OPTIMAL LOCATION SELECTION FOR ELECTRIC VEHICLE CHARGING STATIONS USING GIS

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Abstract
The reduction of the environmental negative effects in the world we live in makes the life process better. Charging stations are needed for the widespread use and efficient use of electric vehicles, which have both positive environmental and economic benefits. Geographic Information Systems (GIS) is an important decision support system that enables both semantic and spatial data to be managed and analyzed at the same time. Besides GIS, using the Analytical Hierarchy Process (AHP) of the Multi-Criteria Decision-Making Methods (MCDM), the electric vehicle charging station location were selected in case study areas in Istanbul, Turkey. Criteria that have economic, environmental and social effects in the study were determined to take into account the characteristics of the study area and analyses were carried out. The results obtained from the study were evaluated according to the charging station suitability to produce scientifically based output products that would benefit decision makers.

Keywords: *Multi-criteria, electric vehicle, GIS*

INTRODUCTION

The economic and social developments that took place over the past 40 years have increased the per capita national income and as a result, the cities have expanded towards the suburbs (Frade et al., 2011). Pollution is alarming for city areas across the country. This concern is not only in big metropolises but in almost every city in our day (Etezadi-Amoli et al., 2010). The realization of renewable energy in a healthy way is possible through the interaction of governments and social parts. Reducing greenhouse gases, reducing fossil fuel consumption and developing a reliable strategy for energy production will reduce the impact of climate change (Charabi and Gastli, 2011). Road traffic gives rise to negative effects for the humans because of the noises and propagates to pollutants such as carbon monoxide (CO) and hydrocarbons (HC) (Helms et al., 2010). Due to the mentioned unfavorable effects, many countries in the field of electricity have experienced mobility. Electric vehicles are more influential in terms of energy consumption, more environmentally friendly and more affordable in terms of fuel consumption. Their use minimizes the emission of carbon dioxide and other greenhouse gases into the environment (Frade et al., 2011). The first models of electric vehicles were not able to compete with fuel-consuming vehicles due to some limitations and high prices. But the developments in battery technology and the high rate of increase in crude oil prices have increased the interest in electric vehicles (He et al., 2013).

One of the factors that are necessary for the widespread use of electric vehicles is charging. There are studies in the literature about electric vehicle charging station planning. Ge et al. (2011) have used the grid method to determine position and size information for electric vehicle charging stations in their work. They discussed the feasibility of the method with the example in the study. Li et al. (2011) have proposed a planning method for electric charging stations using the genetic algorithm method in their study. Traffic flow data is used in the study and it is emphasized that the genetic algorithm method is simple, convenient, coherent and adaptable to the result. Hanabusa and Horiguchi (2011) aimed to determine the locations of electric vehicle charging stations in the most appropriate way using the analytical method. They have explained the theoretical approach towards this purpose. Jia et al. (2012) have pointed out the struggle of locating and sizing the charging stations of electric vehicles and suggested solutions by modeling the road network and considering charging demands in their works.

Geographic Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods are frequently used methods of studying energy. Charabi and Gastli (2011) have determined the selection process of the most suitable solar farm sites for the Oman country by using fuzzy multi-criteria evaluation method with GIS-based. It has been found that

0.5% of the study area is placed in a very suitable class range. Aydin et al. (2013) emphasized the importance of hybrid renewable energy systems in their work. They have studied environmental and economically proper areas in their practice. They have benefited from literature research and local regulations. By combining, the fuzzy decision-making method with GIS carried out case studies to western Turkey. Uyan (2013) perform his work using GIS and AHP in Konya city in Turkey, which has identified areas suitable for solar farms. Topography and local weather features and agricultural facilities are among the criteria used in the study.

In this study, it was aimed to determine suitable areas for electric vehicle charging stations by using GIS and AHP methods.

MATERIALS AND METHODS

Study Area

The study area is determined as Uskudar, Kadikoy and Atasehir districts in Istanbul, Turkey. The designated districts are neighboring to each other. The population was an important factor in selecting the study area. Istanbul has a population of 15,029,231 according to the statistics of the Turkish Statistical Institute in 2017. According to statistics, Istanbul has highest population rates in the country. Also, the population of the study area has high population ratings to other districts in Istanbul. The study extent has an area of 85 km^2. Urban fabric is the dominant land use class in the study area. The using potential of electric vehicles is another deliberation for the selection of study area. The map presentation the study area is shown in Figure 1.

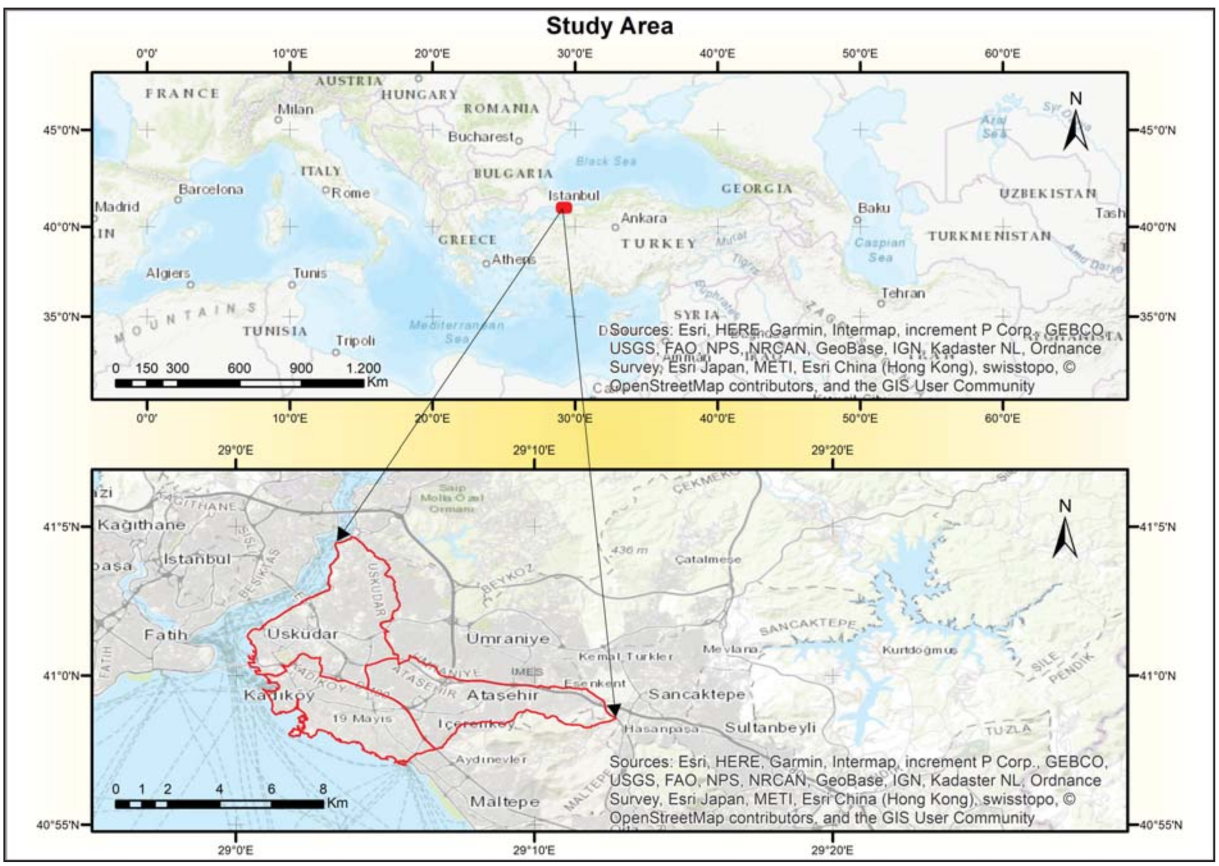

Figure 1. Study area

Calculation criteria weights by AHP

In the study, AHP is employed as an MCDM method widely used in the literature. Many criteria such as environmental, economic and social effects are important in the selection of the electric vehicle charging station location. AHP is one of the methods utilized in decision-making problems involving a large number of criteria. When the numerical ratings of the selection-affecting criteria are indistinct, it becomes problematic to make assessments and weighting the criteria (Saaty, 1980). The AHP brings together decisions both quantitatively and qualitatively to diminish the gaps in the decision-making process while accomplishing weighting in a solid but simple way (Ma et al., 2005). AHP implements Eigenvalue attitude to the pairwise comparison. A method compares the performances of criteria using a numerical scale. Values between 1 and 9 are used in pairwise comparisons. In a pairwise comparison, a 1/9 shows that one criterion is exceptionally less important than the other, indicating that 1 the two criteria have an equal rating, and 9 indicates that a criterion is extremely more important than the other (Vaidya and Kumar, 2006). Table 1 comprises the principle for pairwise comparison scale used in AHP.

Table 1. Principles for pairwise comparisons in AHP

Verbal scale	*Numerical values*
Equally important, likely or preferred	1
Moderately more important, likely or preferred	3
Strongly more important, likely or preferred	5
Very strongly more important, likely or preferred	7
Extremely more important, likely or preferred	9
Intermediate values to reflect compromise	2, 4, 6, 8

A comprehensive literature research has been done to select the criteria used in this study. A hierarchy has been established for AHP by identifying the criteria that can affect the locations of electric vehicle charging stations. The created hierarchy is presented in Figure 2.

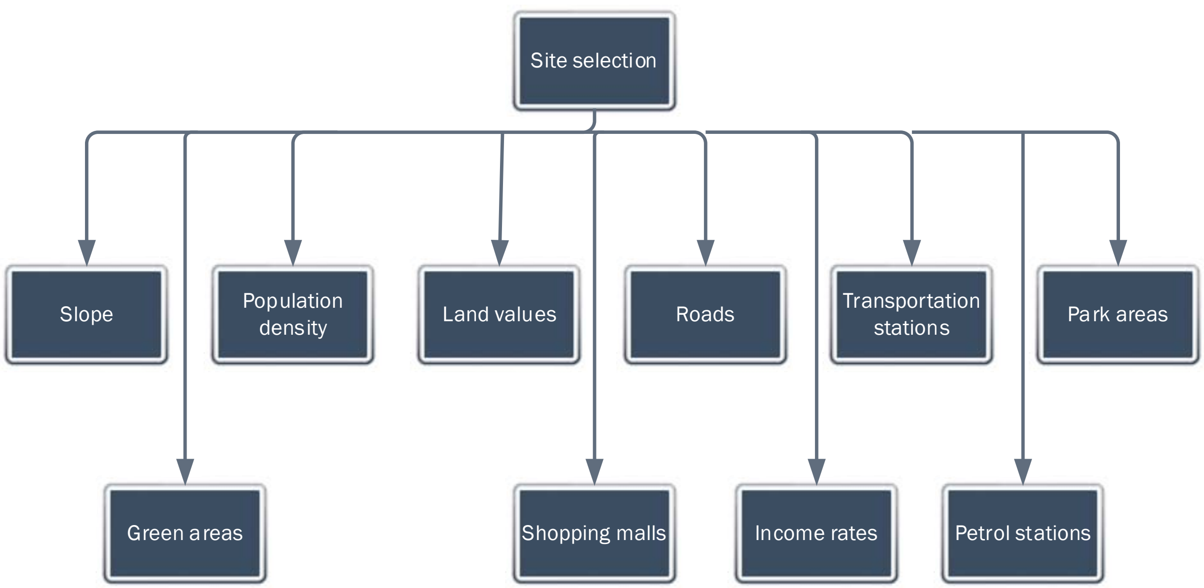

Figure 2. AHP hierarchy

The pairwise comparison matrices according to the hierarchy used are based on the studies in the literature (Gorsevski et al., 2013; Wu et al., 2014a; Wu et al., 2014b; Guo and Zhao, 2015; He et al., 2016). Criteria weights were stated by applying the process steps in AHP theory. One of the scientific advantages provided by the AHP is that it allows the consistency of the generated judgments to be controlled. If the calculated consistency ratio is less than 0.10, calculated weights can be accepted. As a result of the calculations complete in the study, the consistency rate was calculated as 0.053. Since the consistency ratio is below the accepted limit, the calculated criteria weights are employed in the study. The criteria weights calculated according to AHP are displayed in Table 2.

Table 2. Criteria weights

Criteria	*Weights*	*%*
Distance to Green areas	0.324343	32
Slope	0.11314	11
Distance to Roads	0.10179	10
Distance to petrol stations	0.07545	8
Distance to shopping malls	0.065778	7
Distance to park areas	0.058795	6
Income rates	0.051258	5
Land values	0.129244	13
Population density	0.042847	4
Distance to transportation stations	0.037355	4

RESULTS

Map layers of the criteria regulated for the location of the electric vehicle charging station have been arranged. The map layer for each criterion has been converted to raster data format. All map layers have the same pixel value.

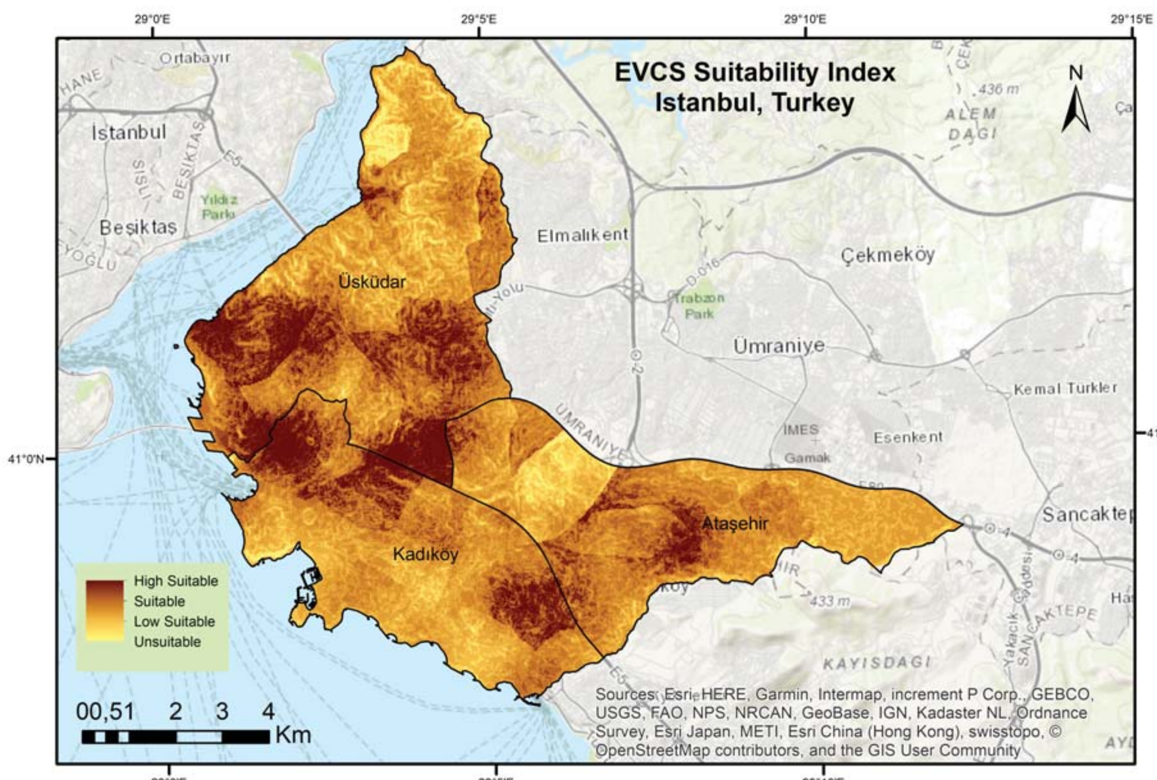

Figure 3. Suitability Index

Weighted sum analysis was performed by matching the criteria weights gained from the AHP calculations to the layers. The raster data obtained as a result of the analysis are shown in Figure 3 by determining the class intervals according to the suitability of the electric vehicle charging station.

AHP and GIS have been used to conclude the locations of the charging stations of the electric vehicles foreseen for future use in the work carried out. The study has been completed by allowing the GIS to organize the spatial data and to perform the analyzes. The ability to make decisions with AHP in GIS is provided in the case study.

Unlike previous studies, GIS was exercised to select the location of the electric vehicle charging stations. Since the factors influencing the site selection included spatial information, GIS was used. Criteria and hierarchy can be re-evaluated in future studies. By using different MCDM methods with GIS, different viewpoints can be gained.

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REFERENCES

Aydin, N.Y., Kentel, E., Sebnem Duzgun, H., 2013. GIS-based site selection methodology for hybrid renewable energy systems: A case study from western Turkey. Energy Conversion and Management 70, 90-106.

Charabi, Y., Gastli, A., 2011. PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation. Renewable Energy 36, 2554-2561.

Etezadi-Amoli, M., Choma, K., Stefani, J., 2010. Rapid-Charge Electric-Vehicle Stations. IEEE Transactions on Power Delivery 25, 1883-1887.

Frade, I., Ribeiro, A., Gonçalves, G., Antunes, A., 2011. Optimal Location of Charging Stations for Electric Vehicles in a Neighborhood in Lisbon, Portugal. Transportation Research Record: Journal of the Transportation Research Board 2252, 91-98.

Ge, S., Feng, L., Liu, H., 2011. The planning of electric vehicle charging station based on Grid partition method, 2011 International Conference on Electrical and Control Engineering, pp. 2726-2730.

Gorsevski, P.V., Cathcart, S.C., Mirzaei, G., Jamali, M.M., Ye, X., Gomezdelcampo, E., 2013. A group-based spatial decision support system for wind farm site selection in Northwest Ohio. Energy Policy 55, 374-385.

Guo, S., Zhao, H., 2015. Optimal site selection of electric vehicle charging station by using fuzzy TOPSIS based on sustainability perspective. Applied Energy 158, 390-402.

Hanabusa, H., Horiguchi, R., 2011. A study of the analytical method for the location planning of charging stations for electric vehicles, International Conference on Knowledge-Based and Intelligent Information and Engineering Systems. Springer, pp. 596-605.

He, F., Wu, D., Yin, Y., Guan, Y., 2013. Optimal deployment of public charging stations for plug-in hybrid electric vehicles. Transportation Research Part B: Methodological 47, 87-101.

He, S.Y., Kuo, Y.-H., Wu, D., 2016. Incorporating institutional and spatial factors in the selection of the optimal locations of public electric vehicle charging facilities: A case study of Beijing, China. Transportation Research Part C: Emerging Technologies 67, 131-148.

Helms, H., Pehnt, M., Lambrecht, U., Liebich, A., 2010. Electric vehicle and plug-in hybrid energy efficiency and life cycle emissions, 18th International Symposium Transport and Air Pollution. Citeseer, pp. 113-124.

Jia, L., Hu, Z., Song, Y., Luo, Z., 2012. Optimal siting and sizing of electric vehicle charging stations, 2012 IEEE International Electric Vehicle Conference, pp. 1-6.

Li, Y., Li, L., Yong, J., Yao, Y., Li, Z., 2011. Layout planning of electrical vehicle charging stations based on genetic algorithm, Electrical Power Systems and Computers. Springer, pp. 661-668.

Ma, J., Scott, N.R., DeGloria, S.D., Lembo, A.J., 2005. Siting analysis of farm-based centralized anaerobic digester systems for distributed generation using GIS. Biomass and Bioenergy 28, 591-600.

Saaty, T.L., 1980. The analytic hierarchy process: planning, priority setting, resources allocation. New York: McGraw 281.

Uyan, M., 2013. GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey. Renewable and Sustainable Energy Reviews 28, 11-17.

Vaidya, O.S., Kumar, S., 2006. Analytic hierarchy process: An overview of applications. European Journal of operational research 169, 1-29.

Wu, Y., Geng, S., Xu, H., Zhang, H., 2014a. Study of decision framework of wind farm project plan selection under intuitionistic fuzzy set and fuzzy measure environment. Energy Conversion and Management 87, 274-284.

Wu, Y., Geng, S., Zhang, H., Gao, M., 2014b. Decision framework of solar thermal power plant site selection based on linguistic Choquet operator. Applied Energy 136, 303-311.

BIOGRAPHY

Dogus Guler received bachelors and master's degrees from Geomatics Engineering Department of Istanbul Technical University. He is now a PhD candidate and research assistant at the same university.

Professor Tahsin Yomralioglu, PhD- he graduated from the Surveying Engineering Karadeniz Technical University (KTU), Trabzon-Turkey in 1985. He worked on Land Information Systems at the University of New Brunswick in Fredericton, Canada. In 1993, he obtained his Ph.D. from the University of Newcastle upon Tyne, England. In 1994, he was appointed as a full-time Professor in 2001 at KTU, then at Istanbul Technical University (ITU) in 2009. He has served a member on various scientific commissions and also worked as a project manager and consultant in several public-private institutions. He established ITU-GeoIT graduate program and the first national GIS R&D innovation center of Turkey.