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Dirección de Investigación e Innovación

21/11/2017

Geolocation of electric bikes recharging stations: city of Quito study case

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Abstract: The aim of this research was to develop a geographical information system with multi-criteria decision making methods for selecting the most feasible location to install electric bikes charging stations in the city of Quito. For such purpose, the ideal solution-similarity preference ranking and weighted overlay techniques have been used as multi-criteria decision making methods. In addition, the analytic hierarchy process method was performed for calculating the weights of each criterion. Moreover, a standardization process that consists on establishing an overall performance index to evaluate the results was applied. Finally, the Pearson correlation coefficient was used to analyze mutual correspondence between multi-criteria decision making methods.

The resulting Pearson correlation coefficients indicate that the two selected multi-criteria decision making methods provided similar results. In this context, the methods analyzed covered similar solutions and indicated that multi-criteria decision making methods are a powerful tool to select ideal locations for electric bikes recharging stations.

Keywords: Optimal location, e-bikes, geographic information systems (GIS), multi-criteria decision making (MCDM) methods.

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1 Introduction

Sustainable transportation should be built by considering constrains related with socio-economic, demographic and environmental megatrends, i.e. major shifts in economic, social and environmental conditions that can impact people and transform societies (Schneider, 2013; Haghshenas et al., 2015). The significant changes in global population size, age structure, household size and urbanization expected in the twenty-first century may have substantial implications for inland transport in terms of transport patterns, energy use and Green House Gas (GHG) emissions (Schneider, 2013). The trend aims to seek the replacement of fossil fuels with cleaner fuels. However, it should be recognized that electric powered vehicles are silent and produce far less pollution than traditional fuel-powered vehicles (Haghshenas et al., 2015)

Due to this reason, many countries have begun to introduce electricity-powered vehicles in their public transport services, with the purpose of reducing the effects of gaseous emissions from fossil fuel-powered vehicles (Schneider, 2013). One of the transportation alternatives that offers a significant reduction of air pollution is the bike thanks to its ability to reduce the number of motor vehicles. The bicycle has been recognized as an ideal manner to democratize urban spaces, as well as a type of transportation suitable for reducing environmental pollution, improve the health of stakeholders and the life quality of population in general terms (Quito, 2014) The organization system of a public bicycles network (stations, bicycles, and infrastructure) is a primary element for boosting any strategy to promote cycling as a means of transport to urban and tourist scale.

In the case of electric cycling, it can be mentioned that this alternative has emerged as a new, sustainable form of active transportation. While e-bikes are alike traditional bicycles (hereafter referred to as regular bicycles) in terms of function, they offer differences in terms of performance due to the addition of an electric motor which provides some level of assistance to the user during travelling (Langford et al. 2015). In recent years, the distribution of electric bicycles (e-bikes) has increased continuously. Regarding the China case, the number of e-bikes has risen substantially (Johnson & Rose, 2015; Piatkowski, 2015). A similar trend can be observed in the US and in Europe (Johnson & Rose, 2015). In Germany, for instance, about 1.6 million electric bicycles are currently on the road and it is expected that this number increases even further (Johnson & Rose, 2015). Moreover, this technology gains relevance in large cities as Kunming and Shanghai, or cities with significant terrain slopes (Ruan et al. 2014). Achieving sustainable transportation with e-bikes implies reducing the environmental impacts at the point of use. For this issue, it is necessary to control how electricity is generated and stored (Haghshenas et al., 2015) with the purpose of avoiding that GHG emissions only change generation location instead of being actually reduced. In such sense, it is especially necessary that electricity does not come from fossil sources and the use of batteries reduces the environmental impacts as much as possible. In the case of Ecuador, it government is improving access to electricity in the country by replacing its fossil fuels with renewable energies in its energy mix, among other political actions (Kastillo et al. 2017; Martínez-Gómez et al. 2016; Villacís et. al. 2015). However, there is no local initiative associated with expired batteries (Martínez 2017; Martínez Gómez, 2017).

Other important topic related with sustainable transportation is the quality of the pedestrian environment since it is a key part of the life quality of the community and its social cohesion. For this matter, it is important to encourage the use of transportation methods as bicycles as real alternatives, moreover it is suggested to boost the lanes exclusivity and look for connectivity between strategic logistic points, and provide integrated public transport systems with the use of the bicycle (Quito, 2014).

This research planned to identify suitable locations for placing e-bike stations that provide shuttle service for pedestrians. For this purpose, geo-referenced maps using GIS have been generated for identifying the location in order to improve the sustainable transportation in Quito. In this sense, several criteria have been considered such as distance to high traffic density roads, distance to road network, or rods with steep access roads and pedestrian and cycling access difficult. In addition, the proposal research takes into account sustainable mobility based on the use of electrical bicycles located in the lower parts of tourist, commercial or social interest in the DMQ. Moreover, the proposal considers to provide greater accessibility to users who do not own is generated private vehicle, since the bike is ideal for short-distance trips (up to 5 km) and such distance cold be increased by adding an electric motor. In the case of Quito, including an electric motor could also encourage stakeholders who may find difficulties due to the significant average slope along the city. (Quito, 2014).

1.1. Application of multi-criteria decision making methods (MCDM) in selection locations

The location of charging stations can be dealt by adopting a multi-criteria decision making (MCDM) model because of its ability to provide adequate solutions. The evaluation of MCDM methods compares different criteria according to their characteristic properties, with the purpose of selecting the best location alternatives. The considered criteria distance to road transport network, distance to distribution substations and transmission lines, distance to areas with tourist attractions, slope, among others. are the variables to be analyzed with the MCDM models (Pohekar & Ramachandran, 2004, Villacreses et al. 2017).

One of the most popular MCDM is the Analytic Hierarchy Process—AHP (Saaty, 1990), its main feature is that the decision problem is modeled using a hierarchy whose apex is the main objective of the problem and the possible alternatives to be evaluated are located at the base. In this paper, the AHP methodology will be used to determine the weight of the criteria or factors in our decision problem.

Another method commonly used is the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) Hwang and Yoon (1981). TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS). Finally, the Weighted Overlay tool applies one of the most used approaches for overlay analysis to solve multicriteria problems such as site selection and suitability models (Sadr et al. 2014). TOPSIS and Weighted Overlay will be used to assess the geolocation of electric bikes recharging stations.

The application o MCDM has been conducted in many applications and disciplines, Recently, Yunna and Geng (2014) developed a model based on the MCDM using AHP method associated with benefits, opportunities, costs and risks (BOCR), for performing a strategic location of wind farms in China. A new fuzzy, multi-mode, resource-constrained project scheduling mode was developed by Sajadi et al. 2017. Ramik, (2015). It was applied to an incomplete preference matrix on Alo-Group by multiple criteria decision making. Shahsavari-Pour et al. (2017) developed a new method for fuzzy numbers ranking on the basis of hypotenuse set. In addition, Patra, & Mondal,. (2017) used a fuzzy cognitive map for Risk analysis in a production system using.

The literature review indicates that MCDM methods can be used for defining the location of charging stations. For this issue, it is important to consider the use of the Geographical Information Systems (GIS) tool that is explained in Section 1.2.

1.2. Geographic information systems (GIS)

GIS has turned into a research tool and application since the 1970s, which involves several academic fields including, for instance, wind power applications. GIS are designed to store, retrieve, manipulate, analyze and map geographical data (Sánchez-Lozano et al. 2013). There are two types of coverage representations that GIS can handle, being raster and vector. The raster is represented by a rectangular grid called pixels, which are sized and contain specific information according to a specific geographic location. Vectors maintain a geometric figure (points, lines and polygons), which define limits that are associated with a reference system (Sánchez-Lozano et al. 2013). This information is stored and presented in a geodatabase which provides an order, structure and standardization of the data (Villacreses et al. 2017). All the geographic information was processed as rasters in this research since the continuous analysis of the spatial variables (distance to road transport network, distance to distribution substations and transmission lines among others) Implies handling elements that can be better understood if presented in such manner. GIS is a powerful tool in gathering and organizing spatial data, as a lot of successful examples to identify potential locations for generating renewable energy emerge (Church, 2002).

The raster processes are faster in the evaluation of problems, including mathematical combinations such as the MCDM methods. The MCDM in a GIS environment is based on factors represented by a layer of georeferenced cartographic information; therefore, every point in the terrain received a value regarding the object activity of the decision (Panagiotidou, 2016). The ArcGIS software was used to rasterize and standardize data layers under linear and logistic functions in this research. With this starting point and the inputs generated, the multi-criteria analysis and the comparison of results were conducted using R, which is a programming language specialized in calculus and statistics.

Several studies relating GIS-MCDM have been conducted about new energy resources such as: Sanchez-Lozano et al. (2013) evaluated solar farm locations in south-eastern Spain based on GIS and MCDM methods, as well as AHP and TOPSIS. GIS with an AHP-OWA aggregation function to derive a wind farm land suitability index to research wind farm location in Oman has been developed by Al-Yahyai et al., (2012) and Aydin et al., (2010) applied GIS-based on the OWA method for wind farm locations in the west of Turkey.

Taking into account the literature review of GIS-MCDM methods and their ability to solve optimal locations in cities or countries. This research aimed to analyze the most feasible location for electric bikes recharging stations on GIS-MCDM. The place of study was the city of Quito, where no previous research has emerged yet. The MCDM methods applied to this research were the AHP method that was implemented for calculating the weights, TOPSIS and weighted overlay. An overall performance index (OPI) has been applied to evaluate the results. Finally, the mutual correspondence between MCDM methods has been evaluated by a Pearson correlation coefficient.

The current research is structured as following: The methodology for the MCDM methods is described in section 2. GIS–MCDM methodology to prioritize locations for electric bikes recharging stations is exposed in section 3. The results are presented in section 4. The conclusions of the research are exposed in section 5.

2. Materials and methods

The materials and methods of this research include the Multi-criteria decision making (MCDM) methods. The MCDM methods explained include the AHP method for calculating the weights, in addition TOPSIS and weighted overlay will have developed to calculate the results of the article. GIS–MCDM methodology to prioritize locations for electric bikes recharging stations are also included in the materials and methods section. The following MCDM methods are explained.

2.1. Multi-criteria decision making (MCDM) methods

MCDM methods are analytical tools employed to judge the best alternative of a set of possibilities and they are easy to adapt to different requirements. Priority based, outranking, preferential ranking and distance based and mixed methods, are some of the popular MCDM methods commonly used to select a location with GIS (Pohekar & Ramachandran, 2004). Shown below the MCDM methods developed in this analysis are exposed.

2.1.1 The Analytic hierarchy process (AHP) method

The AHP is a structured technique to help people to deal with complex decisions. It was developed by Thomas L. Saaty in the (1990) has been considerably enhanced since then. The AHP provides an analytical framework to structure, represent and quantify the problem to evaluate alternative solutions. The AHP method has been widely applied in solving a variety of problems or calculate the weight of the factors, including applications related to GIS (Villacreses et al. 2017). The AHP method steps used in this research, can be observed in figure 1. A great amount of information about the AHP method could be found in literature (Saaty, 1990).

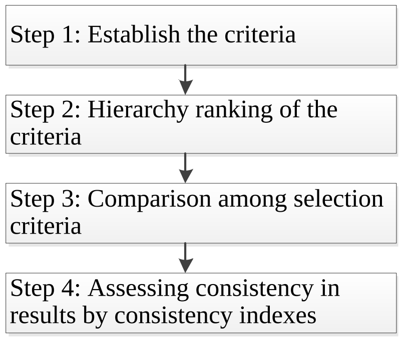

Figure 1. AHP method algorithm

2.1.2. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method

The TOPSIS method is a multiple criteria method to identify solutions from a finite set of alternatives, developed by Hwang and Yoon (1981). The basic principle of the TOPSIS method is to choose the alternative of the shortest and longest distance from the positive and negative ideal solutions, respectively. An ideal solution is defined as a collection of scores or values with the shortest geometric distance for all criterions considered. The TOPSIS method diagram is presented in figure 2. More information about the TOPSIS method could be found in literature as in the research of Hwang and Yoon (1981; and Villacreses et al. (2017)

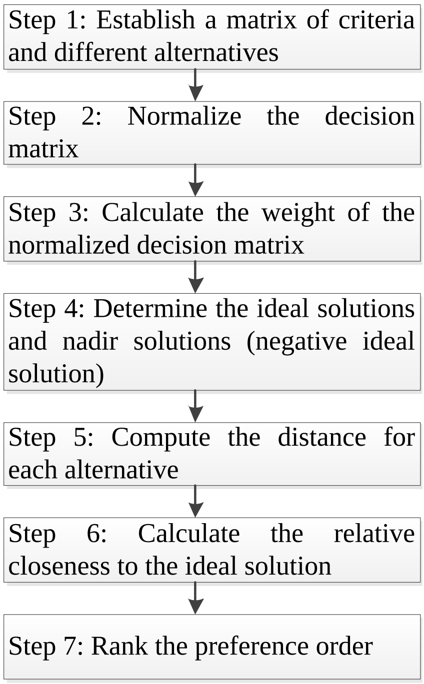

Figure 2. TOPSIS method algorithm.

2.1.3. Weighted overlay

The weighted overlay was used for suitability modeling (to locate suitable areas), higher values generally indicate that a location is more suitable. It reclassifies values in the input raster into a common evaluation scale of suitability or preference, risk, or some similarly unifying scale. In addition, the weighted overlay multiplies the cell values of each input raster by the raster weight of importance and it adds the resulting cell values together to produce the output raster. For this study, the scale ranges were from 1 to 100 for each raster. Input coverages are the criteria considered for the analysis. In the literature could be found more information of this method as in the study of Sadr et al. (2014)

2.1.4. Correlation between MCDM methods

Several techniques allow us to compare qualitatively and quantitatively raster maps, recognizing visual or numerical similarities on the analyzed datasets at the current time (Yager, 1993). Numerical comparisons use procedures based on statistical and mathematical modeling to find relationships between large datasets (Siehoff et al. 2011).

As in other studies that are based on GIS techniques, in this research a pairwise comparison of maps using the Pearson correlation is analyzed (He et al. 2012). The comparison has been performed using the raster map values for processing each pixel at each method described in MCDM methods.

In this research, the raster map solution of the MCDM methods was compared with the Pearson correlation expressed in Equation (1).

$$\rho_{xy} = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{\sqrt{n\sum x_i^2 - (\sum x_i)^2}\sqrt{n\sum y_i^2 - (\sum y_i)^2}} \Leftrightarrow \begin{cases} x_i y_i \geq 0 & All\ pixels \\ x_i y_i > 70 & \mathrm{Re}striction \end{cases} \quad (1)$$

Where, x_i and y_i are the values of the raster maps to be compared, ρ_{xy} is the Pearson correlation coefficient and n is the number of values analyzed.

2.2. GIS–MCDM methodology to prioritize locations for electric bikes recharging stations.

Combining GIS with MCDM allows us to evaluate the criteria with its factors through the use of attributes within a certain range of decision rules and assessment (Sánchez-Lozano et al. 2013; Villacreses et al. 2017). For this assignment, a methodology based on the spatial analysis for the multi-criteria evaluation was used (figure 3). The research was performed in two stages; the first one is the definition of factors and restrictions in the investigated area. Consequently, the information is prepared by a rasterization and a standardization process. The second stage consisted in an evaluation of the most suitable site through MCDM methods. The AHP method was used to quantify the importance of the different factors used during the process. Hence, TOPSIS and weighted overlay were used to evaluate the different alternatives.

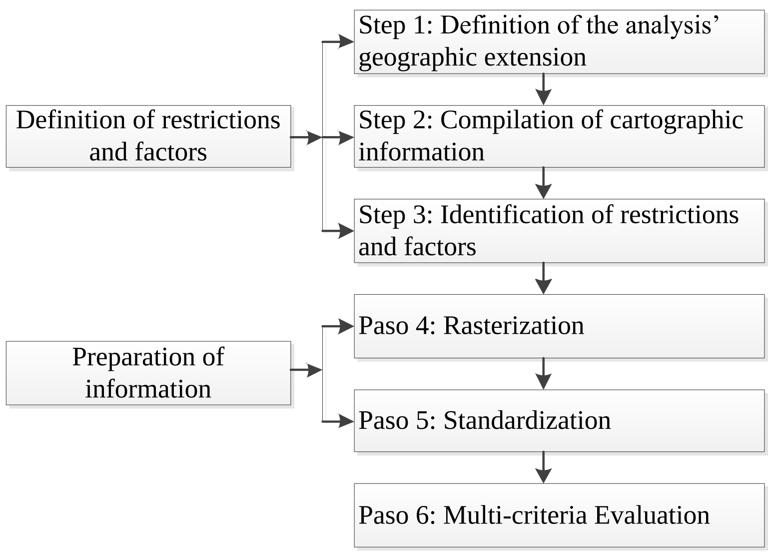

Figure 3: Steps to develop the MCDM methods

2.2.1. Definition of restrictions and factors

The definition of factors and restrictions include the definition of the analyzed geographic extension which in this study is Quito (Ecuador); It is following by the compilation of cartographic information and identification of factors and restrictions by raster; then, the definition of criteria and factors; Finally the preparation of the information to The following point to explain is the definition of the analyzed geographic extension are explained.

a). Definition of the analyzed geographic extension

The capital of Ecuador, Quito, has been selected for the implementation of electric bikes recharging stations in this research. Quito hosts more than two million of habitants in 18869 hectares. The urban area of Quito is divided into 34 parishes and 5 administrative areas as shown in figure 4. The modeling for the city of Quito was operated with a spatial resolution of 5m x 5m and the integration of a digital map that uses geoprocessing resources. All the information considered in this research was presented in the raster format, with the same resolution and extension as the City of Quito (Quito, 2014).

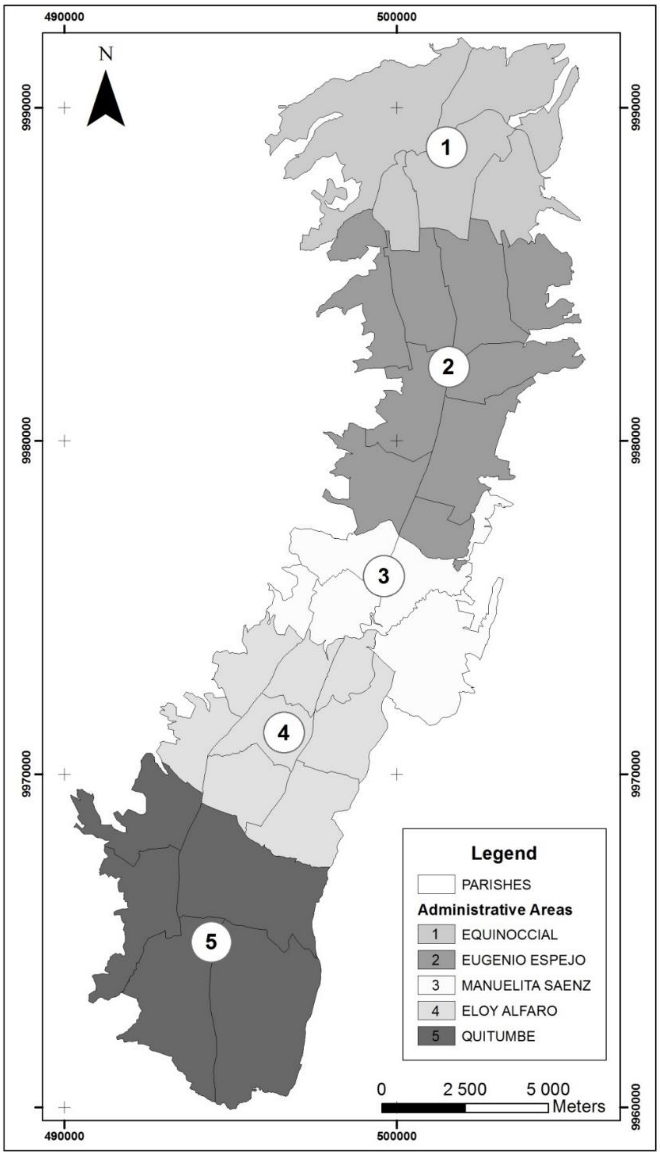

Figure 4: Quito separated by different districts zones

b). Compilation of cartographic information and identification of factors and restrictions

The raster and vector cartographic information was determined with help from the City of Quito, as it is presented in table 1. The selection of variables includes components necessary for a sustainable mobility, which seeks to improve the life quality of residents and respond to an efficient territorial structure. The components comprehend the (motorized and non-motorized) people and goods transport traffic based on territorial planning from City of Quito, road infrastructure, management and regulatory framework from the system of mobility in the form City of Quito. Therefore, the criteria corresponding to the articulation of these components are presented in table 1. This information is in vector format and its treatment is performed using GIS.

Table 1: Priority factors and restrictions

Criteria	Institution	Year
Digital elevation model	City of Quito – Secretary of transport	2013
Road network	City of Quito – Secretary of transport	2013
Bus Rapid Transits (BRT) stops	City of Quito – Secretary of transport	2013
Green areas with tourist attractions	City of Quito – Secretary of EPMMOP	2013
Bikeways	City of Quito – Secretary of transport	2013
High traffic density roads	City of Quito – Secretary of EPMMOP	2013
Electrical network of Quito	ARCONEL-Ministry of Electricity and Renewable Energy	2015

c). Definition of criteria and factors

The criteria were considered as factors within the multi-criteria evaluation and was not available any restriction for that process. Furthermore, efforts need to be extended to identify those criteria that influence a given application to eliminate unsuitable alternatives and select the most appropriate choice using simple and logical method as in the articles of Sanchez-Lozano et al. 2013 and Villacreses et al. (2017). In this case, factors undergo a weighting analysis which influence positively or negatively on the decision for discrimination of locations. The factors used in the analysis are presented as following:

- <u>Digital elevation model</u>: This variable is derived from the digital elevation model from the City of Quito, according to the technical characteristics of electric bicycles for the bikeways of Quito. The bikeways could exceed 10% slope, with regarding the horizontal plane, due to the topography of Quito. Therefore, the locations must be in the high areas of the city, because the BRT do not access to these places. The grid was rescaled from 0 to 100 for more % slopes until 15 %.
- <u>Road network</u>: Mobility management involved displacement based on the value and cost of each trip. It gave priority to travel modes higher value and lower cost occupant (in terms of street space, parking costs, risks of accidents and pollution emissions). For example, public transportation, mobilization cycling and walking, which usually cost society less per trip than car travel with a person. The bikeways could be included in the road network. For this reason, the grid was rescaled from 0 to 100 where 100 was the minimum distance to arterial roads
- <u>Bus rapid transits (BRT) stops</u>: The city of Quito has 5 BRT lines, which

connect 30 Km from Quitumbe at the south of Quito to Carcelen at the north. The BRT stops were located every 500 m. BRT systems should be promoted, because is one of the most valuable conveyance in Quito. For that purpose, the grid was rescaled from 0 to 100 where 100 was the minimum distance to BRT stops.

- Green areas with tourist attractions: Some green and tourist areas are located in the high areas of the city and the privileged view you get from the city. The system of mobility from City of Quito considered to promote these specific areas with the use of the electric bicycle.
- Bikeways: The current network of cycle paths has a total of 64.84 km, of which about 22% are urban utility bike paths and 14% of mixed cycle paths, which can be used for everyday urban transit, including recreational and connections. The cycle route with a distance of 30 km, could integrated from south to north Quito every Sunday, by the so-called "Ciclopaseo" (Mobility Master Plan).
- High traffic density roads: These pathways are the largest displacement of motorized trips recorded in the city. They were of interest in the analysis since the electric bike could circulate in these pathways and help the population to move faster.
- Electrical network of Quito: The existing electrical grid covers the entire study area, which means that all sites and population is served by this service. Therefore, in the multi-criteria analysis this variable gets the score of 100 points on the scale of assessment to be used. What causes this variable is not considered in the analysis within GIS, because it becomes a binary coverage that takes a value of 1 and does not interfere in the analysis.

d). Preparation of information

The analyzed data employed in this study was available as vector structures (point, lines or polygons), or as a matrix structure, called raster. To convert vector coverage to a raster format requires an acquainted extension grid. The precision of the extension grid is defined by the cells size. In this case, the pixel size was 5m x 5m, and the extension grid covered the city of Quito. The MCDM requires a raster where each pixel contains a numeric attribute according to the represented variable. Therefore, rasterization is considered a previous assignment in order to continue with the MCDM methods.

In the rasterization process, the type of variable to be transformed is considered, because each one has different behaviors. On the one hand, a raster model derived from original information is considered as a factor model. Moreover, vector structures are simply transformed to raster like structures when dealing with a restriction. Rasterization processes of applied values in different coverages are summarized in table 2.

Table 2: Rasterization processes applied to each layer of information

Coverage	Rasterization	geoprocessing	Mathematical transformation
Digital elevation model	calculation of slopes		logistic growth function
Road network	vector to raster	Euclidean distance	logistic growth function
BRT stops	vector to raster	Euclidean	logistic growth function

		distance	
Green areas with tourist attractions	vector to raster	Euclidean distance	logistic growth function
Bikeways	vector to raster	Euclidean distance	logistic growth function
High traffic density roads	vector to raster	Euclidean distance	logistic growth function
Electrical network of Quito	vector to raster	Binary raster	-

After the rasterization method of the geoprocessing variables, it is necessary to consider factors such as digital elevation model, distance to BRT stops, etc., which do not have a linear behavior in the standardization process for the site selection. The optimal values of these factors must be prioritized in each case, so most of the times a linear function should not be used.

The standardization process consists on a rescale of raster values that starts using a mathematical function (line or curve), specified according to predefined standardization criteria. The resulting scale is a range of continuous whole values between 1 and 100, where the minor value is the less important and the highest value is the most representative. In this assignment logistic or linear functions were used according to the variable, as illustrated in table 2.

The data was rescaled to the values from 1 to 100 where higher score is given to sites that meet all the criteria. It has been considered different variables as selection criteria and which areas should be on steep slopes, have a road access network, to be as close to stops BRT, if possible, be green areas, be as close to the bikeways existing to have an interconnection with them and be as close to roads with high traffic density in order for the community to use this system.

The resulting coverage of the standardization process mentioned in table 2 is illustrated in figure 5. All factors that were considered as factors present values between 1 and 100 for this calculation. However, the electrical network of Quito was considered as restrictions were added in just one binary layer map that represents values of 0 (Restricted) and 1 (Unrestricted), as illustrated in figure 6.

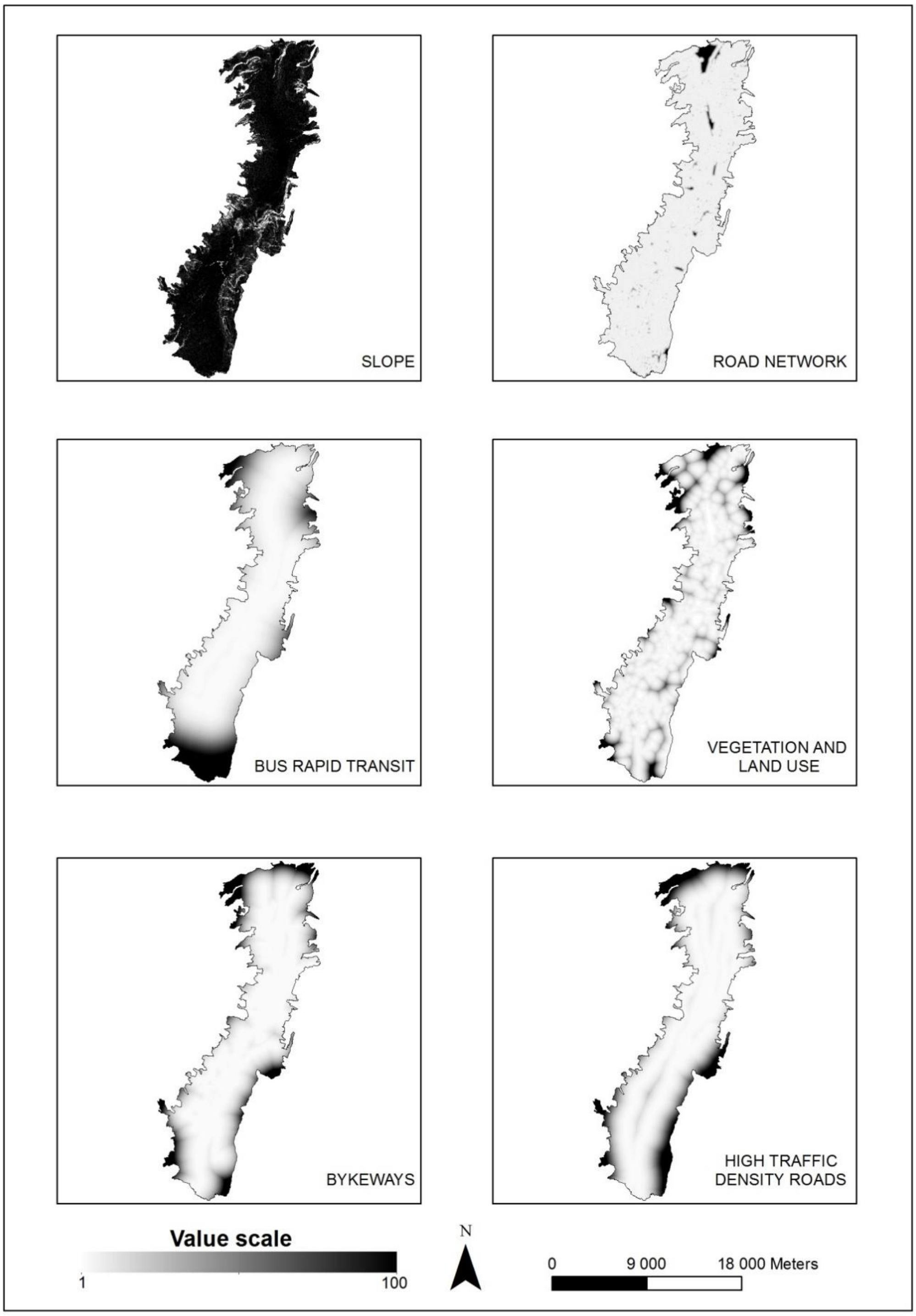

Figure 5: Construction of the thematic shape with added factors

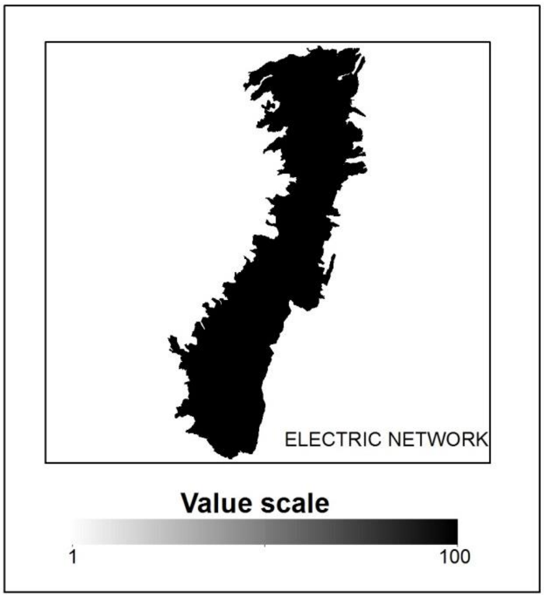

Figure 6: Shape of the electrical network of Quito for the analysis

2.2.3. MCDM evaluation

The MCDM methods are based on the calculation of the weights by AHP method followed by TOPSIS method to identify high sites within the city of Quito.

Once the factors evaluated have been specified, the standardization is defined to rescale raster values, it is necessary to calculate the weigh from the specific criteria, to put the problem under analysis. The introduction of electric bikes recharging stations is considered desirable; however, it is necessary to define the hierarchy of the variables. Three variables were determined by their importance for this research: digital elevation model, green areas with tourist attractions, and traffic engineering. The factors were classified according to its correspondence and importance within the different elements. Figure 7 presents the hierarchy of criteria subject to serve as a starting point for the application of the AHP. Starting from this process electric network is not considered because every city is covered by the information aforementioned.

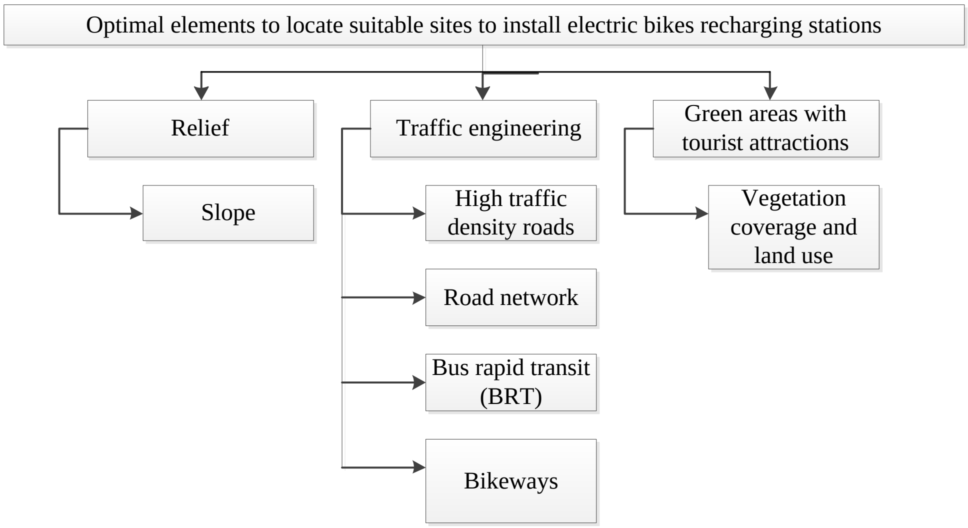

Figure 7: Hierarchy of criteria and factors.

The obtained results of the application of the AHP method are presented in table 3. Therefore, the most important element was the traffic engineering (63.7%), the second one was the Green areas with tourist attractions (28.5%), and the least important was the digital elevation model (10.5%).

Table 3: Component weights and its factors

Element	Weight	Factor	Weight
Traffic engineering	0.637	Distance to high traffic density roads	0.360
		Distance to road network	0.167
		Distance to bus rapid transits (BRT) stops	0.075
		Distance to bikeways	0.035
Green areas with tourist attractions	0.258	Distance to green areas and tourist attractions	0.285
Digital elevation model	0.105	Slope	0.105

3. Results and discussion

Six factors employed in this study were the inputs to the TOPSIS and weighted overlay methods, to find the most suitable location for installing electric bikes recharging stations in the city of Quito. The results have been obtained based on the relative weights calculated with the AHP method, which are illustrated in table 3. In addition, an OPI to evaluate the results from 1 to 100 was accomplished.

Once the multi-criteria method is applied zones that satisfy 90% are selected in determined criteria. These areas were transformed to vectors and afterwards used to make a selection by localization, where it was indicated that the neighborhoods of the DMQ that contain all the zones that satisfy 90% of the criteria are selected.

The evaluation of the score from 1 to 100 makes clear that the score is proportional to the degree of suitability of the land. A high score indicates that the analyzed area is convenient to introduce an electric bikes recharging station. This assignation allows choosing category ranges with more flexibility and precision, in a way that the best results are obtained with the least possible risks.

The ranking of the land suitability index map in the study area for TOPSIS and weighted overlay methods is illustrated in figure 8. The case study results show the most appropriate locations in dark brown. These places were in 49 neighborhoods distributed between the north, center and south were selected. They were near to green or touristic zones, BRT stops and could be connect with the bikeway network as can be observed in figure 9 and table 4. Through the multi-criteria interest zones were determined that are distributed in the whole urban town. While nowadays, the most of the bikeways are presented in the hypercenter of the city in districts Eugenio Espejo and Manuelita Sanz (figure 4), with these results it could pretended a connection towards the south and north, while now the stops are only in the flattest area of the city.

In this way it is demonstrated that the study can help to improve the transport system towards a transport with less impact with the environment. Since the use of the bicycle would reduce the use of cars, which is a big problem in a city with a long profile like Quito. The study could be done in other types of cities. In the first place, the need for electric bicycles would have to be taken into account, for this it would be necessary for the city to have a different shape. The bicycle without batteries could be used. On the other hand, existing transport systems should be taken into account. In case of removal this has a BRT system, but in other cities may have other types of systems such as the metro.

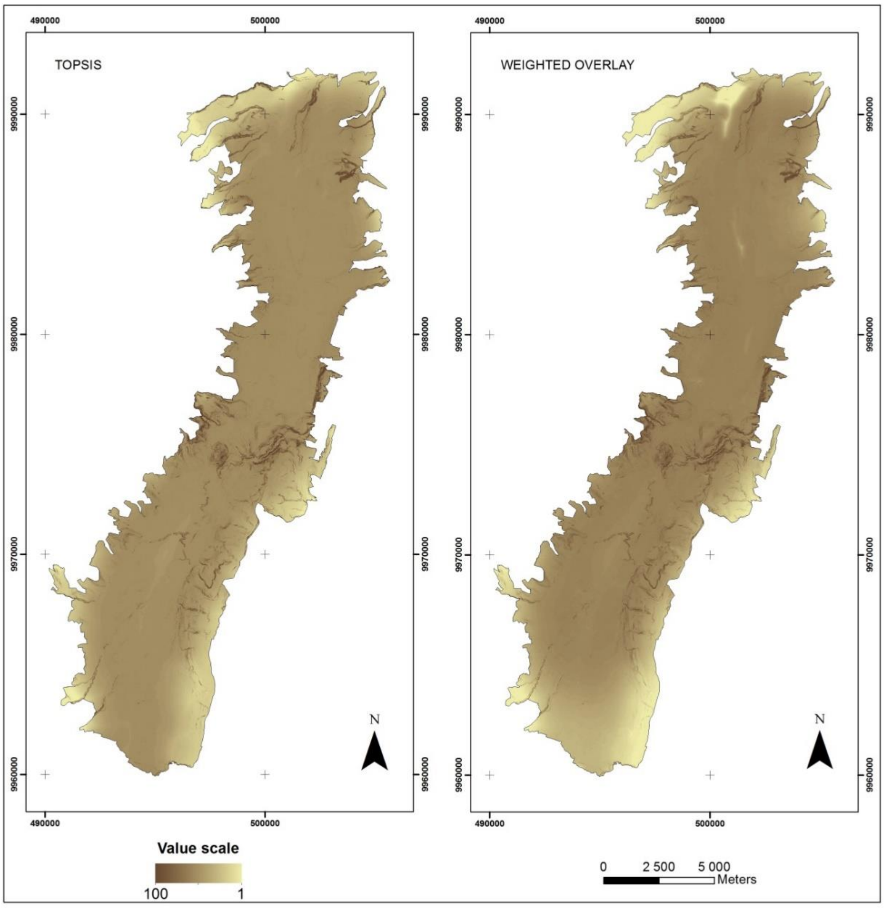

Figure 8: Ranking of the land suitability index map in the study area for TOPSIS and weighted overlay methods

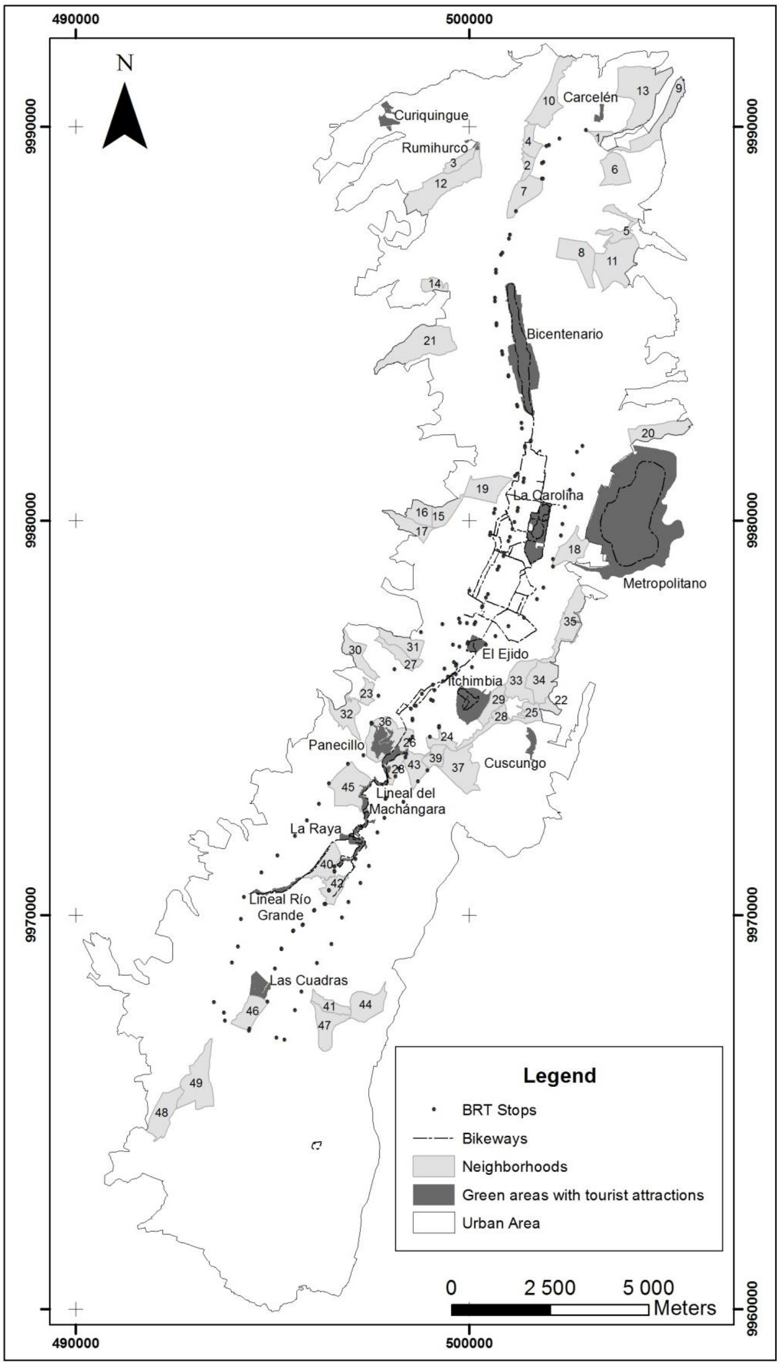

Figure 9: Identification of the most appropriate locations of electric bikes recharging stations in the city of Quito.

Table 4: Identification of the Neighborhood and administrative are most appropriate for the locations of electric bikes recharging stations in the city of Quito.

Id	Neighborhoods	Administrative Areas
1	Presidencia Republica	Equinoccial
2	Nameless	Equinoccial
3	Justicia Social	Equinoccial
4	Balcon Del Norte	Equinoccial
5	Nameless	Equinoccial
6	Bellavista Carretas	Equinoccial
7	Ponciano Bajo	Equinoccial
8	Collaloma 9 De Junio	Equinoccial
9	Pusuqui Chico Bj	Equinoccial
10	Nameless	Equinoccial
11	Comite Del Pueblo	Equinoccial
12	El Condado	Equinoccial
13	Mastodontes	Equinoccial
14	Pablo Art Suarez	Eugenio Espejo
15	Ninguilla	Eugenio Espejo
16	S.Vicente	Eugenio Espejo
17	La Primavera	Eugenio Espejo
18	Bellavista	Eugenio Espejo
19	Granda Centeno	Eugenio Espejo
20	Las Bromelias	Eugenio Espejo
21	La Pulida	Eugenio Espejo
22	El Guabo	Manuelita Saenz
23	Libertad Bajo	Manuelita Saenz
24	Area De Proteccion	Manuelita Saenz
25	Las Orquideas	Manuelita Saenz
26	La Sena	Manuelita Saenz
27	La Chilena	Manuelita Saenz
28	Boliva Rodriguez	Manuelita Saenz
29	Area De Proteccion	Manuelita Saenz
30	Pavon Grijalva	Manuelita Saenz

31	La Independencia	Manuelita Saenz
32	Colmena Alta	Manuelita Saenz
33	La Vicentina	Manuelita Saenz
34	Santa Lucicia 2	Manuelita Saenz
35	Guapulo	Manuelita Saenz
36	Panecillo	Manuelita Saenz
37	S.Jose De Monjas	Manuelita Saenz
38	Nameless	Eloy Alfaro
39	Luluncoto	Eloy Alfaro
40	El Calzado	Eloy Alfaro
41	S.Cristobal	Eloy Alfaro
42	Tnt. Hugo Ortiz	Eloy Alfaro
43	Mexico	Eloy Alfaro
44	Lucha Los Pobres	Eloy Alfaro
45	La Magdalena	Eloy Alfaro
46	Ruccullacta	Quitumbe
47	Pueblo Unido	Quitumbe
48	Nv Horizonte Sur	Quitumbe
49	La Ecuatoriana	Quitumbe

To validate the results with the different MCDM methods, an analysis of the results by a Pearson correlation coefficient has been performed. The results of the Pearson correlation coefficient for each MCDM method for TOPSIS and weighted overlay methods presented a correlation of the results above 84%. These results indicate that the two raster of MCDM have similar results in a value greater than or equal to 84% of the best places to install an electric bike station. Similar results of correlation were obtained in the validation of Villacreses et al. 2017. In this study the Wind farms suitability location using GIS-MCDM methods obtained a correlation of the results is above 93%. While in the case of the TOPSIS method, the correlation of the results is about 53%.

In addition, it can be verified as it was commented before that correspond with green or touristic zones and BRT stops, which correspond with the most important criteria in the study. It should be borne in mind that these results have to do with the weights of the factors that have been taken into account. In this sense it must be said that the slope was an important parameter weight factor of 10.5 %. However, there are a number of factors that are more important as distance to high traffic density roads with 36 %, distance to road network with 16.7 % and distance to green areas and tourist attractions 28.5 %. These factors take into account the idea of improve sustainable transport. For this idea, they are reproducible for any city, as well as this study.

4. Conclusions

This research helps the surrounding literature in location optimization. In addition, it is the first study on the location of charging points for electric bicycles. This study developed and applied GIS with two MCDM methods and the Pearson correlation coefficient to assess the suitability for location electric bikes recharging stations in the city of Quito.
The study has been conducted in the city of Quito, which is a city with large slopes, where electric bicycle is necessary. However, the most important factor takes into account the idea of improve sustainable transport as high traffic density roads with 36 %, For this idea, the study is reproducible for any city.
The results show that the places most appropriated to locate electric bikes recharging stations were settled in the north, center and south of whole urban Quito. While currently the bikeways are concentrated in the hypercenter of the city, with these results it could possible to develop an infrastructure of bikeways to connect towards the south and north.

The study demonstrates that the use of GIS-MCDM tools facilitate the selection of the most feasible location in the field of transport sources. This is because the methodology is reproducible taking into account the factors of the city. However, different factors and different values of these would give different results according to the city

These techniques will help researchers to find locations from the point of view of transport development. In addition, it contributes with new added credibility of the use of expert validation the existing literature about GIS-based suitability studies

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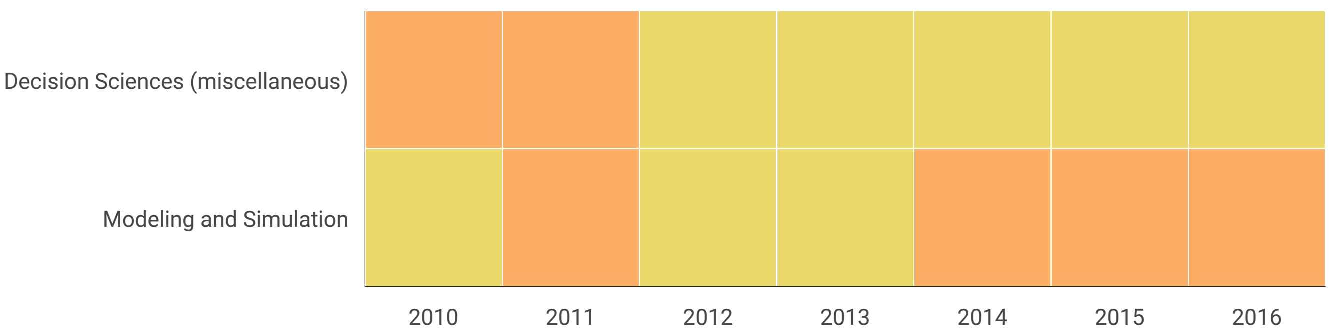

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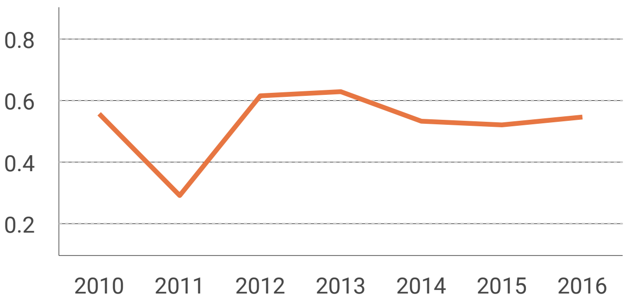

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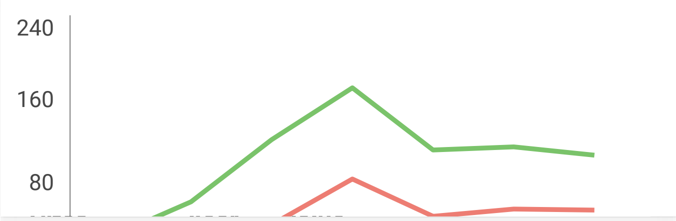

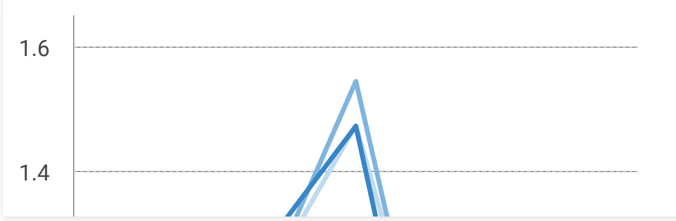

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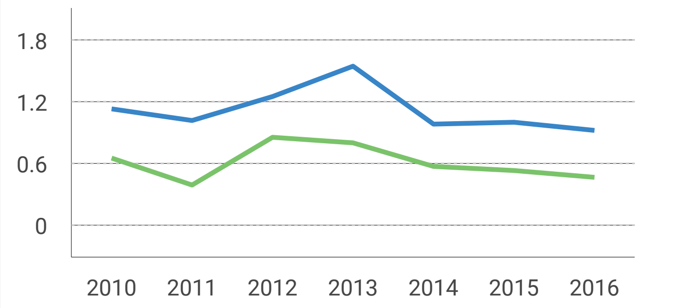

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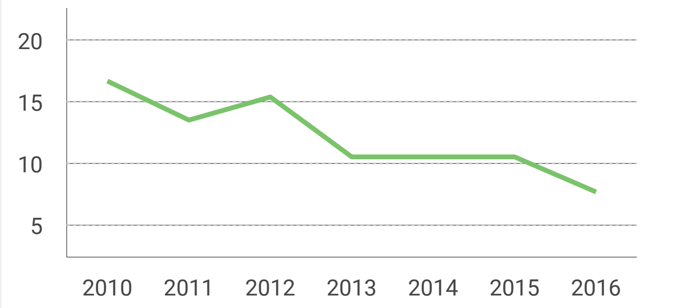

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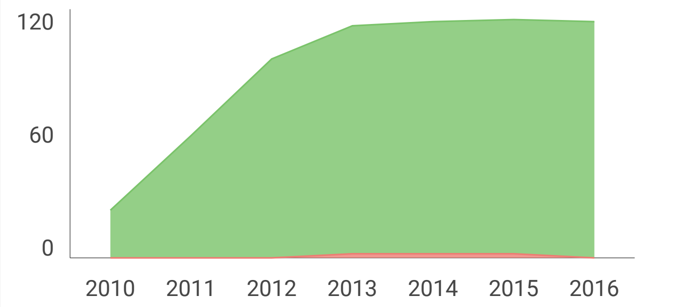

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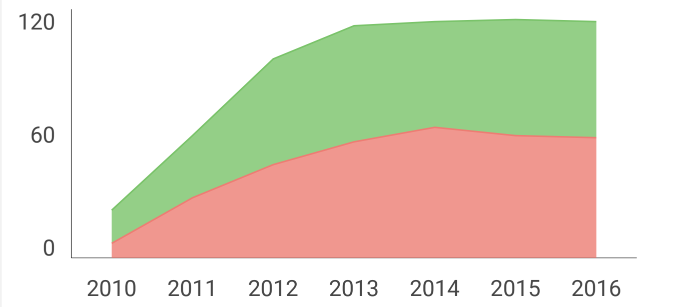

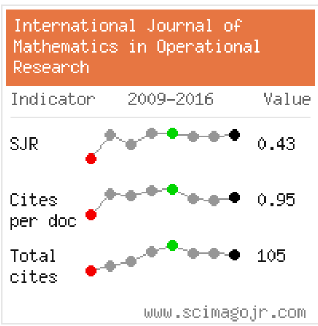

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