Investigation of Optimal Charging Locations for Electric Vehicles in Istanbul

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Abstract

Electric vehicles have a great potential to decrease the adverse effects of transportation, especially in metropolitan cities. On the other hand, adoption of the electric vehicles requires supporting infrastructure such as charging stations and policies to enhance the transition from conventional gasoline vehicles to electric vehicles. Hence, determining optimal charging station locations is an important task for both having an economically feasible transition and reinforce the market shares of electric vehicles. This paper investigates the optimal locations for charging stations in Istanbul, Turkey. An integer programing model is developed and optimal charging locations in Istanbul is determined for three different market penetration scenarios, namely 10%, 25%, and 50% market penetration. The results can be useful for policies aiming to enhance use of electric vehicles, thus minimizing the environmental impacts of transportation, as well as fossil fuel dependency.

Keywords

Electric vehicles, Optimal charging station, Integer-programing, Sustainable transportation

I. Introduction

A well-developed sustainable transportation system is an essential component for sustainable development of metropolitan cities and researchers have been assessing the issues such as environmental, social, economic impacts of transportation systems using operations research tools (Alirezaei et al., 2017; N. Onat et al., 2017; Tatari et al., 2015). Private cars are the common transportation mode in cities, contributing the negative affect of transportation including greenhouse gas emissions (GHG) and energy consumption, air and noise pollution, petroleum dependency, and energy security (Ercan et al., 2017, 2016; Onat, 2015a; Onat et al., 2015; Zhao et al., 2016). All these environmental, social, end economic concerns make promoting sustainable transportation system more significant (Onat, 2015b; Onat et al., 2014). Alternative vehicle technologies, particularly electric vehicles (EVs), have great potential to solve the listed problems (N. C. Onat et al., 2017; N.C. Onat et al., 2016a, 2016b). The benefits of electric cars displacement of petroleum are listed as “increased transportation energy efficiency, reduced carbon emissions, reduced criteria emissions, reduced fueling cost, improved consumer acceptance and improved transportation energy sector sustainability” (Bradley and Frank, 2009; Noori et al., 2016; N.C. Onat et al., 2016c; Nuri Cihat Onat et al., 2016).

Electric vehicles are emerging technological phenomenon in the transportation and they have spread through cities. However, this technology is still found to be expensive; hence it is generally preferred by wealthy people. This is stated a result of survey which conducted by EV users in California as “The maximum income asked in both surveys is different and therefore the highest income to compare is $150,000 a year. Plug-in EV owners’ income is higher than the general population and new car buyers up to $150k” (Tal, G. et al., 2013). Radtke et al., (2012) examined the underlying reason of people preferring and not preferring electrical vehicles in Japan. Among 265 participants, the most important reason of not considering electric vehicles was found to be expensive prices of electrical vehicles, followed by participants concerned about the number of charging stations (see Figure 1 for more details) (2012, p.8). These two surveys conducted from different regions, America and Asia, and they had similar findings that high income people are more likely to prefer EVs due to its high prices.

Furthermore, EVs need charging stations for owners, requiring a proper infrastructure optimally spread around the city. In the literature, there are studies about finding optimal solutions for charging stations of electric vehicles. For example, Baouche et al., (2014) examined Lyon, France and used p-dispersion model with a cost constraint, which includes travelling between each charging stations, and server investment constraint, which includes travelling between each charging stations and server investment cost. They concluded that potential locations of charging stations should be centralized public places, suggesting shopping centers and/or Center Business District are the best optimal charging station location in Lyon. Frade et al., (2011) proposed an optimization of charging units of EVs in Lisbon, Portugal by using Maximal Covering Location Model (MCLP) with respect to demand of charging stations. Similarly, Hess et al., (2012) proposed genetic programming approach and identified optimal charging locations among possible locations such as parking lots, shopping malls, homes, campuses, etc. One common point of these studies was their emphasis on the development of charging station infrastructure for city of interest.

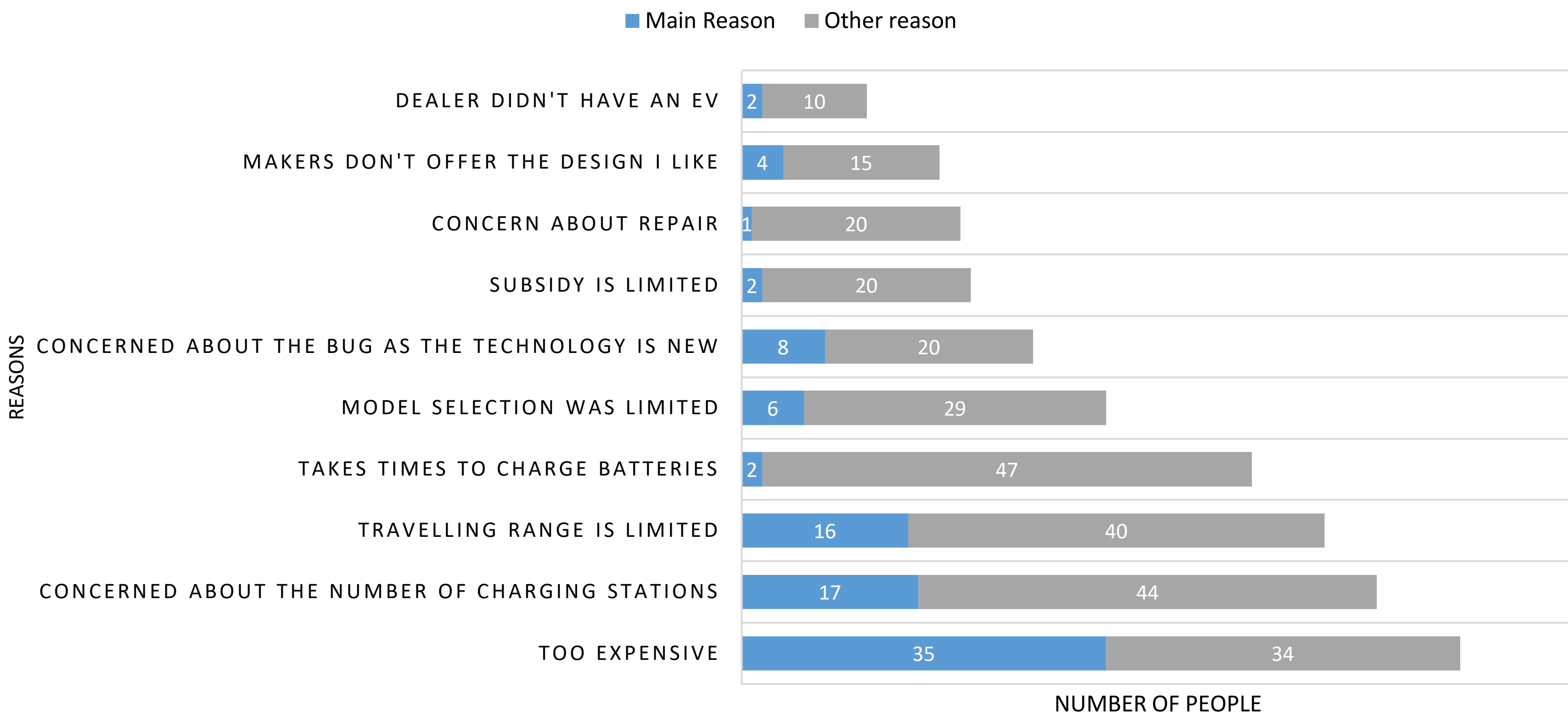

Figure 1. The reason for not preferring of EV (adapted from Radtke et al, 2012,p.8)

Istanbul, Turkey, region of interest in this study, is a metropolitan city with over 14 million population. Traffic and transportation is one of the biggest problem. Addition to traffic, other detrimental effects such as carbon emission, air and noise pollution etc. need to be eliminated. To make a livable city, electric vehicles may be an option. However, Istanbul does not have required infrastructure for EVs like charging stations. In this paper, the main objective is contribution to improvement of charging station infrastructure in Istanbul by finding optimal locations among candidate points based on different market penetration scenarios. An integer-programming model is proposed to realize this goal, further explained in methodology section. The article is organized as follows: In Section 2, the model and parameters explained in detailed way. The result of General Algebraic Modeling System (GAMS) Software will be interpreted via visualization, three different market penetration based scenario will be compared in Section 3. Conclusion and prospects for future work will be stated in section 4.

II. Methodology

Integer Programming formulation in GAMS Software were used to determine optimal charging locations among given possible locations in Istanbul. First, possible charging station locations were determined and then, an integer programming optimization model was developed to select the optimal locations among the set of possible locations.

A. Determination of the possible location to allocate charging station

The model had built based on the best choice of the optimal charging location among the candidate location. Determination of possible locations was the first problem has occurred. Based on the market research of EVs, higher level of wealth was chosen as criteria for the initial targeted population. For this reason, the scope of the project is reduced to 9 districts having higher life quality index. Life Quality Index (Seker, 2011) calculated based on demographics, literacy rate, health condition, income, transportation, environmental quality, and social life standards, which were used for identifying the high level of wealthy population in Istanbul. Districts had greater than 0.20 in Life Quality Index considered as primary and secondary district of life quality with higher level of wealth. Considering these criteria, ten districts (please see Table 1) were covered in the model. Adalar (0.35 Life Quality Index) were excluded from the analysis since Adalar is composed of few little islands in the Sea of Marmara and the number of private vehicles are very low compared to other districts.

#	District Name	Life Quality Index
1	Kadikoy	0.88357
2	Besiktas	0.80406
3	Beyoglu	0.75627
4	Sisli	0.72874
5	Fatih	0.58166
6	Bakirkoy	0.53927
7	Sariyer	0.53367
8	Atasehir	0.37717
9	Adalar	0.35148
10	Uskudar	0.27815

Table 1. Ten districts in Istanbul with the life quality index more than 0.20 (adapted from Seker, 2011)

Within these districts, like the similar studies mentioned before (Baouche et al., 2014; Frade et al., 2011; Hess et al., 2012), the shopping centers, public parking areas and gas stations were considered as highly preferable places to allocate charging facilities. Public parking areas were selected from the ones owned by municipality, others were assumed as negligible and not included to the analysis. Additionally, only A+ shopping malls which are generally give places to luxury brands were included considering the target population interests. The all list of public parking areas, their name, coordinates, density, parking capacity and address information were gathered from ISPARK (established by Istanbul Metropolitan Municipality to manage the parking areas in Istanbul). Additionally, the list of gas stations, their name and coordinates are provided by ISBAK (established by Istanbul Metropolitan Municipality to manage the technological infrastructure of Istanbul). To determine A+ shopping centers, there was not a prepared list, that’s why the international luxury brands which were targeted A+ customers, were based upon. Eventually, the 394 possible locations consist of 283 parking areas, 98 gas stations, and 13 shopping centers were included to the analysis for these specific 9 districts. The distribution of these candidate locations across nine districts can be seen in Table 2.

	Shopping Center	Parking Areas	Gas Stations	Total
Atasehir	1	5	13	19
Bakirkoy	5	27	20	52
Besiktas	2	45	6	53
Beyoglu	0	28	11	39
Fatih	0	70	6	76
Kadikoy	0	40	0	40
Sariyer	1	18	0	19
Sisli	2	48	9	59
Uskudar	2	19	16	37

Table 2. Illustrates the number of candidate locations for shopping center, parking areas and gas station for 9 districts.

B. Allocating the charging station by integer optimization problem

To allocate the charging stations, there are many methods and models such as P-Dispersion model that designs a system that minimizes the distance travelled by the users (Pisinger, 1999), Maximal Covering Location Problem which locates a fixed number of facilities in order to maximize the population covered within a service distance S, while maintaining mandatory coverage within a distance of T (T>S) (Church and ReVelle, 1974, p. 103) or Maximum Expected Covering Location that is stochastic model which assigns each server a probability based on its operability (Daskin, 1983, p. 48), are called as set covering problem, which describes the minimum number of facilities required to meet all system demand. As another approach to set covering problem, integer-programming model was utilized.

The proposed model aims to select minimum number of points to locate facility among given possible locations based on the certain distance (denoted as S) between two locations. Therefore, the model is:

Objective function:

$$Min \sum_{j \in J} x_j \quad (1)$$

Constraints:

$$\sum_{j \in J} x_j N_{ij} \geq 1 \quad (2)$$

$x_j = (0,1)\ for\ all\ j\ \in J$ (3)

$$x_j = \begin{cases} 1\ if\ a\ facility\ is\ allocated\ to\ site\ j \\ 0\ otherwise \end{cases}$$

i refers to set of demand nodes, j, set of facility site and N_{ij}, matrix of covered location set

To build model, the data were restructured in terms of GAMS Software. First of all, the distance between all possible locations were calculated from their coordinates. To achieve that, Haversine Formula, Equation (4), (Chopde and Nichat, 2013, p.298) was used to convert spherical distances referring actual coordinates, into the kilometers.

$$hav\left(\frac{d}{r}\right) = hav(latitute2 - latitute1) + cos(latitute1)\ x\ \cos(latitute2)\ x\ hav(longitude2 - longitude1) \quad (4)$$

where earth radius (r) is assumed as 6371km.

By using Equation (4), the shortest distance from node i to node j calculated. There were 394 candidate locations, so 394x394 matrix were used as template representative location map. Secondly, the S distance where considered as covered demand, needs to be determined. As referring point for S, the distance from gas station was chosen. According to Petroleum Market Law Article 8 distance between two gas stations is determined by law as 1km in one direction (2003) so it is 500m in round-trip. From this distance criterion, the distance between charging location was calculated by division of its market penetration rate with Equation (5)

$$S = \frac{1\ km}{Penetration\ rate} \quad (5)$$

The model was applied based on three different market penetration scenarios, 10%, 25% and 50%. The S distance was calculated with Equation (5) and the Table 3 shows the associated results with different market penetration rate.

Market Penetration Rate	S Distance
10%	5000m
25%	2000m
50%	1000m

Table 3. S distances for different market penetration rate

Thirdly, matrix modified as binary values by using S. If the distance which calculated with Equation (4) was lower than S distance that means it is covered by that location which turns out 1; otherwise 0. This table was called N_{ij}.

III. Results

To make the paper longer term, different scenarios were created based on possible market penetration rate. In this paper, three scenarios were investigated, namely 10%, 25%, and 50% penetration rates. The optimal locations were selected according to these three market penetration scenarios. Figure 2 shows the chosen 9 districts.

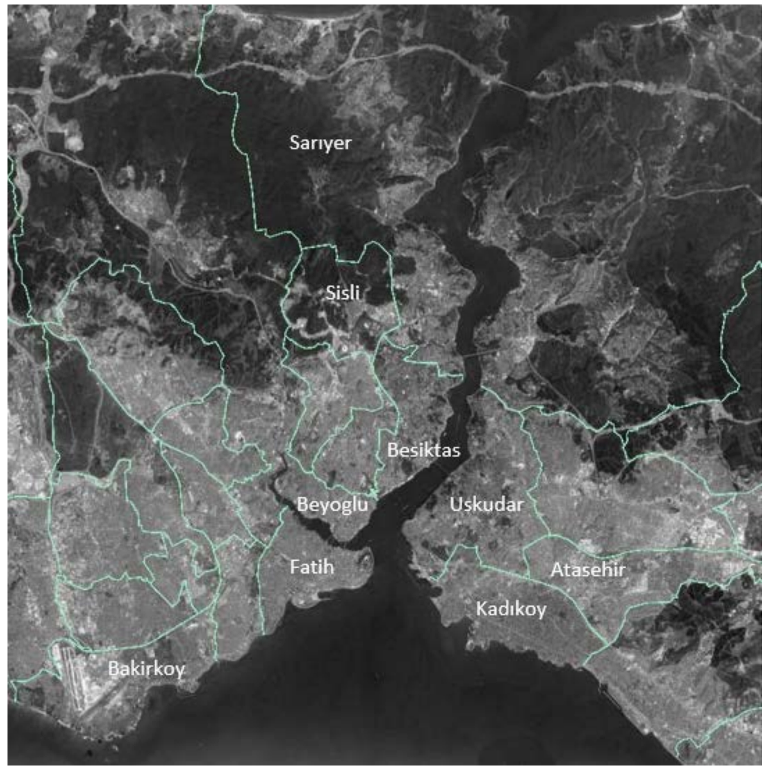

Figure 2. Map of 9 district

A. Validation of model

Model is developed after testing and validation. Initially, MCLP was utilized and tested to allocate the number of charging station while maximizing the population covered within a comfortable distance between possible locations (Church and ReVelle, 1974). However, after the testing the model with GAMS Software, the output was found to be economically infeasible. Because there wasn't any constraint to limit the selection of facility such as cost function or energy demand. Therefore, model was modified, instead of maximizing covered location, minimizing allocated location was selected as an objective function. Furthermore, we created new binary matrix between the possible locations, which allowed our model to control whether the certain location covers other location, or not. This modified version of MCLP were used for this study.

B. Scenario 1: 10% penetration rate

At 10% penetration rate, the S distance was calculated as 5000 m by Equation (5). According to result of GAMS Software, 7 points were selected to locate charging station out of 394 possible locations. Figure 4 shows 7 possible charging station generated with 10% penetration including four possible charging station in parking areas (Blue P) and 3 possible charging station in gas station (Red Circle). The selected locations showed that nearly all chosen 9 district include a charging location in center of that district. At analyzing the results on map, some locations do not include any selected charging location because analysis does not consider the Sea of Marmara as borders. The model measures the distances regardless of borders. The reason of ignorance the sea blockage is that Asia and Europe side can easily access due to improved transportation system, which is 3 bridges across the Asia and Europe sides and also Eurasia Tunnel. That's why, the 10% penetration was resulted as 7 charging station out of 9 district instead of 9 charging station.

Figure 3. Optimal charging location for 10% market penetration

Charging stations had almost spread equally between districts. Table 4 illustrates the spread of charging stations for 9 district for 10% penetration rate. Except Sisli, all district had one charging facility, which was very reasonable. Sisli is located between Beyoglu and Besiktas. That's why, the charging stations in Beyoglu and Besiktas covered the Sisli within S distance which is 5000m. That supports that the model doesn't consider border.

	Shopping Center	Parking Areas	Gas Stations
Atasehir	-	-	1
Bakirkoy	-	1	-
Besiktas	-	1	-
Beyoglu	-	1	-
Fatih	-	-	-
Kadikoy	-	-	1
Sariyer	-	-	1
Sisli	-	-	-
Uskudar	-	1	-

Table 4. Number of optimal charging location for 9 districts for 10% penetration rate

C. Scenario 2: 25% penetration rate

Next scenario is 25% penetration rate which assumes that electric vehicle deploys in the market. The S distance getting shorter than previous penetration, so 30 optimal charging stations were determined by the software for S as 2000 m which is presented in Figure 4. With a decrease of distance between selected of two charging station, more charging stations were set as optimal. More charging stations with shorter distance between each other, allow the selection of more than one charging station for each district. The same situation, which had occurred at 10% penetration results about sea border, still exists for 25% penetration. Seaside of Europe side had close optimal charging locations that covered Asia side.

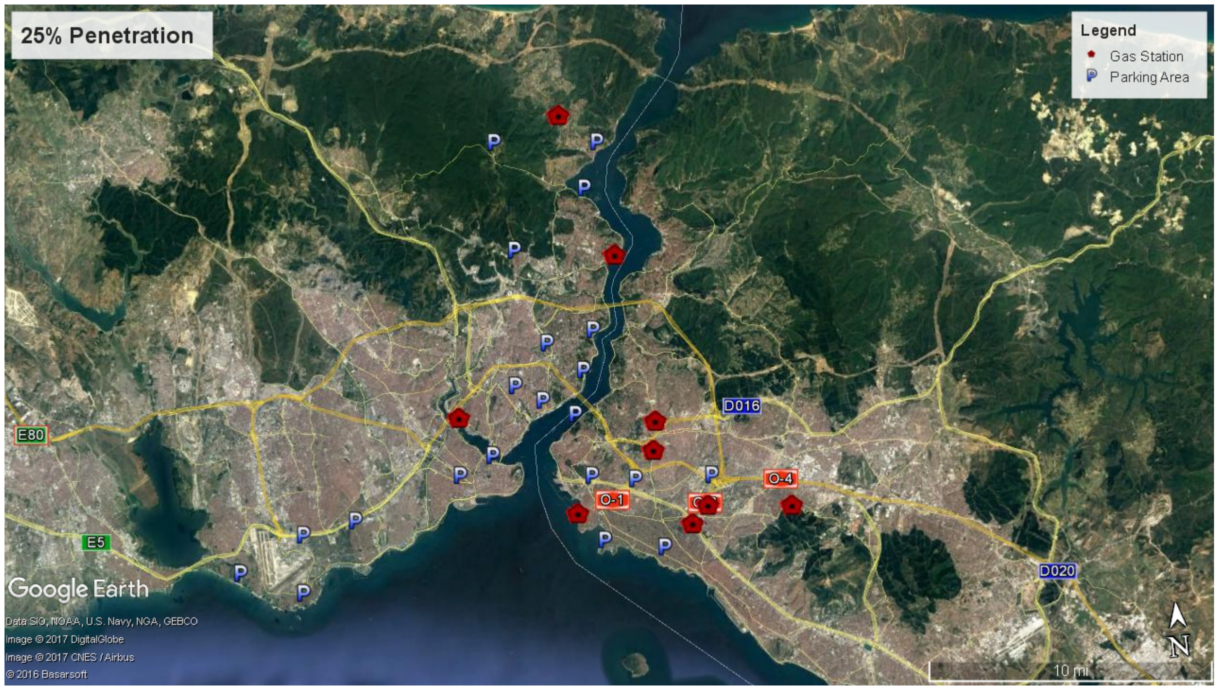

Figure 4. Optimal charging location for 25% market penetration

In Table 5, demonstrates at 25% penetration rate there are 30 possible charging locations for electric vehicles; 21 parking areas and 9 gas stations in these 9 districts. There are no shopping centers which have charging stations in any of the districts, parking areas that have charging units are in every district except Beyoglu. Almost half of the districts do not have any refuel points for the electric vehicles in their gas stations. Finally, each county has average 3 charging units but Beyoglu, Fatih and Sisli are below the average.

	Shopping Center	Parking Areas	Gas Stations
Atasehir	-	1	2
Bakirkoy	-	4	-
Besiktas	-	3	-
Beyoglu	-	-	1
Fatih	-	2	-
Kadikoy	-	3	2
Sariyer	-	4	2
Sisli	-	2	-
Uskudar	-	2	2

Table 5. Number of optimal charging location for 9 districts for 25% penetration rate

D. Scenario 3: 50% penetration rate

At 50% penetration, the optimal charging stations' number increased to 73 out of 394 possible locations and S distance is determined as 1000 m. The charging station spread over districts can be seen in Figure 5. The number of optimal charging station increase while the S distance decrease.

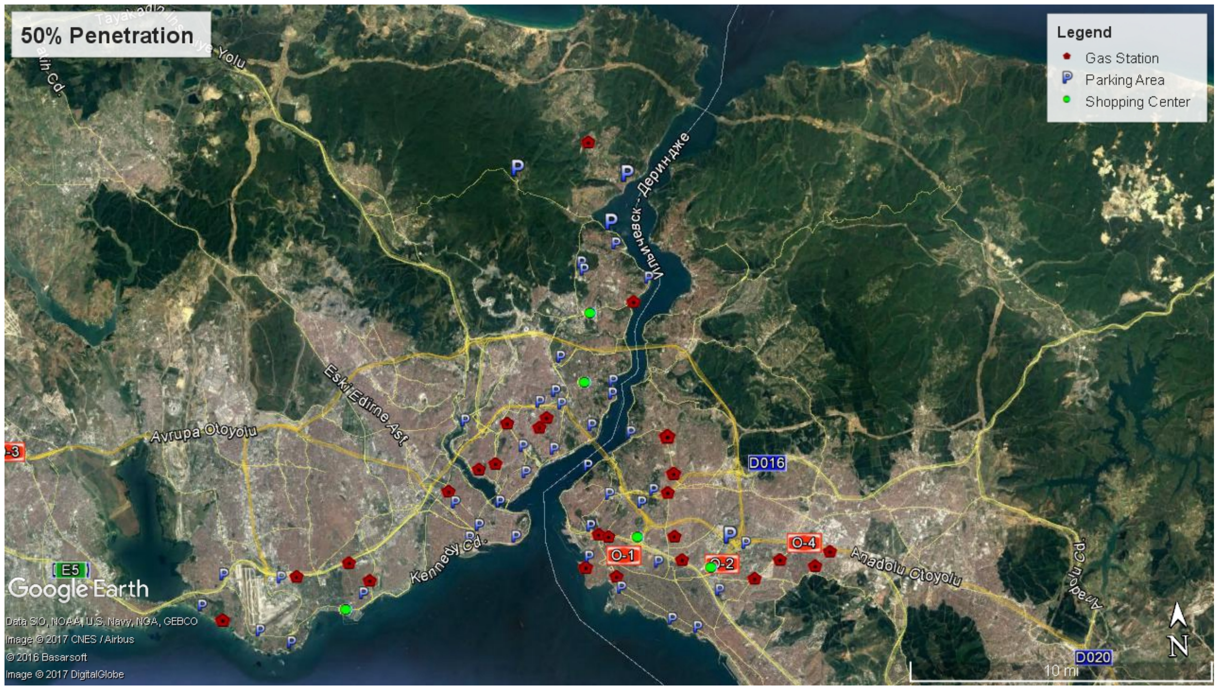

Figure 5. Optimal charging location for 50% market penetration

The number of optimal charging station for each district can be seen in Table 6. The average number of optimal station is 8 for each district which is 8 times higher for 10% penetration rate. The distribution of charging station was more stable between shopping center, gas station and parking areas. Because the total number of parking areas as potential charging location was higher than shopping centers and gas stations, number of parking areas as optimal locations were higher number compared to others.

	Shopping Center	Parking Areas	Gas Stations
Atasehir	1	3	6
Bakirkoy	1	6	4
Besiktas	1	-	5
Beyoglu	-	2	2
Fatih	-	5	1
Kadikoy	-	5	4
Sariyer	1	8	2
Sisli	-	3	3
Uskudar	1	6	3

Table 6. Number of optimal charging location for 9 districts for 50% penetration rate

E. Conclusion

This paper presented a study on optimal locations of the electric vehicle charging stations for in Istanbul. It was significant for Istanbul because EVs would be spread in transportation as an environment friendly alternative to gasoline-powered vehicles. There is a need for proper infrastructure and determination of accurate locations for electric car drivers to promote the deployment of electric vehicle. Therefore, candidate charging locations were chosen among the public places such as shopping centers, public parking areas or gas stations in high income distinct Next, methodology proposed an integer programming problem with minimization of the number of allocated site as limited with the certain distance (S). The model was solved by GAMS Software and visualized with Google Earth.

A. Initial target population: High life quality district

Scope of paper were limited with 9 districts which have higher life standards than other districts. The reason behind districts choice was that the early adaptors of the EV were expected to have high-income level due to high prices of EV. Furthermore, 9 districts are located in the center of Istanbul, both in Asia and European side.

B. 50% Penetration rate resulted the best optimal locations

This high penetration rate gave opportunity to people to not have range anxiety because of having enough infrastructure of charging station. So, in these 9 districts, the charging locations become normalized such gas stations which were mandatory places for current daily life in Istanbul because of current number of gasoline vehicles. The distance between two charging location was short. So, it allowed people to select alternatives and not pushing them to leave their routine followed road. The crossed areas that were created by optimal charging locations has increased and nearly all points have a crossed covering areas which provide high flexibility for EV users.

In this paper, methodology suggested that determine possible locations of charging units where were specified as potential point for refueling electric vehicle such as shopping malls, parking areas and gas stations like similar studies selected, then solve the integer programming to find the optimal number and the place of the charging station among possible locations. Moreover, in second step allocating the charging station by integer optimization problem was solved by GAMS Software and also related models used to validate and test the model. For further implementation, three different scenarios based on different market penetration rate were solved and the results transformed to visual map. As a future extension of this work, the model will include a stochastic extension and studied location will be enlarged. Because the number of candidate points and the districts needs to be greater while the penetration rate increase, only limited potential locations are taken into consideration in this paper. Additionally, alternative to electric vehicle such as self-driving car should be examined in further studies.

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