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A MULTIDISCIPLINARY SUSTAINABILITY INDEX TO ASSESS TRANSPORT IN URBAN AREAS: A CASE STUDY OF DONOSTIA-SAN SEBASTIAN, SPAIN.

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ABSTRACT

The management of urban transportation systems represents one of the most formidable challenges for local government that generates several problems related to the wellbeing and the comfort of the public that commute and travel in their daily life. Improvements to various policies and practical measures can move us closer to the ideal of sustainable urban areas with sustainable urban transportation systems. Nevertheless, these aspirations in no way ensure unanimity over the most effective actions to take and the extent of their benefits. In response, a mathematical model has been developed for decision-taking purposes using multi-criteria analysis adapted to urban transportation systems. This model not only takes account of environmental parameters, but also examines economic, social, and urban models, the characteristics and condition of the transport fleet and freight distribution vehicles, in order to generate a sustainability index value for the transportation system of urban areas.

Keywords: Urban Transport, Multi-criteria analysis, Sustainability, Policy assessment, Index of Sustainability

1. INTRODUCTION

Urban transport in large cities is one of the main lines of social investment. Hence, levels of public debt can have direct consequences on the efficiency of the transport fleet, pollution and the environment, not only in urban agglomerations but in the region and its watersheds. The transport system is often the most important function of urban structures in terms of land use, density and land area. These features mean that urban transport is a major variable for sustainable development (European Comission, 2011).

One of the principles of sustainability and its methodology is vertical integration of its systems (Dernbach, 2003). Integration concept is used to describe a decision making process considering all applicable legal and policy tools to achieve a particular result. When integration must be done among multiple decision-makers, their interest can be mutually supportive or antagonistic. If there is a hierarchical relationship between decision-makers, vertical integration occurs and higher levels have authority over lower levels. As urban transport is a system that serves people, commerce and the administration that governs an urban nucleus, all the stakeholders must have a representation in the decision making process.

Greater mobility expands alternatives for housing, employment and per capita purchases, so the urban planning of land use and transport systems should be simultaneously designed. Any transport-related policy, action or works will have the potential to affect accessibility, functions and land prices.

Sustainable urban design seeks a pleasant, prosperous, democratic, peaceful, compact, and green urban environment. In general, the definition of a sustainable transport system is as a transport system that can be used indefinitely, where demand for land and the requirements of the ecosystem are in harmony and comply with sustainable limits, while improving the efficiency and the quality of urban life and social equity (European Conference Of Ministers Of Transport, 2004). Sustainable urban transport must be an objective for city governments and any action, decision or policy must move in this direction. In this regard, The European Commission (European Comission, 2011) adopted a roadmap of 40 concrete initiatives over the next decade to build a competitive transport system including a section referring to urban transport.

In recent years, there have been successive investigations related to these issues with different approaches. Some of this literature is concerned transport sustainability at a national level and other transport sustainability at a local level. For example, some of these works are focused on approaches to reduce greenhouse gas emissions from the transport sector suggesting different policies to put a stop to this trend, to reduce energy consumption and to promote sustainable transport (Chapman, 2007; Ciari, Balac, & Balmer, 2015; Graham-Rowe, Skippon, Gardner, & Abraham, 2011; Marsden & Rye, 2010; Stanley, Hensher, & Loader, 2011; Sudhakara Reddy & Balachandra, 2012; Yedla, Shrestha, & Anandarajah, 2005). On the other hand, there are studies examining the influence of different variables in the modal choice and travel behavior in order to obtain a reduction in motor vehicle use (Fishman,

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Washington, Haworth, & Watson, 2015; Susilo, Williams, Lindsay, & Dair, 2012; Wei, Xia, Guo, & Marinova, 2013). Banister focused on cities, mobility and climate change, arguing that the current situation is unsustainable (Banister, 2011). This author presented an alternative, based on the sustainable mobility paradigm that looks at ways to reduce the need to travel in cities (Banister, 2008). He concluded that sustainable mobility must explore ways of encouraging less rather than more travel, to overcome the problems of capacity and to address the environmental imperative.

All these researches have as objective to improve sustainability of transport acting on different issues. Each one is focused on some of the factors and characteristics related with transportation sustainability. If several actions are proposed in this direction, the need to evaluate the improvement obtained with these actions arises. In this regard, the European Environment Agency (EEA) has issued annual reports since 2000, on the basis of the available data in its series of publications “Transport and Environment Reporting Mechanism” (TERM) on transport sustainability measurements (European Environment Agency, 2013). The TERM 2013 report includes an assessment of progress towards the transport-related environmental targets set out in the 2011 White Paper and other transport and environment regulations. It also includes a focus on the environmental impacts of urban transport. Besides, some authors offered in their research report background on sustainability definitions and issues, theory on how to apply sustainability, performance measurement for sustainability, and references and resource material in order to use it as a guidebook (Zietsman, Ramani, Potter, Reeder, & DeFlorio, 2011).

Focusing on urban transport systems, there have been successive investigations related to these issues obtaining different groups of indicators for monitoring the development of transport sustainability at a local level. For example, the research project PROPOLIS, developed and tested integrated land use and transport policies tools and comprehensive assessment methodologies in order to find sustainable long-term urban strategies and to demonstrate their effects in European cities with positive results in most of the case cities. The conclusion was that if using the same type of package approach combining pricing, investment and land use policies their goal was reached, the approach could be transferable and similar strategies could work also in other European cities (Lautso et al., 2004). Other investigations were focused on create and/or test different indicators or methodologies on sustainable transport or mobility with different policy implications (Ahvenharju et al., 2004; Alonso, Monzon, & Cascajo, 2015; Brand, Anable, & Tran, 2013; Haghshenas & Vaziri, 2012).

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In summary, we may conclude that transportation in urban environments is one of the main factor responsible for environmental degradation and that possible solutions should be directed at reducing the need to travel (especially by private car). Several policies and actions related with different variables could be taken to enhance this topic, but which one will be the best election?. A tool is therefore essential to evaluate the sustainability of the transportation system of any urban area/region using multidisciplinary indicators. This work contributes in this field with the development of an index to evaluate the sustainability of the transportation system of an urban area adjustable to the characteristics of any environment. Once this initial data is obtained, influence of any action or policy can be evaluated recalculating the index value providing simplified and meaningful information on transport sustainability for decision-makers.

2. URBAN TRANSPORTATION ASSESSMENT MODEL

The objective of this paper is to conduct an integrated study of urban transport system sustainability, taking into account the characteristics of the urban environment in which it functions, as well as the basic characteristics required in all urban transport systems (European Conference Of Ministers Of Transport, 2004).

Much of the existing literature has referred to sustainability as a balance between three factors, the environment, the economy and social aspects (Krajnc & Glavič, 2005; Litman, 2008; Quaddus & Siddique, 2001; Tanguay, Rajaonson, Lefebvre, & Lanoie, 2010) However, when sustainability assessment was the main objective, environmental parameters were mainly taken into account to examine impacts such as resource consumption and emission rates. As the consequences of these impacts are economic costs, some tools and evaluation factors for sustainability were found that relate to the economy. Regarding the social aspects of sustainability, it was more difficult to find social parameters with which to assess sustainability, but these gaps have been filled with several studies (Fischer & Amekudzi, 2011).

On this basis, as in addition to traditional factors, it is assumed that urban transport sustainability is related to other factors such as energy, land use, or modal split and they must be taken into account to evaluate the sustainability of an urban transport system. Several studies have been undertaken that use this situation as a starting point to apply different indicators and evaluation methods (Bilbao-Ubillos, 2008; Egilmez, Gumus, & Kucukvar, 2015; Scipioni, Mazzi, Mason, & Manzardo, 2009; Shiau & Liu,

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2013; Tirachini, Hensher, & Rose, 2014; Zito & Salvo, 2011). Some of them included policy-oriented considerations in the process (Fitzgerald, O'Doherty, Moles, & O'Regan, 2012; Shiau & Jhang, 2010) and others presented hybrid approach based on different methods of evaluation and prioritization of transport sustainability strategies applied to concrete cases (Awasthi & Chauhan, 2011; Shiau, 2012). Paez et al. developed a web-based accessibility calculator prototype for the Greater Montreal Area in Canada. The model was implemented in a user-friendly way in order to be used by members of the public or planners/policy makers to measure the level of accessibility for a specific address and personal profile by various modes of transportation (Paez, Moniruzzaman, Bourbonnais, & Morency, 2013).

All these studies used different methods and indicators for assessing the sustainability of specific urban areas and their transport systems and, in each case, were used to evaluate different specific aspects. Along these lines, this research introduces the "Index of sustainability of transport in urban environments", which is obtained by taking account of a set of general factors associated with urban transport in the field of sustainability. The paper describes a multi-criteria methodology to quantify the transport sustainability of any city, with the objective of obtaining an initial sustainability index value, so as to compare the benefits that will be achieved with the different strategies and policies.

The proposed methodology comprises a set of elements at three levels (**Fig. 1**):

1. The first corresponds to the main requirements where transport managers group a set of criteria with a common denominator.
2. A second level refers to the sustainability evaluation criteria, where alternatives or solutions are given to assess sustainability requirements in accordance with the characteristics of urban transportation.
3. The evaluation process culminates by quantifying the criteria at a third level that corresponds to the indicators. The indicators reflect numerical assessments of their appropriateness for sustainability on a predefined scale.

In addition to the traditional requirements proposed as the basic pillars of sustainability within the transport system of an urban environment, we propose additional requirements that fall within the overall set. These additional requirements are important since they group a number of specific criteria that are related to the objective under one heading.

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In view of the above, a set of six requirements have been defined that may be considered from the perspective of sustainability, which serve to evaluate the sustainability of transport in urban environments. The breakdown is as follows:

2.1 Environmental Requirement

Focused on the assessment of policies and actions related to reductions in the emission of pollutants and greenhouse gases (directly related to health, pollution and environmental problems), and seeking to enhance non-motorized transport modes of transport. Indicators and their assessment objectives are in **Table 1**.

2.2 Economic Requirement

This requirement is aimed at assessing the growth of transport in relation to economic growth. It is also focused on reductions in energy consumption levels of transport. Within this overall goal of reduced energy consumption, the objective is to decrease the weighting attached to fossil fuel derivatives. It will be of great interest for the study of different economic policies that may generate sustainable behavior for users, such as fuel and vehicle taxes, road charges and other instruments. Indicators and their assessment objectives are in **Table 2**.

2.3 Social Requirement

Transport users who travel seek safety, speed and comfort, nevertheless there is a direct relationship between the number of deaths on the roads in our cities and the number of trips by car. There are half as many fatal road-traffic accidents in cities with well-developed public transport systems, than in cities with less-developed transport systems. The statistics on serious injuries and fatalities for public transport are about 10 or 20 times less per passenger * km than for the private car. Focusing on affordability, all citizens should have access to a reasonable level of public transport and mobility in urban areas without resorting to private vehicles. On the other hand, schoolboys, the elderly, those without driving licenses and the socially underprivileged need public transport. The social requirement is an attempt to assess these aspects. Indicators and their assessment objectives are in **Table 3**.

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2.4 Urban Model Requirement

One of these additional requirements is related to the interdependence between urban form and transportation and effect of this interdependence on environment and Sustainable Urban Development concerns. These concerns are low density housing, separate urban land-uses, decrease in accessibility and quality of urban services, increasing car dependence and nonrenewable energy usage, pollution, traffic congestion, low public transportation patronage, and increasing number of fatalities and accidents on roads. Numerous researches have examined various aspects of the relationship between land use and transportation. For example, Kenworthy discussed ten critical responses to make existing cities and new urban development more ecologically based and summarized them in a simple conceptual model that placed the nexus between transport and urban form at the heart of developing an eco-city (KENWORTHY, 2006). Other study compared the land use transport interactions in Melbourne, Australia and Riyadh, Saudi Arabia (Alqhatani, Bajwa, & Setunge, 2012). Their work attempted to identify the land use and socioeconomic determinants of travel patterns. Statistical analyses using Journey to Work (JTW) census data and origin and destination (OD) travel patterns at the suburb level were used to examine relationships between urban form and travel patterns. As the interaction between Land Use and Transport Planning is not an issue clear and scientifically solved, Colonna et al. in their paper aimed to introduce an innovative proposal using a deductive approach in order to better understand the origin of modern land use policies and to optimize their future development (Colonna, Berloco, & Circella, 2012). As this matter involves many subjects and it needs the point of view of many cultural approaches, the authors wanted to offer a useful contribution to the debate on this topic. Aljoufie used a cellular automata-based Land-Use Transport Interaction (LUTI) model to assess and simulate different land use and transport policy interventions in Jeddah, a rapidly growing city, over a 20 years period (2011-2031) (Aljoufie, 2014). Yigitcanlar and Kamruzzaman aimed to highlight the importance of the interplay between transport, land use and the environment, providing evidence from the literature including the Transport, Land Use and the Environment Special Issue contributions and global best practice cases to showcase new empirical approaches and investigations from different parts of the world that contribute to the wealth of knowledge in exploring the interplay between transport, land use and the environment thoroughly (Yigitcanlar & Kamruzzaman, 2014). Therefore, because of this interdependence, policies to enhance sustainable land use will improve sustainability of the urban transportation system.

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Each urban environment approaches a particular urban model and the sustainability of its transport system is directly related to this model. For efficient and sustainable urban transport, a compact and diverse city model in all of its aspects is required. Indicators and their assessment objectives are in **Table 4**.

2.5 Characteristics of the fleet of vehicles Requirement

This requirement is focused on the evaluation of policies and measures aimed to reduce motorization's progression and renew the fleet of vehicles reducing the use of fossil fuels in favor of more ecological alternatives. Indicators and their assessment objectives are in **Table 5**.

2.6 Freight distribution Requirement

Freight transport has a minor role in transport planning procedures in most cities although it contributes significantly to pollution, noise disturbance, traffic congestion and safety problems in urban areas. Local governments have introduced different policy measures like time-access restrictions, Low emissions zones (LEZ) improvement, congestion charging, etc. based on the results of different studies related with these issues. In this regard, a research work considered the importance of urban freight transport in maintaining the economic vitality of the city; the negative impacts that it imposes; the concept of urban sustainability and the development of sustainability strategies; and the means and measures by which freight transport could be made more sustainable (Anderson, Allen, & Browne, 2005). Freight transport operations of seven different companies in three urban areas in the UK were investigated considering four policy measures on these operations. Adding rewarding conclusions to the discussion about policy making for urban distribution. Lindholm and Blinge presented the results of a study on the state of urban freight transport policies and planning among Swedish local authorities and they were compared with existing research in the European context in order to find possible links between the freight transport awareness and the successes or failures of measures addressing urban freight transport issues (M. E. Lindholm & Blinge, 2014). A questionnaire sent to all Swedish municipalities and a literature study were combined to map the state of policy and planning within the freight transport as well as the knowledge and awareness of the area in order to discuss the importance of adequate knowledge and personnel resources in municipalities as well as communication, information dissemination and knowledge Exchange. Results showed absence of coordination, sufficient resources and effective knowledge transfer among stakeholders in urban freight transport. Lindholm focused her research on the local authority perspective of sustainable urban freight transport aiming to contribute to the understanding of how freight

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transport affects the urban environment and how awareness and knowledge within the local authority effects the urban freight transport situation (M. Lindholm, 2010). The results concluded that knowledge and awareness in the area of urban freight transport is low, which generates a low level of interest in the subject and makes it hard to predict outcomes of certain actions. The implication for local authorities is that the issue of urban freight transport should gain a higher priority on the agenda. Filippi et al. proposed a methodology for ex-ante assessment of measures to alleviate the negative effects of freight transport in urban areas (Filippi, Nuzzolo, Comi, & Site, 2010). The application of the methodology to the inner urban area of Rome showed that an urban distribution centre could be more effective in reducing environmental externalities than policies based on vehicle fleet renewal. Akyol and Koster examined whether it was possible to develop time-window policies that enhance environmental sustainability and distribution efficiencies, while meeting the objectives of the municipalities (Akyol & De Koster, 2013). On the basis of an evaluation of 99 different time-window policies, results showed that harmonizing time windows between neighboring cities leads to the best overall performance. Ruesch et al. provided further results on the institutional integration of freight transport in public planning, on urban freight measures and strategies and on the implementation of measures and success factors (Ruesch et al., 2012).

In developed societies, excessive and inefficient consumption increases the need and frequency of supply. Distribution activity over the last mile, in the final stage of the supply chain operations have to negotiate physical barriers (narrow streets, pedestrian zones, overloading of roads, etc,). It is therefore necessary to work on finding the best logistics solutions to ensure the effective daily supply of products to urban areas, without compromising the environment, livelihood and quality of life for residents and other users of these areas. Indicators and their assessment objectives are in **Table 6**.

The need for structuring in the definition of this model is proposed through the "*requirement tree*", (Dasgupta & Tam, 2005), which is designed to act as a basis for the identification and arrangement of the system criteria (**Fig.2**).

Indicators are variables are selected and defined to measure progress towards an objective (Litman, 2008) and OECD defined sustainable transportation indicators as statistical measures that give an indication of the sustainability of social, environmental and economic development (Joumard & Gudmundsson, 2010).

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This study began with a selection of country-level transport sustainability indicators by researchers. Taking these indicators as a starting point and comparing them with urban sustainable transportation indicators listed in different studies, the researchers then grouped a set of city-level transport sustainability indicators related with various aspects of urban transport in order to use them in the evaluation of different criteria.

The process of assigning weights to each hierarchical level was conducted by a panel of experts, using the Delphi method, which allows a group of individuals (Expert Panel) to address a complex problem. The members of the panel were chosen to complete this process on the basis of their skills, knowledge and independence.

In this study, the Expert Panel was formed by professionals from the construction and planning sector (Municipal and Basque Government employees with an important role in planning, mobility and traffic and transport infrastructure in urban and interurban areas, researchers at technology centers and universities) and the selection was based on the guidelines defined by (Hallowell & Gambatese, 2010). These authors suggest that the ideal Expert Panel would be formed of a highly qualified and diverse group of between 8 and 16 people. In this case, a total of 10 experts were selected from a database of 50 professionals from 30 different organizations (government, technological centers and universities) in the transportation sector.

The selection of the most important criteria was done by the committee members using the Delphi method, which is a structured communication technique, originally developed as a systematic, interactive forecasting method which relies on a panel of experts (Turoff & Linstone, 2002). Through this systematic process, group members completed a questionnaire to chose, at an early stage, the sustainability evaluation criteria for an urban transportation system. The questionnaire was checked against the set of criteria presented by the researchers. In a second phase, after the initial collection of the criteria, the panel of experts grouped them into different requirements. Ranked these criteria into the corresponding requirement, a relative weight is assessed to each one. The *Analytic Hierarchy Process* (AHP) was used to facilitate the value judgments (indicator weights) by the committee members, and the key indicators were selected based on the relative weights of the indicators. In the final phase, these results were collected and all those with a relative weight of less than 5% were removed, leaving 18 final evaluation criteria.

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The set of criteria resulting from the consultation, as well as the weights associated with each one in the sustainability evaluation of the requirements are shown in **Fig.2**.

Every requirement in the global tree, corresponding to the index for measuring the sustainability of transport in urban areas, was given the same weight for evaluation purposes (**Fig.2**). Urban model, characteristics of vehicle fleets and freight distribution aspects were separated from the classic triple line (economic, environmental and social aspects), following a consensus reached in the panel discussion between committee members and researchers.

3. EVALUATION METHODOLOGY

The assessment methodology used in this research, is 'The Integrated Value Model for Sustainability Assessment' or MIVES [*Modelo integrado de valor para evaluaciones de sosteniblidad*]. The MIVES methodology has been developed by a group of researchers from different Spanish universities and institutes: UPC (Polytechnic University of Catalonia), UPV/EHU (University of the Basque Country), UDC (University of La Coruña) and TECNALIA. MIVES methodology is very useful for comparing alternative project designs and choosing those that contribute more than any other to sustainable development. This method has been successfully applied to different fields of sustainability evaluation. For example, the method is applied in different studies concerning sustainability of industrial buildings (Cuadrado, 2009; Cuadrado, Roji, Tomas San Jose, & Pedro Reyes, 2012; San Jose, Garrucho, & Cuadrado, 2006; San-Jose, Ganucho, Losada, & Cuadrado, 2007) and representing various sectoral points of view, sustainability related to the Spanish Structural Concrete Code (EHE in Spanish) is analyzed (Aguado, del Cano, Pilar de la Cruz, Gomez, & Josa, 2012; del Caño, Gómez, & de la Cruz, 2012; Pons & de la Fuente, 2013).

First of all, to gain a global idea of the process, we shall mention the main steps followed by the sustainability evaluation methodology:

a. Define the problem to be solved and the decisions to be taken.
b. Produce a basic diagram of the decision model, establishing all the aspects that will form part of the assessment in the form of a requirements tree that may include qualitative and quantitative variables.

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c. Prepare an evaluation tree with three different levels composed of requirements, criteria, and indicators.

d. Find the relative weights of the different stages to be evaluated.

e. Each indicator is given a value function, with the objective of comparing the valuations of indicators with different units of measure. For example, it is able to compare such variables as: time, cost, temperature, indicators quantified with attributes, etc. In this way, a weighted sum of the different values of each variable may be calculated. Each value function offers a range of possible solutions, a set score or an output register, between a minimum value of “0” (the worst of the solutions) and the maximum value of “1” (the best of the proposed solutions), (Tam, Tam, Zeng, & Chan, 2006).

f. Completing the set of output registers and based on the proposed system of weighting at each stage; partial results may be progressively obtained with the requirements, as well as the value of the “Sustainability index”. All these values are in turn defined at a point between 0 and 1.

When the evaluation tree is complete, the next task is to obtain sustainability priorities or weights from the different assessment or hierarchy levels of the assessment model.

In recent years, various studies have been carried out regarding preference assignation of certain criteria in relation to others, based on attributes where complete information is lacking (Chen, Li, & Wong, 2005; Malakooti, 2000; Seo, Aramaki, Hwang, & Hanaki, 2004). The method used to obtain sustainability weights is based on the Decision Method *“Analytic Hierarchy Process (A.H.P.)”* (Cuadrado, 2009; Saaty, 2004).

In the first step of the study, a set of pair-wise comparison matrices are created. Each decision matrix generated is a square matrix of order “n”, where “n” is the number of elements to be prioritized. The eigenvector associated with the largest eigenvalue of each matrix represents the order of priorities. Moreover, the eigenvalue is a measure of the consistency of the judgment being made. This offers a way of verifying whether the allocation of preferences was successful. Eigenvector and eigenvalue calculations were performed with the following expression (equation (1)):

$$(A-\lambda\cdot I)\cdot w=0 \tag{1}$$

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Where "A" is the reciprocal comparison matrix between pairs or the decision matrix, "ω" is the eigenvector of the "A" matrix and "λ" is the maximum eigenvalue.

Moreover, the consistency of the matrix must be checked using the consistency relation, which is basically the relation between the consistency index and the random index equation (2):

$$C.R. = \frac{C.I.}{R.I.} \leq 0{,}1 \qquad (2)$$

Where "$C.R.$" is the consistency ratio, "$C.I.$" is the consistency index and "$R.I.$" is the random index. The consistency index ($C.I.$) is defined below in equation (3):

$$C.I. = \frac{\lambda_{\max} - n}{n - 1} \qquad (3)$$

Where "λ_{max}" is the largest eigenvector and "n" is the order of the decision matrix.

The Random Index "$R.I.$" is the maximum value of the consistency index "$C.I.$" for a decision matrix that is randomly generated. Its values depend on the matrix size and are shown in **Table 7**.

The criterion evaluation is done using the indicators, because they numerically quantify the degree of compliance of one criterion. It takes a value between a maximum value ("1" in this methodology) and a minimum value ("0"). These values, between 0 and 1, have been standardized for the global set of evaluation elements (requirements, criterion and indicators) to normalize the results, so that they may be applied in the quantification process.

The indicators are intended to measure criterion with different units: for example, regarding environmental issues, if atmospheric emissions of greenhouse gases (GHG) are taken as an indicator, the result will be kg of CO_2, but in the case of a modal split the result will be a percentage without units. The presence of a wide range of units raises the main problem of how to assess the global sustainability of an urban transportation system with a single value, on the basis of all of these multiple values. For this reason, the initial assessment of the indicators is done in their associated units, and after obtaining these results, these values are converted into dimensionless units. Alarcon et al (2010) emphasized the need to define a general equation that reflects the preferences of the decision maker in a clear and easily applied way (Alarcon, Aguado, Manga, & Josa, 2011). Their paper proposed a new general equation to fulfill these requirements. By modifying certain parameters, this general equation represents the most commonly used relationships (linear, convex, concave and S-shaped). The proposed equation, called

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value function v_i, is applied to each indicator, by assigning a value to it on the scale (0-1). This function aims to model the physical behaviour of the indicator, by the assignation of a numerical value to the different coefficients and parameters in use (**Fig.3**). The value function is defined by five parameters, which when changed result in the following shapes: S-shaped, concave, convex and linear. The equation for the value function varies with the values assigned to the constants: K_i, C_i, X_{max}, X_{min} and P_i. **Table 8** and **Fig.4** show the values each variable needs to adopt for the different values functions:

Alternatively, decreasing functions can be used; functions that adopt the maximum value at X_{min}. The only difference of the value function is that it replaces the variable X_{min} by the variable X_{max}. Setting values of X_{min} and X_{max} and values assigned to the constants of the value functions must be done using external sources provided guidelines. These guidelines must be coherent with the objectives in different European sustainable programs for different areas with influence in transport sustainability, (European Comission, 2011; European Conference Of Ministers Of Transport, 2004).

Thus, this process is applied to all of the indicators until the entire sub-level of indicators is defined. Having defined values v_i and weights λ_i at the sublevel that corresponds to the indicators, the additive value function V_{SC} is applied through equation (4):

$$V_{CR_k} = \sum_{i=1}^{j} \lambda_{i,k} \times v_{i,k}(x_{alt}) \tag{4}$$

where,

V_{CR_k}:	Criterion k value
$\lambda_{i,k}$:	Indicator weight i of criterion k
$v_{i,k}(x_{alt})$:	Indicator value i of criterion k
j:	Number of indicators hanging from criterion k

Then, as can be seen in **Fig.5**, the next levels are solved using a similar procedure. The methodology described here shares the principle that the decision-maker always takes decisions based on personal knowledge and experience, leaving the option open of organizing all the (tangible or intangible) types of factors in a systematic way. In this way, it provides a solution with a very simple structure, because the method identifies the relative priority of each alternative on a quantifiable scale emphasizing the importance of intuitive criteria and the consistency of comparisons between alternatives based on the sound judgment of the decision maker.

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4. PRACTICAL APPLICATION

The urban area of Donostia-San Sebastian was selected to illustrate the methodology described in this paper and its application, a coastal port and municipality located in the Basque Country. It lies on the coast of the Bay of Biscay, 20 km (12 miles) from the French border (**Fig. 6**) and is the capital city of Gipuzkoa. The municipality has a population of 186,500 (2013), an extension of 60.89 km^2 and a population density of 3061.41 hab/km^2. The main economic activities are commerce and tourism and it is one of the most famous tourist destinations in Spain.

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Commercial activity is very intense in the centre, with a high concentration of banks and major shops. Downtown family businesses are gradually giving way to the branches of large multinationals, some of which have multiple locations throughout the city. Its proximity to France attracts a lot of visitors from over the border who fill the shops and large local surfaces. There are four big commercial surfaces in the city, one in the south district, two in the centre and the last one, the largest, located in the East district of the city.

The city of Donostia-San Sebastián is considered a reference in terms of sustainable mobility as a result of the policies developed since the turn of the last century, which have been continually applied up until the present. These policies target the following objectives:

- A profound change in the conception of urban traffic and the functionality of the road network, which led to major changes in the management of traffic, eliminating transit traffic and limited access.
- Coordinated policy pedestrian axes, mainly in the expansion of the city.
- A parking policy with surface parking control with new parking for residents and visitors.
- A firm commitment to cyclist mobility.
- Improving and optimizing the urban bus network.
- Finally, the promotion of footpaths between districts by removing barriers and implementing modes of vertical transportation (elevators).

The irregular terrain of the city is divided into 18 districts. Five of the eighteen districts are located on hills or hillsides involving pedestrian mobility problems. Having analyzed its vertical transportation needs, the city council installed 7 lifts, 5 mechanical ramps and 1 escalator. Given its topography, connecting the lower and the upper levels of the city, which opens up new routes for pedestrians and cyclists reduces the use of private vehicles and thereby changes the mobility habits of the city dwellers.

Mobility in the area follows two distinct patterns. On the one hand, internal mobility to and from the centre of Donostia-San Sebastián, with a significant component of non-motorized mobility and public transport trips; on the other hand, external mobility to the municipality, grouped into three corridors (to the west, the south and the east). If one-way trips are followed, without considering the return trips, the total number in the area within and around Donostia-San Sebastián was 101,500, of which 72,000 corresponded to trips into the city from the outlying areas. It has a typically metropolitan behaviour with numerous movements to access the city and local public transport. In the urban area, 242,000 one-way trips took place. Most travel originated in the Eastern corridor, where the major population nucleus is located. The largest volume was in the Eastern corridor (75,000 trips), followed closely by the Centre (60,000 trips). These areas respectively attracted 31% and 25% of trips in the Donostia-San Sebastián area. The Southern and Western corridors had similar volumes, with around 40,000 displacements, each representing 17% of the total for Donostia-San Sebastián. Motorized mobility represents approximately 50% of the urban trips, approximately 69% by private car with the rest by public transport. As can be seen, there is a very significant level of non-motorized mobility in the city.

Mobility information and data were obtained from recent statistics (2012) available in different yearbooks published by the city council and the government of the Basque Country**. Table 9, Table 10** and **Table 11** provide a summary of the urban mobility distribution, dividing the city into five corridors.

Finally, it should be mentioned that mobility in public transport is mainly by urban bus, while the use of the train is marginal.

Before presenting all of the results for the case of Donostia–San Sebastian, a brief explanation follows on the way one of the indicator values was obtained. The evaluation of the Social requirement is done with four criteria: Security, Noise, and Comfort of public transport and Accessibility. If the Noise is taken as an example, this indicator may be assessed by considering:

- Noise levels due to traffic.
- The percentage of the population affected by these noise levels.

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From the viewpoint of sustainability, the objective would be low noise levels and a low percentage of the population that is affected. Based on the exposure-effects relationship summarized by the WHO (World Health Organization), noise guideline values at night are recommended for the protection of public health from night noise (**Table 12**).

From the noise maps for a given urban environment, noise level exposure of the population can be achieved. Donostia – San Sebastián has been divided into 17 different sub-zones corresponding to its 17 districts (**Fig. 7**). Six different ranks are defined taking into account the recommendations of the WHO (**Table 13**):

Depending on the percentage of boroughs exposed to different ranks, the following quantification for the level of acoustic comfort is proposed in the form of a points system for the evaluation of the indicator (**Table 14**):

The worst case scenario would be one in which a corridor passes through all sub-zones so that their noise levels are ranked at 6. Besides the noise level, the percentage of the population that is affected by this noise level has to be evaluated. A points system is proposed to evaluate this indicator (**Table 15**).

From the noise maps obtained in 2012, Donostia-San Sebastian had different noise levels for boroughs and 27% of population were affected by noise levels higher than the recommended limits of the WHO. The results are represented in **Table 16** and **Table 17**. Linear normalization was used to normalize the points of both indicators.

When normalized values are obtained, applying their weight to each of the second criterion of the third requirements is assessed (**Table 18**).

The results obtained for Donostia with the methodology described in this paper are shown in **Table 19, Table 20, Table 21**, **Table 22**, **Table 23** and **Table 24** (each table shows only one requirement).

A graphical representation using a spider diagram depicts the set of results obtained for all requirements. As can be seen, the average value is exceeded on four requirements: environmental, social, freight distribution and characteristics of the vehicle fleet (**Fig.8**).

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Taking into account the total value of all requirements, assuming they are all equally weighted, the index value for the sustainability of urban transport that is obtained using an arithmetic mean, in the case of Donostia-San Sebastian is "0.57 ".

5. CONCLUSIONS

The present methodology is user friendly, accessible, versatile and intuitive. No specific studies are necessary to obtain the input data that are publicly available in the statistical summaries provided by local government. The index is intended to be a global tool, adjustable to the reality of any urban environment with different characteristics. . In order to avoid problems concerning data collection and their interpretation, each indicator has a brief description of the required data. Thereby, these descriptions can be used as a guideline for different users of the tool. The results are easily understood and give an idea of sustainability in the urban area in either a global or a particular way. By applying this methodology, a total value for sustainable transportation can be calculated and the aspects that form the requirements are those that can be improved to obtain better global results.

The practical results obtained using the proposed methodology for the case of Donostia-San Sebastian are consistent and logical, in view of the reality of the urban environment. The main activities of the city are commerce and tourism, and its industrial activity is hardly insignificant (only 3.2% of the economic activity is related to this sector). Regarding mobility, almost half of all journeys in the city are done by walking and a network of cycle lanes criss-crosses the city. It has a rather complicated orography, but several methods of vertical transport have been installed to facilitate these steep rises (lifts, escalators, etc.) while maximizing pedestrian mobility. From the point of view of sustainability, the urban model of Donostia-San Sebastian is improvable. It has a low intensity of residential land use and urban compactness (few habitants and buildings per hectare), therefore the efficiency of the public transport system of the city is not as good as it would be with a more appropriate urban model. Some districts of the city with low population densities and those located at the periphery have no other choice than to use private vehicles as a mode of transport, decreasing the sustainability of the system.

This tool may furthermore be used by policy makers as an evaluation tool. When the numerical value of sustainability is obtained, any change in the urban transport system will modify this initial value, so different changes in the transport design or different transport plans may be evaluated, because they can be numerically quantified and compared against the preceding values.

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Finally, if sustainability issues were given greater consideration during the general planning process of urban areas, there would be a greater likelihood of people living in pleasant, green zones that are compact and environmentally friendly.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Aguado, A., del Cano, A., Pilar de la Cruz, M., Gomez, D., & Josa, A. (2012). Sustainability assessment of concrete structures within the spanish structural concrete code. *Journal of Construction Engineering and Management, 138*(2), 268-276. doi:10.1061/(ASCE)CO.1943-7862.0000419

Ahvenharju, S., Könnölä, T., van Grol, R., Walker, W., Klautzer, L., Röhling, W., . . . De Ceuster, G. (2004). *SUMMA
Deliverable 3 of workpackage 2
Operationalising sustainable
Transport and mobility:
The system diagram and indicators*

Akyol, D. E., & De Koster, R. B. M. (2013). Non-dominated time-window policies in city distribution. *Production and Operations Management, 22*(3), 739-751. doi:10.1111/j.1937-5956.2012.01414.x

Alarcon, B., Aguado, A., Manga, R., & Josa, A. (2011). A value function for assessing sustainability: Application to industrial buildings. *Sustainability, 3*(1), 35-50. doi:10.3390/su3010035

Aljoufie, M. (2014). Toward integrated land use and transport planning in fast-growing cities: The case of jeddah, saudi arabia. *Habitat International, 41*, 205-215. doi:10.1016/j.habitatint.2013.08.010

Alonso, A., Monzon, A., & Cascajo, R. (2015). Comparative analysis of passenger transport sustainability in european cities. *Ecological Indicators, 48*, 578-592. doi:10.1016/j.ecolind.2014.09.022

Alqhatani, M., Bajwa, S., & Setunge, S. (2012). Land-use transport interaction: A comparison of melbourne, riyadh. *8th International Conference on Traffic and Transportation Studies (Ictts), 43*, 3-13. doi:10.1016/j.sbspro.2012.04.072

For Peer Review Only

Anderson, S., Allen, J., & Browne, M. (2005). Urban logistics—how can it meet policy makers' sustainability objectives? *Journal of Transport Geography, 13*(1), 71-81. doi:http://dx.doi.org/10.1016/j.jtrangeo.2004.11.002

Awasthi, A., & Chauhan, S. S. (2011). Using AHP and dempster-shafer theory for evaluating sustainable transport solutions. *Environmental Modelling & Software, 26*(6), 787-796. doi:10.1016/j.envsoft.2010.11.010

Banister, D. (2008). The sustainable mobility paradigm. *Transport Policy, 15*(2), 73-80. doi:10.1016/j.tranpol.2007.10.005

Banister, D. (2011). Cities, mobility and climate change. *Journal of Transport Geography, 19*(6), 1538-1546. doi:10.1016/j.jtrangeo.2011.03.009

Bilbao-Ubillos, J. (2008). The costs of urban congestion: Estimation of welfare losses arising from congestion on cross-town link roads. *Transportation Research Part A-Policy and Practice, 42*(8), 1098-1108. doi:10.1016/j.tra.2008.03.015

Brand, C., Anable, J., & Tran, M. (2013). Accelerating the transformation to a low carbon passenger transport system: The role of car purchase taxes, feebates, road taxes and scrappage incentives in the UK. *Transportation Research Part A-Policy and Practice, 49*, 132-148. doi:10.1016/j.tra.2013.01.010

Chapman, L. (2007). Transport and climate change: A review. *Journal of Transport Geography, 15*(5), 354-367. doi:10.1016/j.jtrangeo.2006.11.008

Chen, Z., Li, H., & Wong, C. T. C. (2005). EnvironalPlanning: Analytic network process model for environmentally conscious construction planning. *Journal of Construction Engineering and Management-Asce, 131*(1), 92-101. doi:10.1061/(ASCE)0733-9364(2005)131:1(92)

Ciari, F., Balac, M., & Balmer, M. (2015). Modelling the effect of different pricing schemes on free-floating carsharing travel demand: A test case for zurich, switzerland. *Transportation, 42*(3), 413-433. doi:10.1007/s11116-015-9608-z

For Peer Review Only

Colonna, P., Berloco, N., & Circella, G. (2012). The interaction between land use and transport planning: A methodological issue. *Siiv-5th International Congress - Sustainability of Road Infrastructures 2012, 53*, 84-95. doi:10.1016/j.sbspro.2012.09.862

Cuadrado, J. (2009). *Establishment of a general methodology for measuring sustainability in the life cycle of industrial buildings*

Cuadrado, J., Roji, E., Tomas San Jose, J., & Pedro Reyes, J. (2012). Sustainability index for industrial buildings. *Proceedings of the Institution of Civil Engineers-Structures and Buildings, 165*(5), 245-253. doi:10.1680/stbu.10.00029

Dasgupta, S., & Tam, E. K. L. (2005). Indicators and framework for assessing sustainable infrastructure. *Canadian Journal of Civil Engineering, 32*(1), 30-44. doi:10.1139/L04-101

del Caño, A., Gómez, D., & de la Cruz, M. P. (2012). Uncertainty analysis in the sustainable design of concrete structures: A probabilistic method. *Construction and Building Materials, 37*, 865-873. doi:http://dx.doi.org/10.1016/j.conbuildmat.2012.04.020

Dernbach, J. C. (2003). Achieving sustainable development: The centrality and multiple facets of integrated decisionmaking. *Indiana Journal of Global Legal Studies, 10*(1)

Egilmez, G., Gumus, S., & Kucukvar, M. (2015). Environmental sustainability benchmarking of the US and canada metropoles: An expert judgment-based multi-criteria decision making approach. *Cities, 42*, 31-41. doi:10.1016/j.cities.2014.08.006

European Comission. (2011). *White paper: Roadmap to a single european transport area - towards a competitive and resource efficient transport system. publication office of the european union, luxembourg.* Luxembourg: Publication Office of the European Union.

European Conference Of Ministers Of Transport. (2004). Assessment and decision making for sustainable transport.

European Environment Agency. (2013). *A closer look at urban transport- TERM 2013: Transport indicators tracking progress towards environmental targets in europe*. Copenhagen: EEA.

For Peer Review Only

Filippi, F., Nuzzolo, A., Comi, A., & Site, P. D. (2010). Ex-ante assessment of urban freight transport policies. *Procedia - Social and Behavioral Sciences, 2*(3), 6332-6342. doi:http://dx.doi.org/10.1016/j.sbspro.2010.04.042

Fischer, J. M., & Amekudzi, A. (2011). Quality of life, sustainable civil infrastructure, and sustainable development: Strategically expanding choice

 Journal of Urban Planning and Development, 137(1), 39-48.

Fishman, E., Washington, S., Haworth, N., & Watson, A. (2015). Factors influencing bike share membership: An analysis of melbourne and brisbane. *Transportation Research Part A-Policy and Practice, 71*, 17-30. doi:10.1016/j.tra.2014.10.021

Fitzgerald, B. G., O'Doherty, T., Moles, R., & O'Regan, B. (2012). A quantitative method for the evaluation of policies to enhance urban sustainability. *Ecological Indicators, 18*, 371-378. doi:10.1016/j.ecolind.2011.12.002

Graham-Rowe, E., Skippon, S., Gardner, B., & Abraham, C. (2011). Can we reduce car use and, if so, how? A review of available evidence. *Transportation Research Part A: Policy and Practice, 45*(5), 401-418. doi:http://dx.doi.org/10.1016/j.tra.2011.02.001

Haghshenas, H., & Vaziri, M. (2012). Urban sustainable transportation indicators for global comparison. *Ecological Indicators, 15*(1), 115-121. doi:http://dx.doi.org/10.1016/j.ecolind.2011.09.010

Hallowell, M. R., & Gambatese, J. A. (2010). Qualitative research: Application of the delphi method to CEM research. *Journal of Construction Engineering and Management, 136*(1), 99-107. doi:10.1061/(ASCE)CO.1943-7862.0000137

Joumard, R., & Gudmundsson, H. (2010). Indicators of environmental sustainability in transport. *NRETS. INRETS,* , 422.

KENWORTHY, J. R. (2006). The eco-city: Ten key transport and planning dimensions for sustainable city development. *ENVIRONMENT & URBANIZATION, 18*(1), 67-85.

For Peer Review Only

Krajnc, D., & Glavič, P. (2005). A model for integrated assessment of sustainable development. *Resources, Conservation and Recycling, 43*(2), 189-208. doi:http://dx.doi.org/10.1016/j.resconrec.2004.06.002

Lautso, K., Spiekermann, K., Wegener, M., Sheppard, I., Steadman, P. M.,Angelo, Domingo, R., . . . Gayda, S. (2004). *PROPOLIS: Planning and research of policies for land use and transport.* (PROPOLIS Final Report ed.). Helsinki: LT Consultants:

Lindholm, M. (2010). A sustainable perspective on urban freight transport: Factors affecting local authorities in the planning procedures. *Procedia - Social and Behavioral Sciences, 2*(3), 6205-6216. doi:http://dx.doi.org/10.1016/j.sbspro.2010.04.031

Lindholm, M. E., & Blinge, M. (2014). Assessing knowledge and awareness of the sustainable urban freight transport among swedish local authority policy planners. *Transport Policy, 32*, 124-131. doi:http://dx.doi.org/10.1016/j.tranpol.2014.01.004

Litman, T. (2008, Sustainable transportation indicators. *A Recommended Research Program for Developing Sustainable Transportation Indicators and Data,*

Malakooti, B. (2000). Ranking and screening multiple criteria alternatives
with partial information and use of ordinal and
Cardinal strength of preferences. *IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS PART A, 30*(3), 355-368.

Marsden, G., & Rye, T. (2010). The governance of transport and climate change. *Journal of Transport Geography, 18*(6), 669-678. doi:10.1016/j.jtrangeo.2009.09.014

Paez, A., Moniruzzaman, M., Bourbonnais, P., & Morency, C. (2013). Developing a web-based accessibility calculator prototype for the greater montreal area. *Transportation Research Part A-Policy and Practice, 58*, 103-115. doi:10.1016/j.tra.2013.10.020

Pons, O., & de la Fuente, A. (2013). Integrated sustainability assessment method applied to structural concrete columns. *Construction and Building Materials, 49*, 882-893. doi:http://dx.doi.org/10.1016/j.conbuildmat.2013.09.009

For Peer Review Only

Quaddus, M. A., & Siddique, M. A. B. (2001). Modelling sustainable development planning: A multicriteria decision conferencing approach. *Environment International, 27*(2–3), 89-95. doi:http://dx.doi.org/10.1016/S0160-4120(01)00066-6

Ruesch, M., Hegi, P., Haefeli, U., Matti, D., Schultz, B., & Rütsche, P. (2012). Sustainable goods supply and transport in conurbations: Freight strategies and guidelines. *Procedia - Social and Behavioral Sciences, 39*, 116-133. doi:http://dx.doi.org/10.1016/j.sbspro.2012.03.095

Saaty, T. L. (2004). Decision making - the analytic hierarchy and network processes (AHP/ANP). *Journal of Systems Science and Systems Engineering, 13*(1), 1-35. doi:10.1007/s11518-006-0151-5

San Jose, J. -., Garrucho, I., & Cuadrado, J. (2006). The first sustainable industrial building projects. *Proceedings of the Institution of Civil Engineers-Municipal Engineer, 159*(3), 147-153.

San-Jose, J. T., Ganucho, I., Losada, R., & Cuadrado, J. (2007). A proposal for environmental indicators towards industrial building sustainable assessment. *International Journal of Sustainable Development and World Ecology, 14*(2), 160-173.

Scipioni, A., Mazzi, A., Mason, M., & Manzardo, A. (2009). The dashboard of sustainability to measure the local urban sustainable development: The case study of padua municipality. *Ecological Indicators, 9*(2), 364-380. doi:http://dx.doi.org/10.1016/j.ecolind.2008.05.002

Seo, S., Aramaki, T., Hwang, Y., & Hanaki, K. (2004). Fuzzy decision-making tool for environmental sustainable buildings. *Journal of Construction Engineering and Management-Asce, 130*(3), 415-423. doi:10.1061/(ASCE)0733-9364(2004)130:3(415)

Shiau, T. (2012). Evaluating sustainable transport strategies with incomplete information for taipei city. *Transportation Research Part D: Transport and Environment, 17*(6), 427-432. doi:http://dx.doi.org/10.1016/j.trd.2012.05.002

Shiau, T., & Jhang, J. (2010). An integration model of DEA and RST for measuring transport sustainability. *International Journal of Sustainable Development and World Ecology, 17*(1), 76-83. doi:10.1080/13504500903495706

For Peer Review Only

Shiau, T., & Liu, J. (2013). Developing an indicator system for local governments to evaluate transport sustainability strategies. *Ecological Indicators, 34*, 361-371. doi:http://dx.doi.org/10.1016/j.ecolind.2013.06.001

Stanley, J. K., Hensher, D. A., & Loader, C. (2011). Road transport and climate change: Stepping off the greenhouse gas. *Transportation Research Part A: Policy and Practice, 45*(10), 1020-1030. doi:http://dx.doi.org/10.1016/j.tra.2009.04.005

Sudhakara Reddy, B., & Balachandra, P. (2012). Urban mobility: A comparative analysis of megacities of india. *Transport Policy, 21*, 152-164. doi:http://dx.doi.org/10.1016/j.tranpol.2012.02.002

Susilo, Y. O., Williams, K., Lindsay, M., & Dair, C. (2012). The influence of individuals' environmental attitudes and urban design features on their travel patterns in sustainable neighborhoods in the UK. *Transportation Research Part D: Transport and Environment, 17*(3), 190-200. doi:http://dx.doi.org/10.1016/j.trd.2011.11.007

Tam, V. W. Y., Tam, C. M., Zeng, S. X., & Chan, K. K. (2006). Environmental performance measurement indicators in construction. *Building and Environment, 41*(2), 164-173. doi:10.1016/j.buildenv.2005.01.009

Tanguay, G. A., Rajaonson, J., Lefebvre, J., & Lanoie, P. (2010). Measuring the sustainability of cities: An analysis of the use of local indicators. *Ecological Indicators, 10*(2), 407-418. doi:http://dx.doi.org/10.1016/j.ecolind.2009.07.013

Tirachini, A., Hensher, D. A., & Rose, J. M. (2014). Multimodal pricing and optimal design of urban public transport: The interplay between traffic congestion and bus crowding. *Transportation Research Part B: Methodological, 61*, 33-54. doi:http://dx.doi.org/10.1016/j.trb.2014.01.003

Turoff, M., & Linstone, H. (2002). **The delphi method: Techniques and applications**.

Wei, J., Xia, W., Guo, X., & Marinova, D. (2013). Urban transportation in chinese cities: An efficiency assessment. *Transportation Research Part D: Transport and Environment, 23*, 20-24. doi:http://dx.doi.org/10.1016/j.trd.2013.03.011

For Peer Review Only

Yedla, S., Shrestha, R. M., & Anandarajah, G. (2005). Environmentally sustainable urban transportation—comparative analysis of local emission mitigation strategies vis-à-vis GHG mitigation strategies. *Transport Policy, 12*(3), 245-254. doi:http://dx.doi.org/10.1016/j.tranpol.2005.02.003

Yigitcanlar, T., & Kamruzzaman, M. (2014). Investigating the interplay between transport, land use and the environment: A review of the literature. *International Journal of Environmental Science and Technology, 11*(8), 2121-2132. doi:10.1007/s13762-014-0691-z

Zietsman, J., Ramani, T., Potter, J., Reeder, V., & DeFlorio, J. (2011). *A guidebook for sustainability performance measurement for transportation agencies. NCHRP report 708.* Whashington: Transportation Research Board.

Zito, P., & Salvo, G. (2011). Toward an urban transport sustainability index: An european comparison.*3*(4) Retrieved from http://dx.doi.org/10.1007/s12544-011-0059-0

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FIGURE CAPTIONS

Fig. 1 Scheme of the different levels of the set of elements and their assessment procedure.
Fig. 2 Requirements tree for urban transportation
Fig. 3 Graphical representation of the general function
Fig. 4 Different forms of the value functions
Fig. 5 Scheme of the procedure to obtain the Sustainability Index
Fig. 6 Aerial view of San Sebastián (source: Google maps)
Fig. 7 Seventeen different sub-zones corresponding to the 17 boroughs of Donostia-San Sebastian (source: City council).
Fig.8 Summary of results for Donostia-San Sebastian

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Fig. 1 Scheme of the different levels of the set of elements and their assessment procedure.

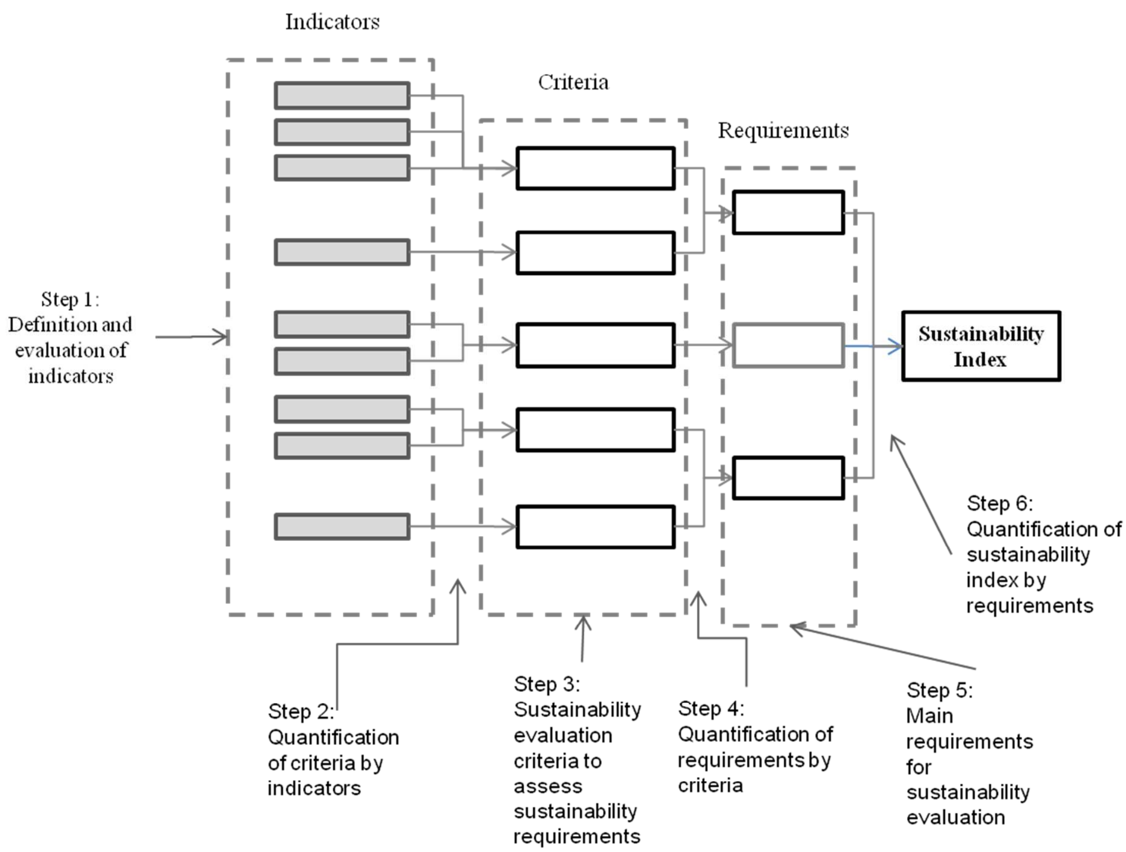

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Fig. 2 Requirements tree for urban transportation

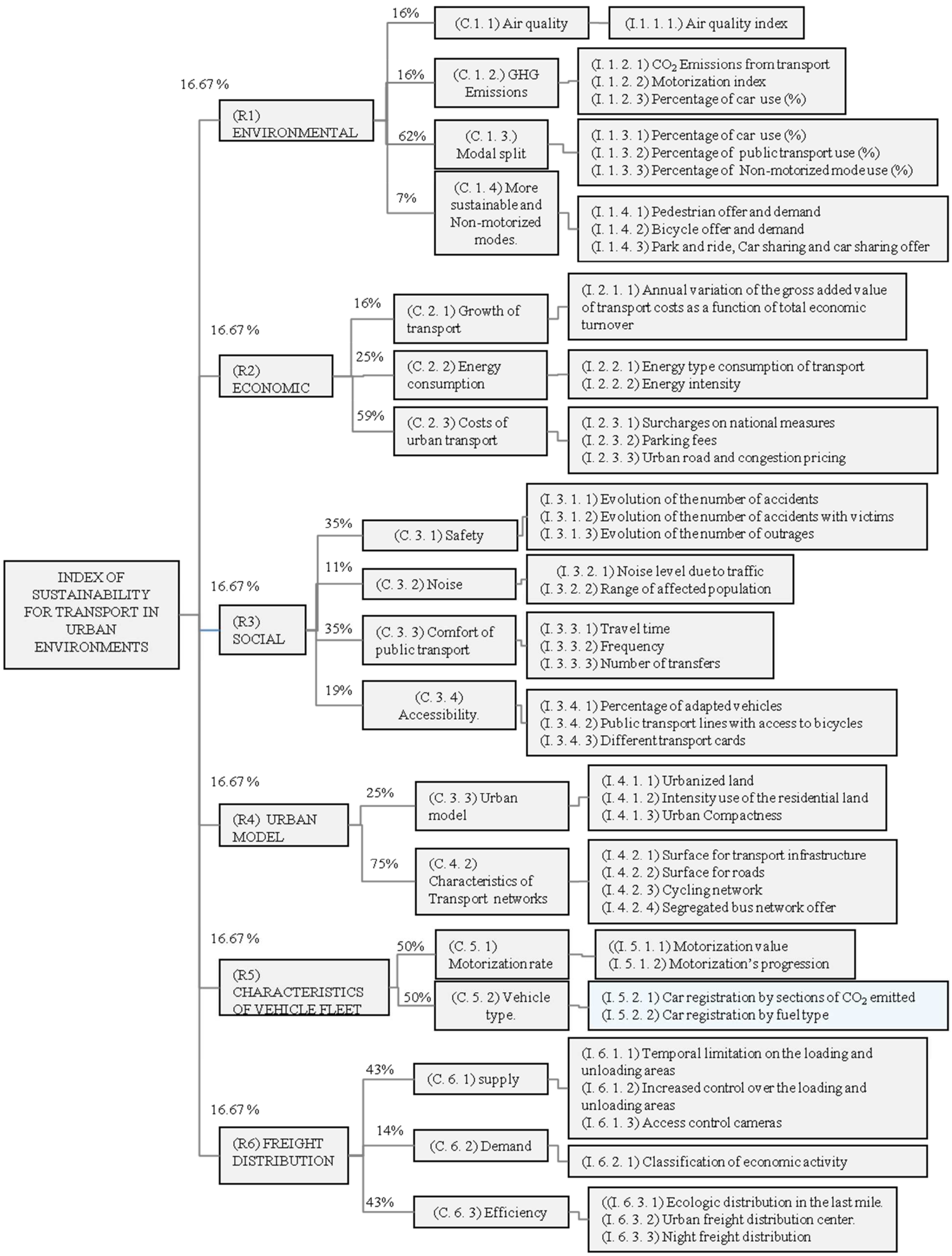

Fig. 3 Graphical representation of the general function

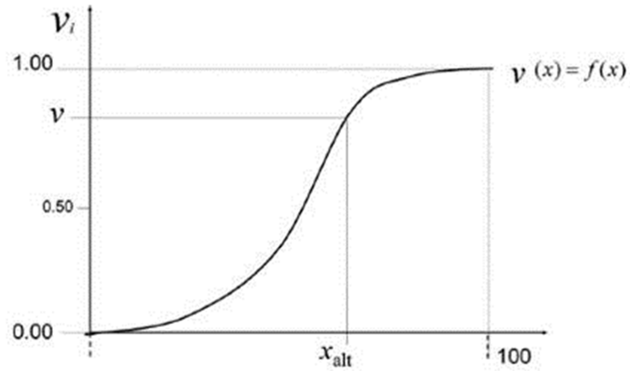

Fig. 4 Different forms of the value functions

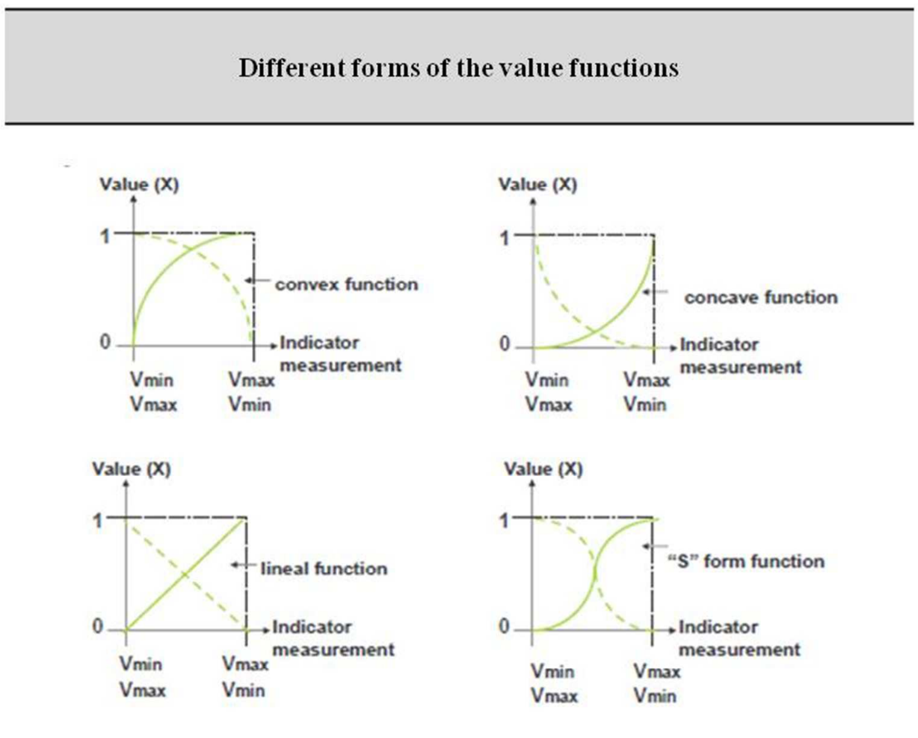

Fig. 5 Scheme of the procedure to obtain the Sustainability Index

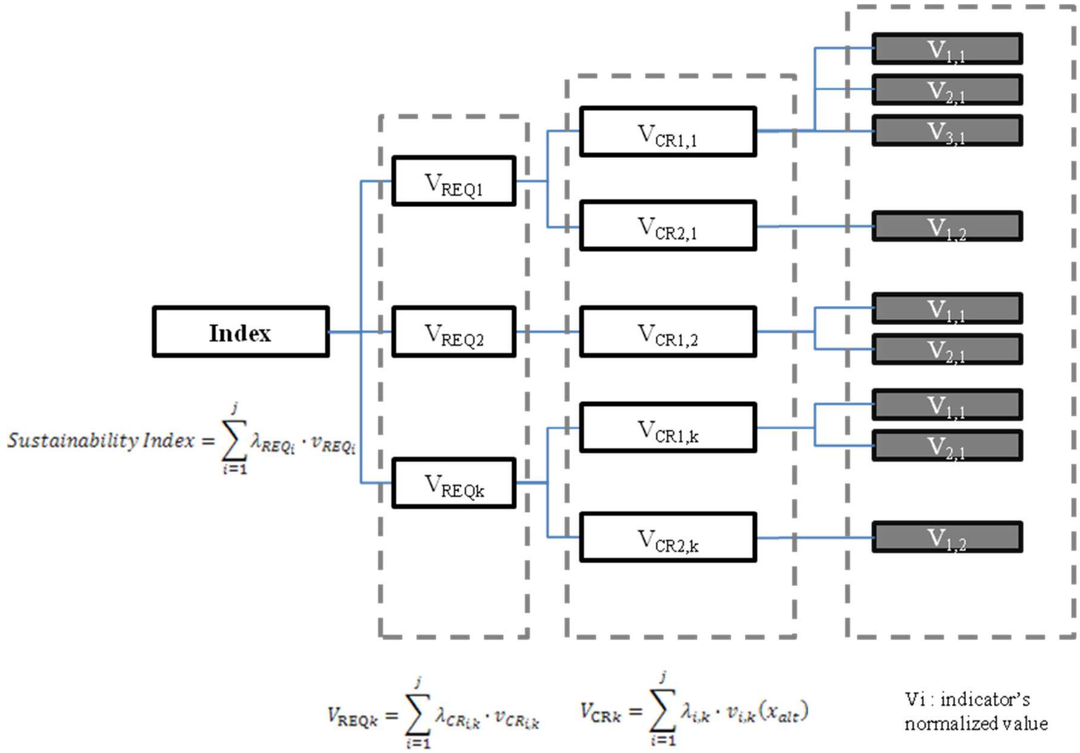

Fig. 6 Aerial view of San Sebastián (source: Google maps)

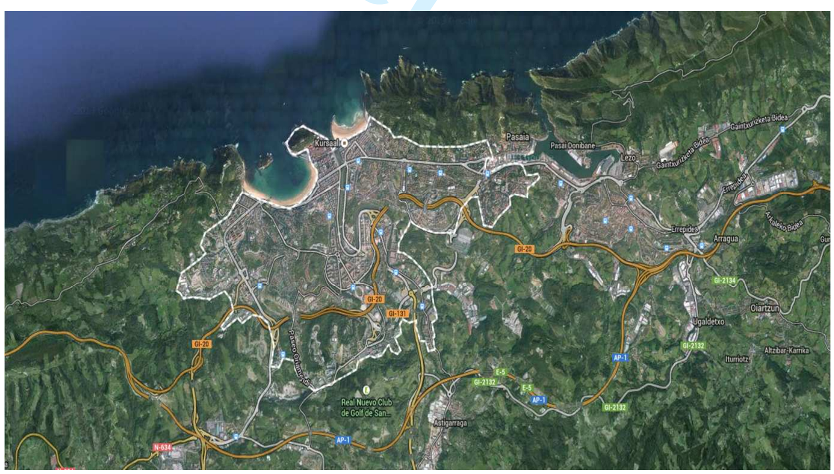

Fig. 7 Seventeen different sub-zones corresponding to the 17 boroughs of Donostia-San Sebastian (source: City council).

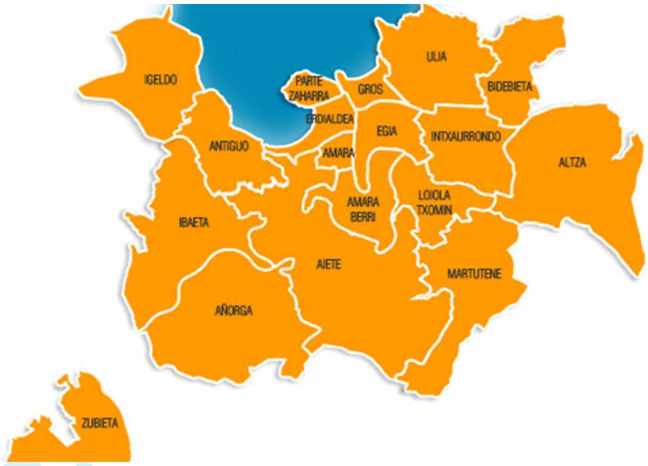

Fig.8 Summary of results for Donostia-San Sebastian

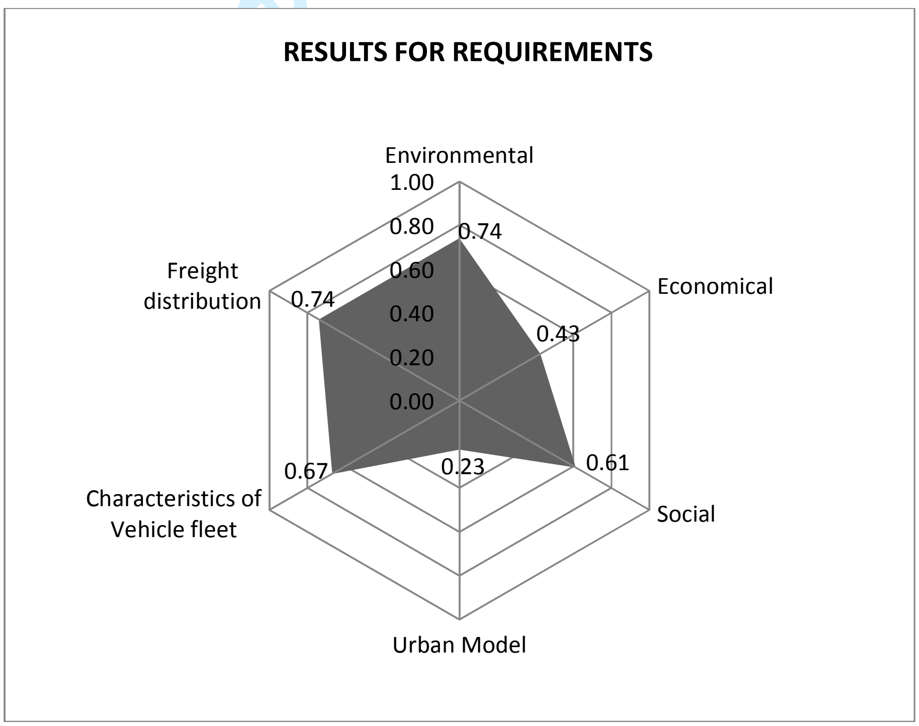

TABLE CAPTIONS

Table 1. Indicators for assessing environmental requirement.

Table 2. Indicators for assessing economic requirement.

Table 3. Indicators for assessing social requirement.

Table 4. Indicators for assessing urban model requirement.

Table 5. Indicators for assessing characteristics of the fleet of vehicles requirement.

Table 6. Indicators for assessing freight distribution requirement.

Table 7. Random index of a matrix of up to 15 elements.

Table 8. Variable values for different value functions.

Table 9. Number of motorized trips generated between corridors.

Table 10. Number of public transport trips generated between corridors.

Table 11. Number of non-motorized trips generated between corridors.

Table 12. Recommended night noise guidelines for Europe.

Table 13. Proposed ranks for night noise.

Table 14. Points system for noise levels.

Table 15. Points system for the percentage of the affected population.

Table 16. Noise levels for different districts.

Table 17. Population affected by noise levels higher than the recommended limits of the WHO in Donostia-San Sebastian.

Table 18. Evaluation results for noise criterion.

Table 19. Environmental Requirement.

Table 20. Economic Requirement.

Table 21. Social Requirement.

Table 22. Urban Model Requirement.

Table 23. Vehicle fleet characteristics Requirement.

Table 24. Freight distribution Requirement.

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Table 1. Indicators for assessing environmental requirement.

Indicator	Measurement
Air quality index	PM_{10}, SO_2, NO_2, CO and O_3 pollutant emissions.
CO_2 emissions	Evolution of the percentage of CO_2 emissions from transport (5 years).
Motorization	Vehicles /habitant (5 years).
Percentage of car use	Evolution of percentage of car use (5 years).
Percentage of car use	Percentage of car use (% value).
Percentage of public transport use	Percentage of public transport use (% value).
Percentage of Non-Motorized mode use	Percentage of Non-Motorized mode use (% value).
Pedestrian offer and demand	Existence of footpaths between subzones and their quality.
Bicycle offer and demand	Existence of segregated network, 30 areas, bicycle parking and public bicycle.
Park and ride, Car sharing and car pooling	Existence of park and ride, car sharing and car pooling.

Table 2. Indicators for assessing economic requirement.

Indicator	Measurement
Gross added value of transport	Comparison of Annual variation of Gross Added Value of transport and economy.
Energy type consumption	Percentage of fossil fuel derivatives.
Energy intensity	Energy consumption/ GDP
Surcharges on national measures	Existence or not in each urban subzone.
Parking fees	Existence or not in each urban subzone.
Urban road and congestion pricing	Existence or not in each urban subzone.

Table 3. Indicators for assessing social requirement.

Indicator	Measurement
Accidents	Evolution in 5 years period.
Accidents with victims	Evolution in 5 years period.
Outrages	Evolution in 5 years period.
Noise level	Noise level exposure of the population in each subzone of the urban area.
Population range affected by noise.	Percentage of the population affected by this noise level.
Travel time of PT	Comparison of travel time of PT and private car between subzones of the urban area.
Frequency of PT	Frequency of PT between subzones of the urban area.
Number of transfers PT	Number of transfers of PT between subzones of the urban area.
Adapted PT vehicles	Percentage of adapted PT vehicles
PT with access to bicycles	Percentage of PT to high areas with access to bicycles without time restrictions.
Transport cards	Existence of different transport cards.

Table 4. Indicators for assessing urban model requirement.

Indicator	Measurement
Urbanized land	Evolution of the percentage of urbanized land (5 years).
Intensity use of residential land	Habitants/Ha
Urban compactness	Dwellings/Ha
Surface for transport infrastructure	Evolution of the percentage of the surface for transport infrastructure.
Surface for roads	Evolution of the percentage of surface for roads
Cycling network	Evolution of km-s/10000habitants
Segregated bus network	Percentage of segregated network

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Table 5. Indicators for assessing characteristics of the fleet of vehicles requirement.

Indicator	Measurement
Motorization	Motorization value (vehicles/habitant)
Motorization progression	Evolution of the Veh*km (5 years)
Car registration by section	Evolution of car registration by sections of pollutants emitted (5 years)
Car registration by fuel type	Evolution of car registration by fuel type (5 years)

Table 6. Indicators for assessing freight distribution requirement.

Indicator	Measurement
Temporal limitation on loading and unloading areas	Existence of temporal limitation on loading and unloading zones.
Control on loading and unloading areas	Existence of control on loading and unloading zones.
Access control	Existence of access control cameras.
Activities	
Last mile distribution	Existence of ecologic distribution in the last mile.
Urban freight distribution centre	Existence of urban freight distribution centre to optimize distribution.
Night freight distribution	Existence of night freight distribution

Table 7. Random index of a matrix of up to 15 elements.

Size of the matrix (n)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Table 8. Variable values for different value functions.

Form	P_i	K_i
Concave	< 0.75	< 0.9
Convex	> 2	> 0.1
Linear	1	= 0
“S” curve	$2 < P_i < 10$	$0.1 < K_i < 0.2$

Table 9. Number of motorized trips generated between corridors**.**

CAR/Taxi/Motorbike						
	CENTER	EAST	WEST	SOUTH	REST	TOTAL
CENTER	692	830	627	1121	585	3855
EAST	5702	13853	7480	5595	4787	37417
WEST	2159	2715	2624	1605	2379	11482
SOUTH	2245	4856	2889	3717	2849	16556
REST	3799	2378	2823	2588	2689	14277
TOTAL	14597	24632	16443	14626	13289	83587

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Table 10. Number of public transport trips generated between corridors.

Public Transport						
	CENTER	EAST	WEST	SOUTH	REST	TOTAL
CENTER	229	750	856	387	267	2489
EAST	6409	4697	2390	3346	1983	18825
WEST	1807	395	650	582	199	3632
SOUTH	3548	1335	1080	1251	893	8107
REST	2821	539	690	675	343	5070
TOTAL	14814	7717	5667	6241	3686	38124

Table 11. Number of non-motorized trips generated between corridors.

Walking and bicycle						
	CENTER	EAST	WEST	SOUTH	REST	TOTAL
CENTER	11731	1437	1543	2161	1173	18044
EAST	9328	37805	3054	2395	348	52928
WEST	1601	778	7242	422	1351	11394
SOUTH	6663	2096	1668	14508	1688	26624
REST	1851	713	5419	362	2998	11344
TOTAL	31174	42828	18926	19848	7558	120334

Table 12. Recommended night noise guidelines for Europe.

Night noise guideline (NNG)	Interim target (IT)
$L_{night,outside}$ = 40 dB	$L_{night,outside}$= 55 dB

Table 13. Proposed ranks for night noise.

Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6
<40 dB	≥40-45(dB)	>45-50(dB)	>50-55(dB)	>55-60(dB)	> 60 dB

Table 14. Points system for noise levels.

Identification of maximum rank	Points
Number of sub-zones with maximum noise levels within Rank 6	1 point for each sub-zone
Number of sub-zones with maximum noise levels within Rank 5	0.8 point for each sub-zone
Number of sub-zones with maximum noise levels within Rank 4	0.6 point for each sub-zone
Number of sub-zones with maximum noise levels within Rank 3	0.4 point for each sub-zone
Number of sub-zones with maximum noise levels within Rank 2	0.2 point for each sub-zone
Number of sub-zones with maximum noise levels within Rank 1	0 point for each sub-zone

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Table 15. Points system for the percentage of the affected population.

Intervals of affected population	Points
0 - 10 %	0
10 – 15 %	0.5
15 – 20 %	1
20 – 25%	1.5
25 -30 %	2
30 – 40 %	3
40 – 50 %	4
50 – 60 %	5
≥ 60%	6

Table 16. Noise levels for different districts**.**

Sub-Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Maximun Rank	5	2	5	4	6	3	5	6	4	4	5	5	5	4	6	4	5
Ponts	0.8	0.2	0.8	0.6	1	0.4	0.8	1	0.6	0.6	0.8	0.8	0.8	0.6	1	0.6	0.8
TOTAL POINTS	**12.2**																
NORMALIZED VALUE	**0.28**																

Table 17. Population affected by noise levels higher than the recommended limits of the WHO in Donostia-San Sebastian.

Percentage of affected population	Points
27.6	**2**
NORMALIZED VALUE	
0.67	

Table 18. Evaluation results for noise criterion.

Indicators	Normalized values	**Weight (λ_i)**
I.3.2.1. Noise level due to traffic	0.28	0.30
I.3.2.2. Percentage of affected population	0.67	0.70
Criterion	Value	Weight (λi.k)
C.3.2. Noise	0.553	0.11

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Table 19. Environmental Requirement.

Criterion of the Environmental requirement	Value	Weight	Results
Air quality	0.94	16%	0.15
GHG emissions	0.60	16%	0.09
Modal splits	0.76	61%	0.47
More sustainable and NON-motorized modes	0.40	7%	0.03
Environmental Requirement			**0.74**

Table 20. Economic Requirement.

Criterion of the Economic requirement	Value	Weight	Results
Growth of transport	0.17	16%	0.03
Energy consumption	0.67	25%	0.17
Costs of urban transport	0.39	59%	0.23
Economic Requirement			**0.43**

Table 21. Social Requirement.

Criterion of the Social requirement	Value	Weight	Results
Safety	0.58	35%	0.20
Noise	0.55	11%	0.06
Comfort of Public transport	0.51	35%	0.18
Accessibility	0.9	19%	0.17
Social Requirement			**0.61**

Table 22. Urban Model Requirement.

Criterion of the Urban Model requirement	Value	Weight	Results
Urban model	0.15	25%	0.04
Characteristics of transport network	0.25	75%	0.19
Urban Model Requirement			**0.23**

Table 23. Vehicle fleet characteristics Requirement.

Criterion of the Vehicle Fleet Characteristics requirement	Value	Weight	Results
Motorization rate	0.63	50%	0.32
Vehicle type	0.71	50%	0.36
Characteristics of the Vehicle Fleet Requirement			**0.67**

Table 24. Freight distribution Requirement.

Criterion of the Freight distribution requirement	Value	Weight	Results
Supply	1	43%	0.43
Demand	0.17	14%	0.02
Efficiency	0.67	43%	0.29
Freight distribution Requirement			**0.74**

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