, as has been reflected here. On the other hand, high quality PT networks with high PT modal shares give very good results for the aspects relating to social and environmental sustainability.

Social sustainability is positively correlated with public transport share, urban density and GDP per capita. The number of fatalities per inhabitant did not show any correlation with these

**Table 9**ANOVA analysis results from *k*-means procedure.

	Cluster		Error		F	Sig.
	Mean square	df	Mean square	df		
ScoreZ( $CI_{econ}$ )	3.679	3	0.577	19	6.374	0.004
ScoreZ( $CI_{soc}$ )	6.034	3	0.205	19	29.413	0.000
ScoreZ( $CI_{env}$ )	4.406	3	0.462	19	9.533	0.000
ScoreZ( $CI_{sust}$ )	5.973	3	0.215	19	27.814	0.000

**Table 10**

Composite indicators (CI) obtained for each city.

Population	City		CI <sub>econ</sub>	CI <sub>soc</sub>	CI <sub>env</sub>	Aggregated CI <sub>sust</sub>
>5 mill. inhab.	1	Paris	−0.18	0.49	0.61	0.34
	2	London	−0.16	0.85	0.18	0.32
	3	Madrid	−0.24	0.14	0.83	0.27
	4	Barcelona	−0.15	0.07	0.52	0.17
5–1.5 mill. inhab.	5	Stockholm	−0.44	0.61	−0.20	0.02
	6	Valencia	−0.21	0.18	−0.10	−0.03
	7	Murcia	0.44	−0.12	−0.51	−0.10
	8	Seville	−0.12	−0.39	0.45	−0.01
	9	Amsterdam	0.06	0.57	−0.26	0.13
1.5–1 mill. inhab.	10	Bilbao	−0.23	0.61	0.83	0.45
	11	Asturias	0.14	−0.61	0.12	−0.13
	12	Malaga	−0.10	−0.30	0.40	0.01
1–0.5 mill. inhab.	13	Majorca	−0.12	−0.31	−0.27	−0.24
	14	Gran Canaria	0.39	0.55	−0.72	0.05
	15	Cadiz	0.14	−0.84	−1.34	−0.73
	16	Saragossa	−0.14	−0.56	0.81	0.04
	17	Gipuzkoa	−0.53	−0.12	0.48	−0.03
	18	Tarragona	0.85	0.10	−1.05	−0.09
<0.5 mill. inhab.	19	Granada	0.21	−0.32	0.31	0.06
	20	Pamplona	0.47	0.37	0.29	0.37
	21	Girona	−0.22	−1.20	−0.40	−0.63
	22	Corunna	0.19	0.99	−0.48	0.24
	23	Leon	−0.03	−0.77	−0.51	−0.46
Minimum value			−0.53	−1.20	−1.34	−0.73
Maximum value			0.85	0.99	0.83	0.45
Range of variation			1.38	2.18	2.17	1.18

variables, although it penalised cities with extreme negative values such as Leon and Girona, and favoured those with extreme positive values such as Stockholm. Accessibility, measured by km of public network per service area, was higher in wealthier and denser cities: those with greater GDP tend to invest more in their networks; and high accessibility is obviously more easily achieved in less dispersed areas. Equity, measured by discounts for young and old people on public transport fares, was also addressed in CI<sub>soc</sub>; GDP was clearly correlated with this aspect: wealthier cities offered more social discounts than poorer ones. Lastly, as expected, transport systems with good accessibility and greater social discounts had higher public transport shares.

Environmental sustainability is negatively correlated with private motorised share and positively correlated with public transport share. Cities with extended car use and lower public transport shares had more inefficient public transport services in terms of energy and emissions per passenger. In addition, cities with a longer length of road per area tend to have higher private motorised shares.

Global sustainability is positively correlated with public transport share and negatively correlated with private transport share. Newman and Kenworthy (1999) have already highlighted the barriers to attaining sustainability imposed by automobile dependence: it drives cities to increase their use of land, energy, water, and other materials, and their rates of transport-related emissions, traffic noise and storm-water pollution. The solutions for improving this situation include favouring transit and non-motorised modes, and constraints on urban sprawl.

Urban density also appears to contribute to urban transport sustainability. This is generally accepted by a number of authors (Nicolas et al., 2003; Jeon and Amekudzi, 2005; Savelson et al., 2006; Zhang and Guindon, 2006; Litman, 2009; Haghshenas and Vaziri, 2012 etc), who state that urban sprawl has a significant effect on travel distances and hinders public transport supply.

In this study, rich and highly-populated cities generally tend to be more sustainable. Large cities were usually characterised by economies of scale and density, a broader job offer, and a higher GDP. They therefore invest more capital in their public transport

**Table 11**

CI correlations with cities' characteristics.

		Public transport share	Private motorised share	Urban density	GDP per capita	Population
CI <sub>econ</sub>	Pearson correlation	−0.502 <sup>a</sup>	0.333	0.000	−0.349	−0.296
	Sig. (2-tailed)	0.015	0.121	0.999	0.103	0.170
CI <sub>soc</sub>	Pearson correlation	0.473 <sup>a</sup>	−0.215	0.461 <sup>a</sup>	0.509 <sup>a</sup>	0.375
	Sig. (2-tailed)	0.022	0.324	0.027	0.013	0.078
CI <sub>env</sub>	Pearson correlation	0.517 <sup>a</sup>	−0.575 <sup>b</sup>	0.260	0.358	0.401
	Sig. (2-tailed)	0.012	0.004	0.230	0.094	0.058
CI <sub>sust</sub>	Pearson correlation	0.540 <sup>b</sup>	−0.455 <sup>a</sup>	0.502 <sup>a</sup>	0.498 <sup>a</sup>	0.453 <sup>a</sup>
	Sig. (2-tailed)	0.008	0.029	0.015	0.016	0.030

<sup>a</sup> Correlation is significant at the 0.05 level (2-tailed).

<sup>b</sup> Correlation is significant at the 0.01 level (2-tailed).

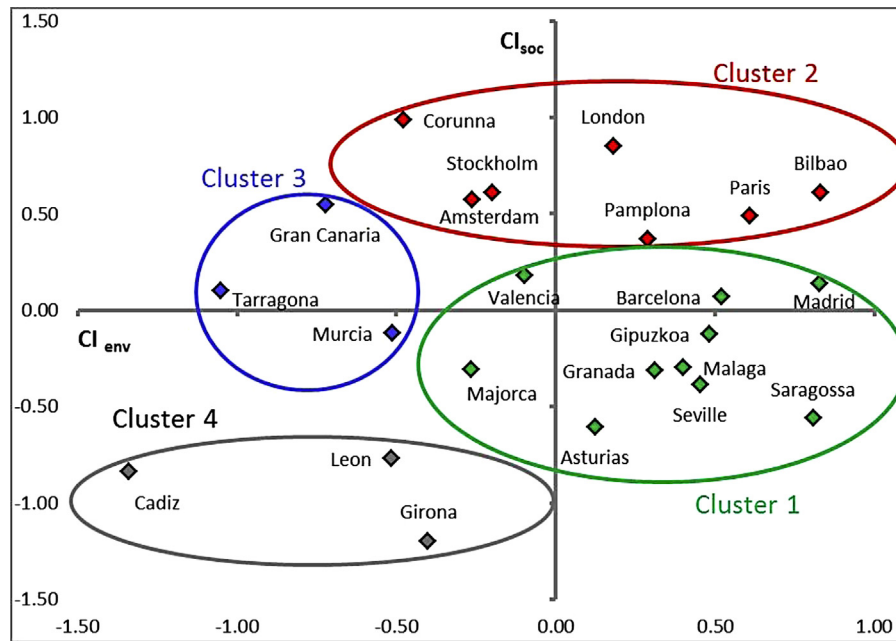


Fig. 3. Clusters with environmental and social CI scores.

networks, sometimes inhibiting some aspects of economic sustainability but clearly contributing to social, environmental and global sustainability.

#### 4.3. Cluster analysis

This section, includes a characterization of the clusters formed<sup>6</sup>. The cities contained in each cluster are shown in Fig. 3, a two-dimensional plot where each city is represented by its environmental CI score on the horizontal axis and its social CI score on the vertical axis.<sup>7</sup> Cluster 1 – comprising ten cities – is clearly the largest and most homogeneous, cities in it are more similar to each other,<sup>8</sup> and most have very good environmental CI scores, as they are located in the positive part of the horizontal axis. Cluster 2, which contains the four non-Spanish cities plus three Spanish ones, is characterised by very good social sustainability scores; which places the cluster in the upper part of the plot. Clusters 3 and 4, are formed by only three cities. Cluster 4 is the least homogenous; its cities are all characterised by negative economic and environmental CI scores. Finally, in Fig. 4, the cities are represented in a three-dimensional plot, which also considers the economic dimension. It can be seen that Cluster 3 is located in the positive part of economic CI axis, contrary to what occurs in almost all cities in Clusters 1 and 2. This figure also shows that Cluster 2 is the most sustainable, as it is located in the front part of the plot, thus performs quite well in the three dimensions.

Table 12 shows the average profiles of the cities assigned to each cluster – with regard to sustainability CI scores and

characteristics correlated with them (according to Table 11). The main features of each cluster are explained below.

Cluster 1 – Environmentally Efficient – characterised by cities with environmentally sustainable transport systems. It includes cities that are very efficient in public transport management, with a high public transport share (14%). The most populated Spanish cities belong to this group, namely Madrid, Barcelona, Valencia, Sevilla and Asturias, plus Saragossa; they have an average population of 2 mill. inhab. Their average global sustainability CI score is positive, but lower than the second cluster, although some cities in this cluster such as Madrid obtained high global sustainability evaluations.

Cluster 2 – Socially Friendly – comprises cities whose transport systems were the most socially sustainable; they usually also achieved high global sustainability scores. According to the results obtained in the correlations analysis, these cities were generally the most populated – with an average of 3.5 mill. inhab. –, the wealthiest – with a GDP of 33,563 per capita – and the densest – 1,693 inhab/km<sup>2</sup> on average. This cluster is characterized by the highest public transport share and the lowest car share, with average values of 18 and 41%, respectively. The cities included in this group were Paris, London, Stockholm and Amsterdam, plus Corunna, Pamplona and Bilbao. According to their global sustainability scores and general characteristics, Madrid and Barcelona could have been placed in this group, but their social indicators were too low to belong to this cluster.

Cluster 3 – Economically Competitive – formed by cities which achieved economic sustainability, namely Murcia, Gran Canaria and Tarragona with an average of 1 mill. inhab., none of which have rail or metro services.

Cluster 4 – Least Sustainable – contains the smallest populations (400,000 inhabitants). These cities were the least sustainable, taking into account the three dimensions. They presented some barriers to achieving sustainable urban transport systems; i.e. they had the lowest GDP per capita (20,584 per capita on average), and rather dispersed populations (137 inhab/km<sup>2</sup>). The cities included in this cluster were Girona, Leon and Cadiz.

On average, global sustainability scores decrease in parallel with public transport use. Clusters 3 and 4 – which have the lowest

<sup>6</sup> We present the clusters done by the *k*-means method; the only difference in the results with the Ward method was the assignment of Valencia to cluster number 1 instead of number 2.

<sup>7</sup> The variables represented allow a clear identification of the clusters, as the *F* value (Table 9) for the social and economic CI were very high, and therefore had a high contribution in the formation of clusters.

<sup>8</sup> Most cities in Cluster 1 aggregate in the first stages of the hierarchical clustering process (see Fig. 2).



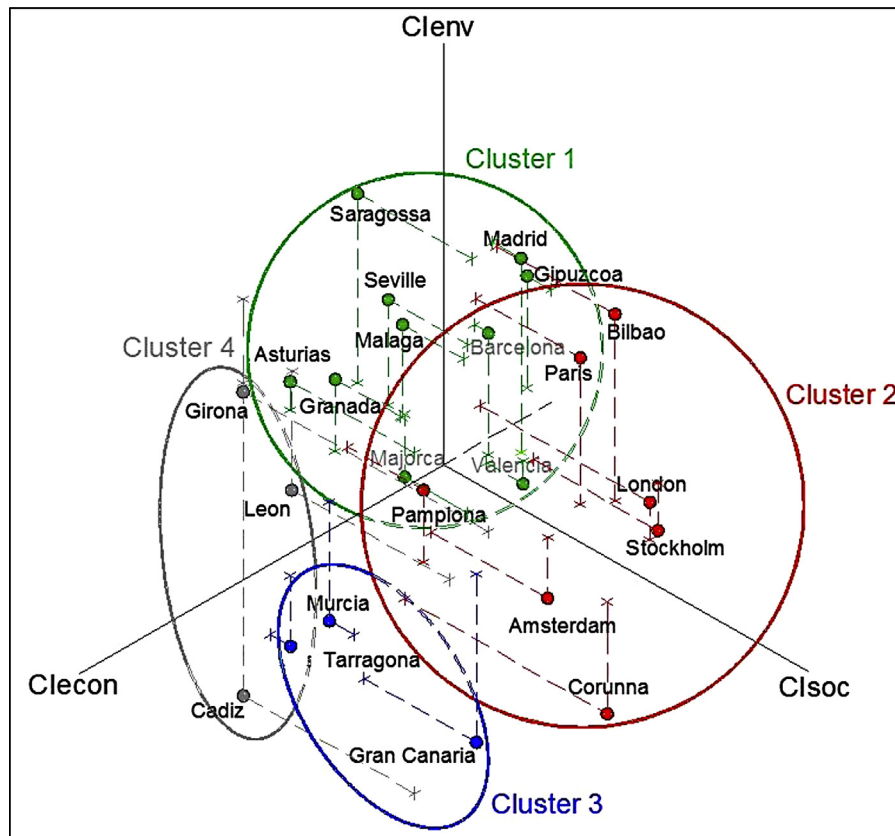


Fig. 4. Clusters with economic, social and environmental CI scores.

Table 12

Average profiles of cities in each cluster (centroid values).

	Clusters (K-means method)			
	1	2	3	4
	Environmentally efficient	Socially friendly	Economically competitive	Least sustainable
Cl <sub>econ</sub>	−0.13	−0.04	0.56	−0.04
Cl <sub>socio</sub>	−0.22	0.64	0.18	−0.94
Cl <sub>env</sub>	0.36	0.14	−0.76	−0.75
Cl <sub>sust</sub>	0.01	0.27	−0.04	−0.61
Public transport share (%)	14.45	18.07	8.20	4.33
Private motorised share (%)	41.82	40.56	53.67	50.27
Urban density (inhab./km <sup>2</sup> )	624	1,693	292	137
GDP per capita (€)	23,595	33,563	22,401	20,584
Population (inhabitants)	1,968,850	3,519,601	974,836	392,938

global CI (−0.04 and −0.61) – also have low public transport patronage (8 and 4%).

## 5. Conclusions

Since concern for sustainable development started to permeate through societies in the United Nations (1972) Stockholm Conference on the Human Environment, cities around the world have been pursuing sustainability goals in their agendas. This in turn has led to a need to define indicators to measure how far these targets have been met (Newman and Kenworthy, 1999).

This study defines indicators for measuring the economic, social and environmental sustainability of passenger transport systems in a group of cities. The intrinsic features of the concept of

sustainable transport required the indicators to be multidisciplinary, and this informed our decision to use composite indicators (CI) based on a benchmarking approach; that is, the scores obtained for each city depend on the performance of the whole sample. The scores were therefore not global, but the methodology could be useful for stakeholders and decision makers to assess their progress compared to other real cases and detect their weaknesses and strengths. All the cities analysed were European, considered by certain authors to be among the most sustainable in the world (Haghshenas and Vaziri, 2012; Newman and Kenworthy, 1999).

The method allowed us to analyse the three sustainability dimensions, and to use the results to compare and classify various cities from an economic, social and environmental viewpoint. CIs can highlight the factors that contribute most to achieving

sustainability in transport; the richest and largest cities usually have more sustainable transport systems. CIs also point to certain transport policies that could improve shortcomings, such as increasing the share of public transport, and avoiding urban sprawl. CIs also allow similar cities to be aggregated based on the sustainability of their urban transport systems. It was found that cities with highest social CIs were also the most globally sustainable. This was the case of all non-Spanish European cities plus some Spanish ones. Mid-sized cities (1 mill. inhab.) without metro, rail or tram modes were the most economically sustainable. Finally, small, disperse and non-wealthy cities were the least sustainable.

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